Alternative Oaks (*Quercus* spp.)

Scott McG. Wilson, **Bill Mason**, **Peter Savill** and **Richard Jinks** review the previous record and future potential for British forestry of selected oak species from North America and Europe.

Attention is focussing on alternative tree species, suitable for growth in Britain and Ireland should climatic change proceed as predicted. There is also increasing awareness of potential threats from novel tree pests and diseases that have proliferated over recent decades. Recently, the Wessex Silvicultural Group has considered this matter (Bladon and Evans, 2015), as have Forest Research (2017b). There is an on-line network promoting novel species with potential to grow well in Britain (SilviFuture, 2017), 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 adapting British forests to predicted climate change.

Discussions on tree species diversification have, to date, concentrated mostly on alternative conifers. However, increasing incidence of ash dieback (*Hymenoscyphus fraxineus*) in ash (*Fraxinus excelsior* L.) since 2012, recent *Cryphonectria* blight in British sweet chestnut (*Castanea sativa* Mill.), together with awareness that conventional hardwood choices including European beech (*Fagus sylvatica* L.) may prove vulnerable to drought in a warming climate in southern Britain, establish a need to evaluate alternative hardwoods. This article explores the potential of selected oaks (*Quercus* spp.) originating from North America and southern Europe, to complement the role of British native oaks (*Quercus petraea* (Matt.) Liebl and *Q. robur* L.), offering fresh options for drought-prone sites. Principal references include Burns and Honkala (1990), Forest Research (2017b), Macdonald et al. (1957), Savill (2013) and Timbal and Aussenac (1996).

Introduction

Oak species (*Quercus* spp) form a large genus within the family Fagaceae (beeches). An estimated 600 oak species occur, most within temperate, semi-arid or sub-tropical forests across Europe, Asia, North Africa and North and Central America (Rohrig and Ulrich, 1991). Greatest oak diversity is found in the United States, Mexico and China. Oaks include deciduous and evergreen species, most are monoecious and wind-pollinated. Oak leaves are morphologically varied – they can be unlobed, but are typically lobed (as in British native oaks) or serrated (as in some dryland oaks). The seeds take the form of cupped acorns, varying greatly in size and typically taking 6-18 months to mature on the tree. Many oaks rely on mammalian or avian vectors (e.g. jays) for dispersal. Acorns are difficult to store prior to propagation, due to prevalence of fungal decay and their inability to survive desiccation.

The infrageneric classification of oaks, and their capacity for interspecific hybridisation, is complex and subject to continuing taxonomic revisions. The genus *Quercus* is currently subdivided into two subgenera, *Quercus* and *Cyclobalanopsis* (International Oak Society, 2018). Only members of the former are dealt with in this paper. Subgenus *Quercus* is further currently subdivided into sections *Quercus* (the white oaks), *Protobalanus* (the intermediate oaks), *Lobatae* (the red oaks) and *Cerris* (taxonomic position currently under review). Of the oak species dealt with in this paper red oak (*Quercus rubra* L.) is in section *Lobatae* and Turkey oak (*Q. cerris* L.) is in section *Cerris*. The remaining species – Hungarian oak (*Q. frainetto* Ten), Downy oak (*Q. pubescens* Willd.), Evergreen/ Holm oak (*Q. ilex* L.), Algerian/

Mirbecks oak (*Q. canariensis* Willd.) and Pyrenean oak (*Q. pyrenaica* Willd.) are all in section *Quercus* (the white oaks), together with the British native oaks, with which interspecific hybridisation may occur in some cases.

A minority of oaks are sufficiently cold hardy for use in Britain under predicted climates – a selection feature in this article. In addition to two native oaks, those with significant silvicultural records in Britain include northern red oak from eastern North America, Turkey oak from Asia Minor and south-eastern Europe and evergreen holm oak from the western Mediterranean. Given predictions for greater warmth and drought in southern Britain under climate change, we also include oaks from southern Europe, offering potential resilience to future climates, but with limited records in Britain. These include Hungarian oak from south-eastern Europe, downy oak (*Q. pubescens* Willd.) from south-central Europe and Algerian oak from south-western Europe/north-west Africa (see Figure 1a and b for distribution maps).

We emphasise the potential for introduced oaks to offer fresh opportunities for British forestry on sites unsuitable for native oaks, including those becoming too dry for native oaks under future climates. Introduced oaks should not replace native oaks where those currently perform well, as their biodiversity, landscape, cultural and timber values remain superior.

North American oaks

Red oak (*Quercus rubra* L.)

Taxonomy and distribution

Red oak (formerly *Q. borealis*), within the 'red oak' section, is native to the eastern United States and Canada, occurring in temperate forests with diverse conifer and hardwood associates. Its native range runs from Georgia and Alabama northwards to Nova Scotia, Quebec and Ontario. First introduced to Britain between 1720 and 1740 (Macdonald et al., 1957; Mitchell, 1974), it is, to date, the most successful American oak for forestry in Britain, forming small plantations across the country. It has been planted extensively in Continental Europe (including France (Timbal et al., 1994), Germany, Hungary and the Low Countries) where it regenerates well, becoming naturalised.

