
# Timber properties of species with potential for wider planting in Great Britain

Andrew Price, Dan Ridley-Ellis, Steven Adams, Stefan Lehneke, Adam Ash and Elspeth Macdonald December 2024

Diversifying the range of tree species planted in Great Britain is an important goal in adapting to climate change and increasing the resilience of British forests. The wood properties and utilisation potential of less widely planted species are important considerations for forest managers but, for many species, there is limited relevant information available on their properties, especially for construction timber. This study examined the main physical and mechanical properties of eight species: European silver fir, Pacific silver fir, grand fir, Caucasian fir, Serbian spruce, Japanese red cedar, sycamore and silver birch. Sample material was obtained from a mixture of experimental trials, demonstration plots and normal forest stands in the age range 40–60 years. Measurements of wood density, bending stiffness and bending strength were made on structural-sized samples and indicative EN 338 strength classes were estimated. The results suggested that European silver fir, Pacific silver fir and Serbian spruce could all potentially be graded into the C16 strength class with a near 100% yield, while grand fir would be limited to the C14 strength class. Japanese red cedar fell below C14, limited by strength, density and stiffness. Caucasian fir was limited by strength to about C14. When silver birch and sycamore were graded against the softwood 'C' strength classes, they met the requirements of C40 and C20 respectively. Neither species, however, graded well in the hardwood 'D' strength classes. More testing is required for formal grading assignment, as these preliminary indications are based on sampling that is not fully representative of future scaled up commercial production.

# Introduction

There is widespread interest in diversifying the range of tree species grown in British forests in order to increase resilience to both climate change impacts and to the growing incidence of damaging pests and diseases. Additionally, a wider range of tree species would help to improve biodiversity and the provision of ecosystem services (Reynolds *et al*., 2021; Messier *et al*., 2022). Experimental trials, forest gardens and arboreta have provided some information on the growth rate and survival of many species that are not currently widely planted, but relatively little is known about their wood properties and potential for use in different applications. The data that do exist are often derived from tests on single trees or very small sample sizes, generally of unknown seed origin, and provide little information about the variation in wood properties at a population level (Ramsay and Macdonald, 2013).

A previous study by Edinburgh Napier University and Forest Research examined the timber properties of Norway spruce (*Picea abies*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*) and noble fir (*Abies procera*), based on three study sites for each species and using both structural and clearwood samples (Gil-Moreno, 2018; Gil-Moreno, Ridley-Ellis and McLean, 2016; Gil-Moreno, McLean and Ridley-Ellis, 2023). The results suggested that all these species had the potential to produce sawn timber suitable for use in construction. The project reported here aims to complement this earlier study by collecting data relating to the physical and mechanical properties of eight additional species when grown under British conditions.

# Species selected for study

Tree species growing in Britain can be categorised into four groups (Kerr and Jinks, 2015, in Reynolds *et al*., 2021):

1. Principal tree species: species where silvicultural knowledge provides confidence to enable successful deployment across Britain. The species are either already widely used or are increasing in usage. They will continue to be important unless they are affected by a new pest or disease or they become adversely affected by climate change.

2. Secondary tree species: species that have demonstrated positive silvicultural characteristics in trial plots but gaps in knowledge constrain wider use. These species are being actively evaluated to increase understanding and inform future deployment.

3. Plot-stage species: species that have demonstrated some positive silvicultural characteristics at the specimen-stage and are now subject to further testing and development in a limited number of trial plots.

4. Specimen-stage species: species that have rarely been trialled for forest potential in experimental plots but have demonstrated, as specimens in tree collections, positive traits of good form, growth rate and hardiness to warrant further testing in plots on a limited scale.

Species in categories 2 and 3 are collectively termed 'emerging species' (Reynolds *et al*., 2021) and it is from this group that five of the conifers included in this study were selected. In addition, one conifer and two broadleaves which are classed as principal species, but which have not been widely managed for timber production in the UK in recent times, were included. The species chosen were all identified, in consultation with forest industry representatives, as potentially of interest for the diversification of British forests:

Principal species:

- Sycamore (*Acer pseudoplatanus*)
- Silver birch (*Betula pendula*)
- Grand fir (*Abies grandis*)

Secondary species:

- Serbian spruce (*Picea omorika*)
- European silver fir (*Abies alba*)
- Pacific silver fir (*Abies amabilis*)
- Japanese red cedar (*Cryptomeria japonica*)

Plot-stage species:

- Caucasian fir (*Abies nordmanniana*), also known as Nordmann fir.

Most of the species selected for study are managed for commercial timber production in other countries and appear in European strength grading standards (Ridley-Ellis, Gil-Moreno and Harte, 2023). In particular, European silver fir is widely grown for timber in continental Europe, where it is generally marketed and graded together with Norway spruce as 'European whitewood' (Savill *et al*., 2016). In western North America, Pacific silver fir and grand fir are commonly sold in a mixture with western hemlock and other species as 'Hem-Fir' (Forest Products Laboratory, 2010). Both of these *Abies* species are processed for a range of end uses including general construction and engineered timber products. In Turkey, Caucasian fir is used in building, furniture manufacture, veneer and plywood (Caudullo and Tinner, 2016; Savill *et al*., 2016) and a 2021 visual strength grading entry was added into the latest version of EN 1912 (British Standards Institution, 2024). Japanese red cedar is an economically important species for timber production in Japan, where end uses include construction, bridges, furniture and paper (Savill, 2015). A 2012 visual strength grading assignment for Japanese red cedar grown in Réunion has also been added into the most recent version of EN 1912 and, in 2022, European machine grading settings were approved for this species grown in the Azores.

