FINAL REPORT

SEPTEMBER 2000

A Survey Of Sitka Spruce Stem Straightness In South Scotland

A collaborative project commissioned by the Forest Research Timber Quality Steering Group, Borders Forestry Action Group and Dumfries and Galloway Forestry Action Group. The project was funded by The Forestry Commission, Forest Enterprise, the Scottish Forestry Trust, Scottish Woodlands Ltd., Tilhill Economic Forestry Ltd., Scottish Enterprise Borders, Scottish Enterprise Dumfries & Galloway, the United Kingdom Forest Products Association and Lothian Estates.

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EXECUTIVE SUMMARY

Key Points

1. This report presents a survey conducted in 1999 of the straightness of Sitka spruce stands in South Scotland planted before 1975. It provides no information on stands planted after 1975.

2. The survey encompassed 156 Forestry Commission stands and 101 private forestry stands and a total of 23,100 trees were measured. Each site consisted of a sub-compartment of at least 5 hectares in area.

3. The sample area represented 3.9% of Forestry Commission Sitka spruce and almost 2.5% of private Sitka spruce stands in the Scottish Borders and Dumfries and Galloway region.

4. There has been a reduction in stem straightness in the period covered by this survey.

5. The reduction in site mean straightness score with more recent plantings is partly due to these sites tending to be at higher elevation and also because more recent stands were planted at wider spacings and have been subject to less thinning. However, there are additional factors not accounted for in the survey but which may be the result of changes in plant provenance, reduction in forest maintenance and/or a decline in plant quality.

6. The age classes covered by the survey are already represented by current harvesting operations. The implications for future harvesting depend on the mix of material purchased. However, on average the percentage of straight stems available for sawmilling from individual sites will decline in South Scotland.

Additional Points

7. This report is the final output of a collaborative project entitled "*A Survey Of Sitka Spruce Stem Straightness In South Scotland*".

8. The project objective was to make an assessment of Sitka spruce stem straightness, as measured by the straightness scoring system, in a sample of forests in the Scottish Borders and Dumfries & Galloway regions.

9. The Timber Quality Steering Group comprising Forestry Commission representatives, growers, timber users, and independent scientific advisors advised the project. This group meets at 6 monthly intervals.

10. 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.

11. Concerns about the quality of future home grown sawlog supplies have been voiced throughout the forestry and wood using industries. It is feared that the proportion of stems of sufficient straight length for use as sawlogs is declining.

12. Straightness, which defines log-length was identified as the most important single factor affecting log quality in Sitka spruce (HGTAC Technical sub-committee).

13. It was felt desirable to have an assessment of the stem straightness of Sitka spruce in British forests and to begin to determine regional influences and any differences between public and private forestry.

14. The assessment method is based on an estimate of straight log lengths available in the first 6m of the stem.

15. The survey was designed to provide a description of Sitka spruce stem straightness in South Scotland forests and to determine the relationship between stem straightness scores and selected stand and site characteristics.

16. The stands selected were stratified by the following criteria:

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

    A site was classed as thinned where 50% or more of plots within the site had been thinned. Site stocking density at time of canopy closure was derived based on the mean site within-row and between-row spacing.

17. The sample was weighted by age class and reflected the geographic distribution of Sitka spruce stands in South Scotland.

18. Stem straightness of a sample of 80 or 100 trees were assessed at each site, following the method described in the protocol (Appendix 1). Measurements of spacing, slope and top height were made together with an indication of any tree forking and thinning.

19. Methley (1998) developed a prototype method of assessing log straightness in standing Sitka spruce trees. The scoring method adopted for this survey is based on the method developed by Methley (1998) with the addition of a "logs greater than 5 metres" category, making a 7 point scoring system to account for logs of 4.9 metres (Macdonald et al., 2000).

20. A Forest Officer who was involved in the development of the survey method trained all survey assessors to a common standard. 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 consistency of data collected.

21. The variables considered for inclusion in a predictive model were the factors planting period, yield class and thinning, and the variables stand density, elevation and DAMS[1] score.

22. The final model explains just over 60% of the variation in mean site straightness score. It has effects for the factors planting period, yield class and thinning, and the variables stocking density, elevation and DAMS score. There are interaction effects between planting period and Yield Class, between density and planting period and between density and Yield Class.

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[1] DAMS (Detailed Aspect Method of Scoring) is a measure of windiness derived from elevation, topographic shelter, funnelling, aspect and region of the country (Quine and White, 1993)

23. Specific elements of the final model are based on sparse data and should therefore be treated with caution; e.g., there were no data for thinned sites of Yield Class ≤12 planted in 1971-75.

24. Sites with higher site mean straightness scores have a greater range of scores within the site.

25. Straightness score does not improve with age in the 15 years prior to typical felling ages.

26. Stands planted more recently than 1960 tend to have poorer form than those planted between 1941-60 and higher Yield Class stands tend to have poorer form compared to those with Yield Class ≤12 (see Figure 2, Figure 3 and Figure 4).

27. There is a positive effect of stocking density so that for a particular planting period and yield class there is increased straightness with increasing stocking.

28. Elevation and windiness (DAMS score) have a negative effect on straightness.

29. Straightness score increases if the stand has been thinned. This was apparent even though both systematic and selective thinning are included in the analysis.

30. No obvious difference in straightness was found between similar Forestry Commission and private forestry stands. Statistical evaluation is still to be carried out.

31. No obvious difference in straightness was found between similar stands in the Scottish Borders and Dumfries & Galloway. Statistical evaluation is still to be carried out.

32. The reduction of straightness score with increasing elevation, windiness and Yield Class may be due to an increased vulnerability to leader loss during summer winds.

33. Improved straightness at closer spacings is probably due to the constraints imposed by neighbouring trees that force individual trees to grow more vertically.

34. Within any site there is always a range of stem straightness scores. The sites with lower mean scores are those with a lower proportion of particularly straight stems.

Introduction

35. This report is the final output of a collaborative project entitled "*A Survey Of Sitka Spruce Stem Straightness In South Scotland*". The project was jointly funded by the Forestry Commission, the Scottish Forestry Trust, Scottish Woodlands Ltd, Tilhill Economic Forestry Ltd., Scottish Enterprise Borders, Scottish Enterprise Dumfries & Galloway and the United Kingdom Forest Products Association.

36. The Timber Quality Steering Group comprising Bob Selmes (Policy and Practice Division, FC), Andrew Smith (BSW), Graham Chalk (Tilhill Economic Forestry), Duncan Pollard (Scottish Woodlands), David Rook (Scottish Forestry Trust) and Nick Purdy (Forest Enterprise) advised and directed the project. The group met at 6 monthly intervals.

37. The objective of this project was:

> To make an assessment of Sitka spruce log straightness, as measured by the straightness scoring system, in a sample of forests in the Scottish Borders and Dumfries & Galloway regions.

38. This report provides a brief review of the background to the project and describes the methodology behind the survey, carried out between March 1999 and January 2000. A summary of findings is also included showing the straightness of existing Sitka spruce stands in South Scotland.

Background

39. Timber production in Scotland is due to rise significantly over the next 20 years, with annual sawlog output availability to be double current levels by 2020 (Smith and Gilbert, 1999, Appendix 3). Domestic demand for sawn timber over the same period is forecast to remain relatively static (Whiteman, 1996). Successful marketing of Scottish sawn timber is therefore dependent upon gaining increased market share from timber imported from outside the UK and from competing materials. 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.

40. Concerns about the quality of future home grown sawlog supplies have been voiced throughout the forestry and wood using industries. It is feared that the proportion of stems of sufficient straight length for use as sawlogs is declining. These concerns, which mainly involve Sitka spruce, are based on the 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).

41. Investment in sawmilling technology to process the increased softwood supply for the construction market requires 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).

