LOG QUALITY ASSESSMENT IN SITKA SPRUCE

A collaborative project funded by Forestry Commission, Forest Enterprise, Scottish Enterprise, Tilhill Economic Forestry Ltd., Scottish Woodlands Ltd. and the United Kingdom Forest Products Association.

Final Report
Stem Straightness Survey in Sitka spruce: Argyll, Grampian, Highland and N.E. England

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Executive Summary

1. This report gives details of the work undertaken to survey the Sitka spruce resource in three regions of Scotland and Northern England and to test the model of stem straightness originally developed for South Scotland in order to refine or redevelop it. The protocol for carrying out the straightness assessment is described in appendix 1.

2. The main objective was to predict the quality of standing timber within the existing forests in Northern Britain prior to 1976. The survey was designed to provide a description of Sitka spruce stem straightness in Northern Britain to determine the relationship between stem straightness scores and selected stand and site characteristics. The survey was also designed to complement the survey previously undertaken in South Scotland, to provide a descriptive understanding of Sitka spruce stem straightness in the Argyll, Highland, Grampian and North England regions and to test the stem straightness model developed from the South Scotland survey.

3. Development and testing of the stem straightness assessment method is catalogued in previous project reports. The protocol has been published as a Research Information Note (Macdonald *et al*. 2001)

4. The survey covered approximately 1.9 % of the Sitka spruce cover managed by the Forestry Commission and the private sector within the four regions. The survey assessed 18,319 trees on 140 randomly chosen sites on FC land and 72 sites on private sector land. These represented 1897 ha and 915 ha respectively.

5. The forests in the selected areas represent a significant proportion of the total Sitka spruce resource in Northern Britain. Approximately 149,944 hectares of Sitka spruce was planted up to and including 1975, this area is likely to be felled during the next 10 – 15 years. About 12% (18,540 hectares) are located in Grampian Region, 25% (37,949 hectares) in Highland Region, 39% in Argyll and Bute (58,491 hectares) and 24% (34,964 hectares) in the Kielder region. (Source: National Inventory of Woodland and Trees).

6. Potential sites were stratified by planting year and yield class and site selection was based on a random sample. The number of surveyed sites reflected the area of each stratum in each region. Only sites of 5 hectares and over were used, with 8 plots marked for sites less than 10 ha and 10 plots for sites of 10 ha and over. Each sample plot contained 10 sample trees.

7. There was no significant difference in mean straightness scores between the regions.

8. There are a number of silvicultural factors that have an effect on mean straightness scores. Thinning has a positive influence on the mean straightness score. Mean scores were significantly higher in thinned stands than non-thinned. Planting year and dbh also had a significant effect on the mean straightness score. The earlier the planting the greater the score and the greater the dbh the higher the score.

9. The link between dbh and straightness score has also been observed at the stand level. Statistical tests on standing and felled trees have suggested that this is a real effect and not due to observer bias.

10. Elevation and DAMS did not show any clear trends with stem straightness, unlike the South Scotland survey. This possibly reflects the broader geographical and environmental range encountered in this broader survey. In the regional models they generally showed a negative correlation with stem straightness.

11. Assessment of the stem straightness model developed for South Scotland using data collected in this survey showed poor correlations between predicted and actual site scores. The highest correlation was found for the Highland region with r = 0.55, the lowest Argyll with r = 0.30.

12. A model to predict stem straightness has been developed for the rest of Scotland and N.E. England. It accounts for 48% of the observed variation. The high levels of unaccounted variation

could be due to environmental factors not accounted for or past management history that could not be modelled. Further models have been developed for each of the different regions surveyed, including those two regions - Dumfries and Galloway and the Borders - that were surveyed as part of the South Scotland survey. All the data collected to date was then analysed to provide a model to cover the entire survey are, the "All Scotland" model which accounts for 50.4 % of the observed variance in the data.

13. In summary, there appears to be a continuing decline in the stem straightness of plantation grown Sitka spruce. There is the potential that due to the link between dbh and straightness score that the poorer form trees, being smaller will become suppressed over time. This could have the effect of improving the mean straightness score of the stand but is yet unproven. Certainly over the next 5-10 years the proportion of green sawlogs as a percentage of volume harvested is likely to drop.

Introduction

14. The work contained in this report follows on from a survey of stem straightness in Sitka spruce undertaken in South Scotland (Stirling *et al.* 2000). The South Scotland survey provided information on the quality of the standing crop of timber and developed a model to predict stem straightness based on site and management factors. The objectives of this survey were similar but aimed at a broader regional coverage that included four main regions, Argyll, the Highlands, Grampian and North England. These areas provided a broad geographic and environmental range for testing the model initially developed for South Scotland and covers the main Sitka spruce growing areas in Great Britain.

15. Timber quality in Sitka spruce is determined primarily by stem straightness but this requires a standardised method of assessment that can be applied to stands throughout Britain. Methley (1998) initially developed an assessment method based on a visual estimate of straight log lengths in the first 6 m of the stem of standing trees. This was refined and validated by Macdonald *et al.* (2001). This method allows an objective measurement of stem quality that is amenable to statistical analysis and modelling. Hence, the survey results presented the opportunity to investigate the link between stem straightness in Sitka spruce and various factors and model the response. One longer term aim of this work is to integrate the models developed from the survey work with volume forecast models to provide an assessment of the quality of future sawlog supplies in Great Britain (Rothnie and Selmes 1996).

16. The survey work was undertaken between May and December 2000 on both Forest Enterprise and privately owned land. The Forestry Commission, Forest Enterprise, Scottish Enterprise, Tilhill Economic Forestry Ltd., Scottish Woodlands Ltd., and the United Kingdom Forest Products Association jointly funded the project.

Methodology

17. The stem straightness survey was designed to cover a randomly selected proportion of pure Sitka spruce stands within the designated areas of Northumberland, Argyll, Highland and Grampian. The distribution of spruce within these areas represents a significant volume of timber to be felled within the next 10-15 years. An estimate of the total area of Sitka spruce high-forest within the regions was obtained from the National Inventory of Woodlands. This data was broken down into 10-year age classes with the estimate of area planted between 1971 and 1975 being calculated by taking 65% of the area planted between 1971 and 1980.
18. Data was provided by Forest Enterprise (FE) for their holdings in the regions concerned. Information on planting in the private sector for the whole of Scotland was contained in the FC Annual report for 1980.
19. The distribution of Sitka spruce by area is given in Table 1. The total area of Sitka spruce high-forest in the survey area amounts to 149,944ha.

Table 1: Area of Sitka spruce High Forest Category 1 (Areas obtained from National Woodland Inventory)

Location		Area of Sitka spruce High Forest Category 1- Hectares				
		1941-1950	**1951-1960**	**1961-1970**	**1971-1975 (65% 1971-1980)**	**Total for 1941-1975**
Argyll	FC	1,205	8,474	15,083	17,777	42,539
Argyll	Non FC	228	1,559	7,686	6,479	15,952
Total for Argyll		**1,433**	**10,033**	**22,769**	**24,256**	**58,491**
Highland	FC	2,164	5,582	13,020	4,483	25,249
Highland	Non FC	740	1,686	4,881	5,393	12,700
Total for Highland		**2,904**	**7,268**	**17,901**	**9,876**	**37,949**
Grampian	FC	1,748	1,600	4,020	2,661	10,029
Grampian	Non FC	778	2,291	2,715	2,727	8,511
Total for Grampian		**2,526**	**3,891**	**6,735**	**5,388**	**18,540**
North England	FC	2,607	7,687	6,629	6,505	23,428
North England	Non FC	795	1,351	5,036	4,354	11,536
Total for North England		**3,402**	**9,038**	**11,665**	**10,859**	**34,964**
Total area	**FC**	7,724	23,343	38,752	31,426	**101,245**
Total area	**Non FC**	2,541	6,887	20,318	18,953	**48,699**

Sampling Strategy

20. For Forest Enterprise sites the FE Sub-Compartment Database (SCDB) provide a list of possible sites that fit the following criteria. Each district provided a list of Sub compartments, from their SCDB, with the following characteristics:

- Classed as Productive High Forest
- Species = Sitka spruce only
- Planting years 1941-1975
- Yield class 6 or greater (excludes areas in check)
- Area 5.0 – 20.0 ha inclusive

21. Areas of spruce that were initially planted as a self-thinning mixture were taken into account where the majority of the stand had a final crop of Sitka spruce. The self-thinning mixtures were recorded as thinned areas.

22. The above characteristics were combined with a further series of criteria

Planting Year - ≤ 1960, 1961 - 1970, 1971 - 75
Thinning - thin/no thin
Yield Class - ≤12, 14/16, ≥18
Spacing- ≤1.7m, 1.8 - 2.0m, ≥2.1m

23. These combinations give a total of 54 different stand types. Replicating each combination three times gave a total of 162 stands, which was the minimum required for the survey as described in table 2. It was not always possible to stratify stands according to the above criteria because of the lack of available stand data within the area being surveyed.

24. The original data was checked for any anomalies, making sure that all possible variables could be covered within each district and region. Table 2 indicates the percentages of plots by area and the number of plots available for modelling. Sampling was undertaken to reflect the breakdown of sites by region and planting year as outlined in tables 1&2.

Table 2: Distribution of sites relating to the planting period and area.

Planting Period	Area of SS	% of total	Sample Plots by % area	Required for modelling	Actual number sampled
1941-1960	40,495	27%	44	54	68
1961-1970	59,070	39%	63	54	69
1971-1975	50,379	34%	55	54	75
Total	149,944	100%	162	162	212

25. It was envisaged that the data collected from these sites would be analysed in the same two ways as the data from South Scotland.

    1. Summarised to provide a description of Sitka spruce stem straightness in the four regions, broken down by planting year class and region.

    2. To examine and model the relationship between stem straightness scores and selected stand/site characteristics, initially planting year (age), Yield Class, spacing, thinning treatment and windiness.

For each of these sub-compartments the following information was provided in an Excel spreadsheet:

Location information:

- forest
- geographic block
- compartment number
- sub-compartment number
- component
- grid reference
- county code

Crop information:

- planting year
- yield class
- area
- rotation (1st or 2nd)
- mixture code
- (spacing & thinning type)

Site information:

- soil code
- altitude
- terrain class
- windthrow Hazard Class

Site Selection - FC Sites

26. Initially the SCDB was used to stratify the sites by planting year and yield class, with information on thinning and spacing used where available. Information on thinning treatment and spacing was incomplete within some of the forest districts. Where it was available sites were further stratified. A random sample of sites was selected from within each stratum.

27. 152 sites were selected at random from within the strata. Of these 152 sites, 140 were surveyed. The remaining 12 sites were removed from the survey as they were not suitable because of wind damage or felling. The total area of sub-compartments surveyed was 1,897ha which amounts to 1.9% of FC Sitka spruce in the area.

Site Selection - Non-FC Sites

28. A total of 80 sites were selected randomly from private forests with 72 actually surveyed in line with the proposed stratification for FC sites. The specific number of sites selected was weighted using the data obtained from the National Inventory of Woodlands. We found that certain stratum were difficult to locate especially in the 1941 - 1960 age class. This illustrates that very few crops of Sitka spruce are still standing at this age through felling or possibly wind damage.

29. The private sector sites were stratified in the same way where possible. Due to varying types of database it was not always possible to obtain a random selection because of the lack of information or the lack of sites.

30. Sites sourced for survey included forests owned or managed by:

Tilhill Economic Forestry Ltd.	Seafield Estates
Scottish Woodlands.	MoD Otterburn
Balmoral Estates	Northumberland Estates
Glenlivet Estates	

31. The total area of sub-compartments surveyed was approximately 915ha which amounts to almost 1.9% of non-FC Sitka spruce in the area.

