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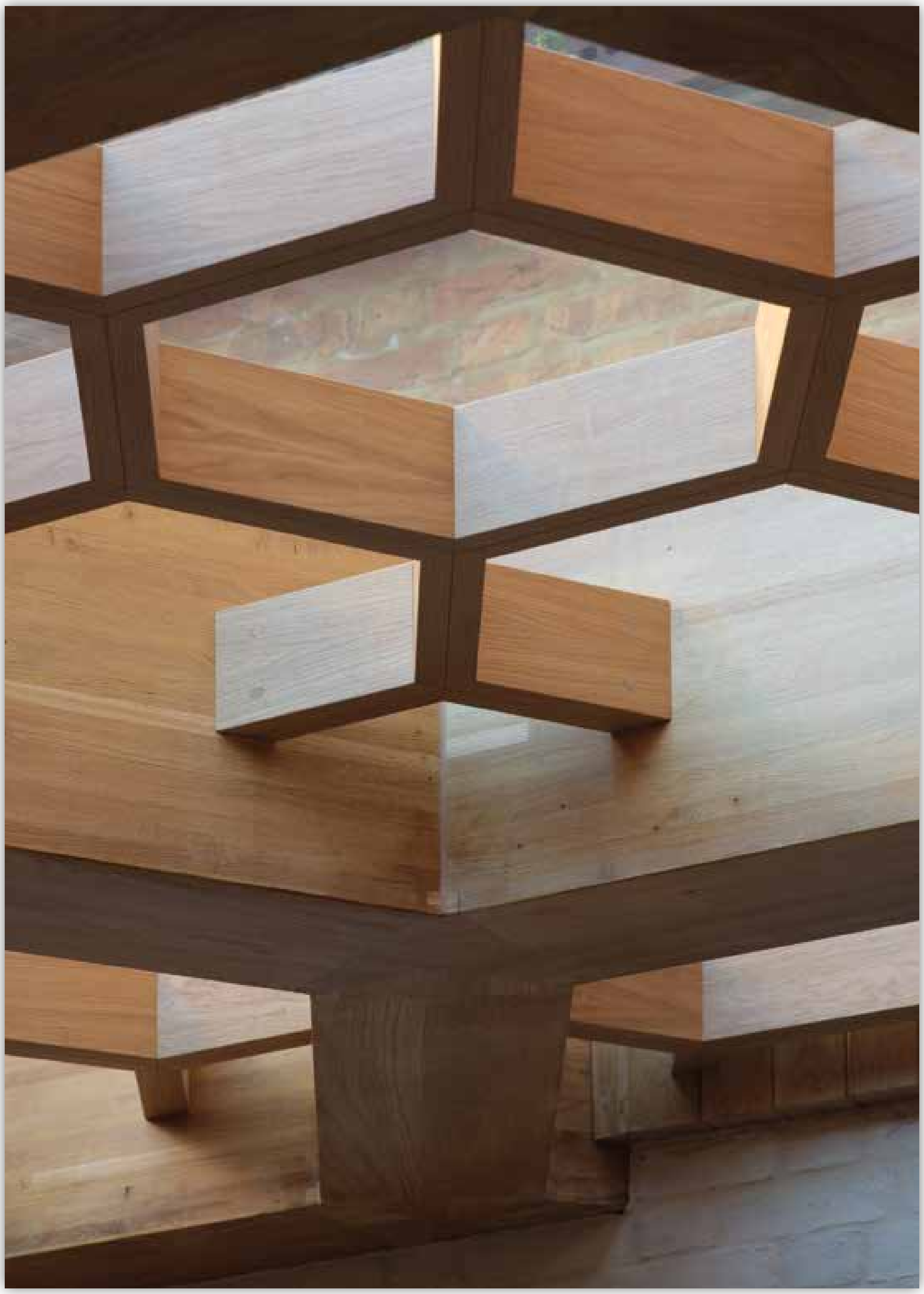

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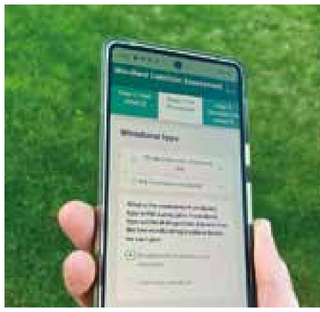
Front cover:
A hexagonal roof structure constructed from UK-grown oak glulam, which was designed and manufactured by Buckland Timber. Read more about Buckland Timber's journey with locally grown timber in their article on page 123 of this issue. (Photo: Philip Vile, Photographer, courtesy of Spaarc Architects)



