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Validation of a stem straightness scoring system for Sitka spruce (*Picea sitchensis* (Bong.) Carr.)

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Summary

This study describes the refinement and testing of a prototype scoring system for the visual assessment of stem straightness in Sitka spruce. The original system comprised a six-point scoring system from 1 (least straight) to 6 (straightest) based on an estimate of straight log lengths in the first 6 m of the stem. A longer log length category and additional score were added to the system to increase relevance to industry practice. The use of aids to measurement to improve the objectivity and accuracy of the visual assessment was tested. A purely visual assessment was as accurate as the measurement tools and was considerably quicker and easier to complete. A study to establish appropriate sampling levels indicated that between 60 and 100 trees should be assessed to obtain an acceptable estimate of the median and interquartile range of straightness scores for a stand. An investigation of the relationship between stem straightness score and yield of logs of different quality suggested that the scoring system may be used to differentiate between stands of different log quality.

Introduction

Reliable information about the quantity and quality of timber available from forests over time is a key requirement for the wood-processing industry, forming the basis for strategic investment and marketing decisions. This type of resource evaluation is also important to inform the sustainable management of forests and to enable owners and managers to maximize economic return. In British forestry, there has been a strong emphasis on measurement of the quantity of the standing timber resource. Growth and yield models are available (e.g. Matthews and Methley, 1998) and long-term forecasts of softwood availability are published regularly by the Forestry Commission

(e.g. Halsall *et al.*, 2006), based on these models and information about average rotation lengths. The volume forecasts, however, generally assume that trees are defect free and therefore predict the maximum volume of timber that might be available, without any allowance for downgrading as a result of timber quality. The wood-processing industry needs to have some idea of the quality of the standing timber resource to determine the volumes available for processing into different markets. For the sawmilling sector, the distribution of lengths of logs that could be cut is of particular importance since this has a large impact on the types of products that can be produced.

During the 1990s, the need for improved information about the quality of the home-grown

timber resource was increasingly recognized. Concerns about the quality of future Sitka spruce (*Picea sitchensis* (Bong.) Carr.) sawlog supplies were raised by both the growing and the processing sectors of the forest industry in Great Britain (McIntosh, 1997). In response to these concerns, a pilot study was initiated under the auspices of the Home Grown Timber Advisory Committee Technical Sub-Committee. The aim of this study was to 'establish a system for stand quality classification and to demonstrate its relevance to sawmill output' (Methley, 1998).

Tree quality classification systems

A number of systems have been developed for classifying log and timber quality in forest stands and trees on the basis of a visual assessment of external features such as stem straightness, branching characteristics and damage from biotic or abiotic agents.

In tree-breeding programmes, scoring systems to assess stem straightness and branching are widely used as selection criteria. For example, Cooper and Ferguson (1981) describe a system of visual scoring for evaluation of bole straightness in cottonwood. Using a 1 (straightest) to 9 (most crooked) scoring system to assess the first 10 m of stem, they found that observation from two sides of the tree, at 90 degrees to each other, enabled observers to make acceptably consistent assessments of bole quality. Barnes and Gibson (1986) used a more complex system to measure stem straightness in provenance trials of tropical pines. The position and length of straight lengths in the first 6 m of stem were recorded and a score was assigned to each tree, with straight lengths in the lower part of the stem carrying greater weight than those higher up. This system was found to be effective for quantitative assessment of stem straightness in provenance trials and to have the advantage of allowing comparisons to be made between sites and trials. In contrast, Lee (1992) describes a system for screening the breeding population of Sitka spruce in Great Britain that ranks trees on any one site for straightness and branching quality, using a scale of 1–6. While this system is valuable for selecting trees for a breeding programme, it is not possible to use it to compare stem form between trials or sites.

