Assessing timber quality of Scots pine (*Pinus sylvestris* L.)

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Abstract

Scots pine (*Pinus sylvestris* L.) is the only conifer species native to Great Britain that has the potential to produce significant volumes of timber, and as such it has a key role to play in the rural economy. Timber production from Scots pine forests in northern Scotland is forecast to increase over the next 15 years. An evaluation of the timber quality of the Scots pine resource is a key requirement to inform industry and support strategic investment and marketing decisions. In this paper we describe the validation of methods developed for assessing the quality of standing Scots pine timber from measurements on trees and logs. A standing tree visual assessment was based on a stem straightness scoring system developed for Sitka spruce, with the addition of an estimate of the height of the lowest dead branch, known to be an important indicator of quality in pine. These measurements could be used to estimate of the proportion of sawlogs meeting the requirements for higher quality log grades and to give an indication of the likely appearance grade of the sawn timber. Measurements of stress wave velocity in trees and logs, using portable acoustic tools, were found to be good predictors of the mechanical properties of sawn timber. Segregating trees or logs on the basis of acoustic measurements had the potential to increase the strength class assigned to sawn timber.

1 Introduction

Scots pine (*Pinus sylvestris* L.) is the most widely distributed conifer species in the world with a natural range stretching from Spain to Norway and from Scotland to Siberia (Mason, 2000). This species is found in all member states of the EU, where it constitutes approximately 20% of the commercial forest area, and it is of considerable importance as a timber producing species, particularly in Nordic countries (Mason and Alia, 2000). In Great Britain the area of Scots pine is approximately 220 000 hectares, representing around 16% of the conifer forest area and 10% of the total forest area (Forestry Commission, 2007). Almost two-thirds of the Scots pine forest area is in Scotland, and the species is of particular importance in northern Scotland (Grampian and Highland areas) where it represents about 30% of the conifer resource.

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The availability of Scots pine timber from northern Scotland is predicted to increase by about 15% per annum over the next 15 years (after Halsall *et al*., 2006), and it will represent approximately 20% of the softwood timber harvest in these areas. The management of Scots pine forests, including timber marketing and utilisation, is therefore of considerable importance to the local economy. Over the last four years a number of studies have been conducted with the overall aim of increasing the value of the Scots pine resource in north Scotland to the rural economy (Macdonald *et al.*, 2008). For example, a questionnaire-type survey reviewed the management, harvesting and utilisation of the Scots pine timber resource. Results showed that primary processing of around 80% of the Scots pine timber harvested took place within 80 km of where it was grown, emphasising the importance to the local economy. About half of the Scots pine roundwood harvested in the study area was processed into wood-based panels. Most (90%) of the remaining material was converted into agricultural and domestic fencing. Only small quantities were used in higher added-value markets such as construction products (4%), decking (2%) and sleepers (1%).

A subsequent market development study evaluated opportunities for Scots pine timber, focusing on the potential for processing and adding value locally. Outdoor uses such as garden, landscaping and playground products or stress-laminated timber bridges scored highly in the assessment, due to the ability to improve durability through preservative treatment. In construction the use of Scots pine in massive timber panels was considered a viable option, should a manufacturing plant be established in Scotland. External cladding, either coated or preservative treated, was identified as a potential market for boards cut from the outer part of Scots pine logs, provided these were graded to meet market requirements in terms of allowable numbers and sizes of knots.

The possible expansion of the use of Scots pine in any of these added-value markets is dependant on a reliable supply of timber of the required quality being available. Log straightness and knottiness (number, size and condition of knots) are key factors which determine product potential. Variability in quality characteristics within and between stands is also a key issue, highlighting the need for techniques to identify better quality stands, and the best trees in stands. Here we report on work to test and validate methods for assessing Scots pine timber quality in standing trees and logs, and to link these assessments to sawn timber properties and performance. In this study the application of a stem straightness scoring system developed for Sitka spruce (Macdonald *et al*., 2009) was tested in Scots pine, together with a number of different branching indices. The use of portable acoustic tools to assess wood properties in standing trees and logs was also evaluated.