Mixed species broadleaved and broadleaved/conifer stands in Great Britain for timber production

by Andrew Leslie and Ian Short

Summary:
Using mixed species stands of broadleaves and of broadleaves and conifers, where broadleaves are the final crop, can be a desirable management option. This can increase overall yield, financial return, improve the quality of timber and increase resilience to damaging abiotic and biotic agents. There are few formal trials of such stands, but there is knowledge of how these can be established and managed, developed through the experiences of forest managers and landowners. This article presents a literature review of mixed stands containing broadleaves, focusing on practice in Great Britain.

Introduction

Our native woodland communities, as defined by National Vegetation Classification woodland types, comprise mixed stands of ecologically compatible tree species that reflect climate and soils (Rodwell, 1998). In contrast, much of the productive woodland in Britain is composed of even-aged monocultures (Mason, 2015). More recently, interest in using mixed species stands has been revitalised due in part to damage from exotic pests, pathogens (Figure 1) and by the ongoing impacts of accelerated climate change (Jactel et al., 2017). Mixed stands offer an opportunity to improve the proportion of quality timber from broadleaved stands and may 'overyield' where mixed stands produce more biomass than their component species grown in monoculture (Feng et al., 2022).

Mixed species stands represent 49% of the forest area

Figure 1. Even-aged monoculture of ash severely damaged by ash dieback (Hymenoscyphus fraxineus) in Cumbria. (Photo: Andrew Leslie)

in GB, where mixed stands are defined by the National Forest Inventory as those with less than 90% basal area of one species. Of the area of mixed species stands, 60% were mixed broadleaves and 21% were mixed broadleaved/ conifer, 19% were conifer mixtures, and 60% were even-aged and 40% uneven-aged (Beauchamp et al., 2024). Table 1 shows the inventory results for mixed species stands that cover more than 15,000 ha; there will be many other combinations found covering a smaller area. Of the broadleaved stands, oak (*Quercus* spp.) with ash (*Fraxinus excelsior*), and sycamore (*Acer pseudoplatanus*) with ash are most extensive.

Table 1. Species composition of reported areas greater than 15,000 ha (Beauchamp et al., 2024).

Top two species	Mix type	Area (ha)	% GB Area
Lodgepole pine (*Pinus contorta*)/Sitka spruce (*Picea sitchensis*)	Conifer mix	71,722	2.5
Ash and oak	Broadleaved mix	65,228	2.3
Ash and sycamore	Broadleaved mix	38,941	1.4
Hybrid larch (*Larix* x *eurolepis*) and Sitka spruce	Conifer mix	24,934	0.9
Hybrid larch and Scots pine (*Pinus sylvestris*)	Conifer mix	24,105	0.8
Birch (*Betula* spp.) and Scots pine	Broadleaved/conifer	22,810	0.8
Scots pine and Sitka spruce	Conifer mix	22,738	0.8
Birch and oak	Broadleaved mix	21,071	0.7
Ash and beech (*Fagus sylvatica*)	Broadleaved mix	19,549	0.7
Ash and hawthorn (*Crataegus* spp.)	Broadleaved mix	16,344	0.6
Ash and hazel (*Corylus avellana*)	Broadleaved mix	16,248	0.6
Birch and Sitka spruce	Broadleaved/conifer	16,110	0.6

There are few formal trials of broadleaved mixtures in Britain, but there is a body of knowledge gained through experience of the silviculture of such stands. Using a variety of literature, this article focuses on the range of mixed species stands in Britain, where broadleaves comprise the final crop.

Managing competition between species

For long-lived mixtures, compatibility between species is important. Evans (1984) provided simple rules for lowland broadleaved stands using a conifer nurse. The predicted General Yield Class (GYC) of the conifer should be no more than double that of the broadleaved species, the exception being larch, which has rapid, early height growth and should only be chosen as a nurse if its GYC is no more than 50% greater than the broadleaved species. Mason (2006) proposed that this rule also be applied in the uplands.

