Noble Hardwood Alternatives to Ash

Maples (*Acer* spp.), planes (*Platanus* spp.), hickories (*Carya* spp.), wingnuts (*Pterocarya* spp.), hop hornbeams (*Ostrya* spp.), sweetgum (*Liquidambar styraciflua*) and tulip tree (*Liriodendron tulipifera*).

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review the potential of some less familiar timber hardwood species as substitutes for ash (*Fraxinus excelsior*).

Much thought is being given by foresters to alternative tree species that might be grown in Britain and Ireland if climatic change proceeds as predicted, and in light of threats from novel tree pests and diseases, which have proliferated over the past two decades. Recently, the Wessex Silvicultural Group has considered this matter (Bladon and Evans, 2015), as have Forest Research (2016). There is an online network promoting novel species thought to have potential to grow well in the UK (SilviFuture, 2016), including nine high priority and 20 medium priority species. Read et al. (2009) suggested 49 'emerging' species (24 conifers and 25 hardwoods) with potential for adaptation of British forests to predicted climate change.

To date, less attention has been devoted to alternative hardwood species than to alternative conifers. However, the incidence of *Chalara fraxinea* in ash (*Fraxinus excelsior*) since 2012 prioritises alternative hardwood tree species that might be used in place of ash, particularly for production of high quality hardwood timbers. Ash is currently the third most abundant hardwood in Britain, after oak and birch, extending to some 130,000ha, or 5-6% of national woodland cover. Alongside oak, beech, sweet chestnut and sycamore, it is one of our most important timber hardwoods, meeting specific requirements for furniture and sports goods. Ash has previously been favoured in woodland creation schemes due to its inherent values for biodiversity and timber, ease of establishment and resistance to grey squirrel impact.

Where ash is grown in ancient semi-natural woodlands, mainly for conservation objectives, the preference is to replace it with other site-adapted native species, by infill regeneration or enrichment planting. There are also long-introduced hardwoods, producing valuable timbers, that may be used under suitable circumstances – sycamore (*Acer pseudoplatanus*), sweet chestnut (*Castanea sativa*) and Persian walnut (*Juglans regia*) (Hemery et al., 2010).

However, we might consider a range of less familiar hardwoods from temperate deciduous forests in North America, eastern Asia and south-western Eurasia (Röhrig and Ulrich, 1991) (Table 1, Figures 1a&b). Some are known to produce valuable hardwood timbers suitable for similar applications to ash. Most species have only been trialled in Britain and Ireland in arboreta and forest gardens but a few have been extended to small-scale plantations. In this article we highlight a selection of these 'candidate alternatives' to ash and direct interested readers to available sources of further information. For species-specific information, we have relied in particular on Burns and Honkala (1990), Forest Research (2016), Leopold et al. (1998), Macdonald et al. (1957), Streets (1962) and Willoughby et al. (2007).

