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Best practice prescriptions for propagating and establishing silver birch (*Betula pendula*) for timber production

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Introduction

Silver birch or birch (*Betula pendula*) is one of three native birches found in the UK, the other arborescent species being downy birch (*Betula pubescens*) with the remaining one being dwarf birch (*Betula nana*) (Mitchell 1974). Birch and downy birch are closely related, as downy birch probably arose as a hybrid with birch as one of its parents (Tsuda *et al*. 2017). The relationships between birches is complicated further by them being sympatric, with hybridisation occurring between downy and silver birch, while silver birch is also capable of generating polyploids (Beck *et al*. 2016).

Birch has different ecological requirements from downy birch, which is generally found on waterlogged, peaty soils in more exposed environments, whereas silver birch is found on lighter, drier soils and lower elevations (Savill 2019). In the northern part of its range, it forms stable climax forests but further south it is a tree favoured by disturbance (Atkinson 1992). As a hardy, pioneer tree, it was one of the first tree species to recolonise the UK after the last glaciation (Birks 1989).

The broader distribution of birch is mainly in the north of Europe, growing further north in Europe than any other tree (Beck *et al*. 2016). In the south of Europe, it is generally found in mountainous areas due to its limited tolerance of drought (Beck *et al*. 2016). It is an important tree in Great Britain as birch (*B. pendula* and *B. pubescens*) woodland covers 19,000 ha, or about 20%, of broadleaved woodland (Forest Research 2022a). It is notably rare or absent in the wetter west of northern Scotland (Worrell and Malcolm 1998).

Birch is known for its environmental benefits, such as soil improvement. Under birch stands, Miles and Young (1980) found a transition from a mor to a mull humus type, and an increase in pH, exchangeable calcium, total phosphorus, rates of cellulose decomposition and nitrogen mineralization. They also recorded a decrease in C/N, C/P and C/K ratios in the moorland soils. However, Miller (1984, in Atkinson 1992) found no differences between birch and other broadleaved trees in rates of litter decomposition and nutrient accumulation, and attributed birch's soil-improving abilities to being able to grow and improve soils on which other broadleaves could not grow. This soil improvement increases the number of earthworms (*Lumbricus* spp.) which in turn increases numbers of other soil invertebrates (Price and MacDonald 2012). Birch is also an important component of many NVC woodland types, notably W10, W11, W16, W17 and W18 (Patterson 1993). For certain groups such as specialist insects, the diversity supported by birch is very high, while for others such as lichens and fungi, it is less valuable (Patterson 1993).

Birch also has potential as a timber tree and is the most abundant commercial hardwood in northern Europe (Dubois *et al*. 2020) and its important has increased over the last 70 years (Price and MacDonald 2012). Growth rates can be high for a native broadleaf tree with a Yield Class of 10 m3 ha^{-1} y^{-1} being possible on good sites with improved material, but yields of 4 to 8 m3 ha^{-1} y^{-1} being more typical (Cameron 1996; Price and MacDonald 2012) and wood density is about twice that of most conifers (Worrell 2023). Early growth is rapid, making it a candidate for short rotation forestry, but for larger material, rotations of 40-45 years are typical on good sites and between 50-55 years on more typical sites (Price and MacDonald 2012). There is no degradation in timber quality if birch is grown rapidly (Hynynen *et al*. 2010). Birch grows between 20-100% more rapidly than downy birch, depending on provenance (Worrell 2023).

Unfortunately, there are no developed markets for domestic birch logs in Britain, although there is some demand for the wood for furniture making, turnery and joinery (Price and MacDonald 2012). This demand is currently met by imports (Price and MacDonald 2012) but UK birch could meet the standards set for Finnish veneer (Cameron *et al*. 1995) so there is potential to market domestic birch timber in the future.

Silvics of birch

Birch is a relatively small, short-lived pioneer tree, normally reaching a height of about 20m (Savill 2019) and living to 90-100 years, and exceptionally 150 years (Beck *et al*. 2016). Initial growth is fast but slows rapidly after the tree reaches about 25 years old (Vanhellemont *et al*. 2016). Birch and downy birch look superficially similar, and it is likely they are frequently misidentified, but downy birch is more adaptable and is the more commonly found of the two species (Worrell 2023). A comparison of birch with downy birch is shown in Table 1.

Recommended seed sources

In birch, adaptively neutral genetic variation in populations is very high and because of long range dispersal of seed and pollen and the associated gene flow, there is little difference between populations. However, birch exhibits high levels of adaptive genetic variation, particularly that controlling seasonal growth (Worrell *et al*. 2000; Vakkari 2009; Sole-Medina *et al*. 2020). A study of birch clones in Finland showed considerable differences between clones in timing of budburst and especially cessation of growth, although there were also large differences in phenology between years (Rousi and Pousenius 2005).

Birch is a tree that flowers and seeds at a young age and this has enabled UK seed orchards to be productive within a short period and qualified seed orchard material is now available (Future Trees Trust 2022). It is recommended that this material be used for any plantings of birch for timber.