Preparation for Field Data Collection

32. Details of the stem straightness survey protocol can be found in Macdonald *et al.* (2001) and Appendix 1.

33. Hand drawn 1:10000 maps were used for locating the sites to be surveyed. For the purpose of the survey, only sites of 5 hectares and over were used, with 8 plots marked for sites of less than 10 ha and 10 plots for sites of 10 ha or over. Each plot contained 10 sample trees. Each site was given a unique reference number to allow for easy cross-referencing once the survey had been completed. The number of plots required for each stand was determined based on the straightness protocol (Appendix 1). Each plot was marked randomly on the map by overlaying a map of the sample stand with a transparent grid on which each intersection could be referenced by numbers along the X and Y-axes. Random numbers were used to define the intersections.

Field Data Collection

34. The plots marked on the map were found in the forest as accurately as possible using map and compass. On reaching the plot, the plot number was noted on the map and the plot centre was marked on the ground. Sampling was undertaken using a linear transect. The direction of the transect was defined by a random bearing. The first 10 trees were assessed that were within 1.5m of either side of the transect line and above the minimum acceptable dbh. The trees were numbered 1-10 with DBH and straightness score being taken for each tree. The age class of the stand determines the minimum acceptable dbh (see Appendix 1).

35. The data was collected at three levels; site, plot and tree.

Site Level Data

- Site name
- Sub-compartment number
- Grid reference
- Planting Year
- Name of Assessor
- Date of Assessment

Plot Level Data

- Plot number (1-8 or 1-10)
- Random compass bearing
- In-row and between-row spacing
- In-row and between-row slope angle
- Type of thinning
- Top height

Tree Level Data

- Tree number (1-10)
- Evidence of forking (yes/no)
- Straightness score (1-7)
- DBH

Further Explanation of Data Collected

36. Although most of the terms above are self-explanatory a further explanation of some terms is required.

<u>Random compass bearing:</u>
A list of random numbers between 1 and 360, generated using Microsoft EXCEL was taken into the field and used sequentially to determine the bearing of the transect.

<u>In-row spacing:</u>
The distance between the centres of 6 trees grown in a row was measured. Any point with evidence of a tree was counted, i.e., live trees, dead trees and stumps. Gaps were ignored. Dividing this figure by 5 gave the mean "establishment spacing" per plot that was used to calculate stocking density.

<u>Between-row spacing:</u>
As in-row spacing, measured across the rows.

In-row and between-row slope angle:
Measured using a Suunto clinometer to the nearest degree, used to correct the spacing for slope angle.

Thinned or not-thinned:
All plots showing evidence of thinning of whatever form, including re-spacing, were marked as thinned. There were three categories recorded for thinning: non-thin, systematic and selective thinning.

Top height:
The top height of the tree with the largest DBH within a 5.6m radius was taken for each plot at the start point of each transect. Top heights were taken on all private sites and any FC site not surveyed after 1990. This allowed for the verification of yield class for any given site.

Forking:
Forking above 1.3 meters was noted and the height estimated and recorded.

Elimination of Bias

37. Sites were selected randomly from databases. All plots were marked on the survey map before entering the forest. The bearing along which sample trees were taken was completely randomised.

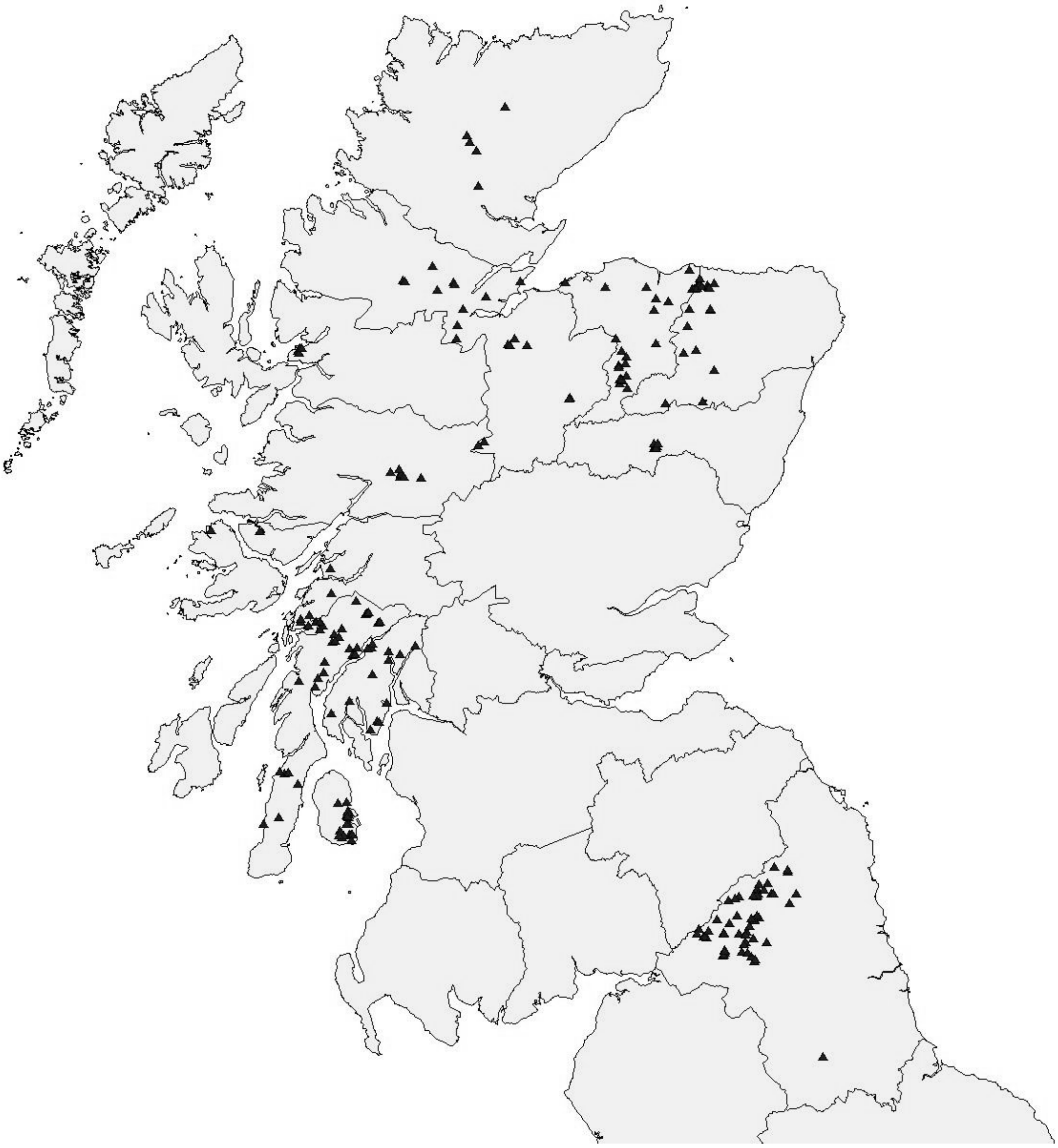
Assessor Training and Staff Changes During Survey

38. A single Forest Research Officer who had initial involvement with the development of the survey method trained all survey assessors to a common standard. This allowed assessors to develop a good understanding of the scoring system as illustrated below.

39. Staff changes were kept to strict minimum throughout the duration of the survey. New and replacement staff were grouped with established assessors to ensure the integrity of data collected.

40. The initial trainer re-assessed a number of sites across the survey region to ensure that consistency was being maintained between different sets of assessors and different regions.

Map 1. Locations of survey sites



Survey Results

41. Table 3 presents a summary of the survey coverage on a regional and ownership basis. It shows that the survey obtained a broadly even coverage in terms of percentage area surveyed. Locations of survey sites are shown on Map 1.

Table 3: A summary of areas of pure Sitka spruce stands surveyed by region and ownership

Region	Actual Area Surveyed	Total[1] Available Area >2ha	Percentage Surveyed
Highland: F.C.	309.1 ha	25,249 ha	1.20%
Highland: Non F.C.	147.0 ha	12,700 ha	1.20%
Total for Highland	**456.1 ha**	**37,949 ha**	**1.20%**
Grampian: F.C.	168.3 ha	10,029 ha	1.70%
Grampian: Non F.C.	262.5 ha	8,511 ha	3.10%
Total for Grampian	**430.8 ha**	**18,540 ha**	**2.30%**
Argyll: F.C.	743.3 ha	42,539 ha	1.70%
Argyll: Non F.C.	166.0 ha	15,952 ha	1.00%
Total for Argyll	**909.3 ha**	**58,491 ha**	**1.60%**
N. England: F.C.	669.66 ha	23,428 ha	2.90%
N. England: Non F.C.	347 ha	11,536 ha	3.00%
Total for N. England	**1016.66 ha**	**34,964 ha**	**2.90%**
Total	**2812 ha**	**149,944 ha**	**1.90%**

[1] Area of Sitka spruce High Forest Cat.1 (capable of producing sawlogs & SRW) - from Woodland Inventory.

Results of the Rest of Scotland and NE England Stem Straightness Survey.

41. A summary of the data obtained from the survey is provided in Tables 4 and 5.

Table 4: Numbers of sites and trees surveyed by region.

Region	No. of Sites Surveyed	No. of sites thinned	% Sites thinned[1]	No. of trees surveyed
Argyll	67	5	7.5	5819
Grampian	49	23	46.9	4000
Highland	43	7	16.3	3620
NE England	53	13	24.5	4880
Total	212	48	22.6	18,319

1. > 50% of plots in a stand are thinned for the site to be considered as thinned.

Table 5: Summary of mean, maximum and minimum values of tree and site characters for the whole survey region.

Character	Mean	Maximum	Minimum
Straightness score	3.04	5.9	1.08
DBH (cm)	24.16	40.96	14.76
Initial stocking (stems ha^{-1})	2875	7990	969
Elevation (m)	232	488	6
DAMS score[1]	14.8	20.6	7.9

1. Ref: Quine and White 1994

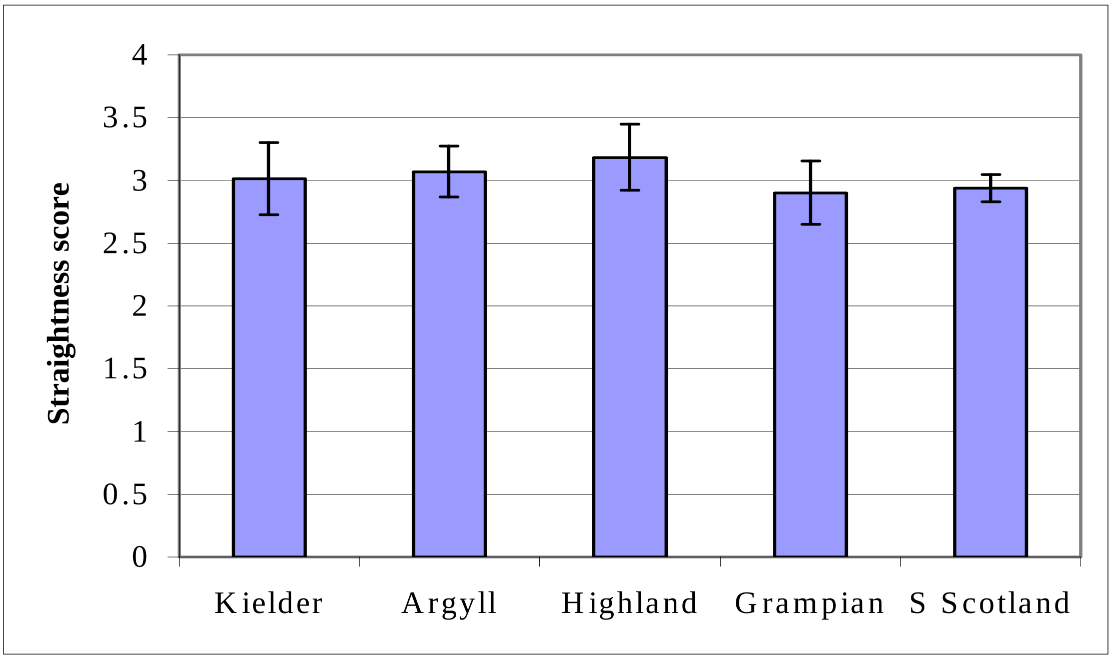
Mean Straightness Score by Region

42. As can be seen from Table 6 there is little variation in mean straightness score between the regions; the Highlands having the highest and Grampian the lowest scores. Interestingly Grampian also has the highest percentage of thinned sites and, as can be seen below, this would suggest a higher mean straightness score. This would indicate that the unthinned sites in Grampian region are poorer than average. However, as can be seen from Figure 1 there is no clear difference in mean straightness score between the regions.