Three other relevant groups of alternative hardwood

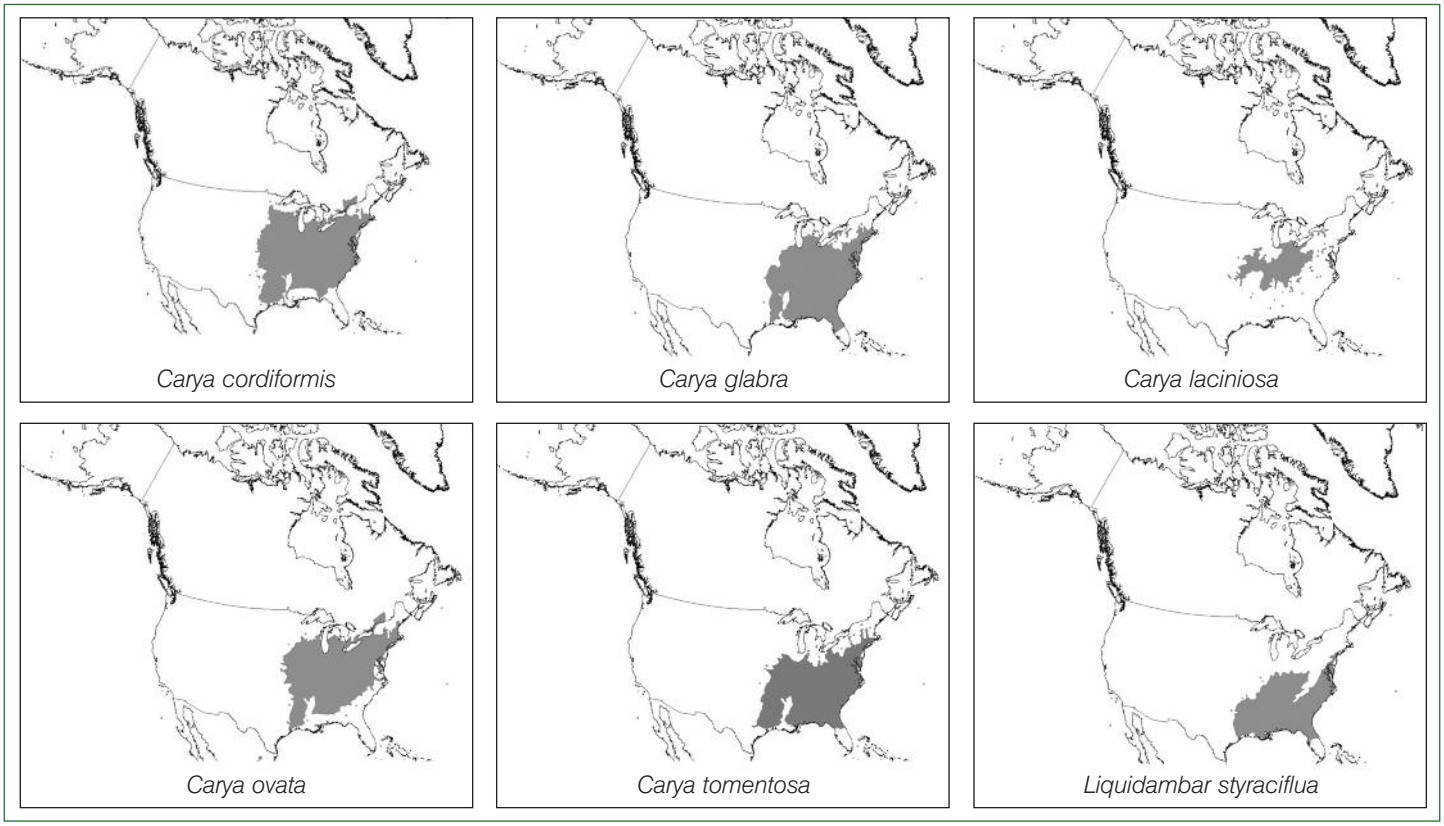

Figure 1a. Distribution maps of hickories (Carya spp.) and sweetgum (Liquidambar styraciflua) in North America. (Source: US Geological Survey, 1999)

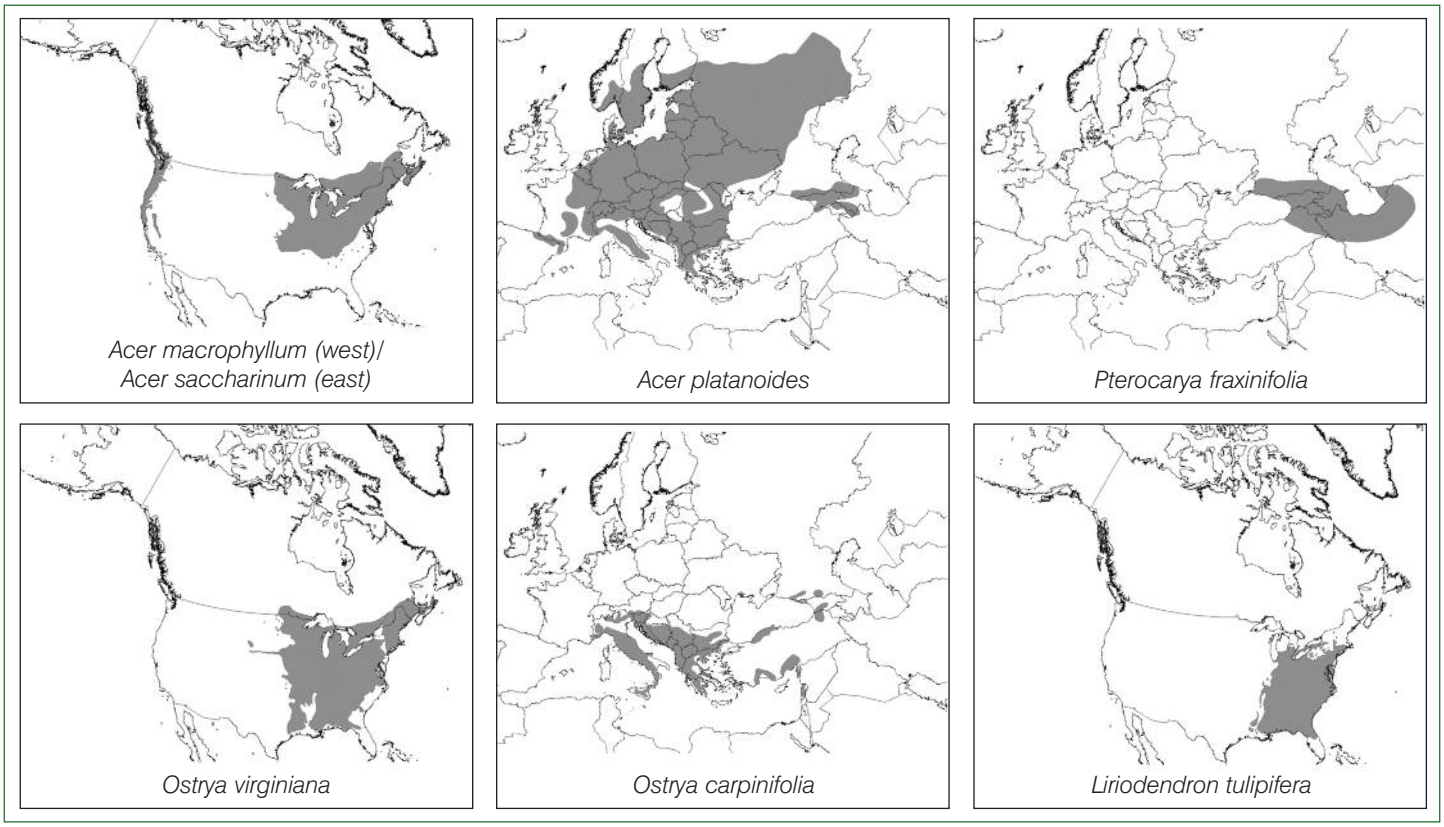

Figure 1b. Distribution maps for maples (Acer spp.), wingnut (Pterocarya), hop hornbeams (Ostrya spp.) and tulip tree (Liriodendron) (Sources: American species: US Geological Survey (1999); Acer platanoides redrawn from Caudullo and de Rigo (2016); Ostrya carpinifolia redrawn from Pasta, de Rigo and Caudullo (2016); Pterocarya fraxinifolia redrawn from Russell and Cutler (2003).

timber species are *Eucalyptus* species, *Nothofagus* species and alternative oaks (e.g. *Quercus pubescens*, *Quercus rubra*). The *Eucalyptus* species were profiled in this series by Purse and Leslie (2016) and the *Nothofagus* and alternative oak species will be dealt with in forthcoming articles. It is also intended to deal with the poplars (*Populus* spp.) and alders (*Alnus* spp.) in a later article in the *QJF*.

Maples (*Acer* spp.) and Planes (*Platanus* spp.)