42. 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; Smith and Gilbert, 1999, Appendix 3). To date there has been no comparable estimate of **quality.** An assessment of timber quality at this strategic level will require a standardised method of assessing quality that can be applied to stands throughout Britain.

43. Methley (1998) and Macdonald et al. (2000) have developed a prototype method of assessing log straightness in standing Sitka spruce trees. For conversion of trees into sawn timber the straightness of the stem is the primary factor affecting optimum conversion into desired lengths, i.e. straightness has been recognised as the single most important factor determining sawlog quality (HGTAC Technical sub-committee). 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. The assessment method is based on an estimate of straight log lengths available in the first 6m of the stem (see Appendix 1).

44. The work described in this report was carried out to gather information on the straightness of the existing resource in South Scotland, likely changes in straightness with time and to provide data for the development of a predictive model for the whole of the United Kingdom.

Methodology

(Also see Appendix 1: Revised Protocol for Stem Straightness Assessment in Sitka Spruce)

45. The South Scotland Stem Straightness Survey encompassed 156 Forestry Commission stands selected at random from Forest Enterprise records (sub-compartment database) and 101 private forestry sites. The population for study was all Sitka spruce stands in the Scottish Borders and Dumfries & Galloway council regions, planted between 1941 and 1975 inclusive, with a Yield Class of 6 or above.

46. It was envisaged that the data collated from these sites would be analysed in two ways:

> *1. Summarised to provide a description of Sitka spruce stem straightness in South Scotland forests, broken down by planting period and region.*
> *2. To examine and model the relationship between stem straightness scores and selected stand/site characteristics, planting period (age), Yield Class, spacing, thinning treatment and windiness.*

Sampling Strategy

47. An estimate of the total area of Sitka spruce high-forest within the two regions was obtained from the National Inventory of Woodlands. These data were 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. This estimate is based on Forest Enterprise (FE) data for the regions concerned and information on planting for the whole of Scotland contained in the FC Annual report for 1980. Trees younger than 1975 were not considered

because they were likely to be too small to meet the criteria required for the stem straightness assessment (Appendix 1).

Table 1: Area of Sitka spruce in Borders and Dumfries & Galloway regions for each planting period covered by the survey

		Area of Sitka Spruce High Forest Category 1				
		1941-1950	1951-1960	1961-1970	1971-1975 (65% 1971-80)	Total for 1941-1980
Scottish Borders	FC	500	1900	3200	5600	8800
Scottish Borders	Non FC	300	700	9200	9100	18300
TOTAL SCOTTISH BORDERS		**800**	**2600**	**12400**	**14700**	**27100**
Dumfries & Galloway	FC	1000	7600	10400	11700	22100
Dumfries & Galloway	Non FC	500	2400	15800	8900	24700
TOTAL DUMFRIES & GALLOWAY		**1500**	**10000**	**26200**	**20600**	**46800**
South Scotland	FC	1500	9500	13600	17300	30900
South Scotland	Non FC	800	3100	25000	18000	43000
TOTAL SOUTH SCOTLAND		**2300**	**12600**	**38600**	**35300**	**73900**

48. 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 88800ha.

49. All stands were at least 5 ha in size (see paragraph 58). The stands were stratified as follows:

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

    Periods 1941-1950 and 1951-60 were condensed into one period. This was because there was relatively little planting in the entire period and there was little change in the types of areas planted or the silviculture practised.

50. Every combination of these factors gives a total of 54 different stand types. Replicating each combination three times gave a minimum of 162 stands required for the survey. In total 257 sites were sampled as shown in Table 4.

Weighting the Sample by Age Class

51. To reflect the different geographic distribution by age class, ideally the sites should be located as indicated in Table 2 and Table 3. The actual distribution is slightly different due to the availability of sites especially in the 1941 - 1960 age class (Table 4).

Table 2: Proposed area and number of sites to be surveyed

Planting Period	Area of Sitka spruce (ha)	% of total area	Number of Sample Plots as % of planted area	Required for Modelling	Suggested Distribution for Survey
1941-1960	14927	17%	43	54	54
1961-1970	38602	43%	108	54	102
1971-1975	35283	40%	100	54	94
Total	88812	100%	251	162	250

Table 3: Proposed distribution of sites by planting period and region

Planting Period	Scottish Borders	Dumfries and Galloway	Total
1941-1960	13	41	54
1961-1970	33	69	102
1971-1975	40	54	94
Total Distribution	86	164	250
Percentage Distribution	34%	66%	100%

Table 4: Actual distribution of sites by planting period, region and ownership

Planting Period	Scottish Borders		Dumfries and Galloway		Total
	FC	Non-FC	FC	Non-FC	
1941-1960	12	2	27	7	48
1961-1970	15	13	46	34	108
1971-1975	25	14	31	31	101
Total Distribution	52	29	104	72	257
Percentage Distribution	20%	11%	41%	28%	100%

Site Selection - FC Sites

52. Initially the Forest Enterprise Sub-Compartment Database (SCDB) was used to stratify the sites by planting period and yield class, with information on thinning and spacing used where available.

53. 162 Sites were selected at random from within the strata. Of these 162 sites, 156 were surveyed. The remaining 6 sites were removed from the survey as they were not suitable, i.e.; the site had been felled or had suffered severe wind damage.

54. The total area of sub-compartments selected was 1618ha which amounts to 3.9% of Forest Enterprise Sitka spruce in the area.

Site Selection – Private Forestry (Non-FC) Sites

55. 101 sites were selected randomly from private forests in line with the proposed stratification for FC sites using the available forest records. The specific number of sites selected were weighted using data obtained from the National Inventory of Woodlands although the actual number of sites surveyed varied from these figures due to difficulties in finding crops 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 in some cases.

56. Sites used for the survey included forests owned or managed by:

Tilhill Economic Forestry Ltd.
Scottish Woodlands.
Lothian Estates.

57. The total area of sub-compartments selected was approximately 1160ha which amounts to almost 2.5% of private forestry Sitka spruce in the area.

Defining Sample Size

58. During the initial validation of the Stem Straightness Assessment Protocol, data taken from a number of Sitka spruce permanent sample plots were analysed to show how many trees were required to provide suitable representation of a site. The analysis showed that in these regions increasing the sample size beyond 60-80 trees did not greatly increase the precision of the estimate (Macdonald et al., 2000). These numbers are very similar to those required for mensurational tariffs. 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.

Preparation for Field Data Collection

59. Once the stands had been selected, 1:10000 maps were made up for each site. The number of plots required for each stand was determined and the position of each plot was marked randomly on the map. The method for randomly designating the sample plots was to overlay a map of the 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 (see also Appendix 1). From the plot centre a bearing was generated by using a list of random numbers between 1 and 360 and used sequentially. The numbers were printed on a waterproof field-sheet. Trees of sufficient DBH up to 1.5 meters either side of this bearing from the centre of the plot were numbered 1-10 with DBH, straightness score being taken for each tree and the presence of any forking recorded.

Field Data Collection

60. 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.

61. The data were 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 not-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

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

In-row spacing:
This was generated by measuring the distance between the centres of 6 trees grown in a row. 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 "established spacing" per plot, which is used to calculate stocking density at establishment.
Between-row spacing:
As in-row spacing, measured across the rows.
In-row and between-row slope angle:
Used to correct the spacing for slope angle.
Thinned or not-thinned:
All plots showing evidence of thinning of whatever form, including respacing, were marked as thinned. No distinction was made between systematic and selective types of thinning.
Top height:
The height of the tree with the largest DBH within 5.6 m of the plot centre was taken. The top height for a sub-compartment was the average of these heights.

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 metres was noted.

Elimination of Bias

63. 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 randomised.

Straightness Scoring System

64. The scoring method adopted for this survey is based on the existing method developed by Methley (1998). Trained assessors carried the survey out using purely visual assessment.