Red oak grows quite rapidly (e.g. 5-6m ht in ten years) and to a considerable height (e.g. 25-30m when mature) and can exceed 100cm dbh. The tallest recorded red oak in Britain was near Malvern at 29.5m tall with 171cm dbh (www.treeregister.org). It typically has a narrow crown when grown in forest competition. It is a medium-tolerant species, shorter lived than British oaks, but can achieve 300-500 years. Mature bark is dark reddish-brown (lighter grey when younger), developing vertical ridges with central reflective stripes. Leaves are larger than in British native oaks (e.g. 12-24cm long), having 7 to 11 lobe pairs (Hora, 1981; Tutin et al., 1964). They are dark green in summer, turning a rich red in autumn. Red oak is monoecious, bearing male and female flowers on the same tree. Acorns are variable, either sessile or pedunculate, 1.25 to 3cm in length, maturing in their second year on the tree.

Climate and soil requirements

Red oak appears climatically undemanding, cold-hardy throughout Britain, windfirm and moderately tolerant of exposure and drought (Forest Research, 2017b). Savill (2013) notes its potential susceptibility to late spring frosts. In its natural range, red oak grows on a range of soils, preferring deep, freely-drained loams on plateaux and concave lower mid-slopes (Burns and Honkala, 1990). In Britain, it does

best on freely-draining soils, such as acid sandy loams, being less nutrient-demanding than native oaks. Willoughby et al. (2007) record notable early growth on acid sandy soils. Within the Forestry Commission Ecological Site Classification (ESC) (Pyatt et al., 2001), a Poor to Medium soil nutrient regime (SNR) and Moderately Dry to Moist soil moisture regime (SMR), are suitable. Red oak is prominent in drier forests in the native range and outperforms British oaks on acid sandy loams, albeit performing poorly on ericaceous sites. It is unsuitable for peats and calcareous soils (Savill, 2013).

Provenance selection

Provenance trials of red oak have been established across Europe in recent decades including Great Britain (Westergren, 2016). Five trials were located in England from the North York Moors to the Forest of Dean, containing variable numbers (6-13) of provenances from southern Canada and northern United States. Data from assessments after 13 years indicate that Canadian provenances from locations immediately to the north of Lake Erie had performed best. Results from parallel German experiments cited by Westergren (2016) suggest that, after ten years, most European provenances were better than material from the native range. Forest Research (2017b) recommend seed sourced from well-grown British or European plantations or the northern part of the native range (e.g. eastern Canada) (Hubert and Cottrell, 2006). There is one Source Identified and one Selected seed stand, both in lowland England.

Seed production and nursery practice

Fruiting begins in red oak from 25 years, is prolific after 30-50 years (Burns and Honkala, 1990; Gordon, 1992; Savill, 2013), and maximal by 80-120 years (Gordon, 1992). The species displays masting cycles, of 2-3 years (Gordon, 1992). Seed production has occurred in Britain, but existing stands are only now at an age when it may become prolific. Older red oak plantations on the Continent have naturally regenerated for several decades (Miltner and Kupka, 2016). There are 280-300 red oak acorns/kg with a 70-85% germination rate (Aldhous and Mason, 1994; Gordon, 1992; Savill, 2013). These display dormancy (unlike British native oaks) (Gordon, 1992) and must be stratified below 4°C for at least two to three months, prior to germination. Seed can be stored moist between -3°C and +5°C for up to six months (Gordon, 1992; Gosling, 2002 & 2007). Otherwise nursery practice appears similar to British native oaks.

Figure 1a - Distribution map of non-native oak species with potential for forestry in Britain - Quercus rubra (Source: US Geological Survey, 1999)

Silviculture and yield

In North America red oak occurs in pure stands and in mixture with pine, maples and other oaks. It is more shade-bearing than sessile oak, but regenerates unreliably under fully-stocked hardwood canopies. Hence Miltner and Kupka (2016) suggest reducing canopy cover to ~25% to recruit satisfactory regeneration. Stump sprouting, akin to coppicing, is a common natural regeneration system. In America release thinning at 30 years is recommended, while delayed thinnings may not produce significant responses, other than unwelcome epicormic growth (Burns and Honkala, 1990). Evans (1984) and Savill (2013) suggest red oak is less prone to epicormics than British native oaks. Growth performance can be assessed by site index and volume yield after 80 years. European yields are in the range 3-10m^3/ha/yr (Savill, 2013). A shorter rotation is recommended than for British native oaks – Belgian reports (Lorent and de Wouters, 2001) recommend 70 to 90 years, with a 60cm target diameter. Regular thinning from onset of canopy closure should leave 80-100 final crop trees/ha.

British experience with red oak features small, single-species, even-aged plantations, many established between 1940 and 1970. Forestry Commission/Natural Resources Wales sub-compartment databases record ~200ha of pure red oak on the National Forest Estate, with mean General Yield Class (GYC) of 6.2 (range 4 to 10). A further ~800ha of mixed compartments contain red oak. Savill (2013) estimates total extent of red oak in British forests at ~700ha. Distribution is concentrated in Wales (see Figure 2), the Marches and English Midlands (notably on sandy soils in Sherwood and Cannock Chase), with scattered occurrences

across southern England (see Figure 3), East Anglia, the Lakes and North York Moors. Private growing of red oak is concentrated on English and Welsh estates. Occasional instances of this species being tried in Scotland include Greer (1979) reporting good initial performance on an upland moraine in Highland Perthshire, a site marginal for native sessile oak. In one North York Moors experiment red oak (in mixture with larch) displayed superior stem form to sessile oak and other native broadleaves after 50 years (Gabriel et al., 2005).