In general, compatibility of growth rates is more a problem when mixing broadleaves and conifers rather than mixing broadleaves (Evans, 1984; Mason, 2006). Shade tolerance is important when predicting the compatibility of tree species in a mixed stand. Schlich (1910) divided mixtures into those with shade bearing species, those with shade bearing and light demanding species and those with light demanding species. Schlich's general rules were that mixtures of light demanders and mixtures of shade bearers should be planted in the same year. However, to reduce excessive competition between shade bearing and light demanding species he recommends planting shade bearers after light demanders, although this could disrupt site capture and increases costs. In general, incorporating a shade bearing species like beech in a mixture provides resilience to delayed management, as it will suffer less from overtopping (Darrah and Dodds, 1967).

A method incorporating both shade tolerance and growth rate was developed by Kerr et al. (2021) who also provided guidance on how planting pattern and its influence on the level of interaction between species can be used to improve compatibility. This has been developed into a spreadsheet management tool (Forest Research, 2023). An intimate mixture results in the highest level of interaction between species and is best achieved by careful matching of growth rates of the species and other characteristics such as shade-tolerance or crown architecture. If faster growing species are mixed with slower growing ones, then to maintain all species in the canopy, regular release of the slower growing species is needed. Interspecific competition can also be reduced through the planting pattern. For example, planting species with different growth rates in discrete single-species blocks results in competition between species only occurring on the edges of these blocks. This approach is recommended by Rodwell and Patterson (1994) for creating robust mixtures for new native woodland.

Darrah and Dodds (1967) conducted a survey of conifer and broadleaved mixtures in England and came to some general conclusions about planting patterns for such mixtures. Traditional alternate row mixtures could be successful when compatible species were used and they were not neglected. For conifer/broadleaved mixtures they needed to comprise more broadleaves than were needed for the final crop and they were intolerant of the inevitable delays in management. Band mixtures of predominantly broadleaves with a component of conifer were successful in growing a broadleaved stand but do not provide the economic return of ones with a higher proportion of conifers. These bands should contain at least three rows of the broadleaves. The arrangement of the bands should also accommodate the spacing between final crop broadleaved trees (Evans, 2024).

Table 2. Top height of broadleaves in pure and mixed stands in the North York Moors. Data for 15 years is from Gabriel (1986) and for 47 years from Gabriel et al. (2005).

Species	Top height (m) at 15 years		Top height (m) at 47 years		
	Pure	With JL	Pure	With JL & SP	With JL
Sessile oak	2.12	3.97	11.2	13.48	15.15
Beech	1.73	4.06	11.57	14.76	13.86
Sweet chestnut	1.73	4.45	12.33	15.69	16.26
Birch	4.15		15.35	16.55	17.19

Forest Development Types, a useful tool for establishing specific mixed species stands, has been developed by Forest Research (2024). For each type of stand this provides information on suitability to soils and climate and a timeline of interventions. An aim of this framework was to stimulate silvicultural innovation, including increasing adoption of mixed species stands.

Benefits of broadleaved mixed species stands

There have been few formal trials of broadleaved mixtures in Britain. However, many landowners and forest managers have developed successful approaches to creating and managing mixed species broadleaved stands, through practical experience. This was captured by Anderson (1950) who describes nurse species that could support primary species across different site types, defined by their ground flora communities.

Moderating adverse abiotic influences

Different tree species respond to abiotic stresses in different ways. For example, a study of mixed stands in Germany showed that the diffuse porous species (sycamore and lime) were more sensitive to drought than the ring porous species (pedunculate oak and ash) (Fuchs et al., 2021). Mixing species with different ecological requirements may decrease the risk of catastrophic loss of the entire stand. However, mixed stands may not offer a solution to the depression in yields caused by damaging events such as drought (e.g. Ovenden et al., 2022). The effects of mixing species on stand resilience to damaging climatic events is likely to be highly dependent on the tree species employed.

The poorer soils, lower temperatures and greater exposure in the uplands encourages use of mixed stands where one species ameliorates the harsh growing conditions, improving the microclimate for other more sensitive tree species. Nursing mixtures are an example of this, where the nurse species improves survival and/or growth of the principal species, and the benefits were recognised by Evans (1984).