65. The existing 6 point scoring system developed by Methley (1998) accounted for a maximum log length defined as "logs greater than 4 meters". This system was further revised with the addition of a "logs greater than 5 meters" category, making a 7 point scoring system. The addition of the extra category ensures that the commonly required 4.9-metre log length can be identified. (Macdonald et al., 2000). A grading system has also been introduced to provide some indication of the spread in straightness scores within a stand (

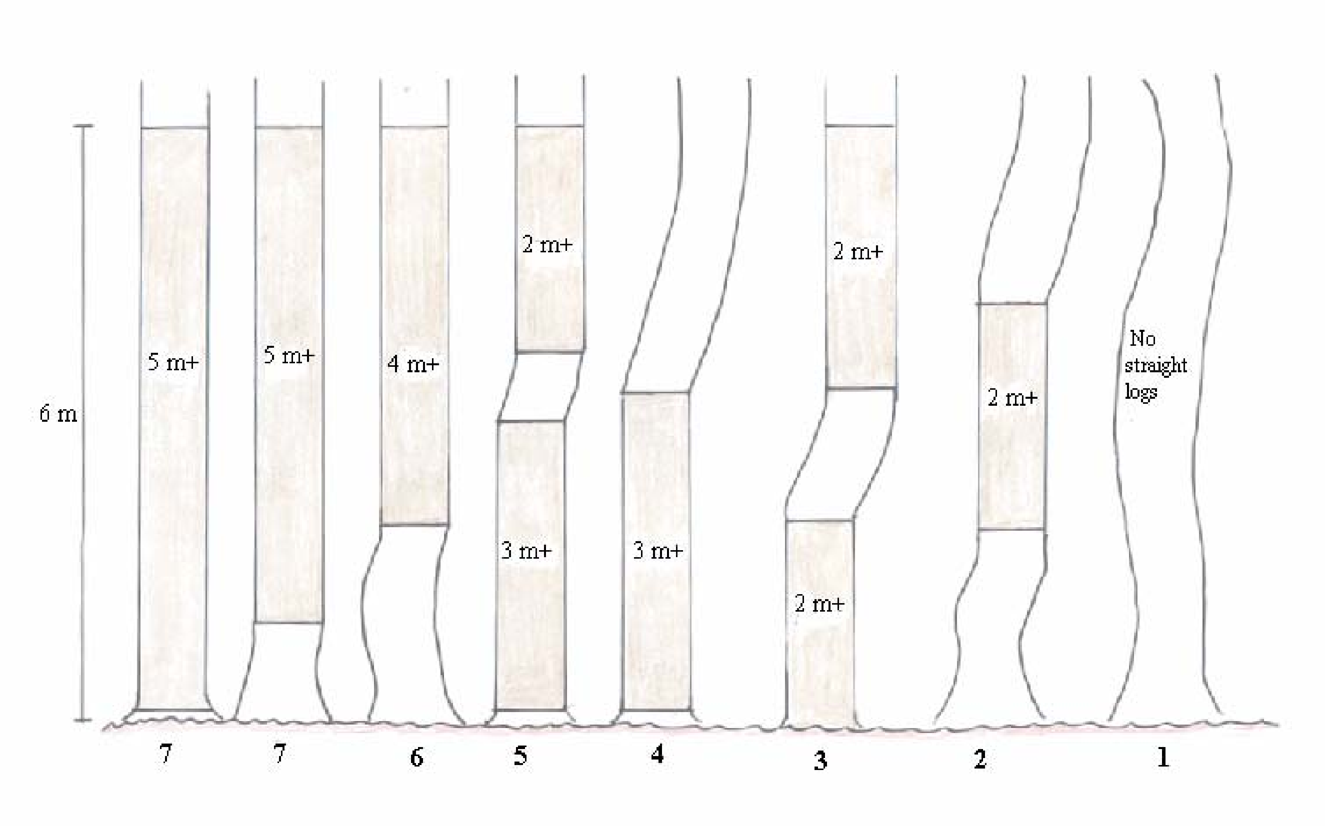
66. Development and testing of the revised stem straightness assessment method is catalogued in Appendix 1.

Assessor Training and Staff Changes During Survey

67. A Forest Research Officer who had had previous 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.

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

Figure 1: Different combinations of log lengths in the first 6m showing gradual reduction in straightness from left to right (Macdonald et al., 2000)



Straightness Score

Table 5: Stand Straightness Grading System

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

Statistical Analysis of Sitka Spruce Straightness Scores *(also see Appendix 2)*

70. A summary of the statistics of the 257 sites surveyed is provided in Table 6. The mean score for each region and ownership represents the average of the mean straightness score for all sites within that region and ownership.

Table 6: Average statistics of stem straightness for surveyed sites

		Number	Mean Score	Variance	S.E. of Mean
Dumfries & Galloway	Forestry Commission	104	3.16	0.901	0.093
	Private	72	2.43	0.741	0.101
	All sites	176	2.86	0.963	0.074
Borders	Forestry Commission	52	3.25	0.605	0.108
	Private	29	2.81	0.756	0.161
	All sites	81	3.09	0.696	0.093
All South Scotland	Forestry Commission	156	3.19	0.800	0.072
	Private	101	2.54	0.768	0.087
All sites		**257**	**2.94**	**0.888**	**0.059**

71. A site was classed as thinned where 50% or more of plots within the site had been thinned. Site stocking density was derived based on the mean site within-row (w) and between-row (b) spacing, i.e., stocking density=10,000/(b*w).

72. There were 257 sample sites comprising 23,100 trees. Site mean straightness scores and variances were calculated from the individual tree data. Relevant summary statistics are attached (Table 6, Appendix 2.1), together with straightness score cross-tabulations (means and counts) for site characteristics (Appendix 2.2).

73. Note that there are only 2 sites that are thinned with a Yield Class ≤ 12.

74. The attached plot of the variance of mean straightness on a site against site mean straightness score (Appendix 2.3) shows a clear positive relationship, inferring that higher site mean straightness scores are more variable.

75. Model A is the analysis of site mean straightness score weighted inversely by site variance (which here gives greater weight to the lower, more precisely determined, site means in the model-fitting). The variables considered for inclusion were factors planting period, yield class and thinning, and variables density, elevation and DAMS score. Relevant interactions were considered where possible.

76. The preliminary analysis (indicating candidate effects) (Appendix 2.4) and the final model are attached (Appendix 2.5). The candidate effect dams.thin (implying a different effect of DAMS score whether the site was thinned or not) did not enter the final model.

77. The final model explains just over 60% of the variation in mean site straightness score. It has effects for the factors planting period, Yield Class and thinning, and the variables stocking density, elevation and DAMS score. There are interaction effects between planting period and Yield Class, between stocking density and planting period and between stocking density and Yield Class. These effects are quantified in the attached model diagnostics (Appendix 2.5).

78. The parameter estimates show the contribution of each model term to the estimated site mean straightness score. A positive value denotes an increase to the estimated straightness score and a negative value a decrease. For the factors planting period, Yield Class and thinning the parameters for the base levels of each, i.e., planting period 1941-60, Yield Class ≤12 and no

thinning, were fixed at zero.

79. The first term, labelled Constant and with a value here of 6.39, is the estimate of the site mean straightness score before contributions due to model factors and variables.

80. Where a factor or variable is present as a main effect only, i.e., not in an interaction term, its contribution to the mean straightness score is straightforward. For a thinned site we have a contribution of 0.276 and, for any site, elevation is multiplied by -0.002358 and DAMS score is multiplied by -0.0544.

81. For effects in interactions the contribution is broken into constituent parts. The interaction effects for planting period, Yield Class and stocking density are tabulated below the Model A diagnostics (Appendix 2.5).