2 Materials and Methods

Six Scots pine sample stands were assessed in two linked studies:

2.1 Study 1

Three Scots pine sample stands located within 50 km of Inverness were selected for this study (Table 1). The age and Yield Class were chosen to be representative of typical Scots pine stands towards the end of normal rotation lengths in north Scotland. Ten sample plots were randomly located within each stand. In each plot the diameter at breast height (DBH), stem straightness and stress wave velocity of every live tree were measured in accordance with standard procedures (Matthews and Mackie, 2006; Macdonald *et al*., 2009; Mochan *et al*., 2009). Three trees were selected at random from each plot from amongst those with a DBH of 28 cm or greater, and for each selected tree the following branching characteristics were visually estimated:

- Height to the lowest dead branch, estimated to nearest 0.5 m.
- Height to the lowest live branch, estimated to nearest 0.5 m
- Height of the lowest live whorl (defined as the whorl where > 75% of branches are green), estimated to nearest 0.5 m
- Diameter of the lowest dead branch – to nearest cm
- Diameter of the lowest live branch – to nearest cm

After each sample tree was felled, the total volume of sawlog size material (16 cm diameter overbark) in the tree was calculated in accordance with normal measurement conventions (Matthews and Mackie, 2006). . The position of "green" logs, as defined in Forestry Commission (1993), that met roundwood specifications for current markets for Scots pine in the study area (Table 2) were marked on the stem and their volume assessed. The highest preference were given to sleepers followed by longer green log lengths since they attract a price premium. Up to two 3.7 m long green sawlogs were then cut from each sample tree (160 logs in total). and the following measurements made on each:

- Log length
- Log top (small-end) diameter over bark
- Stress wave velocity using the HM-200 log tool (Fibre-gen, New Zealand)

Logs were processed into structural timber with dimensions of 47x100 mm, 47x 150 mm and 47x200 mm, and falling boards of 19 mm thickness with widths of 75 mm, 100 mm and 150 mm. All timber was kiln dried using a standard schedule for Scots pine. Falling boards were appearance graded following the G4 method in EN 1611-1:2000 (CEN, 2003b), which applies to softwoods for non-structural applications (e.g., cladding, joinery and furniture). The possibility of predicting falling board appearance grade from standing tree measurements was explored.

Table 1: Sample stand details

Stand (Study no)	Elevation (m asl)	Planting Year	Age at Felling	Yield Class	Stem straightness score†	Tree stress wave velocity‡ (km s^{-1})	Height of lowest dead branch‡ (m)	Number of sample trees felled	Green log out-turn (%)	Number of sample logs tested	Mean Log stress wave velocity (km s^{-1})
Cawdor (1)	150	1928	79	8	6 (4-6)	4.70	3.8	30	54.5	55	3.3
Munlochy (1)	60	1926	81	6	6 (4-6)	4.61	4.6	30	58.9	54	3.5
Harriets (1)	105	1930	77	6	4 (3-6)	4.73	2.8	30	41.4	51	3.3
Laiken (2)	150	1953	55	14	4 (3-6)	4.40	1.4	32	41.7	-	-
Monaughty (2)	125	1928	80	8	6 (4-6)	4.65	3.9	30	58.7	-	-
Keppernach (2)	155	1939	69	8	5 (4-6)	4.25	3.0	30	41.0	-	-

† Stand median score (and interquartile range); ‡ Stand median value

Table 2: Specification for theoretical green log conversion

Log Category	Minimum Top Diameter	Length
Sleeper	35 cm underbark	2.65 m
Green Logs	16 cm underbark	3.1 m 3.4 m 3.7 m 4.3 m 4.9 m
Green Pallet	25 cm underbark	2.5 m

A sub-sample containing two pieces of 47x100 mm of structural timber from each log was selected for mechanical testing. Timber was destructively tested in four-point bending to determine global modulus of elasticity (MOE) and bending strength (f_m) in accordance with EN 408 (CEN, 2003c). Basic density, bulk density, and moisture content were determined on a sub-sample cut from each specimen in accordance with EN 13183-1 (CEN, 2002) and EN408 (CEN, 2003c). The proportion of variation in basic density, MOE and f_m due to intra-tree, inter-tree and inter-site differences was calculated, and the relationships between MOE, f_m and density were investigated. The average MOE of the timber tested from each log was calculated and these average values compared with the dynamic modulus of elasticity predicted from stress wave velocity measurements made on the logs.

The utility of portable acoustic tools to improve the grade out-turn of sawn timber was examined by setting various velocity thresholds and calculating the characteristic values for bending strength, stiffness and density of the timber sawn from those logs which had a velocity greater than this threshold value. These characteristics values were calculated using the procedures described in EN384 (CEN, 1995) and the timber assigned to appropriate strength class based on the requirements given in EN338 (CEN, 2003a).

