# LOG QUALITY ASSESSMENT IN SITKA SPRUCE

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

**Final Report**
**Stem Straightness Survey in Sitka spruce:**
**Wales**

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**April 2002**

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## Executive Summary

1. This report gives details of the work undertaken to survey the Sitka spruce resource in Wales and to develop a predictive model for stem straightness. The protocol for carrying out the assessment is described in Appendix 2.

2. The main objective was to predict the quality of standing timber within the existing forests in Wales prior to 1976. The survey was designed to provide a description of Sitka spruce stem straightness in the five regions of Wales to determine the relationship between stem straightness scores and selected stand and site characteristics. The survey was also designed to complement the previous surveys undertaken in Scotland and Northern England.

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 1.84% of the Sitka spruce cover managed by the Forestry Commission and the private sector within the five regions. The survey assessed 4,490 trees on 35 randomly chosen sites on FC land and 19 sites on private sector land. These represented 613.88ha and 279.25ha respectively.

5. The forests were selected to provide a representative sample of the total Sitka spruce resource in Wales defined as regions in Coed Y Cymoedd, Llanymddyfri, Llanrwst, Dolgellau, and Canolbarth. Approximately 48,572 hectares of Sitka spruce was planted up to and including 1975, which are likely to be felled during the next 10 – 15 years, about 13.8% (6,717 hectares) are located in Llanrwst, 19.2% (9,362 hectares) in Dolgellau, 24.8% in Canolbarth (12,039 hectares) 20.8% (10,060 hectares) in the Coed Y Cymoedd region and 21.4% in Llanymddyfri district (10,394). (Source: National Inventory of Woodland and Trees).

6. The number of sites selected was weighted by age class to reflect geographic location. Unfortunately not all of the original 60 sites were surveyed due to the foot and mouth disease that affected most of Wales last year.

7. 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.

8. There are a number of silvicultural factors that have an effect on mean straightness scores. Thinning and Yield class have 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 as has been found previously. (Mochan *et al* 2001).

9. Stem straightness did not show any clear trends with elevation and DAMS, unlike the South Scotland survey. This possibly reflects the broader geographical and environmental range encountered in this broader survey or the less extreme wind climate associated with forestry in Wales.

10. A preliminary model to predict stem straightness has been developed for Wales (Appendix 1). The 2 factors used were planting year and yield class. The model explained just under 41% of the variation in the site mean straightness scores. The high levels of unaccounted variation could be due to environmental factors not accounted for or past management history that could not be modelled.

11. There is a strong association between dbh and stem straightness both within and between stands. Larger diameter trees have, on average, better straightness scores. One possible hypothesis to explain this observation is that leader loss is the main cause of bends in Sitka spruce and increased leader loss is therefore associated with more bends and reduced growth. Over time this reduction in vigour leads to suppression of the poorer form trees.
12. The model provides a statistical summary of the data and provides an indication of the factors associated with stem straightness in Sitka spruce. Use of the model for sites not within the bounds of the survey stratification should be undertaken with caution. In addition, it should be pointed out that this includes predictions of stem quality in the future since there is evidence from other studies that, due to stand dynamics, unthinned stands can improve their mean straightness score as they mature. Selective thinning will improve the mean straightness score of a stand.

13. In summary, given the caveats above, there appears to be a decline in the timber quality of Sitka spruce within UK forestry, expressed in terms of green sawlogs. The proportion of green sawlogs as a percentage of volume harvested is likely to drop in the future.

**Introduction**

14. The work contained in this report follows on from 2 surveys of stem straightness in Sitka spruce undertaken in South Scotland (Stirling et al 2000) and the rest of Scotland and northern England (Mochan *et al.* 2001). These surveys 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 and aimed to provide broad regional coverage that included the five main forest regions in Wales, Coed Y Cymoedd, Llanymddyfri, Llanrwst, Dolgellau, and Canolbarth. These areas provided the geographic and environmental range for Wales and also cover the main Sitka spruce growing areas in the country.

15. The initial assessment of 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; this was refined and tested by Macdonald *et al.* (2001) to cover the first 6 m of the stem in a standing tree. 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 allows the response to be modelled. One longer term aim of this work is to integrate the models developed from the survey work with the volume forecast models to provide an assessment of the quality of future sawlog supplies (Rothnie and Selmes 1996).

16. The survey work was undertaken between May and November 2001 on both Forest Enterprise and Privately owned land. The Forestry Commission, Forest Enterprise, Tilhill Economic Forestry Ltd., and the United Kingdom Forest Products Association jointly funded the project.

**Methodology**

17. The Welsh stem straightness survey was designed to cover a randomly selected proportion of pure Sitka spruce stands within the designated areas of Coed Y Cymoedd, Llanymddyfri, Llanrwst, Dolgellau, and Canolbarth. The age 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 Wales is contained in the new National Inventory of Woodlands for Wales, due to be published in 2002.

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 40,985ha.

**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- Ha$^{-1}$ | | | |
|---|---|---|---|---|---|
| | | **Pre 1961** | **1961-1970** | **1971-1975 (65% 1971-1980)** | **Total for Pre 1961-1975** |
| Coed Y Cymoedd | FC | 3,970ha | 3,960ha | 1,728ha | 9,658ha |
| Coed Y Cymoedd | Non FC | 101ha | 174ha | 126ha | 401ha |
| **Total for** Coed Y Cymoedd | | **4,072ha** | **4,134ha** | **1,854ha** | **10,059ha** |
| Llanymddyfri | FC | 1,531ha | 1,599ha | 1,050ha | 4,180ha |
| Llanymddyfri | Non FC | 722ha | 2,973ha | 2,518ha | 6,213ha |
| **Total for** Llanymddyfri | | **2,254ha** | **4,572ha** | **3,568ha** | **10,393ha** |
| Llanrwst | FC | 2,847ha | 1,059ha | 342ha | 4,248ha |
| Llanrwst | Non FC | 537ha | 1,214ha | 717ha | 2,468ha |
| **Total for** Llandovery | | **2,254ha** | **4,572ha** | **3,568ha** | **6,716ha** |
| Dolgellau | FC | 2,616ha | 2,616ha | 916ha | 6,148ha |
| Dolgellau | Non FC | 1,011ha | 1,087ha | 1,115ha | 3,213ha |
| **Total for** Dolgellau | | **3,627ha** | **3,704ha** | **2,032ha** | **9,361ha** |
| Canolbarth | FC | 2,537ha | 4,942ha | 1,250ha | 8,729ha |
| Canolbarth | Non FC | 976ha | 1,159ha | 1,173ha | 3,308ha |
| **Total for** Canolbarth | | **3,513ha** | **6,101ha** | **2,423ha** | **12,037ha** |
| **Total area** | FC | 13,501ha | 14,176ha | 5,286ha | 32,963ha |
| **Total area** | Non FC | 3,347ha | 6,607ha | 5,649ha | 15,603ha |

**Sampling Strategy**

20. The survey was stratified in two stages. The first was to identify all possible Sitka spruce sites using the criteria below:

- 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 allowed so long as the majority of the stand had a final crop of Sitka spruce. The self-thinning mixtures were recorded as thinned areas.

22. The second stratification identified a sub population of Sitka spruce sites suitable for surveying work using the same methodology as that used in Scotland and Northern England Hence, 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. Replication was not possible due to restrictions in time and available resources. In addition, 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 required 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 (ha) | % of total | Sample Plots by % area | Required for Modeling | Suggested Distribution |
|---|---|---|---|---|---|
| **Pre-1961** | 16,848 [1] | 35% | 23 | 18 | 22 |
| **1961-1970** | 20,783 [1] | 43% | 22 | 18 | 20 |
| **1971-1975** | 10,935 [1] | 22% | 9 | 18 | 18 |
| **Total** | 48,566 [1] | 100% | 54 | 54 | 60 |

[1] Figure differ due to the rounding up process from the National Woodland Inventory Data.

25. For Forest Enterprise sites the FE Sub-Compartment Database (SCDB) provided a list of possible sites that fitted the following criteria. Each district provided a list of sub compartments, from their SCDB, with the following characteristics provided in an Excel spreadsheet:

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

} Location information

- planting year
- yield class
- area
- rotation
- mixture code
- spacing & thinning type

} Crop information

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

} Site information

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 five 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.

**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. 42 sites were selected at random from within the strata. Of these 42 sites, 35 were surveyed. The remaining 7 sites were removed from the survey as they were not suitable because of wind damage or felling or restricted access due to the foot and mouth disease. The total area of sub-compartments surveyed was 613.88ha which amounts to 1.86% of FC Sitka spruce in Wales.

**Site Selection - Non-FC Sites**

28. A total of 20 sites were selected randomly from private forests with 19 actually surveyed in line with the proposed stratification for FC sites. The specific number of sites selected were 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 suggests that very few crops of Sitka spruce are still standing at this age because of felling or possibly wind damage.

29. The private sector sites were stratified in the same way where possible with data taken from Tilhill's Griffin database. 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.
    Paul Raymond-Barker
    Peter Goodyear

31. The total area of sub-compartments surveyed was approximately 279.25ha which amounts to almost 1.79% of non-FC Sitka spruce in the country.

**Preparation for Field Data Collection**

32. 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 and 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. Plot locations were determined before visiting the site to reduce bias in sampling

**Field Data Collection**

33. Details of the stem straightness survey protocol can be found in Macdonald *et al.* (2001) and Appendix 2.

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 dbh. The trees were numbered 1-10 with DBH and straightness score being taken for each tree. The age class of the stand defined the minimum dbh.

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 10)
- Random compass bearing
- In-row and between-row spacing
- In-row and between-row slope
- Thinned or non-thinned
- 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 the term is required in some cases.

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

In-row spacing:
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.

