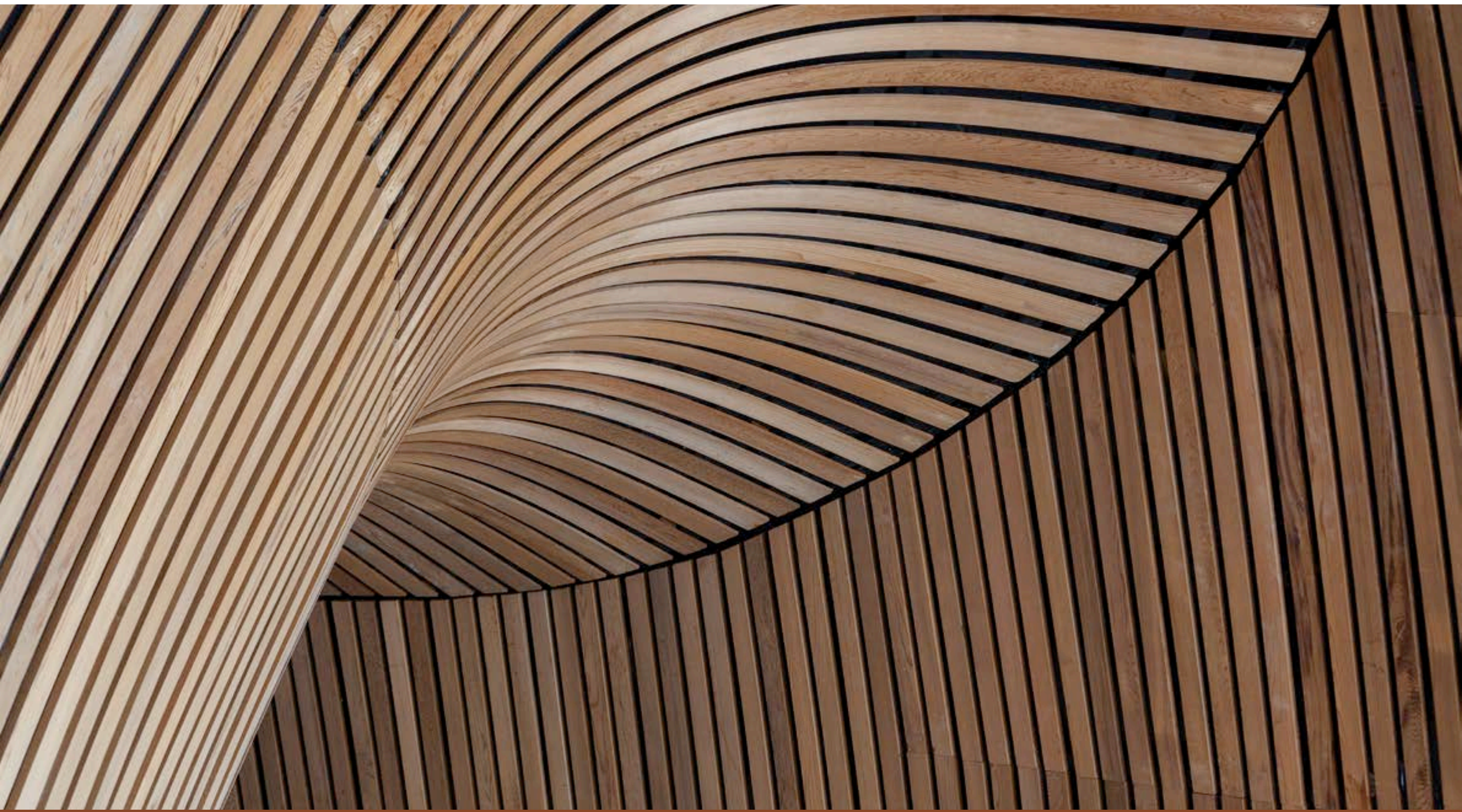
Forestry Commission



Research Note

Timber properties of noble fir, Norway spruce, western red cedar and western hemlock grown in Great Britain