82. The predictions for Model A for specific values of stocking density (2,500 trees/ha), elevation (300 m) and DAMS score (16) are attached in a summary cross-table (Appendix 2.6). Here thinned sites have a slightly higher predicted mean for each site factor combination (to see the overall significant effect of thinning requires the specific table for thinning alone). There is a different Yield Class change within each planting period. For example, for thinned sites planted 1941-60 the mean straightness score decreases from Yield Class ≤12 to 14/16 and increases from Yield Class 14/16 to 18+, whereas for 1961-70 the mean score increases from Yield Class ≤12 through 14/16 to 18+.

83. An example calculation for an individual site is presented in Table 7.

Table 7: Calculation of predicted mean straightness score using Model A for Sitka spruce, YC 14/16, thinned, P61-70, stocking density = 2500 stems ha^{-1}, site elevation = 300 m, DAMS score = 16.

Term	Information	Calculation	Contribution
Constant			6.390
Thinned	Yes		0.276
Yield Class Planting Period	14/16 1961-70		-4.427
Stocking Density	2500	2500 x 8.18/10000	2.045
Elevation	300	300 x -0.002358	-0.707
DAMS	16	16 x -0.0544	-0.870
Final Score			**2.707**

Discussion of Statistical Analysis

84. Consideration of the Model A parameters indicates a positive effect of thinning and a negative effect of elevation and DAMS score on mean site straightness score. Thinning adds just over 0.25 (0.276), each rise of 100 m elevation subtracts nearly 0.25 (-0.2358) and an increase of 5 in the DAMS score subtracts over 0.25 (-0.272).

85. The interaction effects indicate a negative effect of planting period and yield class relative to planting period 1941-60 and Yield Class ≤12; these are associated with a positive effect of stocking density, except for planting period 1971-75 (Yield Classes ≤12 and 18+).

86. Specific elements of the prediction table for Model A are based on sparse data and should therefore be treated with caution, e.g., there were no data for thinned sites of Yield Class ≤12 planted in 1971-75. The practical significance of the predicted means should also be considered, i.e., whilst site means differing by 1.5 may be statistically significant, the practical implication may be different. For example, the product out-turn for two stands with mean scores of 5.8 and 4.3 are likely to be less different than two stands mean scores of 4.3 and 2.8.

Graphical Representation of Key Points

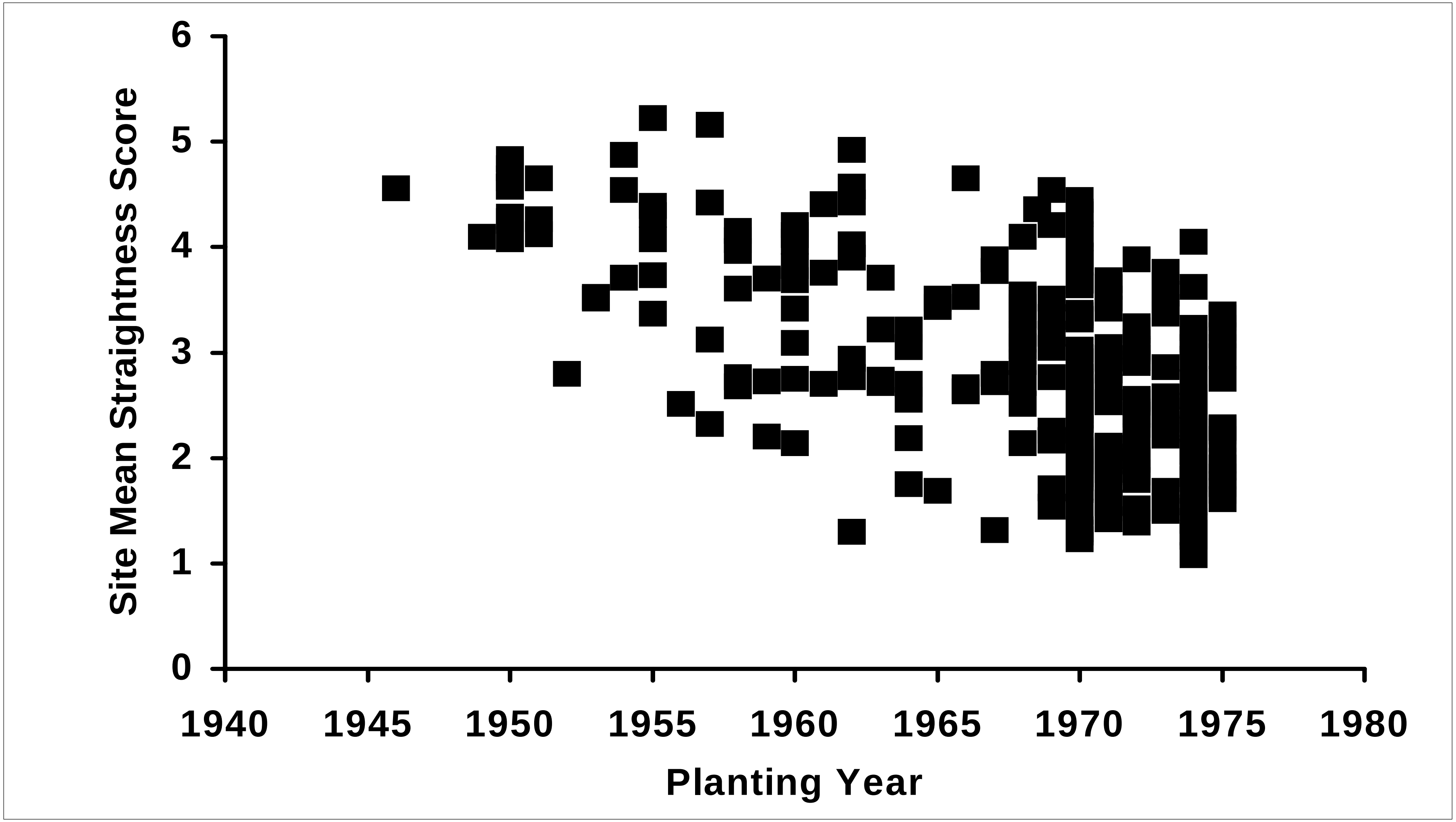


Figure 2: Site mean straightness score as a function of planting year.