A simple, unreplicated experiment in the North York Moors tested growth and survival of sessile oak, beech, sweet chestnut and birch grown as single species, and including the same species grown in mixtures with Scots pine and Japanese larch. Planting a mixed stand improved the growth of the broadleaves (Table 2) and mixing with larch alone had a more beneficial effect than with a mix of larch and Scots pine (Gabriel et al., 2005). Stem straightness was improved in mixture for sessile oak and beech but was poorer for birch and sweet chestnut. A subsidiary trial testing red oak (*Quercus rubra*), two *Nothofagus* species and downy birch (*Betula pubescens*) was also established with the same conifer nurses. An observation after 30 years was that *Nothofagus alpina*, normally susceptible to frost damage, had survived hard frosts and temperatures down to -14°C (Gabriel, 1986).

An experiment at a very exposed upland site at Gisburn, near the Forest of Bowland, tested growth and survival of sessile oak, common alder, Scots pine and Norway spruce in monoculture and in mixture (planted in a checkerboard pattern). General findings after 26 years in the first rotation were that mixtures with Scots pine grew more rapidly than monocultures of the companion species, while those that contained oak performed worse than monocultures of the other species (Jones et al., 2005). Oak itself grew better with Scots pine and with alder than in monoculture. Alder grew more rapidly in a mixture of Scots pine than it did in monoculture. This experiment was replanted with the same species, except for the inclusion of Sitka spruce, and after 20 years it yielded similar results, except for a higher basal area of Scots pine and Norway spruce in mixture. Of the mixtures with broadleaves, the Norway spruce and alder mix basal area was about 40% greater than that of the same species in pure plots, evidence of overyielding, and showed the benefits of growing oak with alder on such exposed sites (Mason and Connolly, 2014).

In the lowlands, where soils and climate are generally better for tree growth, mixed species stands can provide benefits. The provision of shelter through use of nurse species can be important even in the lowlands. Willoughby et al. (2009) found that side shelter benefits the height growth, if not survival, of ash and sycamore, both mid successional trees. Shelter from frost is also important for some broadleaves. Table 3 describes the frost sensitivity of common broadleaved species; hardier species can be used to provide shelter to sensitive species.

Table 3. Susceptibility to frost of broadleaved species (modified from Evans, 1984).

Sensitivity	Species
Very susceptible	Walnuts (*Juglans* spp.), ash, sweet chestnut (*Castanea sativa*), oak, beech, *Nothofagus*, *Eucalyptus.*
Moderately sensitive	Sycamore, horse chestnut (*Aesculus hippocastanum*), some poplars, red alder (*Alnus rubra*), Italian alder (*Alnus cordata*).
Hardy	Birch, hazel (*Corylus avellana*), hornbeam (*Carpinus betulus*), lime (*Tilia* spp.), elm (*Ulmus* spp.), most poplars, common alder, grey alder (*Alnus incana*).

Mixing nitrogen-fixing trees with others is known to improve stand growth in certain situations. An analysis of results from 148 experiments, with 80 being from temperate regions, showed that growth in temperate regions was improved in stands where nitrogen-fixing trees made up a significant proportion of the trees (Marron and Epron, 2019). In a trial in the lowlands of England, planting walnut (*Juglans regia*) with nitrogen-fixing shrubs was found to increase nitrogen in the walnut to an optimum, whereas those without nitrogen-fixing nurses were found to be deficient (Clark et al., 2008). The walnut grown with autumn olive (*Elaeagnus umbellata*), one of the nitrogen fixers tested, also benefited through increased height growth. Evans (1984) described the improved growth in ash through the nitrogen provided by a nurse of alder. It is likely that benefits from growing trees with a nitrogen fixer will be greatest where soil nitrogen is limiting.

Table 4. Comparison of UK hardwood sawlog production with France and Germany (Taylor, 2019).

	Broadleaves area (million ha)	Annual hardwood sawlog production (million m³)	Annual hardwood sawlog production/ broadleaves area (m³ per ha)	Relative sawlog production (UK to other country, UK=1)
France	13.55	4.1	0.3	**6**
Germany	4.7	3.5	0.74	**14.8**
UK	1.5	0.075	0.05	**1**

Figure 2. Oak grown with western hemlock (Tsuga heterophylla) at Micheldever Forest to improve stem form and reduce branching. (Photo: Andrew Leslie)

Improving timber quality

In the UK, the average volume of sawlogs produced annually per hectare of domestic broadleaves is much less than in France and Germany, with the UK average being six times less than in France and fifteen times less than in Germany (Table 4) (Taylor, 2019).