If qualified seed is not available, then there is evidence that moving material north a few degrees latitude will increase growth through increasing the growing season in comparison to local stock (Hubert and Cundall 2006). However, as birch shows a strong response of growth cessation to photoperiod, it is important not to move populations too far northwards in case of increasing risk to frost damage (Li *et al*. 2003). A study collating information from trials in the UK and Scandinavia indicates that material should not be moved more than three degrees of latitude (Worrell 1992), while a more recent review of provenance trials recommended that material could be planted originating from at least two degrees of latitude, or 200km south, of the planting site to improve growth with little risk of maladaptation (Lee *et al*. 2015).

Seed selection, storage and pre-treatment

Seed of silver birch is small, with Worrell (2023) stating that there are 1 to 3 million seeds kg^{-1} and Aldhous and Mason (1994) that there are 1.9 million seeds kg^{-1}. Weight of unfilled or unviable seed is about half this, and Atkinson (1992) found that most seed collected

Table 1 Silvicultural characteristics of silver birch and downy birch

Attributes	Silver birch	Silver birch
Light requirements	Highly light demanding [Pyatt *et al* 2001] requiring at least 5% daylight for survival and 15% for minimal growth (Helliwell and Rowley 2011).	Is more shade tolerant than silver birch and can survive as an understorey tree (Worrell 2023)
Elevation	Up to 350m (Worrell 2023)	Up to 700m (Worrell 2023)
Moisture requirements	Prefers drier and lighter texture soils than downy birch and grows on a wide variety of soils (Atkinson 1992). It will not tolerate waterlogging (Raulo 1978) but sufficient moisture in the upper layer (25cm depth) is important, significantly improving growth of 11 year old birch, particularly dominant and co-dominant trees (Lutter *et al* 2015)	Will grow on almost the full range of forest soils (Worrell 2023), including poorly drained heaths and peaty, waterlogged soils (Savill 2019).
Soil acidity	Birch prefers more acidic soils as increasing pH (from 3.7 to 7.1) decreased growth rate in trials in Estonia (Lutter *et al* 2015).	
Soil nutrition	Absence of birch is thought to indicate a P deficiency in the soil (Savill 2019). Perala and Alvin (1990) support this as they note that birches are sensitive to soil P concentrations.	

was empty, which would explain the poor germination rate of 25% quoted in Aldhous and Mason (1994). Seed arising from qualified seed orchards has a much greater viability and germination rate (J. Clark, personal communication, 23rd August 2023).

Birch produces an orthodox seed with shallow dormancy, which can be stored effectively at 8-10% moisture content at a temperature of less than 4°C, although these recommendations are generic to seed with shallow dormancy (Forest Research 2023a). The seed can be stored at low temperatures in plastic bags for many years or in sealed plastic containers in a fridge (Worrell 2023), although viability has been found to drop by half after eight years when stored at a temperature of 6°C (Valane 1973, in Atkinson 1992).

Germination of birch is often poor in nurseries producing bare-rooted stock. Two pre-treatments were applied to downy birch seed, soaking to a target moisture content of 35% (after De Atrip and O'Reilly 2007) and fully imbibed with greater than 50% moisture content. The target moisture content seeds were exposed to 26 weeks of chilling and then fully imbibed to 19 weeks of chilling before sowing. For those sown in the nursery, a significantly higher number of germinants was obtained through the target moisture content method (De Atrip and O'Reilly 2007). The same study examined germination rates of downy birch under different seed coverings, and standard grit mixed with sand or gravel mixed with sand yielded significantly higher germination than the stand grit covering. The standard grit covering was also compared to using a cloche and hydromulch with the best germination obtained from the cloche and the grit mixed with sand (the sand retained moisture), with the standard grit method being poorest (De Atrip and O'Reilly 2007).

Pretreatment of seed by stratification is not needed to induce germination of birch if there is sufficient light (Brinkman 1974, in Cameron 1996; Sole-Medina *et al*. 2020) or high temperatures of 25-35°C (Vartaaja 1959, in Cameron 1996). However, in low light levels or temperatures lower than 25°C, stratification is required (Black and Wareing 1955, in Atkinson 1992). Forest Research (2023) recommend 3-9 weeks stratification at 4°C. The requirement of light for germination can be reduced by removal of the pericarp or by leaching the seed in water (Black and Wareing 1959, in Atkinson 1992).

Worrell (2023) recommends soaking seed in four times its weight in water, in cold conditions (3-5°C) for 2 to 4 weeks while Valane (1973, in Atkinson 1992) found cooling to 6°C for just seven days as being the optimum. Increasing the time of stratification reduced germination (Valane 1973, in Atkinson 1992). This differing information suggests there is further work to do on identifying optimum germination methods. The use of floating mulches or cloches to provide a benign microclimate for the germination of birch can be recommended to increase germination and this also enables the sowing density to be reduced (Aldhous and Mason 1994).