Between-row spacing:
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, first thinned and secondary 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**

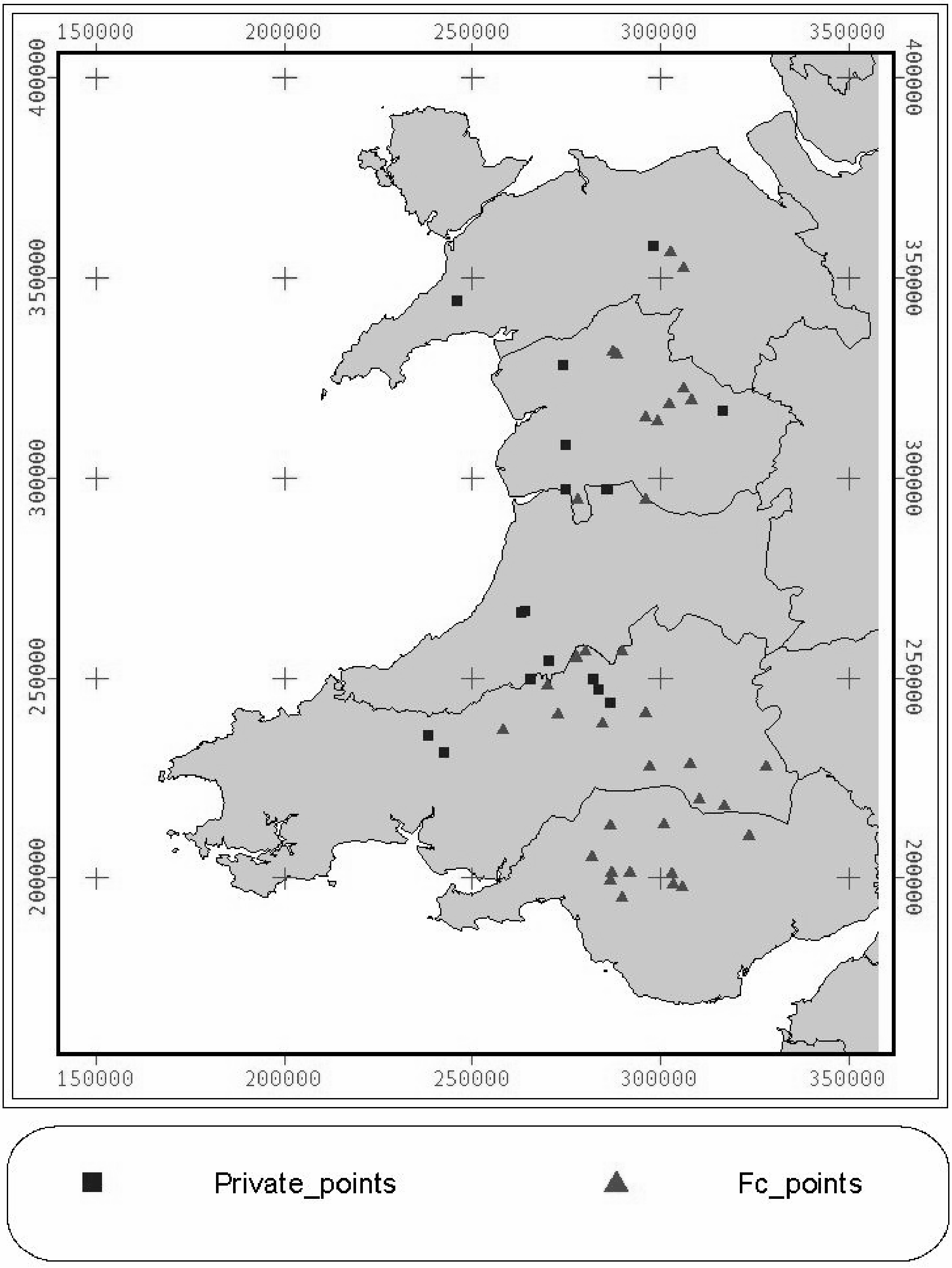
37. Sites were selected randomly from databases. All plots were marked on the survey map before entering the forest. The bearing along which sample trees were taken was completely randomised.

**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.

**Area of survey showing clear point of reference for FC and private sector sites**



**Survey Results**

**40.** 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.

**Table 3: A summary of areas surveyed by region and ownership**

| | | | | |
|---|---|---|---|---|
| | | **Actual** | **Total[1] Available** | **Percentage** |
| | **Sitka Spruce** | **Area Surveyed** | **Area >2ha** | **Surveyed** |
| | | **Ha** | | |
| Coed Y Cymoedd | F.C. | 278.1 | 9,658 | 2.88% |
| Coed Y Cymoedd | Non F.C. | 0 | 401 | 0% |
| **Total for** | Coed Y Cymoedd | **278.1** | **10,059** | **2.76%** |
| | | | | |
| Llanymddyfri | F.C. | 180.9 | 4,180 | 4.32% |
| Llanymddyfri | Non F.C. | 131.8 | 6,213 | 2.12% |
| **Total for** | Llanymddyfri | **312.7** | **10,393** | **3.00%** |
| | | | | |
| Llanrwst | F.C. | 19.3 | 4,248 | 0.45% |
| Llanrwst | Non F.C. | 45.4 | 2,468 | 1.84% |
| **Total for** | Llandovery | **64.7** | **6,716** | **0.96%** |
| | | | | |
| Dolgellau | F.C. | 107.7 | 6,148 | 1.75% |
| Dolgellau | Non F.C. | 34.4 | 3,213 | 1.07% |
| **Total for** | Dolgellau | **142.1** | **9,361** | **1.52%** |
| | | | | |
| Canolbarth | F.C. | 27.8 | 8,729 | 0.32% |
| Canolbarth | Non F.C. | 67.6 | 3,308 | 2.04% |
| **Total for** | Canolbarth | **95.4** | **11,587** | **0.82** |
| | | | | |
| **Total** | | **893 ha** | **48,570 ha** | **1.84%** |

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

**Results of the Welsh 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 |
|---|---|---|---|---|
| Coed Y Cymoedd | 13 | 8 | 61.5 | 1180 |
| Llanymddyfri | 19 | 10 | 52.6 | 1550 |
| Llanrwst | 4 | 2 | 50.0 | 360 |
| Dolgellau | 11 | 4 | 36.4 | 770 |
| Canolbarth | 7 | 4 | 57.1 | 630 |
| Total | 54 | 28 | 51.9 | 4,490 |

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 site characteristics for the whole survey region.**

| Character | Mean | Maximum | Minimum |
|---|---|---|---|
| Straightness score | 3.16 | 4.8 | 1.6 |
| Dbh /cm | 27.0 | 43.4 | 18.9 |
| Initial stocking /stems $ha^{-1}$ | 3,500 | 5,920 | 2,040 |
| Elevation /m | 341 | 493 | 79 |
| DAMS score | 15.8 | 21.4 | 9.3 |

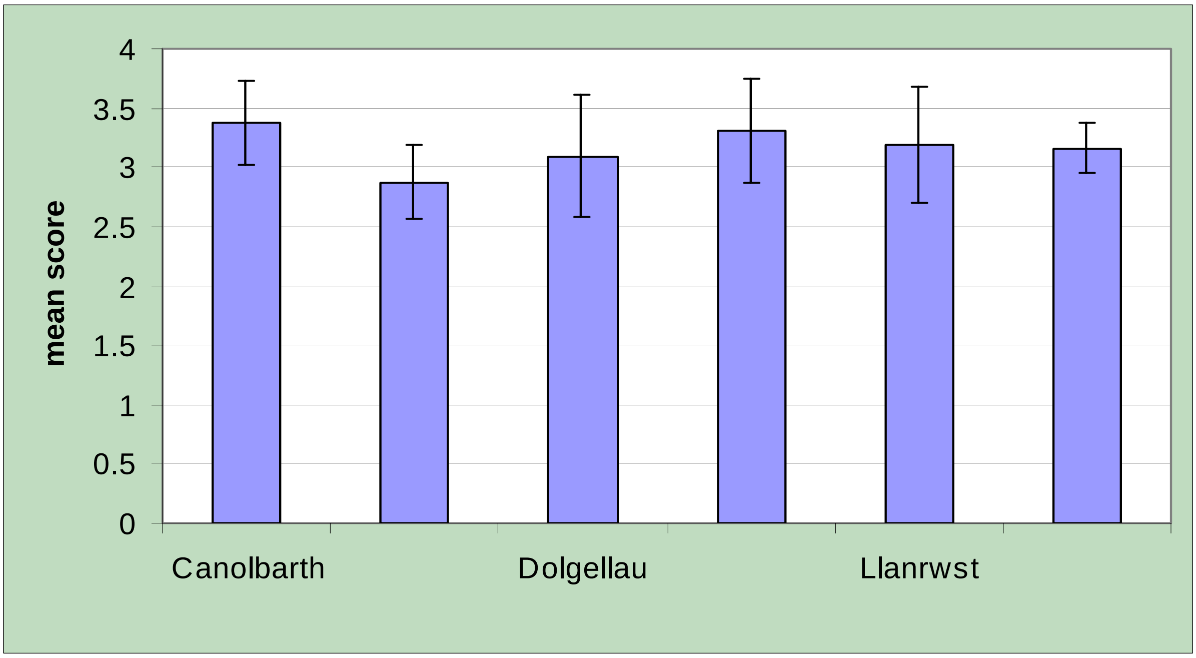
**Mean Straightness Score by Region**

42. As can be seen from Table 6 there is little variation in mean straightness score between the regions; Canolbarth having the highest and Coed y Cymoedd the lowest scores. Interestingly Coed Y Cymoedd also has one of the highest percentage of thinned sites, Table 4, and, as can be seen below, this would suggest a higher mean straightness score. The fact that this is not the case would indicate that the unthinned sites in Coed Y Cymoedd region are poorer than average. However, as can be seen from the 95% confidence limits shown in figure 1, there is no significant 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 |
|---|---|---|---|
| Llanrwst | 3.19 | 0.504 | ±0.493 |
| Dolgellau | 3.09 | 0.873 | ±0.516 |
| Canolbarth | 3.37 | 0.471 | ±0.349 |
| Llanymddyfri | 3.31 | 0.972 | ±0.437 |
| Coed Y Cymoedd | 2.88 | 0.562 | ±0.306 |
| Wales | 3.16 | 0.782 | ±0.2084 |
| S Scotland | 2.94 | 0.888 | ±0.1086 |

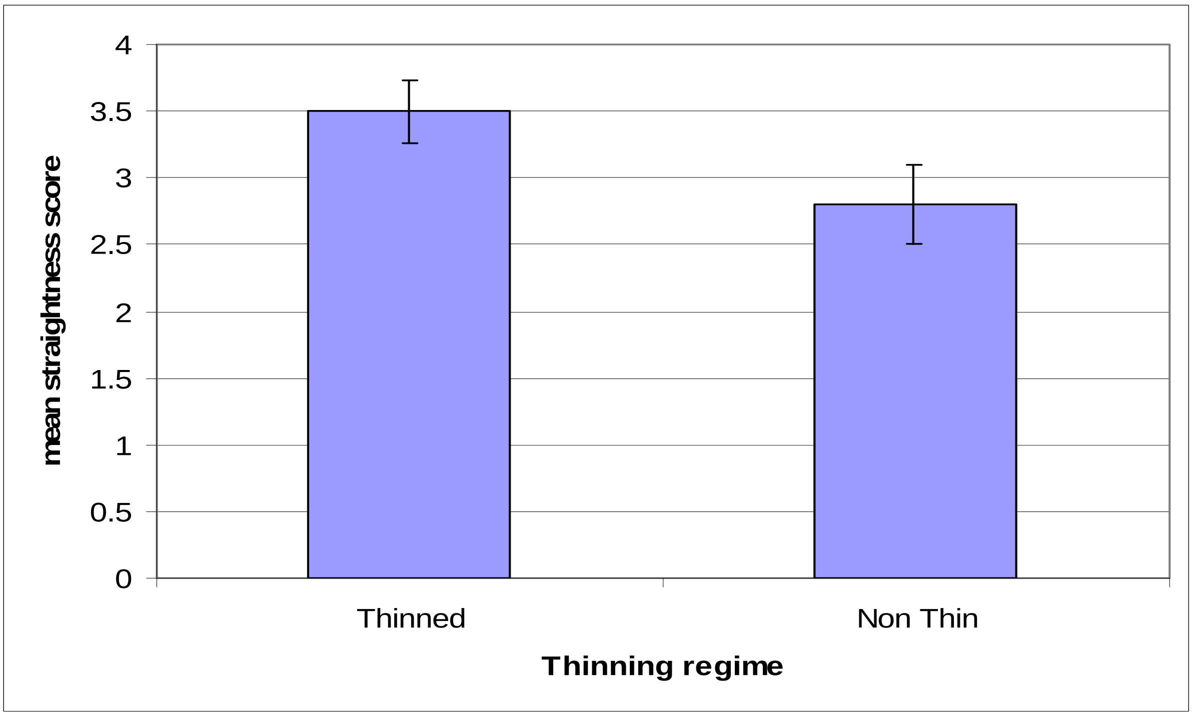
**Figure 1: Mean straightness score on a regional basis. Error bars represent 95% confidence limits.**




**Thinning**

43. As was also noted in the South of Scotland Survey (Stirling *et al.* 2000) and the Rest of Scotland survey (Mochan *et al.* 2001), this survey found that thinned stands have a higher mean straightness score (3.50 (±0.237 for 95% confidence limits)) than unthinned stands (2.80 ±0.295). This is shown in figure 2.