Growing oak in a mixture with a species with a dense canopy as an understorey will inhibit epicormic growth and improve stem form (Figure 2). In

Germany it is considered that to obtain quality stems, beech, lime or hornbeam should be planted with sessile oak which is managed on long rotations to produce sawlogs (>160 years) or veneer (>240 years) (Joyce and Gardiner, 1986). In a study in the English lowlands, planting walnut with autumn olive reduced coarse branching and the number of multiple stems, and increased height growth in the walnut, as did planting with hazel (Clark et al., 2008).

Increasing yield

There are many examples of mixed stands 'overyielding' or producing more volume or biomass than each species in monoculture. Feng et al. (2022), in an analysis across multiple experiments and continents, found complementarity in functional traits to be an important element of overyielding. For example, mixing a light-demanding species with a shade-bearing species may increase the efficiency of use of light within a stand. Other traits influencing overyielding are described in Figure 3. A global meta-analysis across 54 studies also provided evidence for overyielding, and identified important factors such as evenness in the proportions of species making up the mix and also variation in shade tolerance (Zhang et al., 2012). Overyielding would appear to be linked to the attributes of the species present rather than the level of species diversity in the stand (Jacob et al., 2010). Also, in practice, simple mixtures may be better than higher yielding but more complex approaches (Del Rio et al., 2022). For ease of management there are benefits to keeping the number of species in a mixture to two, rather than adopting more complex mixtures, as they are easier to manage and are likely to be more resilient to lack of management, such as delayed thinning (Darrah and Dodds, 1967).

Overyielding in some cases appears to be most pronounced on poorer sites and declines as site quality improves (Toigo et al., 2015; Pretzsch et al., 2013). For example, an analysis of 37 experiments in Europe showed that mixing beech and oak increases productivity by about 30% compared to monocultures of the same species, but the benefits were only found on poorer sites (Pretzsch et al., 2013). However, there are instances on good sites where, at least early in the rotation, there is an increase in yield. An experiment on a good ash site in Devon mixing ash with cherry (*Prunus avium*), ash with beech, and ash with oak investigated the influence of mixture on diameter and height growth and stem form. After five growing seasons the relative yield totals (volume compared with pure stands of the same species) were 1.78 for ash and cherry, 1.77 for ash and oak and 1.44 for ash and beech (Kerr, 2004).

A recent and innovative approach to managing mixed species stands has been applied to a 19 ha compartment at Norbury Park Estate (Roberts et al., 2022). This involved establishing a highly diverse, intimate mixture of 27 species, of which 22 were broadleaves at a stocking density of 2,600 stems ha^{-1}. At age seven there was a line thinning of one in seven rows and of the remaining trees 200-250 quality stems were selected as final crop trees. The competitors to these trees were halo-pollarded at 1.8 to 2.4 m of height, creating an open zone of 1-2 m around the final crop trees. This free growth approach increased growth of the final crop trees, although overall volume production was reduced. This is an interesting approach to managing diverse, intimate mixtures but is management intensive.

