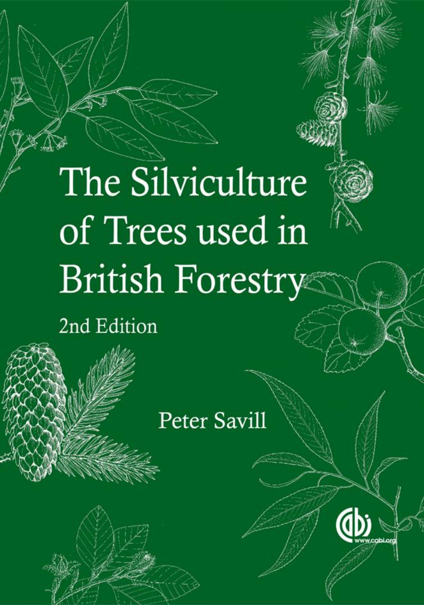

The Silviculture of Trees used in British Forestry

2nd Edition

Peter Savill

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Contents

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The figures in Table 1 were provided by Jackie Watson of the Economics and Statistics Branch of the Forestry Commission, and are reproduced with permission.

The scientific names of the trees used in this book were kindly checked by Stephen Harris, Druce Curator of the Oxford University Herbaria. Several have changed since the first edition was produced in 1991.

Introduction

Many books have been written about trees that grow in Britain. They range from guides for identification to books that have been lavishly illustrated by talented photographers and artists. One of the best known of the former group is Alan Mitchell's (1974) *A Field Guide to the Trees of Britain and Northern Europe* and its successors, and among the latter is Thomas Pakenham's (1996) *Meetings with Remarkable Trees*. Numerous publications by the Forestry Commission also provide much basic information that can be useful when selecting species for specific sites.

Few books, however, cater particularly well for the person who seeks detailed information about the silvicultural characteristics and requirements of individual species. Among the authors to do this were M.L. Anderson in his *Selection of Tree Species*, which was first published in 1950, and Macdonald *et al*. (1957) in their *Exotic Forest Trees in Great Britain*. The information they provided about species, though still very useful, has inevitably become somewhat dated as techniques have changed and knowledge has increased.

More recently, Ray (2001) and Pyatt *et al*. (2001) have produced a computer-based ecological site classification that has proved invaluable in assisting the selection of species, as well as indicating how species might respond to climate change. It is based upon matching a four-climatic variable (accumulated temperature, moisture deficit, windiness and continentality) and two soil variables (moisture and nutrient regimes) with the requirements of 31 possible species of tree. In addition, the shade tolerance of each species is taken into account. Yet computer programs, however sophisticated, can never substitute for educated and informed thinking, knowledge and understanding.

Matching species to site

The climate of an area limits the range of species that can be grown successfully. Temperature, precipitation and wind are usually considered the important elements of climate for forestry.

The more favourable the climate, the greater the range of species from which a choice can be made. In upland regions of Britain where the climate is harsh and soils are often poor, the number is limited to two or three, whereas on good soils, in the better climate of the lowlands, a choice from about 20 may often be possible. These latter sites are said to have greater amplitude.

Forestry has traditionally taken second place to agriculture, and most forest sites are marginal for agricultural production in some way. A large proportion of British forests are at high elevations where growing seasons are much shorter than in the lowlands and exposure to gales is common. Apart from physical problems such as steepness, stoniness and exposure, many forest soils tend to be drought-prone or waterlogged, suffer from extremes of acidity or alkalinity, or have compacted or cemented layers. Two-thirds of the state-owned forests have soils that suffer from poor aeration due to permanent or periodic waterlogging (Toleman and Pyatt, 1974). There are numerous important interrelationships between the physical, chemical and biological influences in a soil that can affect species choice.

In many places today there is considerable past experience of which species will grow and how they will perform, either from existing stands of the same tree on the site itself, or from similar nearby areas. Site conditions should guide species choice in any approach to forest management, and this is particularly important for continuous-cover forestry given its demanding requirements in terms of stand stability, diversity, the use of natural processes and multipurpose management.

Exceptional climatic events can reveal inadequacies in species selection that may not be apparent in more normal periods. This is one reason why extreme caution should be observed before a relatively untried, but promising, exotic tree is planted on a wide scale. A common pattern with introductions everywhere is one of initial establishment in gardens and arboreta and then, if successful, perhaps half a rotation later, this is followed by small-scale planting on estates and by government departments. Large plantations of the most promising species are established some 20–50 years after that (Streets, 1962). Thus, Sitka spruce, which is the major plantation tree in Great Britain and Ireland, was first introduced in 1831. It was established as one of the chief exotics in the early 1920s and by the mid-1950s it became the most widely planted tree.

Premature extensive planting often leads to problems. For example, in Britain the cold winters of 1981–82 and 2010–11 killed many *Eucalyptus* spp. that were being tested experimentally, but at the same time they were also being promoted for widespread planting by a few people.

The general considerations that must be taken into account when deciding what to plant on a site are described in many silviculture textbooks. The amount of information available about the climatic and site requirements of each species, and other features of their silviculture, varies considerably but is closely related to how common and important they are. For some, especially the major conifers, oak and beech, knowledge is quite comprehensive, while for others such as lime and walnut it is scanty and sometimes almost non-existent.

Provenance

When dealing with both indigenous and exotic trees, it is not sufficient simply to decide which species to plant without considering the original geographic source of the seed as well – that is, the provenance. Some of the worst mistakes in plantation forestry are the result of well-intentioned foresters importing seed from stands that look good but which are quite unsuited to the new environment (Lines, 1967). Decisions on what to use must be based on the evidence of trials in the new environment, rather than on untested opinions. The forester has much to gain by using the best possible seed source for raising trees for woodlands. There was an unfortunate period when plants grown from unsuitable seed were widely planted, because well-intentioned but misguided bureaucrats insisted that the cheapest seed was always bought, to the serious detriment of many forests that were planted with it. Seed represents only a minute proportion of total establishment costs of woodland, and it is a false economy to buy anything but the very best that is obtainable. If genetically improved seed that has gone through a breeding programme is available it should always be preferred, especially if it has reached EU 'tested' status.

There are many recorded cases of inappropriate seed leading to problems. For example, in 2006 Alain Valadon reported to a European Forest Genetic Resources Programme (EUFORGEN) meeting in Romania on a case in France where 400,000 hectares (ha) of red oak were planted between 1970 and 2000 (EUFORGEN, 2012). By 2004 only 27,000 ha had survived. Mortality was due to unsuitable provenances being used to begin with, causing problems of poor frost or drought resistance, susceptibility to pests and diseases, and poor adaptation to site conditions.

Climate change

Apart from the fact that it is undoubtedly happening, climate change presents great uncertainties that influence the choice of species, since future conditions are difficult to predict with any precision. It is possible to make guesses based on the most likely scenarios, as Davies *et al*. (2008) have pointed out. In general, it will be best to favour species with greater amplitudes of site requirements and to make use of a wide range of species to spread risks. The most likely picture for climate change in Britain is that winters will become wetter and summers slightly drier, which, combined with increased temperatures, will lead to increased summer soil moisture deficits. There may also be increases in the number of severe winter and summer gales (Ray *et al.*, 2002). These changes are likely to favour species such as Douglas fir, while conditions for Sitka spruce may become less suitable in England but more so in northern and eastern Scotland (Ray *et al.*, 2002).

There are also widespread concerns that the current genetic stock of trees may not be able to cope with future climate change. Kremer (2010), who took the European oaks as a case study, has shown that rapid migration and adaptation, extensive gene flow and hybridization were the main processes that enabled oaks to cope with climatic warming in the past. In considering future evolutionary trends, he concluded that the potential for species to migrate via seed dispersal to more favourable locations (e.g. northwards) will be limited. On the other hand, it is likely that natural selection will act on a diverse gene pool in part due to large population sizes, perhaps allowing local adaptation even if this ultimately reduces diversity. Substantial evolutionary shifts can be expected in a limited number of generations. The high levels of genetic diversity and gene flow from other populations will favour rapid adaptation. However, he believed that many tree populations may be tested to the limits of their adaptive potential, so some intervention may be needed.

Kremer (2010) believes that to enhance the adaptive potential of populations, genetic diversity should be increased by mixing local stock with non-local material. Guidelines that provide information on recommended directions and distances for the transfer of reproductive material need to be developed based on current scientific information, especially data from existing provenance tests. The current guideline for England, for example, is given in a publication by the Forestry Commission (2010). It recommends, among other things, that a proportion of seed in new plantations should come from sources located 2–5° south of the planting site.

Composition of British forests in 2000s

The relative importance of broadleaved trees and conifers can be gauged by the consumption of timbers of each in the country, and by the extent of areas planted with different species. By far the greatest area of forest, 40%, is occupied by Sitka spruce and Scots pine, and the most common broadleaved species, at 9%, are the two native oaks (Table 1). It is difficult to obtain completely reliable figures for consumption in the UK, but estimates by the Timber Trade Federation (TTF, 2009) and conversations between the author and those in the industry indicated that about 90%

Table 1. Area of high forest by principal species based on the National Inventory of Woodland and Trees 1995–1998 (Forestry Commission, 2003).

Species	Area (ha)	% of all high forest
Conifers		
Sitka spruce	683,656	30
Scots pine	219,438	10
Lodgepole pine	134,076	6
Japanese/hybrid larch	107,677	5
Norway spruce	76,206	3
Corsican pine	45,350	2
Douglas fir	45,224	2
European larch	22,485	1
Other conifers	29,209	1
Mixed conifers	16,188	1
Total conifers	1,379,510	61
Broadleaves		
Oak	206,154	9
Birch	155,355	7
Ash	119,232	5
Beech	76,551	3
Sycamore	61,357	3
Sweet chestnut	10,800	<1
Poplar	10,418	<1
Elm	3,743	<1
Other broadleaves	97,915	4
Mixed broadleaves	139,196	6
Total broadleaves	880,722	39
Total all species	2,260,232	100
Felled but not yet restocked	47,040	
Total high forest	2,307,272	

was imported and 10% home-produced, and that 64% of all timber used was coniferous. In terms of the forest areas existing in Great Britain in 2011, 61% was coniferous and 39% broadleaved (see Table 1), and amounted to 2.3 million ha in all, or 13% of the land area. Much of the broadleaved woodland is neglected, unmanaged and not even approaching its potential in terms of sustainable production (LINK, 2009).

Developments in British forestry since 1990

The period of just over 20 years between the first and second editions of this book has been one of unprecedented changes in British and world forestry, some of which affect species use. There have been substantial developments in the forestry profession. We have become aware of the greenhouse effect; Geographic Information System (GIS) has come into everyday use; multipurpose trees, agroforestry, social forestry and urban forestry, though not new, have all become subjects worthy of special attention. Sustainable forest management (SFM), together with ecosystem services, certification and carbon sequestration are familiar to everyone.

Since the introduction of the government's 'Broadleaves Policy' in 1985 there has been an increasing emphasis on multipurpose management of forests, and a growing pressure to diversify even-aged monocultures in terms of both species composition and structure. Sitka spruce monocultures have been the focus for most of the work into how this 'continuous cover' forestry might best be achieved (e.g. Malcolm *et al.*, 2001; Mason *et al.*, 2004), though other species have also received attention (e.g. Kerr, 2002; Davies *et al.*, 2008; Helliwell and Wilson, 2012). Foresters have been required increasingly to act as ecosystem managers rather than simply as growers of wood. This can be difficult in the many cases where the forests were established with the single objective of producing wood because now they are required to deliver wider benefits. In addition, many foresters were not trained in the type of forest management that is required today.

The effects of the removal in 1988 of the generous tax allowances that had driven most of the afforestation, and which had resulted in a more than doubling of the area of forest in Great Britain during the 20th century, became evident in the following decades. Afforestation rates plummeted from almost 30,000 ha in 1988 to 16,300 ha in 1998 and 7000 ha in 2008. At the start of the period field meetings of foresters were usually devoted to discussing silvicultural and economic issues. This changed rapidly to discussions and demonstrations of the most recent pond, glade, trail or coppiced area. Forestry became dominated by social scientists whose aim was to promote public participation. They achieved a great measure of success, and the Forestry Commission's public image improved enormously.

Attitudes to non-native species

Great Britain is full of introductions. The landscape is largely a cultural one, which is a mixture of native species, ancient introductions and more recent arrivals. Modern agriculture, forestry and horticulture all largely depend on the introduced species (Kirby, 2012). Most people, of course, accept and understand this, but a few extreme conservationists dislike, and hope to eliminate, anything that that is not native (i.e. arrived in Britain without help from humans).

Lowland British woodlands suffered from this attitude in the 1990s, when attempts were made to remove exotic conifers (or, as many environmentalists refer to them, 'alien' conifers). The millions of pounds of public money that were spent on removing them before maturity probably exceeded the millions that had been spent on establishing them in the first place. The subsequent 'restoration to broadleaves' sometimes meant clearing the coniferous crop and then leaving the site to regenerate naturally, having collected the grant first. More often than not the restored areas became covered with unproductive 'scrub' rather than woodland.

Profitability of forestry
The restoration to broadleaves was popular with politicians and officials who declared that sustainable forest management, under their guidance, was progressing from one triumph to the next (e.g. Forestry Commission, 2011). The reality, according to the LINK report of 2009, was that English forests, at least, were undermanaged and deteriorating. Thinning and pest control had been ignored and consequently the very wildlife values that were being so loudly proclaimed were becoming seriously impoverished. Woodland plants, butterflies and birds had all declined significantly in variety and number. The reason for this has been graphically illustrated by Nicholls (2006) who, in a series of surveys of the profitability of forestry between 1963 and 2005, concluded that 'There has been a deterioration of the financial performance of many woodlands since the 1960s to the point where management has been reduced or even suspended'.

Pests and diseases
In addition, largely because of the speed and frequency of international travel and in some cases ineffective, or virtually non-existent, controls on the movement of plant material, a number of tree diseases and pests have been introduced, most with potentially devastating effects. They include red band needle blight of pines, ramorum disease of Japanese larch, acute oak decline, oak processionary moth, and the breakdown of resistance to *Melampsora* rusts by most clones of poplars that were in use. Most recently, in 2012, chestnut blight was introduced from France and the ash dieback disease caused by the fungus *Chalara fraxinea* from the Netherlands. In fact, a large and apparently increasing number of indigenous and traditionally used species are under threat, and there is a need to find others to replace them where possible.

New uses for timber
There have been several developments in the use of wood. Among them are such things as glulam, an engineered wood product composed of smaller pieces of wood that have been bonded together with a durable adhesive into large, strong beams or columns. Curved shapes can be made from glulam, which provides huge flexibility in design. It offers a means for using small-dimensioned timber that might previously have gone to much inferior uses, or even be classed as waste.

Growing biomass specifically for the production of renewable energy is a development of a traditional technology that is now receiving the backing of many governments. The EU's 2009 Renewable Energy Directive sets a target for the UK to achieve 15% of its energy consumption from renewable sources by 2020. This compares to 3% in 2009. Woody biomass, often converted into wood chips, can be used in power stations or for institutional or domestic heating. Because of its dimensions or shape, a relatively high proportion – often 60% or even more – of all timber from woodlands is suitable only for fuel or other low-value uses. This can provide part of the supply. Quite commonly, special biomass plantations are also created, mostly with poplars and willows grown on short coppice rotations. Once established, these can produce around 10 dry tonnes (t) ha^{-1} $year^{-1}$ compared with about 4 dry t ha^{-1} $year^{-1}$ from conventional coppice such as hazel and oak.

Various pharmaceutical and other products derived from wood are being developed, most notably from lignin removed from wood in papermaking. Formerly, this was a major pollutant to waterways around pulp mills.

Other developments

Paradoxically, although the period from 1991 was one when the value of forests globally became more widely appreciated than in any other period of history, it was also one of rapidly diminishing support for British forestry. Several universities that had taught forestry closed their undergraduate and graduate courses.

Devolution occurred in Scotland and Wales, and with this the Forestry Commission in each country went its own way. In Wales it will vanish in 2013 after incorporation into Natural Resources Wales. In England more than one attempt was made by politicians to dispose completely of the publically owned forest estate. The plans were thwarted by the strength of public opinion against the proposals.

At the time of writing (2012) there were signs that this depressing situation might be ending. Timber prices have increased very appreciably in recent years with China's entry into the market in a major way, and the promotion of wood fuel has meant that demand for firewood and its price have also increased significantly, allowing woodland management and thinning of young broadleaved plantations to show some financial return for the first time in many years. There appears to be a revival of forestry teaching, at least at Oxford University, with the endowment (by Sir Martin and Lady Wood) and appointment of a new Professor of Forest Science.

This book

This book aims to provide a guide that can be used when selecting species and managing trees. The requirements of individual trees are described for areas in which they are likely to do well. No particular consideration has been given to the relative economics of the different species: the main emphasis is upon the biological suitability of species to sites. It is assumed that the reader is reasonably well informed about the principles of forestry practice.

About 35 species of trees are native to Britain, but according to Mitchell (1974), over 500 species can easily be encountered by anyone looking in parks and gardens. If special collections in botanic gardens are included the number rises to about 1700. The choice of the 35 genera and some 63 species included here has therefore, inevitably, been arbitrary. Because of the current interest and emphasis on conservation, almost all native species that grow to reasonable-sized trees have been included, even though some, such as box, rowan and the wild service tree, will never be anything but minor species. Among exotics, all the commonly planted trees are included and, because climate change might make others desirable, some of those suggested in the Read Report on combating climate change (Read *et al*., 2009) are included. Among those deserving more serious consideration than they have received in the past are *Cryptomeria japonica*, *Sequoia sempervirens*, *Pinus peuce*, *Thuja plicata*, walnuts and red oak.

This book does not provide detailed botanical descriptions of trees, nor has there been any attempt to cover the means by which pests and diseases are controlled. The more serious ones are simply noted as potential risks.

The remainder of the text provides information about the origin and introduction (where applicable) of each species, climatic and soil requirements, other silvicultural characteristics, diseases, natural regeneration, provenance, seed production, nursery treatment, yield and timber characteristics. Information about the ages at which trees first produce seeds should be treated with prudence. It is reasonably accurate for trees in even-aged plantations or groups at fairly close spacings. Widely spaced trees often produce seeds earlier than the times quoted.

The book concludes with two simple keys for identifying the trees most likely to be encountered in woods. It has been tested on generations of undergraduate and graduate students and has proved successful and easy to use.

Species are arranged alphabetically through the text, by scientific names. *In the line drawings a vertical line indicates a scale of 3cm*. It should be noted that it was not always possible to obtain mature specimens of fruits or cones to draw.

ABIES Mill. — Silver firs

There are about 46 species of *Abies*, most of which occur in the north-temperate zone. Only three are grown as forest trees in Britain.

ABIES ALBA Mill. — European silver fir

Origin and introduction

The European silver fir occurs naturally, scattered through the mountains of central, southern and eastern Europe, from the Pyrenees to the Balkans and Normandy. It is especially prominent in the Vosges, Jura, Black Forest and northern Bavaria. It was introduced to Britain in about 1603.

Climatic requirements

High humidity and not too high a temperature are required. The tree does best in Scotland, but large specimens can be found almost everywhere (Macdonald *et al.*, 1957). The European silver fir is sensitive to late spring frosts and like most shade-bearers ideally needs overhead cover when young. Frost-prone flat areas and hollows should be avoided. It does not tolerate exposure particularly well, nor atmospheric pollution.

Site requirements

The European silver fir grows well on most soils that do not dry out including heavy clays, but waterlogged soils, including peats and dry, infertile sands and gravels are best avoided. It does particularly well on fertile calcareous soils, in the west and south-west at moderate elevations, and on north-facing aspects.

Other silvicultural characteristics

The European silver fir can become a large tree, up to 50 m tall, and is recorded by Mabberley (2008) as being the tallest European tree. It self-prunes slowly and is inclined to produce heavy branches unless they are discouraged by close planting. Early growth is slow, like that of many silver firs, but it is a considerable volume producer once established, after

8–10 years. It is said to be a much deeper-rooting tree than Norway spruce and therefore more stable, especially on clayey soils. The species is a very important constituent of many continental European selection forests, where spruce regeneration tends to occur under the European silver fir and vice versa.

Diseases

Since 1910 the European silver fir has suffered badly from attacks by an aphid, *Adelges nordmanniana* (Wilson, 2010), which causes defoliation, dieback and ultimately death. This is the main reason that it is not planted very much today. The relationship between site and severity of attack by *A. nordmanniana* is not fully understood, but stands on suitable soils in cool, moist climates recover better from attack than do those on poorer soils and in warm, dry areas (Varty, 1956).

The European silver fir is less prone to attack by *Heterobasidion annosum* than many conifers.

Natural regeneration

On good sites natural regeneration can be both prolific and persistent. Large 'seedling banks' are formed, if not eaten by deer, awaiting an overhead gap in the canopy before growing.

Flowering, seed production and nursery conditions

The tree flowers from May to mid-June; seeds ripen between mid-September and mid-October. The earliest age at which the tree bears seeds is between 25 and 30 years; maximum production is between 40 and 60 years. There are commonly 2 or 3 years between good seed crops. There are about 22,500 seeds kg^{-1} (range 17,400–41,000). If seed is required for sowing in a nursery, it should be collected as soon as it is ripe, before the cones disintegrate. It is normal to stratify, or pre-chill the seed for 6 or more weeks, prior to sowing in March. Unstratified seed should be sown in January or February (Aldhous, 1972).

Provenance

The tallest sources after 10 years' growth come from such divergent places as Calabria (Italy), Czechoslovakia and the Swiss Jura (Lines, 1978d).

Timber and uses

The white timber is similar to that of Norway spruce though less resinous and, in continental Europe, is used for the same purposes (general construction and paper). It is also known by the same name in the timber trade, whitewood. The average density at 15% moisture content is about 480 kg m^{-3}. It is not durable outdoors.

The European silver fir makes a good Christmas tree, though it has now largely been replaced for this purpose by other species of silver fir, especially *Abies nordmanniana*. Its resin is the source of Strasburg turpentine that is used in many bath products, giving them a pine scent.

Place of European silver fir in British forestry

The European silver fir was widely planted in Victorian and Edwardian times but is used very little in Britain today because, at least in pure even-aged plantations, it is badly attacked by *Adelges nordmanniana*. Even if genotypes resistant to it could be found, it is still unlikely to be widely used because it is a species that will become less suited to Britain, especially the south of Britain, if climate changes proceed as predicted. In the north it might fulfil a valuable role as a shade-bearer, as a minor component of mixed-age and mixed-species woodlands.

ABIES GRANDIS (D. Don) Lindl. — Grand fir

Origin and introduction

Grand fir is native to Oregon, Washington, north-west California and the coast of southern British Columbia, including Vancouver Island. It will grow to heights of 40–70 m in its native range. Brown and Nisbet (1894) referred to it as the ‘Great Californian Silver Fir’ and said it was ‘really worthy of its botanical name, for it is a tree of magnificent growth…’. Separate populations exist further east, in west Montana and north and west Idaho (Steinhoff, 1978). The species achieves its best development in the Olympic Peninsula of Washington. It is one of several north-west American species discovered by David Douglas, who sent seeds to Britain in 1831.

Climatic requirements

In its natural range the tree does best where conditions are cool and moist. It grows well where rainfall is as low as 750 mm but responds to higher levels. The best stands in Britain occur in the wetter parts of the country where precipitation is 1000 mm or more in the north and 1150 mm in the south (Macdonald *et al*., 1957). It is not as demanding as Sitka spruce. Temperatures in Britain are not limiting: it does as well in the north as in the south, but the tree is susceptible to damage by late spring frosts, so hollows should be avoided. Grand fir is sensitive to exposure, unlike noble fir, and should only be planted at low elevations; it will not thrive in areas of high atmospheric pollution or exposure to sea winds.

Site requirements

Though requirements are not excessive, grand fir does best on well-drained, moist, light and deep soils of at least moderate fertility. It should be used cautiously on heavy and infertile soils and will not thrive on calcareous soils. On dry soils it may suffer from drought crack. It appears to root much more deeply than many other conifers (Carey and Barry, 1975).

Other silvicultural characteristics

The most important silvicultural characteristic of grand fir is its strong shade-tolerance, especially when young, and consequently it is valued for underplanting and in continuous-cover systems. It usually has a good, straight stem, though it often tapers markedly. Older trees suffer crown damage on exposed sites and the species is moderately susceptible to windthrow and windbreak. It will grow to over 50 m tall in Britain.

Grand fir is more resistant to *H. annosum* than most conifers but prone to damage and associated wood deterioration due to a syndrome linked with drought, exposure and attack by *Adelges piceae* (Aldhous and Low, 1974), so it is probably safest in the western half of Britain where there is less risk of drought and frost. The litter, like that of Douglas fir, breaks down quickly. In common with all silver firs, early growth is slow though later it can become very fast, averaging 1 m in height a year over the first 40 years.

Flowering, seed production and nursery conditions

The tree flowers in May, seeds ripen in August and September and should be collected immediately, before the cones disintegrate. Grand fir is a rather poor seed producer in Great Britain. The earliest age at which it might bear seed plentifully is between 40 and 45 years. There are commonly 3–5 years between good seed crops. There are about

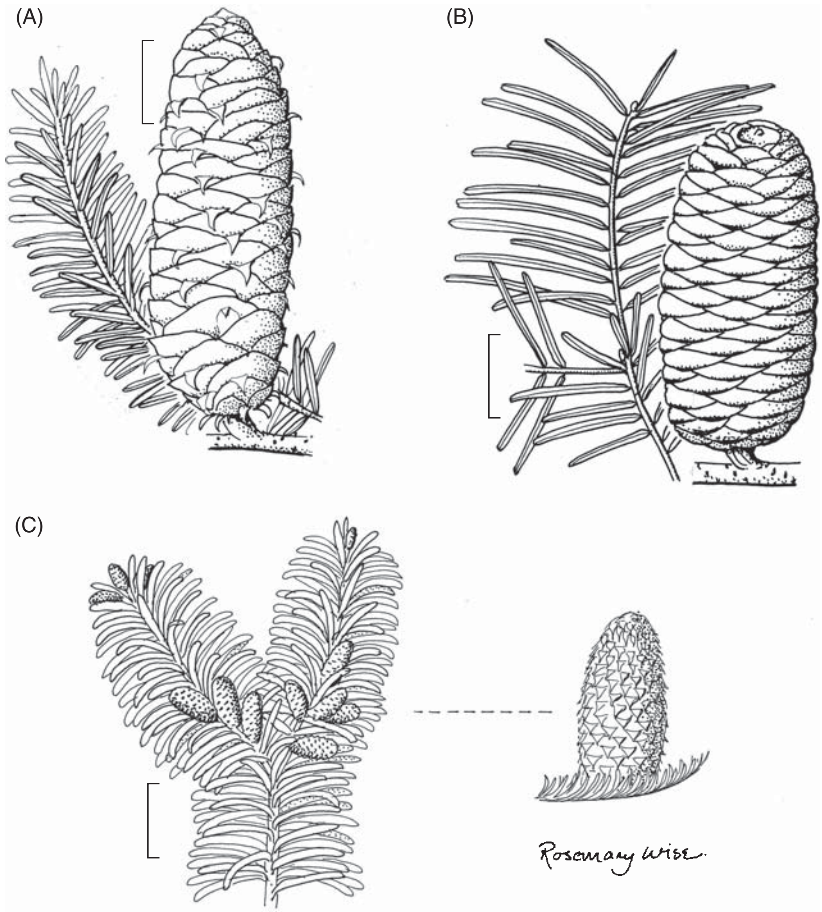

Fig. 1. (A) European silver fir, *Abies alba*; (B) Grand fir, *Abies grandis*; (C) Noble fir, *Abies procera*.

40,600 seeds kg^{-1} (range 26,200–63,500), of which 20,000 are normally viable. The treatment of the seed and sowing times in nurseries are the same as for the European silver fir.

Provenance

In Britain there appears to be a latitudinal cline of increasing vigour in a southerly direction among provenances from the coasts of Canada and the USA. Inland origins grow too slowly to be of much use (Lines, 1978a). Limited Forestry Commission experiments have shown differences of ten yield classes between the most and least vigorous provenances. Many existing stands are thought to originate from sources at the poorer end of the range (Lines, 1978b). The best growth after 6 years has been found in provenances from the Olympic Peninsula in Washington (Lines, 1986, 1987).

Yield and timber

On suitable sites grand fir can be one of the most productive trees in Britain. Yield classes in excess of 30 m^3 ha^{-1} $year^{-1}$ have been recorded, and on many sites it will out-produce most other conifers. In fact, its rapid growth in even-aged systems of silviculture and drought cracking has led, unjustly, to its timber having a particularly poor reputation among British sawmillers and there are few existing markets for it. The timber is perceived by most as being much inferior to that of the European silver fir. It is therefore not widely planted, though if it is used more in uneven-aged systems where growth would be slower, its reputation could improve. The average density of the wood is about 450 kg m^{-3} at 15% moisture content. In north-west America it is used as a general construction timber.

Place of grand fir in British forestry

The most important attribute of grand fir is its shade-bearing qualities, which give it an important potential place in continuous-cover silvicultural systems. Though it can be productive on suitable sites, other species are usually favoured, and it is therefore likely to remain a tree of minor importance.

ABIES PROCERA Rehder — Noble fir

Origin and introduction

The natural distribution is more restricted than those of many other north-western American species, being confined to the Pacific coast from northern Washington to northern California, mostly at elevations between 1000 and 1500 m (Franklin *et al.*, 1978). Like grand fir, it was first found by the Scottish botanist and explorer David Douglas and was introduced by him to Britain in 1831.

Climatic requirements

In its natural range noble fir does best where there is a cool, short growing season with abundant precipitation, mostly as snow. There are no well-defined climatic limits in Britain, but it grows best in the north and west, where temperatures and evaporation rates are rather low and precipitation high.

The tree has a high tolerance of exposure and does not become deformed. This valuable characteristic gives it a potentially useful place in the uplands. Noble fir is less moisture-demanding than Sitka spruce, which makes it suitable for well-drained, occasionally dry, exposed sites where Sitka spruce will not grow. It is less frost-tender than other silver firs but can be damaged by late spring frosts. Like most silver firs, it will not tolerate atmospheric pollution or sea winds.

Site requirements

In its native habitat noble fir is a pioneer species that regenerates after major disturbances such as fires. It does not need high fertility and will thrive on most neutral or acidic soils provided adequate moisture is available, though it will not withstand waterlogging. It does best on well-drained deep, moist soils, but grows quite well on boulder clays and some peats, but not in the presence of heather. Very dry sites should be avoided as it is susceptible to drought crack.

Other silvicultural characteristics

In north-west America noble fir will grow up to 70 m tall or more. Early growth is always slow, necessitating prolonged weeding and making the species vulnerable to damage from browsing animals. It is normally windfirm. The tree is relatively resistant to *H. annosum*. It can be used for underplanting and in continuous-cover silvicultural systems, but it is not as tolerant of shade as grand fir or hemlock, and needs freeing quite early.

Flowering, seed production and nursery conditions

The tree normally flowers in June, and seed production is better than the other species of *Abies* in Great Britain. Seeds ripen from mid- to late September and are dispersed early in October. Cones should be collected in late August or early September, because after this the scales loosen prior to the disintegration of the cone and all the seed can be lost. The earliest age at which the tree bears a good seed crop is between 30 and 35 years, but the best ones are usually between the ages of 40 and 60 years. There are commonly 2–4 years between good seed crops. There are about 29,800 seeds kg^{-1} (range 20,300–42,100), of which only 12,000 are normally viable. The treatment of the seed and sowing times in nurseries are the same as for the European silver fir.

Provenance

The most promising source appears to be Larch Mountain, Oregon, at 975 m, which lies east of Portland (Lines, 1987), and provenances from the Washington or northern Oregon Cascade mountains or from good-quality British stands are also suitable.

Timber and uses

The timber of noble fir is regarded in the USA as one of the best of the true firs and it is used for general structural purposes and joinery. It was once used for aeroplanes because its wood is light, strong and can be bent before it breaks (ISI, 2011). In Britain, by contrast, it has a reputation for having poor strength properties, poor durability and a low density (about 420 kg m^{-3} at 15% moisture content). It is said to be suitable for general interior joinery and light structural work (Patterson, 1988).

It is a species of great ornamental value and is popular as a Christmas tree. It is grown profitably in parts of Europe specifically for its foliage, and varieties with blue needles are preferred for this.

Place of noble fir in British forestry

Noble fir will thrive, without becoming deformed, on exposed dry sites at high elevations that are unsuitable for Sitka spruce. This is probably its main place in British forestry. There is little case for large-scale planting because of the slow early growth. Many people believe it could become a much more useful tree if the density of its wood could be increased, by selection and breeding.

ACER

There are 114 north-temperate species of *Acer* and one tropical mountain species in West Malaysia. Most occur in East Asia. There are 14 European species, but only one of these, *Acer campestre*, is native to Britain. Many produce important timbers; one is the source of maple syrup, and there are numerous cultivated ornamental varieties, which are mainly known for their spectacular autumn colours (Mabberley, 1990).

ACER CAMPESTRE L. — Field maple

Origin

Field maple is the only indigenous maple, found most commonly at low elevations in the south of England, in woodlands, hedgerows and scrub. It is absent from Scotland and Ireland, and uncommon in Wales. Its range extends over most of Europe south of Norway, from 55 to 38°N (EUFORGEN, 2011); it extends eastwards to Poland, Belarus and south-west Asia and is also found in the Atlas Mountains.

Climatic requirements

The trees grow best in warmer, drier climates and are consequently more common at lower elevations and in the south of England. They are hardy to low winter temperatures and not damaged by frost.

Site requirements

Field maple is most common on neutral to calcareous soils, especially when heavy, but it will not grow on waterlogged soils. Though it grows on a range of other soil types as well, it is seldom found when the pH is below 6 or above 8. It is frequently associated with ash, together with a ground flora of dog's mercury, bluebell, sanicle, sweet woodruff and similar woodland herbs.

Other silvicultural characteristics

Field maple is a small tree or shrub that seldom exceeds about 15 m tall but occasionally grows to 25 m. It is a later seral species that typically occurs in the understorey of deciduous woodland and is never found invading grassland or the early stages of plantations. As such, it is shade-tolerant when young when it can grow fast, but it is soon overtaken by other species as the forest matures. It coppices well.

Flowering and seed production

The tree flowers in the spring and is unusual among British trees in being insect pollinated. It is regarded as a good bee plant. Seed is produced when the tree is aged around 10 years. There are about 15,000 seeds kg^{-1}. The seeds need 16–18 months' stratification if they are to be grown in the nursery; otherwise they should be treated in a similar way to sycamore.

Timber and uses

The wood of field maple is white, hard and strong. It is slightly heavier than sycamore, at about 690 kg m^{-3}, and is used for similar purposes: furniture, joinery and flooring.

Place of field maple in British forestry

Though only a small tree, field maple's bright amber-yellow autumn colour makes it one of the most striking native species. However, as a timber producer, its size and slow growth mean that it is an unimportant forest tree.

ACER PLATANOIDES L. — Norway maple

Origin and introduction

Norway maple is native to central and northern Europe, Asia Minor, the Caucasus and northern Iran. It was introduced to Britain before 1683.

Climatic requirements

Norway maple is much less tolerant of exposure than sycamore and should never be planted on windy sites. A consequence is that it is far more common in the lowlands of southern England than elsewhere. In common with sycamore, it can withstand moderate pollution by smoke but not salt spray.

Site requirements

Its site requirements are similar to those of sycamore, though it is less demanding of soil fertility and will tolerate drought better. It will grow on most types of soil, except peats, provided they are moist and is successful in a wide range of pH conditions, though does not thrive in extremely acid or alkaline soils. According to Kerr and Niles (1998), it grows best on deep, fertile, moist soils that are adequately drained and have a pH in the range 5.5–6.5. It also does well on heavy soils. The species is regarded as one of the best broadleaves for planting over chalk and is said to grow better than sycamore on more acid soils. Norway maple is a tree best suited to lowland sites and lower hills. It will not thrive at such high elevations as sycamore.

Other silvicultural characteristics

Norway maple is a medium-sized tree that grows to about 25 m tall. It will not thrive in large pure stands but rather singly or ideally in small groups because its rapid early growth may cause suppression of companion species. It does well in mixture with beech, Norway spruce and western red cedar. Norway maple is sensitive to competition from grass when young, and therefore growth benefits considerably from careful weeding.

It grows fast when young, usually faster than sycamore for the first 30 years or so, and needs to be heavily thinned to maintain growth but does not reach such large dimensions as sycamore, or live for as long. It is usually described as moderately light-demanding. On suitable sites, and with proper thinning and care, trees of 40 cm diameter at breast height (dbh; 1.3 m) may be achieved in 40 years.

The tree is usually regarded as being more attractive than sycamore: it produces spectacular yellow or orange-red autumn colours. It makes a good street tree. Many cultivars have been selected for this purpose.

Like sycamore, it is very susceptible to bark stripping by grey squirrels throughout the pole stage and this makes growing it for high-quality timber production extremely difficult in most of Britain. Otherwise it is generally much more free from most species of pests or diseases, though, in common with other maples, it is one of the trees that are potentially at risk from the larvae of the Asian longhorn beetle (*Anoplophora glabripennis*). Street trees will apparently be particularly at risk if the beetle gets a foothold in Great Britain.

Natural regeneration

Norway maple has become naturalized on many sites but especially on sandy soils.

Fig. 2. (A) Sycamore, *Acer pseudoplatanus*; (B) Field maple, *Acer campestre*; (C) Norway maple, *Acer platanoides*.

Flowering, seed production and nursery conditions

In common with sycamore and field maple, Norway maple is insect pollinated. It flowers in the spring and is regarded as a good pollen- and nectar-producing tree for bees. It produces its first fertile seed between 25 and 30 years, with the best crops every 2 or 3 years between 40 and 60 years, though some seed is produced every year. It is usually ready for collection in September or October. There are about 7500 seeds kg^{-1}, of which about 80% normally germinate. For nursery production the seed should be treated in the same way as sycamore.

Provenance

Work by Kerr and Niles (1998) has shown that good growth and form of Norway maple can be achieved from a wide range of sources in Europe. These included Germany, the Netherlands, Denmark and the former Yugoslavia. A provenance from Russia performed poorly, as expected.

Growth and yield

Field trials have indicated that height growth can be fast; up to 18–22 m tall in 40 years is possible (Evans, 1984; Kerr and Niles, 1998).

Timber

The wood is similar to that of sycamore, being white and fine-textured, though harder. It is used for the same purposes. Wavy- (or ripple-) grained maple is in great demand and is sometimes used for making musical instruments. The average density at 15% moisture content is slightly greater than that of sycamore, at about 660 kg m^{-3}.

Place of Norway maple in British forestry

It is considered by Kerr and Niles (1998) to be a useful tree for high pH and heavy soils, and as an alternative species to sycamore (which does better in the north) on sheltered southern sites.

It has become a popular street tree in British towns because:

- early growth is vigorous;
- leaf emergence is early and autumn colour is attractive;
- form and size are ideal;

- the tree tolerates urban influences well;
- it transplants well;
- it grows on a variety of soils; and
- it withstands ice and snow damage better than other maples.

ACER PSEUDOPLATANUS L. Sycamore

Origin and introduction

Sycamore (or plane in Scotland) is native to high elevations in southern and central Europe; it extends northwards to Paris and east as far as the Caucasus. Its time of introduction to Britain and Ireland is uncertain, but it was possibly brought by the Romans, or as late as 1550. It is certainly reported to have been rare in the 16th century and has only become properly established within the last 200 years. Writing in 1794, Samuel Hayes spoke of the fine sycamore trees present in Ireland at the time.

The ecology of sycamore has been described in detail by Jones (1945) and more recently by Taylor (1985). Sycamore is most common in the north and west of Britain.

Climatic requirements

Sycamore is much less sensitive to late spring frosts than most important deciduous trees, and is tolerant of exposure to wind on suitably moist and fertile sites. It makes good windbreaks in exposed and maritime areas, and can recover from the effects of salt spray by producing new leaves, but the foliage itself is not resistant to the effects of salt, as in truly maritime species. Sycamore withstands smoke pollution well. It grows better at higher elevations than any other broadleaved trees except rowan and the birches, and its potential upper limit is determined more by the presence of suitable soil than by climate. According to Leslie (2005), the most northerly woodland in Britain, on the exposed Mey estate in Caithness, is composed of sycamore. Sycamore thrives best in the damper, western, parts of Britain. Predictions for climate change indicate that it will become less suited than at present to south-east England and the Midlands if summer droughts become more frequent (Morecroft *et al*., 2008), but parts of south-east Scotland will become more favourable.

A study by Willoughby *et al*. (2009) showed that providing shelter to both ash and sycamore, even in the relatively sheltered English lowlands, resulted in between two and four times faster growth. Side shelter from nurse species is likely to be most effective.

Site requirements

Though it will grow on a wider range of soils than many species of trees, sycamore does not grow in soils that are either too dry or too wet. Most writers agree that a deep, moist soil, freely drained and of a reasonably high pH and fertility is ideal, but this does not imply that it is particularly site-demanding in Britain. Sycamore grows well and regenerates on neutral shaley soils, on many of the heavier calcareous loams, clay with flints over chalk and even acid sandy soils, provided they are deep and well-drained but retain some water. A feature of the sites where it does best and regenerates naturally is that the decay of organic matter is rapid. Sites to avoid are podzols, heavy clays that are gleyed close to the surface, and where the winter water table comes to within 30 cm of the surface. Sycamore grows particularly well in hilly country.

Other silvicultural characteristics

Sycamore is a hardy tree that will grow to 30 m tall. It is rarely found growing in pure stands and is usually a component of mixed woodland in small groups or in intimate mixtures. It is moderately shade-bearing when young, making it a useful addition to the native tree flora, which is dominated by light-demanding species; however, more mature trees will die rapidly of suppression if their crowns are not kept free. The tree has poor powers of recovery if suppressed after the age at which height growth slows considerably (Hein *et al.*, 2009). Seed production and natural regeneration in moderately shaded woodlands are often prolific, and the species has potential in continuous-cover systems, at least when young, forming large seedling banks under canopies. Regeneration is frequently associated with sites where dog's mercury thrives and where elder also regenerates. These tend to be somewhat drier than sites where ash does best.

Young plants are intolerant of competition from grasses, so if planted in the open, weeding is important. Natural regeneration in open grassland communities is consequently rare. In mixtures, Stevenson (1985) considered that sycamore and European larch are compatible with each other in terms of growth rates.

In windy parts of the country, such as parts of Yorkshire, sycamore tends to produce buttresses at the bases of stems. Growing it in mixture with larch nurses can prevent their development, by preventing excessive swaying in the wind.

Sycamore trees up to 80–100 years old coppice and normally self-prune well, but if pruning should be necessary it should be done in summer. Winter or spring pruning is followed by profuse 'bleeding'.

Grey squirrels prefer sycamore to most other species and can be exceedingly damaging to trees of up to 25 years old by stripping bark to eat the phloem tissue beneath and killing the stems. This has become so serious that the amount of sycamore being planted is likely to reduce considerably unless a solution can be found. The species is less attacked by rabbits than many others, nor is it barked seriously by deer, though seedlings, buds and young shoots are palatable to them and this can result in forked stems.

Pests and diseases

The sycamore aphid, *Drepanosiphum platanoidis*, is often present on the leaves, where it can produce large quantities of honeydew. Sycamore also suffers from 'sooty bark disease' caused by the fungus *Cryptostroma corticale*, which has been described by Young (1978). It can cause dieback and occasionally death, but serious outbreaks are, apparently, only likely in the Greater London area. The tar spot fungus *Rhytisma acerinum* is often seen on sycamore leaves in unpolluted areas. It does no damage to the tree, apart from reducing the photosynthetic area a little.

Natural regeneration

A feature of the tree is that it is one of the few introduced species that has not only become naturalized but is also spreading, especially in the lowlands. It is continuing to invade many different habitats, particularly valley floor ash woods and calcareous beechwoods, though its requirements do not entirely coincide with those of either ash or beech. Because of its invasive tendencies and the fact that it is an exotic, it has become a controversial species. Mabberley (1990), for example, described it as 'an aggressive weed of British woodland'.

As stated above, a characteristic of the sites where it grows best and regenerates naturally is that the decay of organic matter is rapid.

Flowering, seed production and nursery conditions

The tree flowers in mid-April. Sycamore is the only common tree that produces insect-pollinated flowers (though field and Norway maples and lime do, too). It is a good early source of pollen and nectar for bees; seeds ripen in September and October, and are dispersed between mid-September and mid-October. The earliest age at which the tree bears good seed crops is between 25 and 30 years, and the best ones are usually between the ages of 40 and 60 years. Some seed is produced every year, but it is produced plentifully every 2nd or 3rd year. There are about 9400 seeds kg^{-1} (range 5400–15,800), of which 70 to 80% will normally germinate after

4 weeks' stratification at 2°C if it is sown no later than February. About 3500 seedlings are normally produced per kg of seed, of which 1300 are likely to be saleable. The seed is recalcitrant and is best sown immediately after collection or, if stored (for a maximum of 12–16 weeks), it must not be dried below 35% moisture content. It should then be stratified for 8 weeks. Aldhous (1972) stated that if it is stratified too soon the seed may germinate early, before the nursery beds are fit to be sown.

Conservation

Sycamore has two characteristics that are believed to have detrimental effects on the ground flora of deciduous woodland: on some sites its litter decays slowly, and the heavy shade it casts. In a detailed discussion of these characteristics, Taylor (1985) concluded that in long-established woodland in which sycamore is not totally dominant, it does not cause the extinction of species in the ground vegetation. It may even increase diversity by leading to an increase of those species that are shade-tolerant in ash woods. It is in no way the ecological menace that some suggest. Sycamore supports a relatively poor invertebrate fauna compared with most native species. According to Kennedy and Southwood (1984), it has 43 species associated with it compared with 423 on oak. This number is similar to lime, with 57 species, rowan with 58, ash with 68, and hornbeam and field maple with 51 each. All the latter are native species. However, the aphids that thrive on sycamore trees are an important source of food for blue tits and great tits in the early spring (Elton, 1979). It also supports more lichens than most native trees.

The meagre evidence that exists suggests that sycamore will eventually be replaced by another species rather than by itself. In ash–sycamore woodland, for example, the regeneration of either species is less likely under their own canopies than beneath each others' (Waters and Savill, 1991). The proportion of sycamore regeneration therefore declines as the proportion in the canopy increases; consequently, the two species will probably alternate with each other, and it is unlikely that either would dominate.

Woodland that has been undisturbed for some time contains little sycamore. It tends to colonize disturbed woodland areas (Taylor, 1985; Leslie, 2005). Invasion is a slow process up to a point of equilibrium determined by the woodland type. In disturbed woodland invasion is often rapid and apparently aggressive, with sycamore initially becoming a dominant species, but then it declines again down to the equilibrium point. Attempts to eradicate sycamore, a widely practised policy in nature reserves, usually provide ideal conditions for its expansion. This is clearly a waste of effort unless it can be shown that sycamore is undesirable for a reason other than that it is a threat to native trees and shrub species.

Provenance

Continental European botanists have recognized several ecotypes and varieties but none is distinguished in Britain. Cundall *et al*. (1998) have reported on the early growth of British and continental provenances of sycamore in a series of five trials. After four seasons in the field, the ranking of provenances for height was not significantly different, though they had been significant in the nursery, nor was there any provenance × site interaction. There were, however, indications that some continental provenances may be superior to British ones, and also that others are inferior and should probably be avoided. The Future Trees Trust[1] is in the process of selecting and grafting material from exceptionally good 'plus' trees with the aim of developing clonal seed orchards, prior to a breeding programme. Because sycamore is insect pollinated and usually occurs as scattered individual trees and is also self-compatible, it can be deduced that it is more differentiated than wind-pollinated species with a continuous distribution, such as birch and spruce (EUFORGEN, 2011).

Area and yield

An analysis of European height growth curves by Hein *et al*. (2009) indicated that the species grows fast up to 20–25 years and then slows considerably. The British tables (Hamilton and Christie, 1971) show the same pattern. Yields of 750–1000 m^3 ha^{-1} of high-quality timber are achievable on the best sites over rotations of 70–75 years (i.e. about 12 m^3 ha^{-1} $year^{-1}$). This is higher than can be expected from ash, where the maximum is 10 m^3 ha^{-1} $year^{-1}$. Because it grows mostly in mixed stands, not much work has been done on refining growth models. It is estimated that sycamore is the dominant species over 61,400 ha of British woodlands (Forestry Commission, 2003).

Timber

The diffuse-porous wood of sycamore normally has no well-marked figure or grain, or visible distinction between sapwood and heartwood. Logs do not store well and should be sawn and dried soon after felling. The wood is hard, strong and can be worked to a very smooth finish and is stable. Sycamore dries quickly and is a 'friendly' wood to use. Its average density at 15% moisture content is about 610 kg m^{-3}. It is widely used for furniture making and joinery, and is also suitable for flooring but is not durable outside without preservative treatment. Because it is free from smells or

[1] www.futuretrees.org, accessed 24 August 2012.

tastes, it is also ideal for uses associated with food. The white or creamy coloured timbers of sycamore and ash are among the most easily saleable of all British hardwoods as there is a market for all grades. Venables (1985) considered more of these two species should be grown, and more recently Leslie (2005) has stated that sycamore can provide one of the best financial returns of any hardwood tree. 'Wavy-grained' sycamore, which arises occasionally, can fetch extraordinarily high prices and is used for making good violins and other musical instruments, and for veneers: the intensity of waviness increases with age, so the figure is difficult to detect in young trees. Discoloured heartwood tends to occur in larger trees over 45 cm diameter.

Place of sycamore in British forestry

Sycamore is one of the fastest-growing broadleaves and produces a potentially valuable white timber. Silviculturally it is similar to ash in many respects, though it is much more frost hardy and less site-demanding. Both ash and sycamore occur on similar soils and can be relatively fast growing. Both are opportunist species that spread into gaps in the canopy. Unfortunately, sycamore is often badly attacked by grey squirrels and this limits its potential considerably. There is also much prejudice against the species from naturalists' groups.

ALNUS Mill. Alder

An unusual feature of alders is that they fix atmospheric nitrogen through a symbiotic association in root nodules with a nitrogen-fixing, filamentous bacterium, *Frankia alni*. It is similar to the *Rhizobium* bacterium that is found in the root nodules of legumes in the Fabaceae family. Rather than as timber-producers in their own right, the main interest in alders in British forestry derives from this nitrogen-fixing ability; see, for example, the section on walnut. Through it, they have a potential as 'nurses', or as soil improvers on sites with undeveloped soil such as reclamation areas and roadside cuttings.

According to Mabberley (2008), there are 35 species of alder of which five are shrubs or small trees. The genus is distributed throughout the cooler regions of the northern hemisphere, and it also extends over the mountains of Central America to the highlands of Bolivia, Columbia, Peru, Ecuador, Venezuela and Argentina.

Alders seldom grow to large trees. Most are pioneer species that invade gaps and clearings in forests. They are capable of direct colonization even on the most undeveloped soils. They are usually relatively small and short-lived, and give way in most instances to later successional species. Alders are intolerant to shade and competition, and will not grow under a canopy. Only on sites suited exclusively to alder will seedlings regenerate under mature alder trees. They have values for wildlife conservation, especially along the edges of water. In Britain the alders are largely neglected as potentially useful trees.

Alders in general are prone to a number of diseases that are probably brought on by stress resulting from the difficult sites where they usually grow. All alders that are grown in Britain are susceptible to a soil-borne fungal disease discovered in the early 1990s, *Phytophthora alni*. It occurs in young woodland plantations and orchard shelterbelts, but its greatest impact is on the riparian alders of southern Britain. The disease has increased steadily over the years; by 2003 more than 15% of the surveyed trees had been affected or killed by it (Webber *et al*., 2004). The disease tends to be less frequent in trees that are 1–10 m or more away from the water's edge and is especially infrequent in areas that are not exposed to periodic flooding.

ALNUS CORDATA (Loisel.) Loisel. Italian alder

Origin and introduction

Italian alder is native to southern Italy and Corsica, and was introduced to Britain in 1820.

Climatic requirements

It appears to have no major climatic limitations in Great Britain.

Site requirements

It will tolerate both dry and calcareous sites, such as thin soils over chalk and reclaimed sites, but it does best on deep chalky soils and least well on acid soils. Unlike most species of alder, it is less confined to riversides.

Other silvicultural characteristics

It is a medium-sized tree, seldom taller than 20 m, and potentially a valuable pioneer species for sites that are being planted for the first time. Its most useful feature, which is uncharacteristic of most other alders, is its tolerance of comparatively dry sites. Like all alders, it is a strong light-demander and withstands exposure and pollution well.

The coppicing ability of this species is so variable that some authors have claimed that it does not coppice at all. Others say that it coppices best if the stem is cut at a height of 30 cm, rather than at ground level.

Diseases

In common with all alders, this species is susceptible to attack by *Phytophthora alni* (see above).

Flowering and seed production

Italian alder flowers and fruits at an early age. There are 363,000 seeds kg^{-1}, of which half will normally germinate. The seed does not store well.

Timber and uses

The species is suitable for planting for firewood or pulpwood production on coppice rotations, though it is not a high-volume producer per unit area planted. The timber is reddish-orange. Its quality is said to be similar to that of hybrid poplar, although it is heavier, shrinks much more and has high modulus of rupture. It is durable when immersed in water. It is used for turnery and carving, and for the production of moulding, furniture, panelling and plywood (EUFORGEN, 2011).

Italian alder has been described as a superb landscape tree, with an upright conical shape, glossy green leaves, and distinctive bark, foliage, flowers and fruit.

Place of Italian alder in British forestry

Italian alder has a potentially useful place on dry calcareous soils, either as a nurse for beech, ash or maple, or as a cover tree (Wood and Nimmo, 1962). Its value for these purposes has probably been overlooked in the past, and as a consequence it has been planted less than it might otherwise have been.

ALNUS GLUTINOSA (L.) Gaertn. Alder, Black alder

Origin

Black alder is an indigenous species found in all parts of Great Britain and Ireland. Its natural range extends as far east as Siberia and southwards to North Africa. It is the only native British nitrogen-fixing tree.

Climatic requirements

Alder is very hardy indeed and has no serious climatic limitations in Great Britain, though it does not grow well at such high elevations as do birch and rowan. The tree is found up to 500 m in the Cairngorms but is said not to thrive if precipitation is less than 1500 mm in places where access to groundwater is not possible (Claessens 2005; Claessens *et al.*, 2010). The frequency of natural populations increases towards higher rainfall areas of the west and north: soil moisture probably exercises more control over local and regional distributions than atmospheric humidity. Even though flushing is early, trees do not suffer from late spring frost damage and are moderately resistant to salt spray. They tolerate exposure reasonably well and better than grey alder. However, straight-stemmed trees will only grow in relatively sheltered situations.

Site requirements

Alder is relatively undemanding except that it will only grow in moist soils, otherwise it will grow on all but the most infertile soils. It is truly at home on sites not subject to drought, such as close to lakes and streams, and on soils with restricted internal drainage, but it also does well on coarse sands and gravels if moisture is adequate and the pH is above 6. However, it tends not to grow as well on calcareous soils as does grey alder. Alder can withstand short periods of flooding outside the growing season, but ideally soil water should be aerated. It does not grow on acid peats and grows badly on dry, sandy soils.

Other silvicultural characteristics

Black alder grows up to a maximum of about 25 m tall, though it is usually no more than half that height in natural conditions. The taproot is able to penetrate anaerobic water sources that other species cannot use (McVean, 1953b), so it sometimes appears to be drought resistant. It is difficult to establish alder on grassy sites unless weed control is good.

In common with all alders, black alder fixes atmospheric nitrogen in large root nodules. They can contribute significantly to the nitrogen content of litter and the soil, and can consequently benefit the growth of companion tree species. Nodule formation proceeds best in the pH range 5.4–7.0 (Ferguson and Bond, 1953), but after nodules have formed, growth is best at a pH of about 5.4. There is also evidence that the fixed nitrogen, subsequently translocated to the leaves of alders, is returned to the litter in nitrate form and this inhibits the development of certain potentially pathogenic fungi of many trees, such as *Poria* and *Armillaria*.

Alder coppices well when young and is notable in that it is among few hardwoods that are not seriously attacked by hares and rabbits. Moderate grazing levels favour the spread of the trees by reducing the shading and smothering effects of tall herbaceous vegetation on seedlings. It can sometimes become invasive.

The early growth of alders is fast, which makes their use as nurses difficult because the trees being nursed can easily be suppressed and killed. The rapid early growth is due to the speedy development of a large area of leaves and the long period in leaf. Alder is not long-lived, especially on poor sites where its life may be only 20–25 years.