**Figure 2: The effect of thinning on the mean straightness score. Error bars represent 95% confidence limits.**



44. Thinned stands represented 51.9% of the total number of sites, indicating that thinning is widely practised in the survey region as a whole. The figure for the Rest of Scotland survey was only 22.6% of stands, less than half the figure for Wales (Mochan *et al.* 2001). There is a relationship between thinning and planting year in that more recent plantings were less likely to be thinned than older sites; as can be seen from Table 7. This could possibly be due to the increased likelihood that more recent plantings would have been undertaken on more exposed sites. However, 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.**

| Pyear Range | No. of sites thinned | No. of sites unthinned | % of sites thinned |
|---|---|---|---|
| Pre 1961 | 16 | 5 | 76.2 |
| 1961-1970 | 7 | 10 | 41.2 |
| 1971-1975 | 5 | 11 | 31.3 |

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

**Planting year and Diameter at Breast Height (dbh)**

45. Possibly linked to the changes in thinning practise noted above there 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: The effect of dbh on mean site stem straightness score. Error bars represent 95% confidence limits.**

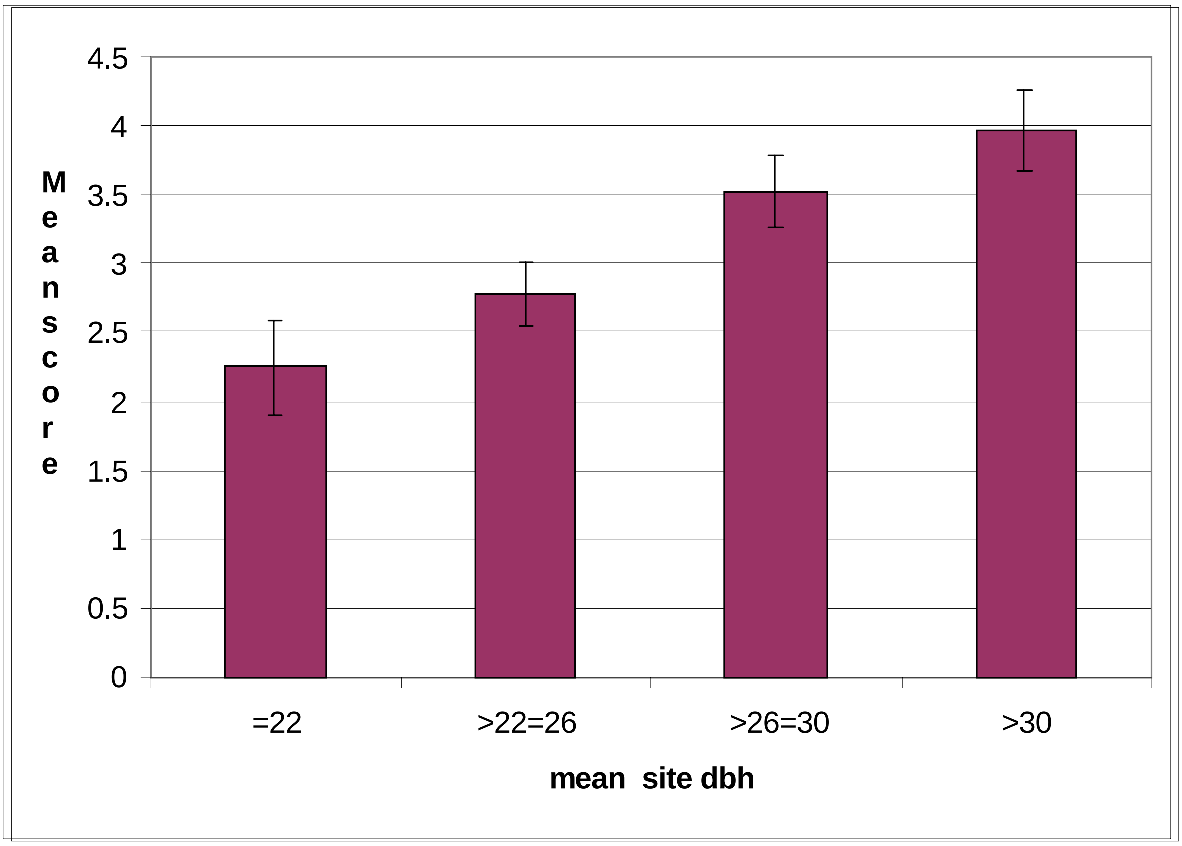
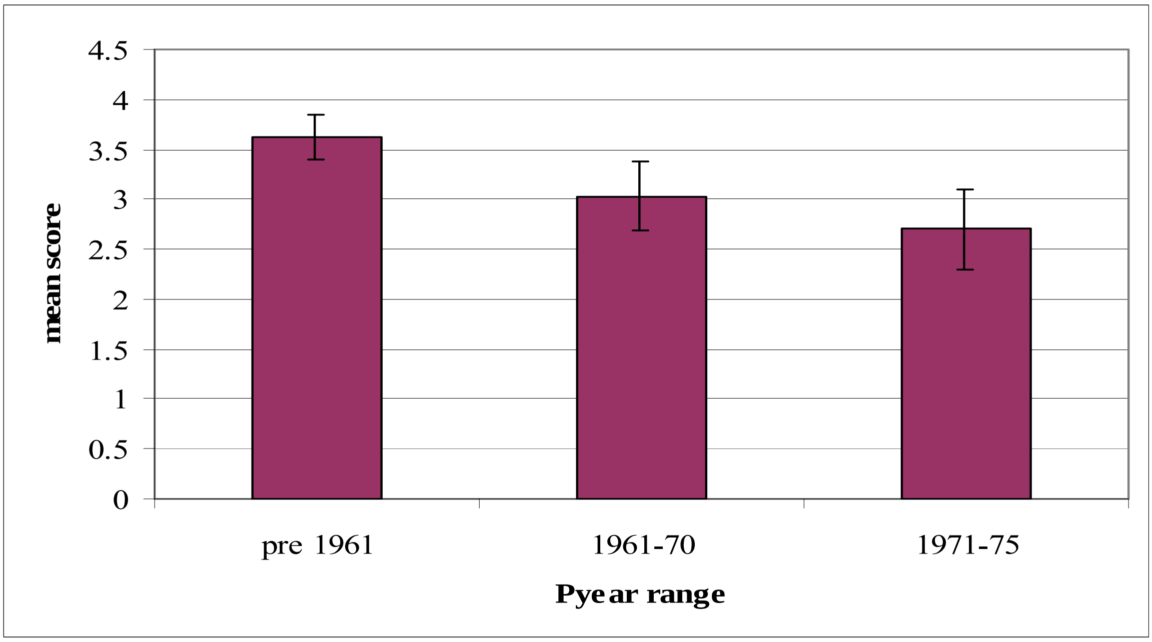


**Figure 4: The effect of planting year on mean stem straightness score. Error bars represent 95% confidence limits.**

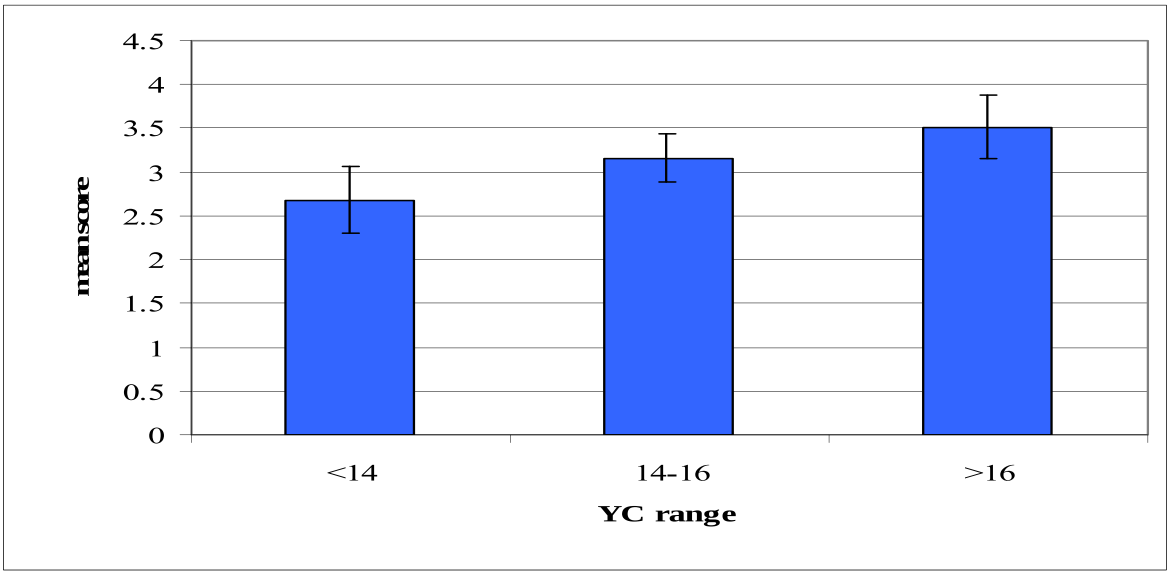



46. This drop in quality associated with newer plantings has been noted in all the previous surveys and now appears to be a general feature of Sitka spruce plantations throughout Scotland, Northern England and Wales (Stirling *et al.* 2000; Mochan *et al.* 2001).

**Yield Class**

47. Unlike the South Scotland survey, which noted a drop in stem straightness with increasing yield class (Stirling *et al.* 2000) and the Rest of Scotland survey which appeared to show no clear effect of yield class on stem straightness (Mochan *et al.* 2001), the Welsh survey showed a very clear trend of increasing stem straightness with increasing yield class. It is suspected that these conflicting trends are linked to the different environmental factors present in these regions, mostly likely the different wind environment encountered. Sites with high yield class and high winds are more likely to suffer from the loss of the relatively long leaders thereby producing trees with a lower straightness score. Baldwin (1993) observed this effect at an exposed Sitka spruce fertiliser experiment. He found that the fertilised plants suffered increased leader loss compared to the slower growing controls.