Raising planting stock and timing of planting

There are two general approaches to producing planting stock: bare root and containerised. For bare-rooted stock, several factors significantly affect its subsequent field performance: root structure and morphology; the balance between roots and shoots; the timing of lifting and transplanting, if transplanting; and its transportation and handling (Goyette *et al*. 2014). A thorough, if dated, account of general nursery practice in Britain is presented in Aldhous and Mason (1994).

In Turkey, cell-grown stock is raised in peat and there is a desire to reduce peat usage. An experiment using peat with different proportions of perlite and zoolite showed that the good growth of birch in peat alone could be matched by 10% zoolite, or 20% zoolite and 10% perlite (Tilki and Memisoglu 2014). Other additions to peat-growing media include biochar. In Finland, the addition of up to 10% biochar did not significantly reduce the moisture content of the growing media but 20% did, and the alkalinity of the biochar had a significant liming effect. While fertiliser application had the greatest effect on seedling growth, the best quality seedlings were grown in 10% biochar with fertiliser, and exhibited enhanced root growth (Köster *et al*. 2021). An appropriate soil pH for raising birch is 5.0-5.5 (Aldhous and Mason 1994), which agrees with 5.3 given by Hanks (1969) for North American birches.

As birch seed are very small, they are commonly sown in seed trays before being transplanted to 200cc cells for cell-grown planting stock. As the UK moves towards peat-free composts, the amount of peat used is being gradually reduced and substitutes found. The growing medium can comprise bark and coir, with a low feed fertilizer incorporated to help nutrition. (Clark, personal communication, 18 March 2024).

Hanks (1969) described the level of nutrition and other soil characteristics used in the nursery when propagating bare-rooted birches (including silver birch) in the USA (Table 2). An experiment using four tree species, including birch, tested the impacts of increasing levels of nitrogen fertiliser from 40kg N ha^{-1} (the normal level of fertiliser application in Irish nurseries and similar to that described in Table 2) up to 160 kg N ha^{-1} in the transplant bed. This resulted in a higher density of larger seedlings with higher root growth potential being produced. For birch (and alder), the additional cost of the nitrogen was more than offset by the increased return from the greater number of saleable plants at the end of one growing season (O'Reilly *et al*. 2008). The nitrogen content of birch seedlings grown in containers was positively linked to field performance (Heiskanen and Rikala 1998).

Concerns about leaching of nutrients from forest nurseries precipitated a study to compare conventional, even delivery of nutrients with demand-driven delivery (more nutrients at times in the year when growth is more rapid). Rytter *et al*. (2003) found that the demand-driven method reduced fertiliser use, while producing a similar sized tree, and height growth in the field after three growing seasons was not significantly different. It is recommended that higher levels of nutrient be used in transplant beds, but that the dosage be varied to reflect the demands of the trees.

Table 2 recommended soil pH, cation exchange capacity and nutrition for birch in the USA (1Hanks 1969) and percentage dry weight for birch in GB (2Aldhous and Mason 1994).

Soil attribute	Quantity[1]	Percentage dry weight [2]
Nitrogen	Available N 37kg ha^{-1}	2.3-2.8
Phosphorous	P_2O_5 67kg ha^{-1}	0.18-0.25
Potassium	K_2O 196kg ha^{-1}	1.0-1.2
Calcium	5 meq per 100g	0.15-0.2
Magnesium	1.5 meg per 100g	0.1-0.15

To ensure planting stock has a healthy root:shoot ratio, the size specifications for bare-rooted oak and other broadleaves is described in Table 3, and for cell-grown broadleaves in Table 4. It is interesting to note that for bare-rooted stock the size and shape of the stock varies by species of broadleaved tree but not for cell-grown stock. This needs some investigation as the container volume and the growing space were found to have an influence on the field performance of birch five years after planting at two forest sites in Finland (Aphalo *et al*. 2003). Two types of trays were used, EK-45 3 3 (9 x 5 cells of 190 cm3 each) and EK-28 (7 x 4 cells of 300 cm3 each), and the growing space was altered by using differing proportions of the cells in the trays. Larger cells and greater growing space produced larger seedlings. Results showed that mean

Table 3. Minimum root collar diameters (mm) for different heights of bare-rooted planting stock (birch = Betula *spp., beech* = Fagus sylvatica*, oak* = Quercus*, ash* = Fraxinus excelsior*, gean* = Prunus avium *and lime* = Tilia *spp.) (Morgan 1999).*

Species	Height range (cm) 20	30	40	50	60
BIRCH	3	4	4.5	5.5	6.5
beech	4	5	6	7.5	9
oak/ash/ gean/lime	5	6.5	8	9.5	11

Table 4 Minimum root collar diameter (mm) and cell volume (cc) for cell-grown broadleaved trees (Morgan 1999).

Attribute	Height range (cm) 10-20	20-40	40-60	60-90
Minimum root collar diameter (mm)	4	4	6	8
Minimum cell volume (cc)	50	100	150	200

root collar diameter was strongly linked to early height growth but that stem dry weight of the seedlings had a stronger influence (Aphalo *et al*. 2003). The larger cells used in this study have the same volume (300 cm3) as those recommended for raising broadleaved trees in Britain (Jinks 1994).