The final conifer species in this study, Serbian spruce, is generally no longer managed for timber production. Within its natural range, in Serbia and Bosnia Herzegovina, the remaining fragmented resource is threatened by poor regeneration, natural succession of other species (including European silver fir and beech), climate change and human pressures; it is classified as a 'vulnerable' species and remnant populations are legally protected (Savill *et al*., 2017; Ballian, Ravazzi and Caudullo, 2016).

Of the two hardwood species, only silver birch is managed for commercial production in northern Europe, particularly Finland, with a range of end uses for the timber including veneer, plywood, furniture, engineered wood products and paper (Heräjärvi, 2001; Hynynen *et al*., 2010). Research is ongoing to investigate birch's potential as a productive timber species for diversification of forests in other areas of Europe (e.g. Dubois, Verkasalo and Claessens, 2020; Dubois, Claessens and Ligot, 2021; Skovsgaard *et al*., 2021), and a route to strength grading of Swedish and Norwegian grown birch is expected in the near future (Lemke *et al*., 2023).

Although sycamore is not widely managed for commercial production, its timber is valued for a number of end uses including furniture, flooring, joinery and musical instruments (Krabel and Wolf, 2013). Like birch, there is increasing interest in the role that sycamore may play in future diversification of the productive forest resource in Europe (e.g. Hein *et al*., 2009; Huber *et al*., 2023; Whittet, Lopez and Rosique-Esplugas, 2021) and sycamore grown in Germany can already be visually strength graded via an assignment in EN 1912 (British Standards Institution, 2024).

Information about the native range, site requirements, vulnerability to pests and pathogens and use in Britain of each of the selected species can be found in Forest Research's [Tree Species Database].

# Methodology

## Study sites

Identifying stands which were suitable in terms of tree age, condition and accessibility for harvesting proved challenging given the scarcity in Britain of many of the study species. The sample stands selected varied in size and in their original planting objective, being a mixture of formal replicated trials, demonstration plots and normal forest stands (Figure 1, Table 1). While the majority of stands were located in Scotland, the opportunity was also taken to include European silver fir, grand fir and Caucasian fir growing in an experimental trial at Thetford Forest in the east of England. Assessments and sampling took place between 2014 and 2016. Due to the restricted options for sampling, it was not possible to limit the timber property assessments to battens where the outer ring number from the pith was less than or equal to 45 (i.e. equivalent to 45 years of growth) as was done in the previous report by Gil-Moreno, Ridley-Ellis and McLean (2016). However, the age range of the trees sampled in this study was narrower than in the previous study, with trees aged between 40 and 60 years at the time of sampling (compared to between 30 and 78 years in the previous study).

**Figure 1** Location of study sites

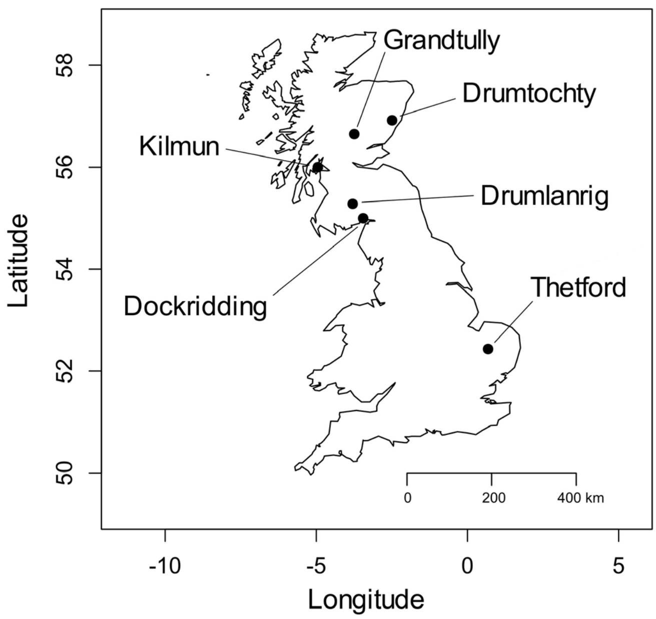

**Table 1** Study site locations, climate and soil

| Study site<br>*Type of stand* | Species | Stand planting year (age at sampling)* | NGR | Elevation (m asl) | Accumulated Temperature (day-degrees >5.0°C $annum^{-1}$) | DAMS windiness score | Soil type |
|---|---|---|---|---|---|---|---|
| Drumtochty Forest, Aberdeenshire<br>*Experimental trial* | European silver fir | 1965 (50) | NO700810 | 350 | 982 | 14 | Podzol |
| | Grand fir | | | | | | |
| Grandtully Wood, Perthshire<br>*Forest stand* | Silver birch | 1974* (40) | NN931523 | 130 | 1102 | 8 | Brown earth |
| Kilmun Forest Garden, Argyll<br>*Demonstration plots* | Pacific silver fir | 1958 (56) | NS161827 | 110 | 1351 | 12 | Upland brown earth, podzolised |
| | Japanese red cedar | 1954 (60) | NS164823 | 30 | 1387 | 11 | |
| Drumlanrig Castle, Dumfries & Galloway<br>*Forest stand* | Sycamore | 1965* (50) | NS859000 | 90 | 1437 | 10 | Brown earth |
| Dockridding Wood, Dumfries & Galloway<br>*Forest stand* | Serbian spruce | 1964* (50) | NY073680 | 10 | 1565 | 14 | Flushed basin bog (juncus) |
| Thetford Forest, Suffolk<br>*Experimental trial* | European silver fir | 1966 (50) | TL823851 | 40 | 1764 | 12 | Podzolic brown earth |
| | Grand fir | | | | | | |
| | Caucasian fir | | | | | | |

*Stand planting year/age estimated due to lack of available information.