Visual tree scoring systems are also used for stand valuation purposes and can provide a useful means of predicting the economic return from a forest stand. Brisbin and Sonderman (1971) describe a system for assigning tree grades to the eastern white pine group of species in the northeastern US. The grades are based principally on the external characteristics of the lower 16-foot (4.9 m) section of the stem: grade 1 has the fewest defects and grade 4 the most. When the assessment system was tested on a sample of 75 trees, the predicted value of the sawn timber, estimated on the basis of the tree grades assigned, was within 5 per cent of the actual value of the sawn timber cut from the trees (Brisbin, 1972). Similarly, Miller (1975) found that a simple stem straightness scoring system for radiata pine (*Pinus radiata* D. Don), dividing trees into four classes on the basis of a visual assessment of sweep in the lower 9–12 m of the stem, gave a good indication of log quality and yield of sawn timber.

Sauter *et al.* (2004) describe a system used in the German federal forest inventory to provide industry with improved information about future timber supplies as a means of guiding investment in future processing capacity. For conifer species, five quality classes are defined on the basis of stem form, knots, bark features and damage, assessed on the lower 10 m of the stem. A picture series showing characteristic trees of each quality class is used by observers to aid tree assessment.

Standing tree quality assessment systems can also be used as an aid to silvicultural decision making. Belli *et al.* (1997) developed a tree quality scoring system for loblolly pine (*Pinus taeda* L.) aimed at providing guidance for selection of trees during precommercial thinning. The scoring system allocates trees to four classes, taking into account stem straightness, stem forking, branch size, cankers and other damage.

The successful implementation of these systems suggests that it is possible and practical to use visual stem quality assessment systems to inform forest management decisions, provided adequate observer training and calibration are put in place.

A prototype system for Sitka spruce

For the pilot study with Sitka spruce in Great Britain, stem straightness was identified as the

most important single factor affecting log quality (Methley, 1998). Although knots were acknowledged to have a significant impact on log and sawn timber quality, they were not considered the primary cause of downgrade in Sitka spruce logs. An assessment method based on a visual estimate of straight log lengths in the bottom 6 m of the stem was devised, with a scoring system of 1 (least straight) to 6 (straightest). The definition for log straightness applied in the scoring system was that used for the classification of softwood sawlogs in Britain (Forestry Commission, 1993). In this, the specification for straightness within the higher quality green category states: 'Bow not to exceed 1 cm for every 1 m length and this in one plane and one direction only. Bow is measured as the maximum deviation at any point of a straight line joining centres at each end of the log from the actual centre line of the log' (Figure 1).

The conclusions from the pilot study were that the scores for the two stands assessed correlated well with the observed output of log lengths at a commercial mill and that with further training a consistent standard of assessment could be achieved.

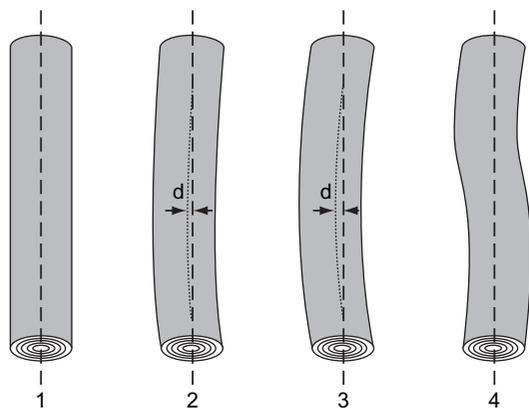Methley (1998) recommended refinement of the prototype method and further work to establish

Figure 1. Specification for log straightness (after Forestry Commission, 1993). Logs 1 and 2 qualify as straight logs; logs 3 and 4 do not qualify. Maximum deviation (*d*) on log 2 does not exceed 1 cm over 1 m length. Maximum deviation (*d*) on log 3 exceeds 1 cm over 1 m length. Log 4 shows bow in more than one direction.

- the correct levels of sampling and the most cost-efficient survey method;
- whether a quality assessment made in a younger stand can provide information on the quality of the stand when it is due to be felled and
- ways of converting quality assessments and scores to predict volumes of different products.