**Figure 5: The effect of yield class on mean straightness scores. Error bars represent 95% confidence limits.**



**Elevation and DAMS**

48. There appeared to be no effect of elevation on stem straightness (figure 6). 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 Llanymddyfri is far more severe than a similar elevation in a sheltered position in the Llanrwst 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 7). This would suggest that the wind climate in Wales was not a dominant factor influencing stem straightness in the region. The reduced dominance of wind exposure in forestry is also suggested by the higher proportion of thinned stands in Wales compared to Scotland

**Figure 6: The effect of elevation on mean stem straightness. Error bars represent 95% confidence limits.**

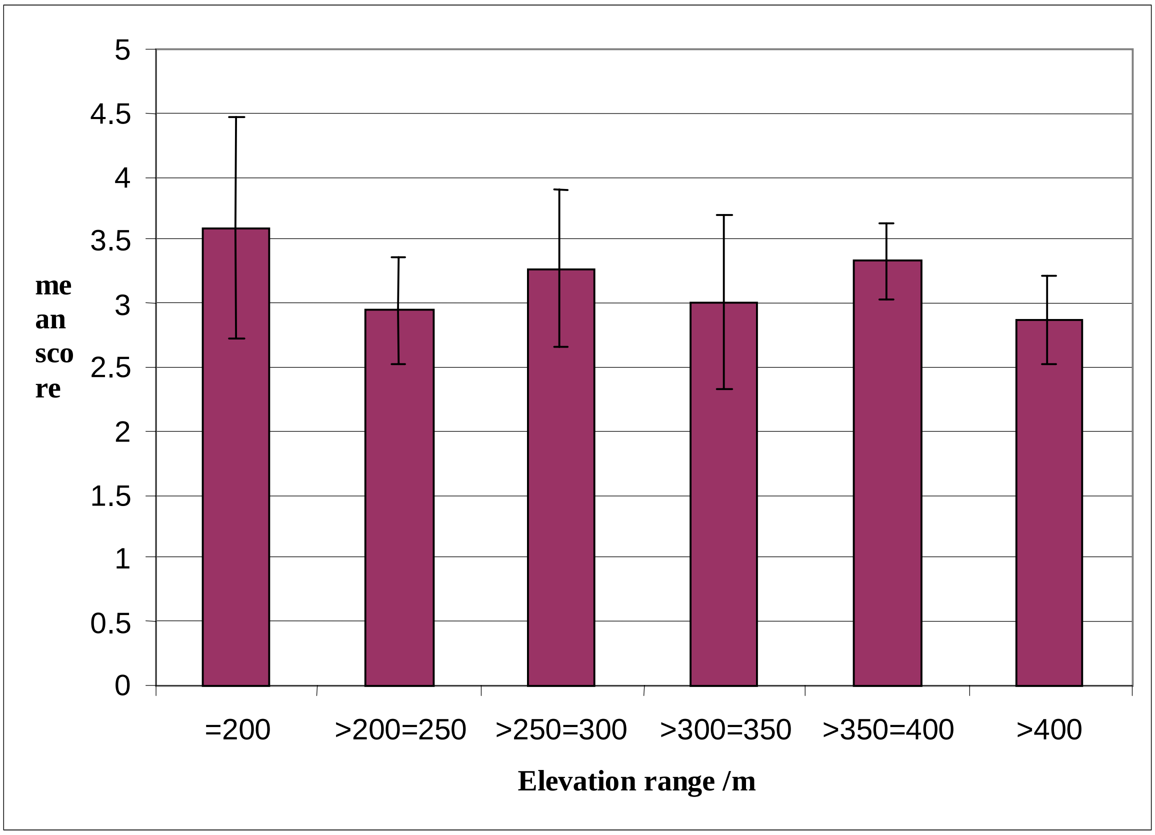
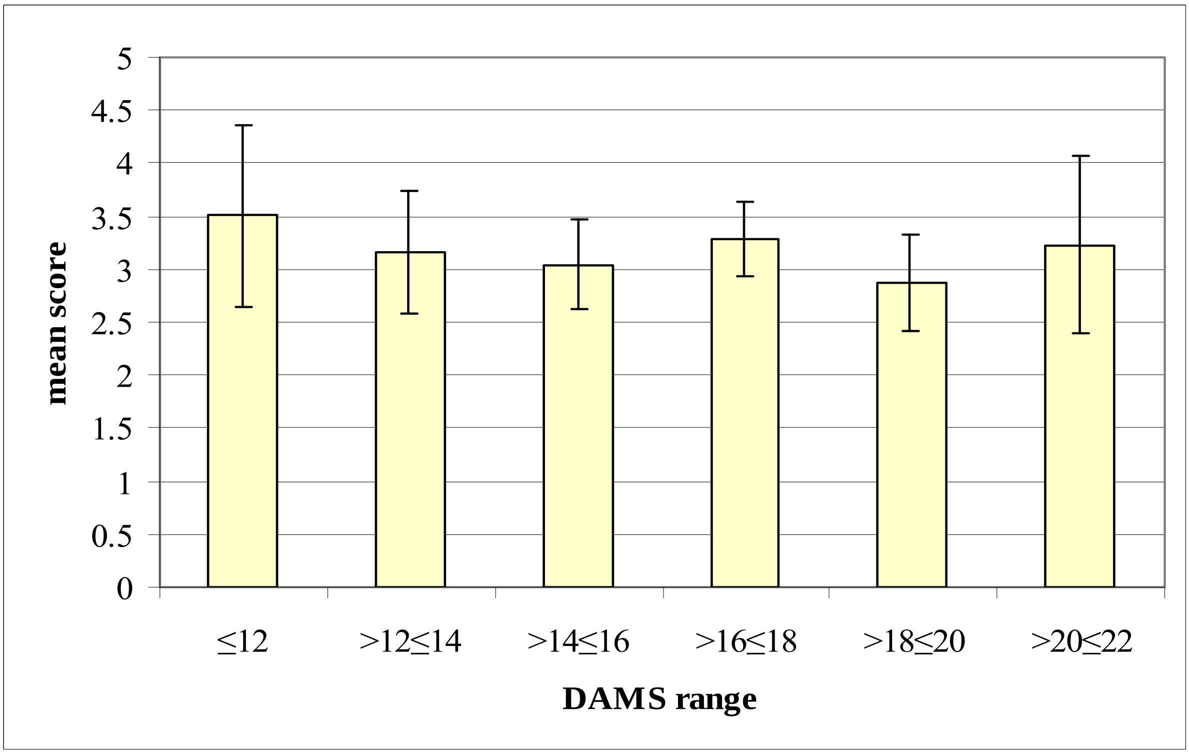


**Figure 7: The effect of wind exposure as measured by DAMS score on mean stem straightness. Error bars represent 95% confidence limits.**



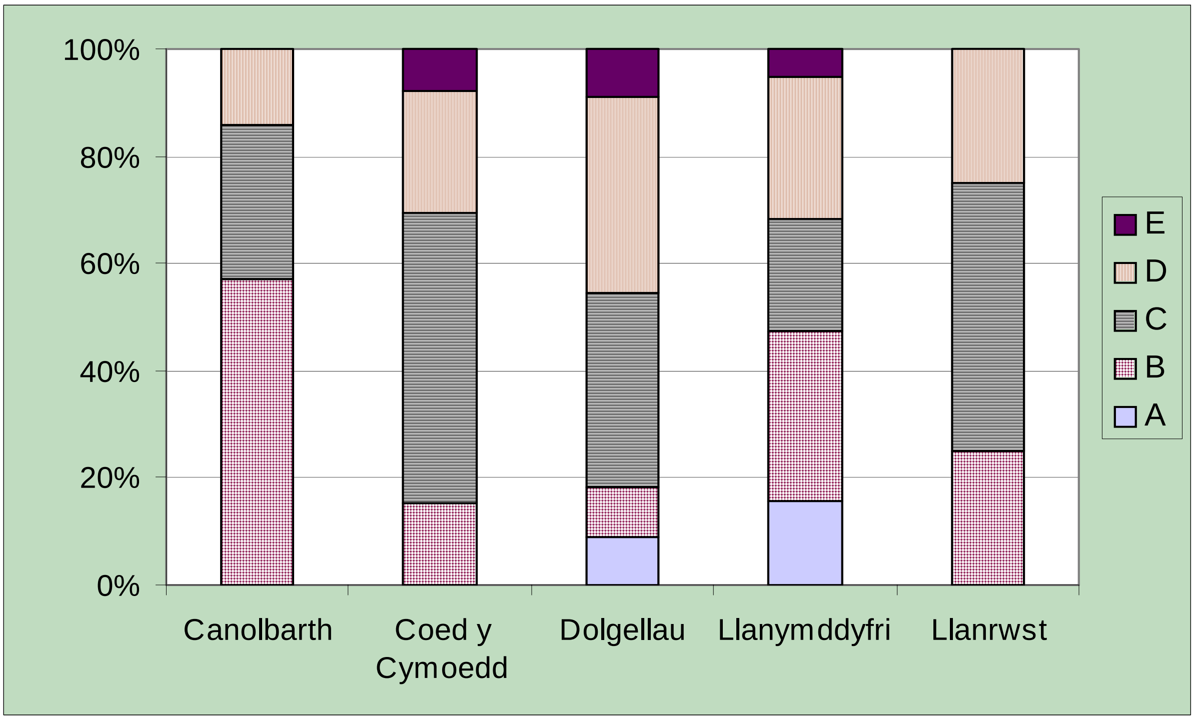

**Site Straightness Grades**

49. 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 was 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 |

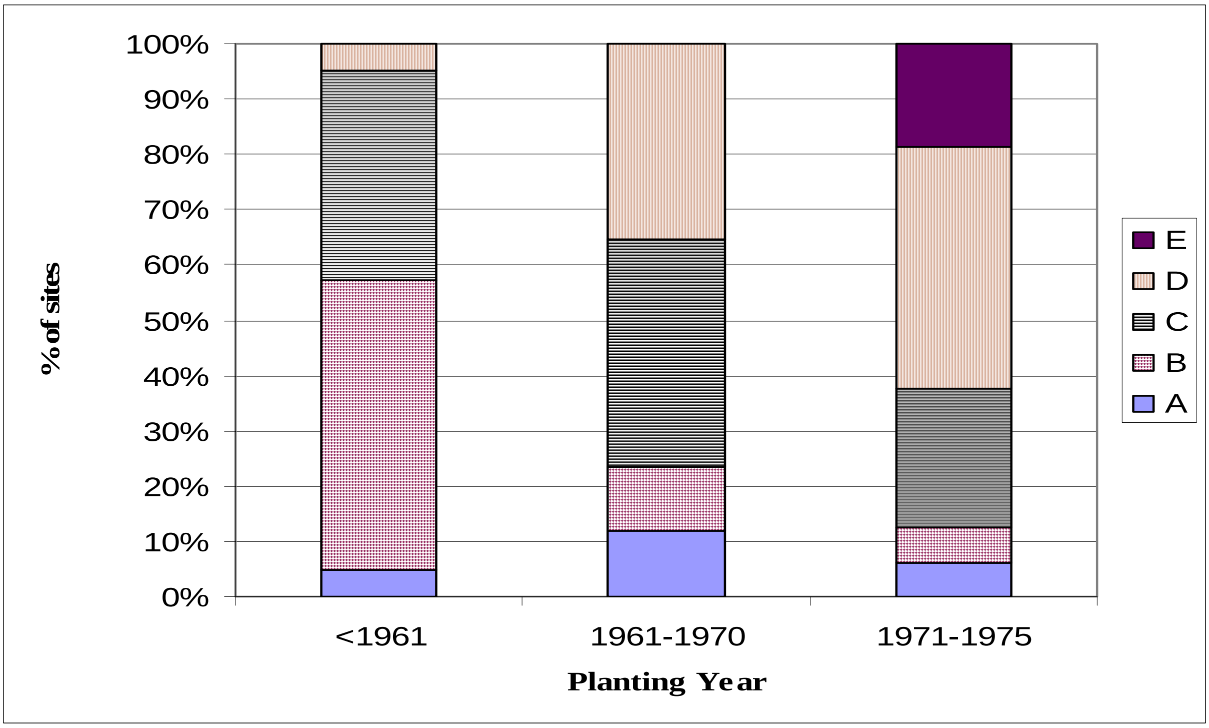
50. Applying these grading rules to the survey data showed that there was little variation in the proportion of grades on a regional basis (figure 8). Llanymddyfri had the highest percentage of stands with grades A and B, but Canolbarth had the highest percentage of sites with grades A to C. It should be noted, however, that the distribution of stands across the regions was not ideal and there were relatively few sites in the Llanrwst region.