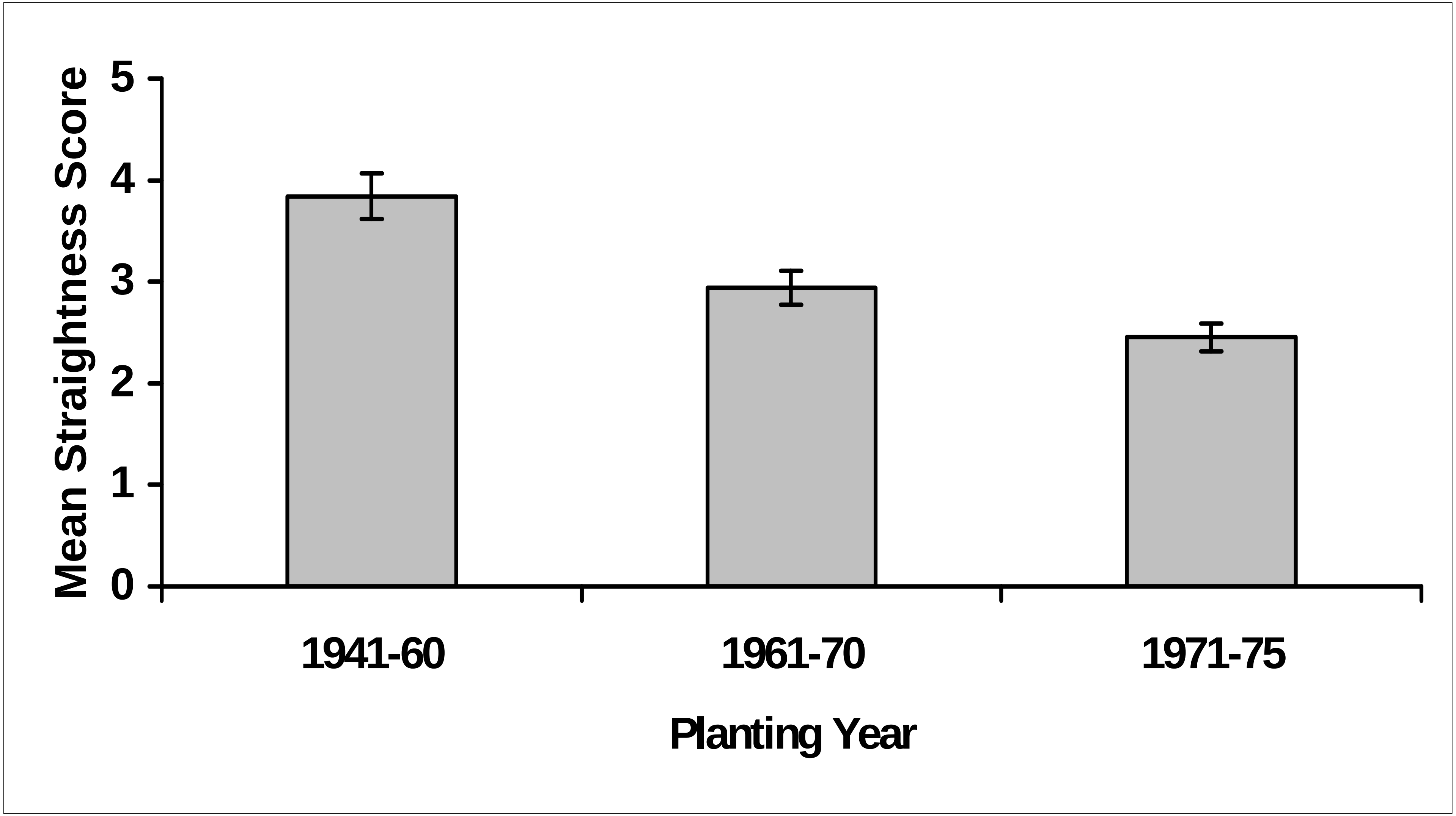


Figure 3: Histogram of mean straightness score for three planting periods sampled. Error bars show 95% confidence limits for the mean.

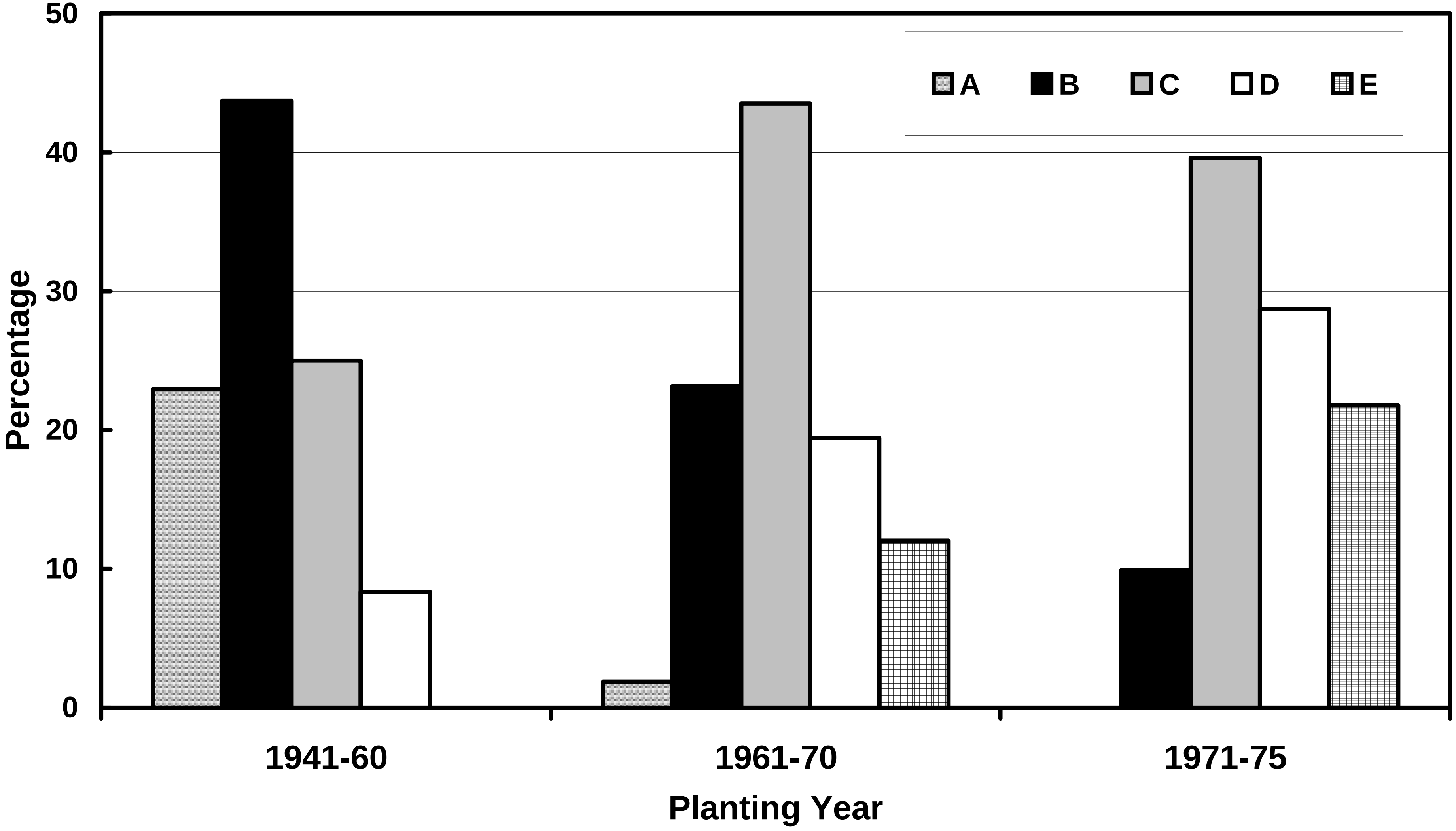


Figure 4: The distribution of straightness grades by planting period. See Table 5 for explanation of scoring system.