Table 6: Mean straightness score on a regional basis.

Region	Mean score	Standard deviation	95% Confidence limit
Kielder	3.01	1.076	±0.2900
Argyll	3.07	0.847	±0.2029
Highland	3.18	0.887	±0.2651
Grampian	2.90	0.897	±0.2512
S Scotland	2.94	0.888	±0.1086

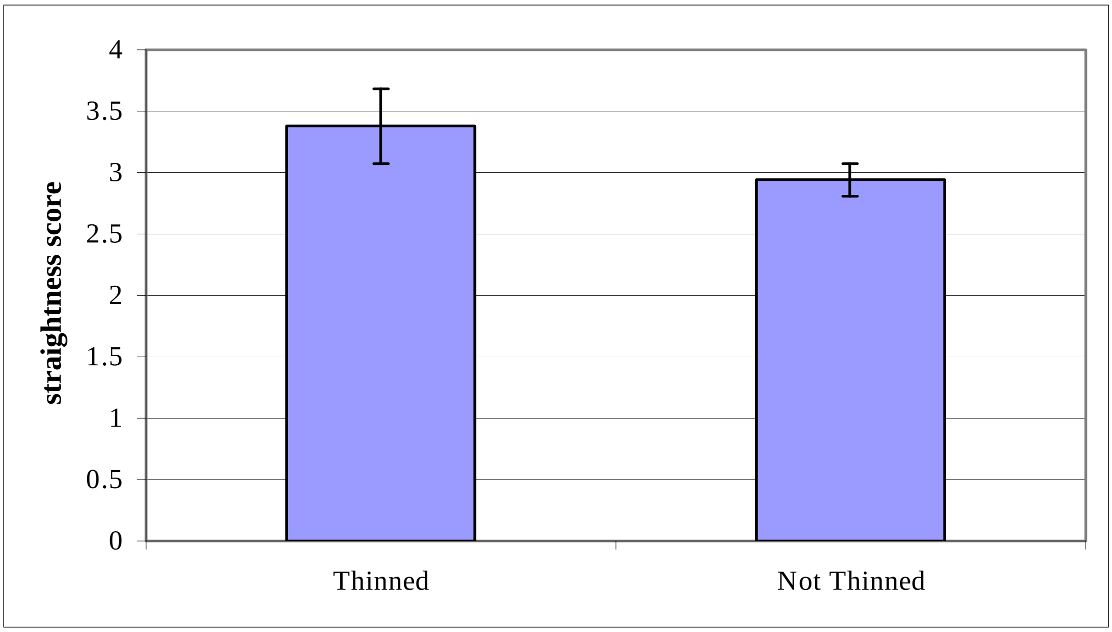
Figure 1: Mean straightness score on a regional basis. Error bars represent 95% confidence limits.



Thinning

42. As was also noted in the South of Scotland Survey (Stirling *et al.* 2000), this survey found that thinned stands tend to have a higher mean straightness score (3.38 (±0.304 for 95% confidence limits)) than unthinned stands (2.94 ±0.131). This is shown in Figure 2.

Figure 2: Mean straightness score with respect to thinning. Error bars represent 95% confidence limits.



43. However thinned stands represented only 22.6% of the total number of sites, indicating that thinning is not widely practised in the survey region as a whole. In addition, the relationship between thinning and planting year indicated that more recent plantings were less likely to be thinned than older sites; as can be seen from Table 7. Since the survey was not designed to examine the change in thinning practise over time these results should be only considered as indicators of a general trend.

Table 7: Summary of thinned sites by region and planting year.

Region	Planting Year	No. of thinned sites	% of sites thinned[1]
Argyll	Pre 1960	0	0
	1961-1970	5	16.7
	1971-1975	0	0
Grampian	Pre 1960	13	76.5
	1961-1970	7	53.8
	1971-1975	3	15.8
Highland	Pre 1960	6	46.2
	1961-1970	1	7.7
	1971-1975	0	0
NE England	Pre 1960	6	24.0
	1961-1970	4	30.8
	1971-1975	3	20.0

[1] Percentage given is on a per region and planting year range basis.

Planting year and Diameter at Breast Height (dbh)

44. Possibly linked to the changes in thinning practise noted above was a strong trend towards increased stem straightness with age, expressed either as planting year or dbh. This can be seen in Figures 3 and 4.

Figure 3: Mean stem straightness score with respect to dbh. Error bars represent 95% confidence limits.

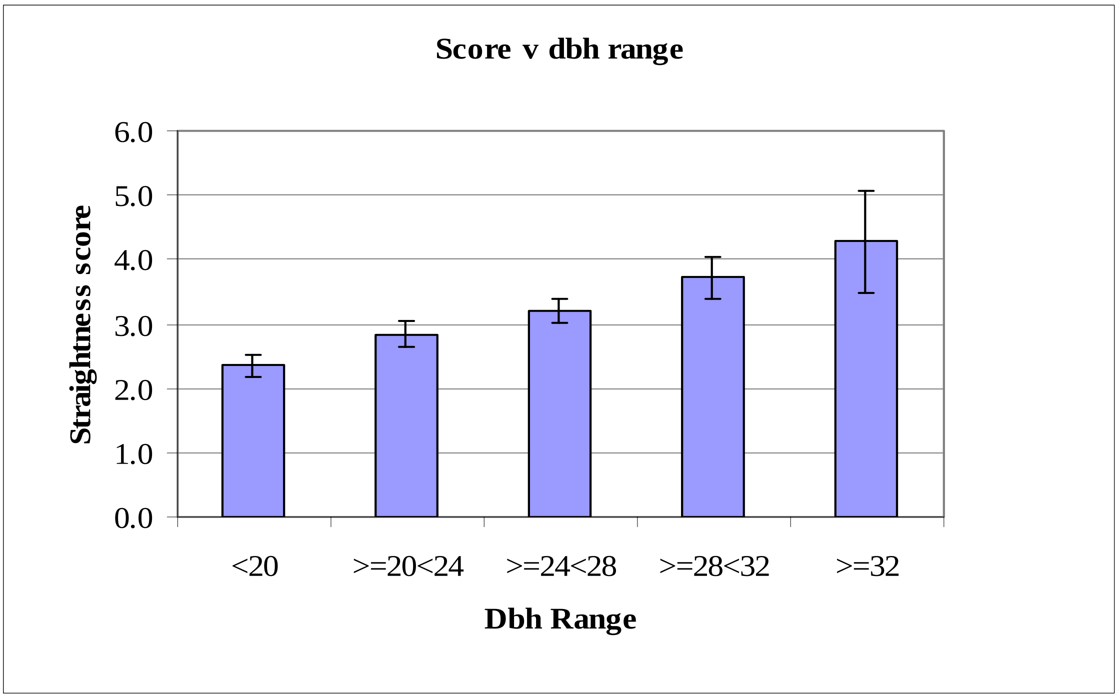
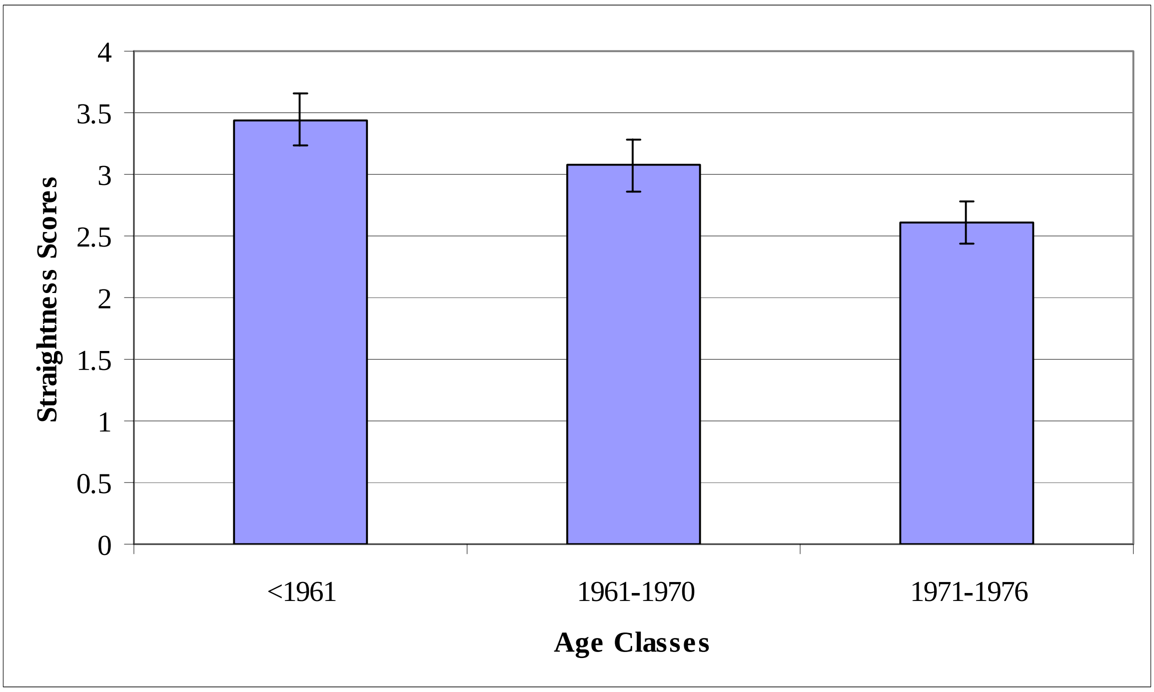


Figure 4: Mean stem straightness score with respect to planting year. Error bars represent 95% confidence limits.



45. This difference in quality associated with newer plantings was noted in the South Scotland survey and now appears to be a general feature of Sitka spruce plantations throughout Scotland and NE England (Stirling *et al.* 2000).

46. The strong trend of better straightness scores with larger dbh was also noted at the stand level. For 40% of the stands, trees with scores 6 and 7 had significantly larger mean dbh than trees scoring 1 and 2 in the same stand. This raised the issue of observer bias, i.e. larger trees appearing to be straighter to the surveyor. However, work carried out on 400 trees that were assessed both standing and felled showed that this trend was observed consistently, suggesting, therefore, that within a stand the smaller trees, on average, have poorer form.

47. Hence, more recent plantings could improve with maturity and any differential may be less distinct should a comparable survey be carried out in 10 or 20 years time. Recent work has suggested that individual Sitka spruce trees do not straighten over the time scales considered (Macdonald and Barrette, 2001) and hence any improvement would need to come from the suppression and mortality of the poorer form trees. As yet it is unclear whether such stand dynamics occur at a sufficient rate to alter the mean straightness score for a stand.