**Figure 8: Stand straightness grades on a regional basis, expressed as a percentage of stands per region.**




51. 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 9).

**Figure 9: The effect of planting year on straightness grade (percentages are relative to stands within each year range).**

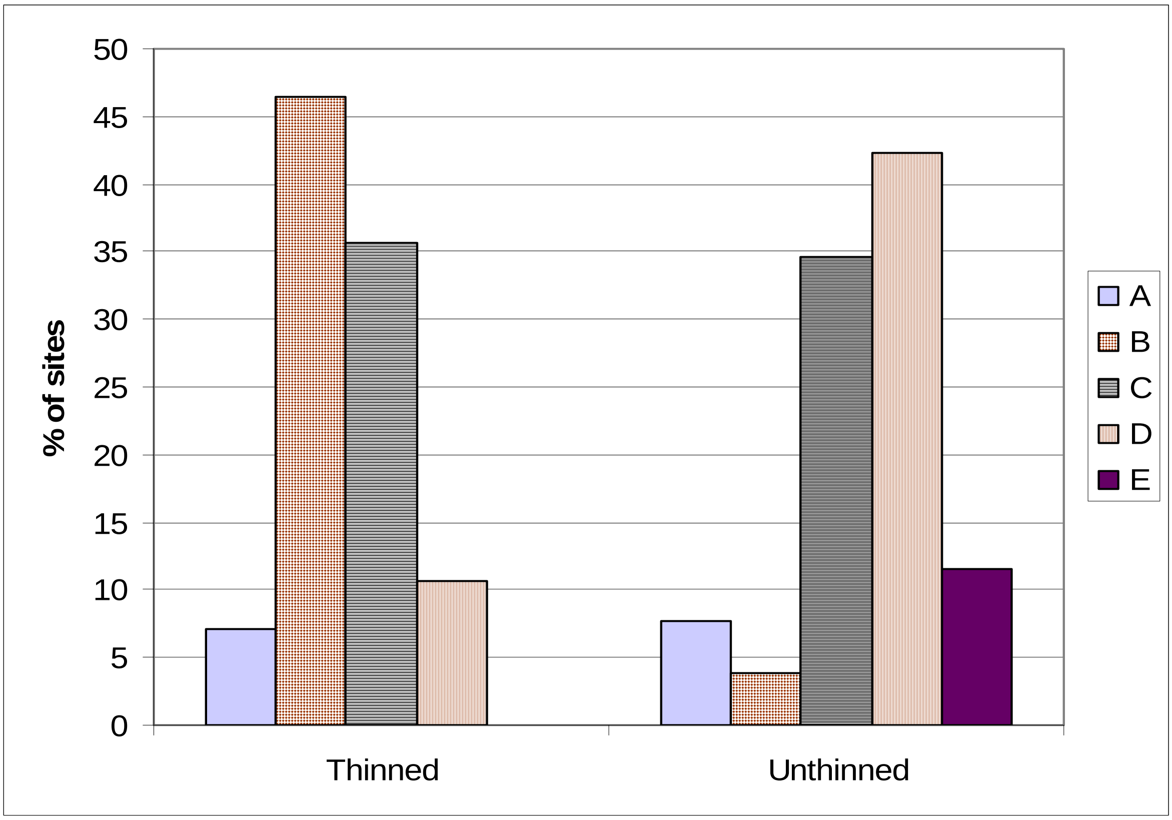


52. The decline in grades indicates an apparent general decline in quality in the standing crop as a whole. There are various possibilities for this decline, for instance thinning age; the older stands being more likely to be thinned at least once compared to the younger ones. Alternatively it could 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.

53. The relative distribution of grades over time is likely to be dynamic in Britain due to the long phase of plantation establishment. Until new plantations become a relatively small proportion of the commercial forest estate, the picture presented in figure 9 is likely to alter with time and large-scale changes in silvicultural practise.

54. The effect of thinning is shown in figure 10 and reflects the differences noted in the mean scores. There was a higher percentage of thinned stands in the higher grades, A and B compared to unthinned stands, although it should be noted that there are some high quality, grade A, unthinned stands. The presence of grade D stands that have been thinned is due to the inclusion of systematic thinning and the possibility that thinning has been poorly carried out in some sites. Figure 10 also show a significant increase in Grade E stands where areas have not been thinned.

**Figure 10: The effect of thinning on straightness grade (percentages are relative to stands within each thinning regime).**



**Developing a Model for Wales**

55. As with previous surveys, sites were chosen to represent a range of factors: yield class, planting year and thinning history. There were 54 sites, comprising 4490 trees; each site had between 4 to 10 plots and each plot had 10 trees. For each site, density, elevation and DAMS score were also recorded, together with soil class, nutrient and soil moisture regime. Site mean straightness scores and variances, and site mean dbh, were calculated from the individual tree data.

56. For modelling purposes the response was site mean straightness score weighted inversely by site variance. The factors considered for inclusion were planting year, yield class and thinning, and the variables density, elevation and DAMS. Relevant interactions were considered where possible.

**Results**

57. A partial data listing for all 54 sites is given in Appendix 1 (A1)Table 1. The crosstabulation of site mean score for the three main site factors are given in Table 8. The data are sparse with respect to these features, with two combinations of yield class, planting year and thinning not represented and a further four accounted for by only one site. The crosstabulation of tree counts by site and score are given in (A1)Table 2.

**Table 8. Crosstabulation of Site Mean Score by Yield Class, Planting Year and Thinning**

| | | **No thin** | | **Thin** | |
|---|---|---|---|---|---|
| Yield Class | Pyear | No of Sites | Mean Score | No of Sites | Mean Score |
| ≤12 | ≤1960 | 1 | 3.91 | 2 | 3.02 |
| | 1961-70 | 4 | 2.57 | 1 | 4.08 |
| | 1971-75 | 6 | 2.20 | 0 | - |
| 14-16 | ≤1960 | 3 | 3.37 | 9 | 3.64 |
| | 1961-70 | 2 | 2.87 | 3 | 2.81 |
| | 1971-75 | 4 | 2.34 | 0 | - |
| ≥18 | ≤1960 | 1 | 3.68 | 5 | 3.89 |
| | 1961-70 | 4 | 2.98 | 3 | 3.71 |
| | 1971-75 | 1 | 4.53 | 5 | 3.23 |

58. The variables included in the final model were planting year and yield class. The details are shown in (A1)Table 3 and indicate a positive effect of increasing yield class and a negative effect of more recent planting years on site mean stem straightness. The model explained just under 41% of the variation in the site mean straightness scores. The predictions in Table 9 suggest the highest estimated score (3.95) is for sites planted before 1960 with yield class 18 and over, and lowest score (2.17) for sites of yield class less than 12 and planted on or after 1971.

**Table 9. Predictions (with standard error (se)) from Basic Model**

| YClass | ≤12 | | 14-16 | | ≥18 | |
|---|---|---|---|---|---|---|
| Pyear | Prediction | se | Prediction | se | Prediction | se |
| ≤1960 | 3.20 | 0.214 | 3.48 | 0.174 | 3.95 | 0.209 |
| 1961-1970 | 2.45 | 0.198 | 2.73 | 0.204 | 3.19 | 0.185 |
| 1971-1975 | 2.17 | 0.174 | 2.44 | 0.195 | 2.91 | 0.195 |

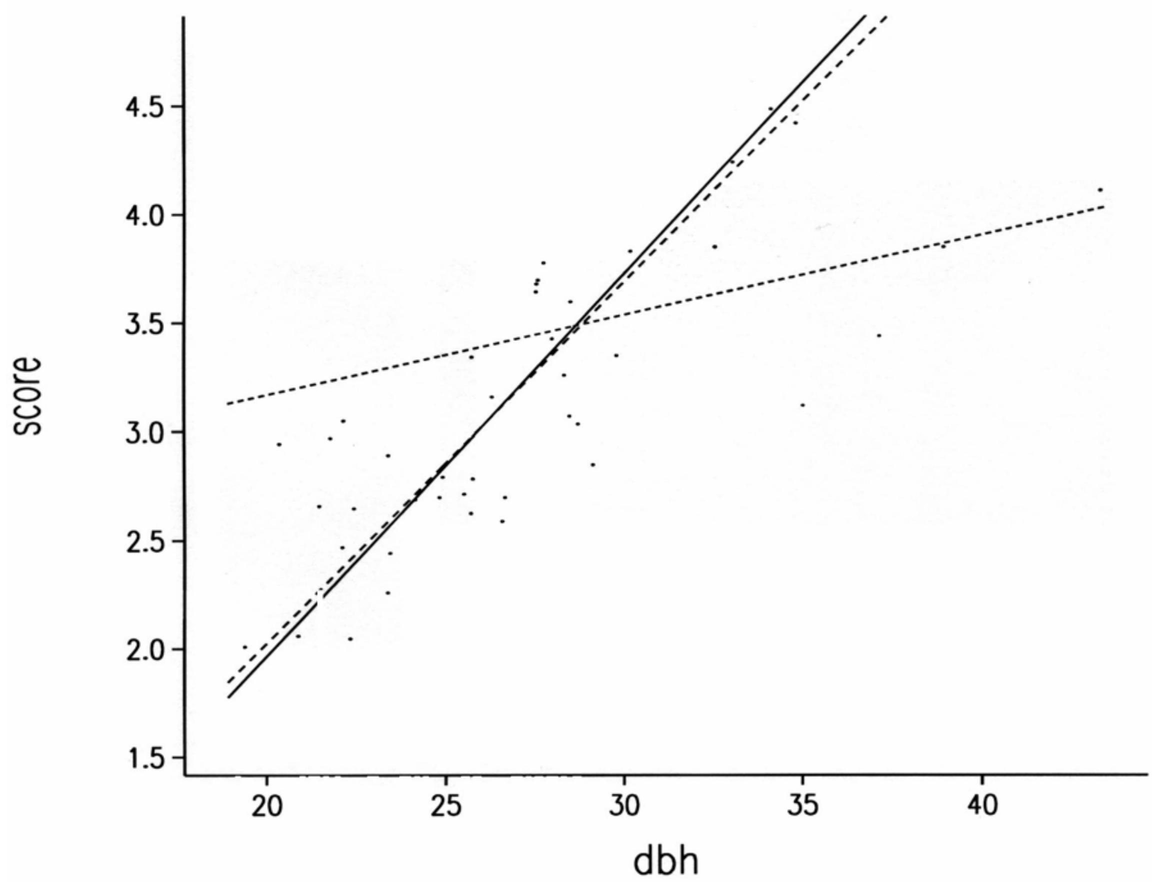
59. A model with just thinning was considered and although thinning was significant it accounted for only 28% of the variation in site mean score. Neither DAMS, density, nor elevation entered the models after the main site factors were considered. Soil class, obtained from the Soil Survey of England and Wales, was also considered but did not add anything to the model once yield class was included.