Neither root pruning nor shoot pruning of bare-rooted stock of birch was found to be beneficial to survival and growth in the field (Abod and Webster 1990). The negative effect on root growth of undercutting birch seedlings was confirmed in a study in the UK by McKay *et al*. (1999) and so it is not recommended as a nursery practice.

The effect of six different biostimulants and a water-retaining polymer on bare-rooted birch was investigated to determine if they improved growth and vitality of the seedlings (Barnes and Percival 2006). Water retainer was found to have no effect, but two of the biostimulants (Generate and Resistim) had a positive effect on seedling dry weight and leaf chlorophyll content. Applying Generate to transplant-sensitive tree species, such as birch, has been shown to reduce mortality following transplanting (Fraser and Percival 2003, in Barnes and Percival 2006).

The recommended timing for lifting, storage and planting of bare-rooted stock in Britain is described in Morgan (1999). Lifting and cold storage normally occurs between November and March, starting later and ending earlier in southern nurseries. Planting is normally October to April, with autumn planting not being practiced in the coldest climates.

The lifting date and period of cold storage has been found to strongly influence seedling factors that determine the success of establishment in two-year-old birch trees (Lindqvist 2001). Lifting birch too early in the autumn resulted in 62% mortality and 31% with dieback, whereas lifting later resulted in no deaths (Table 5). Root growth potential was found to peak at the second date of lifting (15 October) (Lindqvist 2001). Lifting and cold storage of bare-rooted seedlings of broadleaves is recommended in Britain from December to February, with the optimum being in January (McKay *et al*. 1994). This optimum timing is relatively late when compared with Lindqvist's (2001) period of maximum root growth potential. Normally, lifted trees are stored for three months but can be kept for as much as five months (McKay *et al*. 1994).

Table 5. Mortality and die-back after four weeks' growth in controlled environment rooms, with a temperature and humidity of 20±0.5°C and 65±1% in the day and 14±0.5°C and 85±1% at night, respectively, in relation to lifting date (Lindqvist 2001).

Lifting date	% Mortality				% Dieback			
	Days in cold storage				Days in cold storage			
	Total	90	135	180	Total	90	135	180
17/09	62	30	100	55	31.3	26.9	–*	38.1
15/10	0	0	0	0	0.1	0.2	0.0	0.0
13/11	0	0	0	0	0.1	0.2	0.1	0.0
11/12	0	0	0	0	0.2	0.3	0.2	0.0

* No measurable plants as all were dead

Establishment

Site selection

Currently, much of lowland and lower areas of upland Britain are climatically suitable for growing birch (Forest Research 2023b). However, large areas of Great Britain, particularly in the southeast, are predicted to become unsuitable for growing birch for timber, particularly under a high emissions climate change scenario (Broadmeadow *et al*. 2005). Price and MacDonald (2012) recommend planting birch for timber on sites below 300-350m elevation, although this can be increased by up to 100m on very sheltered locations but reduced in more exposed and coastal areas to 150m or lower. Also, it can be established successfully on sites susceptible to early frosts (Raulo 1978). Climate modelling by Broadmeadow *et al*. (2005) predict a future reduction in suitability of sites in southeast England for growing birch but an improvement in yield in some parts of the north of GB.

Silver birch is a relatively undemanding tree, but to obtain good stem form and timber yields, it should be established on better sites (Raulo 1978), e.g. ones that suit oak, where a dbh of 30-35cm can be achieved within 30 years (Savill 2019). For short rotation biomass, birch was identified as being an attractive option on poor quality agricultural sites in Belgium (Walle *et al*. 2007) and in southern Britain, birch grown as short rotation forestry grew twice as fast as ash or sycamore (McKay *et al*. 2022). Furthermore, Atkinson (1992) suggests that silver and downy birch are adaptable, and probably tolerate a wider range of soils than is recognised.

Silver birch is noted as being relatively resistant to butt rot (*Heterobasidion annosum*, formerly *Fomes annosus*) (Raulo 1978; Piri 1996). However, on some sites, birch has proved to be susceptible to infection resulting in high mortality, low productivity and low vigour (Lygis *et al*. 2004). It may be that susceptibility is linked to different strains of fomes.

Planting season

Morgan (1999) gives generic recommendations for the timing of planting of bare-rooted broadleaves in different parts of Britain. The autumn season extends from October to mid-December and the spring planting season from January to April, and into May if cold store plants are used. Raulo (1978) recommends planting birch in Finland in spring, rather than autumn, for example, to reduce vole damage. He also recommends using container-grown seedlings if planting in summer and autumn, a recommendation supported by a study on 18 sites in Finland that showed that it is possible to plant container-grown active planting stock of birch in summer and obtain growth as good as dormant trees planted in spring (Luoranen *et al*. 2003).