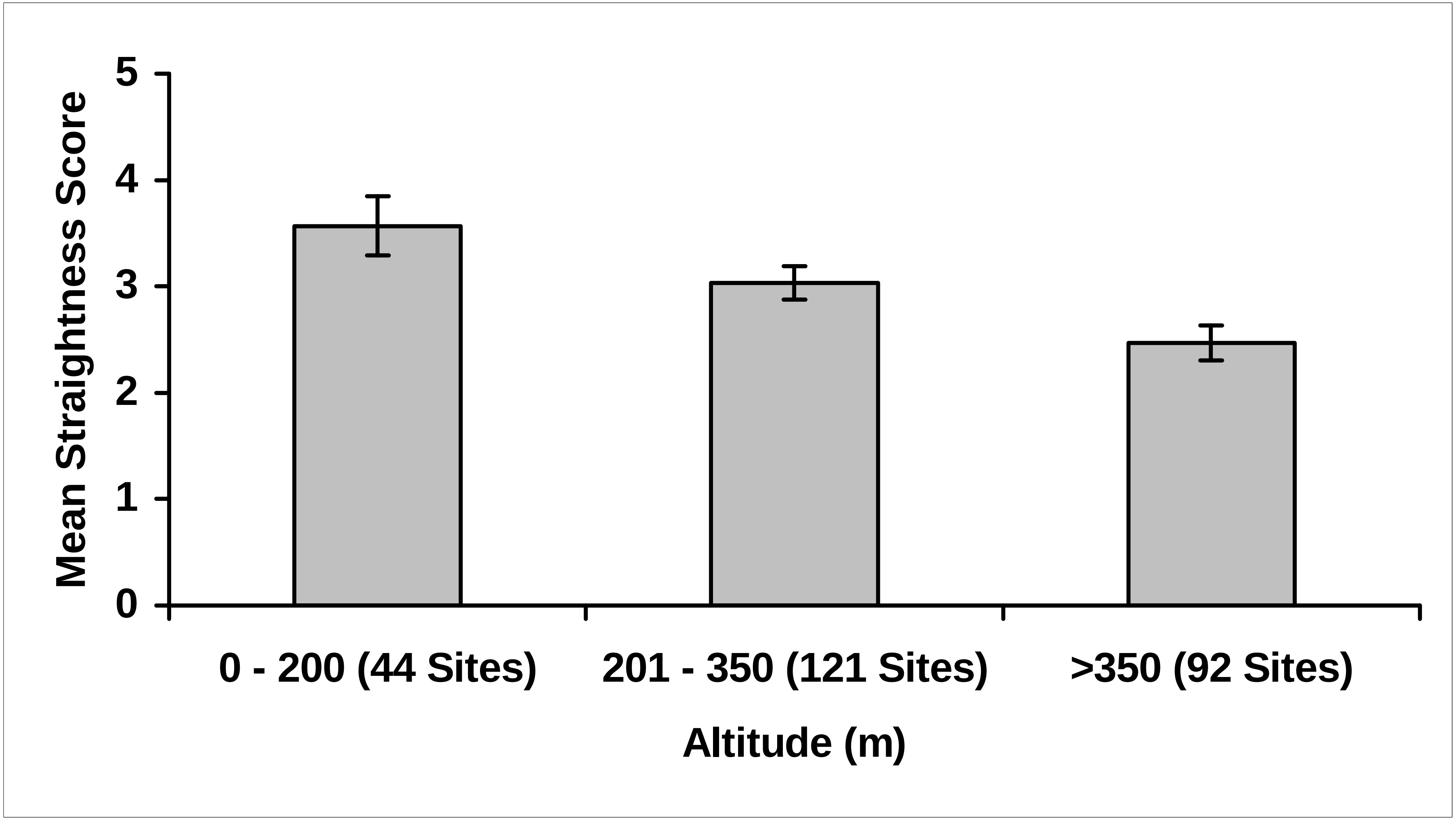


Figure 5: Histogram of mean straightness for different elevation bands. Error bars show 95% confidence limits for the mean.

Conclusions and Discussion

87. There has been a decline in the mean straightness score of Sitka spruce stands in the Borders and Dumfries & Galloway regions over the planting periods (1941-60, 1961-70, and 1971-75) covered by the survey. One explanation is that older trees become straighter with additional radial growth. Testing this hypothesis from data in this survey is not possible but a study using data from FC mensurational sample plots and radial growth patterns in bent trees showed no evidence of straightening for Sitka spruce between 25 to 40 years of age (Macdonald and Barrette, 2000)

88. The main conclusions of this report are concerned with the factors, which are associated with a downturn in stem straightness over the survey sample period.

89. Some of the reasons for a decline with planting period are due to more recent planting being at higher elevations, increases in tree spacing and a reduction in thinning. However, after removal of these effects there is still a strong influence of planting period. Possible reasons for this decline are changes in provenance of the plants, reduction in forest maintenance and/or a decline in plant quality. Checking the genetic origin of the stands surveyed will be attempted at a future date if it is possible to obtain planting records from Forestry Commission district offices. A decline in plant quality might have resulted from the large amount of planting that took place in the 1960s and 1970s in the region and a consequent reduction in quality control of the plants used.

90. The reduction in stem straightness with increasing elevation, windiness (DAMS score) and, generally, Yield Class may be due to a number of reasons. One possibility is increased risk of leader loss for faster growing trees or those at higher elevations and windier locations during summer storms but this hypothesis requires testing. Increased elevation may also result in increased frost damage to growing tips.

91. Straightness improves with closer spacing. At close spacings trees are constrained to grow directly upwards from a young age due to the close competition of neighbours. At wider spacings there is more lateral room for growing tips to exploit in the search for light and this can lead to bent stem form. In the past 5-10 years there has been a move to closer spacing, although achieving full stocking still poses many problems.

92. Thinning leads to an increase in stem straightness. Although there was no discrimination in the survey between different types of thinning enough examples of selective thinning must have been included to enhance the straightness of thinned stands.

93. Although the analysis shows that stem straightness in older crops in markedly better than in the crops planted between 1971 and 1975, the survey does not provide any information or prediction of stem straightness in crops planted after 1975.

94. The validity of the final model for stem straightness must be further tested. Further validation should allow for an industry standard model to be utilised within the upland forestry industry.

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APPENDIX 1: Protocol for Stem Straightness in Sitka Spruce

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 as the standard, 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.

Introduction

1. 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.

2. 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).

3. 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).

4. 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 will require a standardised method of assessing quality that can be applied to stands throughout Britain.

5. 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.

6. 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.

   A collaborative project funded jointly by the Forestry Commission, the Scottish Forestry Trust, Scottish Woodlands Ltd, Tilhill Economic Forestry Ltd and the United Kingdom Forest Products Association was undertaken in 1998/99 to follow up these recommendations. 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.

Revised Protocol

Sampling

7. 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.

8. 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

9. 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.

10. 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.

11. 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

12. 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.

13. 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.*"

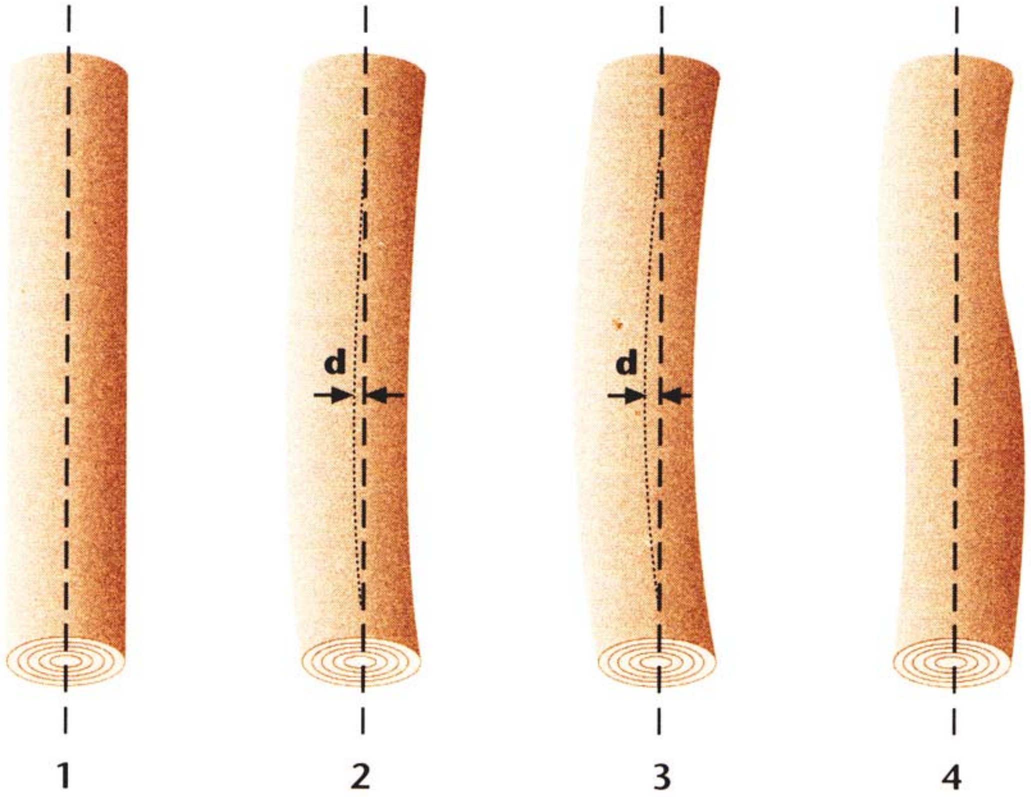

Figure 1: Logs 1 and 2 qualify as straight logs; logs 3 and 4 are not straight. Maximum deviation (d) on log 2 does not exceed 1 cm over 1 m length. Maximum deviation (d) on log 3 exceeds 1 cm over 1 m length. Log 4 shows bow in more than one direction.