The maples (*Acer* spp.) in the Sapindaceae family, and the planes (*Platanus* spp.) in the Platanaceae family, offer several potential timber hardwood alternatives to ash. Native field maple (*Acer campestre* L.), and sycamore (*Acer pseudoplatanus* L.) (introduced from Continental Europe centuries ago) are most familiar. Norway maple (*Acer platanoides* L.), introduced from Continental Europe in 1683 (Macdonald et al., 1957), has broad site tolerances, and has been used successfully in plantations on a modest scale in southern and eastern England (Figure 2). The London plane (*Platanus* × *hybrida* Brot) is a hybrid between western plane (*P. occidentalis*), native to eastern North America, and oriental plane (*P. orientalis*), native to south-eastern Europe/Balkans (Feng et al., 2005; Grueva and Zhelev, 2010). It is believed to have arisen in the Oxford Botanic Garden around 1670

Figure 2. Norway maple, Westonbirt Arboretum, Glos. (Photo: John White)

Table 1. Principal characteristics of the alternative hardwoods evaluated.

[1]First line of each entry refers to ESC Soil Moisture Regime (SMR) and the second line to ESC Soil Nutrient Regime (SNR) (Pyatt et al., 2001).

[2]For common ash (*Fraxinus excelsior*) the equivalent wood density is 680kg/m^3

Species	Scientific names	Region of origin	Frost limit /°C	[1]Estimated ESC soil preferences	Shade tolerance	Typical max. ht/m	Seeds /kg	[2]Wood density (12% MC) /kgm^{-3}
Norway maple	*Acer platanoides*	Western / central Europe	-29 to -35	Moist / Fresh Rich / V. Rich	High	18-21	11,000	645
Bigleaf/ Oregon maple	*Acer macrophyllum*	Pacific NW America	-17 to -23	Moist / Fresh Medium / Rich	Medium	25-30	5,000-8,000	545
London plane	*Platanus x hybrida*	NE America x Mediterranean	-17 to -23	Fresh / M. Dry Medium - Calc	Low	30+	450,000	560
Shagbark hickory	*Carya ovata*	Eastern North America	-23 to -29	Moist / Fresh Medium / Rich	Medium	25-30	200-250	800
Mockernut hickory	*Carya tomentosa*	Eastern North America	-23 to -29	Moist / Fresh Medium / Rich	Medium	25-30	70-250	815
Caucasian wingnut	*Pterocarya fraxinifolia*	Caucasus / Turkey / Iran	-17 to -23	V. Moist / Moist Medium / Rich	Low	25-30	15,000-20,000	610
Hop hornbeam / ironwood	*Ostrya virginiana*	Eastern North America	-29 to -35	Moist / Fresh Poor / Medium	High	10-20	60,000-70,000	785
American sweetgum	*Liquidambar styraciflua*	Eastern North America	-23 to -29	Moist / Fresh Medium	Low	24-26	130,000-200,000	590
Tulip tree	*Liriodendron tulipifera*	Eastern North America	-29 to -35	Moist / Fresh Medium / Rich	Low	45-60	10,000-40,000	455

Figure 3. London plane, Derby Arboretum, Derby. (Photo: Scott McG. Wilson)

(Macdonald et al., 1957) and has been used as an urban street tree and in small plantations (Figures 3 and 4). Read et al. (2009) suggest other maples of interest are (a) bigleaf or Oregon maple (*Acer macrophyllum* Pursh), native to Pacific Northwest America (Day, 1955; Niemec et al., 1995) (Figure 5), and (b) silver maple (*Acer saccharinum* L.), native to eastern North America (Leopold et al., 1998) (Figure 6).

Figure 4. London plane, Richmond, Surrey (Photo: Scott McG. Wilson)

Figure 5. Bigleaf or Oregon maple - Kilmun Forest Garden, Argyll. (Photo: Bill Mason)

Figure 6. Silver maple - Westonbirt Arboretum, Glos. (Photo: John White)

These two species were introduced to Britain in 1825 and 1735 respectively (Macdonald et al., 1957) and have been tried in arboreta and forest gardens. Maples and planes of interest are medium to large trees, often achieving over 20-30m in height, with a spreading crown, smooth or platy bark and broad pinnate/palmate leaves. Native ecosystems where these species are found are usually temperate mixed hardwood forests with fertile, moist soils. Bigleaf maple is exceptional in occurring in a mainly coniferous ecosystem (Turk et al., 2008).

Climatic and site requirements

Maples and planes are most suitable as substitutes for ash on moist, fertile soils in warmer, lowland parts of Britain, including valley woodlands. These are the conditions of the lowland mixed ashwood (NVC W8) ecosystem (Rodwell, 1991) and analogous plantations. These conditions most closely resemble the species' native temperate mixedwood ecosystems. Cold hardiness for British conditions is good across this group. With the exception of sycamore, maples and planes are unsuited to wind-exposed conditions and are less likely to be useful substitutes for ash in upland ashwoods (NVC W9). Evidence from a plot at the Kilmun Forest Garden, Argyll does suggest that bigleaf maple can perform well under more sheltered upland conditions on less fertile soils, and so it, along with sycamore, offers opportunities for better upland sites. Maples and planes grow best with a soil moisture regime (SMR) of Fresh to Moist and a soil nutrient regime (SNR) of Poor to Rich, in terms of the Forestry Commission Ecological Site Classification (ESC) (Pyatt et al., 2001). None tolerates very infertile, sandy, waterlogged or peaty soils. Where soil conditions are droughty and/or calcareous, selection of species from this group is restricted to field maple, Norway maple and London plane. Such sites occur in limestone ash-beechwoods (NVC W12).

Provenance, seed production and nursery practice

Maples produce winged seeds or samaras, carried some distance from the parent tree by the wind. Field maple and sycamore reproduce well by natural regeneration in Britain and Ireland. Norway maple produces seed early, and copiously by 25 years, typically with 11,000 seeds per kg with a 70% germination rate. Seed can be over-wintered in moist sand. No nursery problems are reported. Forest Research (2016) recommends seed is taken from good British stands or selected stands in Western Europe. This is supported by provenance trials, reported by Kerr and Niles (1998), comparing European provenances.