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The softwood processing sector in Great Britain has been built around the use of a very small number of timber-producing species – predominantly Sitka spruce. The recent increase in outbreaks of host-specific tree pests and diseases has led to an interest in diversification, through planting a wider range of tree species, to mitigate any risk to the softwood resource. However, there is a lack of evidence about how this diversification will impact on the future merchantability of timber. This Research Note investigates the structural timber properties of noble fir, Norway spruce, western red cedar and western hemlock grown in Great Britain and compares the results with published values for British-grown Sitka spruce. The study was carried out using timber from even-aged plantations growing in a range of latitudes representative of productive conifer forests. Twenty-seven trees per species were felled, processed into structural-sized battens, kiln dried and destructively tested in a laboratory according to current European standards. Characteristic values of mechanical properties and density were determined and indicative yields for different strength classes were calculated. The results showed that all of the species investigated can produce structural timber, but that western red cedar has the least desirable properties for this purpose. Some further work is under way in order to investigate the effect of rotation length on the timber properties of these species.

Introduction

Sitka spruce (*Picea sitchensis*) accounts for approximately half of total standing coniferous volume in Great Britain and forms the staple supply for the British forest products sector. Recently, diseases such as *Phytophthora ramorum* in larches and *Dothistroma* needle blight in pines have raised concerns about the reliance on a Sitka spruce monoculture. One of the most effective ways to minimise the impact of host-specific pest and diseases is to introduce a greater diversity of tree species. However, there is a lack of information about the wood properties of the other species that are being considered, and consequentially how they might be incorporated into the supply chain for wood products. The properties of key commercial importance are those relating to the use of timber in structural applications, namely stiffness, strength and wood density.

The three key properties for construction timber are strength, stiffness and density. Strength describes the force the timber can carry without breaking, stiffness describes the amount the timber moves in response to the force, and density is used to calculate things like strengths for connections made with screws and nails. These properties are usually described with reference to timber grades.

Background

The Forestry Commission established plantations of a wide range of species in the first half of the last century (Aldous and Low, 1974), but the information derived from these was mainly concerned with growth. The information currently available about the key wood properties of the timber produced is very limited. A report reprinted in 2002 (Lavers, 2002) includes some information about the physical and mechanical properties from some testing of small, defect-free samples with a little information about structural-sized pieces. That information is too limited to provide representative data about wood properties for construction and is far short of what is required for strength grading according to European Standards. In Europe, structural timber is assigned to strength classes, most commonly those defined in EN 338:2016 (CEN, 2016a). These grades facilitate safe design with timber by prescribing minimum characteristic values of strength, stiffness and density at 12% moisture content.

Aim

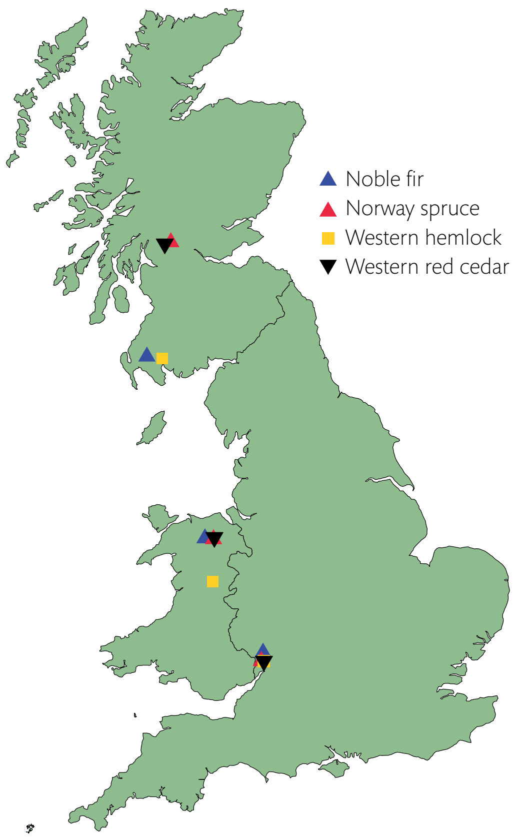
The aim of this study is to take a first look at the timber properties of some conifer species that currently form a minor component of the British forest resource. The first four species we have investigated are noble fir (*Abies procera*), Norway spruce (*Picea abies*), western red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*). Noble fir, western red cedar and western hemlock are native to the Pacific coast in northwest America. Norway spruce is native to Scandinavia and Central and Eastern Europe, as well as the north of Russia.