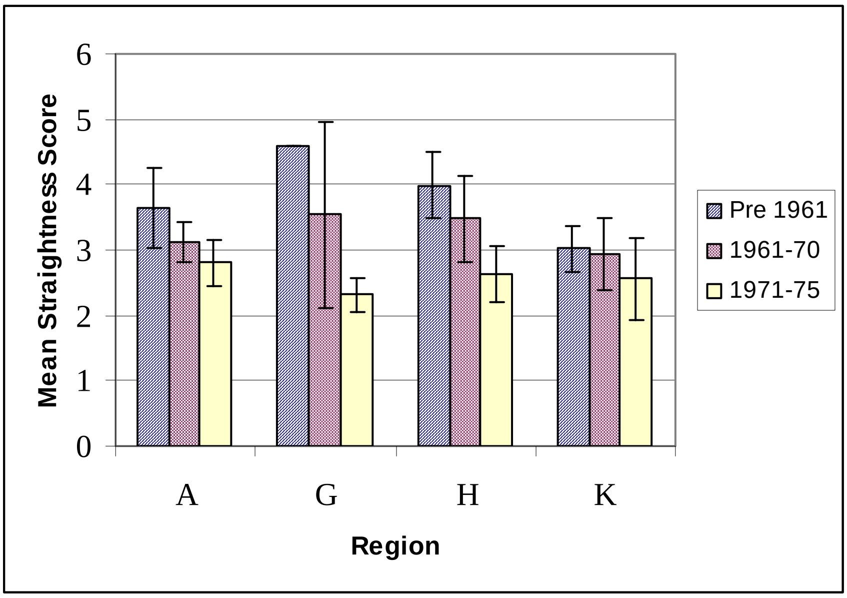
Location and Planting Period

48. There is a difference between mean straightness scores within each region in relation to ownership and planting year, but the trend is not as clear for all the regions as Figure 4 would suggest. There is a steady decline in the mean score over the planting periods within the FE sites in all regions (Figure 5a). However, the Private sector areas remain more constant throughout the time period (Figure 5b). Over all sites there is no significant difference between the mean straightness score for FE and the Private Sector. Note that due to the relatively small numbers of sites within each region/planting year/ownership category the error bars are relatively large and the differences perhaps not as clear cut as the mean values suggest.

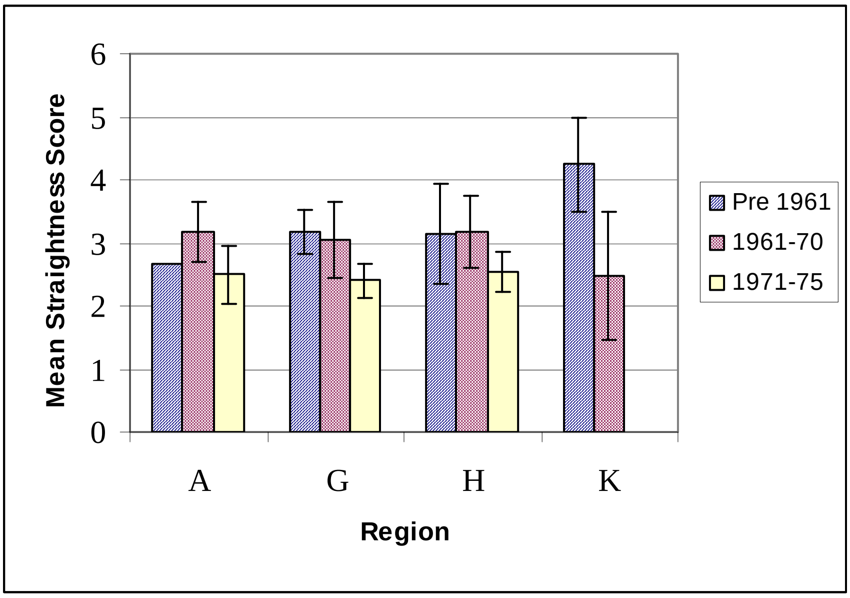
49. The histogram also shows that there were no areas surveyed in North England within the private sector between 1971-1975. This was due to the lack of available land that met the criteria.

Figure 5: Mean straightness score with respect to region and planting period. Error bars represent 95% confidence limits.

a) Forest Enterprise sites



b) Private sector sites

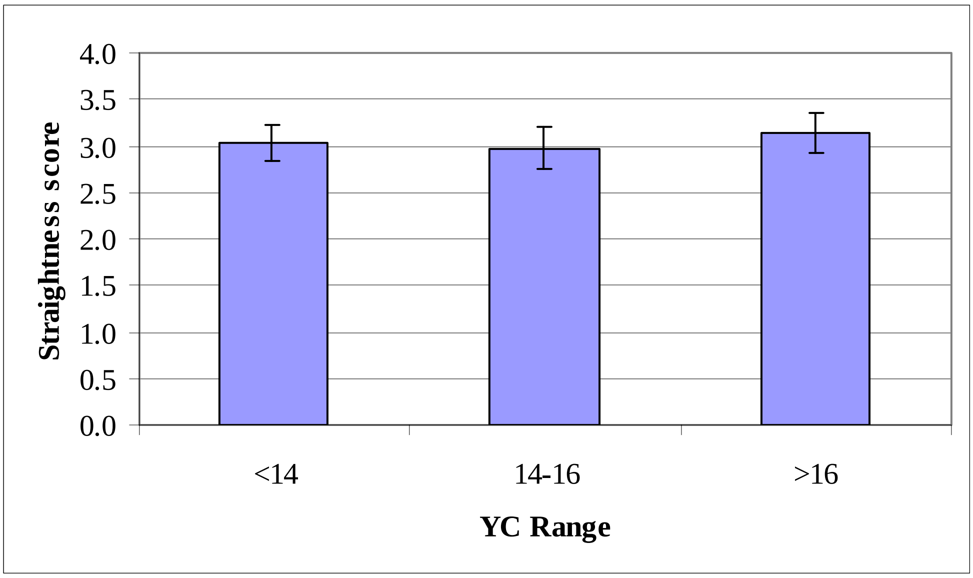


Note: A = Argyll, G = Grampian, H = Highland, K = N.E.England
Bars without confidence limits represent only one site.

Yield Class

50. Unlike the South Scotland survey, which noted a drop in stem straightness with increasing yield class (Stirling *et al.* 2000), there appeared to be no clear effect of yield class (YC) on stem straightness across the region of the survey (Figure 6).

Figure 6: Mean straightness score with respect to yield class. Error bars represent 95% confidence limits.



Elevation and DAMS

51. There appeared to be no effect of elevation on stem straightness (Figure 7). This is not surprising since the large geographical coverage of the survey encompasses very large differences in environmental conditions for any given altitude. For instance the wind climate at 20m elevation on the west coast of Kintyre is far more severe than a similar elevation in a sheltered glen in the Grampian region. However, examining the effect of DAMS score on stem straightness did not provide a clear trend of decreasing stem quality with increasing wind exposure (Figure 8), but regional models have shown a generally negative trend with DAMS.

Figure 7: Mean stem straightness score with respect to elevation. Error bars represent 95% confidence limits.

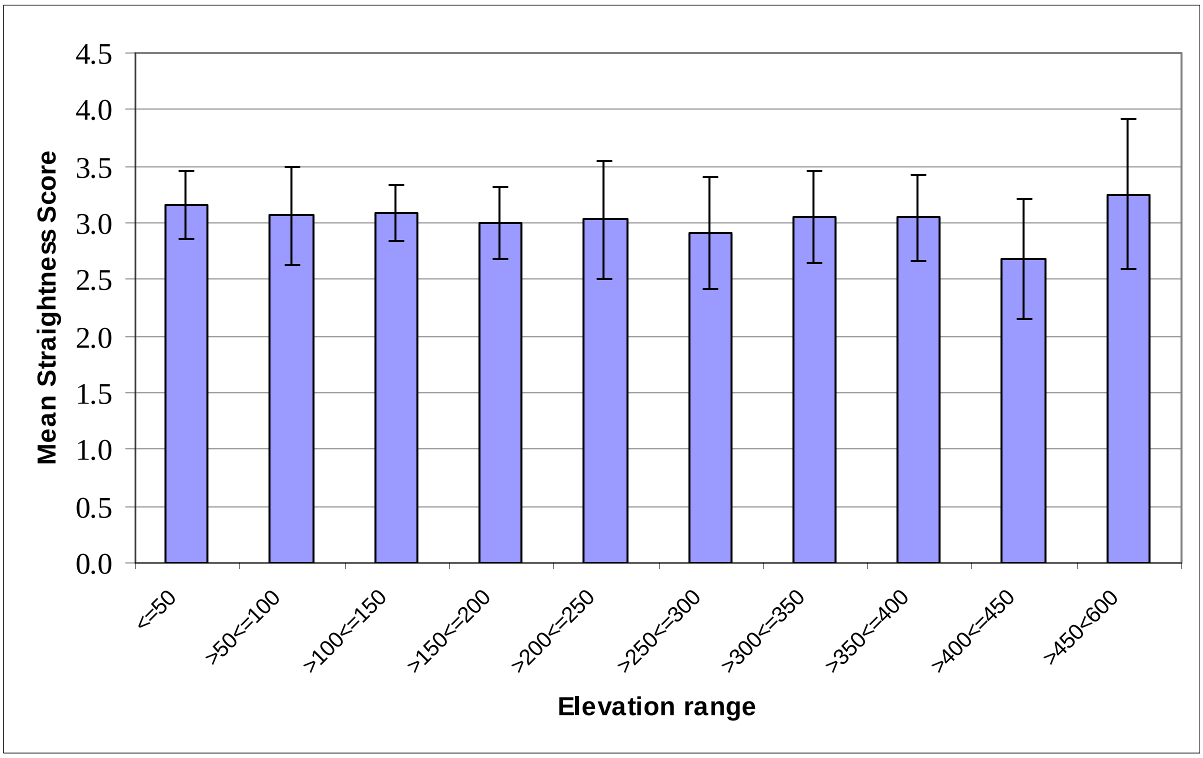
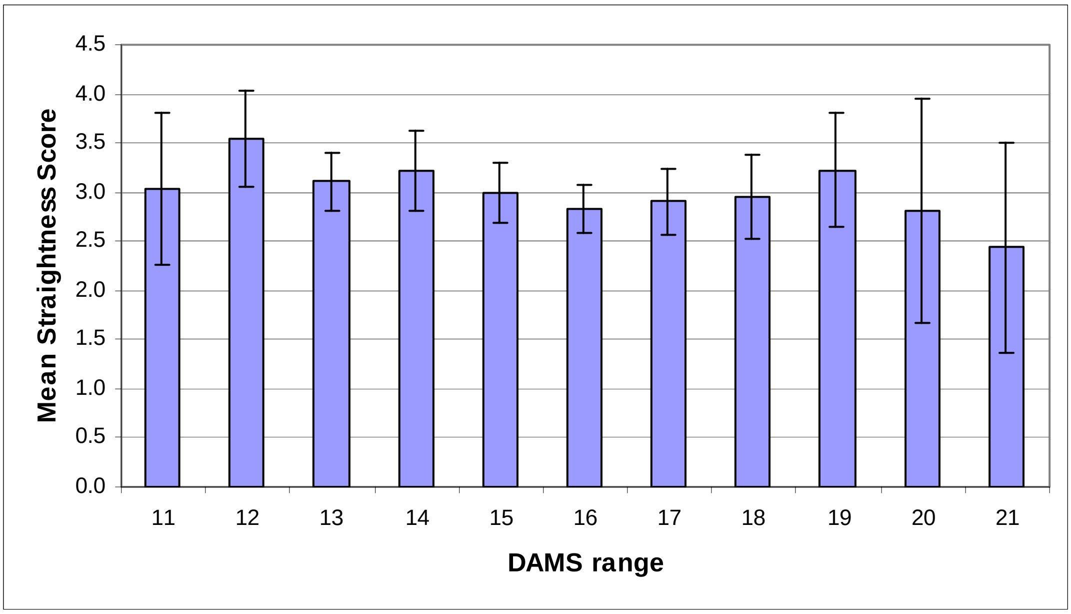


Figure 8: Mean stem straightness score with respect to wind exposure as measured by DAMS score. Error bars represent 95% confidence limits.