Alder is sensitive to shading, so that the internal regeneration of alder in woods is unknown except on sites unsuited to the growth of any other trees. Thinning has to be started early, and has to be heavy and frequent around selected final crop trees, to achieve marketable timber before heart rot sets in. Trees do not respond to delayed thinning.

Alder is the principal or only food of 141 insects and mites (Kennedy and Southwood, 1984), and if planted along the banks of rivers and lakes, these insects can provide an important source of food for fish. A policy of planting for this purpose is followed in parts of Canada and the USA. Matthews (1987) considered that alders might have a place in the British uplands for diversifying the large areas of coniferous forests.

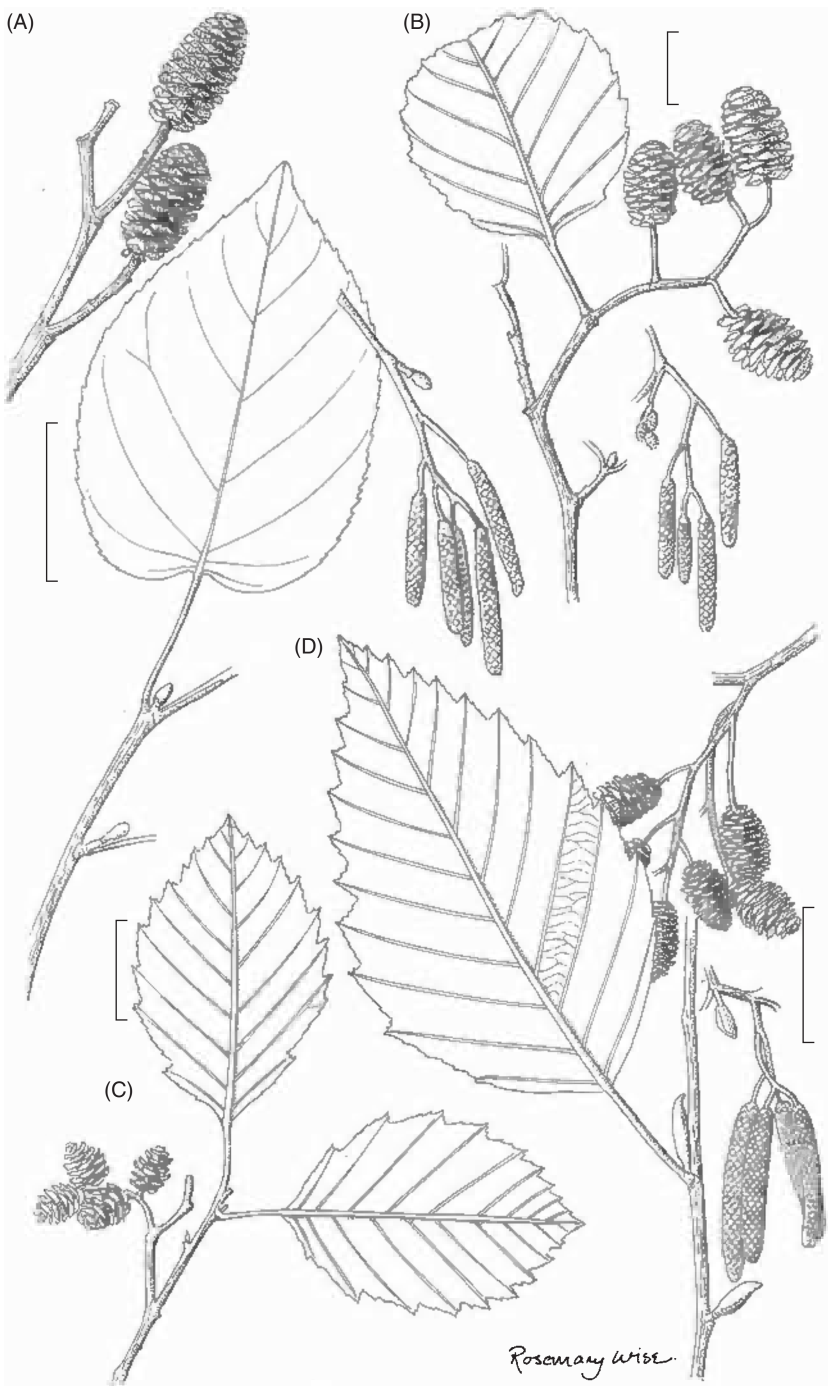

Fig. 3. (A) Italian alder, *Alnus cordata*; (B) Black alder, *Alnus glutinosa*; (C) Grey alder, *Alnus incana*; (D) Red, or Oregon alder, *Alnus rubra*.

Natural regeneration

As mentioned above, alders are natural pioneers in successions. According to Claessens (2005), for natural regeneration to be successful, the seeds must be in contact with the mineral soil. Seedlings will only survive and become established on soil surfaces that come within the capillary fringe of the water table in drier regions, where surface layers remain continuously moist for 20–30 days in the period April–June. Seedlings do not survive if there is competition for light. These conditions do not arise every year in most places. To regenerate naturally alder requires high levels of both light and moisture, and this is usually achievable only on disturbed sites.

Flowering, seed production and nursery conditions

Alder flowers between early March and late April, before the leaves are fully out in the spring, the catkins having formed the previous autumn. The seeds ripen between September and November, and are best collected for nursery purposes in October. They are dispersed from the time they ripen to early spring. The earliest age at which the trees bear reasonable amounts of seed is about 15–20 years and the best seed crops are usually after the age of 30, at 2–3-yearly intervals. There are about 767,000 seeds kg^{-1} (range 582,000−1,406,000) of which 35% are normally viable.

Nodule formation on the roots of alder transplants may not occur satisfactorily if they are planted on sites that are being reclaimed, resulting in comparatively poor growth, unless the young plants are inoculated with *Frankia* in the seedbeds of nurseries. An application of extract of crushed nodules, collected from healthy, well-grown tree roots, is now recommended to nursery managers as a standard treatment for alder seedbeds (McNeill *et al*., 1989).

Provenance

McVean (1953a) has described some of the variation that occurs in alder over Great Britain and Ireland, and it is clear that it is considerable. Comprehensive provenance trials with black alder are now being carried out in many European countries (though not in Britain) and are revealing the variation associated with geographical origin. Worrell (1992) has found that survival in alders of British origin is better than provenances from continental Europe, while Matthews (1987) stated that the alders are promising subjects for improvement by selection and breeding. Several varieties exist in cultivation.

Area and yield

The fixation of atmospheric nitrogen requires much energy, which might otherwise be diverted into vegetative growth: for this reason alders are not productive trees, especially on sites where soil nitrogen is low. As they are such relatively short-lived trees, they seldom grow to large sizes. Growth rates up to age 7–10 are fast but they then slow rapidly. The maximum rotation for growing timber is 60–70 years if heart rot is to be avoided. Maximum mean annual increments range from 4 to 14 m^3 ha^{-1} $year^{-1}$ (Claessens *et al.*, 2010). No recent figures exist for the area of woodland where alder predominates, though in 1978 it was estimated that there were perhaps 10,000 ha of alder of all species in Britain.

Timber and uses

The timber of black alder is light (about 530 kg m^{-3} at 15% moisture content), not very strong, soft and resilient. A blow causes a temporary depression unaccompanied by a permanent indentation, in complete contrast to redwood, for example, which can be dented easily. The boundary between the heartwood and sapwood is very clear. The heartwood is typically orange in colour, but it can be dark brown. One of its main attributes is its resistance to decay when submerged in water, but otherwise it rots quickly. It is sometimes used for making sluice gates and other structures along streams and rivers. Alder is a traditional timber for general turnery work, is acceptable for hardwood pulp and is used for making medium-priced furniture.

Where alder timber is available in large quantities, as in the western USA, it tends to be much better accepted and widely used. At one time charcoal made from alder was used in the manufacture of gunpowder, and the wood was in demand for sawing to make herring-barrel staves (Brown and Nisbet, 1894). Alder wood has been used by many electric guitar manufacturers since the 1950s. It is apparently appreciated for its ‘bright’ tone. It is similar to poplar in grain and texture, and is one of the weakest of hardwoods.

In some parts of the world there is considerable interest in growing alders on short rotations for fuel, but on good sites they are not normally as productive as other tree species.

Place of black alder in British forestry

Because of its nitrogen-fixing ability, black alder is often planted on reclamation sites where soil nitrogen is in short supply. Apart from this specialist use it is likely to remain a minor species in British forestry.

ALNUS INCANA (L.) Moench — Grey alder

Origin and introduction

Grey alder is found over most of central Europe and extends westwards to France. It is also native to Scandinavia and has been planted in Britain since it was introduced in 1780.

Silviculture

In most respects, the silviculture of grey alder is the same as that for black alder. It is slightly less hardy than black alder, and while having no serious climatic limitations in Great Britain, it will not withstand excessive exposure. It will grow on all but the most infertile soils, but requires sites not subject to drought. Grey alder grows better on slightly drier and more calcareous sites than black alder. It is a light-demanding pioneer species. It has a rather wider site tolerance than either black or red alder, being suited both to moderately dry and to wet soils of poor to medium nutrient status. However, it does not tolerate alkaline soils and will not grow on peats or nutritionally poor soils (Forest Research, 2011).

Grey alder coppices well when young and often spreads by root suckers, especially after mature trees have been felled. They can sometimes become invasive.

It is more resistant to *Phytophthora alni* than black alder.

Flowering and seed production

Grey alder flowers from late February to May. Seeds ripen between September and November. It produces an average of 1,460,000 seeds kg^{-1} (range 961,000–1,980,000), of which only 25% are normally viable.

Provenance

No provenance studies have been undertaken in Britain, so, according to Forest Research (2011), seed should be obtained from good British stands or possibly from western Sweden or Norway.

Timber

The timber is essentially the same as that of black alder.

Place of grey alder in British forestry

Similar to black alder.

ALNUS RUBRA Bong. Red or Oregon alder

Origin

Red alder has an extensive natural range along the Pacific coast of North America, where it is closely associated with Sitka spruce. It was introduced to Britain in the second half of the 19th century.

Site requirements

Site requirements for the spectacular, sustained and rapid growth that occurs so rarely are not really understood. Red alder is reported to have grown particularly well on a clay-with-flints soil over exposed chalk in Hampshire and on calcareous boulder clays in Northamptonshire (Macdonald *et al*., 1957). In common with black alder and grey alder, it has the reputation of being drought resistant once taproots have developed. Fraser (1966), for example, has shown one sample of red alder rooting to 89 cm on a surface water gley soil, where Sitka spruce only rooted to 45 cm.

Silviculture

Red alder has proved to be a most disappointing species as a timber-producing tree in Britain, though growth for the first 10–15 years can be spectacular. It can reach 15 m tall in 15 years, after which growth usually declines rapidly and the trees begin to die back. They seldom fulfil the signs of their early promise. There is little indication that the poor performance is related to unsuitable provenances, as several, at least from British Columbia, have been tried.

Red alder is more susceptible to spring frosts than either grey or black alder; this may be a contributory factor to the dieback from which it suffers.

Timber

The wood of red alder is similar to that of black and grey alders. It is an important pulpwood in north-west America.

Place of red alder in British forestry

Red alder is a species that causes intense interest at intervals due to its rapid early growth, which is, unfortunately, extremely seldom sustained. Its most likely value in Britain is as a parent of hybrids in any future breeding programme.

ARIA NIVEA Host **Whitebeam**

The scientific name of this species was, until recently, *Sorbus aria* (see p. 205)

Origin

The tree is usually found on chalk and limestone, and also on sandstone hills from Kent and Hertfordshire to Dorset and the Wye valley. It has been widely planted elsewhere.

Climate and site

Apart from requiring a well-drained soil, the species is not demanding. It will grow in both acid and alkaline conditions and will tolerate drought, unseasonable frosts, exposure, salty sea winds and atmospheric pollution. It is very hardy.

Silviculture

Whitebeam is a small, short-lived, rather uncommon, native tree, which occasionally grows to 20 m tall. It is a colonizing species, though it becomes reasonably shade-bearing with age. It is normally found in open situations where it can be a useful pioneer, especially in windy places and on chalky soils. Whitebeam makes a valuable nurse for beech (Anderson, 1950). It is rather susceptible to fireblight (*Erwinia amylovora*). It coppices well and also produces root suckers occasionally.

Natural regeneration

The seeds of whitebeam are distributed by birds, and regeneration will appear on suitable sites in open places, though never prolifically.

Flowering, seed production and nursery conditions

Whitebeam produces showy white, insect-pollinated flowers in May and June. The seeds, in attractive red berries, mature in September and October. Propagation in the nursery normally requires the berries to

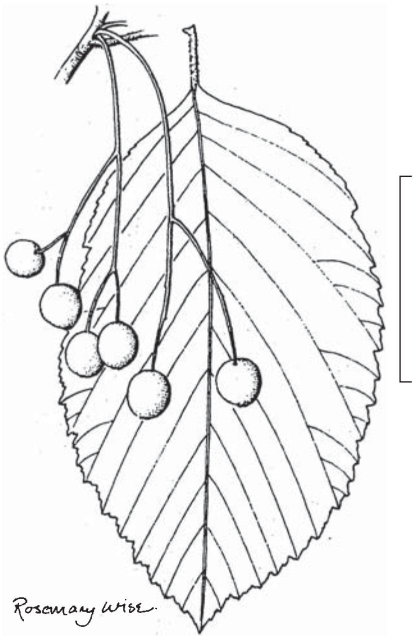

Fig. 4. Whitebeam, *Aria nivea*.

be macerated in order to separate out the seeds, which should then be stratified and sown the following spring. If the seed is not separated it may remain dormant for an additional year (Aldhous, 1972). There are about 1500 seeds kg^{-1} of fruit.

Timber

The wood is hard, heavy (at about 860 kg m^{-3}), fine-grained and white, but is never found in large dimensions. In the past it was widely used for turnery and joinery, and, because of its hardness, as cogs in early machinery. It is said to be durable.

Place of whitebeam in British forestry

In common with a related species, rowan, whitebeam has considerable decorative value and is often planted for this purpose in towns. This is its main use today, though the closely related Swedish whitebeam is probably used more frequently. Otherwise, it is an occasional and attractive constituent of woodlands.

BETULA

There are 35 species of birches in the northern hemisphere, four of which occur in Europe, with three native to Britain. One of them, *Betula nana* (dwarf birch), is a localized shrub of mountains and moorlands. Most birches are attractive, rather short-lived (*c*.70 years) pioneer species of small trees. They are hardy and their main values are as soil improvers and nurses to protect more tender species from frost damage. They seldom grow to large dimensions.

In recent years there has been a resurgence of interest in birch as potentially productive native species for use in upland and more northern parts of Britain.

BETULA PENDULA Roth — Silver birch

BETULA PUBESCENS Ehrh. — Downy birch

Origin

Silver birch and downy birch may only be distinct at a sub-specific level, according to Mabberley (2008), and are native to the whole of Europe (including the British Isles) and to parts of Asia. They extend to the northern limits of tree growth. Though not often planted, natural regeneration is plentiful and they are among the most common of all British forest trees. Silver birch is more common in the south and east of Britain, while downy birch occurs more in the north and west.

Climatic requirements

Both species are extremely hardy and have no major climatic limitations, although silver birch does better in slightly drier conditions than downy birch. They both thrive at elevations at which no other broadleaved species except rowan will grow, but the form of the trees can be adversely affected even by quite low levels of exposure.

The birches (particularly downy birch) are more sensitive to atmospheric pollution caused by sulphur dioxide and nitrogen dioxide mixtures than many other trees (Freer-Smith, 1984).

Site requirements

The ranges of the two species overlap, but silver birch occurs most commonly on lighter acid soils, heaths, gravels and shallow peats in the drier south and east of the country at low elevations. It will also grow on heavy clays, and on chalk and limestone soils, but on these it is much less common. Downy birch replaces it on badly drained heathlands and on damper soils generally, especially in waterlogged and peaty conditions in the north and west at higher elevations. On sites where both species flourish, silver birch is considered the faster growing and higher yielding tree. The absence of birch from a site is often said to indicate a deficiency of phosphate in the soil.

Both species are reported to grow over a wide range of soil pH conditions, but to grow good birch trees of 30–35 cm (dbh) over a rotation of about 30 years, oak or ash sites are required.

Other silvicultural characteristics

Birches seldom grow taller than 20 m, though may occasionally reach 25–30 m. Their main features are their ability to colonize bare areas quickly, their intolerance of shade, their lack of affinity for any particular soil type and their ability to grow on nutrient-poor soils (Atkinson, 1992).

In Britain the birches are pioneers in forest or heathland recently cleared by felling or fire, in gaps left by canopy trees, as primary colonizers of gravel and scree, and in habitats climatically unsuitable for most other tree species. They become established most effectively on bare soils but establish poorly in even the lowest vegetation (Atkinson, 1992). Both species are gregarious and often occur in even-aged stands. These may be pure birch stands (often a mixture of silver birch and downy birch), or they may be mixed with other species. Apparently, early mycorrhizal infection is an important factor in the successful establishment of birch.

The birches grow fast when young but very seldom achieve large dimensions in Great Britain. Except on the most favourable sites, they rarely attain 30 cm dbh. In parts of continental Europe they will grow much bigger. Though light-demanding, the birches will grow as an understorey in open forest.

Vegetative reproduction by sprouting from buds at the base of the stem occurs as a response to damage such as burning, felling or grazing. Clusters of buds are more common in downy birch than in silver birch, which possibly explains the slightly poorer sprouting ability of the former. Nevertheless, both species are regarded as rather weak at coppicing in comparison with many other broadleaved trees.

The main silvicultural values of birches are:

- Their improving qualities on soils such as podzols (Miles, 1981). These arise because birch has access to sources of calcium that are unavailable to many other species because they can root more deeply and also penetrate iron pans. Calcium and other plant nutrients are deposited on the surface in fallen leaves, and gradually the surface pH of the soil increases, eventually allowing earthworms to colonize the site. These then mix the surface organic layers with the mineral soil.

- Because of their hardiness, birches can be valuable nurses for oak, beech and frost-tender conifers on sites liable to early frosts.
- The considerable amenity value, especially of silver birch.

Birches have uses in the afforestation of industrial waste sites and for the shelter they can provide for wild and domestic animals, especially in hilly areas. They are of more interest to foresters in the more exposed districts of northern England and Scotland than elsewhere. Where there is a market for birch, encouraging natural regeneration can be quite a profitable silvicultural option (using the conventional net discounted revenue criterion) because regeneration is free, rotations short (often 30–40 years) and yields reasonable for broadleaved species. Willoughby *et al*. (2007) have also described recent interest in using direct sowing in some upland situations where natural regeneration fails to occur. For direct seeding they recommend sowing a minimum of one million viable seeds per hectare (i.e. about 0.5 kg) into weed-free and brash-free seedbeds no later than the middle of March, and that browsing mammals and insects are controlled or excluded. Grazing by deer and sheep inside and immediately outside woodland prevents regeneration of upland birch woodland.

Because of their tolerance to a wide range of soils, relatively small sizes and attractiveness, the birches are favourites for planting in small gardens and in unpolluted urban areas.

They have few pests. They are sometimes browsed by deer, and when a choice of both species is available, downy birch seems to be preferred. ‘Witches’ brooms’ are quite common on birch trees and are caused by the fungus *Taphrina betulina*. The species are among the most susceptible of broadleaves to honey fungus, *Armillaria* spp.

Natural regeneration

As mentioned above, natural regeneration is plentiful and this causes birches to be among the most common of all British forest trees. In fact, natural regeneration can be so prolific that it can be a nuisance in plantations of other species.

Flowering, seed production and nursery conditions

The birches flower before the leaves are fully out: silver birch may begin in late March, but the main flowering period is April. Birches are wind pollinated. In the south seeds ripen in July and August in

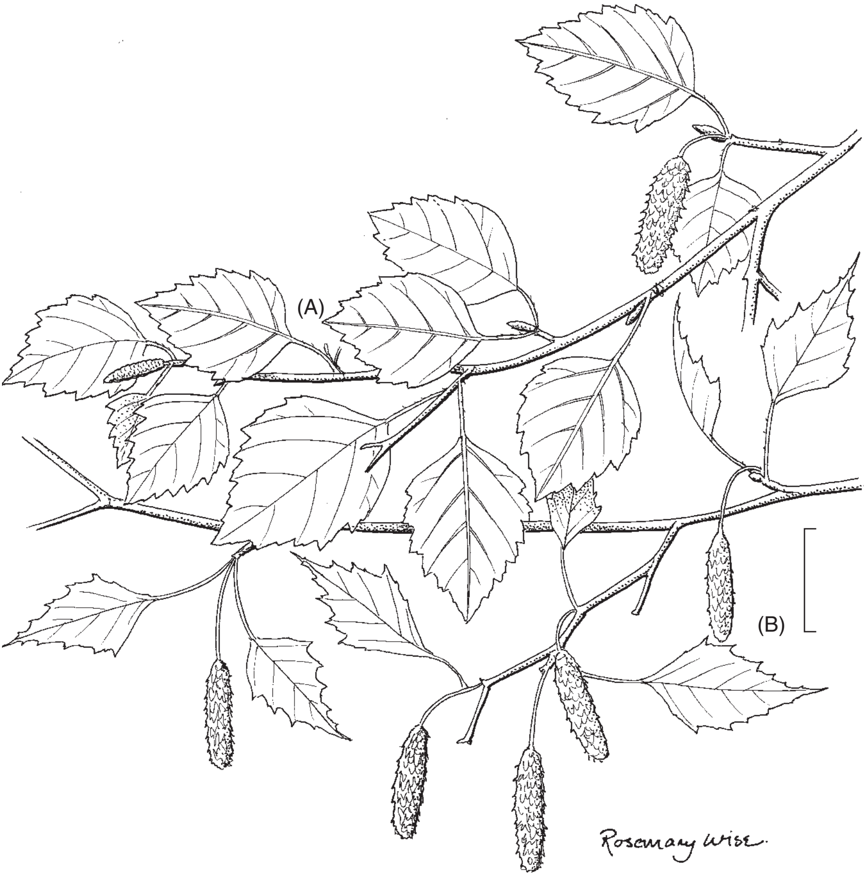

Fig. 5. (A) Downy birch, *Betula pubescens*; (B) Silver birch, *Betula pendula*.

silver birch and in August/September in downy birch. They ripen a few weeks later in the north. They begin dispersal at once, and seed continues to be released throughout most of the winter. The first good seed crops appear at about 15 years, and the best ones between 20 and 30 years. Seed is commonly produced in profusion every year or every other year. There are about 1,900,000 seeds kg^{-1} of silver birch (range 1,200,000–2,900,000) and 3,570,000 kg^{-1} of downy birch (range 1,650,000–9,900,000), of which 40% normally germinates. For nursery purposes the seed should be collected immediately before natural dispersal and stratified for 2 or 3 months before sowing in March or early April. Aldhous (1972) stated that birches are very sensitive to seedbed surface conditions; these should be smooth, well-firmed, with an even, light covering and kept moist. Birch seeds lose their viability quickly. Less than 10% remain viable after 1 year.

Provenance and breeding

Atkinson (1992) and Worrell (1992) have summarized the results of several studies carried out in Scandinavia and Scotland on the effect of growing birch seedlings at different latitudes. The primary outcome of these trials is that when seed lots are transferred over ranges of latitude greater than 3° (about 300 km) their growth is reduced, but when transferred over shorter distances growth is predominantly the same.

For provenance selection Lines (1987) recommended that seed should be collected from British stands of good appearance taken from similar or slightly more southerly latitudes than that of the planting site. Hubert and Cundall (2006) evaluated up to 40 Scottish and northern English sources planted at four contrasting Scottish sites. Their results show that seed sources from the south and east of the trial sites are generally more vigorous than those from the north and west. This could possibly be explained by the fact that more southerly sources come into leaf earlier in the spring and lose their leaves later in the autumn than those from further north, so they have a longer growing season. Thus, transfer of northern English silver birch to Scottish sites gives an increase in growth rate compared with most local material, at least in the early years, but the long-term reaction of such provenances to spring and autumn frosts and exceptionally low winter temperatures, especially at more exposed sites, is not known. Care should be taken to avoid moving birch provenances over distances greater than about 2–3° north or south.

In view of their widespread occurrence, there is scope for breeding to improve the qualities of these species, and this work is in progress (Hubert *et al*. 2010). Birch is a rewarding tree for breeders because it flowers early and produces plentiful seed: potted grafted cuttings of superior trees grown in a polytunnel will produce seed in only 3 years. Considerable progress has been made in recent years jointly by the Forest Research Agency and Future Trees Trust, and 'Qualified'[1] seed for some areas of Scotland became available for the first time in 2012.

Two types of birch trees can commonly be found: smooth- and rough-barked trees. The latter give an attractive 'flaming' grain to the wood, but unfortunately it is overwhelmingly the smooth-barked specimens that provide the trees included in breeding programmes. There are a number of ornamental forms of silver birch.

Area and yield

Birches occupy some 155,400 ha, or almost 7% of the total forest area of the country (Forestry Commission, 2003). Much of it was classed as 'scrub' in the Forestry Commission census of 1979–1982 (Locke, 1987). Though this term is no longer politically acceptable, it implied that much was unmanaged, and this is almost certainly still the case. The birches are the fourth most common trees in Britain (after Sitka spruce, Scots pine and the oaks).

Maximum yields of about 7 m^3 ha^{-1} $year^{-1}$ may be obtained on the best sites.

Timber and uses

The wood is diffuse-porous, fine-textured and of uniform, sometimes decorative, appearance. Fast growth does not reduce its quality. By most measures it is one of the strongest timbers commonly grown in Britain. It can be worked easily but is not naturally durable (Lorrain-Smith and Worrell, 1991). Its average density at 15% moisture content is about 670 kg m^{-3}. The wavy markings on some boards give a spectacular 'flaming' sheen that is sought-after by cabinet makers. There is a limited market for birch wood suitable for turnery, but trees of good form have a potentially much wider range of uses, including plywood, particle board, furniture and high-class joinery as well as pulp. If treated with preservatives it can be used for pallets and fence posts.

A highly decorative and much sought-after form of silver birch is known as Karelian birch (from its place of origin in Finland and neighbouring parts of Russia). It is believed to be caused by a virus infection.

Birches produce an abundance of slightly sugary sap in spring and it is sometimes collected for making wine. Birch twigs are widely used on horse race courses, to fill out steeplechase fences.

Place of birches in British forestry

There is little tradition of using birches as anything much beyond nurses and soil improvers in Britain, but an interest has developed in recent years in their potential as productive native species for use in upland areas. If efforts at breeding them for improved form are successful they could become economically important trees, as they are in Finland.

Note

[1] Under EU regulations reproductive material (seed, plants, cuttings, etc.) of most species has to be categorized in one of the following four groups: (i) *Tested* material comes from selected individual trees or stands that have been evaluated for genetic quality or, in comparison to accepted standards, have been shown to be superior;

(ii) *Qualified* material originates from selected superior individual trees that have not undergone any form of testing; (iii) *Selected* material is collected from stands showing superior characteristics such as better form, growth rate, health or wood properties; and (iv) *Source-identified* material comes from general or specific locations within a single region of provenance or native seed zone with a specified altitudinal band but with no specific superior qualities recognized (Forestry Commission, 2007).

BUXUS SEMPERVIRENS L. — Box

Origin and distribution

The evergreen box is one of about 30 species of box, two of which are western European. Although it is thought to be native at some sites, including Box Hill (Surrey), Boxley (east Kent), Ellesborough and Kimble Warrens (Buckinghamshire) and possibly elsewhere, it has been widely cultivated since Roman times and the limits of its native range are uncertain. It was widely planted in Victorian times for pheasant cover, and its recorded introduced range has increased dramatically since 1960 due to widespread planting and more efficient recording of introduced trees. The species is believed to be native to western and southern Europe, extending from southern England southwards to northern Morocco and eastwards through the northern Mediterranean region to Turkey. It is widely naturalized outside its native range.

Climatic requirements

Box can withstand temperatures down to −25°C: it is thus hardy, though it does best in regions where winters are relatively mild.

Site requirements

In natural conditions the species typically grows on soils derived from chalk and limestone, often as an understorey in forests of larger trees, and is most commonly associated with beech. It also sometimes occurs in open dry montane scrub, particularly in the Mediterranean region. Box Hill, Surrey, is named after its notable box population, which comprises the largest area of native box woodland in England. Virtually pure box woodland can be found on loose, dry, crumbly chalk on steep slopes. On such sites bigger trees, including beech and yew, become unstable and soon fall.

Chard (1949) noted that box favours the lower and outer edges of 'hanging' woods, on south-facing slopes above the level at which valley frosts occur, in the few places in Britain in which it is indigenous. These are the same sites where walnut will grow particularly well.

When planted box will grow on most soils that are well drained, ranging from light sands to heavy clay soils, and on a wide range of pHs, from 5.5 to 7.4, so will thrive on acid, neutral and basic soils. However, it does best on chalky soils and is unusual in this respect.

It will grow well on both dry and moist soil, but soils prone even to short periods of waterlogging should be avoided.

Other silvicultural characteristics

Box is normally a shrub, sometimes a small tree. It is evergreen, of rather contorted form, growing to 1–9 m tall, with a trunk up to a maximum of 20 cm diameter. Its flowers are a good source of nectar for bees.

Box is a slow-growing late successional species and as such is a strong shade-bearer but grows best under a light woodland canopy and will even grow in dry shade. Little is known about appropriate silviculture for the species. The CABI *Forest Science* database[1] yields few abstracts on the species and none provides information that is helpful for its management as a potential producer of valuable wood.

In spite of this, there is no reason to suppose that box is fundamentally different from other trees and shrubs. On the right sites it is likely to respond well to weed control when young and reductions in competition from neighbours when older. It is known to be normally a rather contorted shrub, and if the production of straight wood is an objective, it will certainly respond to pruning, which it withstands well.

The foliage of box is poisonous, which causes the species to be viewed as a problem in places where grazing is practiced. In parts of North West Anatolia (Turkey) this has resulted in attempts to eradicate it and caused it to be classed as a protected Red Data book species.

Box is a popular ornamental plant in gardens, being particularly valued for ornamental hedging and topiary because of its tolerance of close shearing, its small leaves and pungently scented foliage. The scent is not to everyone's liking: the herbalist John Gerard found it 'evill and lothsome' and at Hampton Court Palace Queen Anne (1702–1714) had box hedging grubbed up because the smell was offensive. Plants are tolerant of being trimmed, can be cut right back to the base if required and will usually coppice freely.

Diseases and pests

This species is notably resistant to honey fungus but suffers from a number of dieback diseases, including *Cylindrocladium buxicola*. This was reported as a pathogen of the genus in the 1990s in Great Britain and since then has spread throughout northern Europe. Where waterlogging occurs it can also be killed by *Phytophthora parasitica*. Box rust, *Puccinia buxi*, is an occasional problem, especially on old plants.

Box is not palatable to either rabbits or deer.

[1] www.cabi.org/forestscience, accessed 25 August 2012.

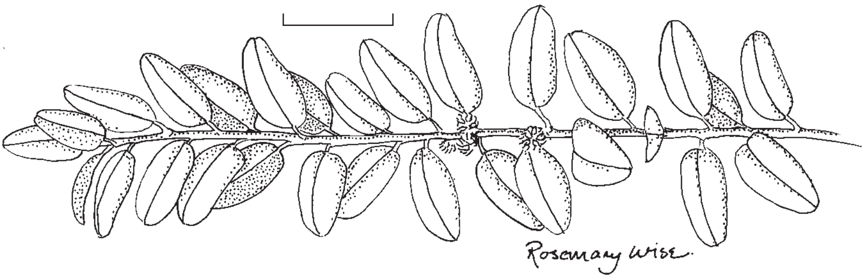

Fig. 6. Box, *Buxus sempervirens*.

Natural regeneration and nursery propagation

On sites where the species grows well natural regeneration can be both prolific and vigorous.

In nurseries seed stratification is not necessary but can lead to more regular germination. Cuttings from short side shoots with a heel will root easily if taken in September.

Provenance

Nothing has been written about provenance, but many named varieties of box have been developed for their ornamental values.

Area and yield

The area covered by box in Great Britain probably does not amount to more than a few hundred hectares. No information exists about growth rates, except that they are low.

Timber and uses

Due partly to its slow growth, the wood is the heaviest (at 950–1200 kg m^{-3}) and hardest of any that will grow in Britain. It is also free of grain produced by growth rings and is in limited demand for making musical instruments and for inlaid work, and formerly for mathematical instruments such as rulers, wood turning and tool handles. Most now comes from Turkey. At one time it was used for engraving but has been largely replaced by Venezuelan box (*Casearia praecox*) and Japanese box (*Betula microphylla*).

For musical instruments such as the classical oboe, dense, slow-grown wood is required that provides good sound projection. Ideal logs are

20–23mm diameter grown on rotations of 120–150 years. Box was once used for making these instruments but was replaced for a long period by African blackwood (*Dalbergia melanoxylon*), which is now becoming scarce, so demand for box is increasing again.

Place of box in British forestry

Box is a very minor species in British forestry, but there is a limited demand for it, for making high-quality musical instruments.

CARPINUS BETULUS L. Hornbeam

Origin

There are some 41 species of *Carpinus*, and *Carpinus betulus* is one of two native to Europe. Its natural range extends from the Pyrenees to southern Sweden and eastwards to Iran. In Britain it mainly occurs in the south-east of England at elevations below 600 m.

Climatic requirements

These are not clearly known, but it appears to require warm summers and so is normally a tree of lowlands. Hornbeam is very hardy, even in frost hollows.

Site requirements

The tree is adapted to a wide range of soils, from wet, heavy clays to light, dry sands and mildly acid to alkaline conditions but not chalky soils. It does best on moderately fertile damp sites: Evelyn (1678) suggested it was suited to cold hills, stiff ground and the most exposed parts of woods. It requires more fertile sites than beech.

Other silvicultural characteristics

Hornbeam is usually a small- to medium-sized tree, seldom exceeding 25 m tall. Stems are often fluted and crooked, and the tree tends to branch low down so the stem is short, though this tendency can be minimized by growing it in close proximity with neighbours. The species is one of few strongly shade-bearing native trees, though slightly less so than beech. Its main silvicultural value is as an understorey tree on soils that are too moist for beech, including those prone to waterlogging. In continental Europe it is commonly encouraged on such soils as an understorey to oak, to help in the suppression of epicormic branches. Hornbeam coppices very well and was once important as a coppice or pollarded species, when it was grown for fuel and basketmaking. Hornbeam, like beech, is less browsed by deer than oak, but it can be severely attacked by grey squirrels.

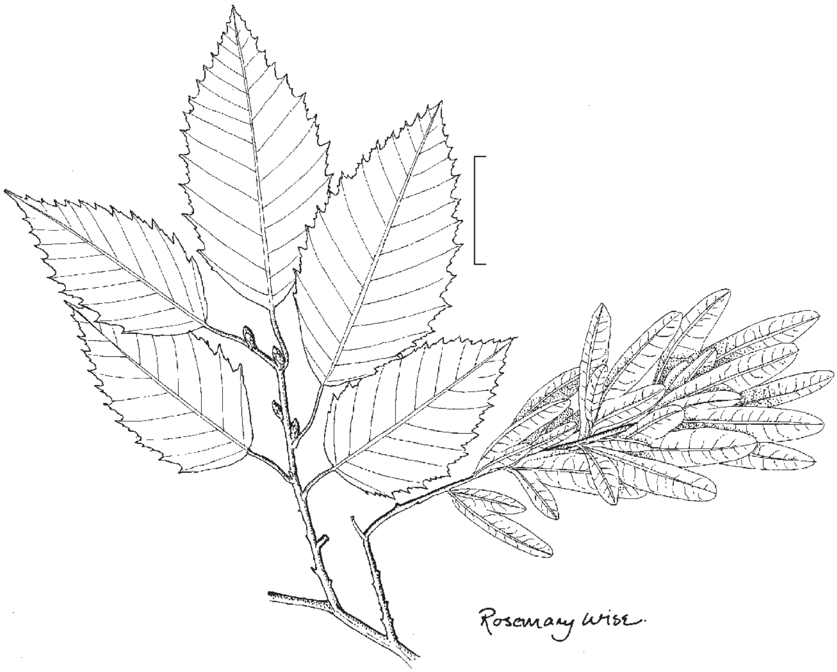

Fig. 7. Hornbeam, *Carpinus betulus*.

Natural regeneration

On suitable soils natural regeneration can be plentiful and vigorous.

Flowering, seed production and nursery conditions

The tree flowers in March as the leaves come out. Seeds, which are produced prolifically, ripen between August and November, and are dispersed from then until the spring. They are best collected for nursery purposes in November. The earliest age at which hornbeam bears seeds is about 20–30 years, but the best seed crops are usually at intervals of 2–4 years between the ages of 40 and 80. There are about 24,200 seeds kg^{-1} (range 16,000–30,800), of which 45% normally germinates. Seeds need stratifying for about 1 year before being sown in the nursery unless they are collected and sown ‘green’ (i.e. as soon as they are ripe but before they have dried fully on the tree).

Provenance

No specific work has been done, but Worrell (1992) speculated that as a relatively recent colonizer in Britain after the ice age, hornbeam is unlikely to be affected by the use of continental European seed, particularly when material from the near continent is planted in England. Continental European authors usually state that big differences in stem quality can be found according to provenance.

Area and yield

No recent figures are available about the area of hornbeam in Britain, though Locke (1987) estimated that there were 3400 ha of coppice being worked in England.

Timber and uses

The wood is hard, strong, tough and white, and finishes very smoothly. It was once the main source of very hard wood in Britain and was available in larger sizes than the equally prized boxwood. It is used for anything that requires a high resistance to wear such as piano mechanisms, drumsticks, billiard cues, chopping blocks and for flooring as a satisfactory alternative to maple. Its utilization is not helped by the fact that the tree is frequently fluted and of poor form. Because the wood is very dense (about 770 kg m^{-3} at 15% moisture content), and consequently has a high calorific content, it makes an excellent fuel.

Its modest size, dense crown and ability to withstand cutting, and dead leaf retention during winter makes it a popular hedging plant and a common tree for planting in streets, parks and gardens. As a street tree a fastigiate variety is normally used.

Place of hornbeam in British forestry

Hornbeam is of limited importance in Britain. As a shade-tolerant tree its main silvicultural value is as an understorey species on soils prone to waterlogging. Its wood is valued for a number of specialized purposes, though never in large quantities.

CASTANEA SATIVA Mill. — Sweet chestnut

Origin and introduction

There are 12 north-temperate species of *Castanea*. Sweet chestnut is the only European species, being native to southern Europe, western Asia and parts of north Africa: essentially across the Mediterranean region, from the Caspian Sea to the Atlantic Ocean. It is widely cultivated elsewhere and was probably introduced into Britain by the Romans, and is now extensively naturalized in south-east England.

Climatic requirements

The tree needs a warm summer to do well. Northern Britain is too cold and parts of the east too dry for it to thrive. It does best in the south of England, on the right soils. Generally, it needs reasonable levels of precipitation with no dry season, or only a very short one (EUFORGEN, 2011). The tree is rather frost-tender and will not tolerate exposure from the wind.

Site requirements

Sweet chestnut grows best on deep, reasonably fertile, light soils (especially greensands), with ample but not excessive moisture. It does moderately well on clays and other stiff soils if the subsoil drainage is good. It does not require high fertility but grows badly and may die back on infertile soils, calcareous soils, badly drained sites and deep heavy clays. According to Rollinson and Evans (1987) the ideal pH is 4–4.5.

Other silvicultural characteristics

Chestnut will grow to large dimensions in Britain: up to 35 m tall and 2 m diameter. The species is reasonably shade tolerant and is sometimes planted as a soil improver on lighter soils. It grows fast when young, coppices well and is said to be unpalatable to fallow deer. Where it is not liable to shake (see section on timber and uses), coppice is commonly 'stored' so that it will grow to timber sizes, receiving its first thinning at age 20–22.

Shake

Ring shake is a frequent defect in trees even as small as 40 cm diameter, especially on drought-prone sites. Practically all trees over 60 cm diameter are shaken.

Sweet chestnut is not extensively planted in Britain mainly because of the widely held belief that it is difficult or impossible to produce logs that are not shaken. Shake is a problem of over-mature trees (Everard and Christie, 1995), though in the Forest of Dean 40 cm dbh trees can be badly shaken on light soils. In a very detailed study by Mutabaruka *et al*. (2005) it has been shown that the majority of trees exhibiting ring and star shake flush later in the spring than sound trees and are normally 60 years old or more. Others have found that trees of more than 60 cm diameter are very likely to be shaken. Shaken trees also tend to have narrower annual rings and larger diameter earlywood vessels compared with their sound counterparts. Most of these findings are similar to those found by Mather (1992) for oak. The incidence of shake can be minimized in the same way: namely by having short rotations and removing trees in thinnings that exhibit late flushing. In addition, in the case of sweet chestnut removal of those that have abundant epicormic shoots, bole curvature or spiral bark is also likely to help.

Diseases

A serious and often fatal disease, chestnut blight, caused by the fungal pathogen *Chryphonectria parasitica*, was discovered for the first time in England in 2012, having been introduced on plants imported from a French nursery. In the eastern USA this disease has virtually wiped out a closely related species of chestnut, *Castanea dentata*, since it was first noticed in 1904. It has also caused serious damage in orchards and forests in continental Europe. However, there is evidence that the pathogen can weaken in virulence in Europe, allowing infected sweet chestnut plants to recover. This weakening or attenuation in virulence is due to a phenomenon known as hypovirulence (Forestry Commission, 2012).

Chestnut roots are prone to 'ink' disease, caused by several species of *Phytophthora*, mainly *Phytophthora cinnamomii* and *Phytophthora cambivora*. The disease can cause significant damage in mild, humid climates on soils that are wet.

Natural regeneration

Though naturalized in south-east England, natural regeneration is unusual and the spread of the tree limited because the seed crop is never good. However, Kirby (2009) believes that with predicted increased summer temperatures, seed set and natural regeneration may improve, though any tendency towards the tree becoming invasive is likely to be countered by the probable spread of chestnut blight (see above).

Flowering, seed production and nursery conditions

Sweet chestnut flowers in late June and July, later than practically any other tree except the limes. Flowers are pollinated by both wind and insects. The large seeds ripen in the autumn if the summer is warm and late enough, but good crops are rare, even in southern England. The earliest age at which the tree bears seeds is 30–40 years; good production begins after the age of 50. The seeds are large, at about 239 kg^{-1} (range 150–330). According to Gosling (2007), they begin to die if their moisture content falls below 40%, which makes them virtually impossible to store beyond the first spring: viability typically declines from 90% to 50% over the 10–24 weeks between collection in October/November to spring sowing in March/April.

Provenance

Studies of provenance variation in Britain started very recently, so provenance researchers (Hubert and Cundall, 2006) currently recommend that material should be sourced from good British stands or from selected stands in Western Europe.

There are a large number of old, grafted cultivars of chestnut, grown for nut production. For these varieties at least resistant genes have been bred into the gene pool to counter major fungal diseases. This has been achieved by hybridization with the more resistant Asiatic species, *Castanea crenata* and *Castanea mollissima*. Despite this benefit of resistance and growing vigorously in humid climates, the earlier bud burst of the hybrids makes them more vulnerable to frost damage than *C. sativa*, and they are also less tolerant to drought (EUFORGEN, 2011).

A programme of selection and breeding sweet chestnut for timber in Great Britain and Ireland was started in 2000 by the Future Trees Trust. It will be many years before seed from this improvement programme can be produced in adequate quantities for planting, partly because of the irregularity of seed years and partly because of the small quantities produced per unit area.

Area and yield

Sweet chestnut is one of the most productive broadleaved species, with mean yield classes of up to 8 m^3 ha^{-1} $year^{-1}$ in some parts of England

(Locke, 1978) and possibly maximum yields of 11 m^3 ha^{-1} $year^{-1}$. In 1987 Locke estimated that there were 29,000 ha of sweet chestnut in Britain, of which 19,000 ha were coppice. More recently the area has been estimated at 10,800 ha of woodland in which sweet chestnut is the predominant tree species (Forestry Commission, 2003). Yields of coppice are similar to those for high forest (Rollinson and Evans, 1987).

Timber and uses

The main features of the timber of sweet chestnut are its natural durability, even at small dimensions, the ease with which the wood can be split and its stability after processing, which is superior to that of oak. The strongly ring-porous timber resembles oak, but it is lighter (about 560 kg m^{-3} at 15% moisture content), less strong and more easily worked. It also lacks the very distinctive medullary rays that are such an attractive characteristic of the timber of native oaks. The heartwood is extremely durable, and an important feature is that, unlike oak, the sapwood is very narrow, rarely exceeding about 1 cm, or about three annual rings. It is a good carpentry and joinery timber. Sound timber works and finishes well and is used for furniture and other similar purposes to oak. In common with oak, the wood also has a slightly corrosive effect on metals and it becomes stained when in contact with iron. As mentioned above, ring shake is a frequent defect in the timber, and spiral grain is also a serious problem in large stems.

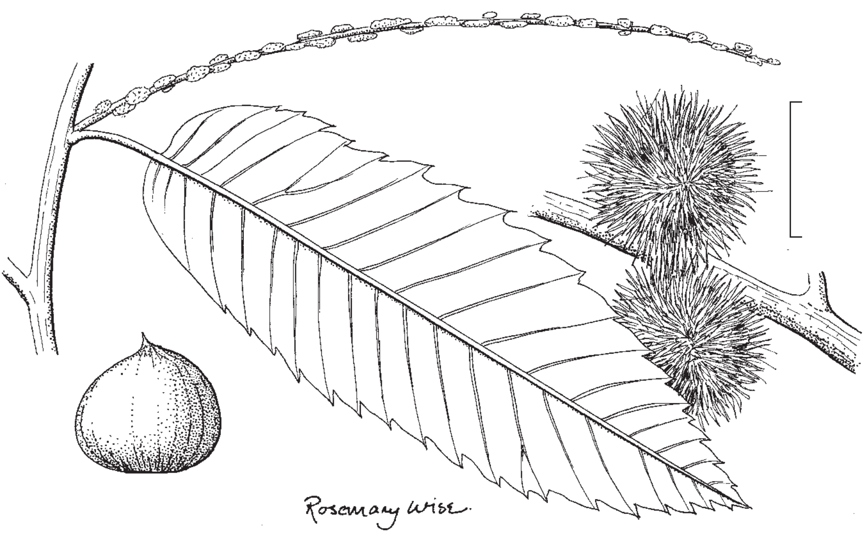

Fig. 8. Sweet chestnut, *Castanea sativa*.

The tree has been cultivated for over 2000 years in parts of continental Europe, especially Spain, for its edible starchy nuts. They were once a staple food after grinding into flour or coarse meal. They are nutritionally similar to wheat, except that they lack the protein gluten, which is a binding agent, so that anything baked with chestnut flour tends to have holes and is crumbly. Chestnuts are still an important source of starch in a few southern parts of Europe, but today they are mostly regarded more as a delicacy; roast chestnuts are a well-known Christmas treat. Elsewhere they are used in confectionery (marrons glacés from France), puddings and cakes, and in stuffings.

At one time extensive areas were grown on coppice rotations for posts, hop poles, fuel and split fencing (Begley, 1955; Evans, 1982). Quite large areas are still actively coppiced, especially in Kent and Sussex where it is the last remaining important coppice species in the country, though the extent of coppicing is declining. Most of it is worked on a rotation of 12–16 years, which is well short of the age of maximum mean annual increment, but provides for the technical requirements of the split fencing markets. In the Forest of Dean sweet chestnut is grown on a small scale for pulpwood, on 25–30-year rotations.

Place of sweet chestnut in British forestry

At present sweet chestnut has a restricted distribution, mainly in the south of England, but it is one of few species that is likely to become much more widely used if the climate changes in the predicted way. It produces a valuable and sought-after timber that is similar in some respects to oak. Among its advantages over oak are that it grows faster and rotations are much shorter.

CEDRUS Trew — Cedars

Most taxonomists (e.g. Farjon, 2012) describe cedars as a genus of two or four species, of which the Indian *Cedrus deodara* (deodar) is generally agreed to be sister to a clade containing the other three taxa: *Cedrus atlantica* (Atlantic cedar), *Cedrus brevifolia* (Cyprus cedar) and *Cedrus libani* (cedar of Lebanon).

These cedars are often referred to as 'true cedars', to distinguish them from numerous other species, both broadleaved and coniferous, that are also called cedars, such as western red cedar, *Thuja plicata*.

Cedars are often cultivated as ornamental specimen trees in parks and large gardens. Mabberley (1990) states that part of their attraction is that they rapidly develop 'an air of antiquity'. There is very little experience of them as forest trees in Britain, but as climate change proceeds they may have a place as potentially productive species on dry sites.

CEDRUS ATLANTICA (Endl.) Carr. — Atlantic cedar, Atlas cedar

Origin and introduction

The Atlantic cedar is indigenous to Morocco and Algeria in the Atlas and Riff Mountains, between 1000 and 2000 m, where it forms pure stands. It is the only African tree that thrives in Britain and was introduced in 1841.

Climatic and site requirements

Forest Research (2011) states that the species appears to be hardy at least to −20°C in Britain, but growth and survival are poor in high rainfall areas, so planting should be confined to warmer regions with less than 1500 mm of rain. It does not withstand exposure well but is not sensitive to late spring frosts, and it is capable of withstanding periods of drought. It will tolerate urban pollution better than most conifers.

It grows best on soils of poor to medium nutrient status that are dry to fresh in terms of soil moisture. According to Mitchell and Wilkinson (1989) it also grows well on dry calcareous soils. Peats and other wet soils should be avoided.

Other silvicultural characteristics

The tree occasionally grows to about 30 m tall in Britain. Macdonald *et al*. (1957) believed that it would make a productive species on good sites in the south of England. Growth starts slowly but eventually becomes quite vigorous. It is a strong light-demander and said to grow much faster than the cedar of Lebanon.

Diseases and pests

The Atlantic cedar is susceptible to a similar range of diseases to Lawson's cypress and Leyland cypress. These include cypress canker, *Seiridium cardinale*, as well as the cypress aphid, *Cinara cupressivora*.

Flowering, seed production and nursery conditions

The tree seldom flowers before it is 50–60 years old. Flowers appear in September or October and the seeds take 2 years to mature. Cones should normally be collected in April before they begin to disintegrate, and the seed should be sown immediately, otherwise viability will be lost quickly.

Provenance

No provenance testing has been carried out in Britain and there are few forest plots on which to base information. The current recommendation from Forest Research (2011) is that seed should be sourced from the native range or from French stands.

Timber and uses

The wood is renowned for its strong and persistent fragrance. Heartwood is light brown and distinct from the lighter-coloured narrow sapwood. Growth rings are very distinct. The wood is straight grained, rather resinous and the texture is medium to fine. It is easy to work and finishes well. It is reasonably durable and suitable for outdoor uses. The density at 15% moisture content is about 580 kg m^{-3}. There is a tendency for the wood to warp when drying. It tends to be soft, brittle and not very strong, lacking shock resistance and toughness.

Place of Atlantic cedar in British forestry

The Atlantic cedar is a tree that might be suitable for wider cultivation in plantations if climate change proceeds as predicted, particularly on drier,

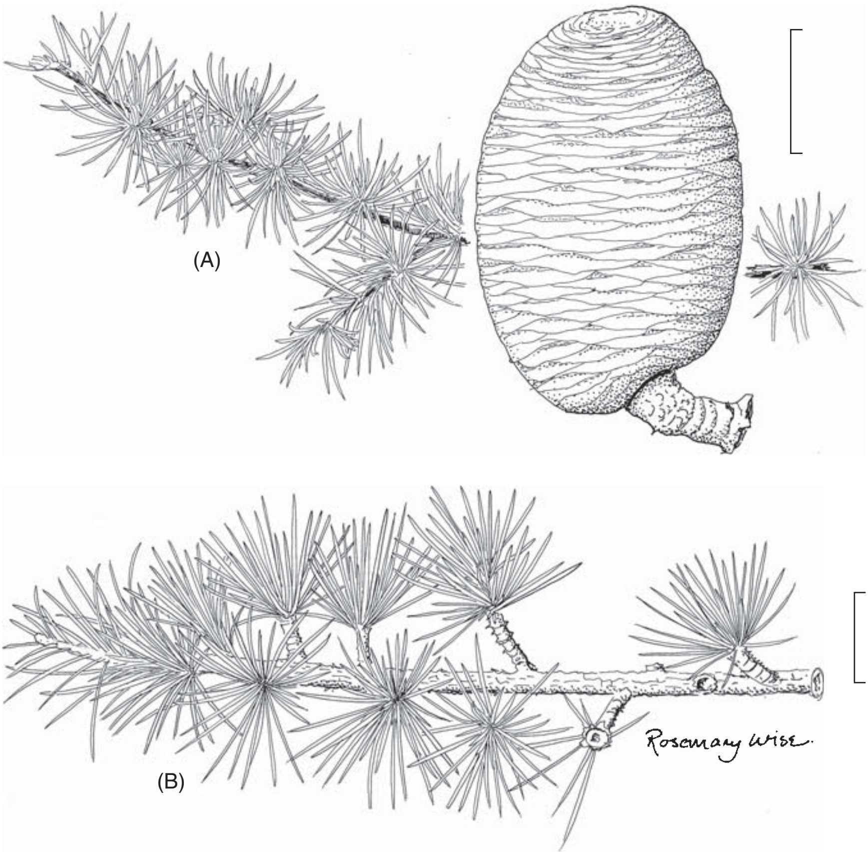

Fig. 9. (A) Atlantic cedar, *Cedrus atlantica*; (B) Cedar of Lebanon, *Cedrus libani*.

warmer sites in southern and eastern Britain. It is one of very few conifers that will grow on calcareous soils.

CEDRUS LIBANI A. Rich — Cedar of Lebanon

Although this cedar has been grown as a specimen tree for over three centuries, practically no systematic trials have been carried out into its potential as a forest tree.

Origin and introduction

The cedar of Lebanon is native to the mountains of Asia Minor, Syria and Lebanon. Farjon (2012) states that it grows between 1300 and 2100 m elevation. Quite hardy, this light-demanding and calciphile species grows rather slowly. This was the first cedar to be introduced to Britain, in around 1638.

Climatic and site requirements

In common with the Atlantic cedar, this species appears to be hardy to at least −20°C in Britain. However, most trees were killed during the exceptionally harsh winter of 1739/40. Almost all of the huge and ancient-looking cedars of Lebanon on lawns of stately homes date from after that year. It has been hardy since then, though young trees are sometimes killed by severe frosts.

It is not particular about soil, but according to Brown and Nisbet (1894) it needs a dry, deep, open soil with a permeable subsoil.

Other silvicultural characteristics

The species is a strong light-demander and has a wide-branching habit, which some writers say may be detrimental in plantation-grown trees unless grown in mixture with other species. However, Brown and Nisbet (1894) state that '…if it be at all confined among other trees, it rises with an upright stem like any other coniferous tree.' They also say that it is much too slow growing to be recommended as a timber tree.

Diseases

This species is largely free of major pathogens, except that it is reported to have some susceptibility to root rot caused by honey fungus, *Armillaria* spp. It can also suffer from various aphid infestations (Forest Research, 2011).

Flowering, seed production and nursery conditions

Similar to Atlantic cedar.

Provenance

There have been very few forest plots and there are no known provenance trials with this species in Britain. The current recommendation from Forest Research (2011) is, as for Atlantic cedar, that seed should be sourced from the native range.

Timber and uses

Similar to that of the Atlantic cedar, except that Brown and Nisbet (1894) said that, although the wood is of great durability when grown in its native mountains, it is soft and of inferior quality when grown in Britain.

According to the Royal Botanic Gardens, Kew, it was partly due to the efforts of the 18th-century landscape gardener, 'Capability' Brown, that the species was popularized. He designed more than 170 parks and gardens in England, planting cedars in many of them.

Place of cedar of Lebanon in British forestry

In common with the Atlantic cedar, this species could increase in importance if climate change proceeds as predicted, particularly on drier, warmer sites in southern and eastern Britain. It might be slightly less attractive than the Atlantic cedar, which grows faster and possibly with less of a tendency to produce large branches.

CHAMAECYPARIS LAWSONIANA (A. Murray bis) Parl. — Lawson's cypress

Origin and introduction

Five species of *Chamaecyparis* are found in Eastern Asia and North America. Lawson's cypress was discovered and brought to Britain in 1854 by William Murray, the original seed being sent to Messrs Lawson, seedsmen of Edinburgh, after whom the tree was named in Britain. In North America it is known as Port Orford cedar. It is native to the Klamath and Siskiyou Mountains of north-west California and south-west Oregon, mainly at elevations from 1200 to 1800 m. It extends up to 65 km inland on seaward-facing slopes but is found mostly within 5–24 km of the coast.