Bigleaf maple is monoecious, with combined male and female flowers, producing seed from age 10 years (Iddrisu and Ritland, 2004). There are 5,000-8,000 winged samaras per kg, which can be stored for a year if collected dry (10-20% MC). In nature regeneration from seed is good under a partial canopy but poor in open areas and under denser canopy shade. This species will also reproduce vegetatively from stumps, often at an excessive density for quality timber production. It grows rapidly in the nursery, reaching 1-2m within a year, but limited planting is actually undertaken within the native range. There are no provenance trials in Britain, but Forest Research (2016) recommends use of Washington provenances.

Silver maple produces seed from 11 years of age. There are 2,000-7,000 samaras per kg. This species regenerates well from seed under suitable conditions in the native range. Seed is rarely set in British conditions but natural regeneration has been found locally in Surrey. Silver maple seed germinates in the nursery without stratification (Leopold et al., 1998). There are no British provenance trials, but Forest Research (2016) recommends silver maple from the northern part of its native range, to ensure cold hardiness for Britain.

The *Platanus* species are monoecious and produce seed balls (2cm in diameter) containing a mass of light seeds (~450,000/kg). The dispersing seed balls, and urban pollutants they accummulate, can cause allergenic effects. Seed production begins before age 10 and is optimum from 50-200 years for *P. occidentalis* (Burns and Honkala, 1990). The London plane is a fertile hybrid and natural regeneration has occasionally been observed. Some plants are produced by nurseries for the horticultural trade in Britain. There have been no provenance trials for planes in Britain and no guidance is available on provenance selection.

Silviculture

The maple species naturally form a component of mixed-hardwood stands on productive sites. Silvicultural regimes and yield predictions for these species in Britain currently rely on experience with even-aged sycamore. Macdonald et al. (1957) present growth and production data from older Norway maple trial plots in Britain. Kerr and Niles (1998) report early height growth data from provenance trials in southern England and Savill (2013) discusses silvicultural aspects for this species. Norway maple grows rapidly for its first 40-50 years and is difficult to manage in mixtures (Forest

Research, 2016). Macdonald et al. (1957) suggest that Norway maple can out-perform beech in mixture unless carefully thinned.

Bigleaf maple is moderately shade tolerant and can be managed in mixtures with oceanic conifers, making it attractive for diversifying upland conifer forests on better soils. Thinning to final spacing by 15 years is recommended, with a spruce-compatible rotation of 40-50 years. The productive bigleaf maple stand at Kilmun Forest Garden reached 11m after 22 years, 28m after 63 years and is estimated as achieving GYC 14 (Mason et al., 1999). Silver maple is regarded as a light-demanding species but its shade tolerance increases on productive sites (Forest Research, 2016). Growth in plantations can be rapid based on American experience, with Burns and Honkala (1990) reporting 25m height after 43 years.

There is little experience of plantation silviculture with London plane in Britain, with most trees being in urban park and landscaping contexts where 30m height is frequently achieved. This species is light-demanding and must be well thinned in plantations to permit adequate crown development. Based on experience with the parent species *P. occidentalis* (Burns and Honkala, 1990), plantations in North America are fast-grown, yielding 7-15$m^3ha^{-1}yr^{-1}$ over conventional rotations, and potentially much higher in shorter-rotation coppice woodlots.

Pests and diseases

The major challenges with the maples are their vulnerability to bark stripping by grey squirrels, as with sycamore, and susceptibility to leaf spot diseases and *Verticillium* wilts (Forest Research, 2016). Root-rot fungi such as *Phytophthora* and *Armillaria* (honey fungus) can be a problem, particularly in mature specimens. The specific butt rot fungi *Ganoderma applanatum* affects bigleaf maple. Susceptibility to *Phytophthora ramorum* has been demonstrated in the Pacific Northwest and might constrain deployment in Britain on infected ex-larch sites. The sapstreak disease (*Ceratocystis virescens*) is a serious threat to silver maple in North America, but is not thought to be present in Europe.

Traditionally, the main disease of the planes was anthracnose (a fungal disease of leaves), which affected London plane less severely. More recently, canker stain (*Ceratocystis fimbriata* f. *platani*) and Massaria disease (*Splanchnomena platani*) have emerged as serious threats to planes growing in Continental Europe and the latter is now known to occur in Britain.

Timber properties and utilisation

Interest in these species centres on their attractive, light coloured hardwood timbers suitable for furniture making, decorative carpentry (e.g. kitchen worktops) and musical instruments. Figured material can attract especially high values for such applications, as in the case of sycamore. *Platanus* is one of several species known as lacewood in the timber trade as, when quarter-sawn, it has a distinctive and highly decorative appearance of dark reddish-brown flecks against a lighter background. These timbers are relatively hard and strong, but not particularly durable. They are less suitable for physically demanding applications such as hardwood flooring and sports goods, for which ash is favoured. Hardwood pulp and woodfuel are potential markets for smaller dimension and inferior grade material.

Species Profile

Hickories (*Carya* spp.)

The hickories (*Carya* spp.) are a large group of hardwoods within the wider Juglandaceae family, also containing walnuts and wingnuts (see below). The species most likely to be sufficiently cold-hardy for British conditions are those native to the northern Appalachians and New England. The species of primary interest are shagbark or little shellbark hickory (*Carya ovata* (Mill.) K. Koch), proposed by Read et al. (2009); the mockernut, big bud or white heart hickory (*Carya tomentosa* (Poir.) Nutt.); pignut hickory (*Carya glabra* (Mill.) Sweet); bitternut or swamp hickory (*Carya cordiformis* (Wangenh.) K. Koch) and big shellbark, bottom shellbark or king-nut hickory (*Carya laciniosa* (Michx. f.) Loud.). These are medium to large deciduous trees capable of reaching 25-30m tall, exceptionally 35-40m. All have paired compound pinnate leaves, some visually resembling those of ash. Hickories typically produce a long clean bole with crown profile varying by species. The bark is smooth and grey when young, becoming fissured or shaggy with age and species (Figure 7). The record of the hickories in Britain is not distinguished, with Macdonald et al. (1957) reporting slow early growth in arboretum collections. In southern English collections mature specimens have exceeded 20m tall. Performance at Kilmun, Argyll has been poorer, with *Carya tomentosa* failing completely and *Carya ovata* having few survivors.