Red oak typically out-performs British native oaks by one or two yield classes on dry sandy soils (Evans, 1984), but is equivalent on better soils. Macdonald et al. (1957) report on Forestry Commission permanent sample plots in the Forest of Dean (Glos.), Bedgebury (Kent) (see Figure 3) and Herriard Park (Hampshire). See Table 1 for more recent measurement data. After 40-75 years, growth has been good, with GYC 6-8 typical, and GYC 10 occasional. Few plots have been established in upland Britain, but one at Brechfa Forest Garden in mid-Wales, established in the 1950s, was performing well after 40 years (Danby and Mason, 1998), while another at Kilmun Forest Garden in Cowal, Argyll (see Figure 4) reached 19.2m height after 41 years (see Table 1). This plot had an estimated GYC of 8, intermediate between *Quercus robur* (GYC 10) and *Q. petraea* (GYC 6) within the same collection. Health of the Kilmun plot has declined in recent years (BM, unpublished).

Pests and diseases

Red oak is very susceptible to grey squirrel damage. Various fungal pathogens affect it in the native range, including oak wilt (*Ceratocystis fagacearam*) and *Nectria*, causing stem

Figure 2. Red oak in Cwm Ystwyth, Ceredigion. Age 59 years; GYC6. (Photo: Scott McG. Wilson)

Figure 3. Red oak at Bedgebury Pinetum, Kent. Age 55 years; GYC10. (Photo: Scott McG. Wilson)

canker. Defoliation by gypsy moth (*Lymantria dispar*), introduced to America, is damaging if repeated in successive years, and weevils can destroy a significant proportion of acorns.

Red oak is susceptible to *Phytophthora* infections (Brasier, 1999) and inadvisable where infected larch has recently grown. Honey fungus (*Armillaria*) also affects red oak, especially when weakened by environmental factors. Oak processionary moth might affect red oak as with native oaks. Acute oak decline (Denman, 2014) susceptibility is not established.

Table 1. Growth and yield of different oak species in Forest Research sample plots. (nd indicates no data for that parameter)

Species	Location	Age (yrs)	Top height (m)	Basal area (m^2ha^{-1})	Standing volume (m^3ha^{-1})	Cumulative volume (m^3ha^{-1})	Estimated yield class
Red oak	Herriard Park, Basingstoke	72	24.2	14.7	155	nd	8
	Alice Holt	58	22.0	25.2	246	471	8
	Bedgebury	55	22.5	29.6	nd	nd	8
	Bedgebury	43	22.1	23.6	218	323	10
	Kilmun	41	19.2	11.6	nd	nd	8
Scarlet oak	Bedgebury	65	22.4	21.9	211	375	8
Pin oak	Bedgebury	63	19.3	15.3	118	300	6
Hungarian oak	Bedgebury	49	16.0	10.1	73	nd	6
Mirbeck's oak	Bedgebury	55	19.9	27.6	nd	nd	6
	Brechfa, Wales	40	15.3	16.7	100	150	6

Timber properties and utilisation

Red oak timber has average density of 790 kg/m^3 at 15% moisture content (Savill, 2013). Genet et al. (2013) discuss effects of growth rate on timber density. While normally regarded as mechanically inferior to British native oak timbers (Edlin and Mitchell, 1985), Forest Products Research Laboratory (1964) found red oak had at least equivalent strength. It is ring porous, with 1-3 layers of large springwood vessels. If grown on freely-draining sandy soils, it is prone to shake (Savill, 2013), degrading its timber properties for sawn uses. Red oak timber is less durable and visually attractive than British native oaks (Edlin and Mitchell, 1985) and no direct substitute in furniture grades. Vessels do not 'self-seal' with tyloses as in white oaks, and hence red oak timber is unsuitable for cooperage. However, it absorbs preservatives more readily, rendering it suitable for exterior carpentry, including fencing. Sawn applications include furniture, palletwood, flooring and panelling, while smaller-dimension material supplies pulpwood and woodfuel. Red oak is valued for decorative landscaping due to its autumn colour, along with closely-related scarlet oak (*Q. coccinea* Muenchhausen).

Figure 4. Red oak at Kilmun Forest Garden, Argyll. Age 54 years; GYC6. (Photo: Scott McG. Wilson)

Other North American *Quercus* species

There are numerous oaks native to North America. Those from California or the south-eastern United States are generally too warmth-loving to be useful for British forestry. Most offer few advantages over European sub-Mediterranean oaks for British use. Of north-east American temperate oak species, northern red oak offers the best complementary traits to British native oaks. Scarlet oak has been used for amenity horticulture in Britain, due to its attractive autumn foliage. Growth performance of scarlet oak at Bedgebury in Kent was similar to that of red oak (Table 1). Carey (2004) reported a plot at Avondale in Ireland had performed poorly, although productivity was still estimated at Yield Class 6. Pin oak (*Q. palustris* Muenchhausen) has also been tried in Britain. Large specimens to 25m can be found near some stately homes, although performance of a plot at Bedgebury was slower than *Q. coccinea* and *Q. rubra* (Table 1); Macdonald et al. (1957) felt that dry site conditions there were unsuitable for pin oak. A pin oak plot at Avondale failed (Carey, 2004).