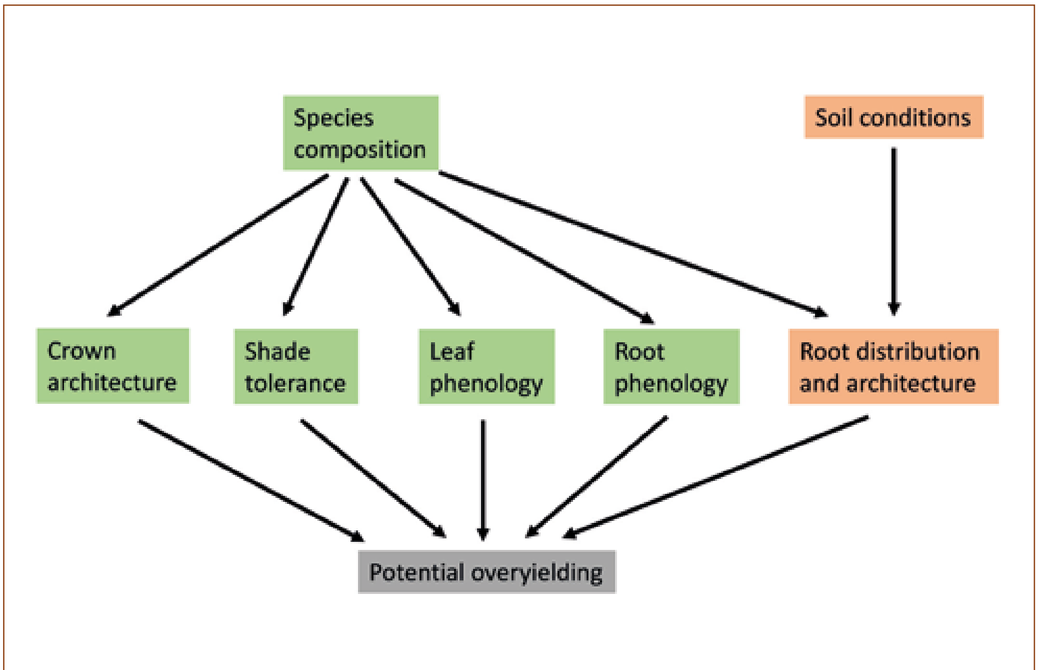


Figure 3. Factors influencing overyielding through complementarity or reduced competition for resources (modified from Lu et al., 2018).

Improving financial return

There are economic reasons for establishing mixed species stands. Growing a species that has a shorter rotation with species that have longer rotations can improve the financial return from a forest stand (Figure 4). In Britain, this has often involved growing a conifer to provide shorter term financial returns with a broadleaved species to provide longer term returns. Up to 50% of the stand can be planted with conifers without detrimentally affecting the quality of the final broadleaved crop (Kerr et al., 1992). The current England Woodland Creation Offer grants, while focused on pure conifer or broadleaved stands, can support conifer/broadleaved mixtures (Chris Watson, Forest Resilience Advisor, pers. comm 2024).

Bolton (1949) notes that sycamore grows much better in a mixed stand – with shelter from the other species – than in pure stands. He also recommended growing sycamore and European larch or Japanese larch at a ratio of five larch to one sycamore for economic reasons, as early thinnings of larch had a market and sycamore did not. Table 5 describes the general compatibility of five conifers when grown with oak, beech and ash. These combinations conform to those recommended by Schlich (1910).

Improving resilience to biotic agents

Mixed stands can have greater resilience to damaging biotic agents because the level of damage will differ between tree species. This has been called the 'insurance hypothesis' by Pautasso et al. (2005) as it is likely that following a devastating pest or pathogen incident, not all tree species in a mixed forest will be lost. Mixing tree species may also reduce the apparency of host trees to their pest or pathogen, and also may reduce transfer of these damaging agents from one tree to another tree of the same species. In France, decreasing the proportion of pedunculate oak in mixed species stands reduced damage by leaf miners, but not leaf chewing insects (Castagneyrol et al., 2013). Some broadleaves are prone to damage by pathogens when grown in monoculture. For example, growing large areas of cherry in monoculture is not recommended due to damage by canker (*Pseudomonas syringae*) (Kerr and Evans, 1993).

Table 5. Compatibility of conifers and broadleaves (Kerr and Evans, 1993).

	Norway spruce	European larch	Scots pine	Corsican pine	Western red cedar
Oak	✓	✓	✓		
Beech	✓	✓	✓	✓	✓
Ash	✓	✓			

Figure 4. Oak, Scots pine and larch planted in Ireland to be grown on different rotations. (Photo: Ian Short)

Conclusion

Mixed species broadleaved stands have a place in modern forestry in Britain. There is limited but positive evidence that their use can increase overall yield and, through a nurse, moderate unfavourable climatic or soil conditions for a more sensitive tree species, and certain species can improve soil nutrition. However, in an era of climate change and the devastating introduction of novel pests and diseases, mixed stands can also provide an insurance policy as different species will be subject to varying degrees of damage. By using a faster growing species in a mix, with a slower growing final crop species, the financial returns can be improved. Finally, the use of a nurse species that provides competition and shade can improve the form and decrease branching in the final crop species.

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