Climatic and site requirements

Hickories are climatically sensitive, requiring a warm temperate regime without severe frosts. Species suitable for British conditions are those hardy down to -15°C or below. They are therefore most likely to be appropriate substitutes for ash on moist fertile soils in the warmer, lowland parts of Britain, including valley woodlands. These are the conditions of the lowland mixed ashwood (NVC W8) ecosystem and analogous plantations. Most successful trial introductions of hickories to date have been within southern England. There is no evidence to suggest that hickories could be used to substitute for ash in upland ashwoods (NVC W9). Hickories tolerate a wide range of soils, but not very infertile sandy soils. Within the native range in the eastern United States the more northerly species occupy freely-draining montane

Figure 7. Shagbark hickory, Westonbirt Arboretum, Glos. (Photo: John White)

Figure 8. Young hickory, Forest of Dean, Glos. (Photo: Scott McG. Wilson)

upland soils of moderate fertility. There is considerable edaphic variation between hickory species and native ecotypes, which is explored in more detail by Burns and Honkala (1990).

Provenance, seed production and nursery practice

All hickories are wind-pollinated monoecious species, with separate male and female flowers forming on the same plant. They produce heavy, nut-like 'drupe' fruits, some of which are used for for human or animal foods – this applies particularly to shagbark and shellbark hickories and pecan (*Carya illinoiensis* (Wangenh.) K. Koch). In *C. ovata* there can be only 220 such seeds per kg. Seed production begins after 25-40 years and displays a strong 'masting' cycle, as in oak and beech (2-3 years is typical for *C. tomentosa* and *C. ovata* in their native ranges). Hickory seeds display pronounced dormancy, which must be broken by stratification (e.g. 60-150 days at 1-5°C in the case of *C. ovata*). There is a particular difficulty with propagating *Carya* spp. in the nursery due to noted intolerance of root disturbance at transplanting – this may imply that containerised nursery systems or direct sowing of germinated seed would be more effective. It is difficult to source plants in Britain, but seed is available on the international market. There are no domestic provenance trials and consequently, no provenance advice is available. Those trying hickories in Britain (Figure 8) should favour northern species and provenances, and perform ecological site comparisons.

Silviculture

In America hickories are slow-grown, medium-tolerant, late-successional components of temperate hardwood forests, more silviculturally comparable to species such as hornbeam than to ash or sycamore. Hickories are not particularly suitable for even-aged plantation silviculture (Burns and Honkala, 1990) and selection silviculture is preferred (Cowden et al., 2014). Most prescriptions in the American literature are for natural oak-hickory stands, with a variety of red and white oak species, where hickory is a minority component. This stand type has extended northwards since the early 1900s, replacing the former oak-chestnut community, devastated by chestnut blight. Hickory is generally slower growing than its oak companions and can be suppressed by mid-rotation unless released by thinning. However, if preserved it is a long-lived component and can be managed on rotations of up to 200 years. Consideration might be given to trialling oak-hickory plantations in lowland Britain, especially if sweet chestnut is seriously affected in future by chestnut blight (*Cryphonectria*).

Pests and diseases

Little is known of the susceptibility of hickories to pests and diseases present within Britain and Ireland, due to the lack of previous trials. Deer and grey squirrel susceptibility in the earlier, smooth-barked, phase may be significant.

Timber properties and utilisation

An advantage of many hickory species is their hard, heavy, tough timbers, suitable for furniture, interior carpentry, fencing and particularly tool handles and sports goods (Sachsse, 1980; Seeling, 1998). Some are therefore potential substitutes for ash, particularly in the sports grades (e.g. hockey/hurley sticks), although growing time required to reach suitable dimensions might be considerably longer. The firewood of many hickory species is favoured in the North American range and is suitable for smoking and barbecuing meat and fish.

Wingnuts (*Pterocarya* spp.)

Caucasian wingnut (*Pterocarya fraxinifolia* (Poiret) Spach) is one of six species of *Pterocarya* within the wider walnut family (*Juglandaceae*). Its native range is within montane forests of the Caucasus region, Turkey and Northern Iran, from 400 to 1200m asl (Avsar and Ok, 2004). The other wingnut species are found in China and Japan. Caucasian wingnut is a medium-sized tree, reaching 25-30m tall, with a short thick bole and rounded, spreading crown (to 20m wide) (Figures 9 and 10). However, this describes open-grown specimens, and stem form in forest stands may be superior (Figure 11). The bark is grey, smooth when young, becoming furrowed with greater age. The leaves are simple pinnate, as in walnut, and can superficially resemble those of ash, although they reach 60cm in length. The species was introduced to Britain after 1800 and is found in tree collections and arboreta. It often occurs as multi-stemmed clusters or 'stools'. Some trial plots were established in Britain during the 1980s.

Climatic and site requirements

Caucasian wingnut favours temperate moist forest conditions and can be damaged by frosts exceeding -30°C, but appears to be able to tolerate -20°C. It is believed to be relatively tolerant of exposure and drought once established. It does best in moist, fertile alluvial or riparian soils (Ebrahimi et al., 2005; Maharramova, 2015), rarely being found more than 200m from open water, and forms a component of mixed stands containing alder, oak, elm, maple and beech. It can tolerate a range of non-ideal soils, including compacted and acidic types. It is most likely to be ecologically compatible with site conditions in lowland valley ash woodlands and plantations (NVC W8) and lowland oak-ash woodlands (NVC W10). Its suitability for upland ashwood sites (NVC W9) is uncertain, but it might tolerate more sheltered examples.