Climatic requirements

In its native range Lawson's cypress does best in climates with high precipitation and humidity. It thrives in the western, moister parts of Britain but grows well in drier parts too. The tree is hardy to late spring frosts, except when very young, but is not suitable for use on exposed sites and so should be used in the lowlands. Unlike many conifers, it withstands atmospheric pollution well, which is one reason why it has become such a popular garden tree and hedging species in towns.

Site requirements

The tree is not particularly demanding but does best on deep, fertile, well-drained soils. It is unsuitable for use on peat or dry heathery ground and sites prone to waterlogging, and grows slowly on heavy clays. It is one of few conifers that will grow well on calcareous soils.

Other silvicultural characteristics

Lawson's cypress will grow to about 25 m tall in Britain. It is very shade tolerant. Natural pruning is extremely slow. It is less susceptible to damage by *Heterobasidion annosum* than many conifers. In the 1950s it was fashionable to plant Lawson's cypress round the outside of lowland woods to minimize penetration of wind and thus to 'keep them warm' for game.

Diseases

In 2010 a fatal disease of Lawson's cypress, *Phytophthora lateralis,* was introduced into Scotland and later to other parts of the UK. It kills the roots and can extend up the trunk of affected trees and girdle them, leading to the trees' death.

Natural regeneration

The species produces seed frequently and regenerates freely. It will become established particularly under a thinned canopy and where there has been some soil disturbance by mixing the litter layer with the mineral soil.

Flowering, seed production and nursery conditions

Lawson's cypress is usually a prolific seed producer. It flowers in the spring, and seeds ripen in September and October of the same year, and are dispersed up to May. The tree bears seed from an early age, 20–25 years, and the best seed crops are produced at intervals of 2 or 3 years between ages 40 and 60. There are about 463,000 seeds kg^{-1} (range 176,400−1,322,800), of which 230,000 are normally viable. Cones should be collected as soon as they change from bright green to yellow and the tips of the seed wings are visible and a light brown colour, normally in September. The seed should be sown in nurseries between late February and mid-March: no special treatment is required (Aldhous, 1972).

It is also easy to propagate from cuttings.

Provenance and cultivars

In plantations the form of Lawson's cypress can vary from trees with excellent, straight, finely branched stems to a multi-stemmed candelabrum-like habit. As no provenance testing has been carried out in Britain, the recommendation is that seed should be obtained from good British stands or from the natural range of the species. Seed collected from hedges or other horticultural sources should be avoided (Forest Research, 2011).

Lawson's cypress has a remarkable tendency to vary in cultivation and numerous named cultivars exist: surprisingly, practically all of them have arisen in exotic environments in Europe, rather than its native America. Unfortunately, many plantations in Britain are multi-stemmed, possibly due to the use of unsuitable seed sources.

Area and yield

There are believed to be fewer than 2200 ha of Lawson's cypress woodland in Great Britain, excluding those in amenity and garden plantings. No British yield tables exist for the species, but those for *Thuja plicata* are said to provide a good indication of growth potential. Yield classes range from 12 to 24 m^3 ha^{-1} $year^{-1}$, with ages of maximum mean annual increment between 50 and 70 years.

Timber and uses

The wood, known in the British timber trade as Port Orford cedar, is light yellow to pale brown with no clear distinction between sapwood and heartwood. It has a fine, even texture with a straight grain and a fragrant smell. It is more resistant to decay than many timbers, easy to work to a smooth finish and is stable in service. In its native North America the wood is used for boatbuilding and joinery. The average density at 15% moisture content is about 500 kg m^{-3}.

Because of the natural variability of the species, its pollution resistance, the fact that it is so easy to propagate from both seed and cuttings, and its dense impenetrable habit, it is popular as an urban ornamental

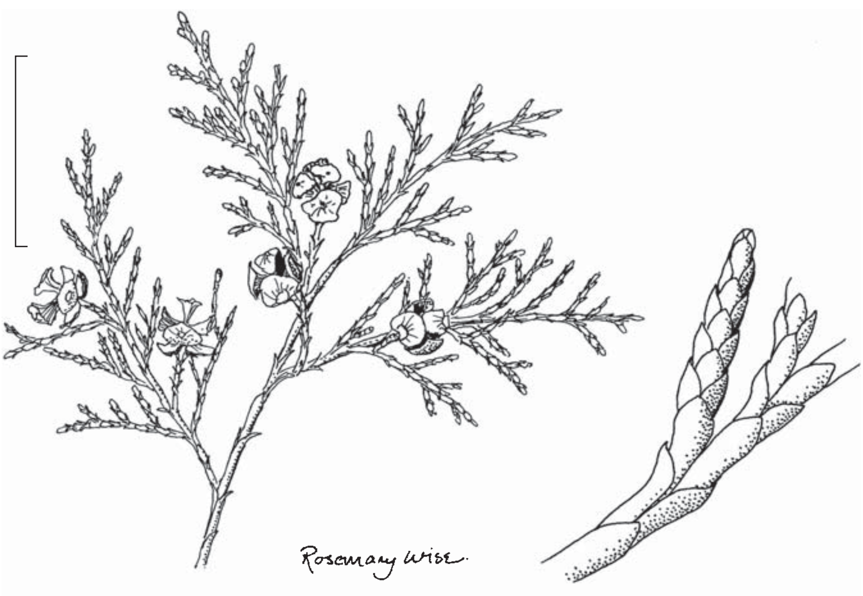

Fig. 10. Lawson's cypress, *Chamaecyparis lawsoniana*.

tree in gardens. It is even more often used for hedging because of its rapid growth. Its foliage is valued by florists.

Place of Lawson's cypress in British forestry

Lawson's cypress has always been a minor species. However, the fact that it seeds frequently and regenerates quite freely, withstands pollution well, and is easy to propagate both from cuttings and seed in the nursery, means that it is probably grown much more commonly than it should be. This is because on sites where it does well, other species such as western hemlock, western red cedar and grand fir do better. However, its significance is likely to decline with the spread of *Phytophthora lateralis*.

CORYLUS AVELLANA L. Hazel

Origin

The genus *Corylus* includes about 18 species in the temperate regions of the northern hemisphere. *Corylus avellana* is native to Europe and common throughout almost all the British Isles to elevations of about 600 m; it also occurs in North Africa and western Asia.

Climatic and site requirements

There are no particular climatic limitations in Britain. Hazel tolerates exposure to strong winds well and to urban pollution but not salty sea winds.

It grows best on damp but not waterlogged soils that are no more than moderately acid and will also thrive on dry calcareous soils. Soils to avoid are dry, sandy ones and peats. Hazel is frost-hardy.

Other silvicultural characteristics

Hazel is usually seen as a multi-stemmed shrub, 1–6 m tall, but sometimes as a small tree up to 10 m. It is not particularly long-lived, perhaps 70–80 years. Hazel is reasonably shade-bearing, normally being seen as coppice in the understorey of lowland oak woods, sometimes in ash woods, and in hedges. It also forms scrub on exposed limestone.

Hazel is particularly susceptible to being browsed by deer and cattle, and must be properly protected after coppicing if the new growth is to survive.

It used to be a plant of considerable economic importance, which arose partly from its ability to produce numerous straight coppice shoots. It was widely planted or propagated by layering. It was then coppiced, both in pure coppice stands and as a major coppice component in coppice-with-standards systems. As pure-managed coppice about 2000 stools per hectare were planted, and they were cut on a 6–9 year cycle (Hibberd, 1988); when in coppice-with-standards the rotation was 14–16 years.

Enrichment of a woodland understorey with hazel can be a useful way of reducing bramble growth in continuous-cover systems. It also provides a useful habitat for birds, including game birds.

Flowering, seed production and nursery conditions

Hazel flowers in the early spring, before the leaves emerge. The fruits ripen in September and fall from October onwards, retaining their viability for about 6 months. For nursery production they are usually stratified for 3 or 4 months and sown in early April.

It layers easily, which involves leaving a few stems on the stool at the time of coppicing, bending them over to the ground and, after cutting a slit on the downward-facing side (to promote root growth), pegging the shoots to the ground and covering the pegged area with earth. Roots develop from this point and, in time, a new plant.

Provenance

No detailed work has been carried out, but Worrell (1992) thought that since hazel was an early arrival in Britain after the ice age, the survival and growth of continental provenances might therefore be expected to be much poorer than British provenances, particularly when planted in the north and west of Britain.

Area and yield

There were estimated to be some 8600 ha of hazel ‘scrub’ in Great Britain in 1980 and almost 1500 ha of coppice-with-standards, with hazel as the principal understory species and oak by far the predominant standard tree (Locke, 1987). This represents a considerable reduction since the 1947–1949 census when it is believed that there were 12,000 ha of simple coppice and 3500 ha of coppice-with-standards.

The yields of hazel coppice were investigated in detail by Jeffers (1956). On a 5-year cutting cycle, with 1700 stems per hectare, yields are about 15 m^3 ha^{-1}, and at 10 years about 47 m^3 ha^{-1}. For well-stocked hazel coppice the production of usable, trimmed, coppice shoots is about 4.5 m^3 ha^{-1} $year^{-1}$.

Uses

Up to the end of the 19th century the many demands on hazel included its uses in the manufacture of wattles for ‘wattle and daub’ plasterwork, sheep hurdles (before wire fencing was common), barrel hoops, garden fencing, thatching spars, fuel for brick kilns and baking ovens, and fascines for laying under roads in boggy areas (Forestry Commission, 1956). The older wood was sometimes used by joiners and sieve makers, and the charcoal for gunpowder manufacture. The leaves were used for cattle fodder

(Schlich, 1891). The nuts, which are produced prolifically from about the age of 10 years, are edible. In Mesolithic and later human settlements in Europe, it has been suggested that they provided a source of food later taken by cereals (Roach, 1985). Hazel was still grown widely for nut production in Kent at the beginning of the 1900s. Today about 75% of worldwide nut production comes from the Turkish province of Ordu.

Most of the coppicing that is done today is by naturalists' trusts and similar organizations. Very limited quantities of produce are sold as thatching spars, and for pea and bean sticks.

Hazel is an attractive plant, especially in late winter when displaying the yellow catkins. Because of its tolerance to urban pollution it is useful for planting along road verges.

Place of hazel in British forestry

Hazel was once a species of considerable economic importance, but today it has little or no value. However, as a native component of traditional woodland systems it is usually considered a species of great nature conservation significance and is managed for that purpose.

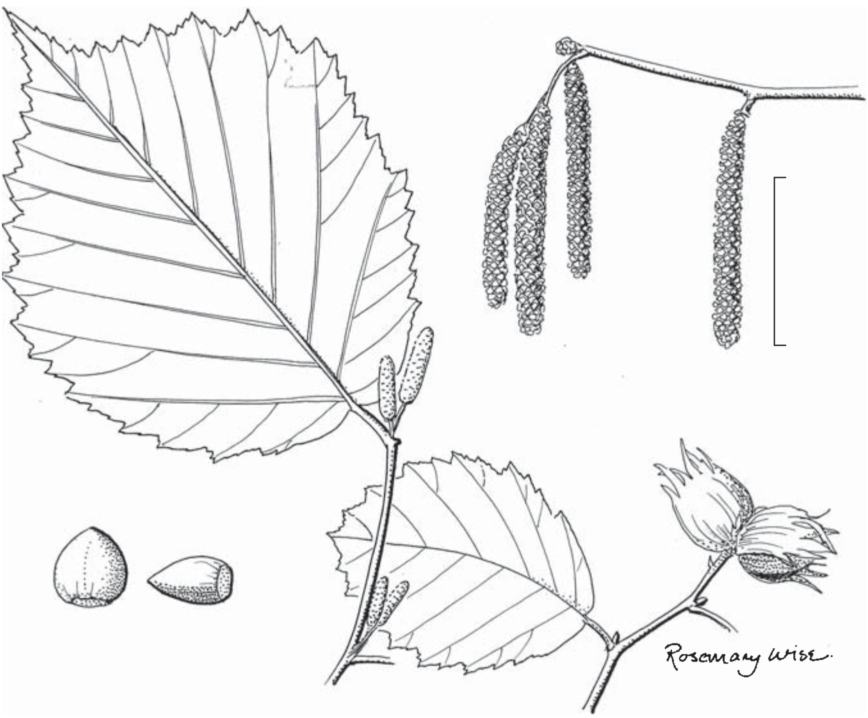

Fig. 11. Hazel, *Corylus avellana*.

CRYPTOMERIA JAPONICA (L.f.) D. Don Japanese cedar, Sugi

Origin and introduction

Japanese cedar, or sugi as it is known in Japan, is indigenous to the central and southern islands of Japan: from Kyushu to northern Honshu, at elevations up to 400 m, and also to various parts of China. Most of the very limited experience with the species in Britain has been with the Japanese provenance. It was introduced in 1842 from China and in 1861 from Japan.

Climatic and site requirements

The species comes from a warm maritime climate and, according to Forest Research (2011), the best growth in Britain is to be found in areas with more than 1200 mm of annual rainfall but which are sheltered. The tree does not stand exposure well, especially in spring. The need for warmth means that the best stands are in Wales and south-west England, where it can be a very high-volume producer.

It grows best on deep, well-drained sandy loams in elevated but sheltered situations. It is not suited to very infertile or dry soils, to peats or to calcareous soils.

Other silvicultural characteristics

On good sites in Britain the tree will grow to over 30 m tall. In Japan, where it is the national tree, it is renowned for growing to great ages (well over 1000 years) and for the very high-quality timber it produces.

Japanese cedar is shade-tolerant, and as with many such species pruning is an important component of a management regime. Unusually for a conifer, it coppices well.

Diseases and pests

Japanese cedar is susceptible to *Phytophthora* root disease, including *Phytophthora cinnamomi*.

Flowering, seed production and nursery conditions

Seeds ripen in September and October during the year of flowering. They should be sown early in spring after stratification for 2–3 weeks at 4°C.

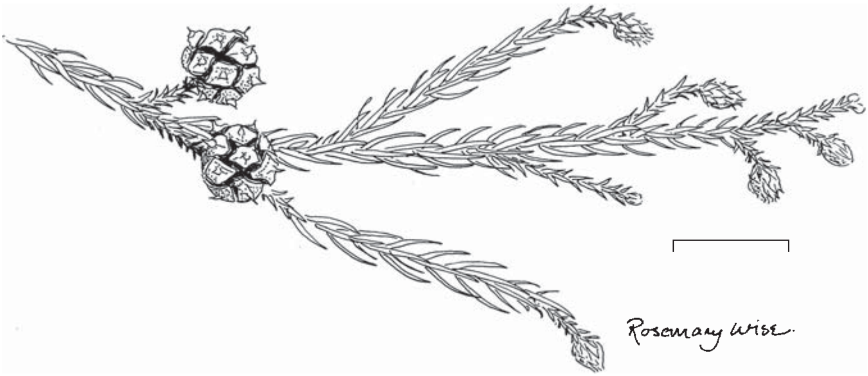

Fig. 12. Japanese cedar, *Cryptomeria japonica*.

Japanese cedar is easy to propagate from cuttings. In Japan many clones have been selected, each suitable for a variety of local conditions. In fact, this species possibly has the longest history of clonal propagation of any tree.

Provenance

Virtually no provenance testing has been carried out in Britain. Forest Research (2011) recommends that seed should be sourced from the northern part of the natural range. It might also be worth trying some Chinese provenances, which could be more cold hardy.

Timber and uses

Cryptomeria japonica is a major timber species in Japan and China. The timber is strong and very durable and has been used for construction purposes for centuries. It is rather soft but is easily worked and is used for buildings, bridges, ships, lamp posts, furniture, utensils and paper manufacture (Farjon, 2012). The density of the wood is about 380 kg m^{-3} at 15% moisture content. The heartwood is a warm reddish-brown colour with some dark streaking. The sapwood is almost white.

Brown and Nisbet (1894), by contrast, described the wood as soft, white and brittle and unlikely ever to become a timber tree in Britain.

In Britain the tree has mostly been planted for ornament in parks and big gardens. In Japan many forms have been selected for their ornamental values, almost all of them dwarf varieties.

Place of Japanese cedar in British forestry

This species is practically unknown in British forestry, but climate warming should increase the range of sites where it will grow well, such as in western Scotland. It is one of relatively few species that seems worthy of serious trials.

x CUPROCYPARIS LEYLANDII (A.B. Jackson & Dallimore) Farjon — Leyland cypress

Origin and introduction

The tree is a sterile intergeneric hybrid between *Cupressus macrocarpa* and *Xanthocyparis nootkatensis*. It is usually believed to have originated at Leighton Hall, Welshpool, from cones collected in 1888, though Mitchell (1985) stated it was first found at Rostrevor, in Co. Down, in about 1870. Many clones now exist, including the golden 'Castlewellan' form, which also comes from Co. Down.

Climatic and site requirements

Although very little work has been done on the silviculture of Leyland cypress, its requirements seem similar in many respects to those of Lawson's cypress. It will thrive on a wide range of soils, including calcareous soils and does best on moist sites. It will tolerate urban pollution and salt spray, but exposed upland sites should be avoided. It is probably best suited to more sheltered sites in western and southern Britain with more than 800 mm of rainfall (Forest Research, 2011).

Other silvicultural characteristics

Propagation must be entirely vegetative, and plants are therefore relatively expensive. Leyland cypress is light-demanding. It has been little used in plantations, and consequently there is little experience with it as a forest tree. Limited experience in Bagley Wood, near Oxford, suggests that after thinning plantations of Leyland cypress they become unusually susceptible to windthrow, for which it appears to have a growing reputation. It is also susceptible to attacks by honey fungus.

Genetics

Many clones are used in horticulture, but 'Leighton Green' has been the most widely used in forestry trials in Britain.

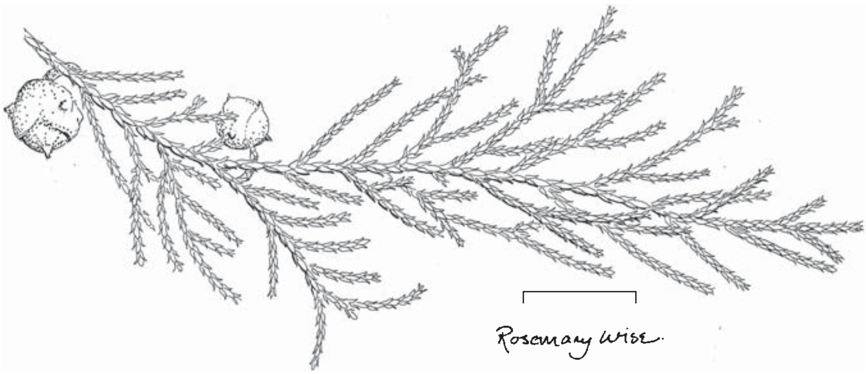

Fig. 13. Leyland cypress, x *Cuprocyparis leylandii*.

Timber

The timber is naturally semi-durable, but little of it has ever become available, so it remains relatively unknown.

Use in hedging

Because of its rapid growth (up to 1 m year^{-1}) and dense foliage, it is used widely as a hedging species. It provides a screen very quickly, but growth is so vigorous that it needs constant attention to keep it within bounds. This characteristic has caused Leyland cypress to be the tree that is responsible for more disputes and litigation between neighbours than any other because high hedges block light. It has led to violence and, in the case of Mr Llandis Burdon of Talybont-on-Usk in Powys, to murder. He was shot dead by a neighbour in 2001 after a dispute over the height of a Leyland cypress hedge.

Place of Leyland cypress in British forestry

Leyland cypress has practically no place at all in modern British forestry, but Forest Research (2011) believes that it could find a role if climate warming progresses as predicted, particularly in western Britain and elsewhere with adequate soil moisture. It will no doubt continue to be the major hedging species.

EUCALYPTUS L'Hérit. Eucalypts

Origin and introduction

There are about 680 species of *Eucalyptus* and almost all occur naturally only in Australia. As exotics they are among the most widely planted, productive and controversial of all species both in the tropics and in the warmer parts of temperate regions. Extensive areas are planted for pulpwood in south-west France, northern Spain and Portugal. Even at these latitudes they occasionally succumb to exceptionally low temperatures and the stems may be killed, though they often regenerate quickly from coppice shoots. *Eucalyptus gunnii* was introduced to Britain from Tasmania in 1846.

Climatic requirements

Eucalypts have a reputation for being frost tender and prone to damage or dying in cold winters, partly caused by the fact that they do not form a winter bud, but are capable of growing continuously in warm weather at any time of the year. The risk is particularly high during spells of sub-zero temperatures that follow a mild period; in persistent, very cold, desiccating winds; and also on warm, sunny days when the ground is frozen, resulting in high levels of transpiration but poor water uptake and consequent desiccation of shoots (Sheppard and Cannell, 1987). *E. gunnii*, one of the most frost-hardy species, will survive midwinter temperatures of −10° to −14°C and even short periods of −18°C (Leslie *et al.*, 2012), but they are susceptible to damage from early autumn frosts. Late spring frosts are less important. However, even the most cold-resistant species can be damaged by climatic extremes in British winters, and therefore careful matching of species to site environmental constraints is critical (Leslie *et al.*, 2012). Precipitation requirements for *E. gunnii* are relatively high: at least 800 mm $year^{-1}$.

Evans (1986) considered that, in general, the use of eucalypts in forestry north of latitude 45° is likely to be very restricted. The south of England is at 50°N, so Britain is probably outside the range where they can safely be grown, but at quite regular intervals occasional enthusiastic Australian visitors manage to persuade research workers to try new species or provenances. The result is that there is a burst of research on eucalypts about every 10–15 years in Britain, which usually ends in failure after the first severe winter, at least in areas that have had cold winters. The species believed to be most hardy in the mid-1980s (*E. gunnii*, *Eucalyptus archeri*, *Eucalyptus pauciflora* ssp. *niphophila* and *Eucalyptus pauciflora* ssp. *debeuzevillei*)

Fig. 14. Adult leaves and flowers of cider gum, *Eucalyptus gunnii*.

come from high elevations in the mountains of south-eastern Australia and Tasmania (Evans, 1986). The latter two species, while reasonably hardy, grow too slowly to be of interest. Twenty years later, in a new rush of activity, only *E. gunnii* from Lake Mackenzie in Tasmania at about 1100 m elevation (41° 43′ S or about equivalent in latitude in the northern hemisphere to Biarritz in south-west France) was considered both sufficiently well-adapted to the extremes of the British climate and to exhibit useful rates of growth (Cope *et al*., 2008).

Eucalyptus glaucescens is said to be almost as resistant to frost as *E. gunnii* and has the advantage over the latter of exhibiting excellent stem form. Leslie *et al*. (2012) say that in the New Forest it showed faster growth than *E. gunnii* and excellent self-pruning. It is also highly unpalatable to deer. In addition, its rapid growth means that where survival is patchy, production is still maintained.

Site requirements

High fertility is not required. Suitable sites are most likely to be in sheltered parts of lowland Britain, particularly south-west England, but even there apparently promising trials have been completely killed in severe winters. Poorly drained sites – including peaty ones – should be avoided, and also those prone to drought.

Other silvicultural characteristics

Most eucalypts are strongly light-demanding trees and must not be planted in the shade. The majority coppice very well and benefit considerably from thorough weed control when very young. Unlike most trees of temperate regions, eucalypts do not have a truly dormant period and so can grow during warm winter weather. Like any fast-growing tree, they use a great deal of soil water during transpiration. They have been planted in some countries to lower water tables to reduce salination of the surface soil and also, in some tropical countries, as a means of reducing malaria by lowering water levels in swamps where mosquitoes breed. The characteristic of using large amounts of water can also create problems in some parts of the world where precipitation is scarce, by lowering water tables and hence reducing the amounts of water available for growing food crops. This reflects poor choice of species and land management rather than anything else.

Provenance

Only *E. gunnii* from Lake Mackenzie in Tasmania (see above) is known to be able to tolerate the climate of the colder areas of Britain (Leslie *et al.*, 2012). There are several subspecies of *E. gunnii*, some of which are shrubby and multistemmed. They offer considerable scope for selection.

E. glaucescens, though appearing promising, is still relatively untested over large areas but has performed well in a number of small trials, some over several decades.

There is an enormous interest from pulpwood growers – for example, in Portugal – in breeding highly productive clones of *Eucalyptus*, usually *Eucalyptus globulus* in that country.

Yield

Mean annual increments of *E. gunnii* in Britain of 10–15 m^3 ha^{-1} $year^{-1}$ on a 12-year rotation have been reported by Evans (1983), and more recently 18–25 m^3 ha^{-1} $year^{-1}$ have been claimed for it (e.g. Anon., 2010; Leslie *et al.*, 2012). Growth rates of 40 m^3 ha^{-1} $year^{-1}$ or more are common in some countries.

Timber and uses

In Britain recent interest in the use of renewable fuels, including woody biomass grown over short rotations, has stimulated the current (2000s) work on eucalypts. They are particularly suited to biomass production because of their high wood density and hence high calorific values. *E. gunnii* is 700 kg m^{-3} at 12% moisture content. They have suitable chemical characteristics and can easily be harvested all year round using conventional machinery, if a single-stemmed growth form is maintained.

E. globulus is widely grown for pulpwood in Portugal, parts of Spain, France and many other warm temperate countries. It is also valued for fuel and building poles in many places. Few commonly grown species produce acceptable saw timber because their rapid growth causes the build-up of stresses within the stem. These lead to serious distortions after the tree has been felled and sawn. There are exceptions however, for example *Eucalyptus delagatensis* (Tasmanian oak).

The leaves of *Eucalyptus* contain an oil that can be extracted by steam distillation. It is used for cleaning, deodorising, as a decongestant, and it also has insect repellent properties. Most is produced in China.

Place of *Eucalyptus* in British forestry

The attraction of eucalypts is that they can grow at rates that are unsurpassed by other species. That they are not planted on more than a trial basis in Britain is because few species or provenances are likely to be truly hardy, except on rare, extremely mild sites. What needs to be determined is whether the return through rapid growth justifies the risk of losing an entire crop. It might be appropriate in some areas of Great Britain but not in many others.

Eucalypts tend to arouse passionate criticism wherever they are planted as exotics because of the amount of water they use and the adverse effects they are said to have on local biodiversity, though this is not always true. For the present and the foreseeable future eucalypts are likely to remain species of insignificant importance in British forestry.

FAGUS SYLVATICA L. Beech

Origin

There are ten species of *Fagus* in temperate parts of the northern hemisphere, of which *Fagus sylvatica* is native to Western Europe. Its range extends from southern Scandinavia to central Spain, Corsica, Sicily and Greece, eastwards to western Russia and Crimea, and westwards to Britain. In the southern part of this range it grows only in mountain forests, at 600–1800 m elevation. In Britain beech is now both widely planted and naturalized at elevations below about 650 m. It is believed to be truly native only to parts of southern England and south-east Wales. Elsewhere many county Naturalists' Trusts regard it as an undesirable 'alien' tree.

Climatic requirements

Beech does best in moist, rather mild and sunny climates where precipitation is well distributed throughout the year and mists are frequent. Like many shade-bearers, it suffers badly from both early autumn and late spring frosts and can be impossible to establish on exposed, open ground without nurses. It grows well in moderately polluted areas. Once established it tolerates exposure well, though crowns may become deformed. It has been much used for shelterbelts on hill farms, for example on Dartmoor, and is suitable for planting near the sea. Its relative vulnerability to drought means that its suitability to parts of southern and eastern Britain will reduce with climate warming, and it should be limited to soils of good moisture status in these parts of the country. Conversely, the warming climate may see greater productivity on suitable sites in the north. Changing climatic conditions may put beech populations in southern England under increased stress, and while it may not be possible to maintain the current levels of beech on some sites, it is thought that conditions for beech in north-west England will remain favourable or even improve. North-east Scotland will also become suitable for the species (Ray *et al.*, 2002).

Site requirements

To grow well beech must have a satisfactory soil moisture regime. It will not tolerate either an excess or deficit of water. It grows best and is the dominant tree on chalk and soft limestone soils if they are not too dry, in south-east England, but is by no means confined to them. For example, it is frequently dominant on well-drained loams and sands. Beech is not a good competitor for water, and if it is in short supply mortality occurs, especially in regeneration (Rust and Savill, 2000). In a survey of beech and other species in the Chiltern Hills, Clements (2001) found that for growth the optimum conditions for beech are on neutral soils of high fertility with little free carbonate but ample available water. Within the area where beech will become less climatically suitable with climate warming, it will be least threatened if grown on deep soils on slopes that receive the least amount of sun and heat (i.e. north-east facing).

Unsuitable sites are either infertile, dry and sandy, or heavy and waterlogged, on both of which it may suffer badly from drought in dry years such as the summer of 1976. It is rare on ‘neutral’ soils (pH 5.0–6.5) according to Peterken (1981). In common with many late successional species, young beech competes less successfully than many trees with grasses and other ground vegetation when grown in the open.

Other silvicultural characteristics

Beech seldom exceeds 35 m tall and is not a long-lived tree, 150–200 years being about the maximum. Its outstanding feature is its great tolerance to shade; it is the most tolerant tree of any British species except possibly yew. Brown (1953) has described its performance and silviculture in great detail. It benefits strongly from shelter on exposed sites when young. Stem form is often poor so that planting must be dense to give adequate selection. It is valued as an understorey to light-demanding species, for example in shelterwood systems, though on heavy soils hornbeam is better for this purpose.

Beech responds well to thinning, even at a relatively advanced age, so that when grown in a shelterwood system the trees left after a seeding cut can put on valuable increment. It coppices weakly but is tolerant to pruning, hence its popularity as a hedging plant.

Brown and Nisbet (1894) quoted a widely held continental European belief that beech conserves and protects the productive capacity of the soil better than any other species of tree, and therefore may well be termed ‘the mothers of the woods’. In mixed woods a suitable admixture of beech enables all species of forest trees to develop much better than when they are grown in pure woods. This is something that Brown and Nisbet (1894) said was then, as now, unrecognized in Britain.

Young beech trees retain their dead leaves over winter, as do trees that are coppiced regularly. This makes it an excellent hedging species. One of the tallest (~30 m) and longest hedges that exists is a beech hedge at Meikleour, near Perth in Scotland.

If a thinning or clear felling suddenly exposes previously shaded beech stems ‘sun scorch’ of the bark often occurs. This can result in large patches of bark and cambium dying.

Pests and diseases

The most serious threat to beech arises from grey squirrels, which can be very damaging to trees of up to about age 40 years, stripping the bark and cambium from around the bases of stems in particular (Mercer, 1984; Rayden and Savill, 2004).

Stressed trees tend to suffer from beech bark disease, especially on wetter clay soils during and after the pole stage. This arises from attacks by a scale insect, *Cryptococcus fagisuga*: later, the wounds caused by the feeding activity of the insect may be infected by the fungus *Nectria coccinea* (Lonsdale and Wainhouse, 1987), which can kill the bark.

Natural regeneration

In much of continental Europe natural regeneration of beech is common and is managed under a variety of silvicultural systems. It performs well in the uniform shelterwood system, but because of its tolerance to shade it can be managed in any of the less regular systems just as well. According to Emborg (2007), beech has a 'stop and go' competitive strategy, in that it can survive periods of severe competition but grows again when conditions improve, slowly reaching a dominant position in the canopy. Beech seed is not dispersed far from the parent trees, so gaps of 20 m or more in diameter are unlikely to be adequately stocked in the middle. The contrast between the apparent ease with which it regenerates on the continent and the rarity of natural regeneration in Britain is so remarkable that many authors (e.g. Jones, 1952) have attempted to determine the extent to which continental methods might be successful in Britain.

Good mast years, from which natural regeneration arises, usually occur at intervals of 5–15 years or more in Britain but much more frequently in many parts of continental Europe, including Normandy. It is generally agreed that a good correlation exists between high levels of seed production and the warmth of the preceding summer, provided that the flowers are not killed by a late spring frost (Matthews, 1963). Most of continental Europe has warm summers, and their rarity in Britain is believed to be the most fundamental obstacle to obtaining regeneration. Jones (1952) considered that so many British beech woods are even-aged because they arise from very occasional exceptionally good seed years.

A satisfactory seed fall in the Belgium Ardennes was considered by Weissen (1978) to be 200–600 seeds m^{-2}. Enormous losses then occur from fungal attacks (e.g. by *Rhizoctonia solani*), from predation by insects (e.g. *Tortrix grossana*), mice and birds, and from severe winter or late spring frosts (Engler *et al*., 1978). In a study near Oxford during the good seed year of 1984, Linnard (1987) found a total fall of 1316 cupules m^{-2} between October and March, indicating a possible fall of 2632 seeds m^{-2}. In fact, only 1500 seeds m^{-2} reached the ground, and of these half were sound: 8% had been damaged by birds, 4% by small mammals and the rest were empty. By the end of March 1985 only 18 sound seeds remained per square metre, of which six had germinated.

In much of Germany where natural regeneration is practised, the regeneration must be fenced to protect seedlings from roe deer. Apart from damaging the trees, deer browsing encourages herbs and grasses to grow, which make conditions much less suitable for regeneration. The young trees must become established within 15 years, which is the average life of a fence.

Though less easily damaged by cold than oak, exposure to temperatures lower than about −6°C can be fatal to beech seed lying on the surface (Jones, 1954). To reduce losses and provide conditions that are suitable for germination and establishment, the ground must be in a receptive condition. The surface should be loose so that the seed is easily buried and on germination the radicle can readily penetrate the mineral soil. A hard soil surface, the presence of matted grass or too much litter all prevent this. Suitable conditions can be achieved by scarifying the soil, deeper ploughing, or preferably both, prior to seedfall (Becker *et al*., 1978). In Britain cultivation is likely to be the most important means of making the best use of the light seed crops that normally occur. These treatments protect the seed from frost and *Rhizoctonia*, and the roots from frosts and drought in the spring. They also eliminate much of the competing ground vegetation for periods of between 1 and 3 years, depending on the species of weeds, by which time the young beech should be sufficiently competitive not to require further attention. A very impressive example of successful regeneration following a reasonably good seed year in 1990 is at East Wood, near Stokenchurch in the Chiltern Hills. R. Pakenham (1996) scarified the ground surface with a Danish Ledreborg plough both before and after seed fall, and subsequent establishment was excellent. On acid soils the addition of phosphate may also help seedling establishment.

The best regeneration in uniform shelterwood systems in France always occurs when a good seed fall immediately follows a seeding felling: if the felling is done after the seedfall, germination may be just as good, but many seedlings are inevitably destroyed in the subsequent work. The use of shelterwood systems may not be so sensible in Britain, where seed years are so uncertain: the use of group selection systems might be better, but they need a great deal of skill. Above all, British foresters who want natural regeneration must be opportunistic and be prepared to do the necessary felling when the seed arrives. This creates obvious difficulties in organizing felling and may flood the market with timber, causing prices to fall.

Successful regeneration is more likely on some sites than others. Jones (1952) considered the best sites to be where there is a moderately shallow loam (about 50 cm deep) over chalk, with a ground vegetation of low herbs such as wood sorrel, yellow dead-nettle, melick, wood millet and creeping soft grass (*Holcus mollis*). On the heavier, deeper soils where bramble and coarser herbs are luxuriant, regeneration is more difficult. Clements (2001) found that regeneration of ash is greatest in calcareous soils, whereas beech does better on acid soils.

Flowering, seed production and nursery conditions

The flowers, which appear in May, are particularly sensitive to damage by late spring frosts; seeds ripen in September and October, and fall up to November, often after a frost. The earliest age at which the tree bears seeds is 50–60, but the best seed crops are usually after 80 years of age and at intervals of as long as 5–15 years or more. As stated above, good seed years tend to occur if the July of the previous year was hotter than usual and if flowers are not damaged by frost in the spring (Matthews, 1963).

There are about 4600 seeds kg^{-1} (range 3400–6400), of which 60% normally germinate. Beech seed has to be stored carefully to ensure it does

Fig. 15. Beech, *Fagus sylvatica*.

not heat or 'sweat'. It can be sown in the year of collection if the site is not prone to late spring frosts; otherwise it can be stored by a variety of methods, described by Aldhous (1972), until sown between early and mid-March of the following spring. Beech seed cannot be kept longer than this.

Provenance

Little work has been done on beech provenances in Britain, though Evans (1981) stated that Carpathian seed is about average, and the best origins tested come from Soignes forest in Belgium and from the Netherlands. The recommendation from Forest Research (2011) is that material from good-quality British stands should be preferred for planting, with registered western European seed stands as an alternative.

A strange and rather counter-intuitive relationship between leaf emergence in spring and elevation was found by Vitasse *et al*. (2009). Working in southern France, they found that along the same climatic gradient species can exhibit opposing genetic clines: beech populations from high elevations come into leaf earlier than those from low elevations, whereas the opposite trend occurred for ash and oak.

Beech is a highly ornamental species and will grow to dimensions that far surpass oak. Several well-known ornamental forms exist, most of which are propagated by cuttings, but copper beeches arise naturally from seed reasonably frequently.

Area, yield and rotation

Beech occupied about 77,000 ha or 3.5% of the forest area in Britain in the late 1990s (Forestry Commission, 2003). Mean yield classes range from 5 to 6 m^3 ha^{-1} $year^{-1}$ in different parts of the country, and the maximum is about 10 (Nicholls, 1981). Rotations of 70–80 years are normal and should not exceed about 100 years if the aim is to grow white timber. If they are longer trees suffer from 'redheart' and are quite often rotten.

Timber and uses

The timber of beech is hard, strong, straight grained, resistant to splitting and even-textured. When freshly felled the colour is whitish to pale brown. The average density of the diffuse-porous wood at 15% moisture content is about 720 kg m^{-3}. It is easily turned and worked, finishes well and bends exceptionally well, especially if steamed. Visually it is rather a plain, uninteresting wood. These properties make it suitable for the manufacture of utilitarian furniture, especially chairs and upholstered furniture frames, turnery and (formerly) kitchen utensils. It is also suitable for flooring, plywood and constructional work. It is rather short-grained and brittle, and not of great value where strength and durability are required. Heat treatment of beech timber improves its stability in use a great deal but also makes the wood more brittle.

A frequent defect of beech timber is known as ‘redheart’. It occurs in trees of more than about 100 years old and can considerably reduce the value of the wood.

The beech woods of the Chilterns were originally managed for the furniture industry, which was based in High Wycombe and dates from about 1870. In the south of England much of the timber that has grown since the spread of the grey squirrel in the 1940s is damaged and of little value. In fact, the time of arrival of grey squirrels in any locality can be dated quite accurately from the bases of felled beech trees by counting the annual rings back to the first one which shows damage from gnawing.

Place of beech in British forestry

Beech is the only large and strongly shade-bearing tree native to Britain. As such, it has a potentially important place in silviculture. Unfortunately, the American grey squirrel has become a huge threat to the species. Climate change may reduce the suitability of many sites in the south of England, but its range is likely to be extended in the north. Though likely to decline in importance, beech will nevertheless remain a significant species.

FRAXINUS EXCELSIOR L. — Ash

Origin

There are 42 species of *Fraxinus* distributed around the north-temperate zone. Ash is found throughout Europe up to about 64°N, and in North Africa and western Asia. It is native to, and widely distributed over, most of Great Britain and Ireland, where it occurs at elevations of up to 450 m. Clapham *et al*. (1985) considered that it may have been introduced into some northern counties.

Genetic analyses of ash across Europe has indicated that following the last Ice Age the dominant origin of ash that colonized Britain was from the Iberian Peninsula (FRAXIGEN, 2005), in a similar way to other species (e.g. the native oaks and holly).

Climatic requirements

The whole of lowland Britain falls within its range of temperature and rainfall tolerances, and a combination of exposure and unsuitable soil is probably responsible for setting its altitudinal limit (Wardle, 1961). This is higher than that of oak but lower than beech (Kerr, 1995). The tree does best in milder, moister areas: shelter is especially important when young, and if provided, it can result in an increase in growth rate of up to four times (Willoughby *et al*., 2009). Ash is frost tender, but because it comes into leaf so late it often escapes damage in the spring.

Site requirements

Really good ash sites are rare and small in extent. It usually does best on calcareous loams (pH 7–8) which are moist, deep and well-drained: ash grows well on slightly damper sites than those where sycamore thrives. It requires sites with a high content of available nitrogen. The species is very site-demanding, and if planted on soils that have recently been in arable agriculture it often becomes nitrogen deficient, a problem that needs correcting by an application of fertilizer. Foliar nitrogen levels need to be at least 2.3% of dry weight to maintain growth and ideally 2.5–3.0% (Bonneau, 1995). Ash will regenerate naturally on a wide range of soils but seldom does well on many of them. Garfitt (1989) stated that contrary to popular belief the ideal site is not a damp valley bottom but a well-drained calcareous soil. This may be a rich deep marl, as in parts of Yorkshire, or a shallow soil over hard, fissured limestone, as in the Pennines, or a modest

20 cm of soil over platy limestone brash in the Cotswolds. It is usually absent from sites where the pH of the surface soil is less than 4.4, and less frequent on other acid soils and in drier regions. The species is not suitable for large-scale planting and is probably only worth persisting with on ideal sites where it will grow to large sizes (Stevenson, 1985). Wood sanicle, wild garlic, dog's mercury and elder often indicate appropriate conditions. Such sites are typical of woodland types W8 and W9 in the national vegetation classification (Rodwell, 1991).

Ash is not suited to heathlands or to the uplands in general, nor to sites subject to prolonged waterlogging or which are compacted. Should it be planted adjoining arable fields it often dies back severely. Ash seedlings may germinate in profusion on heavy wet soils because they only need a small depth of well-drained soil on which to become established. Periodic water shortages during droughts on these sites lead to poor subsequent growth: they should be avoided because ash never does well on them and it usually disappears altogether.

Other silvicultural characteristics

Ash will grow to 30 m tall or more. Though it is a good shade-bearer for its first 7 years or so, it becomes strongly light-demanding later. For this reason crowns should always be kept free from competition. It responds to delayed thinning slowly or not at all. All thinnings should therefore be heavy with the aim of keeping crowns entirely free. The crop should be at its final spacing by age 30–35. Kerr (1995) noted that the most frequent management failing with ash is under-thinning. If thinned properly pruning is relatively important to prevent the development of large branches. Ash competes well with the climber *Clematis vitalba*, where other trees may become smothered, but not satisfactorily with grasses, and so it is not suitable for using on previously unplanted ground unless weed control is thorough.

Ash is rarely successful as a pure plantation species. It is said to be easier to establish than beech and oak, though early side shelter provided by compatible species such as Norway spruce or European larch is essential (Kerr, 1995). Ash is often regarded as a useful component in mixtures. It should be planted in groups rather than intimate mixtures, and good weed control is always essential in the early years. Cherry has a compatible growth rate and is suitable for mixing with it (Pryor, 1985; Stevenson, 1985). Its ability to produce a good root system probably explains the relative ease of establishment of ash. Kerr and Cahalan (2004) have shown that ash has the ability to transpire large volumes of water on sites with good water supplies, in common with other fast-growing broadleaved trees such as alder, willow and poplar. It can also tolerate dehydration, but for good growth sites liable to moisture stress should be avoided.

In Denmark scattered ash are grown in beech stands and felled after 70 years, leaving the beech to grow on for another 30–40 years. In Belgium it is often grown with sycamore, cherry, oak, elm, aspen and birch (Thill, 1978).

Kent, writing in 1775, said that ash has many enemies 'because of the wet, which drips from it, is very noxious to most other plants. And as it shoots it roots horizontally, and pretty near the surface, farmers have a particular dislike to it, because it interrupts the plough.' Similarly, Justice (1765) considered that no other tree would thrive under or near an ash 'because it exhausts all the nourishment round it'.

Many websites state that ash is poisonous to ruminants, but no evidence could be found for this assertion. Forbes and Watson (1992) stated that 'large masses of indigestible material in the stomach can cause severe illness or death; cases have included ash leaves in cattle'. It is probably the indigestibility of the leaves rather than their being poisonous that causes an occasional problem. Ash is certainly not regarded as an undesirable tree on livestock farms; in fact, in Spain at least dried ash leaves were at one time fed to pigs and goats in winter (FRAXIGEN, 2005).

Ash is sometimes used in agroforestry systems, being planted at very low densities, with the grass beneath grazed by sheep or cattle. This can sometimes lead to the soil becoming so compacted that the trees grow badly.

Pests and diseases

A potentially devastating fungal disease of ash, *Chalara fraxinea*, was recorded in Britain for the first time in 2012 and was found to be quite widespread, mostly on young planted trees that had been raised in the Netherlands. It has caused the death of over 90% of all ash trees in many European countries (Skovsgaard *et al*. 2010) and is likely to do the same in Britain. At the time of writing (November 2012) the only possible approach for controlling the disease seemed to be long-term one, of selecting and breeding from resistant individuals, which are said to constitute about 1% of the population, having first established that resistance is likely to be permanent.

Cankers (caused by the fungus *Nectria galligena* and the bacterium *Pseudomonas savastanoi*) may damage trees badly if they are grown on unsuitable sites. Cankered trees should be removed as soon as possible.

Young trees commonly fork, sometimes repeatedly. This may be caused by the ash budmoth (*Prays fraxinella*), though much more likely causes are late spring frost damage and breakage by birds. Another threat comes from an exotic wood-boring beetle, the emerald ash borer, *Agrilus planipennis*. This has caused significant damage to North American ash trees, said to be comparable to Dutch elm disease in the devastation it causes, following its recent introduction into that region. Although there is no evidence that this insect has arrived in Great Britain, the increase in global movement of wood poses a significant risk of its accidental introduction.

Ash is almost immune from grey squirrel damage, but young trees are severely browsed by hares, rabbits and deer.

Natural regeneration

Ash has a remarkable capacity to regenerate naturally both in woodland and non-woodland, as well as on sites where it will not grow well. According to Kerr (1995), natural regeneration is best in woodlands where the canopy is dense and dog's mercury shaded out. Once established it responds well to canopy opening, if it is not browsed by deer. Ash is relatively unusual among broadleaves in that natural regeneration appears in the second spring after a seed fall (see below). Kerr (1995) pointed out that care is required with removal of a parent crop because if it is done too early the seedlings could be smothered by weed growth.

Natural regeneration is often so prolific that the species can become invasive. It does well in group selection systems with sycamore and beech, though ash is a strong competitor for water, which, if it is in short supply, can lead to mortality of beech (Rust and Savill, 2000). This is partly because the root biomass of ash is greater than that of beech (and many other species) for equivalent stem diameters. Ash produces a large root biomass soon after germination (Einhorn, 2007), and it is this characteristic that caused Emborg (2007) to describe it as having a 'rush' competitive strategy, in that it can establish itself quickly in new gaps and then stay in front of competing species by growing fast. Ash coppices well and sound stools of 1000 years old can occasionally be found.

Flowering, seed production and nursery conditions

Ash is unusual in that an individual tree may be female, male or hermaphrodite. The tree flowers in March and April before the leaves emerge; the winged 'keys' mature in August or September and are released from winter to early spring. The seed is sometimes described as being 'doubly dormant' because after falling embryos still require several months to develop; for this they require warm, damp conditions and then need to be chilled before they will germinate. If seeds are collected when green, in July or August, and sown *immediately* they will germinate the following spring, though rather erratically. They should ideally be collected in October and stratified for 16−18 months before being sown in March or April in a neutral soil (Aldhous, 1972). There are about 12,900 seeds kg^{-1} (range 8600−16,000), of which 70% will germinate and 3000–4000 plants will subsequently be saleable. The earliest age at which the tree bears reasonable quantities of seed is 25–30 years, and really good seed years occur at 3–5-yearly intervals between the ages of 40 and 60.

Provenance and improved seed

Recommendations for provenance use by Forest Research (2011) are that material from good-quality British stands should be preferred, with provenances from northern France as an alternative for use in southern Britain.

In 1993 the Future Trees Trust (formerly the British and Irish Hardwoods Improvement Programme) established four ash breeding seedling orchards (Barnes, 1995) using progeny from 36 selected 'plus' trees from around Great Britain. The aim was to achieve an improvement in recoverable volume of between 12% and 15%. It is hoped that these orchards will produce sufficient disease-free individuals for a future breeding programme against *Chalara fraxinea*. After three thinnings, in which the less desirable families and individuals were removed, the first improved seed was produced in 2012, though the extent of improvement was not known at the time of writing. Well-managed tree improvement programmes such as this not only help maintain the genetic diversity of native tree populations but also increase the economic viability of woodlands (Boshier, 2007).

Some continental authors distinguish between ecotypes of ash that grow on calcareous sites and those that thrive on damp, clayey sites, but such ecotypes have not been identified in Britain. Really superior ash trees with long, clean boles and excellent crowns are, according to Larsen (1946) and Garfitt (1989), invariably male trees, though work in 1991 at Oxford University failed to detect differences in stem straightness between male and female trees. There are some varieties of horticultural interest, such as weeping ash and an entire-leaved form.

Area, yield and rotation length

Ash is the third most common broadleaved tree in Britain after the oaks and birches. According to the Forestry Commission (2003), there were over 119,200 ha of ash in the late 1990s, representing 5.4% of the forest area. Mean yield classes range from 4 to 6 $m^3\ ha^{-1}\ year^{-1}$ in various parts of the country, with a maximum of about 10. On the best sites ash is more productive than oak but less than beech. Rotations should ideally be about 60 years, which is when sizes of maximum value are achieved: these are shorter than for sycamore.

Timber

The outstanding property of ash is its toughness and elasticity after seasoning, as indicated by its bending ability, flexibility and ability to absorb shock. This makes it suitable for sports goods and the handles of tools such as hammers. The average density of the wood at 15% moisture content is about 710 kg m^{-3}. It is easy to work when air dried, has excellent steam-bending qualities and takes finishes well. The timber is not durable outdoors.

The wood is ring-porous, and its value tends to increase with the rapidity of growth. Timber with 4–16 rings $inch^{-1}$ is likely to be suitable for most purposes. Faster or slower-grown trees are unacceptable for the more specialized markets, such as sports goods. Ash is said to be twice as valuable as oak, on average, since low-grade oak fetches poor prices. White ash is by far the most valuable, but most ash has some dark coloration in the centre, especially when the tree is planted on less suitable sites. According to Evans (1984), this 'brown' ash is associated with waterlogged soils and slow growth (possibly due to inadequate thinning). Old, stored ash of coppice origin also suffers frequently, though the physical properties of the wood are unaffected. Evelyn (1678) stated

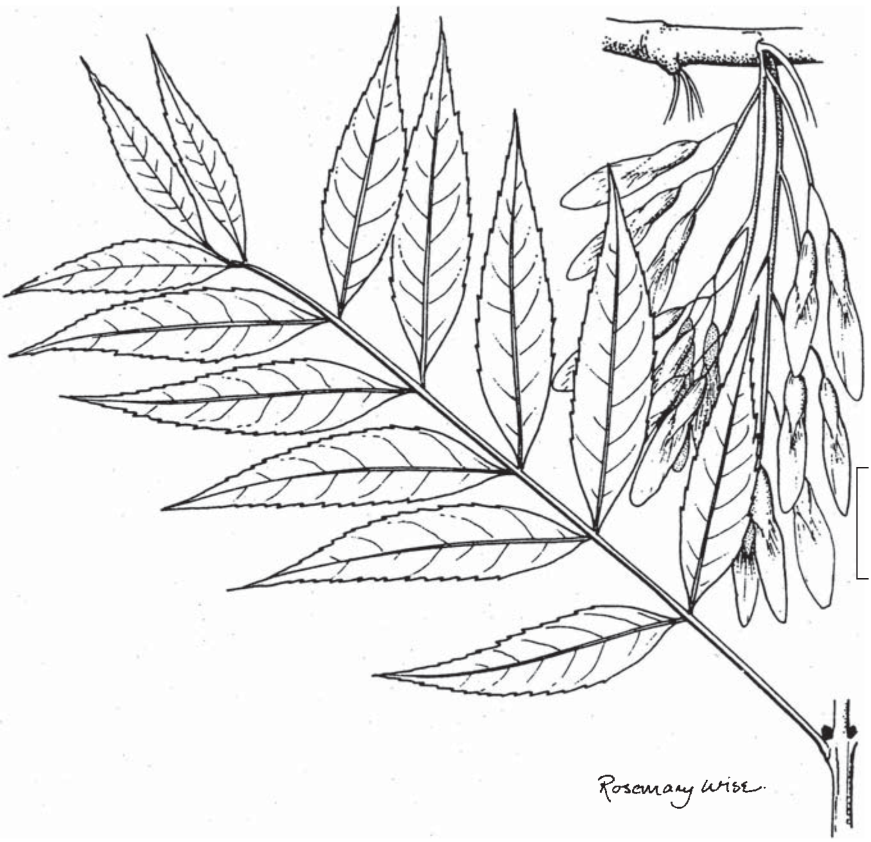

Fig. 16. Ash, *Fraxinus excelsior*.

that curiously veined wood could be found. This was prized at one time by skilful cabinet makers. Occasional trees are found with rippled grain, and these can be very valuable. Most occur in open situations rather than in woodland. Ash makes the best firewood of any British tree because its moisture content is low, so it burns well even when green. In common with all deciduous hardwoods, the sapwood of ash is much more at risk from attacks by wood-boring insects if trees are felled when in leaf. It is, however, easy to treat with preservatives.

Place of ash in British forestry

With the introduction of *Chalara fraxinea* the immediate future for ash is bleak. Most existing trees are likely to die over a few years from 2012. They might ultimately be replaced if resistant individuals are found, but this will take a long time. Meanwhile ash will undoubtedly become a minor constituent of woodlands where it now dominates.

Among its attractions are that the tree produces a valuable timber for which there is normally a good and constant demand; rotations are short; the tree is relatively free from attacks by grey squirrels, unlike most other broadleaved species; and natural regeneration is easy to achieve. It is a species that might have replaced beech on many southern sites as climate warming procedes and sites become less suitable for beech.

ILEX AQUIFOLIUM L. Holly

Origin

There are some 400 species of *Ilex* in tropical and temperate regions. Holly is a widespread, common species found all over Britain, except in Caithness, Orkney and Shetland, and extends southwards to 34°N in Algeria and Tunisia, northwards to Norway at 64°N and as far east as central China (Peterken and Lloyd, 1967). It usually occurs in the understorey of beech and oak woods, where it may often be the dominant species, especially if there is severe grazing. It is also found in hedges and on rocky hillsides to about 550 m (Clapham *et al*., 1985).

Holly occurs as a solitary tree or in small groups, forming nearly pure stands locally. Suckering from roots or, more rarely, layering from branches often gives rise to clonal clumps.

Silviculture

It is a large, rather slow-growing evergreen shrub or small tree, seldom taller than 10 m, but rarely to 23 m. Holly has never been managed as a forest tree in Britain. It is a hardy plant, capable of surviving in most conditions, except where it is extremely wet.

Holly is sensitive to prolonged periods of frost, and its natural distribution is largely determined by this. It is found on a wide range of soil types, from acid podzols to chalk and limestone, but is not normally found on wet soils. Marshall (1803) thought that thin-soiled heights seemed to be its natural situation. It is one of the most shade-tolerant of all British trees, but to grow to reasonable sizes it requires full light. The tree withstands pollution well.

Holly responds to coppicing and to pollarding at 2–3 m by producing vigorous leading shoots, a power that appears not to decline with age (Peterken and Lloyd, 1967).

Leaves and twigs are palatable to many animals, though the distinctive lower spiny leaves deter them to some extent. Axillary buds of browsed shoots develop to form dense masses of foliage. The height growth of young individuals may be checked indefinitely by heavy browsing, to form low scrub less than 50 cm high. Even small seedlings show remarkable tenacity in the face of repeated nibbling.

The lower spiny leaves protect birds from predators as they feed on its bright-red berries. On higher branches (where grazing animals pose less of a threat) the leaves have virtually no spines.

Holly is often planted for ornament; numerous cultivars exist with variegated leaves and different coloured berries.

Natural regeneration

Holly is normally only planted as an ornamental specimen or as a hedge. Therefore practically all holly that exists in woods is of natural origin, seeds having been distributed by birds. According to Peterken (1965), the browsing pressure exerted by large herbivores including deer, ponies and cattle regulates the success of regeneration, at least in the New Forest, though seedlings must have enough light if they are to survive.

Flowering, seed production and nursery conditions

The tree is normally dioecious (i.e. there are separate male and female trees), and rarely hermaphrodite. The flowers are white and appear in summer. They are insect pollinated. The first conspicuously bright red or yellow berries are produced at age 20, but maximum production starts after 40 years: good crops then occur every 2–4 years. Shading significantly reduces fruit production.