The work presented in this paper addresses principally the following:

1 Further testing of how to assess the straightness score.
2 Establishing the correct levels of sampling.
3 Field testing of the scoring system and preliminary work to establish the link between quality scores and product out-turn.

The question of whether a quality assessment made in a younger stand can provide information on the quality of the stand when it is due to be felled was considered in a previously published article (Macdonald and Barrette, 2001). Results of this study suggested that the straightness of Sitka spruce tended to improve slightly over a 15-year period, but not sufficiently to alter the stem straightness score allocated at the younger age. It was concluded that assessment of stem straightness in younger stands could be a useful predictor of final crop stem quality.

Materials and methods

Review and testing of methodology

A working group reviewed the prototype assessment method and scoring system and considered whether any modifications were required. In the original system, a score of 1 (least straight) to 6 (straightest) was allocated on the basis of the number and length of straight log lengths identified within the first 6 m of the stem (Methley, 1998). The working group revised this to a seven-point scale (score 1–7) to allow the identification of a longer straight log length category than previously, i.e. straight logs greater than 5 m (Table 1, Figure 2). These are lengths from which the commonly required log length of 4.9 m, important for conversion to construction material, could definitely be obtained. The maximum log length

identified in the prototype method, i.e. logs of greater than 4 m, did not guarantee this.

Since the prototype method relied entirely on a visual assessment, consideration was given to whether the use of aids to measurement might improve the accuracy and repeatability of the assessment, enabling greater consistency between assessors and between stands.

During the visual assessment, the assessor had to judge

- The point which was 6 m up the stem
- The straightness of the stem – was any bow greater or less than 1 cm per metre of length and was it in more than one plane?
- The length of straight log lengths.

Measurement equipment which could be either used to measure height up the stem (and there-fore log length) or used to assess deviations from straightness was considered. Three methods were compared:

A. Pole and string: the base of a wooden pole 1.7 m long was attached to the tree at breast height (1.3 m), showing 2- and 3-m levels to help pinpoint heights. A piece of string was carried by the assessor to help assess straightness. The string was held up in front of the eye, pulled taut and aligned with the edge of the stem: this helped to identify sweep and crook.
B. Visual: a purely visual assessment, following training and consolidation, without any aids to measurement.
C. Vertex hypsometer: the Vertex hypsometer (Haglöf Sweden AB, Långsele, Sweden) was used by the assessor to pinpoint 6 m up the stem and to help assess log lengths. Straightness was assessed visually.

A stand of unthinned Sitka spruce in Ae forest (55° 13′ 15″ N, 3° 35′ 5″ W), south Scotland, was selected for the testing of methodologies. The stand was planted in 1953 (age 45 at the time of the trial) and was growing at Yield Class 14. The stand was considered by local staff to be of average quality. A group of 25 trees was selected within the stand and each tree numbered. A team of three observers assessed each of the 25 trees using each of the three methods being tested on three separate days, i.e. each observer completed nine sets of observations

Table 1: Straightness scoring system

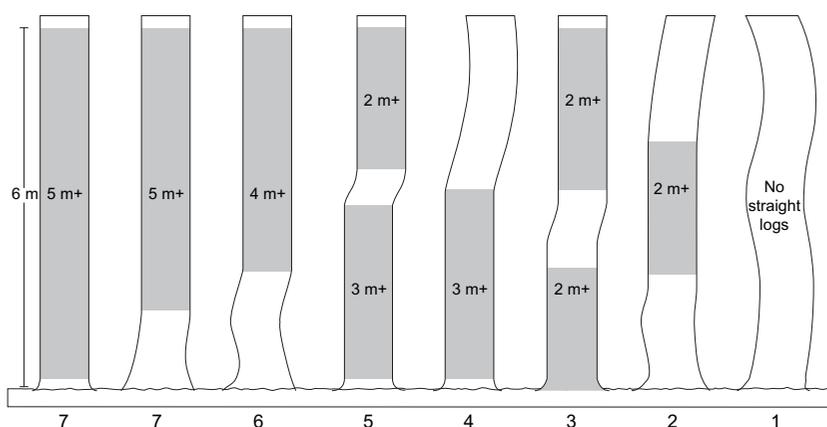| Score	Number and length of straight log lengths counted in butt 6 m
1	No straight lengths ≥2 m
2	One straight length ≥2 m but <3 m
3	Two straight lengths ≥2 m but <3 m
4	One straight length ≥3 m but <4 m
5	One straight length ≥2 m but <3 m and 1 straight length ≥3 m but <4 m
6	One straight length ≥4 m but <5 m
7	One straight length ≥5 m