Planting material selection and handling

A study comparing cell-grown and bare-rooted stock of birch on cutaway peatland in Ireland found that survival was excellent using either stock type, while growth after five years was better in bare-rooted material. In contrast, container-grown downy birch grew more rapidly than bare-rooted stock (Renou *et al*. 2007).

Horgan *et al*. (2003) recommend using containerised stock of 20-30cm height, and bare-rooted stock of 40-50cm should be suited to most sites. Larger seedlings are preferred on weedy sites, but not those of over 60cm in height (Worrell 2023). On fertile arable sites, and where weed competition is not heavy, a seedling with a relatively high root:shoot ratio is more important to growth than a tall shoot (Rytter *et al*. 2003). For successful establishment, Raulo (1978) recommends that the height of birch seedlings planted be taller than the surrounding vegetation at its period of maximum growth.

In Finland, there has been success with planting smaller cell-grown birch of 15-30 cm height, compared with the normal 40-60 cm (Pikkarainen *et al*. 2021). The smaller stock has the advantage of being cheaper to produce and transport, and can be planted using a tube rather than a planting hole. In northern Finland and Sweden, even smaller stock of 5-10 cm height has been planted (Pikkarainen *et al*. 2021). One-year-old plugs of birch were shown to exhibit better height growth and survival than two-year-old bare-rooted material one year after planting across five sites in Lithuania and Latvia (Liepiņš and Liepiņš 2009). A trial in Latvia comparing container grown, traditional bare-rooted stock and bare-rooted stock with the 'improved root system' found that the 'improved root system' gave better survival and percentage growth than the containerised and traditional bare-rooted stock, but the differences between it and containerised material were not significant (Dumins and Lazdina 2018).

It is generally accepted that cell-grown material is more resistant to planting out of season and to poor handling and storage, but is more costly (Forest Research 2002b). The effect of rough handling and desiccation on fine root leakage, size and survival after one growing season was investigated for four species, including birch (McKay *et al*. 1999). Survival was unaffected by rough handling but it increased root leakage and decreased height and diameter of the planted trees. Desiccation had a stronger effect by decreasing survival, and this was compounded by rough handling (McKay *et al*. 1999). However, there are benefits of bare-rooted stock, such as lower cost, and also plugs may be more likely to be pushed out of the ground by frost heave (Owston 1990). These conflicting results suggest that defining the characteristics of a robust seedling through a plant quality index (Kerr 1994) or ideotype or target seedling (Owston 1990) might be a more useful approach.

Nutrition

To grow quality birch timber requires benign site conditions and nutritional deficiencies can be compensated for by the application of fertilisers. On sites where phosphorous is deficient, a rock phosphate top dressing is recommended (Worrell 2023). In Finland, nitrogen fertiliser was applied around the trees at a dosage of 8-20g nitrogen (whether ammonium nitrate with lime, ammonium sulphate or urea) in the year of planting with improved growth only in that first year, with growth returning to the rate of unfertilised trees in the second year (Raulo 1978). This supports Miller's (1981) findings that fertilisers act on improving tree growth and do not make long-term changes in the site's productivity. In addition to shortening the rotation (Miller 1981), more rapid growth of the trees accelerates site capture and reduces weeding and other maintenance costs. However, application of fertiliser can have unintended consequences; there was no difference in growth of birch at a trial in Sweden between soil inversion, and soil inversion with the addition of fertiliser, probably because the nutrients stimulated growth of competing vegetation (Berquist *et al*. 2009).

Mycorrhizae are known to considerably improve growth and survival of birch (Frankland and Harrison 1985; Perala and Alm 1990) and soil characteristics were found to be more important than birch species in determining both growth and level of mycorrhizal colonisation of roots (Frankland and Harrison 1985). On certain sites, there is lack of appropriate mycorrhizal inoculum, such as heathlands (Collier and Bidartondo 2009), which delays colonisation of roots.

A study of ectomycorrhizae on birch in five nurseries in northwest Poland identified 21 taxa of which six were exclusively found on birch, with *Heliotales* being the most common genus. The diversity of species was lower than found in forests, but this may be explained by the narrow age range of trees found in forest nurseries, as it is known that there is a succession of mycorrhizal species as trees and stands age (Rudawska *et al*. 2019). A study of ectomycorrhizae on birch classified them into early-stage and late-stage species, with seedling inoculation only being effective with early-stage ones (Fleming 1985). This observation was supported by Mason *et al*. (1984) who found that species of *Inocybe*, *Hebeloma* and *Laccaria*, as well as *Thelephora terrestris*, colonised roots in the first five years following planting and were followed by species of *Leccinum*, *Cortinarius* and *Russula*. Interestingly, they also found that the type and succession of mycorrhizae in seedlings established in wooded areas is different from those on sites without trees.

Given that birch is sensitive to availability of phosphorous, mycorrhizae are likely to be important in the successful establishment of seedlings, particularly on sites poor in phosphorous. On a reclamation site in Iceland mycorrhizal colonisation at planting improved survival and growth, and reduced shoot dieback in downy birch (Oskarsson 2010). However, an experiment comparing the effect of different mycorrhizal species on downy birch showed that some improved survival while others did not, so more research is required (Oskarsson 2012).