Figure 9. Wingnut, Chelsea Physic Garden, London. (Photo: Scott McG. Wilson)

Figure 10. Wingnut, Derby Arboretum, Derby. (Photo: Scott McG. Wilson)

Provenance, seed production and nursery practice

Caucasian wingnut is a wind-pollinated monoecious species producing 'turbinate' nuts that are dispersed 20-30m from the parent (on a 'helicopter rotor' principle) and can be carried further by flowing water. This differs from hickories, which require a vertebrate seed vector. Wingnut 'drupes' usually have two wings and, when mature, are 3.5-4.5cm wide and 1.0-1.5cm long. Seed production begins from 18-25 years in maiden trees but can be earlier in specimens reproduced vegetatively from root or stump sprouts, the preferred mechanism. Seed is partially dormant, requiring cold stratification for 5-7 weeks (Cicek and Tilki, 2008). Suckers and cuttings can be rooted. There is limited information on nursery practice or provenance variation and no guidance on provenance selection for British or Irish conditions.

Silviculture

Caucasian wingnut is a light-demanding species capable of rapid early growth on suitable sites (Ayan and Syvacyodlu, 2006; Sohrabi et al., 2008) (Figure 12). It can live for up to 250 years. In the native range it is reported to achieve 9-12m in height after 10 years and 30m after 30 years when established from seed. Stem diameter can reach 80-100cm in 60-80 years, which might be a typical rotation for productive silviculture, comparable to that for ash. A trial plot at the John F. Kennedy Arboretum in Co. Waterford, Ireland, was 8m tall after 21 years' growth (hence GYC 2-4). Vegetative sprouts can reach 4m tall after 6 years growth. The species tends to weak apical dominance, poor stem straightness and crown asymmetry. Caucasian wingnut suckers profusely, and, as a consequence, is potentially invasive under suitable conditions, which may constrain its British deployment.

Figure 11. Wingnut, Kennedy Arboretum, Ireland. (Photo: Scott McG. Wilson)

Figure 12. Young wingnut, Murthly Estate, Perthshire. (Photo: Scott McG. Wilson)

Pests and diseases

The species is believed to be relatively resistant to pests and diseases in Britain, including honey fungus (*Armillaria*), however, the basis of evidence to date is very limited.

Timber properties and utilisation

Wingnut produces a soft, reddish white timber, less dense and strong than those of walnut or hickory (density is 610 kg/m^3) (Dogu, 2007). The timber is durable when dry, but rapidly decays if exposed to moisture. This makes it more comparable with alder and poplar. Wingnut timber might substitute for certain applications of ash – light construction (non-exposed uses), furniture making, decorative carpentry, marquetry and veneers. It can also be used to produce plywood. Authors from Turkey and Iran have considered timber properties in detail (e.g. Dogu, 2007; Gungor et al., 2006; Kantay et al., 1999; Muge Gungor et al., 2007).

Hop hornbeams (*Ostrya* spp.)

Hop hornbeams (*Ostrya* spp.) are a distinct genus within the wider Betulaceae family (birches), by contrast with our native hornbeam (*Carpinus betulus*), which is a member of the hazel family (Corylaceae). The two hop hornbeam species of possible interest in Britain are (a) European hop hornbeam (*Ostrya carpinifolia* Scop.), native to mid-elevation forests in southern Europe, Asia Minor and the Caucasus region and (b) American eastern hop hornbeam or ironwood (*Ostrya virginiana* (Mill.) K. Koch), native from south-east Canada through the eastern United States into Central America. These are medium sized trees, reaching 18-24m tall and often grow in the understorey. Leaves closely resemble those of British native hornbeam. The bark is reddish when young, similar to cherry, but becomes grey, loose and flaky as trees age. Another five *Ostrya* species are found in similar forests in eastern Asia, and two in the south-western USA. There have been introductions to arboreta and forest gardens in Britain and Ireland, but no plantation record. Some trials (e.g. *Ostrya japonica* at Kilmun) have failed.

Climatic and site requirements

There is little information available on site requirements of European hop hornbeam, although its occurrence in mixed montane forests of the Mediterranean region suggests that it might be suitable for the climate of southern England, as with Corsican pine and Atlas cedar, especially given predicted climatic warming. For *Ostrya virginiana* we have a better understanding of site requirements, based on American experience. A wide range of climates appear acceptable, given that the species grows naturally as far north as Manitoba, Ontario and Nova Scotia. Preferred soil conditions are moist, with acid to neutral pH, but some use can be made of drier, less fertile and calcareous soils, albeit with slower growth. Edaphic matching in British conditions appears to be with lowland oak or oak-lime-hornbeam woodland (NVC W10) (e.g. on plateau sites with heavy, poorly aerated (London or Wealden) clay soils) rather than calcareous ash woodland (W8), but this remains to be confirmed.

Provenance, seed production and nursery practice

Ostrya species are monoecious and produce clustered seeds resembling brewing hops, hence the name hop hornbeam. Vegetative reproduction by stump sprouting can be profuse in nature. In *Ostrya virginiana* seed production begins from around 25 years. The seed is doubly dormant and must be stratified for 20-30 days at 20-30^{o}C, followed by 90-150 days at 1-5^{o}C. As the species has been little favoured by American forest managers, there has been limited demand for planting stock. There is little availability from British nurseries at the present time. As there have been no provenance trials of these species in Britain, there is no advice on provenance, but material from the northern part of the range should be hardier.

Silviculture

Ostrya species are late successional shade-tolerants, adapted to the understorey of mixed hardwood forests. If released by gap formation, *Ostrya virginiana* can become dominant, displacing commercially valuable medium-tolerants. However, it can be useful silviculturally as a managed understorey to clean oak. Some silvicultural prescriptions for North American forests seek to reduce or eradicate it. Given the lack of domestic experience with *Ostrya* spp., silvicultural prescriptions and yield predictions developed for native hornbeam (*Carpinus betulus*) (Savill, 2013) are most relevant. Yields are typically low (GYC 2-6). At present it is difficult to identify sites where *Ostrya* might be preferred silviculturally to native hornbeam.

Pests and diseases

The only reported problems are stem and butt rots in the Ontario range, caused by common fungi including *Stereum*, *Phellinus* and *Pholiota*.