Figure 2. Straightness score: different combinations of log lengths in first 6 m showing gradual reduction in quality from left to right (from Macdonald *et al.*, 2001, after Methley, 1998).

over 3 days, a total of 27 sets of observations. The order in which each observer used each method on each day was randomized, as was the order in which the trees were assessed in each set of observations. The time taken to complete each set of observations was recorded.

On completion of the assessments on standing trees, the 25 sample trees were felled and cross-cut at 6 m to allow the butt section to be rolled over for examination. An industry expert, who had been involved in the development of the prototype scoring system, visited the site and visually assessed the felled trees using the 1–7 scoring system.

The ordinal scoring system, with distances between ordered scale points 1–7 not necessarily equal, meant that non-parametric methods of analysis were used. Friedman's non-parametric analysis of variance (ANOVA) was used, with trees considered as randomized complete blocks. Methods were compared for each combination of day and observer, observers were compared for each combination of day and method and days were compared for each combination of method and observer.

For comparison of time taken between observers and methods, the 27 times (recorded for the sets of 25-tree observations) were analysed using ANOVA, with days regarded as blocks.

For comparison of straightness scores with the industry expert, each tree within each of the 27 sets was paired with the industry expert assessment. The paired differences were tested using two non-parametric methods: one-sample sign test (ignoring magnitude of differences) and a Wilcoxon matched-pairs rank-sum test (accounting for magnitude of differences).

Sample size

To establish appropriate levels of sampling, 17 Sitka spruce plots were selected for study from those available within Forest Research's network of permanent sample plots (Table 2). The sample, which was chosen to cover the geographic range of Sitka spruce growing in Britain, included 10 unthinned plots, 5 thinned plots and 2 plots respaced at 10 years old and contained between 45 and 263 trees per plot. The plots ranged in age from 28 to 42 years. Every live tree in each plot was assessed using the visual assessment method and the 1–7 scoring system described above.

The data from the 17 sample plots were examined to determine the minimum number of sample trees that would have to be assessed to give an acceptable estimate of the sample-plot median and interquartile range (IQR) (the difference between the third and first quartile). For each plot of n trees, the median and IQR of 1000 random subsamples of size 10, 15, 20, … n, taken without replacement, were recorded. The percentage of times a subsample median fell within the range of the sample-plot median ± 1 and the percentage of times a subsample IQR fell within the range of the sample-plot IQR were determined. The subsample size required to obtain a percentage of at least 95 per cent in either case was recorded.

Field testing of straightness scoring system

Four Sitka spruce stands scheduled for harvesting were selected to provide a range of stem straightness between sites and to obtain a geographic spread (Table 3). All the stands were unthinned with the exception of Tywi, where most of the area had been systematically thinned with one row in three being removed.

At each site, ten 0.01-ha circular sample plots were located randomly throughout the area. A simple method for randomly designating the sample points was used. A map of the sample stand was overlaid with a transparent grid on which each intersection was referenced by numbers along the x- and y-axes. Random numbers were then used to define the intersections, which acted as the centre of sample plots. The diameter at breast height (d.b.h.) of every live tree in the plot was measured together with the height of the tree of greatest diameter in order to estimate top height. Visual straightness assessment scoring, using the method described above, was completed for the 10 trees closest to the plot centre with a minimum d.b.h. of 20 cm – in some cases trees outwith the 0.01-ha plot.