For mycorrhizal inoculation, the objectives will influence the choice of fungus, the application method and the timing (Landis 2008). If the aim is to improve seedling growth and vitality in the nursery then the spores of an early associate should be applied to the seeds, the soil or as a suspension. If the objective is to improve performance after planting then the spores should be applied late in the growing season or as a root dip when the seedlings are being processed (Landis 2008).

However, it should be noted that fertiliser application can affect mycorrhizal infection. A study of birch in pots and plantings in the field showed that inputs of nutrients depressed mycorrhizal infection and altered the composition of the mycorrhizal community (Newton and Piggot 1991). These findings were supported by work undertaken by Óskarsson and Halldórsson (2008). They found that the application of fertiliser on a rich and a poor site in Iceland planted with downy birch depressed mycorrhizal colonisation on the poorer site during the first year although there was no difference after three years. At both sites fertiliser application boosted growth of the trees, with dry weight being increased 3.6 times on the rich site and 7.7 times on the poor site (Óskarsson and Halldórsson 2008).

Controlling competing vegetation

On sites where there is significant weed competition, such as bracken (*Pteridium aquilinum*) sites or ex-pasture/arable sites, then some form of cultivation, such as mounding, turfing or shallow ploughing is recommended (Worrell 2023). An experiment using very small birch planting stock (5-10cm height) to examine the effect of cultivation and herbicide use demonstrated the importance of weed control on survival, with almost no survival after a year where there was no site preparation (Karlsson 2002). Cultivation treatments yielding best growth and survival differed by soil texture, with treatments inverting or removing the topsoil found to be best on sandy soils, whereas on a silty soil, soil inversion or rotary cultivation were most beneficial. There was no benefit from a pre-planting herbicide treatment if it was followed by cultivation (Karlsson 2002). A trial across four sites in Sweden also showed increased survival of birch seedlings with scarification or inversion, compared with a control of no pre-planting treatment (Berquist *et al*. 2009).

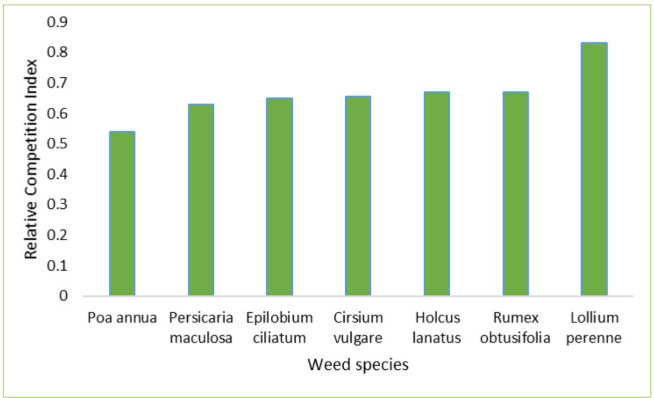
Studies have shown that vegetation cover is strongly linked to growth of young birch (Hytönen and Jylhä 2005; Willoughby *et al*. 2006) and that even sparse weed cover can have a significant effect on growth, but not survival (Willoughby *et al*. 2006). An example of this strong effect is demonstrated in results from a study in Finland. This showed that after 11 years of growth, the volume of birch trees where herbicide had been used to control weed growth was two-and-a-half times that where no weed control had been practised, while mortality was three-and-a-half times lower (Hytönen and Jylhä 2005). Another study in Finland investigated the effect of weeding on growth of birch on former farmland. After twenty years, the volume of birch was much greater in weeded plots, but this was largely due to better survival (76% vs 57% in unweeded plots). Early growth was promoted by weeding but by age twenty years, there was no difference in dbh and height between the weeded and control plots (Hytönen and Jylhä 2013). Thorough weed control is therefore essential for successful establishment, and Raulo (1978) highlighted the necessity of undertaking weeding early in the growing season to provide open, light conditions suited to birch.

There are differences in the toxicity of herbicides to birch. Application of glyphosate and propyzamide to competing vegetation gave a positive effect on growth and survival but terbuthylazine was toxic to birch (Johansson 2000). However, this toxicity was not apparent in another trial (Ferm *et al*. 1994).

Alternative approaches to weed control have been tested, with cover crops being ineffective. However, the use of mulches improved survival but not growth in a trial in southern Finland (Hytönen and Jylhä 2005). Weeding has also been shown to affect the degree of vole (*Microtus* spp.) damage. Particle board mulches and cover crops of clover (*Trifolium* spp.) increased vole damage by providing cover, as did weed cover (Ferm *et al*. 1994).

Some weed species are known to be more aggressive competitors to birch than others. An experiment testing the effect of perennial ryegrass (*Lolium perenne*), bitter dock (*Rumex obtusifolius*), and thistle (*Cirsium vulgare*) showed that all competed for resources with young birch trees, but that ryegrass was a particularly strong competitor (Figure 1) (Willoughby *et al*. 2006).