60. Although dbh was not an original candidate for inclusion there was, however, a strong positive relationship between score and dbh at the site mean level. A model with dbh alone accounted for over 61% of response variation ((A1)Table 4). The effect for dbh was such that sites with a mean dbh 10 cm larger would have a predicted increase in score on average of 1.3 (Table 10). This dbh model suggests that dbh would suffice as a simple predictor of straightness score at the site level. However, there is an interaction between dbh and age when age is included in the model. This indicates that the effect for dbh is less pronounced in older stands ((A1)Table 5, Figure 11).

**Table 10. Predictions (with standard error (se)) from DBH Model**

| dbh | Prediction | se |
|---|---|---|
| 20 | 2.17 | 0.106 |
| 25 | 2.82 | 0.070 |
| 30 | 3.46 | 0.091 |
| 35 | 4.11 | 0.147 |
| 40 | 4.76 | 0.211 |

**Figure 11. Relationship between site mean straightness score and dbh for three age ranges ( ___ age<31, --- age 31-40, ….. age>40)**



61. To further investigate dbh, within sites, three straightness score classes (1-2, 3-5 and 6-7) were formed for dbh ((A1) Table 6). For those sites with at least one tree in each score 1,2,6 and 7 the mean dbh between classes 1-2 and 6-7 was compared. Of the 27 sites where this contrast was feasible, 22 sites had a mean dbh for scores 6-7 significantly greater than that for scores 1-2 ($P<0.05$) ((A1)Table 7). For all the other sites, except one, the higher scoring trees (6-7) within a site had a larger mean dbh than the poorer scoring trees (1-2). This suggests that within sites, trees with better straightness scores have greater dbh and this appears to be unrelated to site mean straightness score.

**Discussion**

62. The main results of the modelling analysis are that straightness score is associated with planting year, yield class and dbh. Unlike the models for Scotland, which omitted dbh but included other silvicultural and environmental factors such as initial spacing, thinning, and wind exposure, these three factors are all linked directly or indirectly with tree size. One possible explanation for these countrywide differences is that the environment in Wales is better for growing Sitka spruce and hence environmental factors do not dominate stem straightness to the degree that they do in Scotland. However it should be noted that the survey in Wales covered only 54 sites compared to the larger surveys undertaken in Scotland.

63. The association between tree size as expressed as dbh, and stem straightness has been noted in the other surveys. This appears to be occurring both within a stand and between stands. However, it would be incorrect to suggest that given a dbh of an individual tree in a stand it would be possible to predict its stem straightness score; there will always be exceptions such as wolf trees. On average it appears that in Wales older faster growing stands will contain straighter trees and within a stand the larger trees will be on average straighter.

64. The observed statistical link between dbh and stem straightness suggests that there may be a causal link between these observations. A potential hypothesis is that the link is via leader loss. Leader loss is likely to be the main cause of bend formation in Sitka spruce and will be controlled by a combination of environmental and genetic factors. Each time a tree looses a leader it has lost the height increment for that year, the more often this happens the more bends the tree will have and the shorter it will be compared to those trees that have not lost their leaders. Over time competition within the stand will increase, favouring the taller, straighter trees and suppressing or killing the shorter, more bent trees. This would then lead to the observed situation where trees with smaller dbh are also of poorer form.

65. It is interesting to note from figure 11 that the relationship between dbh and stem straightness appears to become less pronounced with age once the stands are over 40 years old. This could be due to a combination of factors. Firstly the older stands within the survey contained more thinned stands and selective thinning should reduce both dbh and straightness score range. Secondly, in unthinned stands it is likely that suppression and mortality of the very poorest trees will have occurred, hence reducing the range of scores. In addition, the sampling method used in the survey only assessed trees of sawlog size (≥20cm dbh) in these mature stands, and although smaller trees exist in such stands they were not sampled.

66. The link between stand stem straightness and dbh also implies that there is some improvement in the quality of a stand as it matures. This requires more detailed work and has obvious implications for using models of stem straightness to predict future conditions.

**Conclusions**

67. The Welsh 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 Wales. There is little variation in the proportion of grades on a regional basis.

68 Thinning appears to provide a positive influence on stands. Thinned stands have a higher mean straightness score compared to un-thinned stands. Thinning is the most consistent factor, after planting age, on stem straightness for both surveys. It would therefore appear that thinning is the most effective silvicultural intervention to improve stem straightness.

69. There appeared to be no regional differences in stem straightness within the level of sampling undertaken by the survey. In addition, YC does show a positive influence but elevation and DAMS score do not appear to have a significant effect on stem straightness in Sitka spruce.

70. The improvements in stem straightness with yield class can also be expressed in terms of improved soils. For instance, brown earths scored more highly than gleys which were better than peat soils. However, the survey does not have sufficient data to indicate whether this trend was due to the soils in itself or other linked environmental factors

71. At present the best model accounts for 41% of the variance encountered in the measured data. The model is based on planting year and yield class only.

72. The low levels of variance accounted for by the model for Wales indicate that the factors controlling stem straightness are complex. One of the limitations of the survey is the lack of historical information on plant provenance's, early management regimes, the 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 would be continued thereby providing the opportunity to locate these relatively rare sites and to increase the replication of sites in general. Another option would be to combine the results from all three surveys and use this to develop a general model of stem straightness for the UK. However, further surveying would be needed to test and validate this model if it were to be developed.

73. Straightness score is associated with the planting year, yield class and dbh. This strong link has been observed in the other two surveys covering Scotland and north England

74. There is a significant positive correlation between dbh and straightness score both within a stand and between stands. A tentative hypothesis for this observation is that leader loss is the main cause of bends in Sitka spruce. Once trees have lost their leaders they have reduced competitiveness and are more likely to become suppressed with time.

75. The proportion of sawlogs is likely to drop over the next 5-10 years, although due to the possible stand dynamic process outlined above the reduction in quality may no be as pronounced as the data initially suggests.

## Acknowledgements

We would like to thank the following for their financial support and co-operation in kind in terms of access to the various forest locations: the Forestry Commission, Forest Enterprise, Tilhill Economic Forestry Ltd, Paul Raymond-Barker, Peter Goodyear and the United Kingdom Forest Products Association. Thanks are also due to Forest Enterprise for their co-operation and assistance with the project, in particular to the staff of Forest Surveys and those at the regional Forest Districts.
Thanks also to all Forest Research Staff who contributed to or commented on the work.

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# Appendix 1

## Statistical Data and Models for Wales

### Table 1. Site Mean Data

| Site | Plots | Trees | Score | DBH | PYear | YC | Density | Thin %0 | Thin %1 | Thin %2 | Fork %1 | Fork HT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 100 | 3.8900 | 39.0110 | 48 | 14 | 4024 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 2 | 8 | 80 | 3.0750 | 28.7900 | 56 | 14 | 4194 | 0.00 | 100.00 | 0.00 | 1.25 | 3.40 |
| 3 | 6 | 60 | 3.6833 | 27.6117 | 57 | 18 | 3727 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 4 | 6 | 60 | 2.9333 | 23.4833 | 63 | 10 | 4281 | 100.00 | 0.00 | 0.00 | 3.33 | 3.80 |
| 5 | 10 | 100 | 2.7300 | 24.2380 | 67 | 16 | 5919 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 6 | 10 | 100 | 2.8900 | 29.2130 | 54 | 14 | 4910 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 7 | 6 | 60 | 2.1000 | 20.9683 | 66 | 12 | 3435 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 8 | 6 | 60 | 2.6667 | 25.7900 | 66 | 18 | 3072 | 100.00 | 0.00 | 0.00 | 5.00 | 2.33 |
| 9 | 10 | 100 | 3.7200 | 27.6290 | 59 | 14 | 4257 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 10 | 10 | 100 | 3.8900 | 32.6420 | 54 | 18 | 5670 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 11 | 8 | 80 | 2.8250 | 25.8425 | 58 | 16 | 3807 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 12 | 7 | 70 | 3.9143 | 26.7457 | 57 | 10 | 3237 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 13 | 8 | 80 | 1.8375 | 20.5425 | 71 | 12 | 2545 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 14 | 9 | 90 | 2.7556 | 25.6044 | 68 | 16 | 3578 | 0.00 | 100.00 | 0.00 | 2.22 | 2.00 |
| 15 | 10 | 100 | 2.6300 | 26.6630 | 70 | 18 | 3050 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 16 | 10 | 100 | 2.7400 | 24.9130 | 61 | 12 | 4934 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 17 | 10 | 100 | 3.4800 | 37.2190 | 50 | 18 | 3065 | 0.00 | 100.00 | 0.00 | 9.00 | 3.18 |
| 18 | 10 | 100 | 4.1500 | 43.4190 | 50 | 24 | 4046 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 19 | 10 | 100 | 2.7400 | 26.7430 | 47 | 12 | 4192 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 20 | 8 | 80 | 4.2125 | 27.7725 | 63 | 22 | 4372 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 21 | 10 | 100 | 4.2800 | 33.1430 | 71 | 20 | 2310 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 22 | 10 | 100 | 3.0900 | 22.2330 | 72 | 20 | 3218 | 0.00 | 100.00 | 0.00 | 1.00 | 2.50 |
| 23 | 10 | 100 | 4.0400 | 29.7830 | 66 | 24 | 3540 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 24 | 6 | 60 | 2.4833 | 23.5383 | 66 | 16 | 4093 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 25 | 10 | 100 | 4.4600 | 34.9030 | 68 | 18 | 3195 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 26 | 10 | 100 | 3.3000 | 28.4020 | 58 | 12 | 3698 | 0.00 | 100.00 | 0.00 | 1.00 | 2.00 |
| 27 | 6 | 60 | 3.8167 | 27.8300 | 49 | 14 | 4828 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 28 | 9 | 90 | 3.1111 | 28.5522 | 68 | 22 | 2669 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 29 | 6 | 60 | 3.3833 | 25.8117 | 71 | 20 | 2146 | 0.00 | 100.00 | 0.00 | 1.67 | 3.00 |
| 30 | 9 | 90 | 2.8333 | 25.0056 | 75 | 18 | 2662 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 31 | 10 | 100 | 2.3000 | 23.4680 | 73 | 14 | 2042 | 100.00 | 0.00 | 0.00 | 3.00 | 3.33 |
| 32 | 10 | 100 | 2.5100 | 22.2050 | 67 | 10 | 4242 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 33 | 10 | 100 | 3.3900 | 29.8760 | 55 | 14 | 2994 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 34 | 7 | 70 | 2.9857 | 20.4543 | 74 | 12 | 2978 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 35 | 4 | 40 | 2.0500 | 19.4800 | 74 | 8 | 2653 | 100.00 | 0.00 | 0.00 | 5.00 | 2.25 |
| 36 | 9 | 90 | 2.0222 | 21.8256 | 74 | 14 | 3292 | 100.00 | 0.00 | 0.00 | 4.44 | 4.25 |
| 37 | 8 | 80 | 4.0750 | 25.0675 | 69 | 5 | 3427 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 38 | 10 | 100 | 3.2000 | 26.3780 | 64 | 16 | 3180 | 0.00 | 100.00 | 0.00 | 1.00 | 3.00 |
| 39 | 9 | 90 | 4.5333 | 29.5711 | 72 | 22 | 2375 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 40 | 8 | 80 | 3.6375 | 28.5875 | 50 | 16 | 3929 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 41 | 4 | 40 | 4.5250 | 34.2075 | 53 | 16 | 2849 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 42 | 4 | 40 | 1.5750 | 18.9275 | 71 | 10 | 2787 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 43 | 5 | 50 | 3.1600 | 35.0939 | 58 | 20 | * | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 44 | 10 | 100 | 2.5400 | 27.0130 | 74 | 22 | 2410 | 0.00 | 100.00 | 0.00 | 4.00 | 2.95 |
| 45 | 5 | 50 | 2.3200 | 24.6040 | 72 | 14 | 2345 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 46 | 9 | 90 | 3.4667 | 28.0600 | 50 | 16 | 4515 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 47 | 8 | 80 | 3.0125 | 21.8762 | 67 | 14 | 3637 | 100.00 | 0.00 | 0.00 | 1.25 | 5.00 |
| 48 | 9 | 90 | 4.7556 | 29.1833 | 60 | 18 | 4105 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 49 | 9 | 90 | 2.6889 | 22.5300 | 73 | 12 | 2316 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 50 | 10 | 100 | 3.8700 | 30.2730 | 60 | 16 | 3421 | 0.00 | 100.00 | 0.00 | 0.00 | * |
| 51 | 8 | 80 | 3.7375 | 27.6688 | 59 | 16 | 3259 | 0.00 | 100.00 | 0.00 | 2.50 | 3.00 |
| 52 | 10 | 100 | 2.7000 | 21.5660 | 73 | 16 | 2888 | 100.00 | 0.00 | 0.00 | 1.00 | 2.00 |
| 53 | 8 | 80 | 2.0875 | 22.4188 | 71 | 10 | 3001 | 100.00 | 0.00 | 0.00 | 0.00 | * |
| 54 | 7 | 70 | 1.9143 | 21.3343 | 68 | 22 | 4162 | 100.00 | 0.00 | 0.00 | 15.71 | 3.23 |