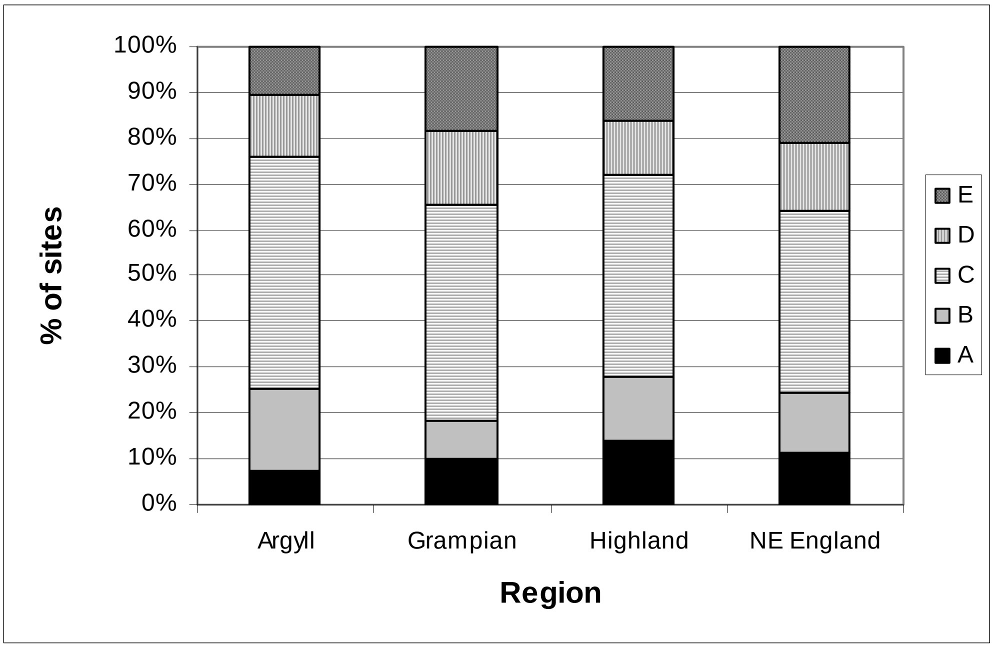
Site Straightness Grades

52. The mean stem straightness score provides no information about the distribution of log lengths within a stand, being the average score of all trees measured. A site straightness grading system was developed to reflect the distribution of scores, and hence log lengths, obtained from a stand. It was also shown that there is a strong link between mean score and grade (Macdonald *et al.* 2001). The grading system is from A to E and is determined from the percentage distribution of scores within a site using the following rules:

Grade A	≥ 40% of trees scored 6 or 7
Grade B	> 50% of trees scored 4, 5, 6, or 7 but <40% score 6 or 7
Grade C	≥ 35% of trees scored 3, 4, 5, 6, or 7 but ≤ 50 score 4 or more
Grade D	< 35% score 3 or more but ≤ 50% score 1
Grade E	as for grade D but > 50% score 1

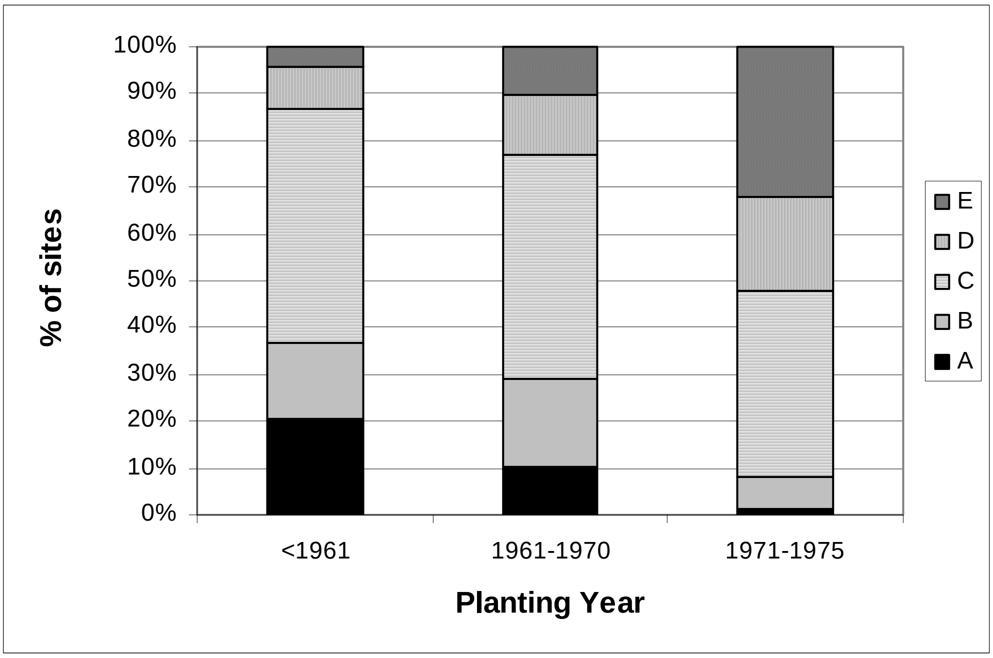
53. Applying these grading rules to the survey data showed that there was little variation in the proportion of grades on a regional basis (Figure 9). The Highland region had the highest percentage of stands with grades A and B, but Argyll had the highest percentage of sites with grades A to C.

Figure 9: Stand straightness grades on a regional basis, expressed as a percentage of stands per region.



54. The change in the distribution of grades with planting year reflects the decline in quality noted for mean stem straightness score. There was a steady decline in the percentage of stands graded A and B and a comparable rise in the percentage of stands graded D and E over the planting periods measured by the survey. The proportion of "average" stands, graded C, appeared to be nearly constant (Figure 10).

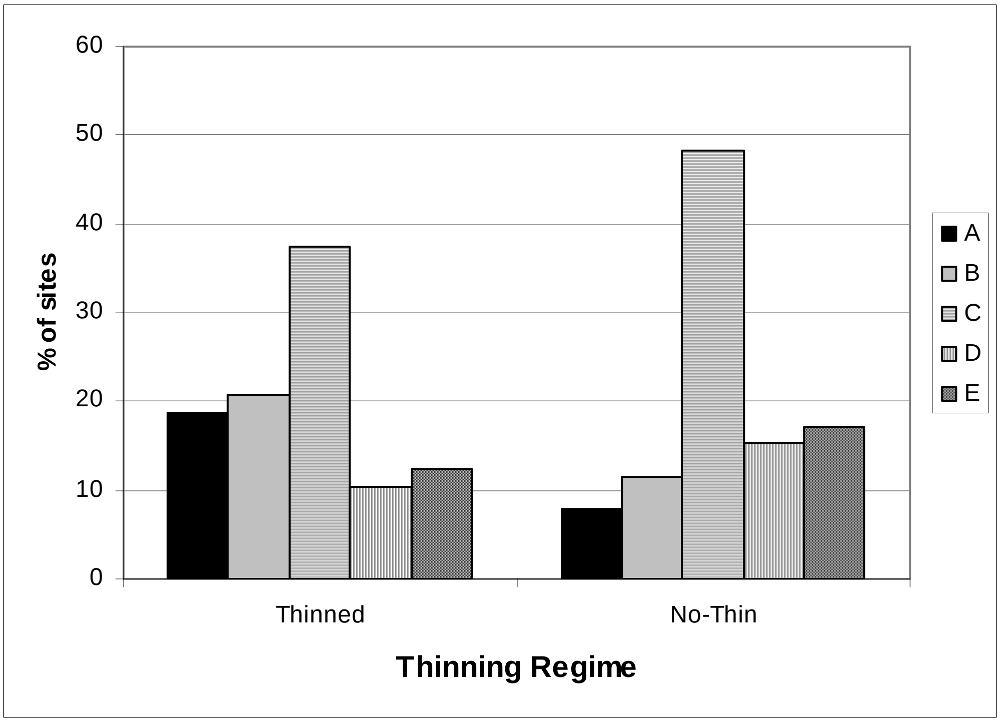
Figure 10: Straightness grade with respect to planting year (percentages are relative to stands within each year range).



55. The decline in grades indicates an apparent general decline in quality in the standing crop as a whole. There are various possibilities for this decline, for instance thinning age; the older stands being more likely to be thinned at least once compared to the younger ones. Alternatively it could represent the felling of poorer stands at a younger age for pulp. These are likely to be managed under a no-thin regime due to windthrow hazard, which is increased as stands mature.

56. The distribution of grades with respect to thinning is shown in Figure 11 and reflects the differences noted in the mean scores. There was a higher percentage of thinned stands in the higher grades compared to unthinned stands. It should be noted that the actual number of thinned stands surveyed was relatively small compared to the unthinned ones. The presence of grade D and E stands that have been thinned is surprising and may be due to the inclusion of systematic thinning as a thinning type, e.g. line thinning.

Figure 11: Straightness grade with respect to thinning (percentages are relative to stands within each thinning regime).



Assessing the South Scotland Model

57. One aim of the Rest of Scotland survey was to test the stem straightness model developed from the South Scotland survey. The site and environmental data collected from the four regions, Argyll, Highland, Grampian and N.E. England was used in the stem straightness model to provide predicted mean stem straightness scores for each site. These predicted scores could then be compared with the actual scores measured for each site. This comparison is shown graphically for each region in Figures 12 to 15.