## Measurements and selection of sample trees

Measurements of diameter at breast height (DBH; cm) and total tree height (m) were made at each sample site in accordance with standard mensuration procedures (Matthews and Mackie, 2006). The variable nature of the sample sites made it difficult to follow identical sampling procedures in each stand: in replicated trials all live trees were measured in the treatment plots, while circular sample plots were used in the larger forest stands and the demonstration plots in Kilmun Forest Garden. The number of trees measured at each site is shown in Table 2. Estimates of mean DBH, top height, mean tree volume, stand volume and stand General Yield Class (GYC) were derived from these measurements (Matthews and Mackie, 2006; Matthews *et al*., 2016a).

Sample trees for testing of wood properties were selected randomly from each of the three upper quartiles of the diameter distribution at each site. The number of sample trees selected varied between stands depending on availability and practicalities in each stand (Table 2).

Sample trees were felled and one 3.1 m sawlog, for conversion to structural-sized battens for mechanical testing, was cut from each tree, with the base of the log at just higher than 1.3 m above ground-level.

In addition, two short logs (1.3 m) for the preparation of small clearwood test samples and cross-sectional discs for assessment of radial growth and wood density variation were cut, one above the 3.1 m log and one at the base of the live crown. Results of measurements made on these samples will be reported in a future publication.

## Sample preparation and testing: structural-sized battens

The 3.1 m logs were processed into structural-sized battens with nominal cross-sectional dimensions of 50 mm x 100 mm (Figure 2). The logs were marked prior to cutting with a pattern which maximised the number of battens cut. The structural-sized battens were then kiln dried and conditioned to an equilibrium dry-basis moisture content of 12% before being measured with a Brookhuis MTG960 handheld grader. In order to determine stiffness and strength, the battens were then tested

**Table 2** Details of the number of trees measured to assess stand characteristics and the number of samples trees felled at each site

| Species | Study site | Number of trees measured for DBH and height | Number of sample trees | Sampling notes |
|---|---|---|---|---|
| European silver fir (ESF) | Drumtochty | 71 | 12 | ESF provenance trial: 6 sample trees from each of 2 provenances - Lajoux and Jura mountains, assessed as mid-ranking for growth by Kerr *et al.* (2015). |
| | Thetford | 131 | 45 | ESF provenance trial: 9 sample trees from each of 5 provenances – Lajoux and Jura mountains as at Drumtochty, plus the two Calabrian provenances ranked highest by Kerr *et al.* (2015) and a highly ranked Austrian provenance. |
| Grand fir | Drumtochty | 65 | 12 | Planted in ESF provenance trial for comparative purposes. |
| | Thetford | 24 | 6 | Planted in ESF provenance trial for comparative purposes (poor survival limited the number of trees that could be measured and sampled). |
| Caucasian fir | Thetford | 21 | 9 | Planted in ESF provenance trial for comparative purposes. |
| Pacific silver fir | Kilmun | 56 | 11 | Salvaged from recent windblow; 9 trees fully blown, 2 leaning. |
| Japanese red cedar | Kilmun | 50 | 12 | |
| Serbian spruce | Dockridding Wood | 52 | 12 | |
| Sycamore | Drumlanrig | 71 | 12 | |
| Silver birch | Grandtully | 101 | 13 | The poor form of trees resulted in only 5 logs suitable for conversion to structural-sized battens. |

to destruction using a four-point bending test in accordance with EN 384 and EN 408 (British Standards Institution, 2012, 2022). Following the same standards, wood density and moisture content were measured on a defect-free sample cut from each batten after testing. Due to limited resources, the destructive testing did not include the European silver fir or grand fir from Thetford. For these samples, only non-destructive measurements were made using the MTG960, which gave values of dynamic modulus of elasticity and whole board density. These were used to estimate sample density and bending test stiffness using standard adjustment factors (dividing by 1.05 for density and 1.2 for stiffness). The results were corrected for moisture content, which was estimated by an electrical resistance moisture meter at the time of measurement with the MTG960.

**Figure 2** (a) Testing structural-sized battens using a handheld MTG timber grading machine; (b) structural-sized battens being loaded into the kiln at Forest Research's Northern Research Station for drying; (c) grand fir logs being cut on the Woodmizer sawmill; (d) sycamore logs being marked with cutting pattern prior to cutting.


Characteristic values of density, bending strength (both 5th percentile) and bending stiffness (mean) were calculated according to EN 384 (British Standards Institution, 2022) and compared to the requirements of the most common strength classes in EN 338 (British Standards Institution 2016b), shown in Table 3, using the procedure described by Gil-Moreno, Ridley-Ellis and Mclean (2016). This method does not include the confidence adjustments for sample size in EN 14358 (British Standards Institution, 2016a), but is based on the non-parametric ranking method for strength and density and simple mean for stiffness. As in the previous study, the results were adjusted for cross-section size ($k_h$ of EN 384) and include the 0.95 adjustment for stiffness, but do not include the adjustment factor on strength used in machine strength grading ($k_v$). This allowed an estimate of the likely EN 338 strength class that could be achieved for near 100% grading yield and an indication of the property most likely to limit the grading. Where grading is limited by stiffness or density it is expected that higher strength classes might be achievable with reasonable machine strength grading yields. When grading is strength limited, higher strength classes could be achieved as long as there is a grading indicator that has a good correlation with strength for that particular species.