Species Profile

Mediterranean oaks

Turkey oak (*Quercus cerris* L.)

Taxonomy and distribution

Turkey oak is native to the Balkans, Italy and Asia Minor, occurring in mixed forests containing other oaks, beech, hornbeam, chestnut and pine (Davies, 1982; Majer, 1984). It occurs from sea level to 1900m asl and was introduced to Britain by 1735 (Edlin and Mitchell, 1985; Savill, 2013). It is grown mainly as landscape specimens in amenity woodlands and arboreta. It is used as an ornamental and windbreak tree across Continental Europe, becoming naturalised. In Britain it forms a minor component of some lowland woodlands dominated by native oaks. There are few British examples of Turkey oak cultivated in plantations.

Turkey oak is a tall, straight-growing tree, exceeding 30-40m in height. The tallest specimen recorded in Britain is 41.2m tall with 181cm dbh (www.treeregister.org). It is less long-lived than some other oaks at 150-200 years (Rameau et al., 2008). Its bark, often deeply furrowed, has a greyish colour (see Figure 5). Buds are surrounded by elongated stipules. Leaves are glossy, longer than in British native oaks at 9-12cm, and have from 7-9 lobe pairs (San-Miguel-Ayanz et al., 2016). The acorn cup is covered in bristles and acorns are larger than in British native oaks, reaching 2-5cm. These are pedunculate (8mm), maturing in their second year (Tutin et al., 1964), with production regular (Savill, 2013).

Figure 5. Turkey oak (bark) at Westonbirt Arboretum, Glos. (Photo: John White, Forestry Comm.)

Turkey oak hybridises with cork oak (*Q. suber*), forming the hybrid *Q. x crenata*, propagated in several artificial cultivars, many showing hybrid vigour and remaining evergreen other than in severe winters, following cork oak. These include Lucombe oak (formerly *Q. hispanica* var. *lucombeana*), produced at Exeter around 1765, and later cultivated at Kew Gardens and elsewhere. Macdonald et al. (1957) report this hybrid cultivar reaching 25m in height. Earlier indications that Turkey oak hybridises with pedunculate oak (e.g. Evans, 1984) have recently been challenged (Savill, 2013).

Climate and soil requirements

Turkey oak, with moderate tolerance of drought, favours lowland climates. It is reasonably tolerant of exposure (Savill, 2013) and atmospheric pollution. Although capable of using a spectrum of soils, it does best in fertile, moist conditions, and can utilise calcareous clays. It is unsuitable for infertile dry sandy soils or peats.

Silviculture and yield

Turkey oak typically has a clean straight bole, superior to that of native oaks, with which it is sometimes confused (Evans, 1984). Growth rate often exceeds that in British native oaks and the species coppices well (Savill, 2013). In the native range Turkey oak is often grown as coppice (Marchi et al., 2016), but can produce timber on rotations of 100-120 years, yielding 10m^3/ha/yr, with final stocking of ~250 stems/ha and basal area of ~35m^2/ha (Morandini, 1981). Macdonald et al. (1957) report one British plantation at Knutsford, Cheshire reaching 29.4m height at 110 years with 70cm average dbh. An upland plot, established in the Forestry Commission's Brechfa Forest Garden in mid-Wales in the 1950s, was performing well after 40 years (Danby and Mason, 1998). A plot at Avondale in Ireland reportedly failed (Carey, 2004). It is unclear where Turkey oak would find a role within British forestry, in preference to pedunculate oak.

Hungarian oak (*Quercus frainetto* Ten.)

Taxonomy and distribution

Hungarian oak (also known as Italian oak) is native to south-eastern Europe and the Balkans, together with north-western Asia Minor and parts of Italy (Davies, 1982; San-Miguel-Ayanz et al., 2016). Despite its name it is uncommon in Hungary. It occurs naturally in association with Turkey oak,

forming the mixed forest type *Quercetum frainetto-cerris*, also co-occurring with beech, hornbeam, hop-hornbeam, chestnut and pines. Its elevation range is from sea level to ~1000m asl. It was introduced to Britain in 1838, but has not been widely cultivated, being less frequent than Turkey oak.

Hungarian oak is a large deciduous species (see Figures 6, 7 and 8), reaching 35-40m in height. The largest specimen in Britain, recorded by Mitchell in 1985, was at Camperdown Park, Angus, being 38m tall (Johnson, 2003). It rarely exceeds 200 years (San-Miguel-Ayanz et al., 2016). Leaves