Figure 12:

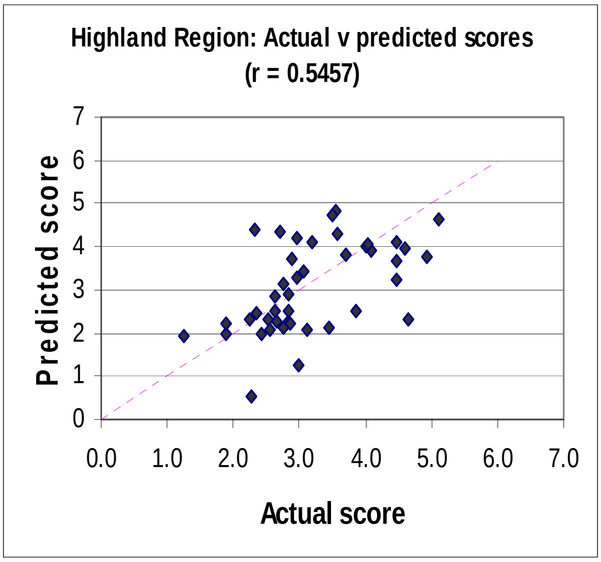


Figure 13

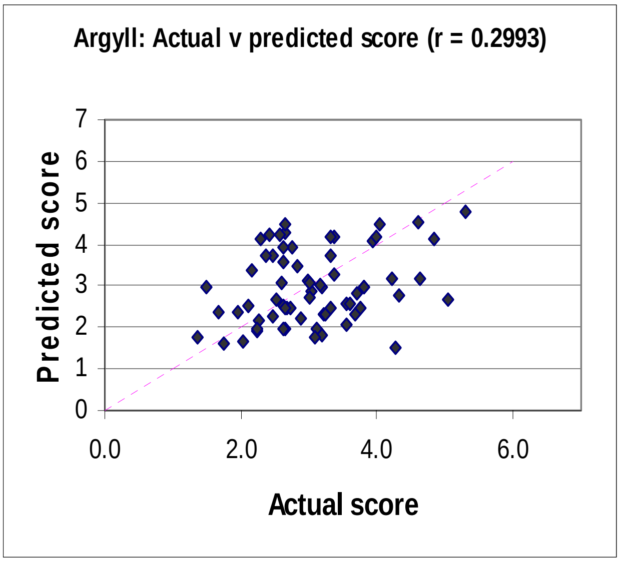


Figure 14

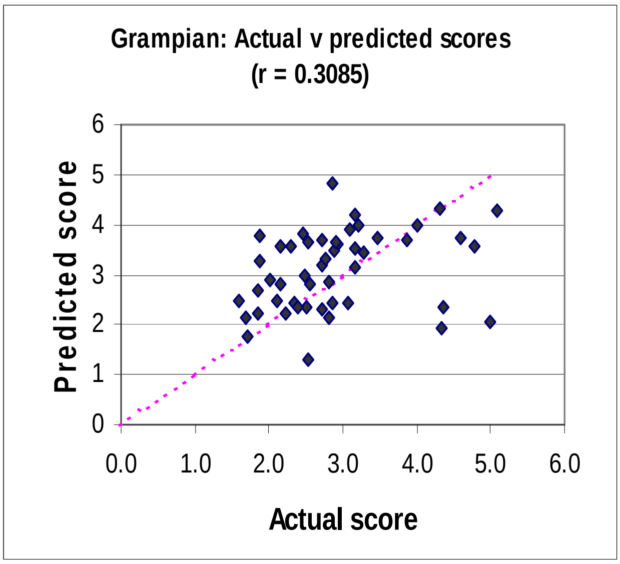
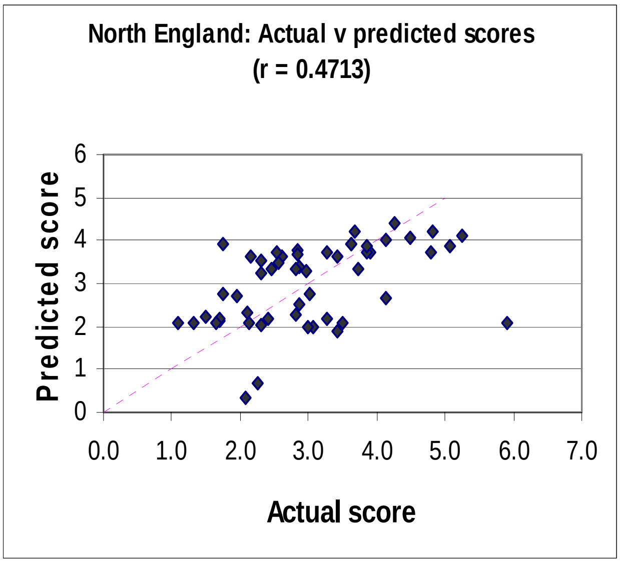


Figure 15



58. The illustrations above show the relationships between the South Scotland model predictions and the regional scores. The dotted straight line is the y=x line along which the points should lie for a perfect match. The four correlation values above clearly show that the best fitted regression line is from Highland region (r = 0.546), but even in this region the points are widely scattered about the y=x line. There is generally a poor correlation between the South Scotland model 'Predicted Score' and the rest of Scotland 'Actual Score'.

59. One might expect the North England data to provide the best fit because of the proximity to South Scotland and the same forest management structure. It is therefore surprising that the r-

value is so low. This suggests that either the combination of factors that is linked to stem straightness is different, i.e. planting year, yield class, stocking, etc. are still important but weighted by different amounts in North England compared to South Scotland, or that some other factors, not taken into account by the model, are operating

60. One explanation for the lower correlations is that a variety of environmental factors have not been taken into account within the Sitka Spruce stem straightness model. These factors include the quality of plants, or changing management regimes between South Scotland and the rest of Scotland that might of had an overall effect on the outcome. Correlations indicate that the model needs further refinement.

Developing other models for stem straightness

61. As with the South Scotland survey, sites were chosen to represent a range of yield class (-12, 14/16, 18+), planting year (1941-60, 1961-70, 1971-75) and thinning history (no thin, thin). There were 212 sites comprising 18,320 trees, arranged in 8 or 10 plots per site, each of 10 trees. Site mean straightness scores and variances were calculated from the individual tree data. For each site density, elevation and DAMS score were also recorded

62. For modelling purposes the response was site mean straightness score weighted inversely by site variance, in order to take into account the higher observed variance associated with higher scoring sites. Considered for inclusion were the factors planting year, yield class and thinning, and variables observed stocking density, elevation and DAMS score. Relevant interactions were considered where possible, i.e., up to three-way interaction between factors planting year, yield class and thinning and each variable.

63. An interaction between two or more terms in a statistical model implies the effect of one term depends on the presence of the other terms. For example, the two-way yield class (YC) by thinning (Thin) interaction, labelled YC x Thin in Table 1, indicates that the effect of yield class depends on thinning and vice versa. Further, an interaction between, say, density and planting year implies that the effect of density changes with year of planting. Such interpretations are readily extended to three-way interactions.

64. Nine data sets were considered: South Scotland, North Scotland (note that this is short hand for Argyll, Highlands, Grampian *and* North England), All Scotland (combined South and North Scotland) and the regions Argyll, Borders, Highlands, Dumfries, Kielder and Grampian. The variables included in the final models are shown in Table 8 and coefficients and model summary statistics are shown in Table 9. Predictions for each model are given in Table 10, stratified by planting year, yield class and thinning with nominal density 2,500, elevation 300m and DAMS score 16. Worked examples for three site types are given in Table 11.

65. The overall picture from Table 8 is that, generally, factors planting year, yield class and thinning were significant effects. Two-way interactions between these effects were sometimes present and three-way interactions were present in only two models (North Scotland and All Scotland). There was usually a density, elevation and DAMS effect, and density was sometimes present in interaction with some of the factors planting year, yield class and thinning. There was little evidence of interaction for elevation or DAMS score, i.e., such effects were consistent across the site factors planting year, yield class and thinning, in contrast to the effect of density.

66. The effects indicated in Table 8 are quantified in Table 9. Note that the effects for the first level of each site factor (i.e. pyear = pre 1961, YC≤12, no thin) are set at zero and the remaining effects are either greater (positive) or smaller (negative) relative to this. This is carried through to two- and three-way interactions. General indications from Table 9 suggest a positive effect associated with the first planting period 1941-60 and with thinning. Yield class 14/16 was usually negative and yield class 18+ was usually positive. The overall effect of density was generally negative, although this tended to become positive when interacting with the later planting years 1961-70 and 1971-75. Both elevation and DAMS score were associated with negative effects.

67. The R-squared values (R-sq (adj)%) in Table 9 range from 37.2% (Borders) to 67.4% (Dumfries). These values indicate the percentage of variation in the response, i.e., site mean straightness score, explained by each model.

68. The predictions in Table 10 (with standard errors) are based on the elements of Table 9, which indicate the contribution of each term to the construction of the predicted site mean straightness score. In all cases it has been assumed that the initial stocking density was 2,500 stems/ha, elevation was 300m with a DAMS score of 16. Starting with a constant, contributions for each relevant term are then added or subtracted to form a final predicted score. In one case, for the Grampian model, the prediction is -0.19 (marked in italics in Table 10), which is impossible. This demonstrates that extrapolation beyond the survey data must be treated with caution. Note that the prediction tables for Argyll, Borders and Highlands are sparse where certain site factors are not included in a model. Therefore the models only provide predictions for non thinned stands and for Borders and the Highlands no differences associated with yield class could be predicted The process of constructing predicted mean scores is outlined in three examples given in Table 11.

69. Predictions based on these models assume that the observed model effects remain consistent over time. This assumption, particularly that a difference between planting years does not change with time, is a moot point where predictions refer to 10- to 20-years hence.

70. All models presented here refer to site mean straightness score. Another approach may be to consider a grade model, where the response, a distribution of score 1 to 7 expressed in terms of percentages, is used to predict a grade A (best) to E (worst) for each site. Initial considerations suggest that such an approach is feasible with the present data, and could represent a more practical interpretation of the stand straightness dynamics. Work is continuing on this approach.

Conclusions

71. The rest of Scotland survey has shown that there appears to be a general decline in quality, as expressed in terms of stem straightness for Sitka spruce, with more recent plantings. This agrees with the conclusion of the South Scotland survey and can be seen as a general feature of the Sitka spruce crop in Scotland.

72. It should be noted that the survey is a "snapshot" observation of the current situation. Any attempt to use the results of the survey to predict the quality of stands in the future will need to make assumptions about tree and stand dynamics. Recent work by Macdonald and Barrette (2001) has suggested that individual Sitka spruce trees do not straighten sufficiently with age, over a 15-20 year time period, to alter their stem straightness score. This would imply that the situation observed would remain static over time at the individual tree level. Therefore the differences currently observed associate with planting year would not improve over time. However, the strong link between dbh and stem straightness observed within and between stands has implications for stand dynamics. Since the poorer form trees are also more often the smallest within a stand there is a possibility over time that they will become increasingly suppressed and either not reach sufficient size for sawlogs or die. If this were to be the case the stand would appear to improve in terms of straightness score with age and stand age rather than planting year would be a better variable to include in the model. Given the work of Macdonald and Barrette (2001), at this stage using planting year and assuming no improvement over time seems appropriate, certainly for shorter term forecasts, e.g. 5-10 years. Further work will be needed to test this assumption and the counter hypothesis of improvement through stand dynamics.

73. Thinning is associated with improved stem straightness in the standing crop and is the most consistent factor, after planting year, on stem straightness for both surveys. It would therefore appear that thinning is the most effective silvicultural intervention to improve stem straightness.

74. There appeared to be no regional differences in stem straightness within the level of sampling undertaken by the survey. The effects of yield class, elevation and DAMS score appear to have an effect on stem straightness in Sitka spruce, but appear to operate at different levels in different regions.

75. Applying the model developed from the South Scotland survey to data collected from the rest of Scotland was not successful. The best correlation between predicted score and observed score was for the Highland region with $R^2 = 0.298$. Interestingly, North East England data did not fit the model well even though the majority of sites in this region were situated in Kielder Forest which is adjacent to the area surveyed in South Scotland.

76. A new model has been developed for the rest of Scotland and north England data which accounts for 48% of the variance encountered in the measured data. In addition, models have been developed for all the regions surveyed and also one to encompass all the data collected to date. These models range from 37.2% to 67.4 % in their explanation of the variance observed in the data.

77. The low correlation between the survey data and the South Scotland model, and the low levels of variance accounted for by the model for the rest of Scotland indicate that the factors controlling stem straightness are complex and variable between regions. One of the limitations of the survey is the lack of historical information on plant provenances, early management regimes, use of fertilisers and the occurrence of chance events such as storm or frost damage. In addition, not all combinations of yield class, thinning regime and planting year could be found, hence the data is sparse for certain combinations leading to high standard errors and uncertainty in the model. Ideally the survey should be continued thereby providing the opportunity to locate these relatively rare sites and to increase the replication of sites in general.

78. At present it is not possible to predict with confidence the straightness of Sitka spruce in regions not covered by this survey and additional surveying will be needed.