14. 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).

15. 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.

16. A score should be assigned to each tree according to the scoring system shown in Table 3 below. 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	-	-	-

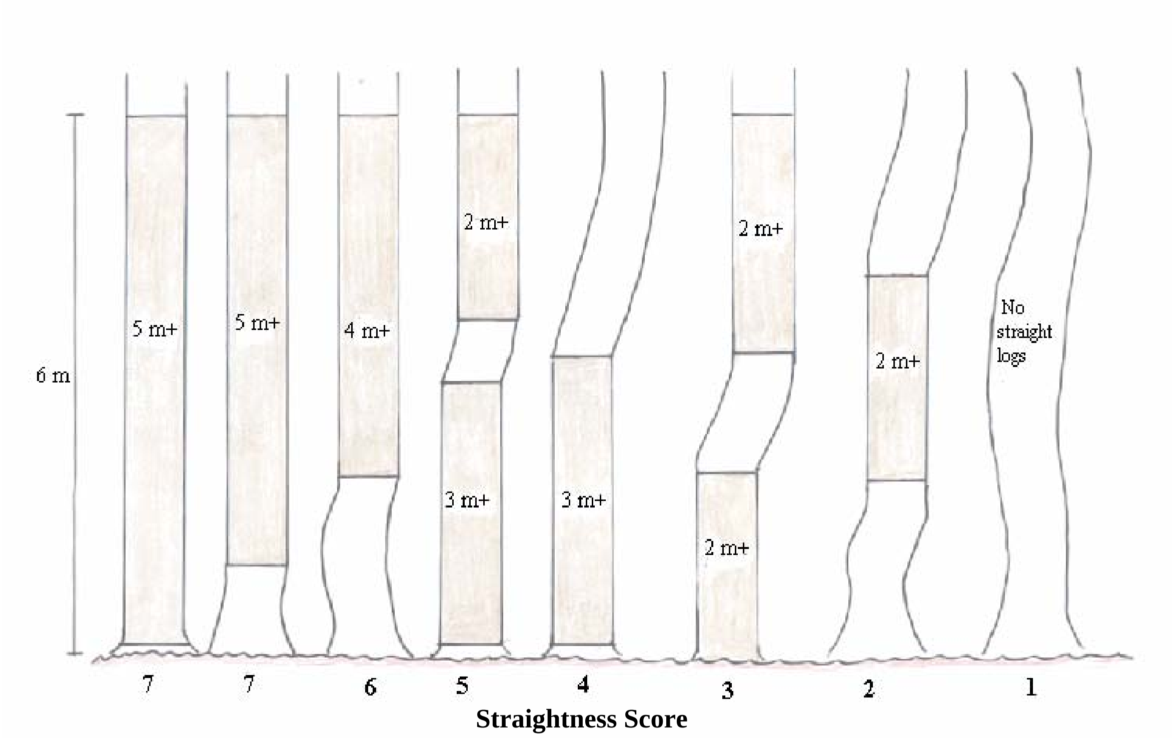

Figure 2: Different combinations of log lengths in first 6 m showing gradual reduction in quality from left to right (After Methley 1998).

17. 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

18. 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

19. 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.

20. 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.

21. 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
- Pre-harvest assessment of felling coupes for valuation purposes and to facilitate the selection of optimal cutting regimes
- Assistance for decision making in forest management, e.g. thinning requirements, rotation lengths, forest design planning

Recommendations

22. The scoring system described in this Information Note is recommended as the standard scoring system for measuring straightness in British forestry. It should be used whenever an assessment of stand stem straightness is required.
23. Straightness Quality Grade (A-E) provides useful information about the stem straightness distribution within a stand and the likely log assortment. It is recommended as the standard grading system to apply to stands.
24. The mean straightness score for a stand provides a method of making comparisons between stands.
25. Although the straightness assessment was developed for Sitka spruce it is equally appropriate for any other conifer species.

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, Borders Enterprise and Dumfries and Galloway Enterprise is gratefully acknowledged.

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Appendix: Refinement and Testing of the Prototype Method

A1 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.

A2 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.

A3 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).

A4 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).

A5 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.

A6 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 2: Analysis of Sitka Spruce Straightness Scores: Supporting Data

APPENDIX 2.1

Summary statistics for site mean data

```
    Identifier   Minimum      Mean   Maximum    Values   Missing
         %fork      0.00     13.94     75.00       257         0
           dbh     16.29     23.32     31.75       257         0
          spbr     1.430     2.037     2.783       257         0
          spir     1.234     2.063     3.330       257         0
          elev       0.0     299.7     545.0       257         0
          dams     10.80     15.67     22.33       257         0
       density      1320      2520      4527       257         0

          s[1]      0.00     26.87     78.00       257         0
          s[2]      5.00     23.64     44.00       257         0
          s[3]     0.000     8.093     27.00       257         0
          s[4]      0.00     11.34     44.00       257         0
          s[5]     0.000     6.518     37.00       257         0
          s[6]     0.000     6.743     30.00       257         0
          s[7]     0.000     6.642     36.00       257         0

            %1      0.00     29.80     92.50       257         0
           %13     18.00     65.13    100.00       257         0
           %47      0.00     34.86     82.00       257         0
           %67      0.00     14.93     61.30       257         0

    Identifier    Values   Missing    Levels
          site       257         0       257
         pyear       257         0         3
            yc       257         0         3
          thin       257         0         2
          type       257         0         4
         grade       257         0         4
```

%fork	**percentage of forked trees per site**
s[1]…s[7]	**number of trees per site in straightness class 1…7**
%1	**percentage of trees per site in straightness class 1**
%13	**percentage of trees per site in straightness class 1 to 3**
%47	**percentage of trees per site in straightness class 4 to 7**
%67	**percentage of trees per site in straightness class 6 to 7**

APPENDIX 2.2

Crosstabulation of straightness score (means and counts)

```
                            Mean
                thin NO_thin    thin
  pyear           yc
1941-60          ≤12    4.03    4.56
               14/16    3.60    3.39
                 18+    3.96    4.25
1961-70          ≤12    2.34    3.38
               14/16    2.67    3.29
                 18+    3.19    3.51
1971-75          ≤12    2.20       *
               14/16    2.38    2.37
                 18+    2.50    3.06

                          Counts
                thin NO_thin    thin
  pyear           yc
1941-60          ≤12       9       1
               14/16      16       6
                 18+       8       8
1961-70          ≤12      25       1
               14/16      28      14
                 18+      18      22
1971-75          ≤12      30       0
               14/16      22       6
                 18+      20      23
```

APPENDIX 2.3

```
                     Straightness score

    -+---------+---------+---------+---------+---------+
    I                                                  I
    I                                                  I
    I                                                  I
6.4 I                                                  I
    I                                                  I
    I                                                  I
    I                                                  I
    I                                                  I
    I                                                  I
5.6 I                                                  I
    I                                                  I
    I                                                  I
    I                        2                         I
    I                      *        *                  I
    I                         *  *                     I
4.8 I                         * 3 *   *                I
    I                           *      **              I
    I                     * ** *           *2          I
    I                        2**  * *                  I
    I                   *  **  *  2  2   *             I
    I                        2   ** ** *               I
4.0 I                    ** **   *  * 2  2 *           I
    I                *  2* *         ***  *            I
    I                2*  *   *   *  *  *     *         I
    I                *  2  2**2 *   2  **              I
    I                 2 * *  * *2 **2 * *              I
    I              2  2*  3*   2  **                   I
3.2 I               * ***2*  *          *              I
    I                ****           *          *       I
    I           *     *3  2*  *           *            I
    I               2*2* *  *          *               I
    I           **  2* 2   *    *   *                  I
    I          *  ** *2*  *                            I
2.4 I            32 *2*  2    *                        I
    I             2*2                                  I
    I           2 3 **                    *            I
    I           2 **                                   I
    I         * *2*  *                                 I
    I            2 *                                   I
1.6 I         *2*                                      I
    I        22*2                                      I
    I       *22**                                      I
    I     * 32*2                                       I
    I     ** * 2                                       I
    I      2 *                                         I
0.8 I     3*2                                          I
    I                                                  I
    I   *2                                             I
    I   5*                                             I
    I  *                                               I
    I *                                                I
0.0 I                                                  I
    -+---------+---------+---------+---------+----------
   1.0       2.0       3.0       4.0       5.0       6.0

               Site variance v Site mean
```