High summer temperatures are probably necessary for the formation of fruit, and if the summer has been cold they do not develop. Good seed years for holly are believed to coincide with good mast years for beech, which Matthews (1963) has shown to be correlated with the July sunshine and air temperature of the previous year, and the absence of severe late-spring frost.

As tradition indicates, berries are ready for collection by Christmas, when they are widely used for decoration. Seeds never germinate in the first year and need to be stratified in damp sand for 16 months before sowing. There are about 45,000 seeds kg^{-1}, of which about 80% normally germinates. In natural conditions they probably germinate over a number of years.

Holly is extremely sensitive to transplanting and can easily be killed by this operation unless it is done with great care, preferably near the beginning or end of the growing season, in May or September, and ideally in wet weather.

Timber and uses

The wood of holly is much denser than that of any other native hardwood except box, at about 800 kg m^{-3}. In 1803 Marshall described it as 'being in good esteem among inlayers and turners; it is the whitest of all woods; its colour approaching towards that of ivory'. The wood is strong, hard and polishes well. It must be well dried and seasoned or else it warps badly. It is highly regarded by cabinet makers. The heartwood of mature trees is used for such things as printing blocks, engravings and turnery. The wood makes a good fuel, burning well even when green.

Holly is quite a widely used hedging plant because it can easily be kept trimmed.

Place of holly in British forestry

Rather like hazel, holly has little or no economic value today. However, as a native and often ornamental component of broadleaved woodland that regenerates easily from seed, it will continue to be a common species.

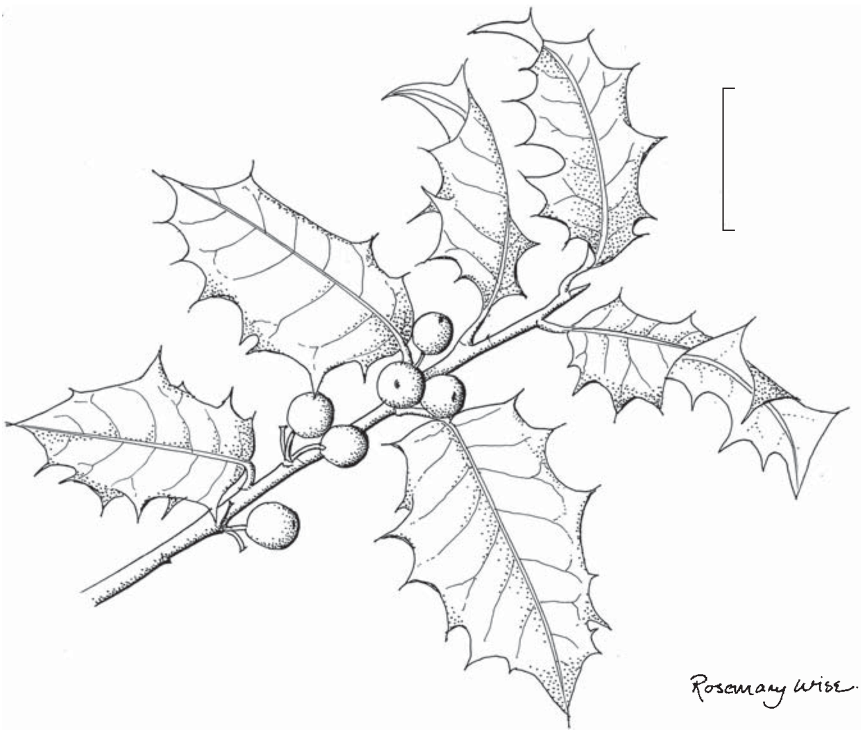

Fig. 17. Holly, *Ilex aquifolium*.

JUGLANS L. Walnuts

There are 20 species of *Juglans* worldwide. Only one, *Juglans regia*, is indigenous to parts of south-east Europe; others are native to eastern Asia and the greatest number is distributed between North America and the Andes.

Hybrids of various species of walnuts are increasingly available, especially *Juglans nigra* × *J. regia* crosses from France (Clark and Hemery, 2010). Some of these, such as the hybrid NG23, have excellent vigour and form. However, the wood of hybrid walnuts lacks the dark and often beautiful figure common in its parents, particularly *J. regia*. They are not considered further here.

JUGLANS NIGRA L. Black walnut

Origin and introduction

Black walnut is native to the eastern USA and south-east Canada, and was introduced to Britain in the early 1600s. It is much less common in Britain than common walnut and grows best in south-east England, most commonly as a tree in parks and gardens. According to the RBG Kew website,[1] the very harsh European winter of 1709 damaged common walnut trees to such an extent over continental Europe that a ban was imposed on the export of the timber to Britain. This was in the middle of a period when fashionable furniture was made primarily from walnut. An alternative had to be sought urgently and was eventually found in the USA in the shape of black walnut.

Climatic requirements

A constant hazard in growing walnuts is the risk of late spring frost damage, though black walnut is said not be as susceptible as common walnut (Brown and Nisbet, 1894). Its requirement for summer warmth is believed to be high (Macdonald *et al*., 1957) as it does not grow nearly as well in the north of Britain as in the south.

Shelter, even in the English lowlands, is just as important for black walnut as it is for common walnut (see under *J. regia* below). The importance of its provision cannot be overstated.

Site requirements

Kerr (1993) reported that even within the native range of black walnut 'probably between one-half and two-thirds of plantations have failed or

[1] http://apps.kew.org/trees/?page_id=102, accessed August 2012.

are unthrifty because of poor siting', and this, he said, is a recurring theme in descriptions of the silviculture of both walnut species. The lure of producing a high-value timber on relatively short rotations has led foresters to introduce the species throughout the world.

In order to reduce the risk of frost damage, planting should be in a sheltered, mid-slope position with a south or south-west aspect. Chard (1949) noted that ideal sites for walnuts are the lower and outer edges of 'hanging' woods, on south-facing slopes above the level at which valley frosts occur. He also observed that box favours similar situations in the few places in Britain where it is indigenous.

The soil should be at least moderately fertile, well drained and of medium texture, with deep rooting possible; very sandy and very clayey soils are unsuitable. The optimum pH is slightly acid to neutral (pH 6–7). Trees grow well in regions of chalk downland and on limestone hills where there is at least a 60-cm depth of soil over the strongly calcareous horizons or chalk bedrock. These exacting site requirements suggest that it is unlikely to be suitable for large-scale planting on arable land or grassland coming out of agriculture.

In its natural habitat black walnut grows on moist, well-drained deep and rich soils. These sites have many plant competitors. The black walnut can grow on them by reducing competition by the production of juglone (see below), in a sort of chemical warfare.

Other silvicultural characteristics

In Britain black walnut rarely exceeds 30 m tall. In common with the common walnut, it has a reputation for being difficult to establish. This is because it produces a substantial taproot in its first year from seed. Nursery-grown plants normally have damaged taproots and young trees consequently take a long period to recover after planting in the field. Effective weed control is essential for at least the first 3–4 years.

Because walnuts do not have a strong central axis and show a sympodial growth habit (i.e. a main stem developed from a series of short lateral branches), formative pruning is usually necessary to produce a single stem and a desirable straight bole (see under *J. regia* below). However, black walnut is a much straighter and better-formed tree than the common walnut.

Trials in the native range of black walnut have investigated interplanting it with European black alder (*Alnus glutinosa* L.) and autumn olive (*Elaeagnus umbellata* Thunb.), both of which are nitrogen-fixing species. Results in the USA (Campbell and Dawson, 1989) on this silvicultural regime have been encouraging, as have similar trials with common walnut in Britain.

In common with many members of the walnut family, black walnut produces an allelopathic chemical known as juglone. It acts to protect the tree from attacks by insects, and it can also inhibit the growth of some plants that grow under its canopy. Black walnut is notable in that it produces far more juglone than any other species.

Juglone is a respiration inhibitor. It is present in all parts of the tree but is particularly concentrated in the buds, the outer covering of the nut (the husk) and roots. It is not very soluble in water and thus does not move rapidly in the soil. Toxicity is especially concentrated closest to the tree, under the drip line. This is mainly due to greater root density in this area and the accumulation of decaying leaves and husks.

Juglone is so toxic that even minute amounts can sicken, sedate or kill people and animals (Coder, 2011). It exists within the tree as various non-toxic precursors that are found in high concentrations in buds, flowers, fruit and in the phloem. Under oxidative conditions, outside living cells, and during and after injury, juglone is formed. In continuing contact with the air or as a result of tissue drying the juglone is decomposed.

Some plants are susceptible to juglone poisoning, while others are apparently unaffected by it and grow well around black walnut trees. Sensitive plants include tomatoes and root vegetables. Those that are apparently unaffected include most grasses, oak, red cedar, hawthorn, *Robinia*, maples and some types of clover.

Flowering and seed production

The tree flowers in May and June, and the seeds ripen and are ready for collection in October. There are 65–200 seed kg^{-1}, of which about two-thirds will normally germinate.

Provenance

The only current recommendations available to growers in southern Britain are those made by Kerr (1993) and Evans (1984): northerly seed origins of black walnut from the states of Vermont, Illinois and Ohio are suitable choices for planting in southern Britain.

A new series of comprehensive trials was established in 2005 jointly by the Earth Trust and East Malling Research in Oxfordshire and elsewhere, using seedling progeny from seven European countries and 13 states in the USA, but they have not yet yielded any results.

Timber and uses

The timber of black walnut is similar to that of the common walnut in being highly valued. It is heavy, decorative, strong and has excellent working qualities. The dark heartwood has historically been used for furniture and in the manufacture of stocks for guns. The density of the wood is about 660 kg m^{-3}. It tends to be darker and more uniform in colour than that of common walnut, and it is the only walnut with traces of purple coloration.

Despite producing edible nuts it is notoriously difficult to extract the edible part from the shell.

Place of black and common walnuts in British forestry

The motivation for planting either species of walnut in Britain is normally to produce a valuable timber on a relatively short rotation. The evidence from trials suggests that they can only be grown successfully on a very limited number of sites in the south of the country and then only if sufficient shelter is available. Black walnut is particularly limited in this way. Walnuts are likely to become more suited to the British climate if global warming proceeds as predicted.

Black walnut often grows more quickly than the common walnut and was described by Mitchell and Wilkinson (1989) as being '…a far finer tree than the common walnut. It grows a straight long bole…'.

JUGLANS REGIA L. Common walnut

Some of the information given below on the silviculture of the species has been obtained from an unpublished report by H.M. Steven, dated 1926. It was prepared at the request of the War Office and presumably reflected concern about the shortage of walnut timber for rifle stocks.

Origin and introduction

The common walnut is native to south-eastern Europe, and westwards to central Asia and China. Its ecology and management in parts of its natural range have been described in detail by Blaser *et al*. (1998). It is one of the ancient introductions to Britain and is known to have been in cultivation since at least 1562 (Brown and Nisbet, 1894). According to Roach (1985), there is evidence that walnuts were grown in Great Britain long before this. Today there are probably fewer trees than at any time since the late 16th or 17th century. Walnut is regarded by some European foresters as a 'forgotten' species. Campaigns for planting it have been waged in the distant past by John Evelyn and others. Evelyn, in his *Sylva* (1678, first published in 1664), wrote: 'In truth, were this timber in greater plenty amongst us, we should have far better utensils of all sorts for our houses, as chairs, stools, bedsteads, tables, wainscot, cabinets, etc., instead of the more vulgar Beech.' In the 1700s walnuts are said to have been relatively common in Surrey, Hampshire and other parts of south-east England. Even up to about 1800 planting was pursued with vigour throughout England, but by degrees both practice and interest has faded. The reason for this is explained by Marshall (1803), who said that mahogany superseded walnut 'in the more elegant kinds of furniture; and beech, being raised at less expense … and being worked with less trouble, has been found more eligible for the commoner sorts'.

Climatic requirements

Mitchell and Jobling (1984) stated that walnut can be found everywhere in Britain except in the Scottish Highlands, but it is most frequent in south Yorkshire, Lincolnshire, Devon, Somerset and Dorset. It is an exacting species, requiring a warm and sheltered site with a long growing season. Though winter cold is not a particular threat, it is liable to suffer badly from late spring and early autumn frosts, and unseasonable frosts in general (Mohni *et al*., 2009). Young shoots and flowers are easily damaged by spring frosts of −1°C in Britain. There are major differences in flushing and flowering times between provenances, and it has not yet been possible to find one that can entirely escape frequent frost damage on cold sites or in frost hollows. A consequence is that crops of nuts frequently fail in Britain. Early autumn frosts will kill shoots that have not yet lignified.

Precipitation is seldom, if ever, limiting in Britain.

The importance of shelter, even in the relatively sheltered English lowlands, can scarcely be overstated. Increment is many times faster and tree form much better if shelter exists.

Site requirements

Walnut is possibly the most site-demanding of all potential timber trees in Britain. In 1597 Gerard wrote 'The walnut tree groweth in fields neere common high waies in a fat and fruitful ground, and in orchards; it prospereth on high fruitful banks; it love not to grow in waterie places.' Low water tables and good drainage over deep (80−100 cm), well-aerated, loamy soils are particularly favourable; a general view is that walnuts do well where beech thrives. The ideal pH range is 6.5–7.5 (Becquey, 1997). Sites to avoid are light sandy soils and heavy soils in general (Klemp, 1979), and also shallow soils over chalk, peaty soils and damp situations.

One of the difficulties of growing walnuts in Britain is the scarcity of available and really suitable sites: most potential ones are used for arable agriculture.

Other silvicultural characteristics

Walnut will live for 150–200 years and will reach 20–25 m tall.

Once past the seedling stage walnuts are intolerant of competition, and mature trees require full light. In forests they should be planted singly or in groups, and the crowns need completely freeing by the age of 30–40 years. Walnut has strong phototropic tendencies and the leading shoots grow towards gaps in the canopy if the trees are shaded.

An unusual feature of walnut is that it produces a substantial taproot of up to 50–80 cm in its first year from seed (Boudru, 1989). This means that nursery-grown plants normally have damaged taproots and

Fig. 18. (A) Common walnut, *Juglans regia*; (B) Black walnut, *Juglans nigra*.

young trees consequently take a long period to recover after planting in the field. For this reason direct seeding is normally recommended today (see under 'Flowering, seed production and nursery conditions', below).

The common walnut has a reputation for being difficult to establish and needs 'arboricultural rather than silvicultural attention' (Macdonald *et al*., 1957). Like cherry and the poplars, its growth benefits considerably from careful early weeding. The frost-tender nature of the species indicates the desirability of using nurses when young. Appropriate nurses can result in enormous improvements both in early form and height growth (Clark *et al*., 2008). However, the strongly light-demanding nature of walnut can make the management of nurses difficult, because unless constant vigilance is exercised they could suppress the light-demanding walnuts (Mohni *et al*., 2009). Mixtures with beech and hornbeam (both shade-bearers) have been suggested in the past, though recently Clark *et al*. (2008) have found that Italian alder and the shrubby autumn olive (*Elaeagnus umbellata*), both nitrogen fixers, are successful in promoting the growth of walnut. The alder has to be removed after about 10 years.

To achieve a clear, straight stem of at least 2.5 m in length (but ideally 4–6 m), some formative pruning is normally essential. It needs to be started early and must not be too 'brutal' if a loss in tree vigour is to be avoided (Becquey, 1997). Branch collar diameters should not exceed 3 cm on branches to be removed, and pruning should not normally exceed one-third of the stem length in woodland conditions. Walnuts 'bleed' profusely after pruning, and it is usually recommended that any necessary pruning, is done in February or late summer (July and August), before the leaves fall, in order to minimize this. Apparently, pruning can cause a change of wood colour in walnut.

In woodland conditions common walnut responds very slowly indeed to delayed thinning. Tree crowns must be kept free at all times to maintain adequate growth rates. Walnut has an extraordinarily high ratio of crown diameter to stem diameter, and hence there should be fewer trees per unit area than with most other species. For example, calculations by Hemery *et al*. (2005) indicate that at 60 cm diameter, there can be 68 walnut trees per hectare, compared with 104 oaks.

Common walnut produces a protective allelopathic chemical known as juglone (described above under black walnut) but in much smaller quantities than black walnut. The lemon-scented leaves deter insects. When horses were used for transport walnuts were quite commonly planted for them to rest under, away from the nuisance of flies.

Spence and Witt (1930) suggested that this species might profitably be planted bordering arable fields with the prospect of crops of nuts during good years and an annual increment in timber value.

Diseases

Walnuts are prone to a bacterial blight, *Pseudomonas juglandis*, when grown together in large numbers.

Natural regeneration

Walnut has become naturalized in much of southern England but it is never common. Natural regeneration occurs occasionally in hedgerows but only rarely in woods. Seeds are probably spread by squirrels and possibly by jays, which collect and bury the nuts for winter caches. Obtaining regeneration throughout its natural range and in other places where the tree is grown appears to be equally problematic. It is normally planted.

Flowering, seed production and nursery conditions

Walnut flowers in June, and the nuts ripen and fall in late September or early October. Flowering and nut production normally begin between the ages of 5 and 15 in seedling trees but earlier in grafted varieties developed for nut production. According to Brown and Nisbet (1894), the nuts will generally ripen in parts of Britain lying to the south of the river Forth but only occasionally to the north of it.

There are about 65–180 walnuts kg^{-1}, of which 75% will normally germinate if they are stratified immediately after harvesting until the spring and sown when the seed is on the point of germinating. Ideally, bad and small nuts should be rejected. Fertile, near-neutral soil is needed for growing good nursery stock.

As mentioned above, walnuts produce large, long, strong taproots and, when young at least, few lateral roots. Fibrous roots are slow to develop. This makes them difficult to transplant successfully. Most authors (e.g. Popov, 1981) state that for these reasons planted seedlings are particularly difficult to establish. Plants from direct sowing of pregerminated seed are much faster growing and have better root systems. Planting walnut seeds directly into tree shelters placed where they are wanted as trees, and covering them with a little soil, gives good results and can save several years of establishment time as well as the cost of having to buy plants. When nursery stock is used it should be planted out as young as possible. By contrast, Aldhous (1972), while recognizing the care that is needed in lifting 2-year-old plants from seedbeds, recommended they should be moved to transplant beds for a further 2 years. If stems exceed about 2 cm in diameter at the base, it is often prudent to ‘stump’ them or cut them off at 2–3 cm above the ground and allow a new shoot to grow. Some authors (e.g. Macdonald *et al*., 1957) also advocate pruning the taproot.

A risk, discovered in Italy, is that roots of micropropagated walnuts will not develop properly, so such trees can lack stability.

Provenance

Several varieties that produce edible nuts (listed by Roach, 1985) are relatively resistant to late spring frosts and most of these originate from the famous French walnut-growing region of Isère, near Grenoble. Provenance and progeny trials are being conducted in Oxfordshire and elsewhere by the Earth Trust, but these have not yet yielded any results.

Timber and uses

The semi-ring-porous walnut wood was the chief wood of fashionable furniture between about 1670 and 1735, but its use declined rapidly as mahogany, which is less vulnerable to woodworm, became available in quantity. Walnut timber is stable. Though the sapwood is white, soft and comparatively valueless, the heartwood is dark brown and often beautifully figured. It scarcely warps or checks at all, and after proper seasoning shrinks and swells very little. It is easy to work and holds metal parts with little wear or risk of splitting. It is strong without being too heavy (density at 15% moisture content is about 670 kg m^{-3}) and can withstand considerable shock. Its colour is dark, so it does not show the dirt. These attributes make it the most valuable wood for gunstocks, particularly as its uniform and slightly coarse texture makes it easy to hold. The one great defect of the timber is that it is susceptible to attacks by the common furniture beetle (*Anobium punctatum*), normally known as woodworm. Inadequately seasoned sapwood is particularly vulnerable. The most valuable and attractive timber tends to be slowly grown, and it is comparatively seldom that it can be found in Great Britain because, on suitable sites, walnut will grow fast. Trees from the mountainous regions of Italy and the region round Grenoble in France have particularly good reputations for producing high-quality timber.

In Italy only the heartwood of walnut is considered usable, and it tends to be narrow. Light-coloured heartwood is preferred. Italian research workers believe that soil, growth rate and genetics all affect wood colour.

There is considerable current interest in France in planting walnuts for their potentially extremely valuable timber, in the belief that decorative temperate woods are likely to be in much greater demand as tropical supplies decline. This echoes what Marshall said in 1803: ‘were the importation of mahogany to be obstructed, the walnut it is probable would become a valuable wood'. The wood is used for making veneers and high-quality furniture. Highly figured veneers are used for cabinet making and decorative panels. Their use was developed and increased considerably after the 1720 ban on the export of walnut to Britain (see under 'Origin and introduction' of black walnut, above). Walnut was one of the finest woods for making aeroplane propellers in the early days of aviation.

The large burrs that are found occasionally on trees are particularly valuable for veneers, producing a fine mottled grain, which are often used on the dashboards of expensive cars. A notable source of these, which have flame figures low in the stem, occurs at the junctions of grafts of common walnut and some Californian species harvested from over-mature (40–60-year-old) trees in Californian nut orchards. Burr wood can be extremely valuable. The 'curl' patterns from just below a fork also fetch high prices.

The common walnut provides the edible nuts of commerce, 70% of which were grown in China and the USA in 2007. According to Spence and Witt (1930), the great majority of English walnuts suffer from insufficient development of the normal oil content of the nut and excessive moisture in the kernel, probably caused by an insufficiently long and hot summer, particularly in more northern areas. This makes them more suitable for pickling. Pickled walnuts are made from tender, young nuts, collected before they become woody and while they can readily be pierced by a needle without the soft shell that is forming inside the husk being felt – usually towards the end of June or early July.

The oil pressed from walnuts sells for high prices in delicatessens. At one time it was used in some parts of France instead of butter and olive oil (Reneaume, 1700–1701). When boiled the husks of the nuts produce a dark-yellow dye, which was once much used for colouring wood, hair and wool.

Place of common walnut in British forestry

See under black walnut.

LARIX Mill. — Larches

There are ten species of larch, all of which occur within the cooler parts of the northern hemisphere.

LARIX DECIDUA Mill. — European larch

Origin

This tree is native to the Alps and Carpathian regions of south-east France, Switzerland, northern Italy, southern Germany, Austria, the Czech Republic, Slovakia, Poland, Ukraine and Romania. It is mostly found at elevations between 1000 and 2200 m (Farjon, 1990). The date of introduction to Britain is not known, but the species was present by 1629.

Climatic requirements

European larch does best where the atmosphere is reasonably dry and sunny, but high temperatures are not required. It is a species that grows up to the tree line in the Alps and will grow well at high elevations in Britain if the site is not too exposed. The tree often flushes as early as mid-March, particularly in milder regions and at low elevations. It is therefore susceptible to late spring frost damage which, apart from killing foliage, may allow infection by canker. Otherwise, European larch has no particular climatic limitations in Great Britain. However, it will not thrive in conditions of low rainfall on soils that do not retain water, such as lowland heaths (Macdonald *et al.*, 1957). It is only moderately tolerant to pollution, and not to salty sea winds.

Site requirements

This is an exacting species requiring at least moderate fertility and moist but freely draining soils. Sites to avoid include poor and non-water-retentive sands, peats, heavily leached soils and soils over chalk, and also those carrying dense heather. The tree needs to root deeply, so badly drained sites that are prone to waterlogging must also be avoided. European larch grows best on the middle and higher slopes of hills, provided they are sheltered.

Other silvicultural characteristics

European larch will grow to over 40 m tall. It is a deciduous, light-demanding, pioneer species, which, according to Anderson (1950), has high water requirements after flushing and so needs a continuous supply of soil moisture. It tends to die on drought-prone sites.

Thorough weed control in the year or two immediately after planting is important, but after that, European larch is more competitive than many other trees and weeding can be relaxed. This is one reason why it is a popular plantation species on many estates.

Because it is so strongly light-demanding, thinning must begin as early as age 12–15 years and must be heavy. Because the trees are very variable in form, selective rather than systematic thinning is essential. Natural pruning takes place rapidly.

Its relatively light crown and compatible growth rate makes European larch a useful nurse for oak on sites where it does not grow too fast.

Diseases

Larch canker, *Trichoscyphella wilkommii*, is a serious and often complex problem on unsuitable sites (Pawsey and Young, 1969); the species is also relatively susceptible to fomes root rot, *Heterobasidion annosum*, and to the leaf cast fungus, *Meria laricis*. It is believed to be more resistant than Japanese larch to ramorum disease, *Phytophthora ramorum*, but is not entirely immune to it.

Natural regeneration

Though seed production is good, natural regeneration rarely persists in great quantities.

Flowering, seed production and nursery conditions

The tree flowers in March and April, and flowers are often damaged by frosts. Seeds ripen and can be collected between September and December, and fall between October and the spring. The earliest age at which the tree bears seed is 20–30 years, and good seed years are usually at 3–5-yearly intervals between the ages of 40 and 60. There are about 158,700 seeds kg^{-1} (range 92,600–269,000), of which 60,000 are normally viable. For nursery purposes seed is usually sown in mid- to late March. Pre-treatment by stratification for 3 weeks is occasionally necessary if the seed has become dormant (Aldhous, 1972).

Provenance

Forest Research (2011) recommends that seed should originate from the Sudeten area of the Czech Republic and Slovakia, collected from between 300 and 800 m in elevation (Lines and Gordon, 1980). Alternatively, seed collected from good British stands has proved satisfactory. These sources are much less vulnerable to larch canker than others.

Trees grown from seed collected at high elevations in the Alps are susceptible to canker and should be avoided. Unfortunately, many existing British stands have originated from high-Alpine seed.

Area and yield

European larch covered 22,500 ha (2% of the forest area of Britain) in around 2000 and was the eighth most common species (Forestry Commission, 2003).

Mean yield classes in different regions range from 6 to 9 m^3 ha^{-1} $year^{-1}$ (Nicholls, 1981), with a maximum of 12. The disadvantages of the rather low levels of productivity are to some extent offset by the early age at which profitable production can begin, and the short rotations.

Timber

Details are given in the section on Japanese and hybrid larches. The average density of the wood of European larch at 15% moisture content is about 590 kg m^{-3}.

Place of European larch in British forestry

European larch is a relatively minor species in British forestry and this is unlikely to change. Its position will be very uncertain until its susceptibility to ramorum disease becomes clearer. Projected climate change will not make conditions any more favourable for its growth.

LARIX KAEMPFERI (Lamb.) Carr. — Japanese larch

LARIX x MARSCHLINSII Coaz — Hybrid larch

Origin and introduction

The natural range of Japanese larch is confined to a small region centred in Nagano Prefecture on the island of Honshu in Japan, between 35° and

37°N, at elevations between 1200 and 2400 m. The species was introduced to Britain in 1861.

Hybrid larch is a cross between *Larix decidua* and *Larix kaempferi*. It first arose naturally in about 1895 at Dunkeld, Tayside, and was noticed in 1904.

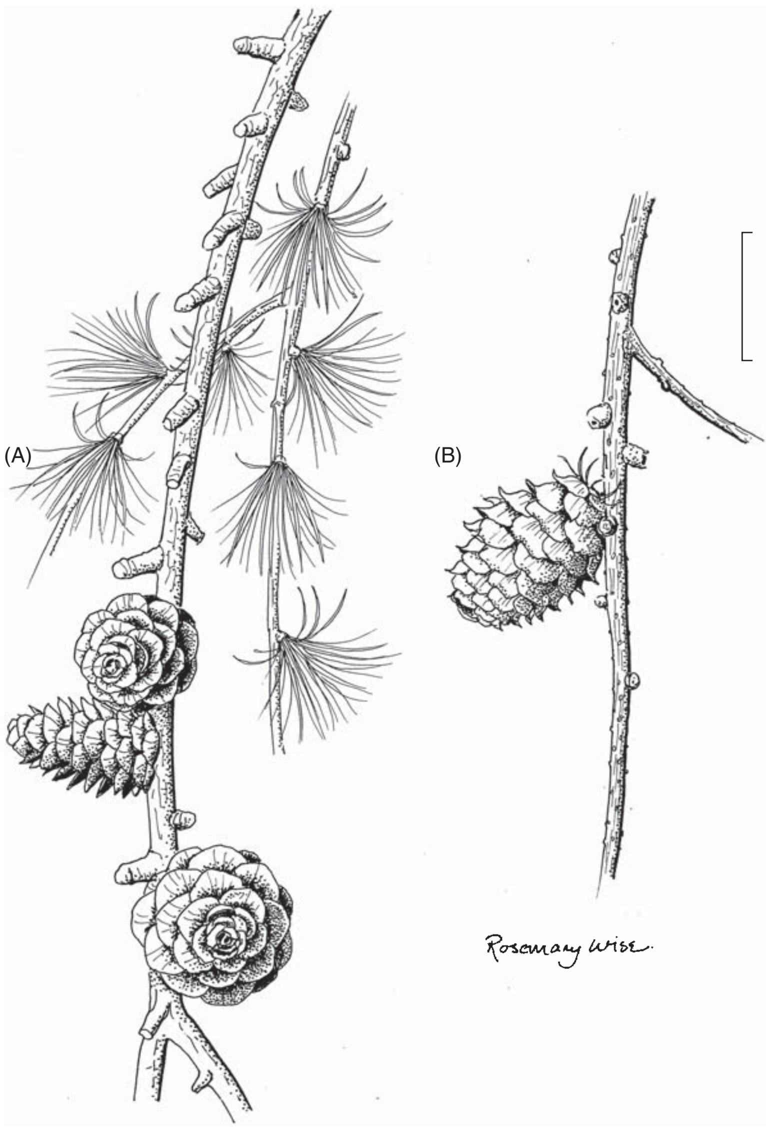

Fig. 19. (A) European larch, *Larix decidua*; (B) Japanese larch, *Larix kaempferi*.

Silviculturally it is usually considered similar to Japanese larch, but in terms of growth it is superior to either parent.

Climatic requirements

In the native range of Japanese larch there is a summer rainfall climate with over 1000 mm a year. In Britain it needs a high atmospheric humidity during the growing season, in contrast to European larch. It does best in hilly districts in the milder, wetter west coast regions. Areas where the precipitation is substantially below 700 mm should be avoided unless the conditions of soil moisture are particularly favourable. Trees stop growing and young ones may die in periods of severe droughts. The range of Japanese and hybrid larches in Britain is not limited by temperature, but these species harden off late in the autumn and are therefore susceptible to early autumn frosts (Macdonald *et al*., 1957). Both species, but especially hybrid larch, tolerate exposure quite well on good soils, and they withstand salt spray remarkably well too. They are also better than European larch at tolerating pollution, though none of the larches is particularly good in this respect.

Site requirements

In its natural range Japanese larch is a pioneer species that colonizes recent volcanic ash deposits. Japanese and hybrid larches thrive over a wider range of conditions than European larch, but do best on well-drained but moist, moderately fertile soils that are not too heavy. They are suitable for upland planting if the soil is reasonably well drained. The presence of dense bracken is often used as an indicator of suitable sites. Dry sites in the south and east of England and elsewhere should be avoided, and also badly drained land where the trees may become unstable and, in dry years, suffer from drought. In exposed situations, especially where the soil is fertile, the trees tend to lean and twist, to the extent that they are useless for sawn timber production.

Other silvicultural characteristics

Both species will grow to about 45 m tall, and they are unusual among conifers in being deciduous. In most respects the silviculture of these species is similar to European larch. Their main attractions are their ease of establishment, rapid early growth, amenity value and the possibility of early financial returns. Their fast early growth makes them particularly useful on old hardwood coppice areas and sites where weeds, especially bracken, are a problem. They are valuable for fire belts and sometimes as nurses for more tender species such as beech and oak, but if they are used for this purpose they must be removed early enough. As with European larch, systematic thinning should never be practised with Japanese or hybrid larches because trees are so variable in form. Selective thinning is essential. Natural pruning is good. The trees are strongly light-demanding and consequently need to be thinned well: at least one-third of the total stem length should be maintained as live crown.

Diseases

A fatal and recently introduced disease of Japanese larch is caused by *Phytophthora ramorum*, which kills Japanese larch trees within 1 year of symptoms first being detected. Until about 2009 the pathogen, known as ramorum disease, had only been recorded on a few other woody species, including *Rhododendron* and bilberry. Until 2011 it was confined mostly to South Wales and south-west England, where large-scale felling was carried out in an attempt to prevent its spread, but it has since been found elsewhere in England. The future of Japanese larch, as a relatively important forest tree in Britain, is now clearly at serious risk. The susceptibility of hybrid larch is still uncertain.

Both Japanese and hybrid larches are susceptible to fomes root and butt rot, *H. annosum*, and also, particularly, to *Armillaria* spp.; however, both are generally free of the canker that is so damaging to many European larch provenances. If conditions are not favourable these larches do not go into check like spruces but tend to die quite quickly. Larches are, on occasions, damaged by grey squirrels.

Natural regeneration

Though seed production is good, natural regeneration rarely persists in great quantities.

Flowering, seed production and nursery conditions

Japanese and hybrid larches flower in late March and early April; flowers are often damaged by frost. Seeds ripen and can be collected in September. They are dispersed naturally over the winter. The earliest age at which they bear seed is 15–20 years, and the best seed crops are commonly at 3–5-yearly intervals between the ages of 40 and 60. There are about 253,500 seeds kg^{-1} (range 125,700–335,100), of which 100,000 are normally viable in Japanese larch, and only half this number in hybrid larch. The treatment of seeds for nursery purposes is the same as for European larch.

It should be noted that only seed of first generation (F1) crosses of hybrid larch should be used. Later generations are much less likely to show any hybrid vigour.

Provenance

Most seed of Japanese larch is now collected from selected British stands and this is recommended. If it has to be imported suitable areas for collection in Japan are given by Lines (1987). Essentially, these are from the central part of its natural range. Hybrid larch seed is usually very difficult to obtain, though work on producing F1 hybrids from cuttings has proved successful.

Area, yield and rotation length

Japanese and hybrid larches together covered 107,700 ha (5% of the forest area of Britain) in about 2000 and together were the fourth most common group of trees in the country (Forestry Commission, 2003). Because of *Phytophthora ramorum*, these larches are no longer being planted and those that remain are being cleared rapidly.

Larches are not high-volume producers. Mean yield classes range from 7 to 11 in different parts of Britain (Nicholls, 1981), with a maximum of little more than about 14 m^3 ha^{-1} $year^{-1}$. Rotations are short in comparison with many other conifers, at about 45–50 years.

Timber

The timber of European, Japanese and hybrid larches is noted for its hardness, natural durability and strength. It tends to distort on drying and is also resinous. Japanese and hybrid larches are described as being ‘milder’ than European, with a tendency for the earlywood to crumble and tear during sawing. Advances in timber engineering methods, such as the ‘gridshell’, now allow small battens of first- and second-grade larch to be finger- and scarf-jointed into structural members for use in large-span roofs, such as the Savill Building at Windsor Park (Wilson, 2010). All three species are used for outdoor work, including transmission poles, the exterior of buildings where something more durable than spruce is needed, and for boatbuilding. Even early thinnings can be sold profitably for rustic work in gardens. Although relatively durable, preservative treatment can be worthwhile. The average density of the wood of Japanese larch at 15% moisture content ranges between 530 and 590 kg m^{-3}, and of hybrid larch about 480 kg m^{-3}.

Place of European, Japanese and hybrid larches in British forestry

The susceptibility of larches to *Phytophthora ramorum* will almost certainly limit their use for the foreseeable future, if not permanently.

Their attractions in British forestry arose from the ease by which they could be established on weedy sites, their rapid early growth and the general usefulness of their timbers, even at small sizes. As the only commonly planted deciduous conifers they also had considerable amenity values in spring and autumn in particular.

The role of Japanese larch could potentially increase in western Britain with climate change, especially if it is planted on mineral soils to diversify spruce forests.

MALUS SYLVESTRIS (L.) Mill. — Crab apple

There are about 40 species of *Malus* within north-temperate regions. The crab apple is native to, and widely distributed in, Europe, including Britain.

Origin

Crab apple trees occur throughout England and Wales but are never common and are rare from central Scotland northwards. They are found particularly in oak woods, along woodland edges, and in hedges and scrub up to elevations of almost 400 m.

Climatic requirements

The species is not noticeably limited by climate in Britain except by excessive cold and exposure.

Site requirements

It grows on a wide range of soils, from acid to basic and clays to sands.

Other silvicultural characteristics

Crab apple grows much more slowly in height than most other trees and reaches rather low final heights of around 10 m (Turok *et al*., 1998), similar to a few related species, including the wild service tree and whitebeam. For these reasons, crab apple cannot be integrated successfully into high forest stands, even in groups. The tree is largely confined to habitats where it can find suitable light conditions for growth, such as the sunny edges of woods and hedgerows. In earlier centuries it used to grow successfully in the low density coppice-with-standards systems, where standing volumes of timber were seldom more than 150 m^3 ha^{-1}, but these have now become obsolete. In continental Europe the understorey of older pine stands also provides a suitable habitat because, even if the canopy is closed, enough light penetrates it. Young trees can be badly browsed by deer.

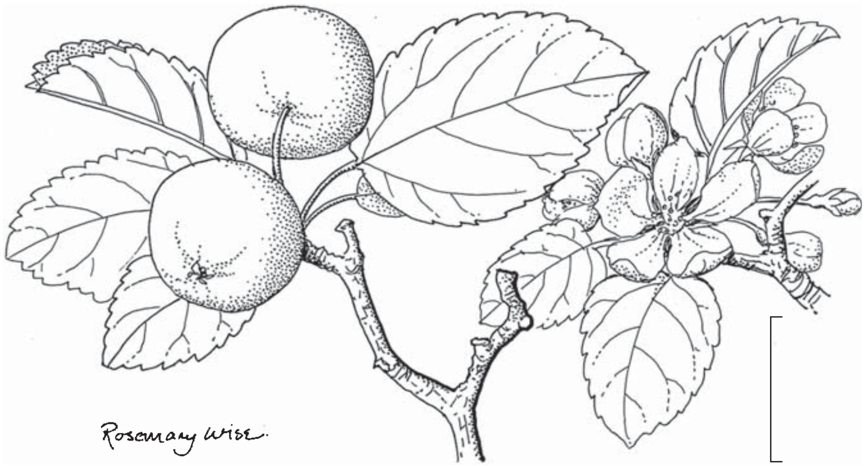

Fig. 20. Crab apple, *Malus sylvestris*.

Flowering and seed production

The tree flowers in May and is insect pollinated. The fruits are normally 2–4 cm in diameter and mature in the autumn. They are almost inedible.

Apple genetics

In the wild the crab apple hybridizes with cultivated apples to the extent that Kleinschmit (1998) doubted whether it still exists as a pure wild form. It is now believed to have had little, if any, role in the evolution of the domestic apple (Juniper and Mabberley, 2008). The genetic makeup of the apples cultivated today is complex because of the easy hybridization between species that has occurred naturally, and over thousands of years of selection and breeding by man (Roach, 1985). However, cultivated apples are now believed to be derived primarily from the central Asian species *Malus pumila* (Juniper and Mabberley, 2008).

Timber and uses

Crab apple trees are seldom straight, so it is difficult to obtain reasonable lengths of timber. Well-grown trees provide wood of excellent quality. It is dense at about 720 kg m^{-3} (similar to ash, beech and oak) at 15% moisture content and has a fine uniform texture with no distinct heartwood. Its main virtue is its resistance to splitting, but it tends to distort unless dried very slowly. When properly seasoned and kept dry it holds its shape well enough to be used for precision work: carving, wood engraving, recorders, tool handles and turnery. At one time it was used for making set-squares and other drawing instruments.

It is believed that the Druids planted apple trees in the vicinity of their sacred groves of oak trees, possibly because they served as hosts for mistletoe, which was of great importance to them.

Place of crab apple in British forestry

The crab apple is an attractive small tree that has no economic place in British forestry but has some conservation value.

NOTHOFAGUS ALPINA (Poepp. & Endl.) Oerst.

NOTHOFAGUS OBLIQUA (Mirb.) Blume — Chilean or southern beeches

Origin and introduction

Nothofagus is a genus of the southern hemisphere, where there are 34 species distributed between New Guinea, New Caledonia, New Zealand and the temperate parts of Australia and South America.

Only species from Chile and Argentina are likely to be of value in Britain. Southern beeches are the dominant components of the temperate and subantarctic forests in Chile from 33° to 56°S and on the drier side of the Andes, south of approximately 39°S. Ten species occur in this region, one of the most abundant of which is *Nothofagus obliqua*. It originates from between 33.5° and 41.5°S in Chile, from an area that is climatically very variable because of large altitudinal differences (Donoso, 1979). It was first brought to Britain in 1849 but died out and was reintroduced in 1902. *Nothofagus alpina* (formerly *Nothofagus procera*) comes from Chile and south-west Argentina, and was introduced in 1931.

Climatic requirements

The most serious limitation to the use of southern beeches in Britain is their lack of cold hardiness. They survive in climatically suitable areas but are easily killed by winter cold. Murray *et al*. (1986) found that both species develop resistance to cold very slowly in the autumn and are damaged by temperatures of −14°C in midwinter. Most trees are killed by temperatures of −20°C. The trees lose their resistance to damage by frost (i.e. they 'deharden') early in the year, in February or March, prior to bud burst in the latter half of April. Such characteristics almost guarantee that southern beech will suffer severely from frost damage at least once during a rotation in most parts of Britain. By contrast, the native beech develops cold resistance rapidly in September, is undamaged by frosts of well below −20°C and does not lose its frost resistance until late April. Frost can cause dieback of shoots and consequent multiple leaders; it can kill the cambium and the resulting damage ranges from irregular swellings to large open fissures, which allow entry to fungal pathogens. These often kill the trees.

If individuals could be selected that are 3–6°C more frost hardy than the population mean, they would avoid frost damage in most lowland regions. Observations by Cros and Duval (1990) in France suggested that

N. obliqua is more cold resistant than *N. alpina*, and the same was found by Deans *et al*. (1992) in southern Scotland.

Apart from frost damage, both species have done well in areas with rainfall ranging from 700 to well over 1000 mm. They are sensitive to prolonged dry spells, which can cause dieback of the shoots and branches. In Scotland dieback and death, mainly from cold, is common. The species seem most suited to the lowlands and hills up to 300 m in the south and west of Britain, but not to the most severe upland climates, especially sites exposed to cold north and east winds.

Site requirements

Neither species is too exacting. They grow well on a wide range of soils, from deep sands to heavy clays. Sites to avoid are those with severely impeded drainage, shallow soils over chalk, calcareous clays and acid peats. On the more difficult sites *N. obliqua* may succeed where *N. alpina* fails, and it tends to produce better results in the south of England (Lines and Potter, 1985). Southern beeches can grow faster than the native beech on all but calcareous soils. Good growth rates are obtained on sites marginal for oak.

Other silvicultural characteristics

Plants are susceptible to drying out between lifting in the nursery and planting: the use of anti-transpirants on stems is sometimes recommended. Early and thorough weeding is essential for good establishment, and growth is best where there is a light overstorey, but this must be removed after 2–3 years. Neither species suffers too badly from grey squirrel damage, even in areas where beech is badly attacked. For nature conservation purposes southern beech is considered better than beech and most conifers (Wigston, 1980). They coppice well if the shoots are in full light. *N. obliqua* has the better form, being narrower, less heavily branched and it nearly always has a single, good straight stem, if undamaged by frost.

Natural regeneration

Both *Nothofagus* species produce reasonably good natural regeneration, and they hybridize with each other.

Seed production and nursery conditions

For nursery production Aldhous (1972) stated that the seed should be stored dry and stratified in early March for 3 weeks before sowing.

N. obliqua produces about 120,000 seeds kg^{-1} and *N. alpina* 100,000. Germination percentages are usually low, at between 25 and 35%.

Provenance

There is still a serious lack of information about the variability of these species. Many of the earlier imports of seed came from areas with climates that are too unlike the British climate for the trees to succeed, probably from too far north in Chile. The serious stem cankers and dieback that result from cold winters may possibly be overcome if more southerly provenances are used, though the logistical problems of acquiring seed from them would be considerable, because few roads exist in southern Chile. Seed from low elevations, south of 38°S (which is at an equivalent latitude to Lisbon or Athens in the northern hemisphere), is recommended by Tuley (1980). Recommendations for the use of various provenances in Britain are given by Potter (1987).

Yield

N. obliqua and *N. alpina* have no equals among broadleaves at their highest levels of volume production, and in some situations they compare favourably with the best conifers. The mean yield class in Britain is 14 m^3 ha^{-1} $year^{-1}$ and maximum local yield classes of 20 occur in places, such as the Forest of Dean. Rotations are unlikely to exceed 45 years (Christie *et al*., 1974). Rates of height growth may be equalled by Japanese larch and among broadleaved species by cherry, sweet chestnut and poplar, but volume production of the two southern beeches is much greater than any of them.

Timber

The timber of *N. alpina* of Chilean origin, known as rauli in the British timber trade, is said to be the best of all southern beech species and is comparable to, though much lighter than, beech (about 470–560 kg m^{-3} at 15% moisture content compared with 720 kg m^{-3} for beech). One of the main uncertainties with these species in Britain is whether the fast-grown trees will produce timber with qualities that have any significant value. Early indications are that this is unlikely. The wood of British-grown *N. obliqua* has a density of about 600 kg m^{-3}.

Place of southern beeches in British forestry

Neither species has an established place in British forestry, but *N. obliqua* and *N. alpina* have attracted interest because of their potentially high levels

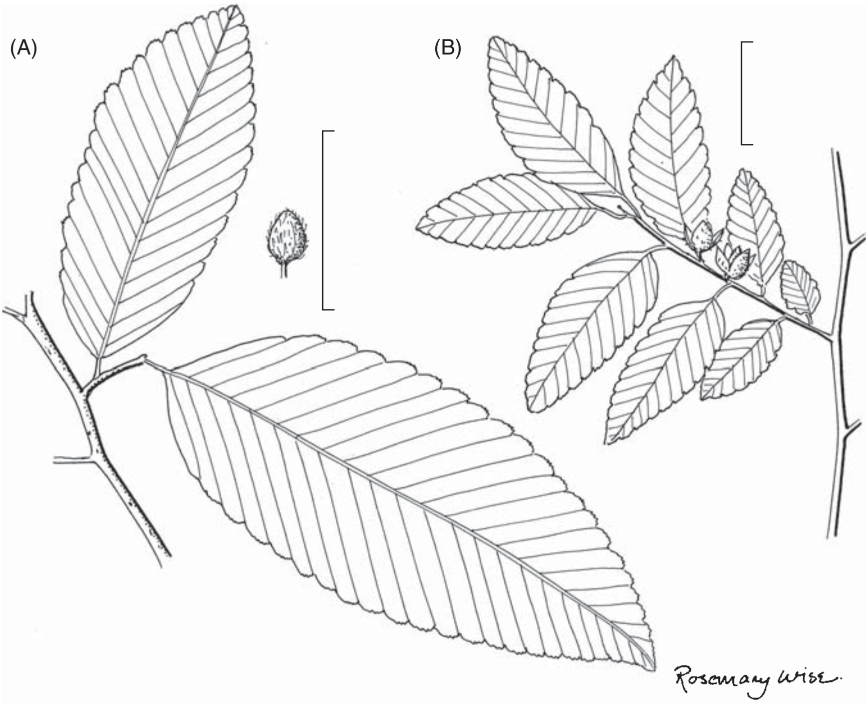

Fig. 21. Southern or Chilean beeches, (A) *Nothofagus alpina*; (B) *Nothofagus obliqua*.

of productivity, even on rather poor sites. Though broadleaved, they can grow as fast as many conifers on some sites, but the lack of winter hardiness and doubts about the value of the timber are both major problems. Much more research, especially provenance research, and an extended period of trials are needed before they could become widely accepted.

PICEA A. Dietr. Spruce

There are 34 species of spruce, which extend between subtropical high altitudes, temperate and boreal regions of the northern hemisphere. Spruces are most common in the boreal forests, where they are the dominant species across vast tracts of Scandinavia, Russia, Alaska and Canada. There are two European species: Norway spruce (*Picea abies*) and Serbian spruce (*Picea omorika*). Of these only the former is important in Britain.

PICEA ABIES (L.) H. Karst. Norway spruce

Origin and introduction

The natural distribution ranges from the Pyrenees, Alps and Balkans, northwards to south Germany and Scandinavia, and eastwards through the Carpathians and Poland to western Russia, where it merges with the north Asian Siberian spruce, *Picea obovata*. It is a high-mountain species in central Europe and a lowland tree outside permafrost areas in northern Europe. It was probably introduced to Britain before 1500.

Climatic requirements

Norway spruce is the most climatically tolerant species in the genus. It will grow in both extreme oceanic and central continental conditions. It has no particularly marked climatic limitations in Britain, except those imposed by exposure, which it will not tolerate nearly as well as Sitka spruce. It thrives in regions where rainfall exceeds about 800 mm. It can therefore be used in drier regions than Sitka spruce but not at such high elevations. Though more hardy than Sitka spruce to late spring frosts it can nevertheless suffer from them badly. It will not tolerate salty winds or urban pollution.

Site requirements

The tree does best on moist, even moderately waterlogged rushy land of medium to high fertility, including heavy clays and the less acid peats. It will thrive on sites where deep rooting is not possible, but the penalty for this is that it becomes susceptible to windthrow. If the site is too dry it tends to suffer from crown dieback (Day, 1951). Drought-prone sites should be avoided, especially in eastern Britain. On calcareous soils the species suffers from chlorosis caused by iron deficiency, which makes the leaves yellow. On sites dominated by heather Norway spruce is unable to compete for nitrogen and consequently grows slowly or scarcely at all.

Other silvicultural characteristics

Norway spruce always grows slowly for the first year or two after planting, going into what is often termed 'post-planting check'. The tree is moderately shade-bearing when young and can be used for underplanting, if freed early enough. It recovers well from underthinning.

It is a valuable and commonly used tree in mixtures with hardwoods, especially oak, with which it has a reasonably compatible growth rate at least in the early years. However, care has to be taken that the spruce does not eventually suppress the broadleaved companion species. Many broadleaves have been lost from this cause.

Since the mid-1980s there has been an increasing interest and emphasis upon native woodlands and their associated biodiversity (e.g. Kirby, 1988). This has resulted in large sums of public money being spent on converting lowland mixed, or pure coniferous, plantations on ancient woodland sites (known as PAWS) back to something approaching their original broadleaved composition by removing coniferous components. Norway spruce plantations are frequent targets for conversion.

Pests and diseases

The green spruce aphid, *Elatobium abietinum*, causes some damage to Norway spruce but normally it is less severe than to Sitka spruce. Norway spruce also suffers rather commonly from a problem known as top-dying. This can result in decline and ultimately death, especially on the eastern side of Britain. It is susceptible to fomes root and butt rot, *Heterobasidion annosum*, and various other decay fungi, which can seriously degrade the wood.

Natural regeneration

Viable seed is rarely produced in any quantity in Britain, largely because it does not mature properly. Because of this natural regeneration is unusual.

Flowering, seed production and nursery conditions

On the rare occasions when it is successful, the tree flowers in May. Seeds ripen and are usually ready for collection in October, and are dispersed naturally between October and April. The earliest age at which a tree bears seeds is 30–35, but the best crops are usually between 50 and 60 years. There are about 195,400 seeds kg^{-1} (range 103,600–218,300), of which 110,000 are normally viable. For nursery purposes seed is usually sown in mid- to late March. It requires no pre-treatment if it is sown soon after collection, but if stored it should be stratified for 3 weeks.

Provenance

In general, southern European provenances, from Poland, Romania, Czechoslovakia and Bulgaria, grow best in Britain. These combine fast growth with late flushing times (Lines, 1987). Many seed-bearing British stands are of French, Alpine and Scandinavian origin. They grow slowly and tend to flush too early and so are sensitive to damage by late spring frosts. Seed should not, therefore, be collected from them.

Area, yield and rotations

According to the Forestry Commission (2003) inventory, Norway spruce had been planted on 76,000 ha, or 3% of forest land, in around 2000. This was a considerable reduction from the area recorded in the previous inventory by Locke (1987), probably for the reasons explained above and on p. 6. Mean yield classes range from 10 to 13 $m^3\ ha^{-1}\ year^{-1}$ in different regions (Nicholls, 1981), with a maximum of 22. For equivalent yield classes rotations of Sitka spruce are around 15 years shorter than those of Norway spruce, and on sites where both will grow Sitka spruce is usually more productive. If a choice between the two species exists it is therefore rare to pick Norway spruce.

Timber

Details are given with the description for Sitka spruce. The average density of the wood of Norway spruce, at 15% moisture content, is about 470 $kg\ m^{-3}$, which is somewhat denser than Sitka spruce.

Christmas trees

At one time Norway spruce provided the traditional and most popular British Christmas trees, although its pre-eminent position is being overtaken by various other spruces and silver firs, mainly *Abies nordmanniana* and *Abies procera*. The cultivation of Christmas trees has undergone huge changes since about 1990. Once they came mainly from the tops of trees that had been removed in thinnings, but today their production is highly specialized and good quality is all-important. This is ensured by controlling weeds and insects that might cause a loss or discoloration of the needles, and shaping the trees by shearing, often annually from the fourth year. Norway spruce is normally sold as Christmas trees for domestic use at 4–6 years old and the slower-growing firs up to 4 years older. Big trees grown for large buildings or open spaces are obviously older.

Pearce, in 1979, stated that seed sources from south-west Germany are suitable for Christmas trees. No work on this subject appears to have been done since then in Britain, though it has in Denmark by Madsen (1989).

Place of Norway spruce in British forestry

Norway spruce has a useful place on wet sites, at middle and lower elevations, in regions that have too little rain for Sitka spruce. It is also one of the better conifers for planting in mixture with broadleaved trees because it is not too fast growing. It has been widely eradicated from lowland plantations on ancient woodland sites (PAWS) in recent years, often without replacing the cleared trees with any other species, at least on the publicly owned forest estate (Wilson, 2012). Its use is likely to decline in favour of broadleaved species, but it will nevertheless remain an important species.

PICEA SITCHENSIS (Bong.) Carr. Sitka spruce

Origin and introduction

The natural range of Sitka spruce is a narrow (*c*.80 km wide) but very long strip in the ‘fog belt’ of the Pacific coast of North America, from Alaska southwards to California, spanning over 22° of latitude. It is largely restricted to west-facing slopes, seldom above 900 m in elevation, and it extends inland a little up river valleys. Its inland distribution depends upon the penetration of fog banks. The largest Sitka spruces are found in Haida Gwaii (formerly the Queen Charlotte Islands) off British Columbia and in the Olympic peninsula of Washington, where the trees grow 80 m tall. It was introduced to Britain in 1831.

Climatic requirements

In its native range the climate is maritime, with abundant atmospheric moisture. In Britain Sitka spruce rarely does well where annual rainfall is below 900–1000 mm. It is therefore well suited to higher elevations in the west and north. The much drier east and south should be avoided. One of Sitka spruce's outstanding attributes is its ability to grow well, without becoming deformed, in regions of high exposure: it is better in this respect than any other common conifer. The upper limits of planting are about 600 m on reasonably sheltered sites and 150–300 m lower in exposed western areas. The tree is not tolerant even of mild atmospheric pollution. Lines (1984), for example, showed that in the southern Pennine Hills of England Sitka spruce grows poorly where an experienced silviculturist would have been sure of good growth on apparently similar sites away from industrial pollution.