Norway spruce is already grown and processed, together with Sitka spruce, for structural timber. The species mix is recognised in EN 14081-1:2016 (CEN, 2016b) where it is referred to as 'British spruce' (species code WPCS). This species mix is approximately 90% Sitka spruce and, while it is known that the two species have similar properties when grown in the UK, it is not known exactly how Norway spruce compares, or what the implications of increasing the proportion of Norway spruce would be. In this study Norway spruce was tested in its own right.

Methodology

Material from each of the four species was obtained at three sites: the south west of England, the north of Wales and either the south or west of Scotland. The locations of the sites, called for convenience 'England', 'Wales', and 'Scotland' respectively, are shown in Figure 1. All of the stands investigated were even-aged single species plantations, planted on or before 1983, and had been thinned.

Figure 1 Locations of the study sites.



Three replicate plots were chosen for every species at each site and diameter at breast height (i.e. the stem diameter 1.3 m from the stem base) and height of the standing trees within the plot were measured. Three trees per plot were felled, covering the range of diameters in the plot. Felling in England and Wales occurred in October 2013 whereas in Scotland felling was in October 2014. The characteristics of the sites studied and trees within the plots are given in Table 1.

A 3.1 m long log, with the base at breast height, was cross-cut from each felled tree (Figure 3). Logs were processed into structural-sized timbers, following a bark to bark pattern, with nominal cross-sectional dimensions of 100 mm × 50 mm (Figure 4). This cutting pattern was designed to allow rotation length to be accounted for. As Sitka spruce is typically harvested at a rotation length of 35–45 years, the results here are restricted 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).

Timber battens were kiln dried to between 20% and 12% moisture content, then allowed to further equilibrate in a climate controlled laboratory to 12% moisture content before being subjected to destructive four-point bending tests in accordance with EN 408+A1:2012 (CEN, 2011) to measure bending strength and stiffness (Figure 5). Wood density was measured on a 40 mm long sample cut from each piece of timber immediately after testing.

Characteristic values of bending strength, bending stiffness and density were calculated according to EN 384:2016

Figure 2 Trees selected for felling marked with paint in a stand of noble fir in Wales.

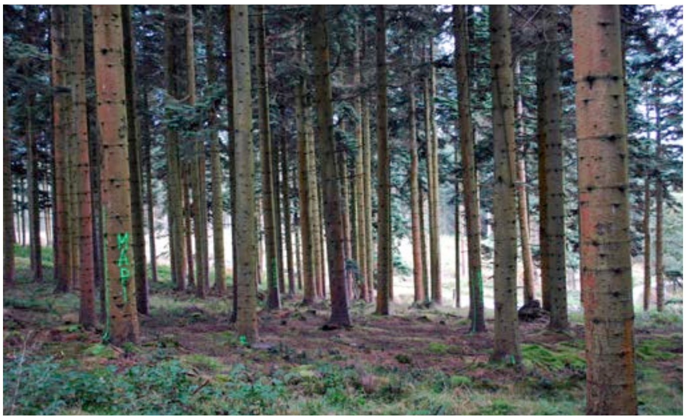


Figure 3 Logs collected from England and Wales and stock in the Northern Research Station before sawing into battens.

Table 1 Characteristics of sites selected and trees within the plots. Diameter at breast height (DBH) and height are mean values with standard deviations in parentheses. Yield class is calculated as per Matthews and Mackie (2006).