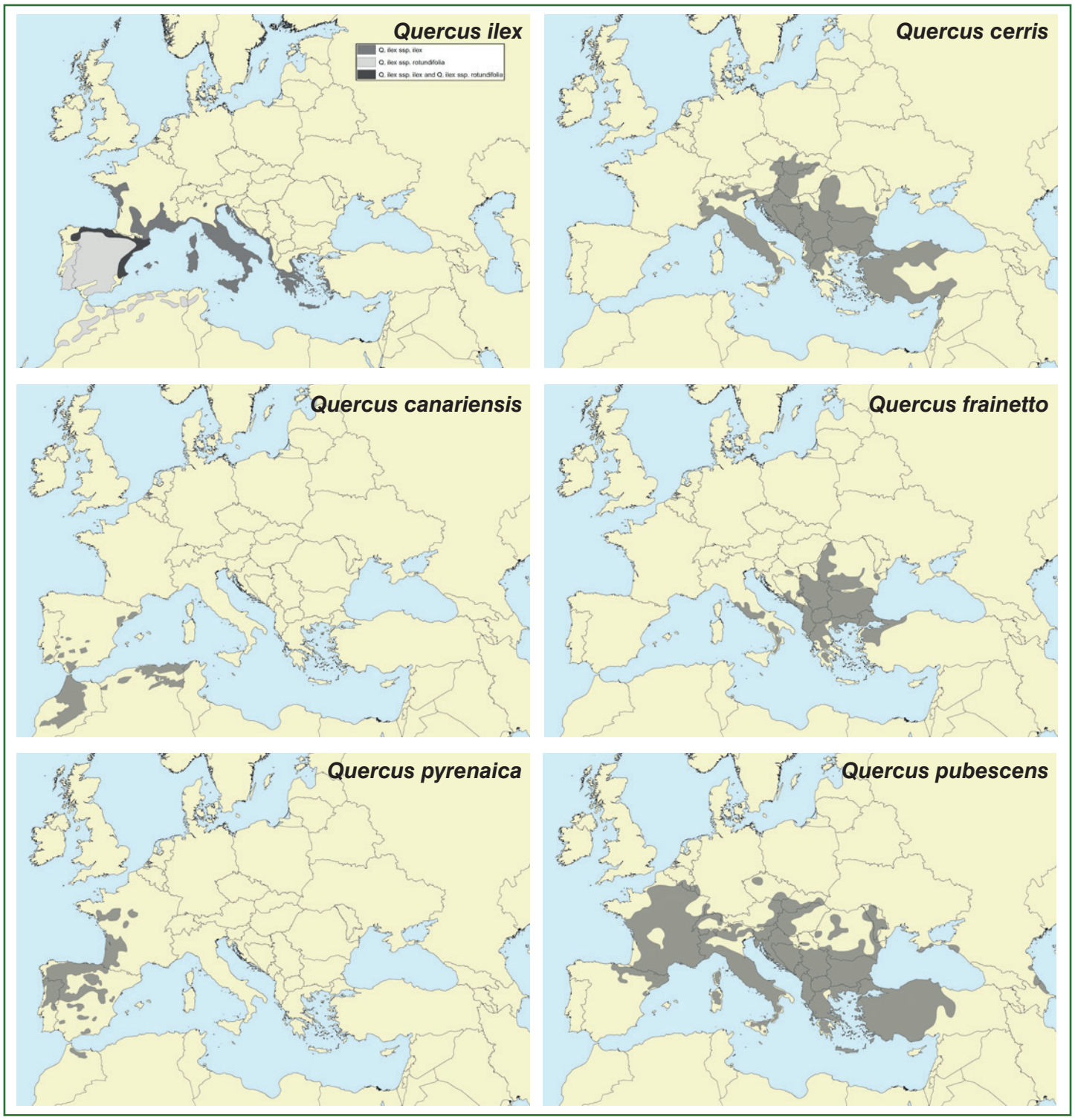

Figure 1b - Distribution maps of non-native oak species with potential for forestry in Britain - Mediterranean oaks. (Sources: Caudullo et al., 2017; Wazen and Fady, 2015)

Species Profile

Figure 6. Hungarian oak at Bedgebury Pinetum, Kent. Age 49 years; GYC6. (Photo: Scott McG. Wilson)

are longer than in British native oaks, reaching 10-25cm, typically with 7-9 pronounced lobe pairs (Tutin et al., 1964). They are dark glossy green in summer, turning yellow-brown in autumn, often being retained through the winter. Acorns are light brown and 15-25mm long, generally held in sessile clusters near the ends of twigs. Unlike some other oaks, acorns of Hungarian oak mature within six months on the tree.

Figure 7. Hungarian oak at Bedgebury Pinetum, Kent. Age 49 years; GYC6. (Photo: Scott McG. Wilson)

Climate and soil requirements

Hungarian oak is adapted to the Balkan sub-continental climate (hot summers and cold winters). Therefore it might be thought useful for parts of eastern England. However, Macdonald et al. (1957) indicate that it has severe spring frost susceptibility in Britain, based on slow initial growth of a trial plot at Bedgebury, Kent (see Figures 6 and 7; Table 1). The species favours clay soils of low-moderate fertility. It can cope with spring water-logging, followed by summer drought, but is unsuitable for soils with high water-tables or a calcareous influence. These requirements might be met in Britain by the London, Barton and Wealden clays of south-east England and the Culm soils of the south-west. East Anglian and Midlands clays might be suitable where there is little calcareous influence.

Silviculture and yield

There is limited British information about this species, mainly derived from specimen trees (see Figure 8), but in Greece and Turkey it is grown in coppice and wood-pasture systems. The only recorded plot in Britain was at Bedgebury (see Figures 6 and 7 and Table 1) where, at nearly 50 years, growth was equivalent to GYC 6. A plot at Avondale in Ireland reportedly grew well initially, achieving Yield Class 4 (Carey, 2004).