Most provenances of Sitka spruce are susceptible to damage from late spring frosts when young, particularly the southerly ones from Washington and Oregon. Cannell and Smith (1984) have shown that young trees planted in the British uplands are likely to be subjected to a damaging spring frost once every 3–5 years. In most places they are sufficiently fast growing to get above the frost level quickly enough for this not to be a

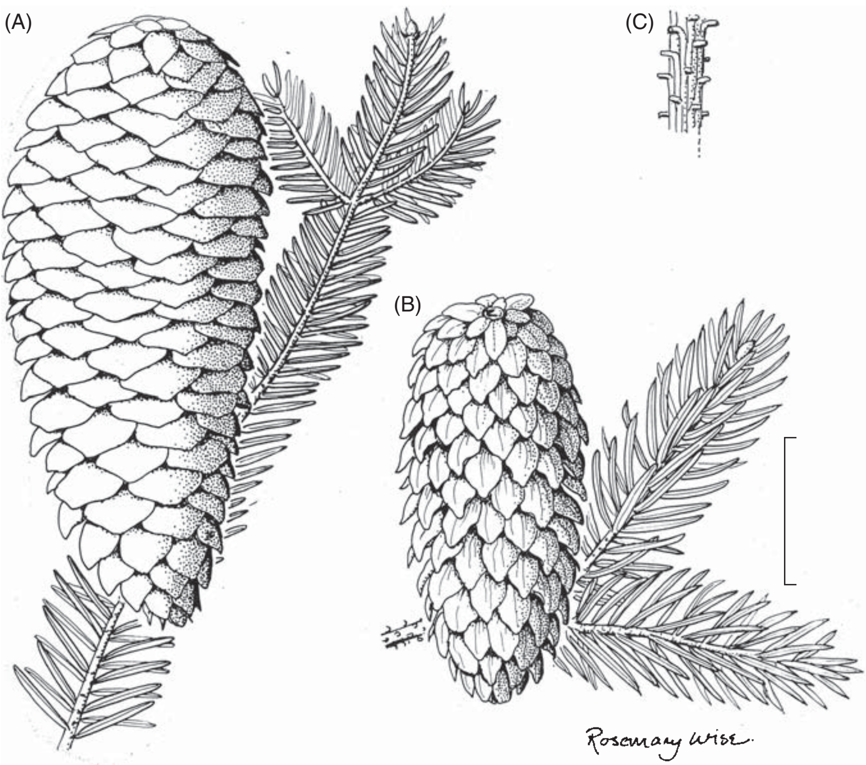

Fig. 22. (A) Norway spruce, *Picea abies*; (B) Sitka spruce, *Picea sitchensis*; (C) Needles of both spruces are inserted onto the small woody projections shown in this enlarged drawing of part of a stem.

serious constraint on planting. However, damage in frost hollows is likely to be more severe and much more frequent, and Sitka spruce will not survive if planted in them. The species, especially Washington and Oregon provenances, is also susceptible to early frosts, which occasionally occur in the autumn, before they have hardened off sufficiently for the winter (Cannell *et al*., 1985). Such damage is much less frequent than spring frost damage, occurring on average every 8–11 years.

Site requirements

Sitka spruce is very accommodating. It grows well on drained peats, is highly productive on gleys and does best on deep, freely drained soils in suitably high rainfall areas. The tree is quite site-demanding, and unless a planting area is at least moderately fertile, nutrients have to be added, particularly phosphate. It is regarded as a 'high input' species in comparison with, for example, lodgepole pine. Dry and shallow soils should be avoided. If these are in the uplands lodgepole pine or noble fir should be planted rather than Sitka spruce. Like Norway spruce, and several other conifers, the tree will not grow in competition with heather because it is unable to compete with it for nitrogen (Handley, 1963): if heather-covered sites are to be planted with Sitka spruce it is necessary either to kill the heather with a herbicide or to provide enough fertilizer nitrogen to enable the spruce to close canopy and suppress the heather.

Other silvicultural characteristics

Sitka spruce will grow to a maximum height of over 50 m in Britain. It can thrive on wet soils where deep rooting is not possible, though if these are located in exposed parts of the country, windthrow is a constant and serious risk, and a frequent occurrence. Natural pruning is rather slow, which makes young plantations particularly impenetrable and prickly. It is unfortunate that the most widely planted tree in Britain should also be one of the most unpleasant in this respect. Very deep accumulations of fallen needles are to be seen on most upland acid sites where decay and consequent nutrient cycling is poor. This often leads to nutrient deficiencies, but Sitka spruce responds well to fertilizers, even after many years of check.

Views differ about the shade tolerance of Sitka spruce. In its native range it is regarded as tolerant (Harris, 1990), but in Britain it is light-demanding and cannot, for example, be used for underplanting.

Throughout most of its natural range in North America Sitka spruce is associated with western hemlock in fast-growing dense stands. It is one of the few conifers that develop epicormic branches along the stem.

Their production is related to light intensity, and roadside trees often develop dense new foliage from base to crown. Thinning can stimulate epicormic branching and could decrease the quality of the wood, although this is not normally a serious problem (Harris, 1990).

Pests and diseases

The species is susceptible to attack by honey fungus and therefore not usually recommended for planting after a broadleaved crop. It is more susceptible than many conifers to fomes root and butt rot, *H. annosum*, particularly on less acid soils. It is defoliated periodically and quite seriously by the green spruce aphid, *Elatobium abietinum* (Carter, 1977; Carter and Nichols, 1988). It is much more seriously affected by this aphid than Norway spruce. Sitka spruce is less palatable to deer than most conifers, but it can nevertheless be severely damaged if there is no other choice.

Natural regeneration

First rotations have been coming to an end increasingly since the 1970s, and it has become apparent that natural regeneration is a reliable means of obtaining a successor crop on many sites on the borders of England and Scotland, and in Wales and elsewhere. It is best in places where crop stability is good and rotations long enough (50 years or more) for the trees to produce large quantities of seed. Re-establishment is often almost entirely by natural regeneration, and this seems likely to become a common method of replacement in the future, except on sites where new provenances or genetically improved strains of Sitka spruce are intended or a change of species is desired. Regeneration is much more successful in the open or under a light canopy than under a denser canopy

Since the late 1990s there has been increasing emphasis on multipurpose management of forests, and pressure to diversify even-aged monocultures in terms of both species composition and structural diversity. This involves practising what is known in Britain as 'continuous cover forestry'. Sitka spruce monocultures have been the focus of much of the work into how this might best be achieved (e.g. Malcolm *et al*., 2001; Mason *et al*., 2004), though other species have also received attention (e.g. Kerr, 2002; Poore, 2007). The aim would be to achieve most of the conversion by natural regeneration. Research by Mason *et al*. (2004) concentrated on determining the critical level of below-canopy light for survival and growth of young seedlings of a variety of species. Their studies indicated that sufficient light in Sitka spruce plantations is available at basal areas of 25–30 m^2 ha^{-1}, which suggests that an irregular shelterwood system with frequent interventions would be a suitable silvicultural system to use. This would provide tree height/gap diameter ratios of greater than two, which is needed by Sitka spruce.

Flowering, seed production and nursery conditions

The tree flowers in May. Most seeds are mature by September, when they can be collected, and they are dispersed naturally between October and the spring. The earliest age at which the tree bears seed is 30–40 years, but reliable seed crops are usually at 3–5-yearly intervals after the age of about 50 years. There are about 463,000 seeds kg^{-1} (range 341,700–881,800), of which 320,000 are normally viable. Sowing times and seed treatments for nurseries are the same as for Norway spruce.

In the 1980s there was a small but increasing use of genetically selected and improved, micropropagated, clonal Sitka spruce that became generally available from the 1990s. The increase in timber volume obtained by planting this material has been estimated by Mochan *et al*. (2008) to be between 21 and 29% at the end of a rotation compared with a control of unimproved Sitka spruce of Haida Gwaii origin. Today practically all planted Sitka spruce is of this improved type, even though it is about twice as expensive as plants grown from seed.

Provenance

Genetically improved material is now widely available and is planted on the great majority of sites where the tree is established (see above).

In Great Britain provenances show a cline of decreasing vigour and increasing resistance to late spring frost damage from Oregon to Alaskan seed sources, possibly with some ecotypic variation in Haida Gwaii (formerly the Queen Charlotte Islands) (Lines, 1978c) where vigour and frost resistance are better. The choice of provenance must attempt to compromise on these two characteristics. In general, seed from Haida Gwaii satisfactorily combines hardiness with adequate growth rates and often gives the best growth on all sites. More southerly provenances can be used in milder parts of Britain, and more northerly ones from Alaska may have a place on exposed or elevated sites (Lines, 1987).

Area and yield

According to the Forestry Commission (2003) inventory, Sitka spruce is planted on almost 684,000 ha (30%) of the forest land in Britain, making it by far the most common species in the country. It is well ahead of the next most common group, the pines, at 17%. Mean yield classes range from 10 to 14 m^3 ha^{-1} $year^{-1}$ in different regions (Nicholls, 1981), and the normal maximum is about 24.

Timber

The typically fast-grown wood of spruces grown in Britain is light in weight, non-resinous and rather coarse textured. On drying it is liable to twist. The timber of both Norway and Sitka spruces is preferred for pulping processes. It also provides material for lightweight types of particle board. The potential market for sawn timber is large, but rapid early growth, a tendency to spiral grain and, in the case of Sitka spruce, the difficulty of avoiding a rough finish means that only a small proportion is suitable for joinery and other high-class structural work. Grading is therefore important. The wood of Sitka spruce is close to the lower limit of strength required for many structural purposes. Any treatment that causes the core of juvenile wood to increase in size is in danger of reducing the strength below an acceptable limit, hence much attention is paid to spacing with this species. There is also scope for selecting and breeding trees with high-density wood (Savill and Sandels, 1983). The average density of the wood at 15% moisture content ranges between 380 and 450 kg m^{-3}. Suitably graded material is satisfactory for many purposes including trussed rafters, internal framing and partitioning, but it should be protected against rot and insect attack. This is difficult as the heartwood is naturally resistant to pressure treatment with preservatives. The wood of slowly grown Norway spruce is resonant, and because of this it is used for making parts of violins and cellos.

Place of Sitka spruce in British forestry

Sitka spruce is the most economically important and widely planted tree in Britain. It has been responsible for most of the enormous expansion of the British forest area in the 20th century. It is the best-adapted species for growing in the wet, upland parts of the country, being tolerant of severe levels of exposure, growing well on a wide variety of sites and at the same time, being highly productive. Its importance is unlikely to diminish.

PINUS L. — Pines

About 114 species of pines are found in temperate, sub-tropical and tropical regions of the world, including 11 in Europe. Seventy species are in the subgenus *Pinus* (the 'yellow' or 'hard' pines). These are mostly 2- or 3-needled pines, and 44 species are in the subgenus *Strobus* (the 'white' or 'soft' pines, which have 4 or 5 needles). Two of the latter species, *Pinus peuce* and *Pinus strobus*, are described below. *Pinus sylvestris*, the Scots pine, is the only pine native to Great Britain and is one of only three native conifers. Other species have been extensively planted, including lodgepole and Corsican pines. In the most recent inventory of woodland (Forestry Commission, 2003) the total area of all pines in Britain was estimated at 408,000 ha, or 17% of the total forest area, making them the second most common genus of trees in the country, after spruces.

The importance of pines has diminished considerably since the 1990s due to the introduction and rapid spread of red band needle blight, caused by the fungus *Dothistroma septosporum* (Brown and Webber, 2008). Up to this time the disease was a major cause for concern mainly on Monterey pine in the southern hemisphere, but it has spread to other species of pines in both Europe and North America and has seriously reduced growth rates and consequently interest in establishing the species. All species of pine commonly grown in Britain are susceptible to the disease.

The oldest living tree in the world, *Pinus longaeva* (the Great Basin bristlecone pine), was believed to be 4844 years old in 2012. Many of the most productive and widely planted timber trees are pines. They also produce pulp and resinous products including rosin and turpentine, and some species have edible seeds (Mabberley, 2008).

PINUS CONTORTA Douglas ex Loudon — Lodgepole pine

Origin and introduction

The range of lodgepole pine extends from south-east Alaska and interior Yukon in the north, to Baja California (Mexico) in the south and extends eastwards as far as the Black Hills of South Dakota (i.e. 33° of latitude and 33° of longitude). The species is most abundant in the northern Rocky Mountains and Pacific coast region. It is found from sea level to about 3600 m and covers a huge variety of climatic and soil conditions, which has led to some subdivision of the species. Lodgepole pine was first successfully introduced to Britain in 1853.

Climatic requirements

It grows well under diverse but generally upland conditions. Appropriate provenances are resistant to winter cold, late spring frosts, salt-laden winds and air pollution, and will withstand great, even extreme, exposure in Britain. Lodgepole pine was often planted in the uplands as a last resort, where no other tree would thrive because of severe climatic and site conditions.

Site requirements

Some provenances will grow fast on the poorest soils such as deep acid peats, hard boulder tills and upland heaths. Performance can be outstanding compared with other species on such sites, provided there is adequate phosphorus in the soil. Lodgepole pine is much more tolerant of competition from heather than Sitka spruce, and if this was likely to be a problem, lodgepole pine was often a natural choice, at least for a first rotation. On fertile lowland sites it becomes a coarse and unattractive tree. On such sites several other species are much more productive and much better formed.

Other silvicultural characteristics

Lodgepole pine used to be commonly planted at high elevations on the poorest western and northern soils, mainly peats, because it is relatively undemanding and will grow well with only low inputs of fertilizers. It has the reputation for drying out peat in some areas (Pyatt and Craven, 1979).

It was also widely planted as a nurse, to provide shelter and to suppress weeds, usually in mixtures with Sitka spruce. However, from the late 1960s this practice was largely abandoned as establishment techniques for spruce improved. Difficulties were also quite frequent, in that the pine grew so much faster than the spruce that the latter was eventually suppressed and killed. Some of these mixtures have led to the discovery of a previously unknown nursing effect of the pine on Sitka spruce on some peaty sites deficient in available nitrogen. This was first described by O'Carroll (1978) and has been much more widely observed since, especially with Alaskan origins of lodgepole pine (Lines, 1987). Spruces in such mixtures often grow at rates that are many yield classes higher than in unmixed crops. The mechanisms involved are not yet understood, though they clearly involve improving the nitrogen nutrition of the spruces and may be connected with mycorrhizae.

Lodgepole pine is susceptible to snowbreak and windthrow on wet soils, and then, unlike spruces, the timber decays within about 1 year, so it must be salvaged quickly; this can be difficult if windthrow is extensive.

The most vigorous provenances are coarse and suffer from basal sweep. These problems lead some foresters to prefer leaving areas unplanted if the alternative was pure lodgepole pine (Davies, 1980).

Pests and diseases

In spite of its virtues, lodgepole pine also has many serious problems, some caused by stress brought on by the extreme environments in which it tends to be grown. It is vulnerable to damage by many organisms: the pine beauty moth, *Panolis flammea* (Stoakley, 1979); pine sawfly, *Neodiprion sertifer*; pine looper moth, *Bupalus piniarius* (Bevan and Brown, 1978); pine shoot beetle, *Tomicus piniperda* (Bevan, 1962); deer; red band needle blight, *Dothistroma septosporum*; and on infected sites, by *Heterobasidion annosum*.

Natural regeneration

Natural regeneration can be prolific, especially on burnt sites, and will mean that mixtures with other species are likely to develop in places.

Flowering, seed production and nursery conditions

Pinus contorta ssp. *contorta* flowers in May and June, and seeds ripen 18 months later, between December and March. They are dispersed in the spring. The earliest age at which the tree bears seeds is at 10–20 years, but the best seed crops are usually at intervals of 2 or 3 years after the age of 30–40. Seed is usually collected in October and November. There are about 298,000 seeds kg^{-1} (range 245,000–364,000), of which 270,000 are normally viable. If the seed has been stratified or pre-chilled it can be sown between late February and mid-March; if it has not, it should be sown in late March (Aldhous, 1972).

Provenance

Three main interfertile races are usually recognized as subspecies of lodgepole pine. They differ markedly in ecology and morphology, and can lead to enormous differences in growth rates and yields of timber. Subspecies *contorta* grows along the Pacific coast of north-west America from British Columbia to California in bogs, on sand dunes and on the margins of pools and lakes. It is short, shrubby and of poor form but is the fastest growing subspecies in Britain. Subspecies *latifolia* is found in the intermountain systems from central Yukon to eastern Oregon and south Colorado, and subspecies *murrayana* grows mainly in the Cascade and Sierra Nevada mountains of Oregon and California (Critchfield, 1957). The latter two subspecies are well-formed, slender, tall, straight trees, but grow much more slowly in Britain than ssp. *contorta*.

A constant dilemma has been to decide how far to compromise on form while retaining vigour. In Britain Skeena River and other interior provenances are recommended, except for use in nursing mixtures, when slower-growing Alaskan origins are better (Forest Research, 2011). The north-coastal provenances possibly have an advantage in that they are less susceptible to damage by the pine beauty moth (Leather, 1987). The correct choice of provenance is complex, but a detailed guide is provided by Lines (1985a). In the future interprovenance hybrids may offer possibilities for combining vigour and good form.

Area and yield

For many years in the latter half of the 20th century lodgepole pine came second to Sitka spruce in the extent of new planting, which was a reflection of the poor quality of the land that was then being acquired for afforestation. By about 2000 the total area was estimated at 134,000 ha or 6% of the forest land in Britain. This in no way reflects the extent of planting today, which is negligible. Mean yield classes range from 6 to 10 m^3 ha^{-1} $year^{-1}$, with a maximum of about 14 for coastal Oregon and Washington provenances, though yield classes as high as 18 are commonly found in Ireland.

Timber

The timber of lodgepole pine is similar to that of Scots pine, except that it contains a greater proportion of heartwood and it is more resistant to penetration by preservatives. It has a straight grain, low distortion on seasoning, high stability and a comparatively uniform texture. A smooth finish can be obtained, even on wide-ringed timber, and it should make a suitable joinery wood. Its value may, of course, be reduced considerably by the poor form of many trees of ssp. *contorta*, and by knots. The average density of the wood at 15% moisture content is about 470 kg m^{-3}.

Place of lodgepole pine in British forestry

Lodgepole pine will grow on the poorest and most exposed sites in Britain where few other trees will survive. Considerable areas of it were established in the second half of the 20th century. However, this is more of historical than current interest because such extreme sites are seldom planted today and several have been cleared of trees and left to revert to blanket bog.

As explained in more detail in the section on Scots pine, the importance of pines in general has diminished greatly since the 1990s due to the introduction and rapid spread of red band needle blight, caused by the fungus *Dothistroma septosporum*. While this disease seldom kills the trees it can reduce the rate of growth significantly.

PINUS MURICATA D. Don — Bishop pine

Origin and introduction

Bishop pine is found in more than 15 scattered colonies along the coast of California, Baja California in Mexico, and on the nearby Cedros and other islands. It was introduced to Britain in 1846. It is one of the closed cone (serotinous) pines, and cones are retained on the trees.

Climatic requirements

These are uncertain, but the tree is close to or slightly beyond the limit at which it can safely be grown in Britain. Its requirements appear similar to those of Monterey pine, though bishop pine is slightly less demanding. It is largely confined to low elevations in south-west England but may be reasonably safe south of a line from the Dee to the Wash, according to Everard and Fourt (1974). Quite large areas have been satisfactorily established by the Forestry Commission at Wareham forest in Dorset.

Site requirements

These are not clearly known. Bishop pine is believed to be more tolerant of poor soils than Monterey pine, but calcareous soils should be avoided.

Other silvicultural characteristics and yield

The tree is often multi-stemmed and coarse. It needs singling and pruning early, often by age three or four, and later needs high pruning if a reasonably straight single stem is to be produced. It often suffers badly from the pine budmoth, *Rhyacionia buoliana*, and also from red band needle blight, caused by the fungus *Dothistroma septosporum*.

The northern 'blue' variety of the species has shown promise as a potential timber tree in Britain, with growth rates of up to 2 m year^{-1} when young, even on poor sandy soils (Farjon, 2012). Yield classes of 20 m^3 ha^{-1} year^{-1} can readily be achieved.

Provenance

The species is quite variable over its natural range: there is a southern 'green' form and a northern 'blue' or glaucous form. The latter is better shaped and appears to be more frost hardy (Tuley, 1979). Other varieties are sometimes recognized.

Place of bishop pine in British forestry

The main source of interest in this otherwise unattractive species is its potential for fast growth. It is unlikely ever to become an important tree in Britain.

PINUS NIGRA J.F. Arnold — Black pine

Origin and introduction

Pinus nigra has a discontinuous distribution in central Europe and the northern Mediterranean region from southern Spain to Turkey and the Crimea (35°–49°N, and 3°W–34°E). It is predominantly a mountain tree but also occurs at sea level along the shores of the Adriatic. According to Farjon (2012), this species has received an excessive number of described names, many of them invalid under the *International Code of Botanical Nomenclature*.[1] Farjon recognizes only two subspecies, each with several varieties:

ssp. *salzmannii*	Corsican pine
ssp. *nigra*	Austrian pine

Only ssp. s*alzmannii* from Corsica is grown as a timber tree in Britain. It originates from Corsica, southern Italy and Sicily, and was introduced in 1759; ssp. *nigra*, from Austria, central Italy and the Balkans, will also grow in Britain.

[1] http://ibot.sav.sk/icbn/main.htm, accessed August 2012.

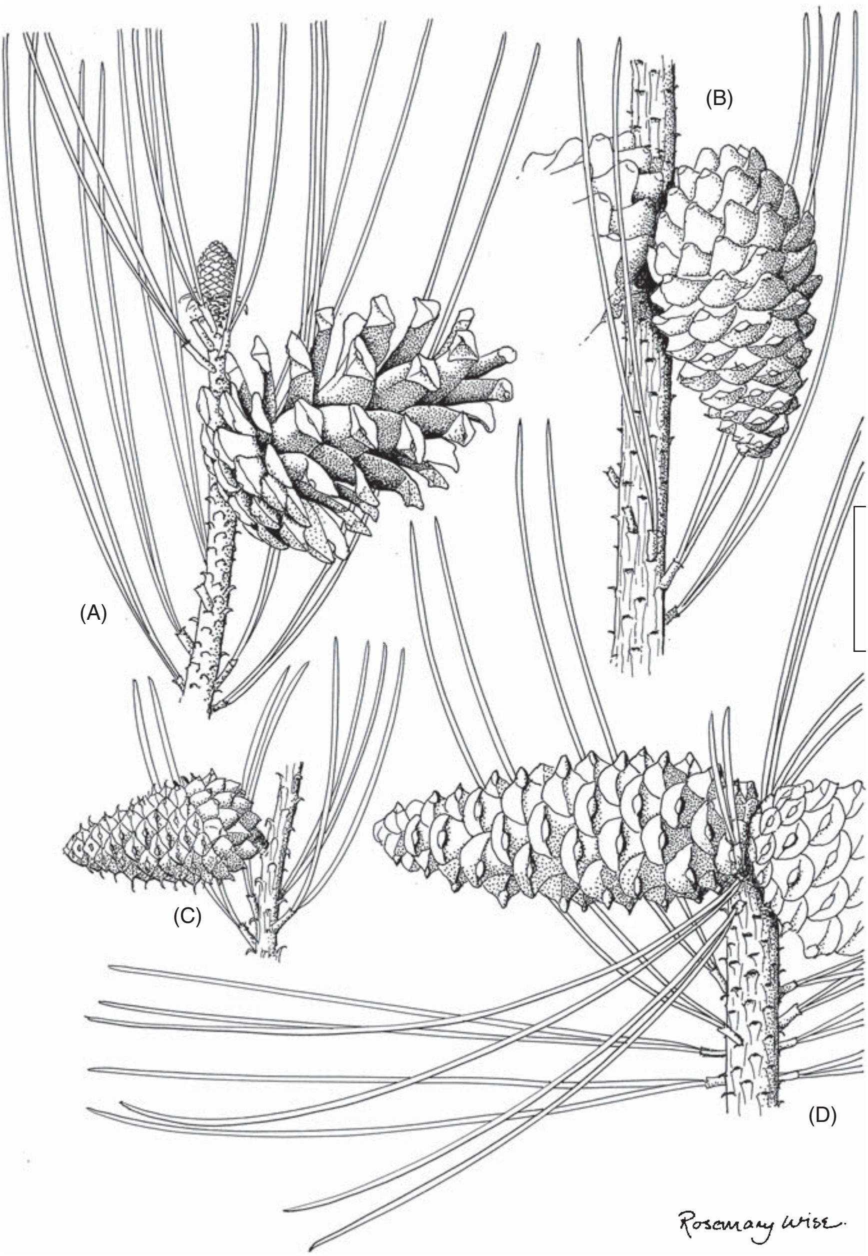

Fig. 23. (A) Austrian pine, *Pinus nigra* ssp. *nigra*; (B) Bishop pine, *Pinus muricata*; (C) Lodgepole pine, *Pinus contorta*; (D) Corsican pine, *Pinus nigra* ssp. *salzmannii*.

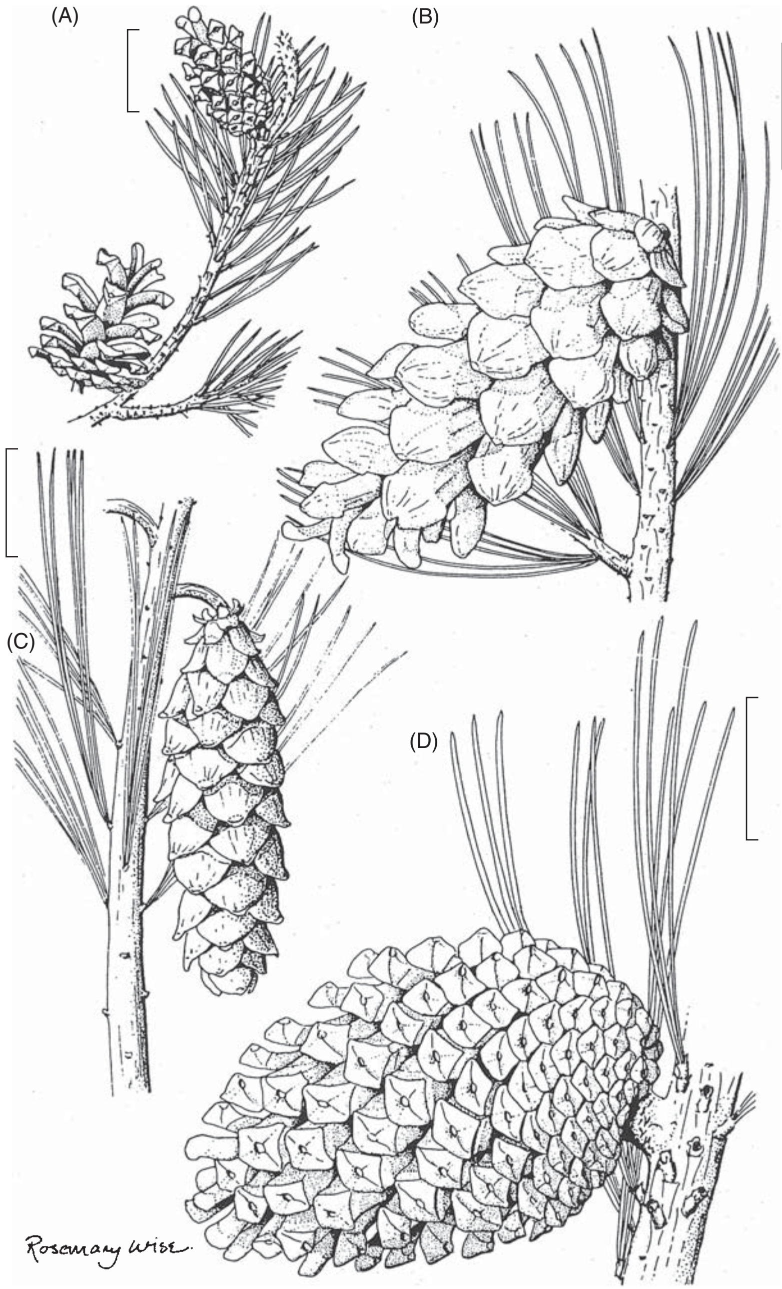

Fig. 24. (A) Scots pine, *Pinus sylvestris*; (B) Macedonian pine, *Pinus peuce*; (C) Weymouth pine, *Pinus strobus*; (D) Monterey pine, *Pinus radiata*.

PINUS NIGRA J.F. Arnold ssp. NIGRA — Austrian pine

Austrian pine is much more at home on exposed chalk and limestone than Corsican pine. It is one of few conifers with this attribute, and it grows well even where the soil is dry and shallow. It can be useful as a nurse for beech on such sites. It will not thrive on wet, heavy soils, but tolerates sea winds and industrial pollution well. It has a coarse and poor form, and largely because of this it is virtually useless as a timber tree. Little information has been published about provenances suitable for use in Britain, but most seed is currently being acquired from Slovenia.

Place of Austrian pine in British forestry

Austrian pine is only worth planting as a short-term nurse where limestone, salt-laden winds or pollution rule out other conifers, and then only as a shelterbelt or for amenity.

PINUS NIGRA J.F. Arnold ssp. SALZMANNII (Dunal) Franco — Corsican pine

Climatic requirements

Until the advent of red band needle blight Corsican pine grew well in the south and the Midlands of England, the coastal fringe of south Wales and along the east coast of Scotland. These are all districts of low summer rainfall and high temperatures and duration of sunshine. In wetter, cloudier districts of the north and west it is usually fatally attacked by a die-back fungus, *Gremmenielta abietina* (Read, 1967). For this reason uplands were normally avoided, but if planted it should be confined to warmer south and west-facing slopes, brashed early and thinned heavily in an attempt to prevent infection by improving air circulation. As a guide, Lines (1987) suggested elevations of no more than 300 m in south-west England as being safe. Wetter upland sites, over 150 m in northern England and lower further north, carry some risk of dieback. In milder parts of the lowlands it grows well on sites that also suit Scots pine. It does best in areas of low rainfall and tolerates smoke better than most conifers. It will also grow better than Scots pine on coastal sand dunes subjected to salty winds. Corsican pine can be difficult to establish in places where frequent and severe late spring frosts occur. The risks of damage can be minimized by planting on ploughed ground or otherwise maintaining bare soil round the plants, as a means of preventing temperatures from falling too low.

Site requirements

Corsican pine grows well on a wide range of mineral soils but with least risk on sands and heavy clays in the midlands, south and east of England. Though more successful than Scots pine on chalky soils, it does not thrive on them.

Other silvicultural characteristics

Corsican pine will grow to larger sizes than the native Scots pine: over 40 m tall. Conventional bare-rooted plants are notoriously difficult to establish. They are sensitive to bad handling and especially to the roots drying out. High and even complete losses with them were common, and this encouraged the use of container-grown (Japanese paper-pot) plants. To ensure reasonable survival with undercut transplants or plants in pots, planting should be carried out as late as possible in the spring. Very little growth occurs in the first year or two after planting, so careful weed control is necessary to prevent smothering.

The tree is strongly light-demanding. Though the form is generally good, branching can be heavy and the species does not self-prune well. Timber quality can therefore be considerably improved by pruning, though this is seldom done.

Trees are not easily damaged by grass fires when in the pole stage or later.

Pests and diseases

One important attribute is that Corsican pine is seldom attacked by rabbits and hares, unlike Scots pine which was often planted in the same areas. In common with most pines, the species is more susceptible to attack by fomes heart and butt rot, *H. annosum*, than many conifers. At Thetford Forest stumps of clear-felled crops are removed from the ground in the worst-infected areas in an attempt to reduce the levels of infection to the succeeding crop.

Corsican pine is rarely attacked by the pine shoot moth, *Rhyacionia buoliana*, or the fungal resin top disease, *Peridermium pini*, both of which can cause severe damage to Scots pine in East Anglia. It is sometimes susceptible to attack by the aphid *Schizolachnus pineti* and the pine looper moth, *Bupalis piniarius*.

Red band needle blight, *Dothistroma septosporum*, causes major losses in increment. Corsican pine is very susceptible to the disease, to the extent that all planting of it was suspended on Forestry Commission land in 2008 (Brown and Webber, 2008). The disease and mortality is particularly severe in dense, unthinned, pole-stage stands where humidity levels are high. Heavy thinning and pruning reduce the extent of infection, because they improve air circulation and reduce the humidity, which promotes infection.

Natural regeneration

Natural regeneration is comparatively rare because the species tends not to produce much seed until it is over 60 years old, which is beyond the normal rotation age in Britain.

Flowering, seed production and nursery conditions

The tree flowers in late May and early June; seeds ripen between December and March 18 months later, and are dispersed in the spring. They are normally collected in January. The earliest age at which the tree bears reasonable crops of seed is 20–30, but the best seed crops are usually at 3–5-yearly intervals between the ages of 60 and 90, which tends to be after the normal commercial rotation age. There are about 57,000 seeds kg^{-1} (range 31,000−86,000), of which 55,000 are normally viable. Most seed is produced in the south-east and east of England. If required for the nursery it should be sown between late March and early April. No pre-treatment is required (Aldhous, 1972).

Provenance

Seed from Corsica grows best in Britain (Lines, 1987), and trees from this source have excellent form. Many British plantations of Corsican origin exist from which seed could be collected, particularly in East Anglia (Kennedy, 1974).

Area and yield

In the late 1990s stands of Corsican pine occupied an area of 45,350 ha or 2% of forest land (Forestry Commission, 2003). Mean yield classes range from 9 to 13 m^3 ha^{-1} $year^{-1}$ (Nicholls, 1981), with a maximum of about 20. The potential mean should be 18 or more on a wide range of sites (Fourt *et al*., 1971), but phosphorus is often limiting. In suitable areas, such as the Brecklands of East Anglia, Corsican pine is always much more productive than Scots pine, which it was replacing until the introduction of red band needle blight. It is now no longer planted.

Timber and uses

Corsican pine makes heartwood much more slowly than Scots pine, but the timber is otherwise similar and can be used for the same purposes. The wood is stable, with intermediate strength: stronger than spruces but weaker than larches. It is suitable for use in building, roofing, flooring and interior framing, provided the correct grade is selected. Large knot whorls are potential zones of weakness. The timber is not durable but can easily be treated with preservatives. Treated timber is used for making sleepers, poles and fences, and these should last for 50 years or more. Freshly felled logs are very susceptible to attack by blue stain fungi and should therefore be extracted, converted and dried with a minimum of delay, though the stain does not affect the strength properties of the wood. The average density of the wood at 15% moisture content is about 510 kg m^{-3}.

Place of Corsican pine in British forestry

Corsican pine was, until the advent of red band needle blight, regarded as the most profitable conifer for planting in much of lowland Britain, particularly on light soils in the east of the country. The disease has caused interest in the species to diminish greatly.

PINUS PEUCE Griseb. — Macedonian pine

Origin and introduction

The species is a five-needled pine that is closely allied to the Himalayan *Pinus wallichiana*. It is native to the Balkan peninsula – Montenegro, Macedonia, western Bulgaria, Albania and northern Greece – where it occupies a total area of no more than 30,000 ha, ranging from 1100 to 2300 m in elevation. It was introduced to Britain in 1864.

Climatic and site requirements

Very little experience exists with the tree in Britain, but such as it is, together with a full account of the tree's performance in its natural habitat, has been given by Lines (1985a). It appears likely to grow well on a wide range of soils, including peats, in such inhospitable places as the central Highlands of Scotland. It withstands exposure and atmospheric pollution well. In its natural range Farjon (2012) states that it is usually found on north-facing slopes on siliceous soils and rarely on carbonate soils.

Other silvicultural characteristics

Macedonian pine is potentially a big tree, growing up to 40 m tall. Difficulties with it arise in the nursery and establishment phases, which is probably why it has received so little attention up to now. Early growth is slow. Until the fifth or sixth year the trees have a dense, bushy form before making strong vertical growth. The bark remains thin for up to 30 years and so is potentially susceptible to being stripped by deer.

The American *Pinus palustris* (longleaf pine) also goes through a similar period of slow growth called the ‘grass stage’, which is believed to be under strong genetic control. Although the length of time individual seedlings remain in this stage is influenced by the environment, it can last for as long as 25 years and often for 15 years. Reasonable stands will reach breast height at about 8 years. Generally seedlings of *P. palustris* remain in the grass stage until they reach 2.5 cm at the root collar, and they invariably begin height growth upon reaching that size. The control of competition is a major factor in stimulating fast diameter growth: if it is good, height growth can begin at the end of the second year (Walker and Wiant, 1973). It is possible that a similar mechanism may operate in *P. peuce*.

Diseases and pests

Macedonian pine is notable for its resistance to diseases that affect so many other pines.

Unlike Weymouth pine, another five-needled pine, the Macedonian pine is resistant to attacks from the blister rust, *Cronartium ribicola*, and to several other pests and diseases of pines. These include red band needle blight, *Dothistroma septosporum*, that is affecting all other pines grown in Britain, and the pine wood nematode, *Bursaphelenchus xylophilus*, another potential threat to many pines. In fact, it seems likely to be a remarkably hardy and healthy tree in Britain.

Seed production and nursery conditions

Seeds are fully ripe in September but are often completely stripped in August, at least in small plots, by squirrels. Lines (1985b) stated that one of the major disadvantages of Macedonian pine is the tendency to poor or delayed germination, which is partly due to incomplete embryo development. Usually some seeds germinate in the first spring but many do not germinate until the second.

Yield

There is increasing evidence that the species could be a high-volume producer in Britain compared with other pines. A feature is that in comparison with other species, basal area growth can be up to 50% greater for a given height. This makes it of interest where the risk of windthrow is high.

Timber and uses

Preliminary studies in Britain indicate that an important attribute of the wood is its stability compared with other common coniferous timbers, though its strength is poor. Its density at around 12% moisture content is about 350 kg m^{-3}, which is considerably lower than Scots pine, at about 510 kg m^{-3}.

It is considered to be a valuable ornamental tree and is much planted in Scandinavian parks and gardens.

Place of Macedonian pine in British forestry

Forestry in the uplands of Britain is often regarded as being too dependent upon very few species. There has been concern for some time to find possible alternatives, particularly to Sitka spruce. Macedonian pine is a possible choice especially because of its resistance to red band needle blight and high-volume production at relatively low heights. Though its potential has been recognized for some time, it never gets beyond this stage. Climate change could provide the impetus for more work.

PINUS RADIATA D. Don — Monterey pine, Radiata pine

Origin and introduction

Monterey pine is native to three small areas in the ‘fog belt’ on the coast of California, round Monterey and Cambria, between 35° and 37°N, and also to three small islands off the coast: Santa Cruz, Santa Rosa and Guadeloupe. It has no economic importance in its native range, but as an exotic it is one of the most widely planted of all trees and is the basis of huge timber industries in New Zealand, Australia, Chile, south-west Europe and South Africa. It was introduced to Britain in 1833.

Climatic requirements

Monterey pine is probably beyond the limit of where it can safely be grown, even in the mildest parts of southern England. Its requirements are not well understood, but it may be hardier to low winter temperatures than is generally believed: tolerance to frosts of −6°C in summer and −14°C in winter have been found in New Zealand (Menzies and Chavasse, 1982). It probably needs a long, warm growing season. Green (1957) considered it required an accumulated temperature above about 1400 day°C (i.e. the sum of the mean monthly temperatures above 6°C × days in the month). Much of southern England has these temperatures, but recent experience suggests that even higher levels may be needed, possibly over 1700 day°C, such as are found in parts of Dorset, Somerset, Devon, Hampshire and Cornwall, at low elevations. Rainfall is not limiting. In unsuitable climates trees of any age may suddenly go yellow and needle retention is reduced; they may die quite suddenly.

Site requirements

Monterey pine has grown well on deep, dry and infertile sandy soils in the south of England, and grows on loams and clay loams. Wet and shallow calcareous soils over chalk should be avoided.

Other silvicultural characteristics, timber and yield

Trees up to about 35 m tall occur in Britain. Growth is rapid where the tree survives, and this is the cause of the interest in the species. Yield classes of 18–22 m^3 ha^{-1} $year^{-1}$ are common in south-west England, with maximum mean annual increment occurring before age 30. The average density of the wood at 15% moisture content is about 480 kg m^{-3}. In common with Bishop pine, the cones of Monterey pine are serotinous, remaining closed and on the tree until opened by the heat of a forest fire; the abundant seeds are then discharged to regenerate the burned forest. The tree is coarsely branched, so pruning is necessary.

Diseases

Monterey pine is attacked very severely by red band needle blight, *Dothistroma septosporum*. Up to the 1990s the disease was a major cause for concern mainly in the southern hemisphere. Pitch pine canker, *Fusarium circinatum*, is also a serious potential disease that has recently been introduced into Western Europe but is not yet present in Britain. It is also attacked by the pine shoot moth, *Rhyacionia buoliana*.

Place of Monterey pine in British forestry

This species is of negligible importance in Britain, but interest in it has arisen in the past because of its rapid rate of growth in the few places where it survives. These are mostly coastal regions in the south and south-west. The species should benefit from climate warming in Britain if the serious disease problems can ever be overcome.

PINUS STROBUS L. Weymouth pine (UK), Eastern white pine (USA)

The species is native to and widespread in north-eastern North America and is found occasionally in Mexico and Guatemala. It grows at low elevations in the northern part of its range and in the mountains in the south, in regions of cool, humid climates. It was introduced to Britain in about 1705 and named after George Weymouth, who first discovered the tree growing in Maine. The name was subsequently appropriated by the unrelated 1st Viscount Weymouth who, at the time, was First Lord of Trade and Foreign Plantations. He called it the Lord Weymouth Pine and planted it extensively on his family's estate at Longleat in Wiltshire.

Its site requirements are said to be quite exacting (Elwes and Henry, 1906): good loamy hardwood sites are needed, or deep sandy or sandy loam soils.

The timber tends to be less dense than that of many pines, at about 420 kg m^{-3}.

Diseases

Weymouth pine, like Macedonian pine, is a five-needled pine. It is a species that appears to have potential in Britain, because of the impressive growth of occasional isolated trees, but it is only rarely planted because fatal infections of the blister rust, *Cronartium ribicola*, soon attack even small stands. The disease is highly virulent and trees are susceptible from the seedling stage onwards. In its natural range blister rust causes high losses. If planted at all it should only be on a small scale and, even then, preferably in mixtures. The disease is common in five-needled pines and was first noticed in 1892. The main alternate host of the rust in Great Britain is the blackcurrant, *Ribes nigrum*, and the risk of infection has precluded the use of the pine.

PINUS SYLVESTRIS L. Scots pine

Origin

Scots pine is one of three native British conifers and the only one of any commercial significance. It is the world's most widespread conifer after *Juniperus communis* (which is also a native species), extending from southern Spain to Norway, across the whole of northern Europe and Siberia, almost to the Pacific Ocean. Farjon (1998) states that over 140 subspecies, varieties and forms have been described in an 'orgy of botanical nationalism', but they are barely distinguishable from each other.

Within Great Britain the Caledonian pine, *P. sylvestris* var. *scotica*, is regarded by some as the name of the native tree of the Highlands of Scotland, though it is not currently accepted by taxonomists at the Royal Botanic Gardens, Kew and Missouri Botanical Garden (Plant List, 2010). The Caledonian pine is found between latitudes 57° 57′N and 56° 22′N and longitudes of 5° 03′W and 5° 38′W (Carlisle and Brown, 1968).

According to the Forestry Commission (undated), native Caledonian pinewoods are found at 84 sites in the north and west of Scotland and cover around 180 km^2.

Climatic requirements

Scots pine is an adaptable species but does best in the drier eastern districts. It does not grow well where exposure is excessive, though Caledonian pine occurs at 625 m in the Cairngorm Mountains. It is not normally regarded as a tree for high elevations unless there is adequate topographic shelter. It is frost hardy, drought tolerant and windfirm but will not withstand atmospheric pollution or salty winds from the sea.

Site requirements

Scots pine grows best on light, non-calcareous, heathland soils, especially sands, gravels and other well-drained sites, at lower elevations. On more fertile sites it will grow vigorously, but stem form is often poor. It has a relatively short life on calcareous soils where it is sometimes used as a nurse. Deep wet peats on exposed, elevated sites should be avoided.

Other silvicultural characteristics

Scots pine will grow up to a maximum of about 35 m tall. The oldest tree recorded in Britain was 395 years (Carlisle and Brown, 1968). Lines (1987) described Scots pine as a typical light-demanding, pioneer species. It is frost hardy and grows rapidly when young. It will regenerate in open stands, but if the regeneration is to succeed it must be released from competition within 10 years otherwise it will not respond. Scots pine is useful as a nurse for broadleaved trees, especially for beech on frost-prone calcareous soils, because it does not grow too fast. The tree does not self-prune well and to obtain clear timber without loose, dead knots, pruning is necessary.

Scots pine is tolerant of low levels of available nutrients. Its mycorrhizae allow it to compete successfully for nitrogen on heathlands dominated by heather, *Calluna vulgaris*, where spruces would fail.

The cellulose of pine needle litter, like that of spruce, is relatively resistant to decomposition by fungi (Carlisle and Brown, 1968) and can accumulate over time on the forest floor. The water draining from such woodland is very acidic (pH 3.7) compared with that of larch litter (pH 4.2–5.3) and birch litter (pH 4.7–4.8). This process can contribute to the acidification of streams and rivers to the detriment of fish spawning (Nisbet, 2001). The process resulted in the Forestry Commission introducing Forests and Water Guidelines, originally in 1988 (Anon., 2011).

Diseases

It suffers from resin top disease, *Peridermium pini* (Pawsey, 1964), particularly in north-east Scotland, and red band needle blight, *Dothistroma septosporum*.

Natural regeneration

Where Scots pine is truly at home, such as in parts of the New Forest, natural regeneration can be both prolific and invasive if it is not browsed too much by deer and sheep.

Flowering, seed production and nursery conditions

The tree flowers in May and June; seeds ripen in September and October of the following year, and are dispersed between December and March. The best seed crops are usually produced at 3–5-year intervals after the age of 60. Seed is usually ready for collection in January. There are about 165,000 seeds kg^{-1} (range 74,000–245,000), of which 140,000 are normally viable. The treatment of seed in nurseries is the same as for Corsican pine.

Provenance

For the native pinewoods of north Scotland the appropriate local seed origin should be used. Elsewhere, seed from British seed orchards is available and should be preferred.

Area and yield

In about 2000 there was an estimated 219,000 ha, or 10% of the total British forest area, covered with Scots pine, making it the second most common species to Sitka spruce. However, this figure gives a false impression of current levels of planting, which are almost negligible. Its susceptibility to red band needle blight, rather slow growth and long rotations compare badly with more exacting species. It was, for example, being rapidly replaced by Corsican pine in eastern England. Mean yield classes range from 8 to 11 m^3 ha^{-1} $year^{-1}$ in different parts of Britain (Nicholls, 1981), with a maximum of 14; rotations vary between 50 and 60 years.

Timber

The wood of Scots pine, known in the timber trade as deal or redwood, has been the standard utility timber of northern Europe for generations. Its average density at 15% moisture content is about 510 kg m^{-3}, though it varies with provenance. It combines adequate strength with light weight, and is easy to nail and work. Clear, narrow-ringed wood can be of excellent quality for joinery and most is suitable for building: wood of this quality is most commonly imported from Scandinavian countries. It is easily treated with preservatives and is useful where a high standard of treatment is required, as in railway sleepers and fencing. An excellent veneer can be made from knot-free material.

Place of Scots pine in British forestry

Scots pine was a traditional species for planting in Britain because of its ability to survive and grow under difficult conditions and the fact that it is a native tree. However, the introduction and rapid spread of red band needle blight caused by the fungus *Dothistroma septosporum* in the 1990s has reduced interest in establishing the species.

Only the native Scots, or Caledonian, pine has seen a resurgence in planting that coincides with the general interest in establishing local races of native species.

POPULUS L. Poplar

In Britain poplars are planted mostly for screening, shelter and ornament, rather than for the production of timber. Their cultivation and uses have been described in detail by Jobling (1990).

About 35 mostly dioecious species occur in the northern hemisphere, in the boreal and temperate zones between the subarctic and subtropical regions. Two species are indigenous to Britain – *Populus nigra* and *Populus tremula* – and one, *Populus* × *canescens*, is doubtfully native. The latter is a natural hybrid between *P. tremula* and *Populus alba* (Culot *et al*., 1995).

Many British people think of poplars as the Lombardy poplar, a fastigiate variety of *P. nigra* that originated in about 1700 in northern Italy. In Britain it was first planted in 1758 as cuttings in the grounds of Blenheim Palace, Oxfordshire, and was subsequently widely used for ornament.

HYBRID POPLARS

Poplar hybrids are the fastest-growing broadleaved trees in the northern hemisphere. Clones said to be capable of producing up to 22 m^3 ha^{-1} $year^{-1}$ are propagated vegetatively from cuttings or sets. Various newly introduced clones showed considerable promise in the mid-1990s and were being planted quite widely and enthusiastically, but within 10 years they all succumbed to various diseases, as explained below. Poplars are now scarcely planted at all since it appears that none can be guaranteed to remain disease-free in the British climate.

Origin

There are numerous cultivated hybrids, varieties and clones. Those in current commercial use are crosses between known individuals of the European black poplar, *P. nigra*, and the two North American species, balsam poplar, *Populus trichocarpa*, and cottonwood, *Populus deltoides*, and also of hybrids of *P. trichocarpa* and *P. deltoides* (known as *Populus* × *generosa*).

Many poplar species interbreed freely, and the presence of numerous natural hybrids presents the taxonomist with difficulties in defining the limits of species. This situation is complicated by the occurrence of leaf dimorphism within species and evidence that some 'species' are themselves intersectional hybrids. The identification of most cultivated poplars is therefore extremely difficult and frequently impossible from morphological characteristics alone.

Climatic requirements

Poplars are near their climatic limits as forest trees for economic production in Britain. On suitable sites they grow best in southern Europe, such as the Po valley in Italy, where summers are hotter. In Britain they must be confined to sheltered sites in lowland regions. About half of all British poplar growing is carried out in East Anglia.

Most poplars are hardy to winter cold throughout Britain but can be damaged by late spring frosts. They are reasonably tolerant of exposure, which explains their use for planting as shelterbelts on fruit farms. Clones of *P. trichocarpa* are better suited to the cooler north and west, while the black poplar hybrids are favoured by the warmer conditions in the south of England.

Site requirements

Cultivated varieties are exacting in their site requirements and suitable sites available for production are few. They need highly fertile, base-rich, loamy soils, or rich alluvial or fen soils, which are well drained but aerated and moist, even in conditions of summer drought, usually with a water table within 1–1.5 m of the surface. Banks of streams and the alluvial soils of river valleys are suitable. Most poplars will grow reasonably well on a much wider range of soils but not fast enough for commercial crops. Sites to avoid are those with acid soils, shallow soils and soils where there is stagnant or slowly draining water.

Other silvicultural characteristics

Poplars are strongly light-demanding and must be established at wide spacings. They are normally planted in pure stands at spacings of about 8 × 8 m. This produces 45 cm dbh trees, with no thinning, on rotations as short as 22 years (Beaton, 1987). At such wide spacings regular pruning is necessary if the wood is not to become excessively knotty. Poplars are most intolerant of competition with weeds and grow extremely slowly when young unless almost complete weed control is practised.

Production among clones being grown for both timber and biomass can be increased significantly by planting mixtures of clones rather than single-clone plots, for the reasons described below.

Because poplar roots are often close to the ground surface they can be troublesome near buildings, blocking drains and damaging paving. It is usually recommended that they are not planted within 40 m of such structures.

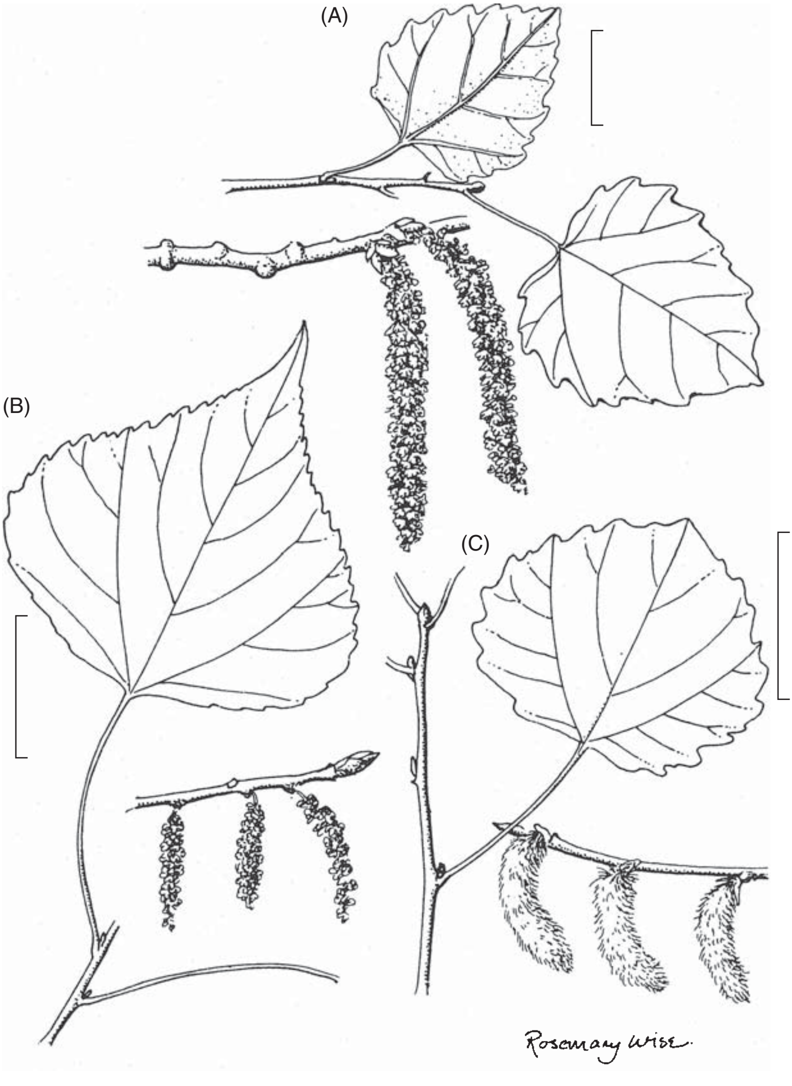

Fig. 25. (A) Grey poplar, *Populus × canescens*; (B) Black poplar, *Populus nigra*; (C) Aspen, *Populus tremula*.

Diseases and pests

The risks associated with using clonal material in forestry are illustrated graphically by poplars: if one individual becomes diseased, all other members of the same clone are likely to become so too.

Poplars suffer from a number of potentially serious diseases. Infection by bacterial canker, *Xanthomonas populi*, via natural openings, such as leaf or bud scale scars, can lead to the death of branches and to the development of perennial cankers on the trunk. Dothiciza is another serious canker, caused by the fungus *Discosporium populeum*. *Melampsora* rust is a leaf disease characterized by the presence of bright orange pustules on the underside of leaves. *Melampsora* spp. affect trees in different ways. Leaves on infected trees shrivel and fall prematurely. The rust can also reduce frost tolerance. A combination of these effects can lead to seriously reduced increment, shoot dieback and often tree death, depending on the timing and severity of the infection. Infection early in the growing season has a more adverse effect than infection in August or September. Sometimes infection occurs late enough for it to have little measurable effect upon growth. The poplar leaf spot caused by *Marssonina brunnea* can cause problems to some clones.

Poplar species and varieties can vary considerably in their resistance to cankers and leaf rusts, which can cause both premature defoliation and death of susceptible trees. Many clones have been produced in breeding programmes in continental Europe and vary in their wood quality, growth rates and resistance to diseases.

In 1985 a number of new Belgian clones were introduced to Britain (Jobling, 1990; Potter *et al*., 1990). They were the result of nearly 20 years of disease screening, testing and selection for resistance to the fungi *Melampsora*, *Marssonina* and *Discosporium*. Screening for disease resistance was done before selection for morphological and production characteristics. The new clones differed from those that had previously been planted in Britain in that they were *P. trichocarpa* × *P. deltoides* (=*P.* × *generosa*) crosses, with parents originating from similar latitudes to those of Britain. They seemed promising and were quite widely planted. However, new pathotypes of the fungi appeared in 1994 and 1997 (Tubby, 2005), and by the summer of 2005 several of the Belgian clones were killed in various parts of the country. As a result the Forestry Commission ceased maintaining a list of approved varieties since it appeared that none could be guaranteed to remain disease free.

Work on both *Populus* and *Salix* clones being grown both for timber and biomass production has shown that establishing plots with mixtures of clones results in significantly more dry-matter production than single-clone plots. This is ascribed, at least in part, to reduced attacks by foliar rusts. Disease onset is delayed, build-up is reduced and disease levels at the end of the season are significantly lower than in monoclonal stands (Dawson and McCracken, 1995; McCracken and Dawson, 1996; Tubby, 2005). According to Tubby (2005), mixtures are likely to be most effective if the component varieties are disease tolerant rather than disease resistant ('tolerance' here implies that although the pathogen can infect the host plant only superficial damage is caused). Disease tolerance is generally controlled by many genes and is more stable than outright disease resistance, which tends to be controlled by a single gene. A consequence of single-gene resistance is that small changes in the pathogen can overcome this defence, with serious consequences.

Most poplars are susceptible to bark stripping by grey squirrels. Defoliation can be caused by sawflies and leaf beetles, and serious damage to the timber may result from the larvae of an agromyzid fly, which bores long tunnels in the stem cambium. An aphid, *Pemphigus bursarius*, migrates in summer from black poplars (especially Lombardy poplars) to the roots of lettuces, sowthistles and related species; a second species, *Pemphigus phenax*, migrates to carrots (Blackman, 1974). Another aphid, *Dysaphis apiifolia*, similarly attacks celery. Quite serious economic damage can be caused if poplars are planted for shelter in regions where such crops are grown.