Species	Site	OS grid	Elevation (m)	Age (y)	DBH (cm)	Height (m)	Yield class
Noble fir	England	SO632199	140	30	28.0 (6.4)	18.2 (2.0)	22
	Wales	SH954532	390	58	35.1 (6.5)	22.8 (2.2)	20
	Scotland	NX279666	115	38	30.7 (9.4)	19.1 (3.1)	22
Norway spruce	England	SO616101	100	44	33.4 (7.7)	23.9 (3.8)	22
	Wales	SJ055527	365	76	39.4 (5.6)	25.4 (2.1)	14
	Scotland	NN554007	60	44	44.5 (6.2)	27.3 (2.6)	22
Western red cedar	England	SO646098	205	35	34.7 (5.9)	19.2 (1.2)	22
	Wales	SJ064549	355	61	32.6 (10.9)	24.9 (3.3)	22
	Scotland	NS489982	95	78	64.0 (13.9)	29.0 (3.9)	14
Western hemlock	England	SO643094	205	44	45.1 (5.2)	26.2 (1.8)	22
	Wales	SJ040021	280	49	28.8 (7.3)	24.6 (3.1)	20
	Scotland	NX450644	40	78	48.8 (10.2)	33.1 (2.0)	20

Figure 4 Processing of a log of Norway spruce in Aberfoyle.

Figure 5 Destructive test of a Norway spruce specimen at Edinburgh Napier University.

(CEN, 2016c) and compared to the requirements of the most common strength classes EN 338:2016 (CEN, 2016a) shown in Table 2. In simple terms, a timber population tested in this way is allocated to a strength class if its characteristic (here 5th percentile) values of bending strength and density equal or exceed the values for that strength class and its characteristic mean bending stiffness equals or exceeds 95% of the value for that strength class. The mean and 5th percentile of a generic population are demonstrated in Figure 6. Timber cannot be allocated to a strength class unless the requirements are met for all three properties, so in the case where one property does not allow allocation of a higher strength class it becomes limiting. Therefore the strength class is determined by

Figure 6 Population statistics associated with timber grades. 95% of values are above the 5th percentile. A timber grade provides a mean value of stiffness and a 5th percentile value for strength and density. Grading removes the unfavorable pieces to increase the mean and/or 5th percentile.

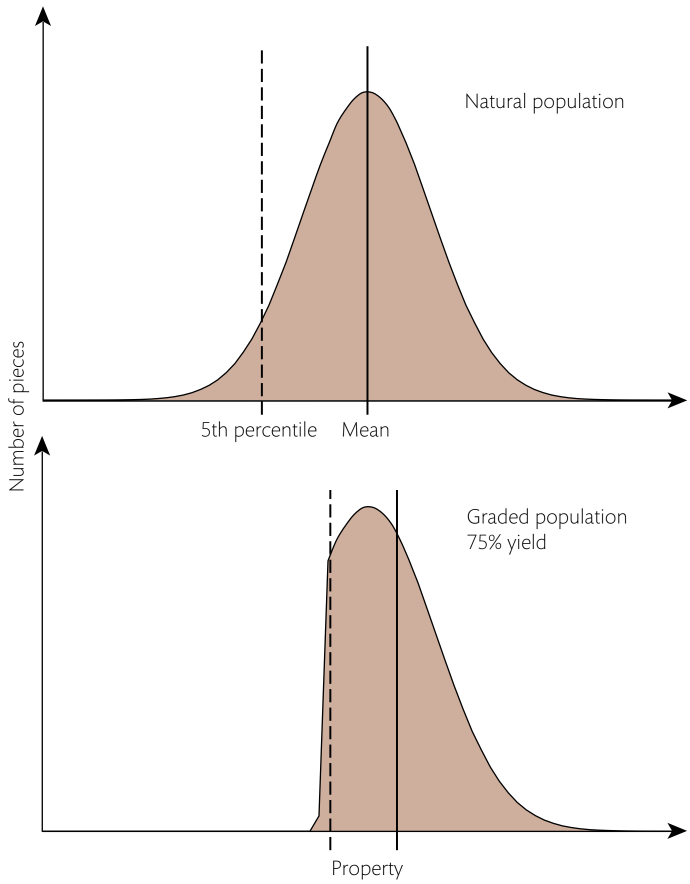


Table 2 Characteristic values for strength classes C14 to C24 (CEN, 2016a). Strength and stiffness values apply to bending.