Figure 8. Hungarian oak at Westonbirt Arboretum, Glos. (Photo: John White, Forestry Comm.)

Downy oak (*Quercus pubescens* Willd.)

Taxonomy and distribution

Downy oak is a deciduous white oak of southern Europe and Asia Minor (Davies, 1982), whose range runs from the Caspian Sea to Atlantic coastal Spain and from Crete to Normandy (see Figure 1b). It is the 'southern equivalent' of sessile oak and potentially interesting for areas of southern Britain experiencing increasing drought under climate change. Its elevation range runs from sea level to 1700m asl (Davies, 1982), more typically 200-1300m asl (San-Miguel-Ayanz et al., 2016). In the Mediterranean region it occurs in lowland mixed woodlands with holm oak (*Q. ilex*), while further north it is found in sub-Mediterranean stands with black pine (*Pinus nigra*), sessile oak and sweet chestnut and in colline and montane stands, with beech and hornbeam.

Downy oak is a moderate-sized tree, generally 10-25m in height. The tallest specimen in Britain is near Shrewsbury at 21.0m tall with 154cm dbh (www.treeregister.org). In forest stands it assumes a narrow crown profile, while many open-grown specimens produce wider-spreading crowns. This is a long-lived species, exceeding 500 years, as with native British oaks. The bark becomes thick and rough with age, deeply furrowed with small flakes. Leaves are leathery (a drought-resistance trait) and 4-12cm long (Tutin et al., 1964), with 3-7 shallow lobe pairs. Both surfaces are downy early in the growing season, with hairs lost from upper surfaces later in summer, when they become smooth and glossy. Acorns are long and narrow (up to 25mm), typically forming sessile clusters near the end of pubescent stalks. Downy oak hybridises with both British native oaks, requiring careful consideration before wider British deployment.

Climate and soil requirements

Downy oak is warmth-loving, adapted to sub-Mediterranean climates with hot dry summers and cool moist winters. Timbal and Aussenac (1996) indicate that it is cold hardy to -20°C, but tolerance of British late-spring frosts is not established. The further it moves north-west from the Mediterranean, it becomes increasingly restricted to favourable micro-climates and calcareous soils. It generally prefers freely-draining, base-rich soils (Rameau et al., 2008). This suggests that deployment in Britain might embrace modified beechwood communities (NVC W12) on drier sites over chalk (Chilterns, South and North Downs) and soft limestones (Cotswolds). Suitable conditions extend as far north as the Limestone Peak of Derbyshire and the Yorkshire and Lincolnshire Wolds (San-Miguel-Ayanz et al., 2016). It is unlikely to be suitable for cool upland sites, heavy lowland soils or infertile sandy soils.

Figure 9. Mediterranean coppice oak woodland, Catalonia. (Photo: Scott McG. Wilson)

Silviculture and yield

There is no record of cultivation of downy oak in Britain, outside arboreta and no known trial plots. In Europe the species is managed in semi-natural woodlands (see Figure 9), sometimes under coppice, rather than forestry plantations (Morandini, 1981; Timbal and Aussenac, 1996). The species is an important economic host of truffle species valued for culinary purposes. In Britain downy oak could be managed in mixed lowland stands together with sessile oak, ash, beech and hornbeam, depending on site types. Where managed for woodfuel a shorter rotation of 15-25 years might apply, as with native British oaks. The species might also be managed on longer timber rotations, compatible with beech and sessile oak. The yield is likely to be comparable to, or below, British native oaks growing on equivalent sites.

Evergreen or Holm oak (*Quercus ilex* L.)

Taxonomy and native range

Holm oak is a large, evergreen oak native to the Mediterranean. It is within the 'white oak' section, together with British native oaks. Although slow-grown, it reaches 15-20m height (exceptionally 25-30m), living for 200-500 years. The tallest specimen in Britain, in Windsor Great Park, is 28.6m tall with 97cm dbh (www.treeregister.org). Two sub-species are recognised: (a) *Q. ilex* ssp. *ilex*, found along the northern Mediterranean littoral, from north-eastern Iberia to western Asia Minor, and (b) *Q. ilex* ssp. *rotundifolia*, found throughout the Iberian Peninsula and along the southern Mediterranean littoral from Morocco to Tunisia (see Figure 1b). The leaves of the latter are rounder and less bitter, and acorns somewhat larger. Holm oak grows in several Mediterranean forest associations depending on elevation

and site, including with other oaks (e.g. *Q. pubescens*, *Q. suber*), Atlas cedar (*Cedrus atlantica*), hornbeam, laurel and pines. The species was introduced to Britain by the 1500s and has been cultivated for ornament, especially in coastal districts. It can be invasive in the south (e.g. Isle of Wight). Holm oak bark is dark, greyish brown, almost black. It has dark, glossy and leathery leaves resembling those of holly (*Ilex aquifolia*), hence its name. These are oval to lanceolate, 3-8cm long and serrated (Hora, 1981; Tutin et al., 1964), with weak lobes. Young leaves are downy on both faces, upper surfaces becoming dark green and glossy with age, while lower surfaces become yellowish brown, persisting until leaves are lost. Foliage is flammable throughout the year in the Mediterranean region. Acorns are usually 12-18mm in length and mature in a single season, producing copious crops in mast years.