Timber properties and utilisation

As with the native hornbeam, these species produce hard, durable timbers, used since antiquity for tool handles (e.g. plane soles) and similar specialist applications (Korkut and Guller, 2008). This is reflected in the colloquial name 'ironwood' given to the American species. The timber varies from white to reddish brown. As the timber is diffuse-porous, the material is considered one of the best substitutes for yew for making archery bows. There is a limited correspondence with the uses to which ash timber is applied in Britain, and hence these species are only likely to be relevant as a minor component of replacement stocking.

Sweetgum (*Liquidambar styraciflua*)

Sweetgums (*Liquidambar* spp.) are a small family of Tertiary relict hardwoods in the wider Altingiaceae family. The two main species are American sweetgum (*Liquidambar styraciflua* L.) and the more rare Oriental or Turkish sweetgum (*Liquidambar orientalis* L.). Emphasis here will be on American sweetgum, which is common throughout the eastern United States, as far north as Connecticut in coastal districts. It is a large deciduous tree, often reaching 24-26m tall, with a clean timber bole and pyramidal crown. The bark is grey and deeply furrowed. The leaves are characteristic five- or seven-pointed star shapes and turn an attractive purple-red shade in autumn, encouraging amenity horticulture. Originally introduced to gardens in southern Britain from around 1680 (Figure 13), there is no record of forestry use in Britain or Ireland and no plots/provenance trials prior to the recently-established EU REINFFORCE series.

Climatic and site requirements

Sweetgum conventionally requires warm temperate climates, only found in south-west Ireland and southern England. However, these conditions may expand geographically in the light of predicted climatic warming to 2080, perhaps to include Wales, Cumbria and western Scotland. It has been possible to produce garden cultivars (e.g. 'Moraine') that are frost hardy to as low as -30°C. Tolerance to wind or salt exposure is notably poor. Preference is for moist, loam and clay soils (including those with imperfect drainage). Moderately acid conditions are accepted, but droughty and sandy soils are unsuitable. There is known to be a risk of chlorosis on calcareous soils. There appears to be overlap with site conditions in lowland ash woodlands (NVC W8), but avoiding direct limestone influence.

Provenance, seed production and nursery practice

American sweetgum is monoecious. A significant proportion of natural regeneration is from root sprouts. Seed production begins from 20-30 years, and continues beyond 150 years. Globular seed balls, composed of numerous capsules, can be collected green, before dispersal. Number of seeds per ball is 5-30 and there are 140,000-220,000 seeds per kg, with marked annual variation in seed viability. Seed requires stratification at 1-5°C for 30-90 days, or soaking for 15-20 days. Nursery practice must preserve lateral rooting to aid successful establishment. There is no domestic provenance trial evidence upon which to base advice on selection, but northerly provenances from New England are likely to have greater cold tolerance. There is widespread availability of decorative garden cultivars from the British nursery trade, but no record of supply of material selected as suitable for productive forestry.

Figure 13. Sweetgum, Chelsea Physic Garden, London. (Photo: Scott McG. Wilson)

Silviculture

American sweetgum is one of the more common hardwoods in managed forests of the eastern United States. It is a light-demanding species that can establish on open-field sites, forming near-pure pioneer stands. However, early growth in plantations is often slow, necessitating extended protection from weed competition and browsing (Figure 14). The species cannot be successfully grown under full canopy shade. Thinning regimes must be regulated to maintain growth but restrict epicormic shoots. Later in the rotation productivity can be high, especially on better sites (Lhotka, 2012). Detail on American silviculture is available in Burns and Honkala (1990) and Leopold et al. (1995).

Pests and diseases

Sweetgum is considered to have few major pests or diseases. There are a number of fungal pathogens affecting it in North America, such as *Fomes*, *Ganoderma*, *Botryosphaeria* and red leaf spot (*Tubakia dryina*). 'Sweetgum blight' is a principally abiotic effect, arising from drought or other stressors.

Figure 14. Young sweetgum, Stourhead Western Estate, Wiltshire. (Photo: Scott McG. Wilson)

Timber properties and utilisation

In North America sweetgum is a valuable commercial hardwood, producing a moderately heavy (590 kg/m^3), hard, smooth, close-grained timber of a reddish tone, suitable for flooring, veneer/plywood, furniture and cabinet-making. It also takes an attractive polish. It is one of the most important commercial hardwood timbers of the south-eastern United States, known as 'satin walnut', used to make reddish panelling for lining railroad carriages as seen in 'Western' films. Although distinct in colour from ash, this timber could be valuable if produced in Britain and therefore it should be worth establishing trial plantations to explore its site tolerances. The timber is not durable and is unsuitable for outdoor uses. Smaller-dimension material can be used for pulp and woodfuel. Native American populations used the turpentine-like resin of sweetgum (known as 'liquid amber' or 'copalm balsam').

Tulip tree (*Liriodendron tulipifera*)

Tulip tree (*Liriodendron tulipifera* L.), also known as yellow-poplar, is a large deciduous tree, being the only western hemisphere representative of the small genus *Liriodendron*, within the wider Magnoliaceae family. It is not a true poplar. It gets its name from its large greenish flowers, superficially resembling tulips. The tree is native to eastern North America from Canada and the Great Lakes southwards to Florida. Tulip tree is the tallest hardwood in temperate forests of eastern North America, reaching 60m tall in nature. It typically has a long, clean bole and a broad, oblong crown. The bark is greyish-brown, smooth when young, deeply fissured with advancing age (Figure 15). Leaf shape is square in outline with weak corner lobes and can be quite large – up to 18cm across. The species was introduced to Britain before 1700, possibly by Tradescant (Macdonald et al., 1957) and has been widely deployed as a stately specimen in parks and designed landscapes (Figure 16). Individual specimens in southern England (e.g. at Killerton, Albury Park and Esher Place) have achieved 30-35m in height and up to 2.5m dbh. There is limited experience in trials – a plot at Kilmun, Argyll failed; another on poor soils at Bedgebury, Kent only achieved 4m in 20 years, whereas a stand near Alice Holt, Surrey has performed better.