Wood property	Characteristic property values for each strength class					
	14	16	18	20	22	24
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

whichever property/properties of bending strength, bending stiffness or density is/are limiting. Using grading, it is possible to remove the unfavourable pieces and thereby increase the characteristic values of the remaining population. This allows a higher strength class to be achieved in exchange for a lower proportion of timber passing the grading process (the yield).

Results

Published data for Sitka spruce timber coming from 12 sites (Moore *et al*., 2013) are provided for comparison. The characteristics values obtained per species are presented in Table 3. British spruce typically attains the C16 strength class and is limited by stiffness (Moore *et al*., 2013). In this study stiffness was also the limiting property, except in the case of noble fir, which was limited to C14 by strength.

Out of the four species studied and relative to the published values for Sitka spruce, Norway spruce had the highest mean stiffness, while western hemlock had the highest mean strength and density. All of the species investigated were capable of producing a high yield of C16 timber, with Norway spruce and western hemlock also here producing high yields of C18 (Table 4). Samples of noble fir were considerably younger than the other species tested.

Table 3 Wood properties restricting the material to a maximum of 45 years old by species tested and comparable published values for Sitka spruce (Moore *et al*., 2013). Strength and stiffness are measured in bending to EN 408:2010 (CEN, 2011).

	Sitka spruce	Norway spruce	Western hemlock	Noble fir	Western red cedar
Number of pieces	955	128	138	126	115
Means age of sample (years)	Not known	19.3 (8.4)	18.6 (9.4)	15.0 (8.4)	19.0 (9.4)
Mean stiffness (kN mm^{-2})	**8.30** C16	**8.55** (1.68) C18	**8.33** (2.04) C16	**7.71** (2.27) C16	**7.44** (1.66) C14
Mean density (kg m^{-3})	387	378 (37)	444 (39)	358 (37)	365 (30)
5th percentile density (kg m^{-3})	**330** C20	**345** C22	**385** C30	**324** C18	**318** C16
Mean strength (N mm^{-2})	32.7	31.1 (9.0)	34.5 (10.7)	31.1 (13.1)	30.1 (8.0)
5th percentile strength (N mm^{-2})	**19.6** C18	**19.1** C18	**18.2** C18	**14.8** C14	**16.3** C16
Strength class	C16	C18	C16	C14	C14

Standard deviations for means are in parentheses. Grade-determining properties are in bold.

Table 4 Indicative yields achieved for species with a rotation length restricted to a maximum of 45 years. Published values for Sitka spruce (Moore *et al*., 2013) are included for comparative purposes.

	C14	C16	C18	C20	C22	C24
Sitka spruce	100%	100%	92%	75%	58%	29%
Norway spruce	100%	100%	98%	81%	62%	30%
Western hemlock	100%	100%	95%	81%	67%	40%
Noble fir	100%	96%	77%	62%	49%	30%
Western red cedar	100%	94%	56%	38%	25%	11%

N.B. These figures represent potential yields for any of the species, in the real world grading yields are variable even for one species.

Discussion

As with 'British spruce' (CEN, 2016b), wood stiffness seems to be the property that will determine grading to the current European strength classes. Norway spruce and western hemlock had the most desirable timber properties, though it should be noted that the properties of noble fir would probably be better had it been possible to sample trees of a comparable age to the other species investigated. It is known that older trees produce higher grades of timber (Moore, Lyon and Lehneke, 2012), and the older samples came out best in this study. With that in mind, western red cedar produced timber with the least desirable properties for structural timber, despite being the second oldest on average. The next stages of this study will carry out detailed investigations into the within- and between-tree variation in timber properties that will allow recommendations about rotation lengths to be made.

Conclusions

The results of this study indicate that timber produced from noble fir, Norway spruce, western red cedar and western hemlock grown in Great Britain is capable of meeting strength classes required for use in construction. High yields of C16 timber, which is the lowest class customarily used for construction in the UK, were obtained for all of the species. An extension of this study with more pieces of timber could be considered to produce grading machine settings.

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