**Table 3** Characteristic values for strength classes C14 to C24 (British Standards Institution, 2016b)

| Wood property | Characteristic property values for each strength class | | | | | |
|---|---|---|---|---|---|---|
| | C14 | C16 | C18 | C20 | C22 | C24 |
| 5th percentile strength (N mm$^{-2}$) | 14 | 16 | 18 | 20 | 22 | 24 |
| Mean stiffness (kN mm$^{-2}$) | 7 | 8 | 9 | 9.5 | 10 | 11 |
| 5th percentile density (kg m$^{-3}$) | 290 | 310 | 320 | 330 | 340 | 350 |

For 'C' and 'D' strength classes, strength refers to bending strength (also known as modulus of rupture, MOR) and stiffness refers to bending stiffness (also known as modulus of elasticity, MOE).

# Results

The details of each sample stand are summarised in Table 4.

**Table 4** Summary of stand parameters estimated in accordance with procedures set out in Matthews and Mackie (2006) and Matthews *et al.* (2016b)

| Species | Study site | Estimated stand parameters | | | |
|---|---|---|---|---|---|
| | | Quadratic mean DBH (cm) | Top height (m) | Mean tree volume ($m^3$) | General Yield Class |
| European silver fir | Drumtochty | 28 | 24 | 0.66 | 20 |
| | Thetford | 26 | 22 | 0.51 | 16 |
| Grand fir | Drumtochty | 23 | 24 | 0.43 | 14 |
| | Thetford | 37 | 24.5 | 1.21 | 14 |
| Caucasian fir | Thetford | 20 | 18 | 0.25 | 12 |
| Pacific silver fir | Kilmun | 33 | 30 | 1.13 | 18 |
| Japanese red cedar | Kilmun | 38 | 27 | 1.17 | 20 |
| Serbian spruce | Dockridding Wood | 32 | 21 | 0.75 | 14 |
| Sycamore | Drumlanrig | 34 | 26 | 0.80 | >12 |
| Silver birch | Grandtully | 23 | 18 | 0.28 | 12 |

## Testing of structural-sized battens

The mean and characteristic values for each wood property are summarised in Table 5, together with the estimated strength class for each species. Coefficients of variation are included (standard deviation as a percentage of the mean) but, with such limited sampling, these are more of a guide to the extent of variation captured by the sampling rather than the variation in the resource. Observations from unpublished grading reports suggest that the expected coefficient of variation of density for a timber resource in a growth area is about 10% to 15%. For stiffness, it is 20% to 30% and for strength 30% to 40%. Where the coefficients of variation are lower, it is a sign that the sampling is likely less variable than the resource overall. This is an expected effect when sampling single sites and a limited number of trees.

An indication of the coefficient of determination ($R^2$) is given for dynamic modulus of elasticity from resonance (a common strength grading method) and bending strength. This value should be treated with caution as the correlation can be strongly affected by growth conditions and is anyway uncertain when the sample size is small.

There are several legitimate ways to calculate grading and, particularly when the sample is small, results are sensitive to the approach used. This is because values are often determined by one or two test results. The approach used here matches that used in Gil-Moreno, Ridley-Ellis and McLean (2016).

Three of the softwood species tested (European silver fir, Pacific silver fir and Serbian spruce) appear likely to grade well as strength class C16, which is the usual UK market minimum strength class (Adams and Ridley-Ellis, 2021). From the samples tested, European silver fir looks to be mostly limited by stiffness, while Pacific silver fir is mostly limited by density and Serbian spruce mostly limited by strength.

Based on samples from the Drumtochty site alone, low density and strength, as well as relatively low stiffness, seem to restrict grand fir to strength class C14. However, when the sampling from Thetford (which was assessed non-destructively only, with no estimation of strength values) is included, the limitation of the sampling becomes more apparent. This is because the overall estimated density of the grand fir, as well as the estimated stiffness for both grand fir and European silver fir, are higher than for the Drumtochty samples alone. This indicates the possibility of strength class C20 for these species and perhaps a reasonable grading yield for a combination of C16 and C24.

Caucasian fir appears to be mostly limited by strength to C14, while Japanese red cedar does not achieve C14 due to low values across all properties. The results indicate that when

**Table 5** Stiffness, strength and density of sawn timber samples, together with estimated strength classes based on characteristic values. Results from previous studies are included for comparison (Gil-Moreno, Ridley-Ellis and McLean, 2016; Ridley-Ellis, Gil-Moreno and Harte, 2022).