**Table 2. Crosstabulation of Site by Straightness Score counts**

| score<br>site | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Count |
|---|---|---|---|---|---|---|---|---|
| 1 | 17 | 19 | 6 | 18 | 8 | 20 | 12 | 100 |
| 2 | 14 | 26 | 5 | 22 | 3 | 8 | 2 | 80 |
| 3 | 6 | 13 | 5 | 19 | 6 | 9 | 2 | 60 |
| 4 | 12 | 16 | 4 | 24 | 0 | 4 | 0 | 60 |
| 5 | 30 | 30 | 2 | 24 | 5 | 7 | 2 | 100 |
| 6 | 24 | 34 | 1 | 25 | 4 | 10 | 2 | 100 |
| 7 | 22 | 23 | 4 | 9 | 2 | 0 | 0 | 60 |
| 8 | 15 | 22 | 2 | 14 | 3 | 4 | 0 | 60 |
| 9 | 8 | 25 | 6 | 34 | 5 | 19 | 3 | 100 |
| 10 | 19 | 19 | 2 | 24 | 6 | 10 | 20 | 100 |
| 11 | 28 | 16 | 3 | 21 | 2 | 7 | 3 | 80 |
| 12 | 3 | 13 | 6 | 28 | 6 | 13 | 1 | 70 |
| 13 | 47 | 19 | 1 | 10 | 0 | 2 | 1 | 80 |
| 14 | 24 | 26 | 5 | 26 | 1 | 8 | 0 | 90 |
| 15 | 30 | 31 | 1 | 30 | 0 | 8 | 0 | 100 |
| 16 | 33 | 28 | 0 | 25 | 1 | 11 | 2 | 100 |
| 17 | 17 | 22 | 6 | 29 | 3 | 23 | 0 | 100 |
| 18 | 10 | 21 | 0 | 27 | 8 | 23 | 11 | 100 |
| 19 | 21 | 38 | 1 | 33 | 0 | 7 | 0 | 100 |
| 20 | 16 | 13 | 1 | 8 | 7 | 20 | 15 | 80 |
| 21 | 3 | 19 | 4 | 34 | 7 | 27 | 6 | 100 |
| 22 | 21 | 31 | 1 | 28 | 4 | 14 | 1 | 100 |
| 23 | 21 | 18 | 3 | 14 | 3 | 20 | 21 | 100 |
| 24 | 30 | 9 | 1 | 11 | 1 | 7 | 1 | 60 |
| 25 | 3 | 10 | 6 | 39 | 8 | 29 | 5 | 100 |
| 26 | 18 | 12 | 16 | 40 | 4 | 10 | 0 | 100 |
| 27 | 13 | 11 | 1 | 13 | 1 | 13 | 8 | 60 |
| 28 | 16 | 24 | 10 | 25 | 5 | 9 | 1 | 90 |
| 29 | 9 | 17 | 3 | 16 | 3 | 12 | 0 | 60 |
| 30 | 26 | 23 | 1 | 30 | 0 | 10 | 0 | 90 |
| 31 | 34 | 34 | 4 | 26 | 0 | 2 | 0 | 100 |
| 32 | 35 | 31 | 0 | 26 | 0 | 6 | 2 | 100 |
| 33 | 12 | 24 | 11 | 35 | 3 | 14 | 1 | 100 |
| 34 | 18 | 22 | 2 | 14 | 2 | 9 | 3 | 70 |
| 35 | 16 | 13 | 4 | 7 | 0 | 0 | 0 | 40 |
| 36 | 36 | 34 | 4 | 15 | 0 | 1 | 0 | 90 |
| 37 | 6 | 23 | 2 | 21 | 2 | 8 | 18 | 80 |
| 38 | 17 | 27 | 6 | 34 | 1 | 15 | 0 | 100 |
| 39 | 7 | 14 | 1 | 28 | 2 | 18 | 20 | 90 |
| 40 | 9 | 17 | 5 | 28 | 5 | 16 | 0 | 80 |
| 41 | 6 | 5 | 1 | 7 | 2 | 9 | 10 | 40 |
| 42 | 25 | 11 | 0 | 4 | 0 | 0 | 0 | 40 |
| 43 | 8 | 17 | 4 | 12 | 1 | 5 | 3 | 50 |
| 44 | 28 | 31 | 10 | 26 | 1 | 3 | 1 | 100 |
| 45 | 25 | 9 | 3 | 8 | 0 | 3 | 2 | 50 |
| 46 | 14 | 32 | 1 | 17 | 3 | 13 | 10 | 90 |
| 47 | 16 | 28 | 3 | 19 | 1 | 12 | 1 | 80 |
| 48 | 9 | 11 | 2 | 20 | 6 | 13 | 29 | 90 |
| 49 | 28 | 31 | 0 | 19 | 0 | 8 | 4 | 90 |
| 50 | 22 | 18 | 5 | 19 | 2 | 10 | 24 | 100 |
| 51 | 8 | 13 | 6 | 33 | 6 | 13 | 1 | 80 |
| 52 | 23 | 31 | 12 | 28 | 0 | 5 | 1 | 100 |
| 53 | 42 | 21 | 1 | 9 | 0 | 5 | 2 | 80 |
| 54 | 29 | 30 | 1 | 9 | 0 | 1 | 0 | 70 |
| Count | 1029 | 1155 | 195 | 1164 | 143 | 553 | 251 | 4490 |

**Table 3. Basic Model Summary**

***** Regression Analysis *****

Response variate: score
Weight variate: 1/ svar
Fitted terms: Constant, YClass, PYear

*** Summary of analysis ***

| | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Regression | 4 | 6.249 | 1.5623 | 10.11 | <.001 |
| Residual | 49 | 7.570 | 0.1545 | | |
| Total | 53 | 13.819 | 0.2607 | | |
| Change | -2 | -3.765 | 1.8827 | 12.19 | <.001 |

Percentage variance accounted for 40.8
Standard error of observations is estimated to be 0.393

*** Estimates of parameters ***

| | estimate | s.e. | t(49) |
|---|---|---|---|
| Constant | 3.205 | 0.214 | 14.98 |
| YClass 14/16 | 0.277 | 0.214 | 1.29 |
| YClass 18+ | 0.742 | 0.215 | 3.46 |
| PYear 61-70 | -0.751 | 0.221 | -3.41 |
| PYear 71+ | -1.038 | 0.214 | -4.85 |

*** Accumulated analysis of variance ***

| Change | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| + YClass | 2 | 2.4839 | 1.2419 | 8.04 | <.001 |
| + PYear | 2 | 3.7653 | 1.8827 | 12.19 | <.001 |
| Residual | 49 | 7.5696 | 0.1545 | | |
| Total | 53 | 13.8188 | 0.2607 | | |

**Table 4. DBH Model Summary**

```
***** Regression Analysis *****

 Response variate: score
   Weight variate: 1/ svar
     Fitted terms: Constant, dbh


*** Summary of analysis ***

              d.f.         s.s.         m.s.      v.r.  F pr.
Regression      1         8.575       8.5749     85.03  <.001
Residual       52         5.244       0.1008
Total          53        13.819       0.2607

Percentage variance accounted for 61.3
Standard error of observations is estimated to be 0.318

*** Estimates of parameters ***

                  estimate         s.e.     t(52)
Constant            -0.414        0.368     -1.13
dbh                 0.1293       0.0140      9.22

*** Accumulated analysis of variance ***

Change                 d.f.         s.s.         m.s.      v.r.  F pr.
+ dbh                    1       8.5749       8.5749     85.03  <.001
Residual                52       5.2439       0.1008

Total                   53      13.8188       0.2607
```

**Table 5. DBH and Age Model Summary**

***** Regression Analysis *****

Response variate: score
Weight variate: 1/ svar
Fitted terms: Constant + Age + dbh + dbh.Age

*** Summary of analysis ***

| | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Regression | 5 | 10.037 | 2.00739 | 25.48 | <.001 |
| Residual | 48 | 3.782 | 0.07879 | | |
| Total | 53 | 13.819 | 0.26073 | | |
| | | | | | |
| Change | -2 | -1.345 | 0.67253 | 8.54 | <.001 |

Percentage variance accounted for 69.8
Standard error of observations is estimated to be 0.281