Climate and soil requirements

This species is warmth-loving, with moderate cold hardiness (Rameau et al., 2008). Timbal and Aussenac (1996) indicate it can withstand -15°C. It is optimal for Mediterranean climates but can use coastal sites along the west coast of France north to the Loire, and in southern and eastern England. It is tolerant of wind exposure and salt spray (Edlin and Mitchell, 1985), but susceptible to atmospheric pollution (San-Miguel-Ayanz et al., 2016). It is vulnerable to British winter cold and late spring frosts, but climatic change may relieve thermal constraints on northward expansion. Holm oak grows best on free-draining soils, ranging from moderately acidic to calcareous. Most British plantations are on drier coastal sites, especially in chalk districts, extending north to Holkham, Norfolk and Scarborough, Yorkshire.

Silviculture and yield

Holm oak is grown in Britain primarily as ornamental specimens (Evans, 1984) and in coastal windbreaks. It has been planted on the Holkham Estate in north Norfolk since the 1740s (Macdonald et al., 1957). Plantations were created at Osborne, Isle of Wight by Prince Albert in the mid-1800s. Isle of Wight plantations cause concern over potential naturalisation and heavy shade – holm oak should not be introduced near ancient semi-natural woodlands. The species has not been widely used for timber in Britain. In the native range silviculture emphasises woodfuel, often from coppices within semi-natural woodlands (Amorini et al., 1996; Morandini, 1981; Timbal and Aussenac, 1996). The majority of growing stock is spontaneous, regeneration being promoted by fire (Curt et al., 2009). Holm oak also occurs in dehesa and montado wood-pastures of Iberia (see Figure 10) – acorns are valued as pannage for pigs and reputed to result in excellent, tasty pork. In future holm oak might be used on dry sandy sites in southern Britain, no longer supporting British native oaks. It could potentially be used together with coastal pines, Atlas cedar and Monterey cypress (*Cupressus macrocarpa*). Objectives would be shelter, soil protection, landscape and woodfuel. Holm oak is slow-growing, rarely exceeding GYC 4 in Britain.

Algerian oak (*Quercus canariensis* Willd.)/ Mirbeck's oak (*Q. mirbeckii* Durieu)

Taxonomy and distribution

Algerian or Mirbeck's oak is in section *Quercus*. It can be deciduous or semi-evergreen (British specimens the latter). Its native range includes southern Iberia and north-western Africa. It does not occur naturally in the Canary Islands, perhaps having done so historically. It is a medium to large tree, reaching 20-30m in height (exceptionally 35m), often with a dense, rounded crown in open-grown specimens. Stem diameter can reach 150cm dbh. The tallest specimen in Britain is near Horsham in Sussex, being 29.0m height with 81cm dbh (www.treeregister.org). The species was introduced to Britain in the 1840s as a gift from King Louis Philippe of Spain to Queen Victoria, and tried in several arboreta. Leaves are dark glossy green, 6-18cm long, with 9-14 shallow lobe pairs (Tutin et al., 1964). They have a partially downy mid-rib on their underside. Acorns are rather rounded, typically 2-2.5cm in diameter, requiring 12 months on the tree to mature.

Climate and soil requirements

Algerian oak is adapted to a Mediterranean climate but shows greater tolerance of late spring frosts than Hungarian oak (Macdonald et al., 1957), performing quite well at sheltered upland sites in Britain (e.g. Brechfa in Wales). There is little information on its soil preferences.

Silviculture and yield

There are two sample plots of this species in Britain, located at Bedgebury, Kent and Brechfa in mid-Wales (see Table 1), which were both growing at a rate equivalent to GYC 6 at the last assessment. This is similar to performance by native oaks at these sites. Algerian oak is potentially relevant to dry lowland sites in Britain, currently carrying pine, chestnut or beech.

Pyrenean oak (*Quercus pyrenaica* Willd.)

Pyrenean oak is native to Iberia and northwest Africa, but it is also cultivated in western France and northern Italy. It is uncommon in the Pyrenees and typically occurs in lowland oakwoods in Spain, accompanying cork oak (*Quercus suber*) in 'dehesa' wood-pastures (see Figure 10). The species coppices well and is used for woodfuel and charcoal. The tallest tree in Britain is in Devon with a height of 26.0m with 88cm dbh (www.treeregister.org). Leaves are 8-16cm with 4-8 lobe/segment pairs (Tutin et al., 1964), glabrous above and pubescent white below. There has been little cultivation in Britain. Pyrenean oak might become relevant to dry lowland areas of southern England, including sites currently carrying pine or chestnut (where disease pressures are active) or native oaks (should these sites become too droughty).

Mediterranean oaks – provenance selection

Unlike in the case of red oak, there are no British provenance trials to guide selection for Mediterranean oaks. For Turkey and holm oaks, which are more numerous, seed collections from good stands of these target species within Britain, containing sufficient individuals, may be a practical option. For these, and the less common species, northerly and higher elevation provenances from within their native ranges may offer better cold hardiness for British conditions.