| Species | Number of battens | Mean density (kg $m^{-3}$) | 5th percentile density (kg $m^{-3}$) | Mean stiffness (kN $mm^{-2}$) | Mean strength (N $mm^{-2}$) | 5th percentile strength (N $mm^{-2}$) | Approximate strength class |
|---|---|---|---|---|---|---|---|
| **Results from this study** | | | | | | | |
| European silver fir (Drumtochty) | 76 | 395 (7%) | 351 *C24* | 8.69 (20%) *C18* | 32.7 (29%) [MOE $R^2$ ~0.4] | 20.0 *C20* | **C18** |
| European silver fir (Thetford), non-destructive testing only | 292 | 417 (9%) | 353 *C24* | 9.71 (19%) C22 | | | |
| Grand fir (Drumtochty) | 59 | 367 (11%) | 305 *C14* | 7.60 (24%) *C16* | 28.0 (34%) [MOE $R^2$ ~0.4] | 15.5 *C14* | **C14** |
| Grand fir (Thetford),non-destructive testing only | 46 | 408 (9%) | 363 *C27* | 9.10 (15%) *C20* | | | |
| Caucasian fir | 31 | 407 (9%) | 359 *C24* | 9.39 (21%) *C20* | 32.3 (30%) [MOE $R^2$ ~0.3] | 14.9 *C14* | **C14** |
| Pacific silver fir | 158 | 379 (12%) | 310 *C16* | 8.83 (20%) *C18* | 35.4 (28%) [MOE $R^2$ ~0.3] | 17.8 *C16* | **C16** |
| Japanese red cedar | 110 | 304 (13%) | 254 *<C14* | 4.94 (33%) *<C14* | 23.5 (34%) [MOE $R^2$ ~0.4] | 13.1 *<C14* | **<C14** |
| Serbian spruce | 89 | 421 (7%) | 379 *C27* | 9.05 (26%) *C20* | 36.0 (34%) [MOE $R^2$ ~0.5] | 16.0 *C16* | **C16** |
| Sycamore | 103 | 547 (7%) | 491 *C50/D24* | 9.25 (15%) *C20/D18* | 40.7 (29%) [MOE $R^2$ ~0.3] | 21.8 *C20/D18* | **C20/D18** |
| Silver birch | 14 | 593 (6%) | 535 *C50/D30* | 13.97 (15%) *C40/D50* | 55.8 (15%) [MOE $R^2$ ~0.1] | 40.4 *C40/D40* | **C40/D30** |
| **Results from previous studies** | | | | | | | |
| Norway spruce | 128 | 401 (9%) | 345 *C22* | 8.55 (20%) *C18* | 31.1 (29%) [MOE $R^2$ ~0.4] | 19.1 *C18* | **C18** |
| Western hemlock | 238 | 443 (9%) | 380 *C30* | 8.61 (22%) *C18* | 36.2 (31%) [MOE $R^2$ ~0.4] | 19.6 *C18* | **C18** |
| Noble fir | 126 | 378 (10%) | 324 *C18* | 7.71 (29%) *C16* | 31.1 (42%) [MOE $R^2$ ~0.4] | 14.8 *C14* | **C14** |
| Western red cedar | 115 | 358 (9%) | 318 *C16* | 7.44 (22%) *C14* | 30.1 (27%) [MOE $R^2$ ~0.4] | 16.3 *C16* | **C14** |
| British spruce (current Sitka spruce and Norway spruce mixture) | ~2000 | 380-410 (10%) | ~330 *C20* | 7.5-8.5 (30%) *C16* | 30-33 (30%) [MOE $R^2$ ~0.4] | ~18 *C18* | **C16** |
| Larch (current European, Japanese and hybrid larch mixture) | ~1000 | 480-530 (12%) | ~400 *C35* | 9.5-10 (25%) *C20* | 37-44 (30%) [MOE $R^2$ ~0.4] | ~21 *C20* | **C20** |
| Douglas fir | ~700 | 450-550 (10%) | ~400 *C35* | 8.5-13 (25%) *C22* | 28-50 (35%) [MOE $R^2$ ~0.4] | ~16 *C16* | **C16** |

**Table 5 notes**

1. Coefficients of variation are given in parentheses
2. Underlining of strength class for a property indicates that the property is grade-limiting for the species.
3. The results for western hemlock contain 100 additional samples when compared with those presented in Gil-Moreno, Ridley-Ellis and McLean (2016). The main difference is a slight increase in stiffness sufficient to raise it just over the requirement for C18.
4. MOE $R^2$=coefficient of determination for strength with modulus of elasticity.

grading Japanese red cedar with dynamic modulus of elasticity, it might be possible to achieve a yield of C14 in the order of 20%.

The two hardwood species tested were graded into the 'C' classes to investigate the potential for grading them with conifers. While 'C' classes are commonly referred to as softwood classes, they are also applicable to hardwoods (British Standards Institution, 2016b and 2022). Sycamore appears to be limited to C20 and silver birch to C40. In each case, both stiffness and strength seem to be limiting. Density is relatively high, particularly in the case of sycamore, but not as high as expected by the existing hardwood 'D' classes, which also have fewer options at the lower end. As a result, neither species performed well when graded against the hardwood 'D' classes, with stiffness limiting to D18 for sycamore and density limiting to D30 for silver birch. It should be noted, however, that the results for silver birch were based on an extremely small sample size of only 14 battens and that the measured stiffness is about 30% higher than expected based on previous testing of UK-grown birch (Dunham *et al.*, 1999).

For comparison, Table 5 also includes the data for Norway spruce, western hemlock, noble fir and western red cedar from the previous research (Gil-Moreno, Ridley-Ellis and McLean, 2016), with data from an additional 100 battens of western hemlock from the England and Wales sites, which were tested after that research note was published. This additional material was slightly stiffer, having the effect of pushing the stiffness limited grading over the borderline from C16 to C18.

The range of values quoted for British spruce, larch and Douglas fir is taken from grading work with representative sampling by geographical area and cross-section, and describes the range expected for single sites (Ridley-Ellis, Gil-Moreno and Harte, 2022). These grades are for near 100% yield, but much higher strength classes can be achieved via machine grading, especially for Douglas fir due to it being mostly limited by strength rather than by stiffness (Gil-Moreno, Ridley-Ellis and Harte, 2019).

# Discussion and conclusions

This study evaluated wood properties and utilisation potential of timber from six conifer species and two faster-growing broadleaved species.

The results of testing structural-sized battens suggest that European silver fir, Pacific silver fir and Serbian spruce could all be graded into the C16 strength class, with the limiting properties for each being stiffness, density and strength respectively. The grand fir tested in this study was limited by density and strength to the C14 strength class, with stiffness also borderline. However, the non-destructive measurement of the timber from Thetford suggests a larger sampling would produce better results.