*** Estimates of parameters ***

| | estimate | s.e. | t(48) |
|---|---|---|---|
| Constant | -1.559 | 0.651 | -2.40 |
| Age 31-40 | 0.253 | 0.994 | 0.25 |
| Age >40 | 3.99 | 1.01 | 3.95 |
| dbh | 0.1761 | 0.0283 | 6.23 |
| dbh.Age 31-40 | -0.0097 | 0.0411 | -0.24 |
| dbh.Age >40 | -0.1393 | 0.0380 | -3.67 |

*** Accumulated analysis of variance ***

| Change | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| + Age | 2 | 4.36391 | 2.18195 | 27.69 | <.001 |
| + dbh | 1 | 4.32796 | 4.32796 | 54.93 | <.001 |
| + dbh.Age | 2 | 1.34506 | 0.67253 | 8.54 | <.001 |
| Residual | 48 | 3.78186 | 0.07879 | | |
| | | | | | |
| Total | 53 | 13.81879 | 0.26073 | | |

**Table 6. Crosstabulation of Site by Straightness Score classes (mean DBH)**

| score<br>site | 1-2 | 3-5 | 6-7 | Mean |
|---|---|---|---|---|
| 1 | 35.0 | 40.9 | 41.8 | 39.0 |
| 2 | 27.6 | 29.6 | 31.8 | 28.9 |
| 3 | 24.0 | 28.9 | 30.7 | 27.7 |
| 4 | 24.0 | 22.8 | 24.3 | 23.5 |
| 5 | 22.4 | 25.8 | 31.9 | 24.3 |
| 6 | 27.2 | 30.8 | 35.2 | 29.2 |
| 7 | 20.7 | 22.0 | * | 21.0 |
| 8 | 24.4 | 28.7 | 26.8 | 25.9 |
| 9 | 26.1 | 27.1 | 31.5 | 27.7 |
| 10 | 27.8 | 33.8 | 37.7 | 32.7 |
| 11 | 25.3 | 26.5 | 27.0 | 25.9 |
| 12 | 25.0 | 26.0 | 31.0 | 26.8 |
| 13 | 20.3 | 21.3 | 24.3 | 20.6 |
| 14 | 25.5 | 24.3 | 31.8 | 25.6 |
| 15 | 27.1 | 26.4 | 24.9 | 26.7 |
| 16 | 24.4 | 25.2 | 27.1 | 25.0 |
| 17 | 34.5 | 37.2 | 42.2 | 37.3 |
| 18 | 41.6 | 43.1 | 45.5 | 43.5 |
| 19 | 25.1 | 29.3 | 29.4 | 26.8 |
| 20 | 26.3 | 28.2 | 28.8 | 27.8 |
| 21 | 31.5 | 32.9 | 34.6 | 33.2 |
| 22 | 21.4 | 23.0 | 23.7 | 22.3 |
| 23 | 27.8 | 28.5 | 32.4 | 29.8 |
| 24 | 23.1 | 23.6 | 26.0 | 23.6 |
| 25 | 30.2 | 34.5 | 37.4 | 34.9 |
| 26 | 25.6 | 28.8 | 35.1 | 28.5 |
| 27 | 25.1 | 27.8 | 31.1 | 27.9 |
| 28 | 25.0 | 30.9 | 34.2 | 28.6 |
| 29 | 22.8 | 26.1 | 32.0 | 25.9 |
| 30 | 23.4 | 26.7 | 27.9 | 25.0 |
| 31 | 22.5 | 25.1 | 33.5 | 23.5 |
| 32 | 21.7 | 22.5 | 24.8 | 22.2 |
| 33 | 28.3 | 30.1 | 33.3 | 29.9 |
| 34 | 19.4 | 20.8 | 23.1 | 20.4 |
| 35 | 19.2 | 20.2 | * | 19.5 |
| 36 | 21.6 | 22.4 | 31.0 | 21.9 |
| 37 | 22.6 | 26.0 | 27.0 | 25.1 |
| 38 | 25.0 | 26.7 | 30.1 | 26.5 |
| 39 | 27.3 | 28.5 | 31.8 | 29.6 |
| 40 | 25.4 | 27.7 | 36.1 | 28.6 |
| 41 | 29.4 | 31.7 | 38.5 | 34.3 |
| 42 | 18.6 | 21.8 | * | 18.9 |
| 43 | 34.6 | 34.4 | 38.6 | 35.2 |
| 44 | 26.3 | 28.2 | 29.0 | 27.1 |
| 45 | 24.2 | 24.6 | 27.8 | 24.7 |
| 46 | 26.0 | 28.6 | 32.0 | 28.1 |
| 47 | 21.0 | 22.7 | 23.6 | 21.9 |
| 48 | 24.6 | 27.1 | 32.7 | 29.2 |
| 49 | 21.6 | 23.7 | 25.9 | 22.6 |
| 50 | 27.0 | 30.4 | 34.2 | 30.3 |
| 51 | 24.6 | 28.6 | 29.5 | 27.7 |
| 52 | 20.4 | 22.7 | 25.0 | 21.6 |
| 53 | 21.9 | 22.4 | 28.0 | 22.5 |
| 54 | 21.0 | 22.3 | 32.0 | 21.4 |
| Mean | 24.7 | 28.3 | 32.8 | 27.3 |

**Table 7. Sites with DBH for scores (1-2) v (6-7) significantly different (P<0.05) (tested for 27 out of 54 sites)**

| site | DBH overall p-value(*) | DBH score(6-7) - score(1-2) contrast | se | p-value | site mean score |
|---|---|---|---|---|---|
| 1 | 0.0000 | 6.84 | 1.55 | 0.0000 | 3.89 |
| 3 | 0.0075 | 6.73 | 2.33 | 0.0054 | 3.68 |
| 5 | 0.0000 | 9.51 | 1.78 | 0.0000 | 2.73 |
| 6 | 0.0001 | 8.04 | 1.92 | 0.0001 | 2.89 |
| 9 | 0.0002 | 5.44 | 1.32 | 0.0001 | 3.72 |
| 10 | 0.0000 | 9.94 | 1.57 | 0.0000 | 3.89 |
| 16 | 0.0576 | 2.63 | 1.10 | 0.0187 | 2.74 |
| 21 | 0.1307 | 3.09 | 1.55 | 0.0496 | 4.28 |
| 23 | 0.0016 | 4.54 | 1.28 | 0.0006 | 4.04 |
| 25 | 0.0025 | 7.29 | 2.08 | 0.0007 | 4.46 |
| 27 | 0.0005 | 6.02 | 1.45 | 0.0001 | 3.82 |
| 32 | 0.0578 | 3.01 | 1.28 | 0.0210 | 2.51 |
| 34 | 0.0438 | 3.66 | 1.45 | 0.0142 | 2.99 |
| 37 | 0.0030 | 4.38 | 1.31 | 0.0013 | 4.07 |
| 39 | 0.0028 | 4.50 | 1.39 | 0.0017 | 4.53 |
| 41 | 0.0031 | 9.11 | 2.66 | 0.0015 | 4.52 |
| 43 | 0.0936 | 4.04 | 1.94 | 0.0429 | 3.16 |
| 46 | 0.0001 | 5.96 | 1.33 | 0.0000 | 3.47 |
| 48 | 0.0000 | 8.04 | 1.49 | 0.0000 | 4.76 |
| 49 | 0.0036 | 4.36 | 1.35 | 0.0018 | 2.69 |
| 50 | 0.0000 | 7.21 | 1.51 | 0.0000 | 3.87 |
| 53 | 0.0003 | 6.13 | 1.44 | 0.0001 | 2.09 |

(*) DBH for scores (1-2) v (3-5) v (6-7)

**Appendix 2**

## 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.*"

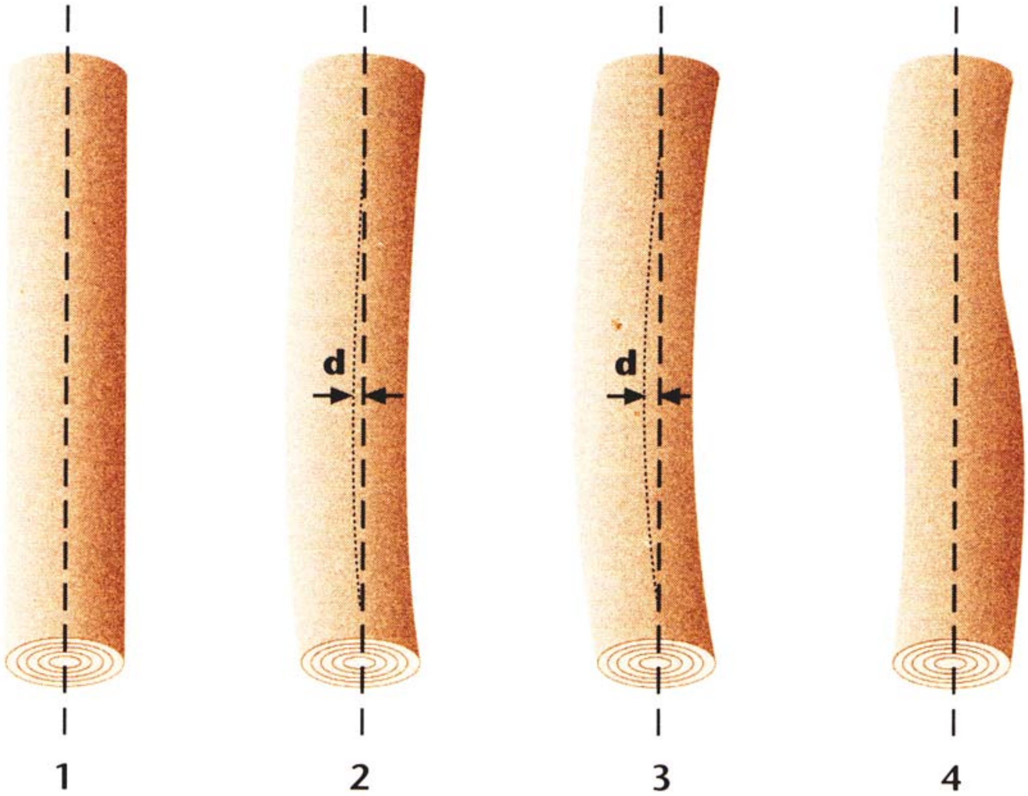


**Figure 1:** Logs 1 and 2 qualify as straight logs; logs 3 and 4 are not straight. Maximum deviation (d) on log 2 does not exceed 1 cm over 1 m length. Maximum deviation (d) on log 3 exceeds 1 cm over 1 m length. Log 4 shows bow in more than one direction.

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 | - | - | - |


**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 3**

## 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.

## Acknowledgements

The original efforts towards the development of a prototype system for the measurement of stem straightness by Janet Methley and other members of Forest Research Mensuration Branch were the catalyst for the work presented in this Information Note. The support of the Scottish Forestry Trust, Scottish Woodlands Ltd, Tilhill Economic Forestry Ltd, the United Kingdom Forest Products Association, is gratefully acknowledged.

Thanks are also due to Forest Enterprise for their co-operation and assistance with the project, in particular to the staff of Forest Planning and those at Ae, Galloway, Llandovery, Moray and Scottish Borders Forest Districts.

The participation of Robin Forestry Surveys in the method development was extremely helpful and we are grateful to them for their input. Thanks also to all Forest Research Staff who contributed to or commented on the work.

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