Mediterranean oaks – seed production and nursery practice

There is little record of nursery production of these species for forestry purposes in Britain. Even in France there appears to be limited nursery experience as most growing stock is either self-sown or coppiced. Some material is produced by British nurseries for amenity horticulture – for example the Hungarian oak cultivar 'Hungarian crown' having the RHS Award of Garden Merit, and some holm oak for coastal plantings. Seed can be stored moist at -3°C and +5°C for up to six months. Seed of *Q. ilex* may require a cold treatment for one month (Gordon, 1992; Gosling, 2002 & 2007). Otherwise nursery practice appears similar to native oaks.

Mediterranean oaks – pest and diseases

Turkey oak acts as the alternate host for knopper gall wasp (*Andronicus quercuscalicis*), which can damage seed production in pedunculate oak (and occasionally sessile oak) by formation of galls on acorns, causing them to become convoluted and infertile. As both oaks must be present for this insect's life cycle to complete, pedunculate oak only becomes affected if Turkey oaks are nearby. Hence, Turkey oak should not be introduced near populations of pedunculate oak.

Figure 10. Oak dehesa wood-pasture, Andalucia. (Photo: Scott McG. Wilson)

Mediterranean oaks are collectively susceptible to numerous *Phytophthora* root infections (e.g. *P. cinnamomi*, *P. ramorum*, *P. quercina*) causing oak declines of varying severity. This applies particularly where moisture stress arises (San-Miguel-Ayanz et al., 2016). They are therefore generally not advised for deployment on sites where *Phytophthora* has been active. Honey fungus (*Armillaria*) affects most oak species. Hungarian oak is susceptible to *Cryphonectria* blight (San-Miguel-Ayanz et al., 2016) and downy oak to gypsy moth (*Lymantria dispar*). Oak processionary moth has been found infesting Turkey oak in Britain (Forest Research, 2017a) and may be able to colonise other oak species. Acute oak decline (Denman, 2014) susceptibility is not yet established for introduced oaks.

Mediterranean oaks – timber properties and utilisation

Timbers of Mediterranean oaks are conventionally regarded as inferior to British native oaks. However, these species are capable of producing timber for traditional sawn applications including decorative carpentry, furniture-making, construction, mining and railway works (Evans, 1984; Macdonald et al., 1957; Rameau et al., 2008; Savill, 2013). Although valued for timber in its native range (Edlin and Mitchell, 1985), British-grown Turkey oak timber is inferior to that of native oaks (Evans, 1984; Savill, 2013). It is denser at 800-880kg/m^3, but hard and brittle, with wide sapwood and a marked tendency to shrinking and cracking during drying (Edlin and Mitchell, 1985). It lacks natural durability, also resisting preservative uptake, rendering it unsuitable for exterior uses. Hungarian oak timber is believed equivalent to sessile oak (San-Miguel-Ayanz et al., 2016). Downy oak and holm oak timbers are dense and hard, hence more difficult to work (Edlin and Mitchell, 1985; Rameau et al., 2008), but holm oak can have attractive colouration and figure for marquetry and parquet flooring.

Downy oak is the third, and holm oak the fourth, most important productive oak in France (Timbal and Aussenac, 1996), although only representing 10% and 3% of oak volume production respectively, whereas *Q. robur* and *Q. petraea* together represent 84% thereof. Their main use today is woodfuel production, often from coppiced stands. Historically, charcoal and tanbark for industry (e.g. iron smelting and leather tanning) were important.

Conclusions

Introduced oaks cannot currently rival native British oaks for ecological or timber values, when the latter are growing on optimal or suitable sites. Neither do they offer significantly greater resistance to pests and diseases currently affecting British native oaks. There is therefore no sound case for planting them in woodlands containing productive native oaks. In certain cases, there are concerns over potential invasiveness and hybridising tendencies that should prevent their use on designated sites, in semi-natural woodlands or those containing native oaks. In some situations a government licence may be required in order to plant non-native oak species. Susceptibility to *Phytophthora ramorum* renders most introduced oaks inadvisable for sites where infected larch or *Rhododendron* has recently been growing.

Selected introduced oaks, including red oak, may find a role for woodland creation on sites sub-optimal for native oaks, on grounds of soil drought or infertility, and where timber of native oaks may manifest shake. These conditions are frequently encountered on lowland heathland and reclamation sites with drought-prone soils (including those currently carrying Corsican pine or chestnut). Under climate change some lowland sites carrying native oaks may become too dry for these over the next rotation. This applies particularly on New Forest, Breckland, Surrey and Berkshire heaths, where soils are free-draining, with annual rainfall below 650mm. Introduced oaks could be grown in such situations in mixture with broadleaves, such as birch, and also potentially with lowland pines, Atlas cedar, Mediterranean *Abies* firs and Monterey cypress. Red oak may also find a role in the foothills of the uplands, especially on the eastern side of Britain, wherever shallow or infertile soils result in poor performance by native oak species.

Woodlands created using introduced oaks might be managed for landscape amenity and soil remediation, soil conservation, carbon sequestration and woodfuel production on short-to-medium rotations. Production of saw-timber should be possible from plantations of red oak, and some Mediterranean oaks discussed here, if grown on longer rotations on better sites.

Acknowledgements

Literature review informing preparation of this article was part-sponsored by small project grants to the corresponding author from Woodland Heritage and the Royal Forestry Society for which the authors are grateful. Information on Forest Research's sample plots was kindly provided by Ian Craig, while Dr Steve Lee and Rob Sykes produced recent assessments of Forest Research's red oak provenance trials.

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