Propagation

Poplars are normally propagated from cuttings in open nursery beds. For the majority of clones these are taken from 'ripened' hardwood cuttings (i.e. from dormant woody stems). Details are described by Jobling (1990). Propagation from seed is rare in Britain.

Area and yield

According to the Forestry Commission's (2003) inventory, there were about 10,000 ha of poplars, mostly hybrids, in about 2000. Yield classes of up to 14 m^3 ha^{-1} $year^{-1}$ were normal with the older clones, but the new ones were said to be capable of 18–22 m^3 ha^{-1} $year^{-1}$. Rotations of between 30 and 40 years were anticipated.

Timber and uses

The quality of timber of different poplar clones can vary considerably. However, the wood of most poplars is the best of all temperate timbers for peeling into thick veneers. It is soft, light coloured, of low but variable density (about 300–550 kg m^{-3} at 12% moisture content) and fine textured, but quality varies according to species, region and conditions of growth.

One of poplar's main assets is that it can be peeled with no prior treatment, due to its high moisture content. The wood is valued for some special purposes because it is tough for its weight and has the unusual attributes of bruising rather than splintering when subjected to abrasion (which makes it valuable for pallets), and of smouldering rather than igniting when violent friction or heat is applied, hence its use for brake blocks and flooring round fireplaces.

The wood is usually white and free of taints and smells, and is therefore valuable for use in contact with food (e.g. vegetable crates). The timber is not durable and the heartwood is resistant to penetration by wood preservatives (Anon, 1980). It is, however, a good sawtimber when dry, being stable and taking a good finish. It can be used for joinery and even for making some musical instruments.

Large areas of poplar were established in the 1950s and 1960s for the match and horticultural veneer markets, but these are declining because imported matches are cheaper than those made of British-grown poplar, and crates made from veneer are giving way to plastic containers for fruit and vegetables. There are other uses for veneers, however, such as separators for loads of bricks when they are being transported.

There has been considerable recent interest in growing poplars as short-rotation biomass crops for the production of energy or industrial uses, particularly in countries that do not have large reserves of fossil fuels (Hummel *et al*., 1988), and as a species in 'agroforestry' systems (Beaton, 1987).

Place of hybrid poplars in British forestry

Hybrid poplar cultivation is very lucrative in parts of continental Europe and other places well suited to their growth. The attraction is their rapid growth as well as the many uses to which poplars can be put: they can provide industrial wood, energy, fodder for animals, shelter and timber for domestic and farm use. However, if an industry is to develop based on poplar, sufficient supplies must be available, and it has been estimated that this would require additional planting at the rate of something like 1000 ha year^{-1} for 25 years. This is unlikely to happen. Poplars in Britain appear to be too prone to diseases for an industry to develop, and they will therefore retain their traditional roles as trees for screening, shelter and ornament rather than timber production.

POPULUS NIGRA L. — Black poplar

Black poplar is Britain's rarest large native tree. It is potentially long-lived and tall, up to 35 m, and has survived either as single trees or small groups along river and stream sides and on floodplains. This type of land has mostly been drained and cleared for agriculture over the centuries (Peterken and Hughes, 1995). It has only survived at all up to the present, mostly in east and central England, because it was considered an attractive and useful timber tree. It was propagated from cuttings taken almost exclusively from male trees because females were considered a nuisance due to the plumed seeds that have large quantities of fluff attached (Tabbush, 1996; Winfield *et al*. 1998). This practice has led to a narrowing of the genetic base because cuttings were probably taken from relatively few specimens.

The British black poplar belongs to the subspecies *betulifolia*. It is on the verge of extinction in large parts of Western Europe (Cagelli and Lefèvre, 1995). The maximum number of trees in Great Britain and Ireland is believed to be about 7000 (Cottrell, 2004), of which as few as 600 may be female. It hybridizes with other species of poplars. Molecular analyses have demonstrated that the British population has low diversity, compared to that in other European countries, and that there is a great deal of clonal duplication. Modern molecular methods provide the opportunity for conservation efforts to be concentrated at the level of the clone rather than that of the individual tree. Work by a number of conservation organizations is attempting to ensure that the species is saved in Britain.

Silviculture is similar to that for the hybrid poplars. Historically this species was widely used as beams in the construction of farm buildings.

Timber

The timber of black poplar is often described incorrectly. Unlike most other poplars, it has a very distinct heart/sapwood interface with white/creamy sapwood, and the heartwood is a light olive-green colour. It is regarded as a decorative timber and was once widely used in cottage joinery. It takes paint very well.

POPULUS TREMULA L. Aspen

Origin

According to Worrell (1995a), aspen is probably the world's most widely distributed tree. Its latitudinal range extends from as far north as trees will grow in Norway (71° N), southwards to North Africa, and its longitudinal range goes to eastern Russia and Japan.

Aspen is native throughout Britain, and northern and central Europe, as a widespread but infrequent species. It is most common in the north and west in many different types of woodland, and is particularly common in the Scottish Highlands and Islands, where it occurs on a diverse range of sites, from sea cliffs to near the tree line.

Climatic requirements

The enormously wide natural range of aspen demonstrates that it is tolerant of a huge variety of climatic conditions. In Britain it will grow in exposed situations and is cold hardy and frost resistant. It will grow at higher elevations than any other poplar.

Site requirements

It thrives on a wide range of sites, from slightly dry to wet soils of poor to rich nutrient status (Forest Research, 2011). It will tolerate wet conditions and droughts but is most common on sites where other poplars also thrive: river banks and in gulleys beside streams.

Aspen will grow well on acid sandy soils and neutral to alkaline clays, but according Worrell (1995b), it grows fast and to its biggest dimensions on freely drained mineral soils, particularly on flushed fine sand/clay; its possible use as a component of forest plantations should be restricted mainly to such sites. Peats should be avoided.

Other silvicultural characteristics

Aspen is a relatively poorly formed tree in Britain. It is short-lived (50–100 years) and will grow to 20 m tall. Though regarded as a light demander, it is unlike many other poplars in that it is sufficiently shade-tolerant to be able to form a stable part of a woodland canopy with a wide variety of other species, either as single trees or in small clonal groups derived from suckers, or on the fringes of conifer forests. In this respect, it does particularly well in mixture with species that cast only a relatively light shade, including Scots pine and birch. In woodlands dominated by dense-canopied shade-bearers it requires gaps created by disturbance of some kind to maintain itself. Aspen self-prunes well, even in relatively open stands.

Aspen will not coppice after about 5 years of age, but it produces suckers freely and prolifically, sometimes up to 40 m from the parent tree, and forms quite extensive clonal colonies in a rather similar way to cherry. Clonal colonies can be eliminated by girdling the parent tree 4–5 years before felling it. This leads to suckers from these trees dying out.

Contradictory statements can be found in the literature about its palatability to deer. In southern England it appears to be unattractive and consequently often escapes browsing damage completely, while Worrell (1995b) states that in Scotland its apparent palatability to deer and grazing animals has led to the widely held view that aspen is scarcer today than in the original forest cover. This difference possibly arises because aspen is more palatable than the main alternatives in much of Scotland (often spruce, pine or heather) but less so than alternative broadleaved species in many English woodlands.

Aspen is said to be host to a large number of invertebrate species (possibly around 190), including a unique and endangered population of saproxylic insects, which depend on decaying wood, and also a number of hole-nesting birds.

Diseases

In common with other poplars, aspen can be attacked by leaf rusts, *Melampsora* spp., which can result in serious defoliation, while older and larger trees can be killed by the stem rot *Phellinus tremulae*. Bacterial canker is also more damaging to aspen than to many other poplars. However, information about the disease susceptibility of aspen is relatively scanty.

Natural regeneration

Natural regeneration from seed is rare and has never been recorded in Britain. As mentioned above, regeneration is mostly achieved by suckering.

Flowering, seed production and nursery conditions

The production of fertile seed seems to be rare in Britain though its frequency is unknown. In Scotland seed matures from the middle of May to the beginning of June and is wind dispersed. The viability of freshly collected seed is reported as high, but at room temperature it declines to zero within about 2 months. It should therefore be sown immediately after collection. On suitable sites germination occurs in less than 24 h.

Aspen can be grown and will regenerate from seed but is normally propagated from root cuttings, root suckers, or leafy softwood cuttings from the current year's shoot (Worrell, 1995b). Cuttings from dormant woody stems, which are used for other poplar species, are not successful with aspen.

Provenance

A large amount of genetic variation has been reported in continental populations of aspen, but no work of this kind has been carried out in Britain.

Limited trials of a small number of Scottish clones have shown good survival and reasonable growth from native material, but there are selected Scandinavian clones that can give faster growth rates (Forest Research, 2011). In contrast, Worrell (1992) speculated that since aspen was an early arrival in Britain after the ice age, the survival and growth of continental provenances might be expected to be much poorer than British provenances, particularly when planted in the north and west of Britain.

Growth and yield

In comparison with other poplars, the average growth rate of aspen is slow and it does not attain large dimensions. This seems to be a particular characteristic of British aspens where, in comparison with those from continental Europe, trees are rather poor. On the continent aspen is a significant timber-producing species (Worrell, 1995b).

Timber and uses

The timber of aspen is similar to that of other commonly grown poplars, though possibly of finer texture than faster-grown kinds. At about 430 kg m^{-3} it is not dense, being similar to willow. It is used for the same purposes as other poplars. Its timber is currently acceptable in Britain as chipwood and could complement the production of poplar timber in the lowlands. Historically aspen has had two specialized uses: making arrow shafts and clogs.

Aspen is an excellent amenity species, with bronze spring foliage and a strikingly yellow autumn colour. These features, and the rustling action and sound of the leaves in a breeze, make it appealing.

Place of aspen in British forestry

Aspen is regarded by Forest Research (2011) as a species that is unlikely to be affected by climate warming and that could find an expanded role as a broadleaved component of conifer plantation forests in upland Britain. It also has a potential place in native woodland establishment and restoration, where suitable planting stock is available. It has been neglected until recently in much of Britain. Timber production from aspen is likely to remain very limited.

PRUNUS L.

The genus *Prunus* contains over 200 species, many of which are found in the northern hemisphere. It includes plums, cherries, almonds, apricots and peaches. Two species are native to Britain. The wild cherry or gean is by far the more important. The other species is the rather confusingly named bird cherry, *Prunus padus* L.

Bird cherry is usually a small, suckering tree, which grows to a maximum of 15 m tall, most commonly in Scotland and northern England. It is rare in southern England (Leather, 1996). It occurs on acid soils, especially in valleys and wet fen woodland. In drier areas it grows where the groundwater is calcareous. The tree is hardy but not tolerant of exposure to strong winds. It is not considered further here.

PRUNUS AVIUM (L.) L. — Cherry, or gean

Origin

Cherry is native to Europe, North Africa and western Asia. It occurs throughout Britain but its regional distribution is patchy, and it is less common in Scotland than elsewhere. It is typically found in small groups, often on the margins of woods. This may be because of the more favourable growing conditions found on banks along the boundaries of woods or possibly because it was planted there.

Climatic requirements

Cherry is essentially a lowland species, seldom being found above 300 m in elevation. It tolerates exposure badly, becoming deformed. It is very winter hardy, but flowers can be damaged by late spring frosts.

Site requirements

Cherry grows best in deep, light, silty, fertile soils with a good water supply, but will grow reasonably well in many soil types and in pHs ranging from 5.5 to 8.5. This has made it a common species for planting in farm woodlands. It does well on the deep soils developed in the thicker layers of drift over chalk and limestone, and on deep-flushed soils on lower valley slopes. Parts of the Sussex and Wiltshire downs, the Chilterns and the Cotswolds are particularly suitable. Soils to avoid are: shallow ones where the weathering bedrock is within 40 cm of the surface; sands; exposed sites; and sites prone to waterlogging.

Sites for establishing cherry orchards for fruit production are on light, well-drained soils such as fertile, clayey, alluvial soils (brickearths) and light-to-medium loams where there is good under-drainage. Fruiting trees do not thrive on cold, heavy clays or badly drained soils of any kind.

Other silvicultural characteristics

Cherry is a medium-sized tree that very seldom grows taller than about 25 m. It is easy to establish and is productive for a broadleaved species. Rotations are short, and the tree has attractive flowers and autumn colour and a much sought-after timber.

The species is strongly light-demanding, except when very young. It has good apical dominance and relatively weak phototropic tendencies. This usually results in it developing and retaining a single straight leading shoot. Because most trees are well formed, stocking levels can be lower than with other more variable broadleaves. They are often planted at spacings of about 3 × 3 m. Partly because of this, branches, which are produced in whorls, tend to grow large. They are also retained for many years after their deaths and will form dead knots in the wood unless timely pruning up to a height of at least 5 m is carried out. Some people believe that pruning can cause a change in colour in cherry wood, though this is possibly ascribable to infection by silver leaf disease (see Diseases section, below).

Young plants are sensitive to competition, and full weed control can more than double early height growth. Cherry grows faster than almost any other species in tree shelters. The tree coppices rather poorly, but prolific vegetative regeneration from root suckers occurs, so that clumps of cherry are often clonal (see Natural Regeneration section, below).

Cherry has a useful place as an early-maturing component in mixtures with other broadleaves. Height growth is well matched to that of the larches for the first 45 or 50 years (i.e. all of a larch rotation). It may suppress oak when planted in mixture, but mixtures with ash are also appropriate, the cherry being removed 10–15 years before the ash or possibly at the same time.

Cherry is a rather short-lived tree and liable to windthrow and heart rot after 60 years. There is often a race against time to achieve sawlog sizes before rot sets in. Thinnings must be heavy and regular to develop unimpeded crowns and suitable diameters early, since recovery from suppression is poor in stands over 40 years old. It is often regarded as an ideal species for woodland edges, where crowding is not a serious problem and the benefits of its attractive appearance are most obvious.

A major virtue of cherry is that it is not often damaged by grey squirrels, but deer are serious pests and can be very damaging. The fruits are eaten by many small mammals and by birds, which is good for wildlife conservation but a nuisance to those who want to collect seed.

Other aspects of the silviculture of cherry have been described in detail by Pryor (1985, 1988).

Diseases

Cherry leaf spot disease, caused by the ascomycete fungus *Blumeriella jaapii*, is regarded as the worst problem of wild cherry in some European countries, and breeding to develop resistance to it is common. It causes premature defoliation, reduced vigour (especially diameter growth) and reduced winter hardiness, which can result in death.

Cherry sometimes suffers from a bacterial canker, *Pseudomonas syringae* pv. *morsprunorum*, that characteristically causes exudations of gum from the bark. It is much more common in orchards of fruiting cherries and plums than in wild woodland trees, because the latter have a much wider genetic base. According to Roach (1985), English cherry orchards suffer from it more than those in the drier areas of France and Italy. It is said to be particularly associated with sites where soils are deep and well drained and, possibly, where soil potassium levels are low (MAFF, 1980). To minimize the risks of bacterial canker in any planting scheme, Kerr and Rose (2004) recommend that the best approach is to replicate the natural pattern of the species in British woodlands, where it is usually found singly or in small groups in mixed broadleaved woodland containing a maximum of 20% cherry.

Silver leaf disease, *Chondrostereum purpureum*, is a fungal disease that infects wild cherry, among a number of other species, through wounds, including pruning wounds. It can kill trees. Since the fungus produces most of its infectious spores in autumn and winter, pruning should always be done in summer so that the wound has time to recover.

Cherry is also attacked by a number of virus diseases. The cherry blackfly, *Myzus cerasi*, forms colonies in spring on new growth: it causes leaves to curl, stunting of shoots and may result in dieback.

Natural regeneration

Cherry produces suckers in great numbers after felling, so small, dense, clonal clumps can often be found. Regeneration from seed disseminated by birds also occurs as rare scattered individuals, and presumably also among the suckers that regrow, but it is not possible to distinguish between a sucker and a seedling without uprooting the trees. Those that survive beyond the juvenile stage are mostly on the edges of woods and in big gaps.

Flowering, seed production and nursery conditions

The tree flowers from early April to mid-May; fruits ripen in June and July, and are commonly collected for seed in September. Cherry normally flowers at less than 10 years old and produces good seed crops every 1–3 years, especially after the age of 30. In natural conditions they are disseminated by birds and small mammals, and seed orchards need to be protected from birds by netting. There are about 5100 seeds kg^{-1} (range 3200–6600), of which 80% normally germinates. Aldhous (1972) stated that cherry seed should be kept cool, in airtight containers, between the time of extraction from the fruit and sowing or stratification. It can be sown immediately after collection, or stratified for 4 months and sown in March or early April.

Genetically improved wild cherries were becoming available for the first time in 2012. Their use is expected to reduce rotations from the current 50–65 years by as much as 10 years. The improvement was undertaken by conventional breeding after selecting parent trees for form, vigour and disease resistance.

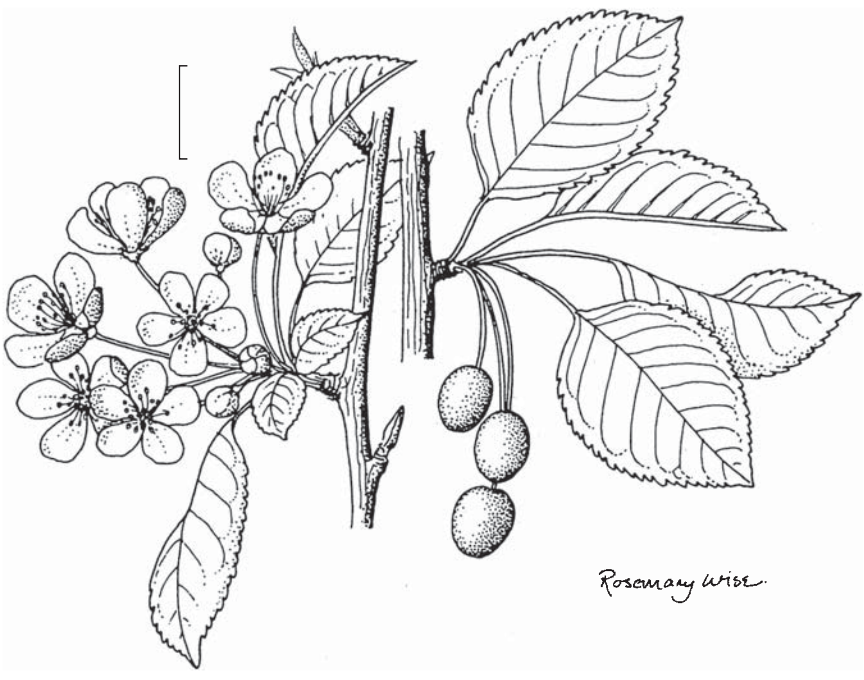

Fig. 26. Cherry, *Prunus avium*.

Provenance

According to Forest Research (2011), there is limited knowledge of provenance variation, and it recommends that seed from seed orchards or good British stands should be used. Material from eastern and southern Europe is not adapted to British conditions and should be avoided.

In continental Europe different races and even subspecies have been recognized, but no work of this kind has been done in Britain. Cherries cultivated for their fruits are derived from two species: the sweet ones are *Prunus avium*, and the acid Morello varieties are *Prunus cerasus*. Duke cherries are considered to have arisen from crosses between the two (Roach, 1985).

For many years up to 2012 wild cherry planted in Great Britain was of continental origin, unknown quality and uncertain adaptability. Seed was collected from stands bred to produce heavy crops of large fruits and to have a wide, open and strong branching habit for ease of picking. These are often called 'jam factory' cherries by foresters. By contrast, trees selected and bred for timber production have light branching and vigorous apical growth.

Kerr and Rose (2004) described an attempt by East Malling Research (EMR) in Kent to breed and commercialize well-formed, canker-free stock in the 1990s. They tested five clones of cherry that were subsequently sold as 'Wildstar' cherries. Four years after planting only one of the clones turned out to be canker-free and to have good form. The other four showed no superiority, either in form or resistance to the canker *Pseudomonas syringae* pv. *morsprunorum*, compared with unimproved stock. The relative failure of this enterprise was ascribed to an inadequate period of testing.

Yield and rotations

Average yield classes of 6–10 m^3 ha^{-1} $year^{-1}$ are found on most sites, which is high for a broadleaved species. Rotations, at about 60 years, are only 5–10 years longer than for most conifers and much shorter than for most broadleaved trees.

Timber

Cherry is sought-after for furniture in particular and for veneer, turnery, cabinet making and decorative joinery. Demand for wild cherry timber is high and greatly exceeds supply, and top-quality wood is hard to find and expensive. The best cherry has a uniform, honey-coloured wood and a silky grain. Butts with a variable colour and 'green' rings are worth only a fraction of the price of the best timber. The average density of the wood at 15% moisture content is about 630 kg m^{-3}. It is not durable outdoors.

The timber is described by Desch and Dinwoodie (1981) as being falsely ring-porous because of the aggregation of vessels at the beginning of each annual ring. It is tough but not as tough as ash when seasoned. It usually works, polishes and glues reasonably well, but unless it is dried carefully and slowly it is inclined to shrink on drying and is rather prone to bowing.

Place of cherry in British forestry

Interest in cherry arises from the high value of its timber, its fast early growth, and its attractive flowers and autumn colour. It will remain an important but nevertheless minor component of broadleaved woodlands.

PSEUDOTSUGA MENZIESII (Mirb.) Franco — Douglas fir

Origin and introduction

There are six species of *Pseudotsuga*: four in eastern Asia and two in western North America. Douglas fir has a wide natural distribution and is a species of great commercial importance in its native North America. It occurs along the Pacific coast from northern British Columbia to northern California, the Rocky Mountains and Mexico, and was introduced to Britain in 1827.

Climatic requirements

The species is moderately accommodating but tends to grow best in the wetter western parts of the country, and satisfactorily though more slowly in the lower rainfall areas of south-east and eastern England, provided there is sufficient soil moisture. It can be damaged by late spring frosts in low-lying places, though less severely than the spruces (Macdonald *et al*., 1957). Douglas fir will not tolerate serious exposure to wind, becoming badly deformed; it tends to be more prone to windthrow on unsuitable sites than many conifers. The tree requires reasonably sheltered conditions for healthy growth. Douglas fir is one of the least tolerant of all species to atmospheric pollution.

Site requirements

Douglas fir is usually regarded as a species best suited to the middle and lower slopes of valley bottoms of at least moderate fertility. It needs a deep, well-drained soil in order to develop a good root system. The soil can be clayey, if on a slope, and the tree will grow well on sandy soils. Adequate moisture and soil aeration are essential. Douglas fir is therefore unsuited to heavy, waterlogged soils where rooting is restricted. If planted on such sites it becomes unstable; it is one of the least tolerant of all species grown in Britain to the anaerobic conditions resulting from flooding. It is also unsuited to calcareous soils and, like Sitka spruce, will not grow in competition with heather because it cannot compete with it for nitrogen and so becomes deficient. On sites where it will thrive, especially in the west, Douglas fir is one of the most desirable species as it is both productive and has a valuable timber.

Other silvicultural characteristics

Most of the tallest trees in Britain are Douglas firs of 60 m or more. Mabberley (2008) mentions a specimen that was felled in British Columbia in 1895 of 133 m, and a tree of 138 m has been claimed. The theoretical maximum height a tree can grow to is said to be about 140 m.

The tree is fast growing, and its stems have a tendency to sweep when young. Grass control is essential for successful establishment of young plants, but the species is more competitive with weeds than many other trees and eventually casts a heavy shade. Its litter decomposes readily on most sites.

Douglas fir is difficult to grow in mixtures with other species, especially broadleaves, because it tends to suppress them. However, it is sufficiently shade-bearing to be useful for planting beneath well-thinned canopies, especially for enriching scrub and in neglected woodland, but it is not so shade-bearing that it will form a lower storey to another species, unless it has a very light canopy.

As with larch, systematic thinning should never be practised with Douglas fir because trees are so variable in form. For this reason, selective thinning is essential. Unless stems are pruned the timber will be knotty because branches tend to be persistent.

Pests and diseases

It is less susceptible to attack by *Heterobasidion annosum* than many conifers. The woolly aphid, *Adelges cooleyi*, which feeds in spring and early summer, causes yellowing and deformity of the needles and can severely check the growth of some provenances when the trees are young. However, in general, Douglas fir remains healthy and well adapted to many parts of Britain.

Natural regeneration

Natural regeneration occurs only occasionally on a scale sufficient for it to be a reliable means of crop replacement, in stark contrast to Sitka spruce in many areas. This is partly because trees are usually felled before seed production becomes sufficient.

Flowering, seed production and nursery conditions

The tree flowers in April; seeds ripen and are ready for collection in September, and are dispersed naturally from then until late March.

Cones should be collected when they are a light golden brown or yellow colour. The earliest age at which the tree bears seeds is 30–35, but the best seed crops occur at intervals of 4–6 years, usually from the age of 50 or 60. This may be beyond the length of normal commercial rotations. There are approximately 87,000 seeds kg^{-1} (range 65,000–100,000), of which 70,000 are normally viable. Seed collected in Britain is often infested with a seed wasp, *Megastigmus spermatrophus* (Forestry Commission, 1961), which can seriously reduce the quantity of sound seed (Kennedy, 1974). For nursery purposes seed is usually stratified or pre-chilled for 3 or more weeks and sown in late March.

Provenance

For the western parts of Britain the best origins come from low elevations with high rainfall in the state of Washington, from the western foothills of the Cascade Mountains, westwards along the 46th parallel to the low coastal range and north as far as Forks in Clallam County (Lines, 1987). Material from the south Washington Cascades can be used on suitable soils in drier zones of eastern Britain (Forest Research, 2011).

Area and yield

According to the Forestry Commission's (2003) inventory, Douglas fir had been planted on 45,000 ha, or 2% of forest land, in around 2000. Mean yield classes range from 10 to 15 m^3 ha^{-1} $year^{-1}$ in different regions of

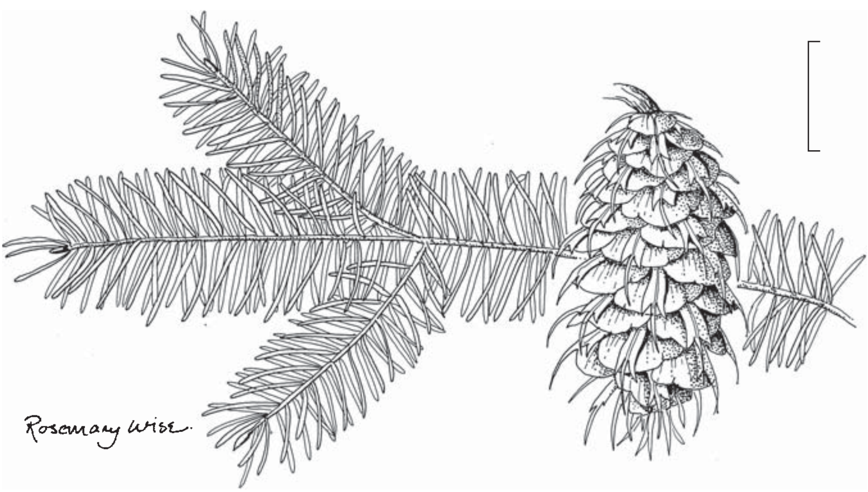

Fig. 27. Douglas fir, *Pseudotsuga menziesii*.

Britain (Nicholls, 1981), and the maximum is 24. Rotations of maximum mean annual increment are similar to those of Sitka spruce, ranging from 50 to 65 years.

Timber

Knot-free Douglas fir is one of the world's finest coniferous timbers, valued for veneering, interior and exterior joinery, and decoration. The timber is light reddish-brown in colour and dries with little degrade. It is fairly stable and presents no special difficulties in sawing and working, though it has a tendency to split when nailed. It is only moderately durable out of doors, and the wood is much less permeable to preservatives than Scots pine and tends to 'bleed' in service. The average density at 15% moisture content is about 530 kg m^{-3}.

Douglas fir timber is often sold as 'Oregon pine'. It attracts higher prices than most other conifers. Markets for small sizes are similar to those for spruce and pine, and for large timber (60–90 cm dbh) there is a distinct market for knot-free structural beams for major building projects (Wilson, 2010). Little clear joinery wood is produced in Britain, but what is available is suitable for carpentry and structural work or for use in the round as transmission poles and fence posts.

Place of Douglas fir in British forestry

As stated above, Douglas fir is one of the world's best coniferous timbers, and demand is likely to ensure that it retains its place as an important but nevertheless relatively minor species in British forestry. The main limitation to its use is the availability of suitable sites for growing it.

QUERCUS L. — Oak

The genus *Quercus* contains about 600 species, which are confined to the northern hemisphere: 27 are European species (Mabberley, 1990). Most oaks occur in more southerly latitudes than Britain, in warm temperate and even tropical montane climates. By far the greatest concentration is in Mexico, which has about 125 endemic species and a further 75 that extend either north into the USA or south towards Columbia. Only four oaks have any potential in Britain, of which two are native: *Quercus petraea*, sessile oak, and *Quercus robur*, pedunculate oak.

QUERCUS CERRIS L. — Turkey oak

Origin

Turkey oak is indigenous to southern Europe and south-west Asia. Its time of introduction to Britain is uncertain, but it was in cultivation by 1735. The tree is superficially similar to the two native species of oaks. It grows to considerable sizes and usually has excellent form. There is apparently a widely held belief that Turkey oak will hybridize with pedunculate oak, but unpublished molecular work by Kevin McGinn at Reading University in 2009 concluded that this is unlikely to have a scientific foundation. He believed that the great variation in leaf shape of *Quercus cerris* creates much confusion.

Climate and site requirements

Turkey oak will tolerate strong winds, but it is essentially a lowland tree.

It grows well in a wide range of soils provided they are moist, though not in dry sandy ones or organic soils. It is unusual in that it will thrive in calcareous soils, even where they are shallow. It can grow under a light woodland canopy or in the open.

Other silvicultural characteristics

Turkey oak is a fast growing and attractive tree that will reach about 40 m tall. A really good-looking, well-formed oak should always be suspected of being a Turkey oak. It grows faster than both sessile and pedunculate oak, and coppices well.

Pests and diseases

Turkey oak is the alternate host of the knopper gall wasp, *Andricus quercuscalicis*, which became common in the 1980s and caused concern about seed production and consequent regeneration of the pedunculate oak. The galls form on the acorns of pedunculate oak. They are typically convoluted and make the acorns infertile. The wasp has a complex life cycle involving the development of an asexual generation on pedunculate oaks, alternating with a sexual generation, which develops in tiny galls on the male flowers of Turkey oak (Speight and Wainhouse, 1989). Knopper galls only occur on pedunculate oaks if Turkey oaks grow close by.

Natural regeneration

Turkey oak seeds regularly, and regeneration is common. Macdonald *et al*. (1957) believed that if the tree were more widespread it would speedily naturalize itself, as sycamore has done.

Timber and uses

Jones (1959) stated that, from the very first references to Turkey oak have almost universally condemned it as a timber tree, so it has been planted mainly for ornament. The timber is hard and brittle, and has an even wider band of sapwood than the two native oaks. It seasons poorly, shrinks considerably on drying and has a limited natural durability. It is suitable only for rough work such as shuttering. Its average density at 15% moisture content varies between 800 and 880 kg m^{-3}, more than 100 kg m^{-3} higher than that of the two native oaks. This makes it an attractive fuelwood, since there is an almost perfect correlation between the amount of heat produced and wood density. It was widely planted as a fuelwood in some parts of Europe in the 1800s (e.g. Majer, 1984).

Place of Turkey oak in British forestry

The main virtues of Turkey oak are its resistance to exposure and adaptability to calcareous soils. It can be of value as a windbreak, especially in the south of England. Unfortunately, its timber is much inferior to that of most hardwoods, and this limits its potential uses considerably. Also, as an alternate host of the knopper gall wasp, which can destroy acorns of pedunculate oak (see above), it is probably better removed from British woodlands than encouraged in them.

QUERCUS PETRAEA (Mattuschka) Liebl. Sessile oak

QUERCUS ROBUR L. Pedunculate oak

These two species are described by Muir *et al*. (2000) as 'a classic example of a taxonomic group that has significantly challenged existing species concepts'. Doubts have been expressed by taxonomists for many years as to whether they are in fact separate species. However, Muir *et al*. have demonstrated, by using microsatellites in molecular analyses, that they are definitely separate taxonomic units. Intermediates between the two species are quite common, and these are hybrids.

These two oaks represent the most iconic of British (or perhaps English) trees. They are among the tallest, most massive and longest-lived trees, though the record for all these characteristics goes to other species. Some have strong historical associations, and oak is even used as the logo of many organizations, including the National Trust.

Because the similarities are greater than the differences, the two species are dealt with together below, and Table 2 shows the main differences. Detailed accounts of the two British oaks have been written by Jones (1959), Morris and Perring (1974), and Newbold and Goldsmith (1981), from which much of the following information originated.

Table 2. Main differences between sessile and pedunculate oaks.

Character	Sessile oak	Pedunculate oak
Site/soil preferences	Acid; freely draining	Wetter, heavier and more alkaline
Frost susceptibility	Slightly less frost tender	More frost tender
Drought resistance	Relatively resistant	Not resistant. Tendency to die back
Shade tolerance	More shade tolerant	Less shade tolerant
Early growth	Relatively slow	Relatively fast
Form of tree	Straighter, taller, longer clear bole; persistent main stem	Low branching, short bole; main stem not persistent
Epicormic shoots	Less liable to produce them due to earlier flushing. Less defoliation risk	More liable to produce them due to later flushing and defoliation
Leaf emergence	One week earlier than pedunculate oak	One week later than sessile oak
Defoliation by caterpillars	Less likely due to earlier flushing	More likely due to later flushing
Acute oak decline	Possibly less susceptible	Possibly more susceptible
Acorns	*c*.316 kg^{-1}	*c*.273 kg^{-1}
Oak lactones and phenolics in wood	High lactones, low phenolics: good for maturing whisky	Low lactones, high phenolics: less good for maturing whisky

Origin

The oaks are native to Europe, including Britain and Ireland, and to western Asia. Within Britain pedunculate oak is dominant mostly in the lowlands of the south, east and central parts of England, while sessile oak is characteristic in the north and west of England, Wales, Scotland and Ireland. The ranges of the two species frequently overlap, and planting over many centuries has obscured the differences in the natural ranges.

Climatic requirements

Sessile oak is said to be less frost tender than pedunculate oak though both species suffer badly from late spring frosts, when temperatures of −3°C will kill new foliage. They usually avoid such frosts by being among the last trees to come into leaf, normally in mid- to late April. Sessile oak grows best on south-facing slopes where summer warmth can stimulate fast growth.

Oak woodland is rare above 300 m altitude in Britain (Jones, 1959). Low wind-trimmed scrub, usually of sessile oak, is often found in exposed situations in the western hills. There are exceptions: Wistman's Wood, at 365–420 m on Dartmoor, is composed of pedunculate oak scrub.

Site requirements

Pedunculate oak is dominant and grows best mostly in the English lowlands on heavy, moister, richer and especially basic soils, while sessile oak, which is more drought resistant, is characteristic of deep, freely-draining, drier siliceous soils in the north and west. The ranges of the two overlap on the damper acid sands and, as stated above, planting has obscured the differences in the natural ranges. Both species tolerate an extremely wide range of soils and often grow together. They are much less site-demanding than many other broadleaved trees.

Pedunculate oak tolerates some waterlogging. Its strong, deep-rooting system allows the species to evade droughts on many soils and makes it windfirm. Shallow, badly drained soils and compacted soils should be avoided. Though it will grow well and root deeply on heavy soils, pedunculate oak benefits from drainage on certain sites (Evans and Fourt, 1981).

Sessile oak is intolerant of flooding. Throughout the lowlands of central, southern and eastern England it is generally restricted to base-deficient sands and gravels where it will do well, but sites of at least moderate fertility are required for acceptable rates of growth. Soils that should be avoided are drought-prone and sandy soils, which give rise to a high proportion of trees with shaken timber (see p. 178), and those with erratically variable water tables, in addition to soils that are shallow, badly drained and compacted.

Within their ranges in Britain the oaks are usually the dominant native trees except that, within the lower part of its altitudinal distribution, beech is liable to be a serious competitor with sessile oak for dominance. Beech is much more responsive to higher levels of available nutrients in the soil than oak; therefore on soils of relatively low nutrient status oak tends to have the advantage.

Other silvicultural characteristics

Among the most impressive oaks in Europe are the sessile oaks in the French forests of Reno-Valdieu and Bellême in Haute-Normandie. Trees of about 240 years old range in total height from 38 to 45 m, with 20–28 m to the first branch: they each contain 10–20 m^3 of timber. In Britain oaks greater than about 27 m tall are not common, and trees taller than 33 m rare. The two species do not differ in respect of the height that they can attain in Britain.

Contrary to popular opinion, the British oaks are not 'climax' species and have none of the characteristics of such species. For example, neither as seedlings nor as adult trees are they really shade-bearing. The widespread apparent 'climax' role of the oaks is due to:

- their ability to outlive most competitors, once established;
- their ability to grow on a wide range of soils; and
- good seed dispersal, which enables them to spread.

Oaks have a considerable pioneer capacity: seed is dispersed widely by birds and mammals, and their large reserves make seedlings competitive with most grasses. They can root quickly in the autumn, withstand summer droughts and can persist in grass until the roots have developed enough to allow rapid shoot growth. Unlike most later successional trees, the oaks are in no way dependent on shade from other trees. In natural conditions they regenerate by species alternation: for example, birch may replace fallen oak trees in northern oak woods, which are in turn replaced by other oaks, but because the oaks are so long-lived the forest remains predominantly of oak. Birch is regarded as an excellent nurse for oak.

In Britain sessile oak is a successional tree in the lower part of its altitudinal range, where the very shade-tolerant beech becomes a competitor for dominance on the more fertile sites. Beech is a stable climax species, being capable of regenerating and self-replacing under the shade of other trees.

Many of the behavioural traits of both pedunculate oak and sessile oak are characteristic of trees in warmer climates. They come into leaf too late to make full use of the growing season and even then are sometimes damaged by frosts. The large fruits are readily killed by desiccation as well as by frosts, and radicles often germinate in the autumn. Seedlings have the ability to shoot and die back repeatedly when growing in adverse conditions, while the taproot thickens and accumulates reserves until it is capable of producing a long, strong shoot in a single season. This is also a feature commonly found in warm climates, as is the ability to produce epicormic shoots, which is an adaptation to fire. Coppicing ability is good, especially in the south, and has probably been selected for by man to some extent through many generations of this treatment in Britain.

The grasses *Deschampsia flexuosa* and *Holcus mollis* are both said to inhibit the development of seedlings, and controlling them with herbicides is necessary.

Young oak trees frequently need some formative pruning if they are to grow straight and unforked. Really badly formed trees can be stumped (i.e. cut off just above ground level) and will usually regrow quickly as straight stems. Natural pruning is not very good, so for the production of high-quality timber high pruning is usually necessary.

Both species are relatively intolerant to shade, but according to Jones (1959), sessile oak is considerably more shade-bearing than pedunculate oak. Many of the differences between the two species, such as the faster early growth of pedunculate oak and the greater suitability of sessile oak for growing in high forest, are in keeping with this difference.

Pedunculate oak has been grown far more commonly than sessile in plantations, possibly because it seeds more frequently and the acorns retain their viability for slightly longer when in store.

Sessile oak is frequently reported to have a better form than pedunculate oak, tending to be straighter and taller, with a greater length of clear bole. Its main stem tends to persist through the crown of the tree; the branches are relatively straight and horizontal; the branching regular with a gradual decrease in size of successive orders of branches and narrow angles between branches; and the foliage is uniformly distributed, forming a dense crown. By contrast, pedunculate oak has a tendency for the main trunk to disappear in the crown; the branches are irregularly divided; the angles between branches wide; and the decrease in size from main branches to twigs is abrupt. The foliage and small twigs tend to be in clusters, resulting in an open crown.

Many of the old oak trees in Britain were grown as standards over coppice, and in these conditions the trees are likely to be significantly shorter than those grown throughout their lives in high forest (Savill and Spilsbury, 1991). As Marshall (1803) observed, presumably about widely spaced trees: ‘Oaks which endure for ages, have generally short stems; throwing out, at six, eight, ten, or twelve feet high, large horizontal arms; thickly set with crooked branches…’. Good comparisons of standards and high forest trees growing in reasonably close proximity can be seen in

Fig. 28. (A) Red oak, *Quercus rubra*; (B) Sessile oak, *Quercus petraea*; (C) Turkey oak, *Quercus cerris*; (D) Pedunculate oak, *Quercus robur*; (E) auricles at base of pedunculate oak leaf.

parts of Germany, such as Iphofen forest in Bavaria, where the differences in height at similar ages are striking.

Constant problems in producing high-quality oak timber are caused by the growth of epicormic shoots and the economic losses associated with shakes in the timber, both of which are believed to be highly heritable (Kanowski *et al*., 1991). They are discussed below.

Epicormic shoots

Epicormic buds that are dormant beneath the bark develop into whiskery shoots when the space and light available to a tree is suddenly increased by thinning and also in response to restriction of the crown or defoliation of the tree by caterpillars. Epicormic shoots produce small knots in the wood, which can decrease its value, except if they originate from the centre of the stem so that it yields what is termed 'pippy' oak, which is decorative and hence valuable. Pedunculate oak is said to be more prone to producing epicormic shoots than sessile because it is defoliated more readily (see under Natural Regeneration, below). Suppressed trees die from the top downwards, and as they do so new epicormics form at successively lower levels. Generally, the better developed the crown, the smaller is the tendency to form epicormic shoots; growers of high-quality oak should always aim to maintain deep-crowned trees. Jones (1959) recorded that when the ratio of diameter of crown to diameter of bole is increasing there is little or no tendency to form epicormic shoots, and the tendency varies with the rate of increase or decrease of the ratio. Wignall *et al*. (1985) found that thinning oaks in summer resulted in less epicormic production than spring thinning. The conventional and widely accepted way to minimize epicormic shoot production is to thin lightly and to ensure that the crowns have room to grow. In continental Europe a lower storey of shade-bearers, usually beech, hornbeam or lime, is often grown with oak to shade the stems and hence suppress the growth of epicormic shoots.

Shake

Oak and sweet chestnut are the two species grown in Britain that suffer seriously from 'shakes' or internal splits in the timber. They occur most commonly on drought-prone sites (Henman, 1984). Water stress is thought to trigger shakes in trees that have a predisposition to the problem. Savill (1986) found that earlywood vessels with greater diameters than average provide the main predisposition. Vessel size has subsequently been found to be a highly heritable characteristic of oak trees (Kanowski *et al*., 1991), so that theoretically it will be possible to select, or to breed, trees with small vessels. In fact, this is currently being done by the Future Trees Trust (see section on Provenance and Breeding, below). Fortunately, it has been found that the trees in any population that come into leaf latest in any year are also those with largest earlywood vessels, and hence are the most predisposed to shake (Lechowicz, 1984; Savill and Mather, 1990). This simple way of recognizing shake-prone trees makes it possible to remove them during early thinning operations, leaving shake-free individuals to grow to the end of the rotation. If trees are marked for removal during the 2–3 week period of flushing in any year, most of those with a predisposition to shake can be recognized and taken out over three or four thinning cycles. The reason for the connection between flushing time and the possession of larger-than-average sized vessels is obscure, but it is possible that the same auxin (indole-3-acetic acid) is responsible for both.

Pests and diseases

A few serious new pests and diseases of oaks have appeared in recent years. Many have been introduced by the ornamental plant trade. The risks associated with the international transfer of material have been known for a long time (e.g. Gibson and Jones, 1977), and they are heightened by the increasing speed and frequency of travel. Some already existing and new ones are detailed below.

Grey squirrels
Oaks of between about 20 and 40 years old are a favourite of grey squirrels, which strip the bark from the upper stem and branches. Unless control can be carried out effectively it is probably not worth attempting to grow oak for timber.

*Oak processionary moth (*Thaumetopoea processionea*)*
A native of central and southern Europe, this was first recorded in the Netherlands in 1991 and was introduced from there into Britain in 2006. Caterpillars attack both species of native oak. Their hairs carry a toxin that can be blown in the wind and cause serious irritation to the skin, eyes and bronchial tubes of humans and animals. Populations of the caterpillars vary widely from year to year and peak occasionally. They can defoliate trees completely, although the trees normally recover the following year. Control measures are extremely difficult to apply effectively and are consequently expensive. They were essentially abandoned in Britain in 2011 and a policy of 'containment' was introduced instead. The spring climate in Britain is unpredictable and is believed by some not to be suited to the long-term survival of the processionary moth. If this proves to be the case then fears about its spread can be allayed, but if it does gain a good hold it may be a considerable problem. In its native southern Europe it is controlled by natural enemies, according to Mabbett (2012).

The knopper gall wasp
This is described in the section on *Q. cerris*. It causes some damage to acorn crops where both Turkey oak and pedunculate oak grow in the same locality. It does not affect sessile oak.

Powdery mildew and other fungi
Powdery mildew, caused by the fungus *Erysiphe alphitoides*, was introduced to Britain in 1908 and is a common foliar pathogen of oak throughout Europe. It attacks young leaves and soft shoots, particularly of young trees,

covering them with a felty, white mycelium, and eventually causes them to shrivel and blacken. Mild overcast conditions promote development of the disease, which usually appears in summer when warmer conditions prevail. It is seldom fatal and trees usually recover completely as they grow.

A large number of other fungal diseases have been listed for oak by Peace (1962) and by more recent authors. In normal circumstances few are particularly threatening.

Acute oak decline

This worrying and relatively recent problem tends to affect pedunculate oak more than sessile oak. It appears to pose a major threat to trees that are more than 50 years old, across central, eastern and south-east England and parts of Wales, as well as neighbouring parts of the Continent. The condition can kill a tree in as few as 4 or 5 years. The syndrome, described by Denman and Webber (2009), is not yet completely understood but is thought to be caused by an interaction between an, as yet, unknown bacterium and the native jewel beetle, *Agrilus biguttatus*. The beetles lay eggs on the bark of sickly trees and the resulting larvae then tunnel through the bark to feed on the phloem and cambium, and this can girdle infested trees. Symptoms include a dark, tarry, fluid bleeding from splits in the bark on stems, and as affected trees approach death there is a notable thinning of the canopy and dieback of the branches. The timber is rendered useless after attacks by the larvae of the beetle, which does not attack healthy trees. Sometimes trees appear to recover though the timber is then blemished.

Gaertig *et al*. (2002), working in Germany, believed that a lack of adequate soil aeration could be a primary cause of oak decline, because fine root formation is reduced in the absence of aeration and this reduces the stress tolerance of the trees. It is also possibly caused by a shortage of soil moisture. There was a serious drought in southern England in 1921 and a period of oak decline developed from 1923 onwards (Day, 1927). On the Continent there was a series of severe droughts from about 1910, and from then up to 1930 oak decline caused consternation. There have been several very dry years from 2009, particularly in south-east England, and these could be a contributory or even the main cause of the recent outbreak. It seems to occur most seriously in the driest parts of the country and mostly on pedunculate oak: the species that requires moister soil conditions. It could be a consequence of climate change.

Natural regeneration

Natural regeneration of both native oaks is usually accomplished in Britain with difficulty, if at all. Some writers (e.g. Rackham, 1980) believe that this is a feature of the last 150 years and that it has been caused by the abandonment of the coppice system of management and increases in the numbers of small mammals, pheasants, squirrels, pigeons and deer, which feed on acorns and browse on seedlings. In addition, the introduction of the oak powdery mildew (see above) in 1908 may be responsible for killing shaded seedlings (Newbold and Goldsmith, 1981). Others, perhaps the majority, believe that oak regenerates in the same way today as it did in former times. It has never been easy. Experience in continental Europe and in the New Forest has been that fencing to protect regeneration from deer browsing is essential. Without this form of protection regeneration will not survive.

There are generally intervals of at least 2 and sometimes up to 10 years or more between heavy acorn crops. In the west germination occurs freely almost anywhere but is best under litter, which has a very suitable microclimate and also offers some protection from predation and frost damage. Temperatures of −6°C for a few hours will kill most acorns (Jones, 1959). In the drier parts of south-east England acorns on the surface fail to germinate because they become desiccated (Watt, 1919). The dormancy of acorns is never deep, and in suitable conditions in autumn some germinate immediately upon falling, but the epicotyls (i.e. the shoots) always remain dormant until they have been chilled over a winter. Dry autumns can be damaging in that they cause the death of roots that emerge from acorns on the surface. If summer droughts occur the acorns that germinate late usually die quickly. Burying acorns by scarifying the soil often results in earlier germination and much more prolific regeneration, in just the same way as has been described for beech, and was once widely practised for regenerating the two oak species. It can be an advantage to create conditions that encourage autumn germination of the radicle so that the seedlings can begin growth early in the spring.

High winter water tables result in high mortality of acorns and seedlings, especially of sessile oak. This is an important reason for retaining a light canopy during the early establishment phase on heavy soils because water tables usually rise on clear-felled sites. Maximum height growth of first-year seedlings occurs in about 30% of full light (equivalent to open-canopied woodland or small clearings), but at least 50% is needed in later years (Jarvis, 1964).

Young oaks are well adapted to survive some browsing by wood mice, *Apodemus sylvaticus*, and bank voles, *Clethrionomys glareolus*, but they do not survive complete defoliation over successive years. Several insects that feed on oak leaves have co-evolved with oaks and time their emergence in spring to the brief period when young oak leaves are most palatable. Defoliation of seedlings by the winter moth *Operophtera brumuta*, the green oak tortrix, *Tortrix viridana,* and other lepidopteran caterpillars, which come down from the crowns of mature oaks before pupation, is one of the main reasons why oaks will not regenerate well under parent trees. Established trees are able to withstand repeated attempts at attack by producing chemical defences (tannins) in their leaves and because they produce several flushes of new leaves each year. For maximum growth and reproduction most caterpillars must complete feeding before any appreciable amounts of condensed tannin is laid down in the leaves. For this reason pedunculate oak, which comes into leaf about a week later than sessile oak in the New Forest, is attacked more easily by defoliating caterpillars. Tannin contents vary widely from tree to tree.

Successful natural regeneration occurs when the canopy is opened rapidly once seedlings are established on the ground because they mostly avoid attacks by defoliators: hence, the use of the uniform shelterwood system is usually considered essential. It is practised impressively in parts of Normandy. Attempts to manage oak by selection or group systems, except by using very large groups, are doomed to failure, and the concept of an intimately mixed, all-age climax oak woodland is impossible, contrary to the beliefs of many officials in County Naturalists' Trusts who frequently attempt, and fail, to create such woodland. One of the major problems with oak regeneration in Britain is that people expect it to happen at no cost and with little effort. This is virtually impossible.

Flowering, seed production and nursery conditions

Pedunculate oak flowers early in May and sessile oak in late May. Acorns ripen between September and November, when they are ready for collection. The earliest age at which woodland-grown trees bear seed is 40–50 years, but the largest amounts are usually after the age of 80 years. Reasonable quantities are produced on average every 3–5 years and good ones at about 8-yearly intervals, or longer. Sessile oak is not such a prolific seed producer as pedunculate oak, possibly because it tends to grow mostly at higher, colder elevations and on rather infertile soils. A consequence of this has been that pedunculate oak has probably been planted on many sites where sessile oak would do better. Also, Jones (1959) stated that acorns used to be transported long distances (e.g. from Sussex to Cumberland) and often did not survive the journeys. The greater ease of storing and transporting pedunculate oak acorns, their larger size and perhaps their more frequent and copious production, all helped to favour pedunculate oak at the expense of sessile oak.

With sessile oak there are commonly 316 acorns kg^{-1} (range 130–649), 80% of which will normally germinate, while pedunculate oak produces larger acorns (273 acorns kg^{-1}, range 110–495). For nursery purposes the acorns should be stored in a cool, well ventilated place, and from January onwards. If signs of shrivelling are observed, they should be sprinkled periodically with water until sown in late March. They can be sown in the autumn they were produced, in well-drained soils, but only if bird predation is unlikely to be severe: protection can be provided by covering the seedbeds with 7–10 cm of extra soil, which is removed in March (Aldhous, 1972).

In some years it can be difficult or impossible to obtain seedlings from nurseries. The irregularity of seeding and the virtual impossibility of storing acorns in a viable condition for more than a few months are serious problems to those concerned with planting. Attempts at preserving acorns for long periods on a large scale have always come to nothing. Among those that have been reported the earliest is probably by Ellis (1768) who found that cleaned and dried acorns enclosed in bees' wax remained viable for a year at least,

> the success of which, if properly followed, may in a few years put us in possession of the most rare and valuable seeds in a vegetating state from the more remote parts of the world, which in time may answer the great end of the improvement and advancement of our trade with our American colonies.

This is a reference to the long duration of sea voyages in the time of sailing ships, when seeds lost their viability in transit. Because of the short period of viability and irregular production, a great deal of the oak seed used in Britain has been imported from continental Europe.

Conservation

The native oaks have 423 species of insects and mites associated with them, far more than any other British plant except the willows, which have 450 (Morris, 1974; Kennedy and Southwood, 1984). This accounts for the considerable value placed on oaks by everyone interested in nature conservation. Some of the invertebrates, such as the caterpillars of the *Tortrix viridana* moth and the winter moth, *Operophtera brumata*, have slightly adverse effects on the growth of oaks in occasional years by causing severe, if not complete, defoliation of trees soon after the first leaves flush in spring. Most invertebrates cause virtually no measurable damage to healthy trees. The caterpillars are immensely important sources of food for fledgling blue and great tits in spring and can be crucial to their survival (Savill *et al*., 2010).

Provenance and breeding

There has been comparatively little work on this subject in Britain. However, the most recent recommendation comes from Hubert (2005) who reported on two series of provenance trials established in 1990 and 1992. They contain continental and British provenances of both native oak species. In terms of height and survival, plants from British 'selected'[1] seed stands have consistently shown good height growth and survival

[1] See endnote on p. 46 for definition of 'selected'.

on most sites. Near-continental sources are average in performance, and Danish and eastern European provenances are poor. British non-selected seed has a variable performance. Scottish provenances when moved south grow slowly but are recommended on more-testing Scottish sites where frost damage is a risk. Much work on the adaptability of the oaks to climate change has been carried out by Kremer in France. Some of his main findings are summarized on p. 4.

The Future Trees Trust established a series of eight Breeding Seedling Orchards (Barnes, 1995) across Great Britain and Ireland in 2001 from the progeny of the best-formed, shake-free, sessile and pedunculate oaks that could be found in Britain, Ireland, and parts of north-west France and the Netherlands. It will probably be at least 2030 before any useful quantities of improved seed come from these orchards. Even when in full production the quantities of seed available will be far too small to fulfil anything but a small fraction of demand. A means of cheap and easy multiplication, such as micropropagation from acorns, is needed urgently if improved oaks are to be made widely available. Unfortunately, this has not yet proved possible on a commercial scale.

Area and yield

Sessile and pedunculate oaks together occupy 206,000 ha or 9% of forest land in Britain, making them the third most common group after Sitka spruce and the pines (Forestry Commission, 2003). Mean yield classes are low, averaging only 3–5 m^3 ha^{-1} $year^{-1}$ (Nicholls, 1981), with a maximum of 8. Rotations for sawn wood or veneer are long, commonly 120 years or more. The best veneer trees in the Spessart region of Germany are grown on 400-year rotations. For economic reasons oak is often grown with a productive conifer, such as Norway spruce or European larch, which will provide some financial return to the owner after 50 or 60 years, leaving a pure crop of oak for the remainder of the rotation.

Timber and uses

There is no reliable way to distinguish between the strongly ring-porous timbers of the two native oaks. It is durable, hard, strong, heavy and attractive, though rather difficult to work. Good oak timber can fetch extraordinarily high prices and is used for furniture, panelling, high class joinery, veneers and barrelmaking. In earlier centuries it was the main shipbuilding timber and it also provided the beams for many of the great buildings in Britain, including York Minster and Windsor Castle, as well as framing for agricultural and domestic buildings. Its decorative appearance, particularly when quarter-sawn (which shows the medullary rays to best effect), made it the dominant timber used for high-quality furniture from 1600 to about 1680, when it began to give way to walnut. Its attributes of natural durability of the heartwood and great strength make it valuable for outdoor work such as fencing, gates and mining timber in the lower grades. In common with sweet chestnut, tannins in the wood (which confer the durability to oak) have a slightly corrosive effect on metals, and the wood becomes stained black when in contact with iron. For this reason, for indoor work oak is always secured with wooden pegs, brass screws or other non-ferrous metals. The average density of the wood at 15% moisture content is about 720 kg m^{-3}.