The 10 sample trees in each plot (i.e. 100 trees in each stand) were felled and delimbed. On each sample tree, the length to 15 cm top diameter overbark and the mid-diameter of this section were measured according to normal measurement conventions (Matthews and Mackie, 2006), from which an estimate of total sawlog volume to 15 cm overbark was calculated. The theoretical

Table 2: Details of Sitka spruce permanent sample plots used in sampling study, including results of stem straightness assessment

Site name and plot number	Location	Planting year	Thinning/ respacing treatment	Initial stocking (stems ha⁻¹)	Trees per plot	General Yield Class	Mean d.b.h. (cm)	Plot stem straightness score		Trees per plot (minimum sample for 95% match)	
								Median	IQR	within Median ± 1	within IQR
Bennan 3574	55° 7′ 32″ N, 3° 56′ 56″ W	1970	No thin	2500	82	24	22.8	4	2–4	75	65
Bennan 3590	55° 7′ 32″ N, 3° 56′ 56″ W	1970	No thin	2500	84	24	21.1	4	2–6	25	25
Bennan 3595	55° 7′ 32″ N, 3° 56′ 56″ W	1970	No thin	2500	79	22	21.9	4	2–6	25	20
Bennan 3571	55° 7′ 32″ N, 3° 56′ 56″ W	1970	Yes – 1986	2500	75	24	24.2	4	2–4	70	75
Bennan 3589	55° 7′ 32″ N, 3° 56′ 56″ W	1970	Yes – 1986	2500	81	24	26.5	2	2–6	35	60
Bennan 3591	55° 7′ 32″ N, 3° 56′ 56″ W	1970	Yes – 1986	2500	81	24	26.7	2	2–4	35	75
St Gwynno 2275	51° 41′ 40″ N, 3° 27′ 42″ W	1961	No thin	3600	110	18	20.2	2	2–4	55	95
St Gwynno 2279	51° 41′ 40″ N, 3° 27′ 42″ W	1961	No thin	3600	128	18	19.4	2	1–4	25	65
St Gwynno 2278	51° 41′ 40″ N, 3° 27′ 42″ W	1961	Yes – 1971	3600	86	18	23.1	2	1–4	45	65
St Gwynno 2283	51° 41′ 40″ N, 3° 27′ 42″ W	1961	Yes – 1971	3600	108	18	19.9	2	1–4	65	45
Kershope 1702	55° 7′ 20″ N, 2° 42′ 9″ W	1967	No thin	3472	173	20	16.2	2	1–3	20	120
Kershope 1715	55° 7′ 20″ N, 2° 42′ 9″ W	1967	No thin	3472	136	20	18.6	2	1–4	25	20
Kershope 1722	55° 7′ 20″ N, 2° 42′ 9″ W	1967	No thin	3472	125	20	17.6	1	1–2	20	20
Mull 3517	56° 38′ 59″ N, 6° 8′ 10″ W	1956	Yes	3922	64	24	33.0	5	4–6	60	20
Mull 3649	56° 38′ 59″ N, 6° 8′ 10″ W	1956	No thin	3460	133	24	20.3	5	3–6	20	85
Leanachan 3561	56° 50′ 53″ N, 4° 56′ 25″ W	1956	No thin	5917	214	12	16.8	2	1–4	25	20
Tummel 3629	56° 43′ 35″ N, 4° 3′ 40″ W	1969	Yes	3086	45	18	17.0	2	2–4	30	45

Table 3: Details of Sitka spruce sample stands studied during field testing of straightness scoring system