2.2 Study 2

Three additional stands (Laiken, Monaughty and Keppernach – Table 1) were selected to test the assessment methods developed in Study 1 and to provide additional data for the predictive model linking stem straightness score and height of lowest dead branch (HLDB) to green log yield. Sample plots were located randomly within each stand and DBH, top height, stem straightness score, stress wave velocity and HLDB were assessed using the methods from Study 1. Thirty sample trees per stand (32 at Laiken) were felled and total log and green log volume calculated.

3 Results

3.1 Predicting green log out-turn

Analysis of the data from Study 1 showed that stem straightness score (*s*) and height of lowest dead branch (*h*) were best able to predict the green log yield per tree (GL%). There was no relationship with the other branch indices tested, with DBH or with stress wave velocity. The statistical model fitted to the data from Study 1 had a generalized coefficient of determination R_G^2 of 0.32. When data from Study 2 were added to those from Study 1, giving a total of 178 trees, a new model was obtained with R_G^2 = 0.49:

$$GL\% = 8.617 + s + 3.478h$$

where GL% is green log out-turn (green log volume per tree as a percentage of total log volume per tree), *h* is height of lowest dead branch (m), and *s* is the fixed effect for stem straightness score. The fitted model indicates that for a 1-m change in *h* there is a 3.5% change in predicted GL%. For a stem straightness score of 1, the term s in the model is equal to 0, while its value is 11.66, 17.44, 22.71, 25.74, 40.60 and 44.20 for stem straightness scores of 2,3,4,5,6 and 7, respectively.

3.2 Appearance grading of sawn timber

The majority (71%) of the falling boards were graded as G4-3 and poorer, with nearly 50% of boards graded in the lowest grade (G4-4) (Table 3). Downgrading of boards was generally as a result of the number of knots, particularly loose knots, in the boards. Of the 792 boards 224 (28%) were assigned to the highest three categories of G4-0 to G4-2 and there was a consistent positive relationship across stands between height of lowest dead branch (HLDB) and the proportion of such boards. For example, the model predicted that a tree where HLDB=2 m would produce just under 23% of falling boards in grades G4-0 – G4-2, whilst a tree where HLDB=8 m would produce just over 43%.

Table 3: Percentage of boards falling within each grade from each sample stand. Boards appearance graded in accordance with BS EN 1611-1:2000.

	Board Grade (%)				
Sample Stand	G4-0	G4-1	G4-2	G4-3	G4-4
Cawdor	6	7	21	19	47
Munlochy	3	3	23	30	41
Harriets	3	4	16	20	57
Overall	4	5	20	23	48

3.3 Mechanical and physical properties of sawn timber

Mean values of basic density, MOE and f_m were 418 kg m^{-3}, 9.31 kN mm^{-2}, and 44.5 N mm^{-2}, respectively. There was a relatively strong relationship between MOE and f_m (R^2=0.68) and moderate relationships between basic density and both MOE and f_m (R^2=0.64 and 0.47, respectively). Over 50% of the variation in MOE was due to differences between individual pieces of timber within a log, with a further 25% due to variation between trees within a site (Table 4). Less than 6% of the variation was due to differences between sites. Similarly, the majority of variation observed in f_m and basic density was due to within-tree differences with almost none of the variation associated with differences between plots or between sites (Table 4).

Table 4: Components of variation in MOE, bending strength and basic density

Stratum	Percentage of Variation Attributable to a Stratum		
	MOE	Bending strength	Basic density
Site	5.59	3.39	<0.01
Plot	0.99	<0.01	0.50
Tree	24.88	7.95	9.75
Log	14.65	30.18	43.24
Batten	53.89	58.48	46.51
Total	100.00	100.00	100.00

The characteristic bending strength of the entire sample of timber calculated in accordance with EN384 (CEN, 1995) was 21.0 N mm^{-2}. The mean density at 12 percent moisture content (504 kg m^{-3}) satisfied the requirement for the C20 strength class, while the mean value of MOE (9.31 kN mm^{-2}) exceeded 95% of the mean requirement for the C20 strength class. Therefore, the timber satisfied the strength, density and stiffness requirements of the C20 strength class.