Figure 1. Indicative relative competition index (RCI) for seven weed species at two birch experiments. Note: RCI = (weed free birch diameter increment – weed presence diameter increment)/weed free birch diameter increment after one growing season. The higher the value the greater the competition with birch from that weed species. Mean of four weed densities (Willoughby et al. 2006).



Site amelioration

A table describing appropriate cultivation under different types of competing vegetation was produced by Worrell (2023) and is reproduced in Table 6. Recent general recommendations for cultivation of different soils have been produced by Haufe (2020), while recent restock sites are not likely to require cultivation (Worrell 2023).

Table 6. Recommended cultivation for different soils and vegetation (Worrell 2023).

Vegetation	Soil	Need for cultivation	Cultivation method
Mire	Gley, shallow peat	Yes, for low density birch	Hand turf
Heathland	Podsol, ironpan, peaty gley	Supports rapid establishment	Scarify Shallow/inverted mounding Hand turf/screef
Acid grassland	Mineral soils	Usually required, especially for timber production	Scarify Shallow/inverted mounding Hand turf/screef
Herb-rich grassland	Brown earths, surface water gley	Usually required, especially for timber production	Shallow/inverted mounding Hand turf/screef
Bracken	Brown earth	Necessary	Shallow/inverted mounding Hand turf/screef
Improved pasture	Brown earth, brown gley	Necessary	Shallow/inverted mounding Hand turf/screef
Ex-arable	Brown earth	Usually necessary	Agricultural plough and herbicide
Conifer restock	All	Can be beneficial if the site is weedy	Scarify/shallow mound or mulch

A high water table will result in poor growth and high mortality of birch, so drainage and cultivation should be practiced on such sites (Raulo 1978). On ex-agricultural sites, cultivation may be required to break up plough pans and also to control weed growth (Raulo 1978). Birch establishes best on sites without, or with only a thin, litter layer and with low or no weed competition (Cameron 1996). Cultivation for spring planting should take place in the preceding autumn, while for autumn planting it should take place at the end of summer. Where machine cultivation is not applied, screefing is known to improve establishment (Raulo 1978).

In Scandinavia, spot mounding and inversion are commonly used for site cultivation in conjunction with cell-grown planting material. Common practice is to plant the seedlings deep (5cm depth) into the mound or inverted sod so that the roots are in contact with the humus layer. This method has been shown to improve growth and survival of 15cm height or greater planting stock, planted in spring, and to reduce damage by pine weevil (*Hylobius abietis*). The effect of deep planting in reducing frost and drought damage on autumn planted stock is not known (Pikkarainen *et al*. 2021) and should be examined further.

Applying three different water retainers either as a root dip or incorporated at planting into the soil showed no positive effects on growth and vitality, and in some cased showed a reduction (Percival and Schaffert 2014).

Protection

Armstrong *et al*. (2001) characterised birch as relatively unattractive as a broadleaved tree to deer browsing and bark stripping, however Bobrowski *et al*. (2015) found that birch was preferred over beech (*Fagus sylvatica*) by red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) for browsing. A study comparing plots where browsing occurred and those where it did not showed that browsing increased mortality in birch and pedunculate oak (*Quercus robur*) more than in beech (Van Hees *et al*. 1996).

Birch responds to being grown in tree shelters, increasing height growth by more than 100% compared with using mesh guards (Potter 1991). This level of improved height growth was also shown by Johansson (2004) in Sweden, but also that shelters encourage the development of a spindly, unstable tree. This is supported by Price and MacDonald (2012) who recommend avoiding using shelters with birch due to the high risk of breakage of the slender stems, and also due to the risk of abrasion. This effect is not long-lasting as two or three years after removal of the shelter, Johansson (2004) found that birch grown in shelters had developed the same level of stem taper as those grown outside shelters. Therefore, if shelters must be used, they should be removed early in the development of the trees. Worrell (2023) notes that birch grows well when protected by plastic netting.

Berquist *et al*. (2009) suggest that temporary fencing, removed after three years may be effective in excluding damage by roe deer due to the relatively fast growth of birch, meaning foliage is above browse height by that age.

Birch is susceptible to vole damage and guards can be used to protect the young trees (Gill 1992). Raulo (1978) suggests some other approaches, including avoiding autumn planting, extensive cultivation the summer before planting to reduce vole populations on site, and use of larger planting stock. He notes that once birch achieves a basal diameter of 4cm, it is resilient to vole damage. If damage occurs, he recommends cutting off the original stem in spring to allow new growth. Rousi (1988) found considerable differences in palatability to voles between different origins of birch, and suggests breeding for resistance to vole damage in birch might be possible.

Planting patterns and use of mixed species stands

A stocking density of 2,500-3,000 stems ha^{-1} is recommended by Worrell (2023), while the relevant Forest Development Type suggests planting between 2,000 and 3,000 stems ha^{-1} (Haufe *et al*. 2021), and Raulo (1978) in Finland recommends 2,500 stems ha^{-1}. A study examining timber quality of birch in terms of stem taper and branching showed no improvement of quality from 2,500 stems ha^{-1} to 5,000 stems ha^{-1} (Niemisto 1995). It is therefore recommended that timber plantations of birch be established at 2,500 stems ha^{-1}. This corresponds to the minimum stocking required for grant funding of planting broadleaved woodland for timber (Scottish Government, no date; Forestry Commission 2024).