Site name	Forest district	Grid reference	Area (ha)	Planting year	Age	Yield Class	Estimated crop details		
							Standing volume (m³ ha⁻¹ overbark)	Mean d.b.h. (cm)	Mean tree volume (m³ ha⁻¹ overbark)
Wauchope	Scottish Borders	54° 28′ 29″ N, 3° 27′ 1″ W	14	1962	36	18	460	18	0.19
Rosarie	Moray	57° 7′ 29″ N, 3° 35′ 40″ W	7	1948	50	16	715	24	0.49
Clatteringshaws	Castle Douglas	55° 3′ 49″ N, 4° 13′ 14″ W	25	1949	49	12	600	22	0.38
Tywi	Llanymddyfri	52° 9′ 28″ N, 3° 43′ 4″ W	23	1963	35	18	480	18	0.27

Table 4: Median stem straightness scores for stem straightness assessment of 25 Sitka spruce sample trees by three observers using three methods on three consecutive days

	Median stem straightness score for 25 sample trees (IQR)			
	Pole and string	Visual	Vertex hypsometer	Observer median
Observer 1	2 (1–4)	2 (1–4)	2 (1–4)	2 (1–4)
Observer 2	2 (1–4)	2 (1–4)	2 (1–4)	2 (1–4)
Observer 3	2 (1–4)	3 (2–4)	2 (2–4)	2 (2–4)
Method median	2 (1–4)	2 (1–4)	2 (1–4)	2 (1–4)

volume of green sawlog material was estimated by simulating the cross-cutting of the tree using a standardized cutting specification.

Green logs	Red logs
4.8, 3.6, 3.0 m	3.6 m (17 cm top diameter overbark)
All 17 cm top diameter overbark	2.5 m (15 cm top diameter overbark)

The length and mid-diameter of each theoretical sawlog were measured, from which an estimate of the volume of green sawlog material was calculated.

The data were analysed using linear regression. The full model considered was $y_{ij} = \alpha_i + \beta_i x_{ij} + \varepsilon_{ij}$, where the response, y_{ij}, and the candidate predictor, x_{ij}, are the mean percentage green log volume and median straightness score for site i, plot $j(i = 1…4, j = 1…10)$, respectively. The site intercepts and slopes are α_i and β_i, and independent random error is $\varepsilon_{ij} \sim N(0,\sigma^2)$. Models with a common intercept, α, or slope, β, were also considered.

Results

Review and testing of methodology

The overall median score for the 27 assessments of the 25 sample trees was 2 (Table 4). The Friedman test was generally non-significant between methods, observers and days, suggesting a consistent allocation of scores per tree. Between methods, the Friedman test was significant in 2 of the 9 days by observer combinations. Between observers, the Friedman test was significant in 2 of the 9 days by method combinations. Between days, the Friedman test was significant in one of the nine observers by method combinations.

There were significant differences in time taken between methods ($P < 0.001$) and between observers ($P = 0.022$) but no method by observer interaction (Table 5). The visual assessment method was significantly faster than either of the other

Table 5: Mean time taken for stem straightness assessment of 25 sample Sitka spruce trees by three observers using three methods on three consecutive days

| | Time taken for assessment of 25 sample trees using different methods (min) | | | |
	Pole and string	Visual	Vertex hypsometer	Observer mean
Observer 1	69	43	84	65
Observer 2	62	48	87	66
Observer 3	59	41	55	52
Method mean	63	44	76	61

Table 6: Comparison between stem straightness scores allocated to each standing tree and stem straightness scores allocated to felled trees by industry expert

Method	% Where standing score = felled score	% Where standing score was between −1 and +1 of felled score
All	45	78
Pole and string	46	75
Visual	44	81
Vertex	46	76

two methods of assessment. On average, the use of a pole and string added 44 per cent to the time taken to assess the 25 sample trees, while the use of the Vertex hypsometer added 72 per cent. It was also found that assessments of the 25 trees became faster each day, taking on average 67 min on day 1 and only 57 min on day 3.