3.4 Predicting timber mechanical properties from stress wave measurements

At the log level, there was a significant relationship between stress wave velocity and the average MOE of sawn boards cut from the log (R^2=0.43), but this relationship was not as strong at the individual sawn board level (R^2=0.32). The effect of log segregation on the properties of the sawn timber is illustrated in Figure 1. This shows that there is an increase in the mean MOE of sawn timber with an increasing stress wave velocity threshold for logs. For example, if all logs with a stress wave velocity of less than 3.1 km s^{-1} were removed from the population, then the characteristic values of strength and stiffness increased to 22.0 N mm^{-2} and 9.55 kN mm^{-2}, respectively. These values were sufficient for the timber to meet the requirements for the C22 strength class. Only 20 logs (12.5% of the population) were removed using this criterion. In order to achieve the requirements of the C24 strength class, this threshold velocity needed to be set at 3.45 km s^{-1} (Figure 1). However, approximately 65% of the logs would be rejected in order for the timber to meet the requirements for C24.

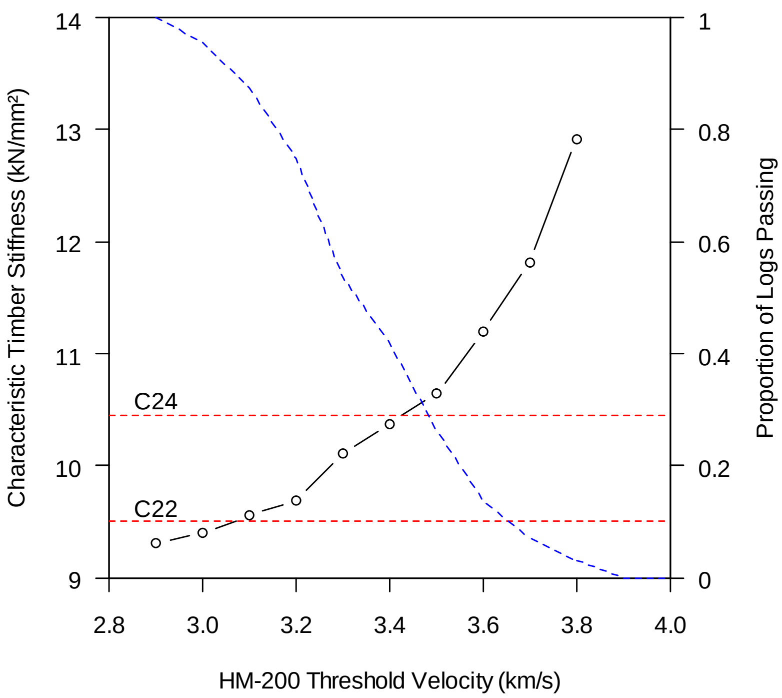

Figure 1: Effect of log segregation using the HM-200 on the characteristic stiffness of sawn timber. The dashed blue line indicates the proportion of logs meeting this threshold.

4 Discussion

4.1 Predicting stand quality and green log out-turn

The model developed from the data collected in the six sample stands explained almost 50% of the variation in green log out-turn at an individual tree level; This was similar to amount of variation explained by the model developed for Sitka spruce (Macdonald *et al*., 2009) where plot median stem straightness score was used to predict plot green log out-turn. These assessment methods offer a simple and practical means of evaluating Scots pine timber quality and could be integrated with standard inventory or pre-harvest procedures. Appropriate training and calibration of assessors’ measurements are required to ensure consistency. Practitioners should also note that the estimates of green log out-turn predicted from these assessments should be viewed as a broad indication of output and a means of differentiating between stands, rather than a precise forecast of actual green log recovery, which will vary according to individual stand characteristics and market conditions.

4.2 Appearance grading of sawn timber

The results of the appearance grading of falling board material were broadly in agreement with those in previous similar studies (Cooper, 2005; Cooper *et al.,* 2008), in which the proportion of boards meeting the requirements of the three highest appearance grades averaged approximately 30%. Sorting in the sawmill to identify the boards which meet the requirements of the higher quality grades would be required if Scots pine timber were to be used in applications such as cladding or joinery.

Results of this study suggest that the height of the lowest dead branch assessment could provide a preliminary method for identifying trees likely to produce a greater proportion of higher quality boards. This is consistent with work on Scots pine by Uusitalo (1997), who found that height of the lowest dead branch was correlated with timber quality of the butt log.

4.3 Mechanical and physical properties of sawn timber

Scots pine structural timber in this study met the requirements for the C20 strength class, which is suitable for a wide range of construction applications. Where higher strength class timber is required, approximately 35-40% of the timber from the stands tested met the requirements for the C24 strength class. This is in agreement with results obtained for a wider range of sites by as part of a study to develop grading machine settings for Scots pine (Chris Holland, pers. comm.). Analysis of the sources of variation in MOE and MOR suggests that there is the potential to improve these values in a population of timber by initial segregation of trees and logs using portable acoustic tools.