Although the timber from both Caucasian fir and Japanese red cedar is used for construction when grown in their native ranges (Savill, 2015; Savill *et al.*, 2016), the material tested in this study indicated C14 for Caucasian fir and well below C14 for Japanese red cedar; the former being limited by poor strength and the latter by both low stiffness and low density. Caucasian fir from Turkey has much better visual grading assignments than the samples used in this study, with even the lowest visual grading class achieving C18 (British Standards Institution, 2024). For Japanese red cedar on the other hand, the results from this study are not dissimilar to the findings from the Azores, where it only achieves C14 even by machine grading (CEN TC124, 2023).

When silver birch and sycamore were graded against the softwood 'C' strength classes, they met the requirements of C40 and C20 respectively. Neither species, however, graded well in the hardwood 'D' strength classes, being limited by density to D30 and D18 respectively. That these hardwoods do not fit well into the established hardwood strength classes is not unusual since these classes were developed for relatively higher density and more commonly exploited hardwoods such as oak and sweet chestnut (although sycamore grown in Germany can be visually graded to D30). This is an emerging issue across Europe now that more varied hardwood species are coming to market and is the reason why 'C' strength classes were opened up to lower density hardwoods in 2016 (Ridley-Ellis, Stapel and Baño, 2016). While the birch data are very limited, they can be compared to the data from Sweden, which are broadly similar (Lemke *et al*., 2023).

The small number of trees tested in this project, as well as the single geographic location for most species sampled, limits the conclusions that can be drawn about the utilisation potential. Results indicate, however, that several of the conifer species tested could potentially be blended into the 'British spruce' C16 market because the timber is similar in appearance, properties and grading (Ridley-Ellis, Gil-Moreno and Harte, 2023). This would require the collection of additional data from a wider geographic area, from which appropriate grading information could be gathered (both for visual and machine grading). A grading dataset for a main commercial species is usually 500 or more boards, but due to the unknown variability of the species in this study, it may be necessary to assess 1000 boards or more. In this respect, European silver fir, Pacific silver fir and Serbian spruce appear the most promising of the species studied in this project, while grand fir is also perhaps worth investigating further given its importance as a commercial species in North America. If found suitable as structural timber for the UK market, these species could be considered along with noble fir, western red cedar, western hemlock and Norway spruce, which were found by Gil-Moreno, Ridley-Ellis and McLean (2016) to produce high yields of C16 timber.

A recent study by Stokes, Jinks and Kerr (2022) analysed data from 87 forest experiments planted between 1929 and 1995, with the aim of comparing the long-term growth performance of 52 conifer species with that of Sitka spruce under the same conditions and site type. Results of their analysis suggested that most of the conifer species tested in this study, and those by Gil-Moreno, Ridley-Ellis and Mclean (2016), could be considered as productive alternatives to Sitka spruce on suitable sites. Grand fir, noble fir, western red cedar and western hemlock were all assessed by Stokes, Jinks and Kerr (2022) as having GYC estimates which were similar to Sitka spruce under a range of site conditions. In the same study, European silver fir, Pacific silver fir, Caucasian fir and Japanese red cedar were estimated as having a GYC no more than three classes below Sitka spruce under some conditions. Serbian spruce was not included in the Stokes, Jinks and Kerr (2022) study.

The task of bringing a wider range of species to the market for structural timber is large, and this early exploratory work is the first stage in determining where future research effort should be targeted. The resources required for a full strength grading assignment of a species under the current system are substantial. Since some of these new species do not fit well to established strength class profiles (particularly hardwoods) the need to adapt standards and industry practice should be explored. This is a common challenge across Europe.

# Acknowledgements

This project, which was funded jointly by the former Forestry Commission GB and the former Forestry Commission Scotland Timber Development Programme, would not have been possible without the generous support and involvement of several organisations and a large number of individuals over several years. We would like to thank everyone who helped and apologise if we have inadvertently omitted anyone from the list below:

- Buccleuch Estates: Jim Colchester, who provided the sycamore trees for this study as well as resources for felling and extraction;
- James Jones and Sons Ltd: David Leslie, who provided the Serbian spruce for this study;
- Forest Research: Robin Adey-Johnson, Carina Convery, Rachael Davidson, David Gil-Moreno, Gary Kerr, John Lakey, Bill Mason, Paul Mclean, Madeleine Murtagh, Victoria Stokes and Stephen Whall;
- Forestry and Land Scotland: Alistair Angus, Mark Brazendale, Peter Fullarton, Dave Garrow, Yvonne Grieve, David Henderson, Fraser MacDonald, David Robertson, Eva Sparrowbroom, Brian Stacey and Charlie Taylor;
- Forestry England: Michael Danks;
- Ian Robb, Robert Carson and Ross Petro (felling contractors);
- John Miller Ltd., JC Yule, Coille Haulage, Ashley Sawmills Ltd. and R&P Distribution Ltd (log haulage).

The authors are also grateful to Ewan Mackie, Barry Gardiner, Andrew Leslie and Chris Quine for helpful comments on earlier drafts of this publication.

# Author affiliations

Andrew Price, Adam Ash and Elspeth Macdonald are researchers at Forest Research.

Dan Ridley-Ellis, Steven Adams and Stefan Lehneke are researchers in the School of Computing, Engineering and the Built Environment, Edinburgh Napier University.

# References


ADAMS, S. and RIDLEY-ELLIS, D. (2021) Alternative UK timber species. In: *Timber 2021 Industry Yearbook.* High Wycombe, TRADA. pp. 104–111.

BALLIAN, D., RAVAZZI, C. and CAUDULLO, G. (2016) *Picea omorika in Europe: distribution, habitat, usage and threats.* Off. EU, Luxembourg. doi:10.2788/038466.

BRITISH STANDARDS INSTITUTION (2012) BS EN 408:2010+A1:2012. *Timber structures — Structural timber and glued laminated timber — Determination of some physical and mechanical properties.* Chiswick, London, British Standards Institution.