When the trees were felled and scored by an industry expert, the median score for the 25 trees was 3 with IQR 1–4 (Table 6). The industry expert's score for each felled tree was compared with the standing tree scores. Neither the sign test nor the Wilcoxon test showed a significant difference in median score between the industry expert and any of the 27 sets of 25-tree observations.

Since the visual assessment method was significantly faster than using aids to measurement, without any loss in the accuracy or consistency of assessment, this method was used for all further stages of the study.

Sample size

The results of the stem straightness assessments made in the 17 sample plots showed a spread of plot medians, from 1 for plot 1722 at Kershope to 5 for plots 3517 and 3649 on Mull (Table 2). The sampling study results were variable, suggesting a median minimum sample size of 30 trees (IQR = 25–55) to give an acceptable estimate of the true-plot median (i.e. a 95 per cent match within ±1) and 60 trees (IQR = 20–75) to give an acceptable estimate of the true IQR (Table 2). The median percentage of plot sample size for

the IQR match was 64 per cent (IQR = 30–80 per cent) and two plots required a full (100 per cent) sample (Bennan 3571 and Tummel 3629).

Field testing of straightness scoring system

The site median straightness scores for the sample sites assessed ranged from 3 for Wauchope to 6 for Clatteringshaws.

The estimated green log recovery was 27 per cent at Wauchope, 33 per cent at Rosarie, 51 per cent at Clatteringshaws and 35 per cent at Tywi. Figure 3 shows the relationship between estimated green log volume recovery per plot and plot-median stem straightness scores for all four sites. The data from these four sites suggest different site intercepts, with a significant difference between those for Rosarie and Clatteringshaws, and a common positive relationship between plot-mean green log percentage and plot-median straightness score (R^2 = 44.3). The range of intercepts (Wauchope = 11.61, Rosarie = 5.78, Clatteringshaws = 14.84 and Twyi = 10.47) indicates a maximum absolute difference in plot-mean green log percentage of 9 per cent between sites. The common slope (β = 5.17) suggests an absolute increase in plot-mean green log percentage of ~5 per cent per unit change in plot-median straightness score.

Discussion

Review and testing of methodology

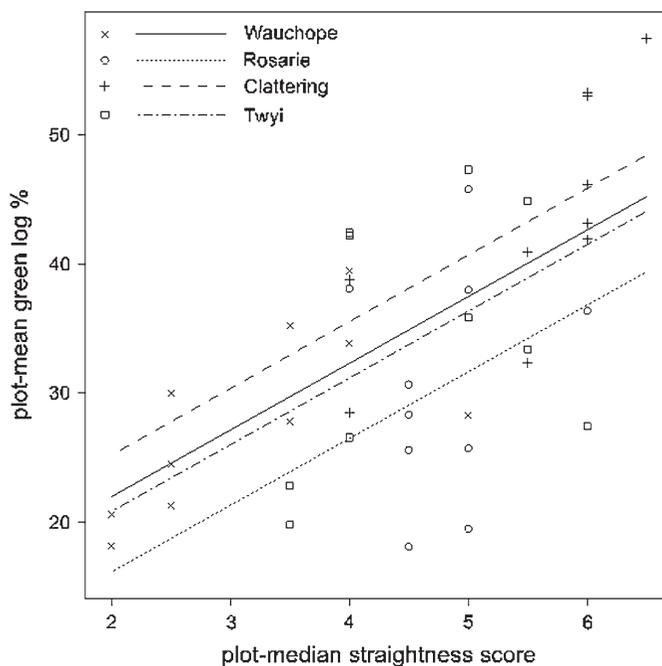The aim was to assess whether the use of aids to measurement improved the accuracy and

Figure 3. Relationship between plot-median stem straightness score and plot-mean green log % per plot for each of the four sites.

repeatability of the straightness scoring, compared with a purely visual assessment. Results of the trial showed that there were no statistically significant differences between the scores allocated to the sample population by the different methods. This suggests that in terms of consistency of assessment, there was no advantage in using the aids to measurement.