Sorting logs on the basis of acoustic measurements is an efficient means of segregating out timber with inferior stiffness and improving the recovery of higher strength class material. This approach has the potential to be useful when sourcing logs for specific end-uses where there are particular stiffness and strength requirements. At a larger scale, it is possible to integrate acoustic log testing technology with sawmill lines which offers timber processors the option of in-line sorting of logs to maximise output of higher strength class material. Future developments in this field include a prototype harvester-mounted acoustic tool, capable of measuring acoustic velocity of logs before they are cut, thus facilitating decision making regarding log specification.

5 Conclusions

This work has shown that non-destructive assessments on trees and logs can be used to predict timber quality in Scots pine in the following ways:

- Visual assessments of stem straightness and the height of the lowest dead branch can be used to estimate the proportion of higher value green sawlog material in an individual tree;
- The height of the lowest dead branch can be used to indicate the likely proportion of falling boards from a tree that will be assigned to the three highest quality appearance classes;

- Portable acoustic tools can be used to assess the mechanical properties of Scots pine timber in standing trees and logs, and offer a means of segregating out trees and logs which are likely to produce timber with inferior mechanical properties.

Integrating these assessment techniques with standard inventory procedures, pre-harvest assessments or log-sorting operations has the potential to provide valuable resource information and to improve the allocation of Scots pine timber to the most appropriate end-products.

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References

CEN (1995). Structural timber – determination of characteristic values of mechanical properties and density. EN384:1995. European Committee for Standardisation, Brussels. 14 p.

CEN (2002). Moisture content of a piece of sawn timber – Part 1: Determination by oven dry method. EN13183-1:2002. European Committee for Standardisation, Brussels. 8 p.

CEN (2003a). Structural timber - Strength classes. EN338:2003. European Committee for Standardisation, Brussels. 14 p

CEN (2003b). Sawn timber — Appearance grading of softwoods — Part 1: European spruces, firs, pines, Douglas fir and larches. European Committee for Standardisation, .Brussels. 12p.

CEN (2003c). Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties. EN408:2003. European Committee for Standardisation, Brussels. 13 p.

Cooper, G. (2005). An assessment of the quality of Scots pine from the Grampian and Cairngorm regions of Scotland. Client Report 221-884. BRE, Watford. 58p.

Cooper, G., Freke, B. and Holland, C. (2008) Maximising the potential of UK grown Scots pine falling boards. Client Report 225-822. BRE, Watford. 42p.

Forestry Commission (1993). *Classification and presentation of softwood sawlogs*. Forestry Commission Field Book 9. HMSO, London.

Forestry Commission (2007). Forestry Statistics 2007 – A compendium of statistics about woodland, forestry and primary wood processing in the United Kingdom (available from http://www.forestry.gov.uk/statistics), 150 p.

Halsall, L., Gilbert, J., Matthews, R. and Fairgreave, M. (2006). United Kingdom: New Forecast of Softwood Availability. Forestry and British Timber. October 2006.

Macdonald, E., Cooper, G., Davies, I. and Freke, B. (2008). Scots pine timber: current utilisation and future market prospects in Scotland. Scottish Forestry, 62 (4) pp 19-21.

Macdonald, E., Mochan, S. and Connolly, T. (2009). Validation of a stem straightness scoring system for Sitka spruce (*Picea sitchensis* (Bong.) Carr.). Forestry 82 (4), 419-429. doi:10.1093/forestry/cpp011

Mason, W.L. (2000) Silviculture and stand dynamics in Scots pine forests in Great Britain: Implications for biodiversity. Invest. Agr.: Sist. Recur. For.: Fuera de Serie n.o 1-2000, 175-197.

Mason, W.L. And Alía, R. (2000) Current and future status Scots pine (Pinus sylvestris L.) forests in Europe. Invest. Agr.: Sist. Recur. For.: Fuera de Serie n.o 1-2000, 317-333.

Matthews, R. and Mackie, E. (2006). Forest Mensuration: A Handbook for Practitioners. Forestry Commission, Edinburgh.

Mochan, S., Moore, J, and Connolly, T. (2009). Using acoustics tools in forestry and the wood supply chain. Forestry Commission Technical Note 18, Forestry Commission, Edinburgh.

Uusitalo, J. 1997. Pre-harvest measurement of pine stands for sawing production planning. Acta Forestalia Fennica 259. 56p.