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Appendix 1

Protocol for Stem Straightness Assessment in Sitka Spruce

Forestry Commission Information Note

By Elspeth Macdonald, Shaun Mochan and Thomas Connolly of Forest Research
Sept 2000

Summary

Information on the quality of standing timber is an important requirement for the British industry. This Information Note presents details of the testing and validation of a scoring system for the visual assessment of stem straightness in Sitka spruce. The protocol for carrying out the assessment is described together with the estimated time to complete it. The system is based upon a 7-point scale of straightness applied to 10 sample trees per plot and up to 10 plots per stand. This system is recommended whenever a straightness assessment is required in British forestry. A system for grading stands has been proposed based on the distribution of scores within a stand. It is important to note that the classification relates only to the straightness of the first 6 metres of the tree and takes no account of other features which determine log or timber quality.

Introduction

1. A prototype method of assessing log quality in standing Sitka spruce trees was developed in the early 1990s and is described by Methley (1998). Straightness was identified as the most important single factor affecting log quality in Sitka spruce. 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 spruce logs. An assessment method based on a visual estimate of straight log lengths in the first 6m of the stem was devised.

2. Methley (1998) recommended refinement of the prototype method and further work to establish:
   - 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;
   - ways of converting quality assessments and scores to predict volumes of different products.

   Details of the refinement and testing of this prototype method are provided in the Appendix. The revised protocol for assessing stem straightness in standing trees is set out below.

Protocol for Assessing Stem Straightness

Sampling

3. The area of the stand to be assessed should be determined: the stand might be a compartment, sub-compartment, felling coupe or similar. If the stem straightness of a whole forest block is to be assessed, the forest should be broken down into coupes or compartments for assessment purposes. Where there are obvious differences in stem straightness between different parts of a coupe or compartment that can be defined on the ground, the stand should be stratified and each stratum sampled separately.

4. The number of sample plots required should be determined from Table 1, based on the area of the stand to be assessed.

Table 1: Number of sample plots required for stem straightness assessment

Area of stand (ha)	Number of plots
0.5-2	6
2-10	8
Over 10	10

5. For each sample plot a sample point should be randomly located within the stand to be assessed. A simple method for randomly designating the sample points is to overlay a map of the sample stand with a transparent grid on which each intersection can be referenced by numbers along the X and Y-axes. Random numbers, which can be generated easily in a Microsoft Excel spreadsheet, are then used to define the intersections. These act as the sample points.

6. The sample plot consists of the first 10 assessable trees (see Section 11) within 1.5 m on either side of a random bearing taken from the sample point. Thus in a stand of 7 ha a total of 80 trees would be assessed made up of 8 plots each consisting of 10 trees. To define the random bearing a list of random numbers between 1 and 360 is taken into the field and used sequentially.

7. Only live trees should be assessed and assessment is restricted to those trees that are large enough to produce sawlog dimension material up to 6m. The minimum diameter at breast height (dbh) for assessable trees is determined by the expected felling date for the stand, as shown in Table 2. These numbers are based on experience of the typical growth of individual Sitka spruce trees and are provided for guidance only.

Table 2: Guideline minimum diameters for assessable trees.

Assessment date	Minimum dbh of assessable trees
≤ 5 years before felling	20 cm
6–10 years before felling	17 cm
11-15 years before felling	14 cm
≥ 16 years before felling	10 cm

Straightness Assessment of Sample Trees

8. For each sample tree a visual estimate should be made of the number of straight log lengths in the first 6m butt portion of the tree.

9. The definition for straightness to be used is that given for green logs in Field Book 9, '*Classification and presentation of softwood sawlogs*' (Forestry Commission, 1993). This specifies:

   "*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.*"

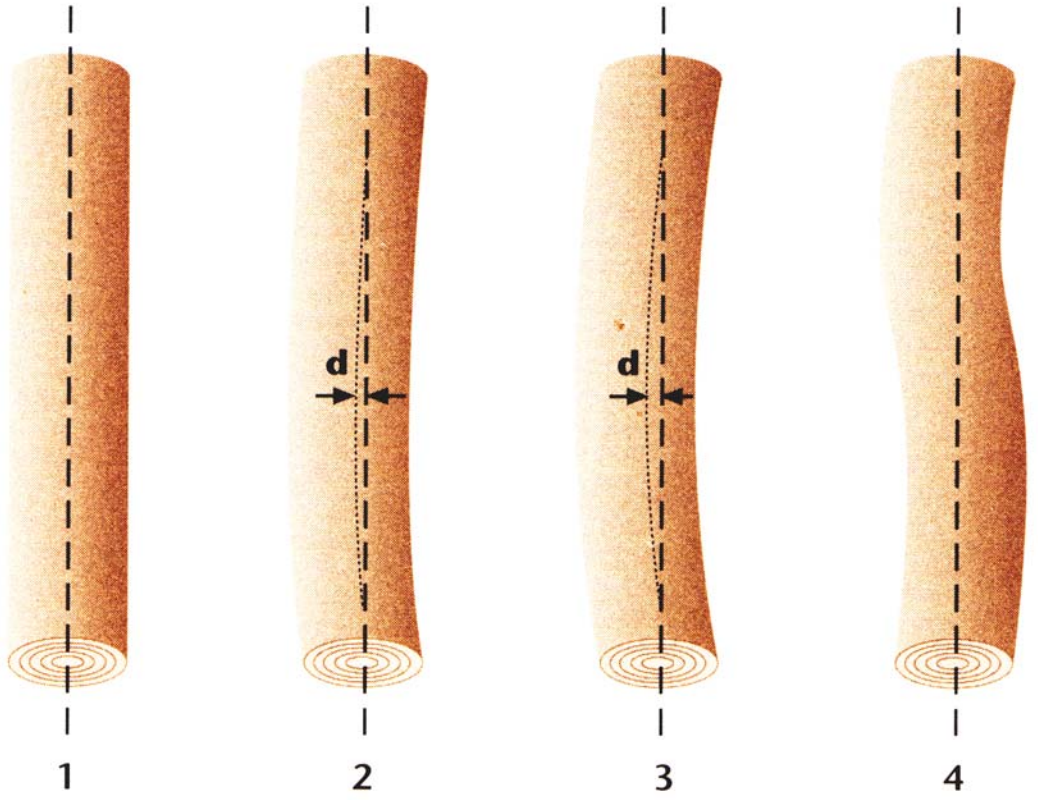


Figure 1: Logs 1 and 2 qualify as straight logs; logs 3 and 4 are not straight. Maximum deviation (d) on log 2 does not exceed 1 cm over 1 m length. Maximum deviation (d) on log 3 exceeds 1 cm over 1 m length. Log 4 shows bow in more than one direction.

10. The categories of straight log length that should be identified are:

   - Greater than or equal to 5 metres
   - Greater than or equal to 4 metres but less than 5 metres
   - Greater than or equal to 3 metres but less than 4 metres
   - Greater than or equal to 2 metres but less than 3 metres

   In theory each of these lengths is therefore a green log or a short green log.

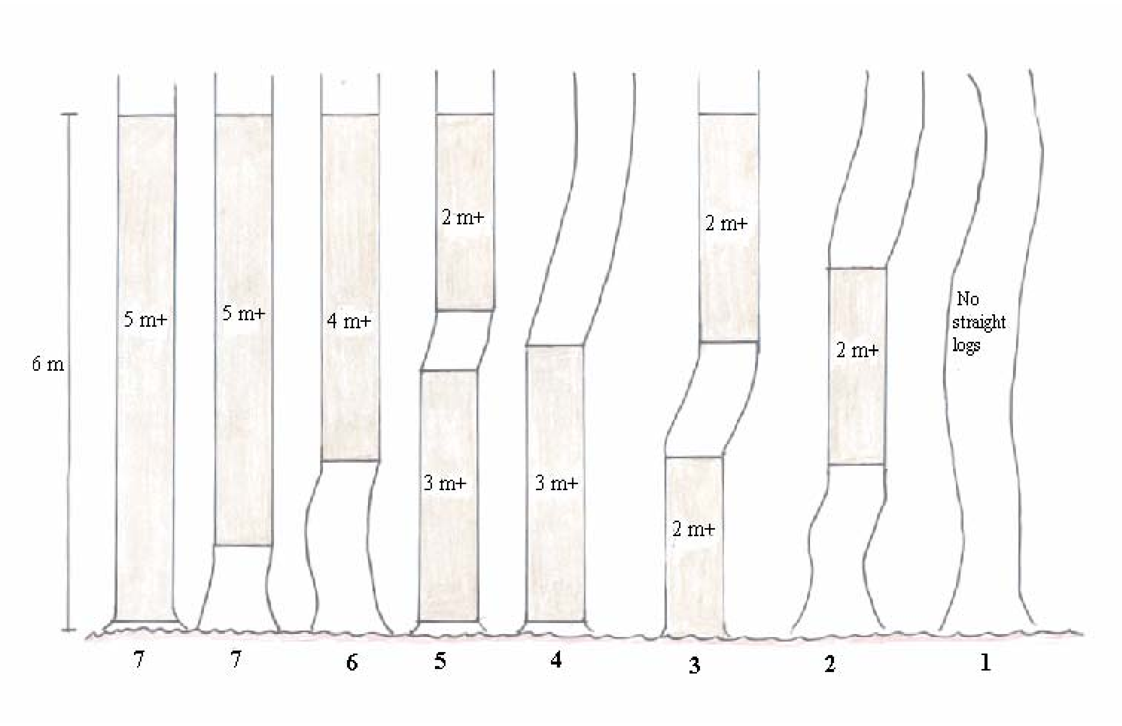
   However, it should be noted that this protocol does not measure knottiness or other defects and some downgrade may therefore occur (Forestry Commission 1993).

11. Normal commercial cutting practice must be ignored and no thought given to wastage. For example if a 3m straight length is identified in the middle of the first 6m, no regard is given to the 1.5m waste above and below the 3m length.

12. A score should be assigned to each tree according to the scoring system shown in Table 3 below.
13. Figure 2 illustrates the different possible combinations of straight log lengths that can be identified.

Table 3: Straightness Scoring System.

SCORE	No. of straight logs counted in 6m butt			
	≥ 5m	**≥4 m < 5m**	**≥3 m < 4m**	**≥2 m < 3m**
1	-	-	-	-
2	-	-	-	1
3	-	-	-	2
4	-	-	1	-
5	-	-	1	1
6	-	1	-	-
7	1	-	-	-



Straightness Score

Figure 2: Different combinations of log lengths in first 6 m showing gradual reduction in quality from left to right (After Methley 1998).

13. Initial estimates by Technical Development Branch based on surveys in two compartments indicate that a 2-man team should be able to measure approximately 13 plots/day. This does not include allowance for any:

- preparatory office planning or post collection data processing,
- travel to and from sites,
- lost time.

The figure is provisional and will be re-evaluated with further work study trials. It is probable, based on the experience of assessors working on a survey of over 270 sites in South Scotland (Stirling et al., 2000), that the number of plots sampled per day will increase with experience.