Oak timber is characterized by having a large number of sapwood rings, usually between 20 and 30 (Savill *et al.*, 1993). Sapwood is far less durable than heartwood, and in this respect oaks compare unfavourably with sweet chestnut, which has a somewhat similar timber but only 2–3 sapwood rings.

The valuable veneer oak grown in the Spessart region of Germany sells for very high prices. Generally light-coloured oak is rare and, because of this, it fetches the highest prices. Narrow annual rings also confer greater value on logs.

Only the best oak trees pay for themselves, and these can be very profitable indeed, but oak timber can be remarkably difficult to sell profitably if it has any of the defects to which it is remarkably prone. Knowles (1821) described three of them as 'foxy', 'doaty' and 'quaggy' oak: its tendency to be reddish in colour (foxy), stained yellow with blackish spots (doaty), or shaken (quaggy). Timber merchants believe that oaks with 'stringy' or 'stripy' bark are much easier to saw than those with 'chequered' bark. Oak also produces large, heavy branches and epicormic shoots. These features all present problems in succeeding in the modern quest for bulk, standardized materials. Even its natural durability is less of an asset today, when most timbers can be treated with preservatives quite easily.

It has been known since at least the time of Theophrastus (371–286 BC) that oaks, like most broadleaved trees, should not be felled when leaves are on the trees because the wood is much more easily attacked by fungi and insects (Theophrastus, 1916). The reason for this is that during the growing season the sapwood contains sugars and other carbohydrates, which make it susceptible to attacks. These carbohydrates are translocated mainly to the roots during the dormant season.

An immensely important historical product of oak, especially between 1780 and the late 1800s, was the bark, from which tannin for curing leather was extracted. Its use declined rapidly towards the end of the 1800s when imports of oak bark and bark of other species from the continent, India (particularly *Acacia catechu* and *Uncaria gambir*), Brazil (*Libidibia coriaria*) and elsewhere replaced British oak (Brown and Nisbet, 1894; Tyler, 2008). Synthetic tanning agents, particularly chromium sulphate, were also introduced.

Really good-quality oaks provide the preferred European timber for making barrels in which wine and whisky are matured. Work by Mosedale and Savill (1996) on variations in levels of tannins and oak lactones in the wood of oak found that sessile oak is characterized by lower levels of total phenolics (tannins) but, by a factor of 10, greater concentrations of oak lactones than pedunculate oak. These differences indicate that differences in flavour of whisky or wine that is matured in oak barrels are likely, sessile oak imparting the preferable taste. These results support the findings of earlier studies.

Place of sessile and pedunculate oaks in British forestry

Sessile and pedunculate oaks are the most characteristic and common native broadleaved trees. In spite of the many problems associated with growing valuable trees, they will undoubtedly continue to play a major part in British forestry. Because of climate change, much more attention than in the past needs to be devoted to matching the species of oak to the site where it is to be grown, to minimize the problems associated with acute oak decline.

QUERCUS RUBRA L. — Red oak

Origin

Red oak has a wide distribution in the eastern USA and the extreme south-east of Canada. It is the most northerly of the eastern American oaks and grows from valley bottoms up to the lower- and mid-slopes of hills and mountains. It is a major species in the hardwood forests of eastern North America and was introduced to Britain before 1692.

Red oak is also an important exotic species in some European countries. For example, it is the third most common species in Hungary, after hybrid poplars and *Robinia pseudoacacia*. An excellent book on the species and its silviculture has been produced in France by Timbal *et al*. (1994).

Silviculture

The species is hardy in Britain, but like the two native oaks is occasionally damaged by late spring frosts. It is far more tolerant of heavy clays and of base-deficient acid soils than the indigenous oaks and will make useful trees on these soils where no indigenous broadleaved species of equal value could be grown. It grows rapidly even on poor acid soils, though not on peats, and does best on acid sandy loams. It will not grow well on calcareous sites. The French believe it has a place on dry, acid sites for which there is no productive broadleaved species at present. It could, for example, be planted in some of the drier parts of lowland Britain on sites too poor for sweet chestnut and where atmospheric pollution is too high for conifers but where reasonably rapid growth is required. In common with pedunculate oak and sessile oak, the timber of this species has a reputation for being shaken. Assuming the causes of shake are the same, the use of red oak on well-drained and drought-prone sites is likely to produce timber that will commonly be shaken. On such sites red oak should probably be regarded as an amenity species and certainly not as one for producing saw timber.

Red oak is decidedly more shade-bearing than *Q. petraea* and will form a good understorey in pine stands. It coppices well and is known for its crimson autumn colour for which it is, perhaps, most often planted. Unlike the native oaks, epicormic branches are not a serious problem, but it has a tendency to fork rather badly and so must be singled and pruned early. Frequent heavy thinnings are also considered necessary in France. Macdonald *et al*. (1957) stated that it is not a long-lived tree and will not grow to the dimensions of the native species.

Natural regeneration

Seed is produced best in the south of England, but even there it is not plentiful. Macdonald *et al*. (1957) believed that the failure to produce viable seed in adequate quantities is probably the reason why it has remained a minor species in Britain.

Flowering and seed production

The tree flowers in May; seeds, which take 2 years to ripen, are ready for collection in September and October. The earliest age at which the tree bears seed is 30–40 years. The greatest quantities are produced at intervals of 2–4 years from ages 50–80. There are about 280 seeds kg^{-1} (range 165–564), of which 80% will normally germinate.

Area and yield

There are said to be about 700 ha of *Quercus rubra* in Britain, though it is widely planted in many parts of western continental Europe. In France for example, where it is an important tree, there is a large programme of selection and breeding.

Growth rates are usually much faster than those found in the native oaks. In the Netherlands they range from yield classes of 3–9 m^3 ha^{-1} $year^{-1}$ (Bastide and Faber, 1972), up to 9.4 m^3 ha^{-1} $year^{-1}$ in Belgium (Laurent *et al*., 1988), and over 10 m^3 ha^{-1} $year^{-1}$ in Hungary (Rédei *et al*., 2002/2004). In Britain similar levels have also been found.

Timber

In Britain the timber is traditionally thought of as being inferior to that of the native oaks for furniture and decorative work, because its colour and texture is less attractive. It tends to be avoided by much of the British timber trade. It is nevertheless in demand in France for furniture making and is also used for flooring and interior joinery. Untreated timber is unsuitable for exterior work because of its lack of natural durability, though it can easily be impregnated with preservatives. It is at least as strong as the native oaks (FPRL, 1964). The average density of the wood at 15% moisture content is about 790 kg m^{-3}.

Place of red oak in British forestry

Red oak is a species that is still of minor importance in Britain, even though it grows well and is quite widely planted by our continental neighbours. It is most commonly used for its spectacular autumn colour but may have a place on dry lowland sites, especially if climate change proceeds as predicted. Regrettably, on such sites, it is likely to suffer from shake, though a breeding programme could probably reduce this risk.

ROBINIA PSEUDOACACIA L. Robinia, Black locust, False acacia

Origin and introduction

There are at least four North American species of *Robinia,* which are in the family Fabaceae. *Robinia pseudoacacia* is native to the eastern and mid-western USA between latitudes 35° and 43°N, where there are two separate populations, one each side of the Mississippi valley. It was introduced to Europe by a French botanist, J. Robin, and is first mentioned in Britain in the 1640s. William Cobbett (1825) was a huge advocate of the species who described it as 'the tree of trees', mainly on account of its very durable wood. However, his enthusiasm often outran his discretion (Macdonald *et al*., 1957). The tree did not perform nearly as well in Britain as he predicted. In natural conditions robinia is a pioneer on disturbed soils or burned sites, this being facilitated by its nitrogen-fixing abilities.

Climatic requirements

False acacia is noteworthy because of its ability to tolerate severe frosts: it is among the few nitrogen-fixing trees adapted to frost-prone areas. As a forest tree it is really only suited to the milder and more sheltered parts of England, as it needs summer warmth to grow well.

Site requirements

It will grow on a wide range of soils with pHs varying from 4.6 to 8.2 but does best on well-drained calcareous loams. Robinia grows reasonably well on dry and infertile sandy soils. Its main asset in Great Britain is as a nurse on such sites, especially those poor in nitrogen, such as strip-mined areas and sandy heathlands. It will tolerate drought and air pollution (Hanover, 1990) but not waterlogging or soil compaction. It is essentially a tree for use in the lowlands.

Other silvicultural characteristics

In Great Britain robinia is a medium-sized tree, up to about 25 m tall, and has a reputation for being a low-volume producer with bad form, and so is unlikely ever to be grown as a timber-producing species in its own right. Like all nitrogen-fixing plants, the tree is a strong light-demander.

It is seldom planted in Britain today because of the nuisance caused by its prolific suckers and the unpleasantness of its vicious thorns (Macdonald *et al*., 1957). Root suckers grow particularly well from exposed roots following soil disturbance, so the species has a value in the control of erosion on slopes and in gullies.

Its broad site tolerance and silvicultural properties have resulted in a wide acceptance in parts of continental Europe. In Hungary it is now a species of major economic importance (Rédei, 2002), as well as in Romania and France, where it is valued both for timber and nectar production by beekeepers and also as a forage species (Keresztesi, 1978). Robinia is now rivalling poplar as the second most widely planted broadleaved species in the world, after the eucalypts.

Diseases

In the USA young trees, particularly in the dbh range of 2–12 cm, are badly attacked by the borer *Megacyllene robiniae*, especially on nutrient-poor sites, to the extent that in 1913 planting of the species was virtually given up. Thirty years later it returned to use because its tolerance to acid soils and nitrogen-fixing properties made it ideal for planting on strip-mined sites, particularly in the Appalachians.

Natural regeneration

In its native habitat robinia is an important colonizing species in areas of disturbed forest. It is not long-lived but regenerates readily from seed, coppice and root suckers. The latter are particularly prolific after the parent tree is felled.

Seed production and nursery conditions

There are about 53,000 seeds kg^{-1}, of which 70% will normally germinate. For nursery purposes seed pods have to be picked from the trees. In common with those of many legumes, the seeds of robinia have impenetrable coats, which can delay germination. A satisfactory method of pretreatment is to put the dry seed into a container with five times its volume of freshly boiled water and leave it to cool. Aldhous (1972) stated that this is more reliable than the alternative of soaking in cold water for 1 week. It should be sown at the end of March or early April.

Provenance and breeding

No provenance research has been carried out in Britain, but the species has been the subject of intensive breeding programmes in some countries, especially in Eastern Europe, including Hungary. According to Hanover (1990), natural variation in numerous traits has often been observed and many cultivars described (including a popular garden variety, *R. pseudoacacia* 'Frisia'). There is a high degree of polymorphism in the species, most of which resides within seed sources with low geographic variation. Clonal selection, early pruning and close spacing have been effective in producing straight-stemmed black locust in plantations, especially in Eastern Europe. In Hungary, for example, a large array of tall clones is in commercial use (Keresztesi, 1983), based on seeds from trees originating from Long Island in New York State. There is clearly scope for testing some of these origins in Great Britain.

Robinia is the source of the inaccurately named but much sought-after 'acacia' honey. In Hungary a breeding programme to extend the flowering period has resulted in the selection and recognition of several clones that show promise both for forestry and apiculture (abundant flowering, high nectar content and long flowering period).

Growth and yield

Growth, especially when young, is extraordinarily fast in some parts of the world. Trees can reach 3 m tall in one growing season and average 0.5–1.5 m height and 0.2–2 cm diameter growth per year. On fertile sites yields of more than 14 m^3 ha^{-1} $year^{-1}$ (9.5 dry t ha^{-1} $year^{-1}$) have been reported over a 40-year rotation with only moderate management. On poor sites, such as strip mines in the USA, oven-dry biomass yields range from 3.1 to 3.7 t ha^{-1} yr^{-1} (Hanover and Mebrahtu, 1991).

Timber

The timber is naturally extremely tough (similar to ash), very durable, and according to Cobbett (1825) it is 'absolutely indestructible by the powers of earth, air, and water'. This natural durability was a huge asset in the days before pressure impregnation of timber with preservatives. Also, when ships were made of wood they frequently rotted within 4 or 5 years of being completed when made of many other timbers. In the 19th century it was used for shipbuilding in the USA. Robinia has an unusually narrow (*c*.0.5 cm) sapwood. It is dense (slightly heavier than oak, at about 740 kg m^{-3} at 15% moisture content) and hard, which makes it suitable for outdoor work. The wood is usually straight grained and fairly coarse textured.

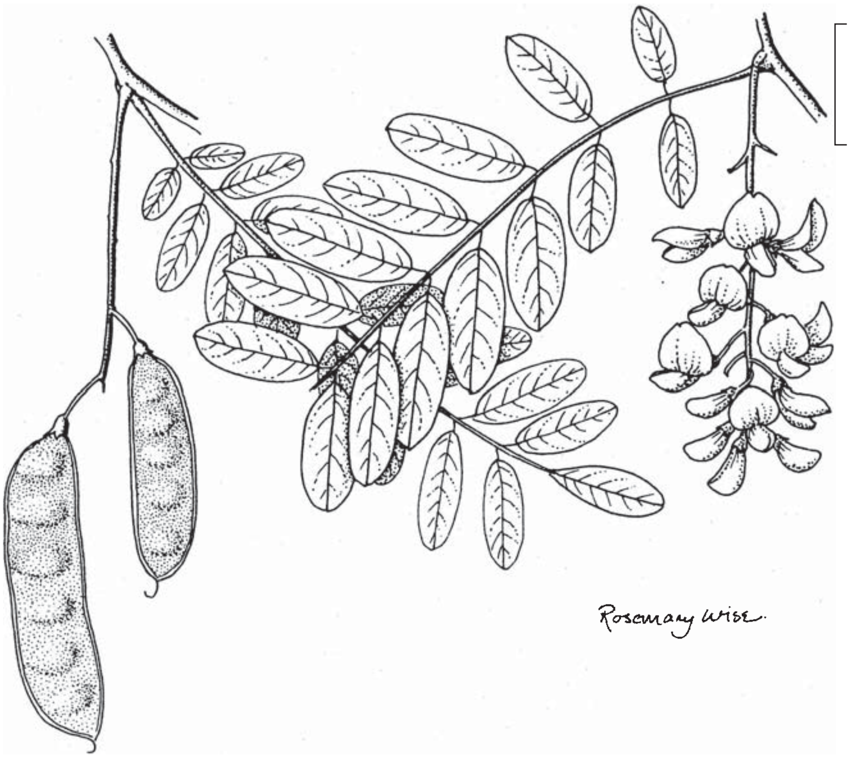

Fig. 29. False acacia, *Robinia pseudoacacia*.

It has a strong tendency to warp. The colour is naturally yellowish green. It has excellent properties for steam bending, and high-pressure steaming can change the colour to golden yellow, yellowish brown, light brown or dark brown. The larger logs can be used for veneers, and it is also used for structural wood and furniture.

Place of false acacia in British forestry

False acacia could be a useful nurse or pioneer species on 'stressed' sites such as reclaimed areas and road cuttings where only subsoil exists on the surface, though several species of alder would normally serve this purpose just as well. Because of its thorns, it is a difficult tree to work with and is likely to remain one of minor importance.

SALIX L. — Willows

Species

About 450 species of willow occur worldwide, most of them in the north-temperate and arctic regions. It is generally agreed that 18 species and 27 interspecific hybrids are native to Great Britain and Ireland. The tendency to hybridize, especially among sallows, makes members of the genus very difficult to identify. The tree willows native to Britain are *Salix pentandra*, *Salix caprea*, *Salix fragilis* and *Salix alba*. None of them is of any importance as a productive forest tree, but numerous species and varieties of willows are commonly planted for ornament. One of the most popular is the weeping willow, *Salix* × *sepulcralis*. Willows are dioecious (i.e. male and female flowers are on separate trees).

Site requirements

Willows are often the first woody plants to become established in wet habitats, and they can be valuable for stabilizing the banks of waterways. They tolerate the low soil oxygen levels around roots in wet places by producing numerous long adventitious roots, to increase the surface area for absorption.

Most tree willows require deep, rich soils for reasonable growth, but they are not long-lived. They will grow on a wide range of soil types with a pH optimum of 6.5 and a range of 5.5 to 7.0. Water consumption of short-rotation coppice willow is high, like that of all fast-growing crops, and can reach 4.8 mm m^{-2} day^{-1} in mid-summer (Bassam, 1998). An annual rainfall of 600–1000 mm is considered ideal for willow growth (DEFRA, 2002) unless groundwater is available, as along riversides.

Silviculture

During the establishment phase willows are more intolerant than many species to competition from weeds.

Most of the pollarded willows that line the banks of English lowland rivers are *S. alba*. Female trees of *S. alba* ssp. *caerulea* have, since about 1820, provided the wood for making cricket bats (Warren-Wren, 1965, 1972). There are now about 2000 ha of cricket bat willow grown in Britain on 12–18 year rotations, mostly in Essex (Evans, 1984). In common with poplars, they do best at wide spacings on stream and river banks where there is moving (aerated) water.

Willows also have potential, though little-used, values in silviculture in being planted as 'sacrificial' trees in places where deer browsing and rubbing is a problem. Deer prefer willows to most other trees, possibly because of the salicin content of the bark, which, like aspirin, can relieve pain and irritation; they may benefit especially when the felt on antlers is being shed. Planting them for this purpose can relieve the pressure on more commercially valuable species.

Willows are hosts to more invertebrates than any other native trees; 450 species of insects and mites are associated with them. They are just ahead of oaks, with 423 (Kennedy and Southwood, 1984). Species of willow, especially *S. fragilis* and *S. alba*, are the woody winter hosts of a damaging aphid of carrots, *Cavariella aegopodii* (Jones and Jones, 1974).

Diseases

A potential threat to growing satisfactory trees for cricket bats is 'water-mark' disease, caused by the bacterium *Erwinia salicis*. Infected trees wilt and die back, and the wood becomes brittle and unsuitable for

Fig. 30. White willow, *Salix alba*.

the manufacture of bats (Preece, 1977; Patrick, 1991). It is controlled by propagating from disease-free parent trees and by the prompt destruction of infected trees. *E. salicis* is a problem that is not confined to cricket bat willow, and it attacks other species of willow too.

There is an ever-present risk that foliar rust diseases caused by *Melampsora* spp. will kill, or at least severely reduce, the productivity of clones of willow. This means that no single clone should be used extensively or for long periods. Most clones used for biomass production eventually become susceptible to attacks by rusts. A means of at least partially overcoming *Melampsora* attacks is to establish plots that contain mixtures of clones. This can result in significantly greater dry matter than in monoclonal plots. Figures of 20% or greater increases are quoted for trials in Northern Ireland by Dawson and McCracken (1995) and McCracken and Dawson (1996). The increase was ascribed, at least in part, to reduced attacks by the rusts and delayed onset of attack, meaning that the build-up of the disease is reduced, and disease levels at the end of a season are significantly lower than in monoclonal stands. These benefits result from the influence of lower densities of susceptible plants, the barrier effect of disease resistant plants and induced resistance due to non-virulent pathogen biotypes. Unfortunately, recommendations for using clonal mixtures are not included in current planting guides for growers, such as DEFRA's (2002) publication *Growing short rotation coppice: best practice guidelines for applicants to Defra's Energy Crops Scheme*.

Propagation

Willows will root easily from cuttings, and this is the main method of propagating them.

Timber, uses and area

The wood of large trees is white, straight grained and light in weight at about 450 kg m^{-3} at 15% moisture content, though cricket bat willow is lighter at 340–420 kg m^{-3}. It is not durable out of doors.

The wood is used for purposes where light weight, easy working and resistance to damage by impact are required: hence its value for cricket bats and at one time for the wooden parts of artificial limbs.

Before the days of plastics and other similar materials willows were enormously important in the economy of the country, for the production of basketwork for numerous purposes: hurdles, screens and containers of all kinds. The leaves were once used for animal fodder.

Short-rotation coppice

Willows make good bioenergy crops because their rapid early growth results in high yields in a few years. The ease of vegetative propagation and ability to re-sprout for many coppice cycles adds to their attraction for this purpose. First-year height growth after coppicing can reach up to 4 m. Members of the subgenus *Caprisalix* (shrub willows) are used primarily for bioenergy production in short-rotation coppice systems, particularly clones of *Salix viminalis* and *Salix dasyclados*.

Willows grown for short-rotation coppice are planted densely and harvested on a 2–5-year cycle after coppicing the first establishment year's growth. Each stool produces up to 20 shoots and normally remains productive for at least 30 years (or around 10 coppice cycles).

The recommended planting design for short-rotation coppice willow is to plant in double rows, with spacings of 0.75 m and 1.5 m between double rows. Within each row the plants should be spaced 0.59 m apart (Bullard *et al.*, 2002; Tubby and Armstrong, 2002), giving a density of about 15,000 ha^{-1}.

As mentioned above, willows are intolerant to weed competition during the establishment phase. Broad-spectrum contact herbicides are usually recommended to remove perennial weeds prior to cultivation, and residual soil-acting herbicides can be applied after planting (Tubby and Armstrong, 2002). Following cutting at the end of the establishment year, the vigorous dense re-growth of up to 4 m per year is sufficient to suppress subsequent weed growth.

One of the main differences between traditional coppice and modern, high-yielding, short-rotation coppice concerns the level of input or intensification: the latter requires regular fertilizer (especially nitrogen from the second year after establishment), herbicide and pesticide treatments to maintain the high yields. Intensive short-rotation coppice is a high-cost/high-return system, compared to the low-cost/low-return system in most traditional existing coppice.

The dry matter content of winter-harvested material is generally in the range 40–55% at harvest, but end-users generally need 70% dry matter, so it must be dried before use.

Maximum commercial yields of short-rotation coppice in Great Britain average more than 10 oven-dry t ha^{-1} $year^{-1}$, depending on planting density and genotype (Wilkinson *et al.*, 2007). Experimental yields have reached more than 18 oven-dry t ha^{-1} $year^{-1}$ using new genotypes, some of which are now commercially available (DEFRA, 2002).

The total area of short-rotation coppice in about 2006, planted under all grant schemes, was said to be about 6000 ha, the great majority of which was willow.

Place of willows in British forestry

Willows have practically no place today in productive forestry in Britain, except as short-rotation biomass crops and to contribute to biodiversity, mainly in upland forests.

SEQUOIA SEMPERVIRENS (D. Don) Endl. Coast redwood

Origin and introduction

The coast redwood occurs naturally along the Pacific coast of the USA in a 725-km long strip in the 'fog belt'. It extends with some breaks from 42° N in the extreme south-west of Oregon to south of Monterey in California at almost 36° N. Its occurrence is confined to areas within about 60 km of the sea, normally at elevations below 300 m. The species was introduced to Britain in the 1840s, probably in 1846.

Climate and site requirements

Its natural range is characterized by mild temperatures, quite high rainfall (620–3050 mm; Morgan, 2009) and intense summer fogs, so that evapotranspiration is low. Within this range it grows mostly on soils derived from sandstones and best where these are overlaid by alluvial deposits, where it forms pure stands or occurs mixed with Douglas fir, Lawson's cypress and other conifers.

In Britain coast redwood generally grows well on fertile soils in the moister, south-western regions (Macdonald *et al*., 1957), though impressive specimens can be found in most lowland parts of the country provided there is an adequate supply of soil moisture. It will tolerate neither waterlogged sites nor drought-prone ones. If soils are suitable the tree grows best in well-watered valley bottoms and on the lower slopes of valleys in south-west England and South Wales where precipitation exceeds 1250 mm. Sites to avoid are exposed areas, very acid soils, heavy gleys, peats and sites exposed to salty winds from the sea. It cannot tolerate serious atmospheric pollution.

Rather like the southern beeches and the walnuts, a limitation to the use of coast redwood in Britain is its lack of cold hardiness. It is easily damaged by frosts and consequently can be difficult to establish in the open. The species must be approaching its climatic limit in some areas: for example, it seldom grows well in Scotland and is rare in most neighbouring parts of continental Europe. It is a species that could possibly be grown more widely in Britain with climate warming, not least because it produces a high-quality timber.

Other silvicultural characteristics

The tallest tree in the world is a coast redwood (at 115.6 m in 2011) in California's Redwood National Park. The species can live for more than

2000 years. Coast redwood is reasonably shade-bearing in that it will not die even if quite heavily shaded but neither will it grow. Like most trees, it needs almost full light to grow fast.

Young trees are sensitive to weed competition, so careful weeding is necessary until they begin to grow rapidly. The trees do not self-prune well, hence dead knots can be a problem in timber if pruning, preferably high pruning, is not carried out.

The main interest in this species is its potential for rapid growth and high-volume production, but this only happens on really good sites. According to Edlin (1966), it grows much faster than Sitka spruce on the best sites. One stand at Leighton in Powys had a standing volume of 2152 m^3 ha^{-1} at age 94 and was said by Macdonald *et al*. (1957) to have the highest volume standing on the ground of any plantation in Great Britain.

A rare feature among conifers is the ability to produce coppice shoots, and redwoods do it with great vigour. On suitable sites, such as at Longleat in Wiltshire, stands can be renewed satisfactorily by this means. This coppicing ability and the thick, soft, fibrous red bark are adaptations to protect the tree from fires, which are common in the southern and eastern parts of its natural range. It is also said to produce root suckers (Mabberley, 1990).

Natural regeneration

Natural regeneration occurs quite freely in Britain, but seedlings are easily injured by frosts.

Flowering, seed production and nursery conditions

In their natural range redwoods start to bear seeds at age 5–15 years (Burns and Honkala, 1990), though little of it is viable. Flowering in Britain takes place in February, but the male flowers are often killed by frost.

One reason why redwood is seldom planted in Britain is that it is difficult to raise plants in any quantities from seed, because often well under 10% is viable. This may be because frost and wet weather conditions that are common during the flowering period prevent pollination. Continuous rain during flowering washes pollen from the male strobili and little is therefore available to reach the receptive female strobili. Dry periods during flowering permit better pollen dispersal and improve seed viability. Morgan (2009) stated that seed collected from the tops of trees (which is expensive) has more than 90% viability, presumably because flowers in the treetops have a better chance of being pollinated. Plants can be raised from cuttings taken from young trees without much difficulty and also by micropropagation.

Provenance

According to Forest Research (2011), only very limited provenance testing has been carried out in Britain, but more northerly provenances are likely to be more cold-hardy.

Timber

The heartwood turns red soon after felling (hence the name of the tree), with the red colour ranging from light pink to maroon. The greatest virtue of the wood is its dimensional stability in service. It is light, with an average density of about 420 kg m^{-3} at 15% moisture content, and is non-resinous. The timber has a reputation for being strong, and the heartwood, especially darker-coloured heartwood (but not the sapwood), is usually naturally durable. Its main drawbacks in use are said to be its softness (Gale, 1962), the tendency for unpruned trees to contain many dead knots that fall out after sawing and for the timber to splinter unless really sharp tools are used. It also dents easily.

The tree often produces burrs, some of which can be valuable. Apparently 'curl' is the most common figure. Morgan (2009) stated that the central parts of logs grown in Britain tend to produce the soundest heartwood without dead knots but would also include the less desirable juvenile core. In its native range the trees have supported a large timber industry. Coast redwood is used in America in house building and, because of its durability, for such things as shingles, cooling towers, silos, greenhouses and farm buildings. The fact that there is no resin in the timber, unlike that of many conifers, makes it less of a fire risk in buildings. The best timber is used for panelling, cabinet making, decks and hot tubs.

The timber is virtually unknown to the conservative British timber trade and consequently is not sought-after.

Place of coast redwood in British forestry

In 1966 Edlin said that most British foresters exclaim that the coast redwood is 'a tree of great promise' but that is as far as it ever goes. The situation is unchanged half a century later. It is still a minor species: one that is planted more for ornament than for production. Its main potential values in forestry are its great productivity, and the dimensional stability and durability of its timber. Many misconceptions about the species exist in Britain, partly because it is often confused with Wellingtonia or giant sequoia, *Sequoiadendron giganteum*, a tree with much less sought-after timber, and partly because coast *Sequoia sempervirens* is called the giant sequoia in the USA.

SEQUOIADENDRON GIGANTEUM (Lindl.) Buchholz
Wellingtonia, Giant sequoia, Giant redwood

Origin and introduction

The name by which the tree is known in Britain is in honour of the first Duke of Wellington (1769–1852), Commander-in-Chief of the British Army and twice Tory Prime Minister. The species was introduced to Britain in 1853, a year after the Duke of Wellington's death, having been discovered in 1850.

It occurs naturally in a number of scattered locations along a 420-km strip that is no more than about 24 km wide, extending along the west slope of the Sierra Nevada in central California. It is found in middle-elevation mixed coniferous forests.

Climate and site

There is very little experience of growing this tree in Britain. Macdonald *et al*. (1957) stated that on limited evidence it is less badly affected by exposure and frost than the coast redwood and that it will grow in most parts of Britain. It is slightly more tolerant to atmospheric pollution than the coast redwood.

It will grow on most soils in Britain except wet ones. Wet acid peats, in particular, should be avoided. It grows best in deep, well-drained sandy loams, in places where underground water is available to maintain the tree during dry periods. Adequate soil moisture is critically important for successful establishment, survival and growth. In its native range fully grown trees are therefore often concentrated near streams. Except for the presence of moisture, soil apparently plays only a minor role in influencing the distribution of the species, judging by the considerable variability in parent material in natural stands and the fact that Wellingtonia grows vigorously when planted in diverse soils around the world.

In its native home Wellingtonia grows in what is described as a 'humid climate, characterized by dry summers' (Weatherspoon, 1990) and where most precipitation falls as snow in winter. Low temperatures limit its upper elevational range, as do severe winters in regions where the species has been introduced. Its distribution at lower elevations is limited mainly by deficient soil moisture during the growing season.

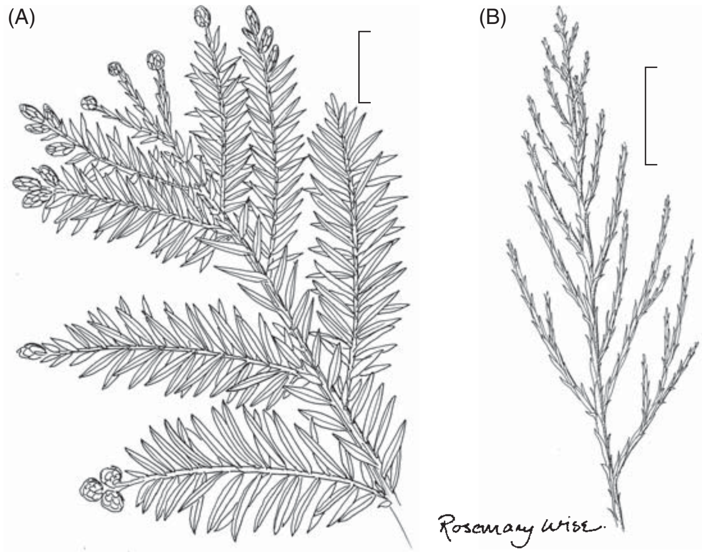

Fig. 31. (A) Coast redwood, *Sequoia sempervirens*; (B) Wellingtonia, *Sequoiadendron giganteum*.

Other silvicultural characteristics

The Wellingtonia has never gone beyond the trial-plot stage in Britain, but it is quite widely planted in parks and gardens. Losses can be high after planting. The tree is a strong light-demander throughout life, being less tolerant of shade than the coast redwood. Height growth of seedlings is slow during the first few years if there is competition for light and moisture, but seedlings in the open perform well and can outgrow any associated tree species provided weed control is thorough. Height growth averaging 80 cm a year for the first 10 years is common. Wellingtonia normally regenerates by seed.

Trees up to about 20 years old may produce coppice shoots after an injury, and trees of all ages may shoot from the stem when old branches are broken, but unlike *Sequoia sempervirens* mature trees do not coppice from cut stumps or grow from root suckers.

Wellingtonia bark is fibrous, furrowed, non-resinous and may be 90-cm thick at the bases of the trunks of big trees. It provides significant protection to the cambium from fires.

Lower branches are killed fairly easily by shading, but the trees tend to retain most of their dead branches, so if timber production is an objective, pruning is necessary to avoid dead knots being included in the wood. Even very large trees have a reputation for being extremely wind firm.

Accounts of the species and its ecology have been written by Hartesveldt *et al*. (1975), Harvey *et al*. (1980) and Burns and Honkala (1990).

It is described as a fire subclimax tree that is relatively resistant to fires, which set successions back to an earlier stage. In its native habitat it grows with *Abies concolor* var. *lowiana*, *Abies magnifica*, *Pinus ponderosa* and other species.

Diseases

Heterobasidion annosum and *Armillaria mellea* can be serious root pathogens, which sometimes kill trees.

Natural regeneration

There is no experience of this in Britain.

Flowering, seed production and nursery conditions

The tree flowers in March and April in Britain. Cones bearing fertile seeds have been observed on trees as young as 10 years of age, but the large cone crops appear much later. They mature in 18–20 months. The cones are serotinous and typically remain on the tree, green and closed and retaining viable seeds, for up to 20 years. They also continue to photosynthesize and their peduncles grow, producing annual rings that can be used to determine cone age. Estimates of percentage germination of seeds removed from green cones range from about 20 to 40%. In natural conditions some seed is shed when the cone scales shrink during hot weather in late summer, but most seeds are liberated only when the cone dries from the heat of a fire or when damaged by insects. Hot air produced by a fire dries cones, resulting in the release of enormous quantities of seed over small areas. The fire creates a seedbed that is favourable for seed germination and seedling survival. Seed dormancy has not been observed in Wellingtonia (Burns and Honkala, 1990). The most important requirement for germination is an adequate supply of moisture and protection of the seed from desiccation.

Cuttings from juvenile material root quickly and mostly without difficulty. As with most species, only limited success has been achieved from rooting cuttings of older trees aged 30 years or more.

Provenance

Provenance tests in Germany have shown differences in cold hardiness and early growth among populations (Weatherspoon, 1990). No trials have been carried out in Britain.

Yield

The species is famous for the huge dimensions and great age to which it grows: the biggest tree, located in Sequoia National Park, California, is known as the 'General Sherman' tree and is estimated to be 2500 years old. Its height to the top of the trunk is 83.8 m, and its volume is estimated at 1486 m^3 (Burns and Honkala, 1990). It is often claimed as the tree with the greatest volume in the world.

The Wellingtonia has been planted widely and often successfully in many parts of the world, according to Weatherspoon (1990). As in California, plantations on suitable sites outperform most other species. An 80-year-old Wellingtonia plantation in Belgium, for example, grew at an average annual rate of 36–49 m^3 ha^{-1}. Many foresters see considerable potential for Wellingtonia as a major timber-producing species of the world.

Timber and uses

The wood is one of the lightest coniferous timbers, at about 340 kg m^{-3} at 15% moisture content, but is extremely durable. It is dismissed by Patterson (1988) as being 'not useful commercially'. This is possibly a view typical of the British timber trade.

In the USA the wood from old trees has the reputation of being fibrous, brittle and having a low tensile strength and so being unsuitable for construction, but immature trees are less brittle. Recent tests on young plantation-grown trees have shown the timber to have similar properties to those of coast redwood, including an absence of resin. This is resulting in some interest in cultivating Wellingtonia as a high-yielding timber tree, both in California and also in parts of Western Europe, where it may grow better than coast redwoods.

Outside its natural range, both in the USA and in many other countries, Wellingtonia is highly regarded as ornamental and shows promise as a major timber-producing species.

Place of Wellingtonia in British forestry

Wellingtonia is known more for the great sizes and ages to which it will grow than for its use as a timber tree. It is unlikely to be planted for more than ornamental purposes in Britain, though it could be a major timber-producing species.

SORBUS L.

Until relatively recent years, three reasonably common native species in the traditional genus *Sorbus* were recognized in Great Britain: *Sorbus aria* (whitebeam), *Sorbus aucuparia* (rowan) and *Sorbus torminalis* (wild service tree). In 1991 Robertson *et al*. argued that the genus *Sorbus* should be divided into five genera: *Sorbus*, *Cormus*, *Chamaemespilus*, *Torminaria* and *Aria*. As a result, two of the three species have been moved to other genera: *S*. *aria* has become *Aria nivea*, and *S*. *torminalis* is now *Torminaria torminalis*. They are dealt with under those genera in this book.

There are also several native but very rare British and Irish species in addition to these three. They occur only in restricted localities in south-west England, Wales, Arran and Ireland. Many are difficult to separate from each other. They are believed to be the result of hybridization events between the three common species that have led to the formation of new species (Chester *et al*., 2007; Robertson *et al*., 2004).

SORBUS AUCUPARIA L. — Rowan, Mountain ash

Distribution

Rowan is native to British woods, scrub and mountain areas, and will thrive at elevations up to almost 1000 m on sites where few other broadleaved trees will grow at all.

Climate and site

It is found throughout Great Britain but most commonly on lighter soils in the north and east. It is rare in much of lowland England (Clapham *et al*., 1985) and usually absent on clays and soft limestones. Rowan is one of the least site-demanding trees. It is cold hardy, frost tolerant and can withstand severe exposure. It grows best on soils of poor-to-medium nutrient status and of slightly dry to moist moisture status. Wet soils should be avoided, but it is found on more infertile soils and at higher elevations than whitebeam.

Silviculture

Rowan is a small tree that seldom grows more than 15 m tall. In common with whitebeam, it is a colonizing, light-demanding species that can be found in the establishment phase of almost all kinds of woodlands in

Britain and in open areas. It is a reasonably strong light-demander and coppices well.

It is palatable to browsing animals such as deer, and this causes multi-stemmed trees to be common. An aphid, *Rhopalosiphum insertum*, migrates from rowans in summer to the roots of oats, other grasses and reeds, and can cause some economic damage.

Natural regeneration

The seeds of rowan are disseminated by birds, and natural regeneration, though never prolific, is reasonably common. The trees also produce suckers from the roots.

Flowering, seed production, nursery conditions and genetics

Rowan is a self-incompatible species, which makes it an obligate out-crosser. The tree first flowers at age ten, in May and June, and is insect pollinated. It produces plentiful seed from age 15, either every year or every other year. The fruits ripen between July and August, and seed treatment for propagation in the nursery is the same as for whitebeam. There are about 5000 seeds kg^{-1} of fruit.

Bacles *et al*. (2004) carried out a fascinating piece of work involving genetic variability of rowan in relation to habitat fragmentation in the severely deforested landscape in Moffat Dale in the Southern Uplands of Scotland. They showed that, contrary to popular belief, high levels of genetic diversity have been maintained in this landscape. Values are only marginally lower than those found in non-fragmented continental European populations. It is believed that seed dispersal of rowan between populations by birds is very effective and that the interpopulation dispersal of seeds by birds is actually enhanced by habitat fragmentation. This is because birds feeding in small remnants are likely to move regularly between these isolated populations in the landscape, as seed supplies at any one site quickly become exhausted.

Provenance

There is no knowledge of provenance variation in rowan, so seed should be sourced from British stands of good form wherever possible. This view is supported by Worrell (1992) who speculated that since rowan was an early arrival in Britain after the ice age, the survival and growth of continental provenances might therefore be expected to be much poorer than British provenances, particularly when planted in the north and west of Britain.

Timber and uses

The pale yellowish-brown sapwood and deeper brown heartwood is strong, hard and tough but not durable out of doors. The wood takes an excellent finish, and because of its hardness, it dulls tools quickly. The density of the wood is about 670 kg m^{-3}. The tree does not grow big enough to provide large-diameter logs but is sometimes used in turnery, furniture, craftwork, and in earlier centuries for tool handles and engraving. It is similar to apple wood. Occasional larger-diameter stems can be valuable.

Place of rowan in British forestry

Today rowan is best known for its ornamental value both in wild upland parts of Britain and in the form of numerous named cultivars in towns and gardens, where it has the additional virtue that it does not grow too big. It produces numerous, attractive, small white flowers in May and handsome scarlet fruits in the autumn.

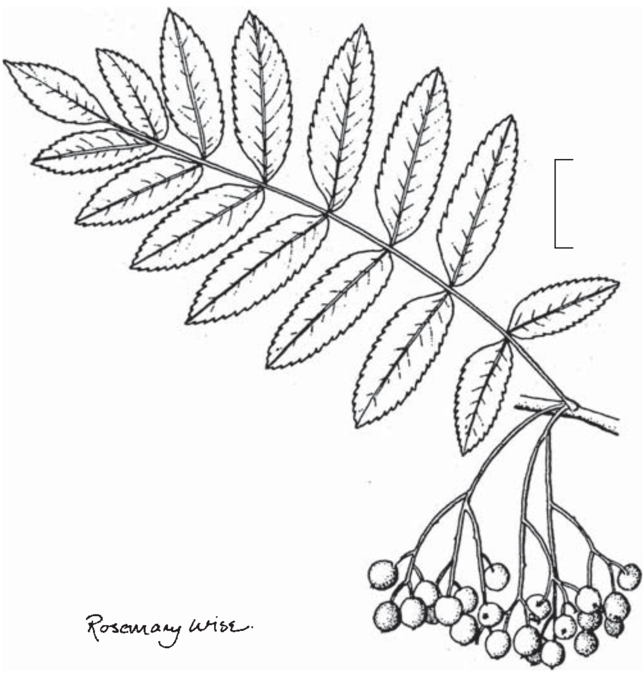

Fig. 32. Rowan, *Sorbus aucuparia*.

TAXUS BACCATA L. Yew

Interest in *Taxus baccata* and other species of *Taxus* has increased enormously since about 1990 at the conclusion of a series of successful clinical trials for treating various cancers with the alkaloid commonly known as taxol. The chemical is found in all parts of the tree except the aril. Taxol was considered to be one of the most promising anti-cancer drugs to be discovered in 20 years. This led to a great deal of destruction of wild yew trees, initially *Taxus brevifolia*, the Pacific yew, in the western USA and Canada, and soon afterwards, *T. baccata*. Tissue culture is now an alternative means for taxol production, but an awareness of the vulnerability of the species has been raised, and major conservation efforts are now in progress. Yew is regarded as an endangered species in much of continental Europe because intensive land use, including forest management, has caused a decrease in populations of the species.

Diameters well in excess of 3 m have been recorded on some truly spectacular trees. This makes them favourite subjects for talented photographers such as Thomas Pakenham (1996). The tree has a reputation for living to a greater age than any other species that will grow in Great Britain. Individuals well in excess of 1000 years old are known.

Much of what is written below comes from an excellent review of the species by Thomas and Polwart (2003).

Origin

There are nine closely related species of yew in the north-temperate region. *T. baccata* is native to Europe, including the British Isles, the Atlas Mountains and from Asia Minor to Iran.

In the British Isles, it grows from sea level to 425 m in England and Wales but is not considered indigenous to Scotland. Within Britain it is native to the chalk downs in the south of England, limestones in the north and oakwoods on other soils. Individual yew trees are widespread, occurring naturally in woods and on cliffs.

It has been extensively planted as an ornamental and in churchyards for many centuries.

Climatic requirements

Yew is a species of the lowlands and middle hills. It grows best in the high humidity of mild oceanic climates. In England it thrives particularly in areas with relatively mild winters, abundant rainfall and where mist frequency is greater than average, as in the coastlands of Hampshire and Sussex and lowland parts of the Lake District. Conversely, severe winter cold or strong cold, and drying winds in the spring appear to restrict yew growth on exposed sites.

Yew is intolerant of severe and prolonged frost. Sensitivity to frost in early spring limits its northerly oceanic distribution in Europe. It is tolerant of drought. Yew will withstand smoke and pollution, and has a high resistance to damage by sulphur dioxide, so it will grow in towns, unlike most evergreen conifers. It is, however, sensitive to air-borne salt spray, which kills the foliage.

Site requirements

Yew will grow on most soils so long as they are not waterlogged. The species sometimes forms pure woods in sheltered places on chalk in the south-east of England and on limestone in the north-west. The yews in Kingley Vale in West Sussex are described by Natural England as constituting one of the finest yew forests in Western Europe. It includes a grove of ancient trees that are among the oldest living things in Britain.

Stands of yew are typically associated with limestone slopes carrying shallow dry rendzinas (Rodwell, 1991). It does better in drier, more exposed conditions than are suitable for beech. Yew grows equally well on

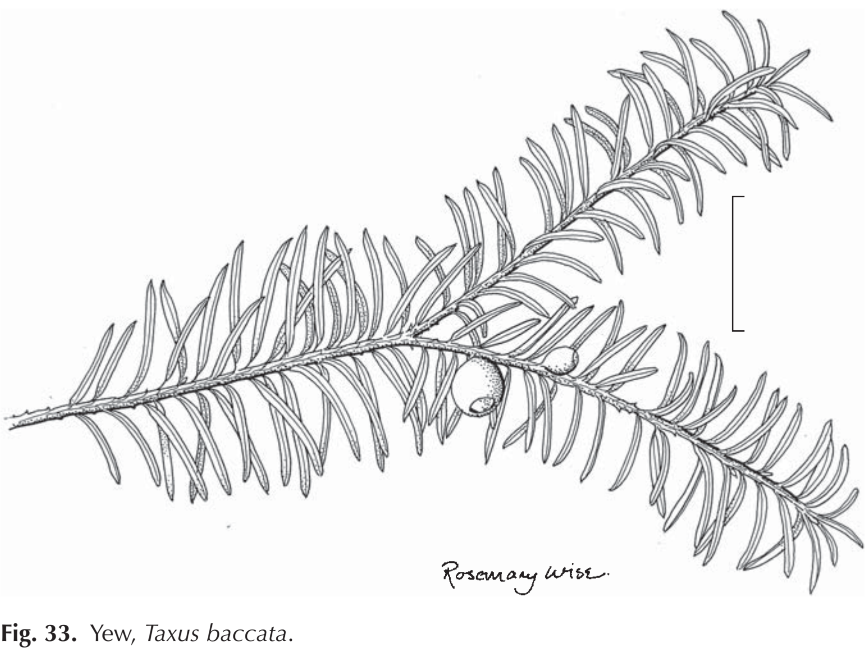

Fig. 33. Yew, *Taxus baccata*.

thin, warm chalk soils, limestone pavement and well-drained calcareous fen peat. Along valley bottoms yew woodland may extend on to somewhat deeper and moister soils.

Yew generally is absent from wet soils, such as wet acidic peat and wet clay.

Other silvicultural characteristics

Yews are not tall trees and will occasionally grow to a maximum of about 25 m, but in terms of diameter growth and longevity they have few equals. In a suitably oceanic climate, yew is gregarious and often forms pure, dense, even-aged stands. These are of 'striking floristic poverty and uniformity' especially on the warm and sunny south-facing slopes over shallow limestone soils (Rodwell, 1991). In more continental conditions it increasingly becomes an isolated understorey tree. It grows slowly, which is why it is not planted commercially, and, unusually among British trees, it is very shade tolerant.

Yew typically has a short stem that is deeply fluted. Owing to its thin bark, it can be badly damaged or killed by fires.

Old trees are able to reproduce vegetatively by branches touching the ground and producing adventitious roots. These can survive independently after the death of the main trunk. Yews will also coppice and produce plentiful epicormic shoots from stems and branches.

Diseases

Yew is unusually susceptible to fungal infections if roots are damaged and can be killed by *Phytophthora* spp.

Natural regeneration

Yew seed is disseminated by birds, which eat the red arils surrounding the seeds. Regeneration appears quite frequently as occasional understory seedlings, though it is never common.

In mixed yew-rich, beech–ash woods with an understorey of yew, rapid growth can be promoted by felling the overstorey (Forestry Commission, 1994). The yew will then be able to outcompete hardwood regeneration and dominate. However, once yew woodland is cut, it is more likely to regenerate to ash or birch in the first instance, with yew as a scattered understorey; thus management should be restricted only to occasional harvesting of yews. It is difficult to establish successfully under a beech canopy.

Flowering, seed production, nursery conditions and genetics

Yew can be propagated artificially from seed and cuttings, by grafting, layering and micropropagation.

It is dioecious and reaches maturity relatively late (*c*.70 years of age). It flowers in the spring, producing minute male catkins. The fruit is a hard seed, partly embedded in a pulpy, conspicuous and bright red, berry-like aril. Seed should be collected from the female trees in November, the arils removed by crushing, and the seed stratified for 16 months before sowing in March (Aldhous, 1972). There are about 4400 seeds kg^{-1}, which can be stored for 5–6 years by drying at room temperature to about 10% moisture content and then storing at 1–2°C.

Working on Scandinavian populations of yew, Myking *et al*. (2009) demonstrated distinct differentiation, partly caused by inbreeding and lower variation than central European populations. These characteristics are typical of marginal populations of tree species and possibly apply to British populations too. It appears important not only to ensure regeneration for maintaining the population sizes but also for promoting natural selection and adaptation to future climates, and to minimize genetic drift and associated differentiation in the long term.

Provenance

No provenance research has been carried out on yews in Britain.

Many cultivars and varieties are recognized, of which perhaps the best known is the fastigiate Irish yew, *T. baccata* 'hibernica'. It was originally discovered in 1780, as a female tree, at Florence Court in Co. Fermanagh and has been widely propagated as an ornamental from cuttings since then. In 1927 male fastigiate yews were discovered in Sussex.

Yew as a poisonous tree

Yew has been directly implicated in the deaths of humans and other mammals from heart failure. Cattle, and especially horses, can suffer quick and fatal effects from eating yew twigs, bark or foliage.

All parts of the yew tree are potentially poisonous except the arils. This is caused by the presence of large quantities of toxic alkaloids, primarily taxine, which are found in the seeds, bark and foliage. However, despite popular opinion and the views of early writers, yew is not invariably toxic to mammals. In fact, it is susceptible to browsing and bark stripping by rabbits, hares, deer and domestic animals including sheep, goats and sometimes cattle. Grey squirrels will browse on bark and twigs. Yew has also been used as an animal fodder in continental Europe and elsewhere.

It seems that animals can develop at least a partial immunity to yew if regularly fed small quantities. Small quantities and habitual access seems to be the key, because there are many records of cattle browsing freely and with no ill effects in pastures with yews, if plenty of other types of fodder are also available. Animals let into fields with yew in winter have been recorded as dying, presumably because yew was the only green food readily available. Access to cut branches has led to many domestic animal deaths. Dried or wilted foliage is reputed to be even more poisonous than fresh foliage, but according to Cooper and Johnson (1984), they are 'as toxic as the fresh plant'.

Growth and yield

The growth of yew is slow compared to most other trees, even under optimum conditions and after eliminating potential competitors. Even the oldest individuals do not attain great heights. Part of the reason for the slow growth is the high energy investment in defence, which increases the resistance of the wood to fungal and insect attacks.

Timber and uses

Yew produces a strong, decay-resistant, non-resinous wood. It is among the densest of all coniferous timbers, at least 670 kg m^{-3} and up to 800 kg m^{-3}. This is high for a gymnosperm, being similar to beech and oak. The wood is one of the most durable of temperate timbers. It is hard, heavy, flexible and impermeable. It is famed as having been the main timber used for making longbows: its suitability for this purpose arises from the prominent spiral thickening of the tracheids, which give the bows the essential elasticity.

Apart from its historical value, yew is used for many purposes, from knife handles to expensive and decorative furniture, and veneers for panelling. The freshly cut heartwood is bright tan to red-brown or purple, becoming a warm brown or golden brown upon exposure and with age. Patches of dark purple, mauve and brown streaks, together with tiny knots and clusters of in-grown bark, combine to give the wood an attractive appearance. Large-dimensioned material is not readily available because most trees are small to medium-sized and are of poor form. Supplies of veneer-quality wood are also limited and are consequently expensive when available. Yew burrs are rare, but when obtainable, they are suitable for conversion into high-class veneers. The wood has a reputation for being extremely stable when dry. The best timber is said to come from trees that have grown on lime-rich soils.

Yew would not be nearly as common as it is were it not for its tolerance of repeated pruning, as demonstrated by its widespread use in topiary and hedging. Unlike other coniferous hedging plants used in Britain, its ability to produce epicormic shoots after a severe cutting means that bare stems soon become green again.

Place of yew in British forestry

Despite the many uses of the wood, including fine furniture, it is unlikely that any yew woodlands have been deliberately planted for timber production in the past or that they will in the future.

About half the yew woodlands in Britain have been designated Sites of Special Scientific Interest.

THUJA PLICATA Donn ex D. Don — Western red cedar

Origin and introduction

There are five species of *Thuja* distributed in eastern Asia and North America. Western red cedar is native to western North America, from Alaska (at 56° 30′ N) to California (40° 10′ N) and from the Pacific coast eastwards to western Montana and Idaho (Minore, 1990). It extends from sea level to 1800 m, though above 1500 m it is a low shrub. Western red cedar is a major constituent in Douglas fir forests on the banks of water courses and in marshy valley bottoms. It was introduced to Britain in 1853.

Climatic requirements

In its natural range western red cedar is restricted to areas with abundant rainfall or snow, high humidity and cool summers. It can withstand low winter temperatures and is moderately resistant to late spring frosts. Western red cedar does not tolerate exposure well but is nevertheless reasonably windfirm on dry sites, but not on wet ones. It can withstand mild maritime exposure but not urban pollution.

In Great Britain it does best on relatively sheltered sites, such as the lower slopes of valleys, in regions with at least 800 mm rainfall, especially at low elevations in the west, but it grows acceptably well where precipitation is lower. It should not be planted at elevations much greater than 200 m, and lower in Scotland and the north of England. According to the distribution map produced by the Botanical Society of the British Isles (BSBI, 2012), western red cedar is much more common in southern England and Wales than elsewhere in Britain.

Site requirements

Western red cedar is at its most competitive on the fertile, heavier-textured, moist lowland soils in southern England, especially on calcareous clays, even periodically waterlogged ones. It requires at least moderate fertility and soils that are not too acid. It will succeed on both wet and rather dry shallow soils and is one of the best conifers for calcareous downlands, ideally under a light canopy (Forestry Commission, 2011). Deep, loose and infertile sandy soils should be avoided, as should drought-prone sites.

Other silvicultural characteristics

Western red cedar is potentially a large conifer, typically growing to a maximum of about 40 m tall in Britain. In its native habitat it has a reputation for being very long-lived.

It is a markedly shade-tolerant species, which will grow faster than other shade-bearers on heavy lowland soils, although early growth is sometimes slow. It is a particularly valuable species to grow in mixtures, either with other conifers or with broadleaved trees, as the narrow crown does not interfere with neighbours. It will keep pace with several species, such as the oaks, beech, ash and cherry, without outgrowing or suppressing them, and will live with faster-growing trees. Western red cedar is useful for enriching and underplanting, and is also valuable in pure stands. A frequent defect of the tree is that it often has a fluted, buttressed and rather swollen stem base. This is usually associated with unpruned trees. The best western red cedar comes from pure stands. In mixtures less wood is recoverable and it is of lower value, often with a pronounced taper and a lot of butt swell.

Pests and diseases

Western red cedar is more susceptible than most conifers to attacks by the two root and butt rots, honey fungus, *Armillaria* spp., and fomes, *Heterobasidion annosum*. Often the bottom 2 m of a stem may contain rot. Affected stems are frequently swollen up to the point at which the rot ends. Small dead knots commonly rot, and to avoid this, early pruning is advisable. Since the foliage is in demand by florists, pruning can often be done profitably at an early age. Western red cedar is less vulnerable to browsing by deer than many species, but it is occasionally attacked by grey squirrels. The aphid *Cinara cupressivora* is a cause of foliage browning.

Natural regeneration

Natural regeneration is prolific in some areas, but there is very little experience of managing it in Britain. As a shade-bearing species it could prove valuable in continuous-cover silvicultural systems.

Flowering, seed production and nursery conditions

The tree flowers from late March to early April and seeds ripen in September. The earliest age at which the tree bears seeds is 20–25 years, but the best seed crops are produced between the ages of 40 and 60. Western red cedar is normally a prolific seed bearer every 2 or 3 years.

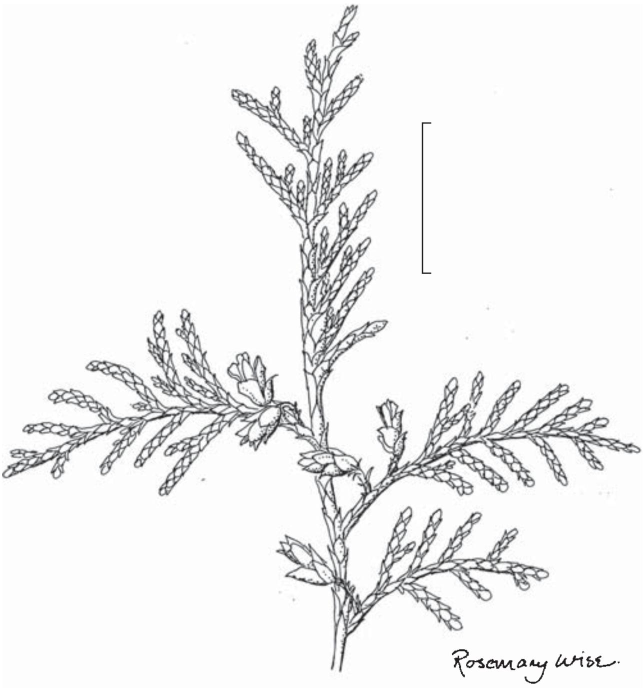

Fig. 34. Western red cedar, *Thuja plicata*.