BRITISH STANDARDS INSTITUTION (2016a) BS EN 14358:2016. *Timber structures. Calculation and verification of characteristic values.* Chiswick, London, British Standards Institution.

BRITISH STANDARDS INSTITUTION (2016b) *BS EN 338:2016 Structural Timber – Strength Classes.* Chiswick, London, British Standards Institution.

BRITISH STANDARDS INSTITUTION (2022) *BS EN 384:2016+A2:2022 Structural timber — Determination of characteristic values of mechanical properties and density.* Chiswick, London, British Standards Institution.

BRITISH STANDARDS INSTITUTION (2024) *BS EN 1912:2024 Structural Timber. Strength classes. Assignment of visual grades and species.* Chiswick, London, British Standards Institution.

CAUDULLO, G. and TINNER, W. (2016) Abies - Circum-Mediterranean firs in Europe: distribution, habitat, usage and threats. In: *San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. (Eds.), European Atlas of Forest Tree Species.* Luxembourg, Publ. OFf. EU. pp. 50–51.

CEN TC124 (2023) *AGR-011-2023-05-10 CEN TC124 WG2 TG1 Approved grading report (AGR / ITT) MTG 960. Table 11-38.CEN Technical Committee TC124 Working Group 2.*

DUBOIS, H., CLAESSENS, H. and LIGOT, G. (2021) Towards silviculture guidelines to produce large-sized silver birch (*Betula pendula* Roth) logs in western Europe. *Forests.* 12 (5). doi:10.3390/f12050599.

DUBOIS, H., VERKASALO, E. and CLAESSENS, H. (2020) Potential of Birch (*Betula pendula* Roth and *B. pubescens* Ehrh.) for Forestry and Forest-Based Industry Sector within the Changing Climatic and Socio-Economic Context of Western Europe. *Forests*. 11 (3), 1–26. doi:10.3390/f11030336.

DUNHAM, R. A., CAMERON, A. D. and PETTY, J. A. (1999) The effect of growth rate on the strength properties of sawn beams of silver birch (*Betula pendula* Roth). *Scandinavian Journal of Forest Research*, 14(1), 18–26. doi:10.1080/02827589908540805

FOREST PRODUCTS LABORATORY (2010) *Wood handbook: wood as an engineering material. General Technical Report FPL-GTR-190.* Madison WI, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. doi:10.2737/FPL-GTR-190.

GIL-MORENO, D. (2018) *Potential of noble fir, Norway spruce, western red cedar and western hemlock grown for timber production in Great Britain.* Edinburgh Napier University.

GIL-MORENO, D., MCLEAN, J.P. and RIDLEY-ELLIS, D. (2023) Models to predict the radial variation of stiffness, strength, and density in planted noble fir, Norway spruce, western hemlock, and western red cedar in Great Britain. *Annals of Forest Science*. 80 (1). doi:10.1186/s13595-023-01214-7.

GIL-MORENO, D., RIDLEY-ELLIS, D. and HARTE, A.M. (2019) Timber grading potential of Douglas fir in the Republic of Ireland and the UK. *International Wood Products Journal.* 10 (2), 64–69. doi:10.1080/20426445.2019.1617984.

GIL-MORENO, D., RIDLEY-ELLIS, D. and MCLEAN, P. (2016) *Timber properties of noble fir, Norway spruce, western red cedar and western hemlock grown in Great Britain.* Research Note. Forest Research, Farnham.

HEIN, S., COLLET, C., AMMER, C., GOFF, N. LE, SKOVSGAARD, J.P. and SAVILL, P. (2009) A review of growth and stand dynamics of Acer pseudoplatanus L. in Europe: Implications for silviculture. *Forestry.* 82 (4), 361–385. doi:10.1093/forestry/cpn043.

HERÄJÄRVI, H. (2001) Technical properties of mature birch (*Betula pendula* and *B. pubescens*) for saw milling in Finland. *Silva Fennica.* 35 (4), 469–485. doi:10.14214/sf.581.

HUBER, C., LANGMAIER, M., STADLMANN, A. *et al.* (2023) Potential alternatives for Norway spruce wood: a selection based on defect-free wood properties. *Annals of Forest Science.* 80 (41). doi:10.1186/s13595-023-01206-7.

HYNYNEN, J., NIEMISTÖ, P., VIHERÄ-AARNIO, A., BRUNNER, A., HEIN, S. and VELLING, P. (2010) Silviculture of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) in Northern Europe. *Forestry.* 83 (1), 103–119. doi:10.1093/forestry/cpp035.

KERR, G. and JINKS, R. (2015) *A Review of Emerging Species Research in FC Programme 3. Internal Report to the Forestry Commission.*

KERR, G., STOKES, V., PEACE, A. and JINKS, R. (2015) Effects of provenance on the survival, growth and stem form of European silver fir (*Abies alba* Mill.) in Britain. *European Journal of Forest Research.* 134 (2), 349–363. doi:10.1007/s10342-014-0856-9.

KRABEL, D. and WOLF, H. (2013) Sycamore Maple (*Acer pseudoplatanus* L.). In: L.E. Pâques (ed.). *Forest Tree Breeding in Europe: Current State-of-the-Art and Perspectives.* Dordrecht, Springer Netherlands. pp. 373–402. doi:10.1007/978-94-007-6146-9_8.

LEMKE, U., JOHANSSON, M., ZIETHÉN, R. and BRIGGERT, A. (2023) New Criteria for Visual Strength Grading of Sawn Timber From Birch Grown in Sweden. In: A.Q. Nyrud, K.A. Malo, and K.. Nore (eds.). *Proceedings of the World Conference on Timber Engineering (WCTE 2023),*. 2023 Oslo, Norway. pp. 740–749. doi:10.52202/069179-0102.