Interpretation of Straightness Score Data

14. Stand mean straightness score is the average of all the individual tree scores in a stand. Stand mean straightness scores can be used to rank stands relative to one another. In order to provide more information about the distribution of scores within a stand and hence an indication of the distribution of green log lengths, five quality grades, A-E, have been defined based on the proportion of trees in a stand being assessed in each of the seven straightness score classes:

Grade A – ≥ 40% of trees scored 6 or 7
Grade B – > 50% of trees scored 4, 5, 6 or 7 but < 40% score 6 or 7
Grade C – ≥ 35% of trees scored 3,4,5,6 or 7 but ≤ 50% score 4, 5, 6 and 7
Grade D – < 35% of trees scored 3,4,5,6 and 7 but ≤ 50% score 1
Grade E - as for Grade D but > 50% of trees scored 1

For example, a stand with the following score distribution:

Score	% of trees	Cumulative %	Score	% of trees	Cumulative %
Score 7	8%	8	Score 3	23%	73
Score 6	15%	23	Score 2	17%	90
Score 5	12%	35	Score 1	10%	100
Score 4	15%	50			

would be defined as Grade C because more than 35% score 3 and over, but only 50% score 4 and over and less than 40 % score 6 or 7. This system has been tested on data from over 270 sites sampled during a straightness survey in South Scotland (Stirling et al., 2000). The grading score for each site was shown to reflect extremely well the mean straightness score for the site. However, it has the advantage of at the same time providing a measure of the spread in straightness scores within the stand.

Applications for the Straightness Assessment Method

15. The stem straightness assessment method described in this Note has only been tested on Sitka spruce, although some of the early work in development of the method included assessment of Norway spruce. In principle, however, the assessment method could be applied equally well to any plantation grown conifer species in the UK.

16. The assessment can be completed on trees of 20 years old and upwards. In young stands (20-30 years) and in those with heavy branching or where branch whorls are very close together, it can be difficult to see the stem clearly enough to assess straightness and particular care is required. This can be exacerbated if light levels are low, so assessment during late spring, summer and early autumn is recommended. Furthermore, heavy branching may mean that the straightness score alone will not be good enough to identify green logs.

17. A range of applications for the stem straightness assessment method can be envisaged, depending on the individual requirements of forest owners and managers:

    - Providing improved information to wood-using industries about the quality of future timber supplies
    - Collection of stand log quality information during inventory, for inclusion in forest databases and linking to Geographic Information Systems
    - Incorporating log quality information into production forecasts
    - Assistance for decision making in forest management, e.g. thinning requirements, rotation lengths, forest design planning

Recommendations

18. The mean straightness score for a stand provides a method of making comparisons between stands.
19. The scoring system described in this Information Note is recommended as the provisional standard scoring system for measuring straightness in British forestry. It should be used whenever an assessment of stand stem straightness is required.
20. Straightness Quality Grade (A-E) provides useful information about the stem straightness distribution within a stand and the likely log assortment in the first 6 metres of the stem. It is recommended as the standard grading system to apply to stands.
21. Although the straightness assessment was developed for Sitka spruce it is equally appropriate for any other conifer species.
22. The suitability of the provisional standard should be reviewed in the light of experience of its use by the industry over the next 2 years.

Appendix: Development of Stem Straightness Scoring System for Sitka Spruce

Background

A1. Timber production in the UK is due to rise significantly over the next 20 years, with annual sawlog output forecast to be double current levels by 2020 (Whiteman, 1996). Domestic demand for sawn timber over the same period is forecast to remain relatively static (Whiteman, 1996). Successful marketing of UK sawn timber is, therefore, dependent upon gaining increased market share from imported timber. Pallet, packaging and fencing markets, which currently absorb more than two-thirds of UK sawn timber production, are likely to become over-supplied (McIntosh 1997), so that greater penetration of the construction sector will be necessary.

A2. Concerns about the quality of future home grown sawlog supplies have been voiced throughout the forestry and wood using industries. It is feared that many sawlogs will be of too low quality to provide material for the construction market. These concerns, which mainly involve Sitka spruce, are based on anecdotal evidence of timber coming onto the market in recent years and on the likely consequences of the changes in silvicultural practice that have taken place over the past 50 years (Brazier, 1977; Mason, 1993).

A3. The investments in sawmilling capacity required to process the increased softwood supply for the construction market are unlikely to take place without improved information about the quality of future sawlog supplies. An assessment of the quality of the standing domestic timber resource, particularly Sitka spruce, is required urgently to enable the sawmilling industry to develop appropriate investment strategies. This requirement was highlighted in a recent market development study (Jaakko Pöyry, 1998).

A4. A forecast of the quantity of timber to be harvested from forests in Great Britain is prepared periodically by the Forestry Commission (e.g. Rothnie and Selmes, 1996). To date there has been no comparable estimate of quality. An assessment of timber quality at this strategic level requires a standardised method of assessing quality that can be applied to stands throughout Britain.

A5. The refinement and validation of the prototype straightness scoring system developed by Methley (1998) is described below.

Refinement and Testing of the Prototype Method

A6. The original six point scoring system was revised to a seven point scale to allow the identification of a longer straight log length category than the previous system, i.e. logs greater than 5 metres. These are lengths from which the commonly required log length of 4.9 metres, important for conversion to construction material, could definitely be obtained. The maximum log length identified by the previous method, i.e. logs of greater than 4 metres, did not guarantee that these lengths could be obtained.

A7. Ways in which the objectivity and accuracy of the prototype log quality assessment method might be improved were investigated during a field trial in an unthinned stand of 45 year old Sitka spruce in Ae Forest District. The use of a hypsometer or a wooden pole to help pinpoint heights on the trees was compared with a purely visual assessment. A team of three observers assessed the same sample of twenty-five trees nine times using each of the three assessment methods every day for three days. The sample trees were then felled and log quality was assessed on the ground collectively by the team of observers and then by a sawmilling expert. There were no significant differences between-observers or between-methods in the log straightness scores obtained. The use of aids to measurement did not increase the consistency of observations between observers or their accuracy in relation to felled assessments. However, the use of aids to measurement added significantly to the time required to complete the assessment, thereby greatly increasing the cost without any apparent benefit in terms of consistency or accuracy. Therefore, a visual assessment was considered the most cost-efficient method of survey.

A8. To establish appropriate levels of sampling, seventeen permanent Sitka spruce sample plots known to have widely varying form were studied. The sample included ten unthinned plots, five thinned plots and two plots respaced at ten years old, and contained between 45 to 263 trees per plot. The plots ranged in age from 28 to 42 years. A log straightness assessment was completed for every tree in each sample plot. Statistical analysis of the data indicated that between 60 and 100 trees, depending on stand area, should be assessed to obtain an acceptable estimate of the mean and distribution of straightness scores for a stand. Randomly located line plots consisting of ten trees on which assessments could be performed were considered the most appropriate sample unit. The trees to be assessed must be alive and with a sufficiently large dbh (see section 19 below).

A9. Since the aim of the assessment is to give an estimate of the quality of sawlogs, it is important to select sample trees that will be of sufficient dimensions to be cut into sawlogs when they are felled. To achieve this, minimum diameters at breast height for assessable trees have been defined according to the expected felling date of the stand, based on taper and growth data for Sitka spruce (see Table 2).

A10. A small study was undertaken to examine the changes, if any, in stem straightness score that are likely to occur between a mid-rotation assessment and the time of felling (Macdonald and Barrette, 2000). Stem quality data from four Sitka spruce permanent sample plots assessed in 1953 and 1963 were reviewed to determine how stem form varied over time at the individual tree level and at the stand level. In addition, detailed stem analysis were completed for ten Sitka spruce trees planted in 1961 to examine changes in stem profile and straightness score over the life of the trees. The results of these studies suggest that while the profile of individual trees may alter slightly with time, any change in straightness score is likely to be confined to a difference of at most one point and that such a change is uncommon. At the stand level this is unlikely have a significant effect on the characterisation of the stand. Therefore, a quality assessment made in a stand up to 15 years before the expected felling date can provide a reasonable prediction of the final stand quality.

A11. The use of the straightness assessment method to make meaningful detailed predictions about volumes of different products from a stand is not straightforward, given local variations in market conditions. Making such predictions across a range of stands is likely to require a more detailed method of assessment, such as the MARVL package developed in New Zealand (Deadman and Goulding, 1978), considering the entire merchantable stem of the tree and incorporating product specifications particular to a given location or market. The straightness assessment method described in this note is useful for differentiating between stands of differing quality at a strategic level, and in particular for highlighting those of especially high or low log quality.

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APPENDIX 3

Analysis of Sitka spruce straightness scores: Statistical Data

Summary Statistics for Site Mean Data

Identifier	Minimum	Mean	Maximum	Values	Missing	
s[1]	0.00	27.31	96.00	212	0	
s[2]	2.00	19.72	37.00	212	0	
s[3]	0.000	6.840	23.000	212	0	
s[4]	0.00	11.39	28.00	212	0	
s[5]	0.000	5.311	20.00	212	0	
s[6]	0.00	8.061	24.00	212	0	
s[7]	0.00	7.778	61.0	212	0	Skew
score	1.080	3.039	5.90	212	0	
density	969	2875	7990	212	0	
dbh	14.76	24.16	40.96	212	0	
thin%0	0.00	76.38	100.0	212	0	Skew
thin%1	0.00	23.00	100.0	212	0	Skew
thin%2	0.00	0.625	25.0	212	0	Skew
fork%	0.00	5.737	35.0	212	0	Skew
forkht	0.00	2.557	6.80	212	51	
elev	6.0	232.3	488.0	212	0	
dams	7.93	14.75	20.56	212	0	
east	43.3	181.0	304.9	212	0	
north	29.9	219.4	436.1	212	0	

Identifier	Values	Missing	Levels
Site	212	0	212
regn	212	0	4
dist	212	0	29
type	212	0	2
pyear	212	0	33
yc	212	0	13

KEY

S[1]…S[7]	number of tree per site in straightness class 1..7
Thin%0	% of plots on a site no-thin
Thin%1	% of plots on a site with one thinning
Thin%2	% of plots on a site thinned twice or more
Fork%	% of forked trees per site
East	easting distance from reference point, based on OS Grid system
North	northing distance from reference point, based on OS Grid system
Regn	Region
Dist	district
Type	ownership type, either FE or private

Cross Tabulation: Counts of sites by Yield class, planting year and thinning regime

	YClass PYear	-12	13-17	18+
NoThin	-60	25	13	5
	61-70	18	23	11
	71+	23	23	23
Thinned	-60	7	15	3
	61-70	1	7	9
	71+	1	0	5

Histogram of score

```
      - 1.5        6 ******
  1.5 - 2.0       18 ******************
  2.0 - 2.5       36 ************************************
  2.5 - 3.0       60 ************************************************************
  3.0 - 3.5       34 **********************************
  3.5 - 4.0       23 ***********************
  4.0 - 4.5       17 *****************
  4.5 - 5.0       11 ***********
  5.0 - 5.5        6 ******
  5.5 -            1 *
```

Scale: 1 asterisk represents 1 site.

Histogram of initial planting density

```
      -   800      0
   800 -  1600    15 ***************
  1600 -  2400    62 **************************************************************
  2400 -  3200    54 ******************************************************
  3200 -  4000    55 *******************************************************
  4000 -  4800    22 **********************
  4800 -  5600     3 ***
  5600 -  6400     0
  6400 -  7200     0
  7200 -           1 *
```

Scale: 1 asterisk represents 1 unit.

Histogram of elevation

```
      -   50       8 ********
    50 -  100     15 ***************
   100 -  150     33 *********************************
   150 -  200     37 *************************************
   200 -  250     25 *************************
   250 -  300     33 *********************************
   300 -  350     24 ************************
   350 -  400     22 **********************
   400 -  450     12 ************
   450 -           3 ***
```

Scale: 1 asterisk represents 1 site.

Histogram of dams score

```
      -  9.0       2 **
   9.0 - 10.5      4 ****
  10.5 - 12.0     19 *******************
  12.0 - 13.5     45 *********************************************
  13.5 - 15.0     36 ************************************
  15.0 - 16.5     58 **********************************************************
  16.5 - 18.0     31 *******************************
  18.0 - 19.5     10 **********
  19.5 - 21.0      7 *******
  21.0 -           0
```

Scale: 1 asterisk represents 1 site.