The hardiness of silver birch makes it a good candidate as a nurse for more sensitive broadleaved and conifer tree species (Savill 2019). Mixed stands of Norway spruce and birch are common in Finland, Norway and Sweden (Johansson 2003). This produces a stratified mixed stand combining two species with complementary ecological requirements: a light demanding and a shade bearing tree species. One of the aims of the mix is to shelter the Norway spruce and these mixed stands are mostly managed to produce a quality stand of spruce, not birch. However, one variation, termed the shelter method leaves 100-150 stems ha^{-1} of birch within the final crop for biodiversity benefits (Johansson 2003).

Adding birch to a conifer monoculture can improve levels of biodiversity. For example, cover and diversity of ground flora was enhanced by intimate mixtures of birch and Sitka spruce (*Picea sitchensis*), compared with Sitka spruce monocultures (Wallace 1998). A study from Sweden has shown that mixing birch with Norway spruce (*Picea abies*) led to an increase in stand-level biodiversity (Felton *et al*. 2022).

Conclusions

Birch has considerable potential as a timber tree in Britain, producing high quality timber but also providing many environmental benefits. Like many broadleaves, most British information on nursery propagation and planting is generic to all broadleaves. However, there is useful information available from Scandinavia where birch is a more important production species.

Further research

Most advice on nursery practice for broadleaves is generic so there are opportunities to develop prescriptions specific to birch.

There is a need for further research on mycorrhizae. Certain types of sites are known to be deficient and there is some understanding of the succession of mycorrhizal species on birch but there are no prescriptions that combine mycorrhizal species, application methods and site types.

Investigate deep planting on mounds to determine effect on growth and where relevant on *Hylobius* damage.

Recommendations

Seed and nursery

- Use qualified seed orchard material where available, and where this is not possible use material sourced from up to 2 degrees south of the planting site from a select stand.

- Stratification of seed is not usually required but in low light or high temperatures it may be necessary.

- Covering the seed with a medium of sand mixed with grit improves germination compared with grit alone as the sand retains moisture.

- Applying biostimulants (Generate) to nursery stock reduces mortality following transplanting.

- In cell-grown stock, a proportion of the peat-growing medium can be substituted with up to a 30% mix of perlite and zoolite, or 10% biochar with fertiliser.

- Seedlings of a size suitable for sale can be produced in one year by increasing applications of nitrogen from 40kg N ha^{-1} to 160kg N ha^{-1}. The nitrogen content of container-grown seedlings was found to enhance field performance so considering higher nitrogen inputs should be considered. A demand driven approach to delivery of fertiliser, where seedlings receive more nutrition during periods of rapid growth, reduced fertiliser use while producing a seedling equivalent to those raised using a standard fertiliser application.

- There are standards for the height and root collar diameter for bare-rooted and cell-grown stock and these should be followed. There is evidence that stock grown in larger containers have larger root collar diameters and that this improved growth in the field and the cost:benefit should be investigated.

- Undercutting, root pruning and shoot pruning is not beneficial to growth and survival in the field.

- Lifting seedlings in the nursery too early (in September) was found to increase mortality, but from October onwards there were no deaths and root growth potential was found to peak in seedlings lifted in October.

Establishment

- Planting in spring, rather than in autumn and winter, may reduce vole damage. If planting in summer or autumn, it is best to use cell-grown stock.

- Where desiccation or poor handling is a possibility, cell-grown stock should be favoured as when planting in summer. However, in other circumstances planting quality bare-rooted stock is likely to be as effective (and cheaper).

- Fertiliser application at planting can improve growth and reduce the period from planting to site-capture, but the effect on growth is not long-lasting. However, care must be taken not to increase weed growth.

- Mycorrhizal innoculation is known to improve survival and growth of birch. On certain sites, such as heathlands, there may be a lack of mycorrhizal fungi, which can delay establishment. Also, the species of mycorrhizae is important as there is a succession of different species as the trees develop.

- Weed competition strongly affects growth of young birch and so controlling competing vegetation, particularly early in the growing season, is very important. Mulches have been shown to be effective in weed control but, along with clover cover crops, provide shelter for voles, so increasing their damage.

- Appropriate cultivation is beneficial where there are soil limitations to growth or where there is weed competition. Cultivation for spring planting should be completed in the preceding autumn and in late summer for autumn planting.

- If tree shelters are used they should be removed early to minimise development of a spindly stem.

- For timber production it is recommended to plant at a density of 2,500 stems ha^{-1}.

- Young trees need to be protected against vole damage and this can be achieved by using vole guards, removing vegetation close to the tree, using larger planting stock and avoiding autumn planting.

- If vole damage is severe, cut back the seedling to allow new growth.

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