Comparing the standing scores on 25 trees with the felled score, allocated by an industry expert, indicated the relative accuracy of the three methods. There was no evidence from the trials conducted that the visual method was any less accurate in predicting the felled score allocated by the industry expert than the other two methods. The level of agreement between the observers' visual scores and the industry expert's scores can be compared with the work of Belli *et al.* (1997). In their study with only four classes, a comparison of the assessment of a sample of trees by researchers with scores allocated by an industry expert showed that the researchers gave

the same score in 53 per cent of cases and were within ± 1 of the expert's score in 93 per cent of cases.

When the time taken to make the assessment is considered, the visual method was significantly faster than the other two methods. It therefore appears that the use of aids to measurement would add considerably to the cost of the operation, without increasing the accuracy or consistency of the assessment. Observers also reported that the visual assessment was the easiest to complete as without any cumbersome equipment the observer was free to concentrate more fully on the straightness assessment.

Sampling

A minimum sample size of ~60 trees gave a generally acceptable estimate of both the stand median straightness score and the IQR. Consideration was given to the way in which the sample

trees within a stand should be selected during a straightness assessment survey. In order to align the procedure as closely as possible with other mensurational protocols, it was decided to adopt a system of randomly located sample plots. Sample plots are a method commonly used when making mensurational assessments of stands. Matthews and Mackie (2006) give numbers of sample plots to be used in stands of different areas and crop variability when assessing stand basal area. For the purposes of stem straightness assessment, the number of plots recommended for uniform plots was adopted: for stands between 0.5 and 2 ha, 6 plots; for stands between 2 and 10 ha, 8 plots; and for stands greater than 10, 10 plots (Macdonald *et al.*, 2001).

Rather than use plots of a fixed area, plots containing 10 assessable trees were selected as the sampling unit, thus ensuring that between 60 and 100 trees were sampled within each stand, which met the minimum numbers derived from the sampling study. The possibility of using either circular or line plots was considered. In 'Field testing of straightness scoring system', circular plots were used consisting of the 10 assessable trees that were nearest to the plot centre. This was found to be time consuming, as the distance of individual trees from the plot centre had to be measured. Based on this experience, it was decided that 10-tree line plots, consisting of the first 10 assessable trees encountered within 1.5 m on either side of a random bearing taken from a random sample point, would be a more practical approach.

Field testing of straightness scoring system

Preliminary investigation of the link between stem straightness score and green log recovery (proportion of total log volume that falls within the green log category) showed that the plot-median stem straightness score accounted for ~45 per cent of the variation in green log recovery observed between plots. This suggests that although the stem straightness assessment is focused on the first 6 m of the stem, it does reflect differences in the stem quality of whole trees and can be used to distinguish between stands of differing stem quality.

Conclusions

1 A prototype method for assessing and scoring stem straightness in standing Sitka spruce was developed and tested. The basis of the method remains the assessment of straight log lengths in the first 6 m of the stem but an additional class was included to identify long straight logs particularly suitable for construction.

2 The use of measuring instruments to aid the assessment of straight log lengths did not improve the consistency or accuracy of assessment compared with a purely visual assessment. The visual assessment was easier to use and significantly quicker to complete.

3 The visual assessment of stem straightness in standing trees gave an acceptable degree of correspondence with scores allocated to felled trees by an industry expert.

4 A sampling study indicated that typically between 60 and 100 trees should be assessed to estimate the median and IQR of straightness scores for a stand.

5 On the basis of the 17 sample study plots and subsequent trials on four harvesting sites, it appears that the scoring system may be used to quantify differences between stands of different log quality.

6 On the basis of this study, a protocol for use of the assessment method at the stand level was published (Macdonald *et al.*, 2001) and has been used as a stem quality assessment technique in a number of studies. When the assessment method is used in the field, training and calibration against an experienced assessor should be undertaken to ensure consistency.

Conflict of Interest Statement
None declared.

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