Climatic and site requirements

As a representative of the magnolia family, one might expect the tulip tree to require warm moist conditions typical of the 'deep south' in the United States. Its best performance to

date in Britain has been in England, south of the Midlands, but it can be cultivated in sheltered locations as far north as Scotland. In its native range it favours cool moist sites, in the southern part of its range often on north-facing slopes, reaching 1400m asl (Keyser and Brown, 2014b). Its ecological context is typically alluvial or colluvial sites in species-diverse temperate valley or 'cove forests'. It does not tolerate climatic exposure and its cold-hardiness is uncertain. It does best on moist and well-drained soils and is not suited to droughty or waterlogged sites. It prefers medium to fertile soil nutrient conditions and growth rate can be restricted by soil infertility. Correspondence to conditions where ash is grown in lowland Britain (NVC W8) is considered good.

Provenance, seed production and nursery practice

The tulip tree is monoecious with bisexual flowers. In nature vegetative reproduction by stump sprouting is significant. Seeds are wind-dispersed brown samaras, which develop in clusters and are 5-8cm long. Seed production begins from 15-20 years and can continue for up to 200 years. Seed weight is variable (11,000-40,000/kg) and viability can be poor (5-20%). For nursery propagation seed must be stratified for 60-90 days at 1-5°C. Fungal root rot (*Cylindrocladium scoparium*) is a serious nursery pathogen. There are no British provenance trials or provenance guidance, but material from the northern part of the Canadian and American ranges is likely to be more cold-hardy for British conditions. Material is available from British nurseries, but mainly as cultivars intended for horticulture.

Silviculture

The tulip tree is an early successional, light-demanding species capable of forming pioneer stands on open ground with rapid early height growth. It is the fastest grown hardwood within its native range until 50 years of age and can persist as a minor component of mixed hardwood stands and live for 300-450 years (Lafon, 2004). The species self-prunes well in dense stands and does not require early

Figure 15. Tulip tree, Westonbirt Arboretum, Glos. (Photo: John White)

Figure 16. Tulip tree, Derby Arboretum, Derby. (Photo: Scott McG. Wilson)

respacing or thinning. Later thinning (as late as 80 years) has been shown to produce a valuable response, limiting density-dependent mortality and allocating increment to final crop trees (Keyser and Brown, 2014a). Maximum mean annual increment is 5-12$m^3ha^{-1}yr^{-1}$ over a typical rotation of 70 years. There is obvious comparability with British ash silviculture and requirements. Burns and Honkala (1990) give silvicultural details.

Pests and diseases

Tulip tree aphids (*Macrosiphum liriodendri*) can be damaging if populations become large. *Armillaria* (honey fungus) can cause rot, and both *Nectria* and *Fusarium solani* can be associated with stem canker damage in this species. *Verticillium* wilt may be fatal if not treated. The species is very vulnerable to fire damage, which can admit fungal decay agents to the stem. By contrast, palatability to deer and rabbit browsing is reported to be low to moderate, which may also be relevant in British situations where the tree is a potential ash substitute.

Timber properties and utilisation

The timber of tulip tree (known in the trade as American poplar or American tulipwood) is regarded as versatile. Light, soft and even-grained, with a creamy-white (sapwood) or yellow-brown (heartwood) colour. It is suitable for furniture and instrument making, light construction, fencing, plywood/veneer etc., together with woodfuel/hardwood pulp. It is not regarded as durable and can start to decay quickly if exposed to the elements. There is only a partial correspondence to applications typical for ash timber.

Conclusions

Species discussed in this article, collectively, have potential as one element of adaptation strategies responding to the *Chalara fraxinea* outbreak in ash in Britain and Ireland. All of these species can produce valuable timbers for furniture making, instrument making, decorative carpentry and sports goods manufacture. They may therefore be attractive to more specialist growers who have been cultivating ash for specific outlets within these sectors.

There is reasonable overlap in site tolerance with ash in the lowland part of its British range, although a selective approach in terms of species and sites is required for upland conditions. There are unlikely to be significant difficulties in managing these species under suitable sheltered lowland growing conditions. Field maple, Norway maple and London plane offer options for drier lowland sites where sycamore would be less suitable. Long-term deployment will be within mixed plantations, managed under continuous-cover systems, which may well contain both native and introduced species. Their likely deployment will be as minority specialist hardwood components. Where oak, beech, sweet chestnut or sycamore might be suitable, less familiar introduced hardwood species may be used to increase species diversity, in the interests of visual amenity, stand resilience and specific economic opportunity.

Other than for field maple and sycamore, we have limited information about potential interactions between these tree species, sites, soils and native biodiversity. There is also an incomplete understanding of potential regeneration dynamics and invasiveness. The history of sycamore gives cause for caution in this regard, particularly on moist fertile sites where ash, rather than oak, is the dominant native hardwood. There are specific reservations about the invasive potential of Caucasian wingnut. We also have an imperfect understanding of the likely susceptibility of these species to pests and diseases already present or capable of occurring within Britain and Ireland – there is clear cause for concern for London plane. Grey squirrel and deer palatability are likely to be similar to sycamore, and potentially worse than for ash at the present time. However, there are indications that hardwoods with a relatively high bark pH, might 're-home' some invertebrate and lower plant biodiversity associated with ash. For these reasons, a prudent shorter-term strategy will be to trial these hardwood species at the experimental plantation scale, including within mixed productive woodlands. These species may be considered for judicious inclusion in woodland creation and restocking in existing plantations distant from ancient semi-natural woodlands. However, they should not be selected as replacements for ash in or near ancient semi-natural woodlands at present. Where reference is made in this paper to matching species to NVC woodland communities (W8, W9, W10) for establishment, these refer to the ground vegetation assemblages present on site and not to ancient semi-natural woodland examples. Trial deployments should be closely monitored, allowing early intervention if pest and disease susceptibility or invasive tendencies become apparent. Timber arising from trial plantations should be used to increase knowledge of wood science, processing and utilisation values, in collaboration with the hardwood sawmilling sector.

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