MATTHEWS, R.W., HENSHALL, P.A., DUCKWORTH, R.R., JENKINS, T.A.R., MACKIE, E.D. and DICK, E.C. (2016a) *Forest Yield: a PC-based yield model for forest management in Britain. User manual.* Edinburgh, Forestry Commission. https://cdn.forestresearch.gov.uk/2022/02/fcsw002.pdf.

MATTHEWS, R.W., JENKINS, T.A.R., MACKIE, E.D. and DICK, E.C. (2016b) *Forest Yield: A handbook on forest growth and yield tables for British forestry.* Edinburgh, Forestry Commission.

MATTHEWS, R.W. and MACKIE, E.D. (2006) *Forest mensuration: a handbook for practitioners.* Edinburgh, Forestry Commission.

MESSIER, C., BAUHUS, J., SOUSA-SILVA, R., AUGE, H., BAETEN, L., BARSOUM, N., BRUELHEIDE, H., CALDWELL, B., *et al*. (2022) For the sake of resilience and multifunctionality, let's diversify planted forests! *Conservation Letters.* 15 (1), 1–8. doi:10.1111/conl.12829.

RAMSAY, J. and MACDONALD, E. (2013) *Timber Properties of Minor Conifer Species. A Report to the Forestry Commission.* https://forestry.gov.scot/publications/forests-and-the-environment/resilient-forests/overview-of-forest-resilience/102-timber-properties-of-minor-conifer-species-a-report-to-the-forestry-commission.

REYNOLDS, C., JINKS, R., KERR, G., PARRATT, M. and MASON, B. (2021) Providing the evidence base to diversify Britain's forests: initial results from a new generation of species trials. *Quarterly Journal of Forestry.* 115 (1), 26–37. http://www.iefc.net/wp-content/uploads/2021/03/Reynolds-et-al-Jan-2021-QJF-avec-compression.pdf.

RIDLEY-ELLIS, D., GIL-MORENO, D. and HARTE, A.M. (2023) Considerations for grading species combinations. General remarks on scenarios and requirements. In: A.Q. Nyrud, K.A. Malo, and K. Nore (eds.). *Proceedings of the World Conference on Timber Engineering (WCTE 2023).* 2023 Oslo, Norway. pp. 780–786. https://doi.org/10.52202/069179-0107.

RIDLEY-ELLIS, D., GIL-MORENO, D. and HARTE, A.M. (2022) Strength grading of timber in the UK and Ireland in 2021. *International Wood Products Journal.* 13:2, 127-136. https://doi.org/10.1080/20426445.2022.2050549

RIDLEY-ELLIS, D., STAPEL, P. and BAÑO, V. (2016) Strength grading of sawn timber in Europe: an explanation for engineers and researchers. *European Journal of Wood and Wood Products.* 74 (3). doi:10.1007/s00107-016-1034-1.

SAVILL, P. (2015) *Cryptomeria japonica* (Thunb. ex L.f.) D.Don Japanese red cedar, or Sugi: Silviculture and properties. *Quarterly Journal of Forestry.* 109 (2), 97–102.

SAVILL, P., WILSON, S., MASON, B., JINKS, R., STOKES, V. and CHRISTIAN, T. (2017) Alternative spruces to Sitka and Norway. Part 1 - Serbian spruce (*Picea omorika*). *Quarterly Journal of Forestry.* 111 (1), 32–39. http://sites.cabi.org/abstract/20173040109.

SAVILL, P., WILSON, S.M., MASON, B. and JINKS, R. (2016) Silver firs (*Abies* spp) of Europe and the Near East: species, silviculture and utilisation potential. *Quarterly Journal of Forestry.* 110, 16–27. http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=A017.

SKOVSGAARD, J.P., JOHANSSON, U., HOLMSTRÖM, E., TUNE, R.M., OLS, C. and ATTOCCHI, G. (2021) Effects of thinning practice, high pruning and slash management on crop tree and stand growth in young even-aged stands of planted silver birch (*Betula pendula* Roth). *Forests.* 12 (2), 1–21. doi:10.3390/f12020225.

STOKES, V.J., JINKS, R. and KERR, G. (2022) An analysis of conifer experiments in Britain to identify productive alternatives to Sitka spruce. *Forestry: An International Journal of Forest Research.* (2014), 1–18. doi:10.1093/forestry/cpac035.

FRRN045/FR/WWW/DEC24

WHITTET, R., LOPEZ, G. and ROSIQUE-ESPLUGAS, C. (2021) Mid-rotation variation in growth, form and phenology of sycamore (*Acer pseudoplatanus* L.) provenances in field trials in England. *Forestry: An International Journal of Forest Research.* 1–10. doi:10.1093/forestry/cpab012.

Enquiries relating to this research should be addressed to:

Andrew Price
Forest Research
Mortimer Forest Office
Whitcliffe, Ludlow
Shropshire SY8 2HD

+44 (0)300 067 5930

andrew.price@forestresearch.gov.uk
www.forestresearch.gov.uk

For more information and to view and download Forest Research publications, visit:

**www.forestresearch.gov.uk/publications**

We will consider all requests to make the content of our publications available in alternative formats. Please send any such requests to publications@forestresearch.gov.uk

You may re-use this information (not including logos or material that is copyright of a third party) free of charge in any format or medium, under the terms of the Open Government Licence. Contact the Information Policy Team at The National Archives (psi@nationalarchives.gsi.gov.uk) or go to: www.nationalarchives.gov.uk/doc/open-government-licence/version/3

© Crown Copyright

ISBN: 978-1-83915-030-2