There are approximately 913,000 seeds kg^{-1} (range 447,000–1,307,000), of which about half are normally viable. Cones should be collected as soon as they change from bright green to yellow, and the tips of the seed wings are visible and a light brown colour. This is normally in September. Seed should be sown between late February and mid-March and needs no special treatment (Aldhous, 1972). Seedlings were difficult to raise at one time because of attacks by the fungus *Didymascella thujina* in the nursery (Forestry Commission, 1967), but this disease can now be treated with cycloheximide fungicides.

Propagation from cuttings for horticultural purposes is relatively easy.

Provenance

Recommended origins for Great Britain are from the northern slopes of the Olympic Mountains in Washington, and some Vancouver Island sources show promise (Lines, 1987). With some seed sources the stems tend to fork and the lower boles are fluted, though excellent form can also be found.

There are many named varieties of western red cedar, selected for their ornamental values.

Yield

Yield classes range from 12 to 24 m^3 ha^{-1} $year^{-1}$, with ages of maximum mean annual increment between 50 and 70 years.

Timber and uses

In its native western North America the timber is sometimes known as 'arborvitae' and is particularly noted for its natural durability, due to the presence of tropolones in the heartwood (DeBell *et al*., 1999). In Britain the relatively fast growth and short rotations make it less durable, because there is often a much greater proportion of sapwood. The average density at 15% moisture content is about 390 kg m^{-3}. The market for sawlogs may be high, but because of the reddish-brown colour of the wood and its chemical constituents, small-dimensioned western red cedar is not acceptable for pulp and most other wood products, including chipwood. Young stems make ideal fencing rails that can be used without preservative treatment. There is a limited but lucrative market for poles (rugby posts, flag poles, ladder poles, etc.), if they are grown slowly enough. It is also used for garden furniture and for making garden sheds and beehives, and it can easily be sold for fencing and allied uses. The wood has a distinctive smell, reminiscent of wooden pencils.

Within its native range the traditional shingles for roofing houses are made from western red cedar because of the ease with which the wood can be split. It is also used in Britain for this purpose, and for wall cladding in houses and bungalows.

A difficulty with red cedar logs is that the bark is very stringy, which makes it difficult to remove because it tends to block peeling machinery.

Place of western red cedar in British forestry

Western red cedar is currently a minor species in British forestry (Forestry Commission, 2011) but with projected climate change it may find an expanded role in diversifying relatively sheltered upland conifer forests. Among its attractions are the natural durability of its wood and its shade-bearing character, which gives it a potential place in continous-cover systems.

TILIA L. — Lime or Linden

There are 23 species of *Tilia* in north-temperate regions, including five in Europe.

The two native British species, *Tilia cordata* and *Tilia platyphyllos*, are dealt with below. A third species, the common lime, *Tilia × europaea* L., is a fertile hybrid between the two and is the most common and widely planted lime in parks, towns and gardens. The two native limes hybridize where their distributions overlap, as in the Derbyshire Dales and the Wye Valley.

Until Pigott's (1988, 1991) reviews of the ecology and silviculture of the species, remarkably little had been written about the limes. Much of the information below is from these two sources, which should be consulted for more detail.

TILIA CORDATA Miller — Small-leaved lime

Origin and distribution

Small-leaved lime is native to England (except Northumberland and Cornwall), as far north as the Lake District, to Wales, and to continental Europe from northern Spain to Norway and eastwards to beyond the Urals. It is a relatively rare tree but nevertheless much the commoner of the two indigenous limes and was the last major tree to reach Britain after the ice age. Its distribution is uneven, but it is found predominantly in long-established woodlands, ancient hedgerows, on cliffs, among rocks, and in wooded ravines and river gorges in England and Wales. It is not native to Scotland or Ireland. According to Pigott (1991), it may also be regarded as a collective species, which extends from Western Europe to eastern Asia and includes at least seven species or subspecies. The current distribution of small-leaved lime in Britain is thought to be limited by cool summers.

According to Pigott (1991), it was rarely planted in parks and towns until recently, and even more rarely naturalized, but since 1960 the species has acquired new popularity and has been planted in many places.

In prehistoric times small-leaved lime was probably much more common than it is today; its decline is due to its selective removal by man and a general cooling of the climate by about 2°C, which has prevented seed development in the cooler parts of the country. If predictions about climate change prove correct, a warming climate should therefore benefit the species and allow it to grow satisfactorily on lowland sites in southern and eastern Scotland.

Climatic requirements

Small-leaved lime is tolerant of very low temperatures in winter. There are no reports of damage in Britain even during the coldest winters. It escapes frost damage during the growing season by coming into leaf late and by the early onset of leaf-fall and dormancy. The leaves are not fully expanded until mid-May, about 10–14 days later than large-leaved lime. Except for ash, this is later than any other common native tree, including large-leaved lime and *Tilia × vulgaris*.

In common with the large-leaved lime, it is normally restricted to valley bottoms because of its intolerance of a dry atmosphere in summer.

Most sites where old coppices of small-leaved lime occur on stagnogleys (soils that are waterlogged in winter and hard and dry in summer) are in the drier parts of England, where the average annual rainfall is less than 700 mm.

Small-leaved lime is reasonably resistant to urban pollution from SO_2, NO_2 and ozone, but probably not as resistant as *T. × vulgaris*, which is by far the most commonly planted lime in large industrial cities. Small-leaved lime does not tolerate exposure from strong winds.

Site requirements

As mentioned above, small-leaved lime is normally restricted to valley bottoms. Its distribution in England and Wales is patchy. It will grow on many types of soil, including podzols, brown earths and calcareous soils, and does best on neutral or slightly alkaline soils (Radoglou *et al.*, 2009). It will also grow on soils with a wide range of textures: from those with a high proportion of clay and silt to those containing mainly sand. In southern England it thrives on stagnogleys developed on compacted, fine-textured materials, which are frequently non-calcareous (stagnogleic brown soils) but may overlie limestone or other calcareous subsoils. On these sites it can compete successfully with oak. In woodlands that provide a variety of soil types, the tendency for distinct patches of small-leaved lime to be correlated with fine-textured soils may be striking. Only in the west and north, where the rainfall exceeds about 850 mm, is small-leaved lime found on limestone as well as acid soils.

Small-leaved lime grows best on fresh to moist soils with a medium to rich soil nutrient regime.

Sites to avoid are nutrient-poor soils, waterlogged soils, peaty soils and dry soils where the tree grows extremely slowly.

Other silvicultural characteristics

The small-leaved lime is a medium-sized tree that will grow to 20–30 m tall. It is one of few shade-tolerant native tree species, although estimates of its degree of tolerance vary. Some class it as being similar to beech, while others regard it as only moderately tolerant and ranking below beech, hornbeam, wych elm and large-leaved lime. Small-leaved lime possesses all the attributes of a dominant tree of the upper canopy of woodland. Seedlings and saplings are relatively tolerant of shade; the species has a 'waiting and persisting strategy', according to Radoglou *et al*. (2009). Mature trees are as tall as, or taller than, most competitors; they possess a monolayer canopy, cast a deep shade and are long-lived. Small-leaved lime is excluded by beech wherever beech can grow strongly. It is used in parts of Europe for shading the stems of oak to prevent epicormic shoot growth.

Small-leaved lime is a deep-rooting tree, and on deep soils it is scarcely affected by periods of drought if, as is often the case, it can gain access to soil moisture at depth.

Although it has a long history of being used in forestry, this has been almost exclusively as a coppice species. Coppice shoots may eventually become separate trees with independent root systems. Unusually among trees, stools retain their vitality for many centuries. According to Pigott (1991), they appear to be almost indestructible. Even conservative estimates indicate ages greater than 1000 years for large groups. New stools can easily be produced by layering. Shoots are also produced when old stems collapse naturally. Large groups of genetically uniform stems are a feature of the tree at its northern limit in Britain.

Soils under lime tend to be much richer in nitrogen and phosphorus, and have higher populations of earthworms, than under other broadleaved species. This soil-improving property may partly be explained by its deep-rooting ability, which enables the tree to gain access to nutrients lower in the soil profile than many other species can reach, in a similar way to that described for birch (p. 42). In addition, the lime aphid, *Eucallipterus tiliae*, may cause an enrichment of nitrogen (Mabberley, 1990) arising from the large amounts of honeydew they produce. They are said to deposit up to 1 kg of sugars m^{-2} each year. These possibly stimulate the growth of nitrogen-fixing bacteria around the trees and thus enhance nitrogen availability at the cost of some carbohydrate taken from the phloem by the aphids. Lime has often been planted in mixture with other species in continental Europe for its soil-improving litter, which decays rapidly.

Pests and diseases

The limes are remarkably free of diseases to which other trees are prone. They are among few broadleaved species that are not damaged by grey squirrels stripping the bark, and they are notable for being resistant to honey fungus (*Armillaria* spp.). However, seedlings and saplings are browsed in preference to many other species by deer, sheep, cattle, voles and other animals. This species is, however, less likely to become infested with lime aphid, *Eucallipterus tiliae*, than large-leaved lime or *T.* × *vulgaris*.

Natural regeneration

Natural regeneration is not common except in the south of England because viable seed is seldom produced. Seedlings rarely persist, however, because they are so palatable to browsing animals such as bank voles. Climate change might result in regeneration becoming much more common.

Flowering, seed production and nursery conditions

The limes are among few British trees that are insect rather than wind pollinated, and they, with sweet chestnuts, are among the last trees to flower, usually in June or July. The flowers are sweet-scented, but not as strongly as those of large-leaved lime or *T.* × *vulgaris*, and are pale whitish-green in colour. Contrary to popular belief, small-leaved lime produces viable seed in most years in southern England. In the north seed is usually sterile because the climate is seldom warm enough for the pollen tube to grow, and consequently fertilization of the embryo does not occur.

The first flowers normally open in mid-July, and flowering is completed in about 10 days (this is 10–15 days after flowering of large-leaved lime and *T.* × *vulgaris*).

The trees first produce seed between 20 and 30 years of age, and large amounts of seed particularly follow summers in which July and August are sunny and warm. There are about 29,000 seeds kg^{-1}, of which 50–60% germinates if collected in central and southern England or 0–15% in northern England. A high proportion of seed collected no later than September and placed immediately in moist soil in the open will germinate in the following April. If air-dried to a moisture content of about 9–10% and then sown and left in the open, only 10–15% of the seeds germinate in the following April and most of the remainder 1 year later, 18 months from harvest.

Provenance

No provenance trials have been undertaken in Britain, so plants should either be of local origin or sourced from stands of good form in Britain or in Western Europe.

Yield

Pigott (1991), on the basis of an analysis of growth in a Forestry Commission sample plot in Hampshire, stated that during the first 50 years growth is comparable to stands of Class 1 in the former Soviet Union, or more than 5 m^3 ha^{-1} $year^{-1}$. It is believed that on the best sites limes will grow at something like 8 m^3 ha^{-1} $year^{-1}$.

Timber and uses

The wood of lime is soft, light (about 560 kg m^{-3} at 15% moisture content), white when freshly cut and has a uniform, fine texture. Its main uses are based on its softness, stability and ability to resist splitting. The wood is perfect for making musical instruments as it does not warp; it is used for piano and organ keys, and at one time it was in considerable demand for the sounding boards of pianos. It is easy to machine and is used widely in turnery and carving, in particular gesso and gilt work. It is not durable out of doors but can easily be treated with preservatives to make it so.

From the Middle Ages to the 18th century the fibrous bark of lime was used for rope making.

T. × *vulgaris* and large-leaved lime have been widely planted in parks and in towns, but small-leaved lime much more rarely because it has too wide a crown to be favoured as an urban street tree.

Place of small- and large-leaved lime in British forestry

From about 1970 planting small-leaved lime has often been recommended as an aid to encouraging biodiversity in woodlands, and many small patches have been established. Neither of the native limes has been treated as a commercial crop in Britain since the 19th century, and they have rarely been planted for commercial reasons since at least the 17th century. As species that are likely to benefit from climate change, the position of limes as timber trees might be re-evaluated.

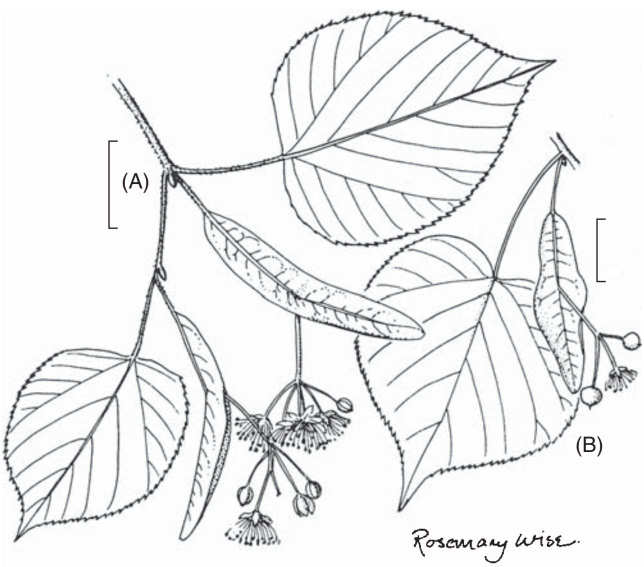

Fig. 35. (A) Large-leaved lime, *Tilia platyphyllos*; (B) Small-leaved lime, *Tilia cordata*.

TILIA PLATYPHYLLOS Scop. Large-leaved lime

Origin

Though the status of large-leaved lime in Britain has been in doubt for a long time, Pigott (1988) stated that on the basis of pollen analysis it is definitely a native tree. In continental Europe it is a more southerly species than small-leaved lime, extending from a single location in southern Sweden to central Spain, northern Greece and southern Italy, eastwards to Poland and the western Ukraine. In Britain it is also found in more southerly regions than small-leaved lime.

Climatic requirements

Like small-leaved lime, it is a rare tree and restricted to valley bottoms because of its intolerance of a dry atmosphere in summer. It comes into leaf in April, normally 10–14 days earlier than small-leaved lime. Damage caused by late spring frosts is rare on large-leaved lime.

Site requirements

Both species of lime are essentially trees of the lowlands and lower ranges of hills. Large-leaved lime occurs predominantly on rendzinas derived from limestone, or basic igneous rocks, being found mostly with beech, ash, sycamore and yew.

Other silvicultural characteristics

Large-leaved lime grows to 20–30 m tall. In most respects the tree is similar to small-leaved lime. Differences include the fact that large-leaved lime does not produce many shoots from the base of the trunk, a feature of small-leaved lime. It grows well in Britain and is said by Huxley *et al*. (1992) to be the only species of *Tilia* that reliably produces viable seed in areas with cool summers.

Pests and diseases

In common with other lime species, large-leaved lime is remarkably free of most of the diseases to which other trees are prone and is not damaged by grey squirrels. However, it is frequently infested with lime aphids, *Eucallipterus tiliae*, as is *T.* × *vulgaris*. The honeydew they produce can be a nuisance on cars and on pavements in urban areas.

Natural regeneration

See under small-leaved lime.

Flowering, seed production and nursery conditions

Contrary to popular belief, both species, but especially large-leaved lime, produce viable seed frequently in southern Britain. There are normally about 7500 kg^{-1}, of which 70% will germinate. The two native limes tend to hybridize where their distributions overlap, as in the Derbyshire Dales and the Wye Valley.

The tree normally flowers in early July, and the flowers last for about 10 days. Similar to *T.* × *vulgaris*, but in contrast to small-leaved lime, they are quite strongly and pleasantly scented. Seeds ripen in October.

Timber and uses

Limes are attractive trees and favourites for planting along roads in towns, presumably because of their sweet-smelling flowers and the fact that they can be pollarded and heavily pruned without coming to much harm. Large-leaved lime and *T.* × *vulgaris* are particularly suitable as street trees because of their narrow crowns.

The timber is similar to that of small-leaved lime: light (544 kg m^{-3} seasoned), soft, with uniform texture and diffuse-porous.

Place of large-leaved lime in British forestry

See under small-leaved lime.

TORMINARIA TORMINALIS Dippel — Wild service tree

The scientific name of this species was, until recently, *Sorbus torminalis* (see p. 205).

Origin

The wild service tree is found over much of northern Europe, the Mediterranean region and North Africa. It is native to England and Wales, from Cumbria and Lincoln southwards. It is rare, patchy and local in distribution. It is not native to Scotland or Ireland. The presence of the species is usually regarded as an indicator of ancient woodland or an ancient hedgerow, because regeneration from seed is unusual.

Climate and site

Precipitation in Britain should not limit the distribution of the wild service tree but low mean annual temperatures might. The species is said to require mean annual temperatures of between 10°C and 17°C, but in lowland England they are not always within this range and they are invariably below it in Scotland and Wales. Hemery *et al*. (2010), in a review of the effects of climate change on broadleaved trees, stated that the range of the wild service tree may shift north to north-eastwards with predicted climate change, but the process is likely to be slow due to the present scattered distribution, poor sexual reproduction and poor seed dispersal, as well as a low competitive ability in comparison with other species. They believed that if natural dispersal is not assisted by humans, a reduction in range is more likely.

The wild service tree shows a marked preference for soils derived from clays or harder limestones (Roper, 1993). It usually grows on clays similar to those favoured by wild cherry. In Lower Saxony the species is well adapted to dry, calcareous, but nutrient-rich sites as a timber tree, and it is particularly common near coasts (Meyer, 1980). It will tolerate short-duration droughts but apparently not late spring frosts. Both dry sandy soils and wet peaty ones should be avoided.

Other silvicultural characteristics

The wild service tree is small, seldom taller than 20 m. It typically occurs as a scattered and uncommon tree in woodlands. It never forms pure stands, and populations of more than 100 trees are unusual (Nicolescu *et al*., 2009). Where it is truly at home, as in parts of France, it is a colonizing species, but it is also reasonably shade-tolerant. In Britain it is light-demanding and a weak competitor with other species. In Italy the tree is regarded as being characterized by slow growth and adapted to low fertility soils (Piagnani *et al*., 2006).

The wild service tree does not self-prune well so needs artificial pruning if clear timber is to be produced, and it has a tendency to fork rather often (Nicolescu *et al*., 2009), requiring formative pruning.

The species can be badly damaged by deer and rabbits. Schmeling (1981) commented that, as a timber producer, it is not really suited to high-forest conditions because its slow height growth and light-demanding nature not only prevent it keeping up with faster-growing species but also cause it to become suppressed and eventually to die. Hence, to survive in dense woodlands, competition must be reduced by consistent thinning to permit adequate crown development. It probably does best as a standard in systems that are coppiced every 25–40 years or in the open. The decline in coppicing over the last 150 years has probably contributed to the current comparative rarity of the species.

Possibly because of its rarity and the value of its timber, a large amount of research has been conducted throughout Europe since about 2000 on the genetics and reproductive biology of the species.

Natural regeneration

Successful regeneration of the wild service tree from seed is rare in Britain because newly germinated seedlings need full overhead light, which is usually not available.

The wild service tree coppices well and older individuals also produce masses of shade-tolerant root suckers for a distance of 3–8 m around the stem, especially after the parent tree dies or has been felled. These grow fast for a few years, but unless they are then freed they become suppressed and may die. As a result of the suckering small clonal patches of the tree occur quite commonly (Hoebee *et al*., 2006), in a similar way to wild cherries.

Flowering, seed production and nursery conditions

The wild service tree, like lime (*Tilia cordata*), is a species that is on the edge of its natural range even in the south of England. The summers are seldom long enough or hot enough for seeds to mature. This is possibly the main reason why the species has been so little used. Though it fruits every year or two, germination percentages are low. A seed wasp, *Torymus*

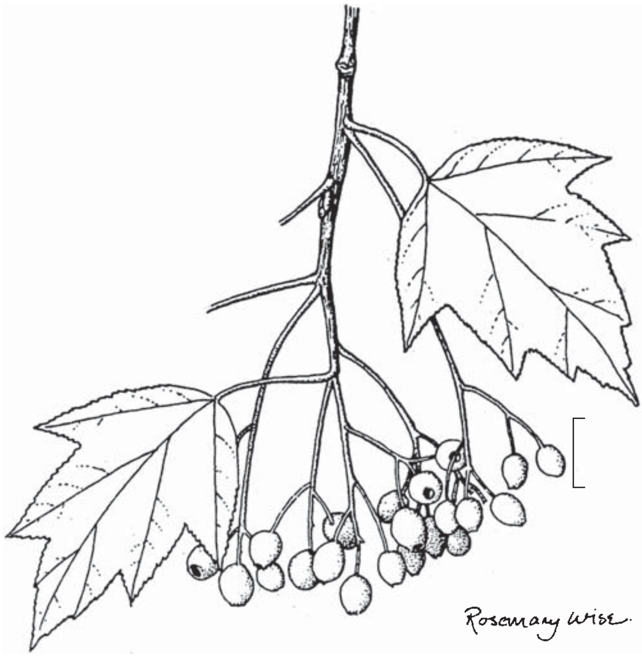

Fig. 36. Wild service tree, *Torminaria torminalis*.

druparum, can be damaging to any potentially viable seed (Winter, 1978). The tree flowers in May and June, and the seeds mature in September and October.

A study by Rasmussen and Kollmann (2004) in Denmark showed that self-pollination is not efficient and that inbreeding depression occurs. They concluded that successful reproduction of the wild service tree is reduced at its northern limit of distribution. The low gene flow between populations might eventually lead to extinction.

Methods of micropropagation have been developed for it. Root suckers, if collected, are slow to grow to usable-sized plants in the nursery because they tend to have such inadequate root systems when small.

Timber and uses

The sapwood and heartwood of the wild service tree are the same colour. The wood of young trees is yellowish-white to light reddish. Old ones have a darker wood, reddish-yellow to red-brown in colour, and fetch much lower prices than younger, light coloured wood.

The wood of the wild service tree is dense (about 750 kg m^{-3}), strong and elastic. It is hard and tough, and is difficult to split. It has a tendency to shrink and to crack and warp when drying, but once it is dry it is stable. It has a low natural durability when exposed to the elements.

The wood is similar in most respects to that of pear and is sometimes, rather enigmatically, sold as 'Swiss pear'. It is valued for furniture, for making veneers, for which light-coloured wood is preferred, and musical instruments, especially flutes, pianos and harpsichords, and, formerly, for measuring and drawing equipment. A minimum diameter of 25 cm is required for most purposes. The wood is relatively easy to work, but because of its high density sharp tools must be used. It has a decorative grain and colour, and in continental Europe can command high prices. Because of this work is being undertaken in France (Lanier *et al*., 1990) to determine the relationships between wood quality and site, and the silvicultural methods required to encourage its growth.

Cobbett (1829) described the fruit as: 'a thing between a sloe and a haw. It is totally unfit to be eaten.' Others disagree, recommending bletting, which involves storing the fruit in a cool dry place until it is almost rotten. It is then said to taste like a medlar or a 'luscious tropical fruit' (Mabberley, 2008; PFAF, 2012). The leaves and bark were reputed at one time to have medicinal properties. These are described by Evelyn (1678).

Place of the wild service tree in British forestry

Interest in the wild service tree arises from its rarity, the challenge it presents in being grown to large sizes and the potential value of its timber. Its yellow autumn colour is spectacular. However, it will never be anything but a minor species and then only in southern Britain.

TSUGA HETEROPHYLLA (Raf.) Sarg. Western hemlock

Origin and introduction

There are nine species of hemlock that occur from North America, through eastern Asia to Vietnam. Western hemlock grows naturally from the Alaskan coast to central California and from sea level to 2250 m. It is particularly abundant along the coasts of Washington and Oregon, and is the dominant species in British Columbia and Alaska along the Coast Mountains, on the coastal islands and the northern Rocky Mountains, especially on well-drained soils in areas with mild, humid climates. It was introduced to Britain in 1851.

Climatic requirements

Western hemlock thrives in a mild, damp climate where frequent fog and precipitation occur during the growing season.

There are no marked regional differences in performance within Britain, though it does best in the humid west where precipitation exceeds 1000 mm. It can also be productive in quite low-rainfall areas but is less suited to the drier east and south-east than Douglas fir. It is mildly susceptible to damage by late spring frosts but recovers well. In exposed areas it is defoliated by strong winds and is more likely to suffer from dieback of the leading shoot on exposed, frost- or drought-prone sites than any other common conifer, especially when young. Its ability to grow replacement shoots can result in multi-stemmed trees.

Though generally windfirm, hemlock is not a deeply rooting tree. Its stability can probably be ascribed to the low drag coefficients in winds, caused by the flexible branches, which stream out in the wind (Raymer 1962; Walshe and Fraser 1963).

Site requirements

Hemlock grows best on deep, moist, well-aerated soils such as acid brown earths on the lower slopes of valleys in upland forests, but it grows acceptably well on both wet and dry sites and the better peats. It will not grow on calcareous soils and requires a soil pH in the range of about 4.0–6.3. Soil texture is relatively unimportant, but height growth becomes slower with increasing soil clay content, probably due to reduced soil aeration or the inability of roots to penetrate compacted soils. According to Packee (1990), western hemlock is poorly suited to sites where the water table is less than 15 cm below the soil surface. Although it will survive on dry soils it grows poorly and tops may die back in years of drought. It thrives particularly well on moderately fertile sites high in available nitrogen, at low elevations, but will grow in wetter regions on less fertile soils.

Other silvicultural characteristics

In Britain hemlock will grow to 30 m tall and rarely to 40 m. In its native habitat it is a climax species, and like most such species it is strongly shade-tolerant. It is more shade-bearing than any other species commonly grown in Britain and is easier to establish under shade than in the open. Within its native range only Pacific yew and Pacific silver fir are considered to have equal or greater tolerance to shade than western hemlock (Packee, 1990). Malcolm *et al*. (2001) believed that unless greater use is made of shade-tolerant species like hemlock, the application of silvicultural systems such as single tree selection will not be possible in Britain.

It is difficult to establish pure on bare ground and does better with a nurse. Like the spruces, it does not compete well with heather.

According to Aldhous and Low (1974), on financial grounds, hemlock is often second choice to Sitka spruce and grand fir, though it could have

Fig. 37. Western hemlock, *Tsuga heterophylla*.

a place on soils too infertile for grand fir and too dry for Sitka spruce. In eastern Scotland and north-east England it is a good alternative to Scots and lodgepole pines if shelter is adequate.

The risks of damage by drought and frost mean that it should not be used for afforestation of open ground, but it can succeed under a light shade.

The roots, especially the fine surface roots, are easily damaged by harvesting equipment, and, because of its thin bark and shallow surface roots, western hemlock is susceptible to damage even from light ground fires. It is also badly affected by SO_2 in polluted environments.

Diseases

Hemlock is more susceptible than many species to being attacked by fomes root and butt rot, *Heterobasidion annosum*, and infected sites should be avoided. However honey fungus, *Armillaria* spp., seldom kills trees. Treating stumps and wounds with chemicals can reduce the rate of infection.

Natural regeneration

Natural regeneration is often good on a wide range of sites, even in dense shade, to the extent that regeneration of other species is unsuccessful. It responds well to release after a long period of suppression. Advance regeneration 50–60 years old commonly develops into a vigorous, physiologically young-growth stand after complete removal of the overstorey.

Because western hemlock can thrive and regenerate on a diversity of seedbeds, natural regeneration can be obtained through a variety of silvicultural systems, ranging from single-tree selection to clear felling. Careful harvesting of mature stands can easily result in adequately stocked young stands if enough regeneration is present.

Flowering, seed production and nursery conditions

The tree flowers in April; seeds ripen and can be collected in September, and are dispersed naturally from October to May. The earliest age at which the tree bears seeds is 20–30 years, but the best seed crops are usually at 3-yearly intervals between 40 and 60 years. There are approximately 573,000 seeds kg^{-1} (range 417,000–1,120,000), of which about half are normally viable. Cones should be collected as soon as they change from bright green to yellow, and the tips of the seed wings are visible and a light brown colour. In nurseries seed should normally be sown between late February and mid-March. It needs no special treatment before sowing, according to Aldhous (1972). Western hemlock seeds remain viable only into the first growing season after seedfall.

Provenance

Vancouver Island sources are recommended by Lines (1987) as good general-purpose origins. Where the risk of frost damage is small more southerly ones can be used.

The stems of trees originating from parts of coastal British Columbia and south-east Alaska are often badly fluted and may be genetically predisposed to the condition (Julin *et al*., 1993). Fluting reduces the value of the timber considerably. Where such trees are found in Britain collection of seed from them should be avoided.

Growth and yield

On the best sites western hemlock grows rapidly. Yield classes range from 12 to 24 $m^3\ ha^{-1}\ year^{-1}$. Packee (1990) stated that in its natural range western hemlock forests are among the most productive in the world and capable of carrying very high volumes of standing timber.

Timber and uses

In North America hemlock is marketed together with *Abies procera* and *Abies amabilis* as ‘Hem-Fir’. The timber is usually described as being intermediate between Douglas fir and spruce. It is non-resinous, and most people say the colour is white (though Wilson (2010) described it as ‘strongly’ coloured). The grain is typically fine and straight. It has good working qualities. Hemlock has a high moisture content when freshly cut and must be seasoned slowly to avoid distortion, but it is stable when dry. At 15% moisture content its density is about 500 $kg\ m^{-3}$. In common with spruces, it is difficult to get timber preservatives to penetrate the wood. Western hemlock is used for constructional work, in situations where its relatively low strength and decay-prone timber are acceptable, and for interior woodwork and other purposes where a fairly high grade of softwood is needed. It is also a major source of pulp in North America and is described as having good-to-excellent pulping characteristics. It is a source for groundwood, thermomechanical, kraft and sulphite pulps.

Place of western hemlock in British forestry

Western hemlock is an important commercial species along the Pacific coast of North America but only a minor species in Britain. Its capacity for natural regeneration means that it is likely to persist in many upland forests, and as a strong shade-bearer it might find a useful place in continuous-cover systems.

ULMUS L.

There are 25–30 north-temperate species of elms, of which six are European. Several species, sub-species and many hybrids are native to Britain. Apart from the distinct wych elm, *Ulmus glabra*, their classification is incompletely worked out and difficult to the person dealing with the trees in the field. Most are probably *Ulmus procera*, of which many strains have been planted over the centuries in different parts of the country. A few are sometimes recognized as separate species or sub-species. Because of the ease by which *U. procera* can be propagated from suckers it is certain that within many localities clonal material has been used quite extensively.

ULMUS GLABRA Hudson — Wych elm

Distribution

The wych elm has a widespread distribution in northern Europe and is the only elm native to Ireland. It has a wide natural distribution, from Ireland eastwards to the Urals, and from Norway in the north to Greece. Unlike English elm, it is found in mixed woods throughout Great Britain and Ireland but most commonly in the north and west.

Silviculture and ecology

Wych elm is normally rather a small tree, seldom more than 20 m tall. It is most commonly found as a natural rather than planted component of mixed broadleaved woods, and in hedgerows and by streams.

It is more of a woodland tree than the English elm. It does best on sites where the relative humidity is high and the soil is fertile, moist, not too acid and well drained. A high level of fertility is not so important. Dry sites should be avoided. It is moderately shade-bearing and casts a dense shade.

Like English elm, it is good at tolerating both exposure from sea winds and atmospheric pollution in towns.

Wych elms produce suckers but much less prolifically than English elms, so regeneration is normally from seed. It coppices well and tends to be a multi-stemmed tree.

Dutch elm disease

Wych elm is susceptible to Dutch elm disease but appears to be slightly more resistant to it than the English elm. This may partly be because of its relative rarity and the fact that it grows in woods rather than agricultural land, so it often escapes the notice of the beetles that carry the disease. Trees can still be found quite easily.

Work by Peterken and Mountford (1998) has demonstrated that the population of wych elm in Lady Park Wood, Forest of Dean, had changed between 1972, when Dutch elm disease struck the area, and 1993. Most of the canopy and subcanopy stems were killed, but a few, slow-growing, subcanopy individuals survived unscathed. Subsequent seedling regeneration and growth of suckers from rootstocks of infected trees was substantial and vigorous. By 1993 the number of wych elms had increased by about 40%, although Dutch elm disease continued to afflict vigorous, exposed individuals.

Peterken and Mountford (1998) stated that the elm population appears to be differentiating into: (i) a large high-turnover subpopulation of fast-growing but repeatedly diseased maiden individuals and sprouts, which appear mainly in regeneration in gaps; and (ii) a small, low-turnover subpopulation of slow-growing individuals rooted in suboptimal dry, secluded sites. The same result was observed by Hahn and Emborg (2007) at Suserup forest in Denmark.

Flowering and seed production

The flowers appear before the leaves in early spring. The winged fruits mature in late spring and the best germination occurs if they are sown immediately, though normally well under 50% of the seed germinates.

Timber and uses

The wood of wych elm is very similar to that of English elm (see below). The average density at 15% moisture content is about 690 kg m^{-3}, heavier than English elm.

Brown and Nisbet (1894) believed that the tree forms a beautiful object in the landscape and ‘cannot be surpassed in the general picturesque effect and grace of its outline’.

Place of wych elm in British forestry

In common with English elm, wych elm has no current place in commercial British forestry. It is likely, however, to remain a valued but minor component of broadleaved woodland.

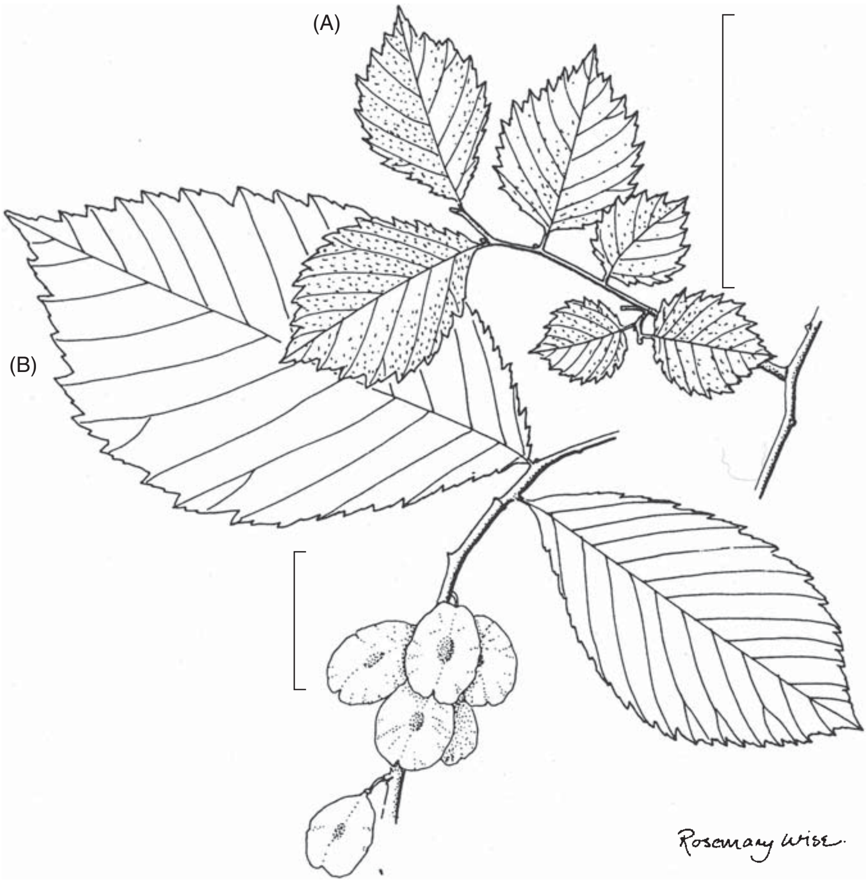

Fig. 38. (A) English elm, *Ulmus procera*; (B) Wych elm, *Ulmus glabra*.

ULMUS PROCERA Salisb. English elm

Origin and distribution

Once believed to be native, the English elm is now thought to have originated from Italy. Gil *et al*. (2004) carried out a survey of genetic diversity of elms and showed that English elms are genetically the same and are derived from clones of a single tree, the Atinian elm in central Italy. It was once widely used for training vines. Clones were originally taken from Italy to Spain by the Romans, and from Spain to Britain.

Silviculture

Where it exists, English elm will grow to about 35 m tall, but within most of its range it is now found only as suckers of 4–5 m tall. The English elm was rarely found in woodland but was widely planted when hawthorn hedgerows were being established during the enclosure movements from 1550 to 1850. English elms are particularly well adapted to growing in hedgerows, being able to establish vigorously from suckers, which spring up in profusion from roots of felled trees. English elms are strong light-demanders, and they are among the best trees at tolerating atmospheric pollution, so were consequently popular urban street trees. They also tolerate salty winds from the sea. They grow best on fertile, generally heavy, lowland soils.

They flower in early spring, before the leaves emerge. The fruits are usually sterile.

Galls on elm leaves are caused by several species of aphids, some of which migrate in summer to the roots of economic plants and cause damage: *Eriosoma lanuginosa* to the roots of pear trees, *Eriosoma ulmi* to currants and gooseberries, and *Tetraneura ulmi* to grasses and cereals (Blackman, 1974).

Dutch elm disease

Dutch elm disease is named after the country in which it was first identified in 1921. It did not originate there and neither is it specific to the cultivar known in Britain as Dutch elm (*Ulmus* × *hollandica* – a hybrid between wych elm, *U. glabra*, and field elm, *Ulmus minor*).

A great deal of information is available about the disease on the Forest Research website,[1] but in summary, the current virulent strain that has resulted in so much mortality of elms is caused by an ascomycete fungus, *Ophiostoma novo-ulmi*, and is spread from tree to tree mainly by the large elm bark beetle, *Scolytus scolytus*. It has been estimated that 25 million trees were killed in Britain alone in the 1970s (Gil *et al*., 2004). Trees usually die within a few months of becoming infected.

Unfortunately, interest in elms today is largely academic because, since the advent of the virulent strain of Dutch elm disease, it has been impossible to plant the species with any prospect of it surviving. Young suckers remain common in hedgerows, but once they reach diameters of about 10 cm and heights of 5 m the bark becomes thick enough for beetles to breed under, and they are soon attacked and die. The disease has caused a profound change to the character of the English midlands in particular, where elms were once a notable feature of the agricultural landscape.

[1] www.forestresearch.gov.uk/fr/treespecies, accessed 29 August 2012.

Work on the selection and breeding of elms resistant to Dutch elm disease has been carried out since the 1930s, especially in the Netherlands (Burdekin and Rushforth, 1981). This approach is showing some promise and a few allegedly resistant clones have been produced, but much still needs to be done before they can be planted with any confidence.

In Britain there are some Dutch elm disease 'control' areas including Brighton. The town is largely protected from the disease by the English Channel to the south and the South Downs to the north. These two barriers prevent the large elm bark beetle getting to the area. The local authority is also both conscientious and vigilant in removing infected sections of trees immediately if they show symptoms of the disease. Some 15,000 mature trees lining streets and in parks still survive in Brighton. The largest numbers in Europe are in Amsterdam and The Hague.

Timber and uses

The ring-porous wood of elm has an interlocking grain, and because of this it is notable for resisting strains that cause other timbers to split. Its value arises mostly from this attribute for making seats of chairs, hubs of wooden wheels, jetties, piers and lock gates. It was also a traditional timber for making coffins. It is resistant to decay when permanently wet, and this property led, in mediaeval times, to lengths being hollowed out to make water pipes (Edlin, 1965). It was also used for timber framing but is less durable than oak for this purpose. Today the main use of the dwindling stocks of elm timber is for making furniture. The average density of the wood at 15% moisture content is about 560 kg m^{-3}. It has a tendency to shrink and swell and is difficult to work. Elm also has the reputation for being shaken quite commonly from ground level up to the branches.

Elm leaves were and in some countries are still used as fodder for many domestic animals and were lopped or 'shredded' for this purpose.

Place of English elm in British forestry

Because of Dutch elm disease English elms have no current place in British forestry.

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FIELD KEY FOR IDENTIFICATION OF COMMON FOREST AND WOODLAND TREES

This key has been devised for use *only* in British forests and woodlands – *not* in parks and gardens. If used outside woodlands it could prove very misleading and other publications should be consulted instead, such as A. Mitchell's (1974) *Trees of Great Britain and Northern Europe* (Collins). This key should cover at least 95% of all trees likely to be encountered, native and exotic, that are capable of growing to heights of 20 m or more. A few generally much smaller but common broadleaved species have been included too, namely holly, rowan, hazel and field maple.

The choice of the 28 broadleaved species and 14 conifers included in the key (about two-thirds of the total number covered in this book) has inevitably been arbitrary.

To use the key, first decide whether the tree is broadleaved or coniferous.

Broadleaved species typically have:

- Leaves that are usually flat and thin; some are hard, dark and evergreen, but not needle-like nor linear.
- A deciduous habit – the leaves fall in autumn (except holly).
- Poor apical dominance: the stem divides into many branches long before the top of the tree (poplars and cherry are often exceptions).
- The trees produce seeds from flowers or catkins (though female catkins of alder are hard and cone-like).

Conifers typically have:

- Leaves (needles) that are many times longer than broad, or sometimes scale-like leaves.
- An evergreen habit (larches are exceptions).
- Good apical dominance – the trunk is continuous from the bottom to the top of the tree.
- Seed produced in cones (yew is an exception).

When you are sure which type of tree you are looking at, use the appropriate key, *with a leaf or branchlet in your hand*, to determine which of two or more descriptions fits best. Each description has a number or name to the right of it. If a number, find this in the left-hand column, and continue in this way till you find the name of the tree. Characteristics shown in italics are particularly useful for identifying the species.

KEY FOR BROADLEAVED SPECIES

1	(a)	Leaves *compound*, consisting of several distinct leaflets growing from the leaf stalk.	**2**
	(b)	Leaves with *lobes* or *deep indentations* around the margins.	**3**
	(c)	Leaves *simple*, *without* lobes or deep indentations.	**7**
	(d)	Evergreen with glossy dark-green, hard leaves; 6–8 cm long, in lower parts of crown, with 6–8 spreading, sharp, yellowish spines.	**Holly** (*Ilex aquifolium*)
2	(a)	Leaves and leaflets *opposite*. Leaflets usually *more than 6 cm* long. Bark light coloured, smooth at first, becoming evenly and shallowly fissured in older trees. Buds *black* and *velvety*. Seed winged.	**Ash** (*Fraxinus excelsior*)
	(b)	Leaves *alternate*, leaflets *opposite*, regularly toothed, *not more than 6 cm* long. Flowers white; fruits red. Small tree to 15 m.	**Rowan** (*Sorbus aucuparia*)
3	(a)	Leaves longer than broad and *lobed*, usually arising in clusters at the ends of twigs. Bark evenly fissured. Crown large. Bears acorns.	**4 – Oaks**
	(b)	Leaf about as broad as long, with 5 (occasionally 3) lobes pointing outwards. Leaves *opposite*. Seeds winged and in pairs.	**5 – Maples**
	(c)	Leaves similar to (b) but *alternate*, often with fewer than 5 lobes.	**6**
4	(a)	Leaves wedge-shaped at base; petiole *long*, 1–2.5 cm. Acorns in clusters of 2–6, on *very short stalks* of 5–10 mm.	**Sessile oak** (*Quercus petraea*)
	(b)	Leaves with *auricles* at base; petiole *short*, 3–7 mm. Acorns in clusters of 2–3, on *long stalk* of 4–8 cm. (*Intermediate forms between these two sometimes occur*, *indicating hybrids*.)	**Pedunculate oak** (*Quercus robur*)
5	(a)	Leaf stalks often red, to 15 cm; leaf up to 18 × 26 cm, with 3 main lobes and 2 minor basal lobes; *very coarsely and unevenly toothed; leathery and dark*. A large tree to >30 m.	**Sycamore** (*Acer pseudoplatanus*)
	(b)	Leaf stalk to 15 cm; leaf 12 × 15 cm, similar to (a) except leaf is *thin-textured*, *bright*, *shiny green*, *with finely pointed lobes and teeth*.	**Norway maple** (*Acer platanoides*)
	(c)	Leaf stalk to 5 cm; leaf to 8 × 12 cm; *teeth rounded*. Usually a small tree, rarely to 20 m.	**Field maple** (*Acer campestre*)
6	(a)	Leaves with 3–5 pairs of lobes, rather *like a maple*, *but alternate*, 10 × 8 cm. Buds globular.	**Wild service tree** (*Torminaria torminalis*)
	(b)	Leaves of sucker shoots and ends of long shoots *deeply palmately 5-lobed*; those of short shoots almost circular, *broadest below the middle*. All leaves *persistently hairy white beneath*. Petioles flattened.	**White poplar** (*Populus alba*)
7	(a)	Leaf tips broadly *rounded or slightly indented*, 10 × 7 cm; margin slightly wavy, irregularly and very shallowly toothed, dark green, with 7 pairs of veins. Buds on 3 mm *stalks*. Female catkins *hard and cone-like*. Generally found near streams or in damp places.	**Alder** (*Alnus glutinosa*)
	(b)	Leaf tips *pointed*.	**8**

Holly (upper crown)

Holly (lower crown)

Ash

Rowan

Sessile oak

Pedunculate oak

Sycamore

Norway maple

Field maple

Wild service tree

White poplar

White poplar (under surface)

Alder

8	(a)	Leaves *very hairy and roughened above*.	**9**
	(b)	Leaves smooth or at least *not* roughened above.	**10**
9	(a)	Bark smooth, silvery for many years, becoming darker and ridged with age. Leaves quite large *shouldered* with abrupt long points, 10–18 cm × 6–9 cm, *very unequal at base*, *c*.17 pairs of veins and *very harshly hairy above*. Leaf stalks *short* (<3 mm), *hairy* and *thick*.	**Wych elm** (*Ulmus glabra*)
	(b)	Leaves variable in shape and size but oblique at base, short pointed, very double toothed, often curled or puckered, *harshly hairy above*, 10–12 pairs of veins and petiole 5 mm. Due to Dutch elm disease only small trees growing from suckers, usually in hedgerows.	**English elm** (*Ulmus procera*)
	(c)	A tall broad bush as coppice and undershrub. Bark smooth, light grey to coppery brown, often peeling. *Young shoots and leaf stalks densely hairy*, and hairs have swollen tips. Leaves almost circular, 10 × 10 cm, heart-shaped at base, sharp, triangular, unequal teeth which are themselves serrated, and *very hairy*. Produces hazel nuts.	**Hazel** (*Corylus avellana*)
10	(a)	Leaves almost circular in outline.	**11**
	(b)	Leaves almost triangular in outline.	**14**
	(c)	Leaves oval to oblong in outline.	**15**
	(d)	Leaves *at least* four times as long as broad.	**16**
11	(a)	Leaves large (to 15 × 15 cm), oblique at base, heart shaped, abruptly pointed at tip; serrated edges, *only hairy on veins* on *both* sides; leaf stalk coarsely hairy at first. Twig ends and buds crimson; buds with two unequal outer scales, appearing 'humped'.	**Large-leaved lime** (*Tilia platyphyllos*)
	(b)	Leaves to 5 × 5 cm, undersides with prominent buff or orange tufts of hairs in axils; leaf paler beneath than (a); leaf stalk hairless. (*Hybrids between these two species of limes* – T. × europaea – *are commonly planted*.)	**Small-leaved lime** (*Tilia cordata*)
	(c)	Leaves not as above.	**12**
12	(a)	Leaf margin crinkled; teeth blunt.	**13**
	(b)	Leaf margin flat; teeth pointed.	**14**
13	(a)	Bark grey and smooth, with *conspicuous rhomboidal lenticels*. Leaves rounded, coarsely toothed with up to 10 teeth, *hairless*, up to 6 cm long, *broadest about the middle*, often broader than long; petiole up to 6 cm *strongly compressed laterally* allowing leaves to tremble. Tree to 20 m; suckers freely.	**Aspen** *(Populus tremula)*
	(b)	Similar to (a) but leaves coarsely toothed with *c*.4–6 obtuse, triangular teeth each side, and greyish-white hairs generally persistent.	**Grey poplar** (*Populus × canescens*)
14	(a)	Shoot roughened by *raised white warts*. Leaves 3–7 cm and pointed; six pairs of veins to protruding pointed teeth that are separated by 2–3 small triangular teeth. Leaf stalk 1.5 cm and *hairless*. Bark often white or silver, and smooth in young trees. A small tree on light soils.	**Silver birch** (*Betula pendula*)

Wych elm

English elm

Hazel

Large-leaved lime

Small-leaved lime

Aspen

Grey poplar

Silver birch

14	(*continued*)		
	(b)	Similar to (a) except that shoots are covered in *short*, *soft*, shiny white hairs; leaves more rounded and *uniformly* toothed; leaf stalk *densely hairy*. Bark brown. Grows on damp soils. (*Intermediate forms between these two birches sometimes occur, indicating hybrids*.)	**Downy birch** (*Betula pubescens*)
	(c)	Bark dark and fissured. Leaves pointed, 5–10 cm, with narrow *translucent borders* and numerous (*c*.20) forward-curved, hooked teeth each side; petiole 3–6 cm, flattened laterally. Trunk and larger branches often with large burrs.	**Black poplar** (*Populus nigra*)
15	(a)	Bark normally *smooth and pale grey* in colour. Buds red-brown, 2 cm long and pointed. Leaves oval, hairless except on margins, 4–9 cm long with *wavy* margin and short teeth at the ends of *6–7 veins* each side. Often a large tree. Characteristic seeds ('mast') and seed cups.	**Beech** (*Fagus sylvatica*)
	(b)	Leaves 3–10 cm long with *about 15 pairs of parallel veins*, and *finely* and sharply *double toothed*; otherwise very similar to beech. Bark light grey, often fluted. Branches ascending at 20–30^{o}.	**Hornbeam** (*Carpinus betulus*)
	(c)	Leaf ovate, usually 8 × 5 cm, irregularly shallowly toothed. When mature, yellow-green above but *densely hairy and pure white beneath*.	**Whitebeam** (*Aria nivea*)
	(d)	Bark *smooth*, often shiny, reddish, with *prominent bands of pale horizontal lenticels*; can be peeled in *horizontal* strips. Leaves to 10 cm long × 4.5–7 cm wide with short points and sharp forward-pointing teeth. Leaf stalk grooved, red above, with *2–5 glands* near leaf base.	**Cherry** (*Prunus avium*)
	(e)	Bark with fissures tending to *spiral* round trunk in older trees. Leaves *large*, 15–20 cm long × *c*.10 cm wide; hard, glossy, dark green with about 20 *prominent, parallel main veins each side,* each ending in a large, abruptly spined tooth, elongated, with pointed apex, and pronounced saw-tooth edges. Produces edible chestnuts that have husks covered in sharp, 1.5 cm long spines.	**Sweet chestnut** (*Castanea sativa*)
16	(a)	Leaves 5–10 cm long and often *at least* 6 times as long as broad, finely serrated and *covered with white silky hairs on both surfaces*; petiole *c*.5–8 mm. Tree to 10–25 m with *branches quite steeply ascending at 30–50^{o}, forming a narrow, silvery-grey crown*.	**White willow** (*Salix alba*) – includes cricket bat and weeping willows.
	(b)	Leaves 6–15 cm and often about 7 times as long as broad, *usually asymmetric at apex*, rather coarsely serrated, *underside hairless* (except when very young), bluish or paler green than top surface; petiole 1–2 cm with 2 small glands at top. Tree to 10–25 m; *branches spreading widely at 60–90^{o}, forming a broad crown*.	**Crack willow** (*Salix fragilis*)

Downy birch

Black poplar

Beech

Hornbeam

Whitebeam

Whitebeam (under surface)

Cherry

Cherry (glands at leaf base)

Sweet chestnut

White willow

Crack willow

KEY FOR CONIFERS

1	(a)	Needles arising from twig *in pairs*, 5 cm or more in length.	**2 – Pines**
	(b)	Needles arising from twigs *in whorls* (on short shoots) as well as singly.	**3 – Larches and Cedars**
	(c)	Needles arising from twig *singly*.	**4**
	(d)	Adult leaves scale-like, completely covering and pressed to twig.	**7 – 'Cypresses'**
2	(a)	Needles dark blue-green in colour, not more than 7.5 cm long. Buds 1.5–2 cm, rather squat and abruptly pointed. Bark deeply fissured at base and *red* towards top of tree.	**Scots pine** (*Pinus sylvestris*)
	(b)	Needles very dark green, more than 7.5 cm long, terminal bud drawn out to long fine point. Bark slightly fissured or scaly and grey in colour. Planted at *low elevations only*.	**Corsican pine** (*Pinus nigra*)
	(c)	Usually an *upland species*. Buds dark brown, long, cylindrical; needles deep green and *twisted*. Cones in whorls of 2–4, *pointing back down stem*.	**Lodgepole pine** (*Pinus contorta* var. *latifolia*)
3	(a)	Needles *evergreen*, stiff and sharp.	**Cedar** (*Cedrus* spp.)
	(b)	Leaf-bearing twigs *pale yellow*. Leaves deciduous, soft, usually 2–3 cm, *green*. Cones tall, egg-shaped, scales are *not* turned outwards as in *Larix kaempferi*.	**European larch** (*Larix decidua*)
	(c)	Leaf-bearing twigs *reddish*. Leaves similar to (b) but broader and greyer, about 4 cm with two *broad grey bands* beneath. Cones flattened, bun-shaped, with edges of scales *strongly turned out and down* like a rose. (*Hybrids between these two larches are commonly planted*.)	**Japanese larch** (*Larix kaempferi*)
4	(a)	Leaves hard, pointed, stiff and spiny, mounted on *small woody projections;* stem smooth to scaly.	**5 – Spruces**
	(b)	Leaves arising direct from twig or small swelling. Leaves soft.	**6**
5	(a)	Needles flat but strongly keeled, 2–3 cm, sharply pointed, very stiff, with two blue-white bands beneath. Foliage appears *blue-grey*. Bark tending to flake off, particularly on older trees.	**Sitka spruce** (*Picea sitchensis*)
	(b)	Needles moderately stiff, spreading each side of and *above* shoot, 1–2 cm, four-sided and *each side the same dark green*. Bark slightly fissured at base and reddish.	**Norway spruce** (*Picea abies*)

Scots
pine

Corsican pine

Lodgepole
pine

Cedar

European larch

Japanese larch

Sitka spruce

Norway
spruce

6	(a)	Leaves long, 2–5 cm, very *flat and arranged like a comb*, with two bright, narrow, silver bands beneath; highly aromatic with a *fruity orange scent*, leaving a saucer-like scar when they fall. Bark smooth and often containing many resin blisters.	**Grand fir** (*Abies grandis*)
	(b)	Leaves parted each side above shoot, of *mixed sizes*: upper rows *c*.0.6 cm, lowest rows *c*.1.7 cm; dark green above with *two bright white bands beneath*. Bark closely and vertically fissured. *Leading shoots drooping* by 50–60 cm.	**Western hemlock** (*Tsuga heterophylla*)
	(c)	Buds pale brown, to 7 mm, *spindle-shaped* like a beech. Leaves 2–2.5 cm, soft with two variably bright white bands beneath. Cones with characteristic *three-pronged* bracts. Bark dark grey-green and resin-blistered in young trees, deeply fissured in older trees.	**Douglas fir** (*Pseudotsuga menziesii*)
	(d)	Shoots grooved below leaves. *Buds minute*. Leaves 2–4 cm, linear, narrowing abruptly to a *sharp point*. Needles soft, dark green above, lighter beneath. Bears *crimson arils*, not cones.	**Yew** (*Taxus baccata*)
7	(a)	*Leading shoot drooping*. Finest branchlets only 2 mm across. Foliage gives a resinous *parsley-like scent*. *Translucent glands* in centre of median leaves (difficult to see). Bark finely vertically fissured and dark brown in colour. Cones, when green, are *globular*; when mature, dry, brown and open.	**Lawson's cypress** (*Chamaecyparis lawsoniana*)
	(b)	*Leading shoot erect*. Finest branchlets at least 2 mm across, usually 3 mm. Has *fruity aroma of pineapple*. Bark finely vertically fissured and dark reddish brown in colour. Cones oval, leathery, 1.5 cm long, scale tips spreading as spines.	**Western red cedar** (*Thuja plicata*)

Grand fir

Western hemlock

Douglas fir

Yew

Lawson's cypress

Western red cedar

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