APPENDIX 2.4

Preliminary analysis for Model A
(site mean straightness score inversely weighted by site variance)

```
*** Accumulated analysis of variance ***

Change                 d.f.         s.s.         m.s.      v.r.  F pr.
+ pyear                   2      39.1826      19.5913     94.08  <.001
+ yc                      2      20.7540      10.3770     49.83  <.001
+ thin                    1       5.1288       5.1288     24.63  <.001
+ pyear.yc                4       3.5790       0.8947      4.30  0.002
+ pyear.thin              2       0.7118       0.3559      1.71  0.184
+ yc.thin                 2       0.3693       0.1846      0.89  0.414
+ pyear.yc.thin           3       0.9833       0.3278      1.57  0.197
+ density                 1       1.2863       1.2863      6.18  0.014
+ elev                    1      10.2008      10.2008     48.99  <.001
+ dams                    1       1.5811       1.5811      7.59  0.006
+ density.pyear           2       2.0213       1.0107      4.85  0.009
+ density.yc              2       2.9310       1.4655      7.04  0.001
+ density.thin            1       0.7973       0.7973      3.83  0.052
+ density.pyear.yc        4       1.5517       0.3879      1.86  0.118
+ density.pyear.thin      2       0.7696       0.3848      1.85  0.160
+ density.yc.thin         1       0.1901       0.1901      0.91  0.341
+ elev.pyear              2       0.5314       0.2657      1.28  0.281
+ elev.yc                 2       0.4496       0.2248      1.08  0.342
+ elev.thin               1       0.3534       0.3534      1.70  0.194
+ elev.pyear.yc           4       0.4517       0.1129      0.54  0.705
+ elev.pyear.thin         2       0.4191       0.2096      1.01  0.367
+ elev.yc.thin            1       0.0077       0.0077      0.04  0.848
+ dams.pyear              2       0.4751       0.2376      1.14  0.322
+ dams.yc                 2       0.2197       0.1098      0.53  0.591
+ dams.thin               1       0.8255       0.8255      3.96  0.048
+ dams.pyear.yc           4       0.8131       0.2033      0.98  0.422
+ dams.pyear.thin         2       0.0552       0.0276      0.13  0.876
+ dams.yc.thin            1       0.5275       0.5275      2.53  0.113
Residual                201      41.8543       0.2082

Total                   256     139.0214       0.5431
```

(Figures in bold indicate candidate effects for final model)

APPENDIX 2.5

Final model and diagnostics Model A
(site mean straightness score inversely weighted by site variance)

```
*** Accumulated analysis of variance ***

Change                d.f.         s.s.         m.s.      v.r.  F pr.
+ pyear                  2      39.1826      19.5913     91.34  <.001
+ yc                     2      20.7540      10.3770     48.38  <.001
+ thin                   1       5.1288       5.1288     23.91  <.001
+ pyear.yc               4       3.5790       0.8947      4.17  0.003
+ density                1       1.4331       1.4331      6.68  0.010
+ elev                   1       9.8881       9.8881     46.10  <.001
+ dams                   1       1.8590       1.8590      8.67  0.004
+ density.pyear          2       2.7745       1.3873      6.47  0.002
+ density.yc             2       2.9464       1.4732      6.87  0.001
Residual               240      51.4759       0.2145

Total                  256     139.0214       0.5431

*** Summary of analysis ***

              d.f.         s.s.         m.s.      v.r.  F pr.
Regression      16        87.55       5.4716     25.51  <.001
Residual       240        51.48       0.2145
Total          256       139.02       0.5431

Percentage variance accounted for 60.5

*** Estimates of parameters ***

                                 estimate         s.e.    t(240)  t pr.
Constant                             6.39         1.01      6.31  <.001
pyear 1961-70                      -2.898        0.928     -3.12  0.002
pyear 1971-75                      -1.703        0.941     -1.81  0.072
yc 14/16                           -3.047        0.703     -4.33  <.001
yc 18+                             -1.305        0.819     -1.59  0.112
thin thin                           0.276        0.115      2.39  0.017
pyear 1961-70 .yc 14/16             1.518        0.392      3.87  <.001
pyear 1961-70 .yc 18+               1.357        0.434      3.12  0.002
pyear 1971-75 .yc 14/16             1.867        0.430      4.34  <.001
pyear 1971-75 .yc 18+               1.039        0.470      2.21  0.028
density                         -0.000276     0.000298     -0.92  0.356
elev                            -0.002358     0.000489     -4.82  <.001
dams                              -0.0544       0.0229     -2.38  0.018
density.pyear 1961-70            0.000365     0.000283      1.29  0.198
density.pyear 1971-75           -0.000367     0.000304     -1.21  0.228
density.yc 14/16                 0.000729     0.000197      3.70  <.001
density.yc 18+                   0.000325     0.000226      1.44  0.151
```

Interaction effects for planting year and yield class
(*with density (x 10(-4)*)**

	≤12	14/16	18+
1941-60	0	-3.047	-1.305
	-2.76	*4.53*	*0.49*
1961-70	-2.898	-4.427	-2.846
	0.89	*8.18*	*4.14*
1971-75	-1.703	-2.883	-1.969
	-6.43	*0.86*	*-0.42*

Predictions for Model A
(site mean straightness score inversely weighted by site variance)

```
*** Predictions from regression model ***

These predictions are estimated mean values.

The predictions are based on fixed values of some variates:

        Variate   Fixed value   Source of value
        density         2500.   Supplied
           elev         300.0   Supplied
           dams         16.00   Supplied

The standard errors are appropriate for interpretation of the predictions as
summaries of the data rather than as forecasts of new observations.

Response variate: smean

                      thin NO_thin            thin
                           predict      se predict      se
        pyear           yc
      1941-60          ≤12    4.12   0.334    4.39   0.341
                     14/16    2.89   0.289    3.17   0.295
                       18+    3.62   0.359    3.90   0.349
      1961-70          ≤12    2.13   0.116    2.41   0.160
                     14/16    2.42   0.109    2.70   0.130
                       18+    3.00   0.142    3.27   0.141
      1971-75          ≤12    1.50   0.145    1.77   0.181
                     14/16    2.14   0.144    2.41   0.161
                       18+    2.04   0.128    2.32   0.138
```

APPENDIX 3: Scotland: New Forecast Of Softwood Availability

SCOTLAND: NEW FORECAST OF SOFTWOOD AVAILABILITY

By Steve Smith and Justin Gilbert, Forestry Commission

Summary

Softwood availability in Scotland is set to double over the next 20 years. The longer term trend indicates that this peak of just over 10 million m^3 in the period 2017-2021, falls thereafter to around 6 million m^3 by the period 2042-2046. The following tables and charts, prepared jointly by the Forestry Commission and the Timber Growers Association and endorsed by the Forestry Commission's Advisory Panel, show the forecast of softwood availability in detail for the first 33 years and in outline for a further 35 years up to the period 2062-2066.

Introduction

This new softwood availability forecast for Scotland covers the next 68 years, enabling interested parties to put the detailed forecast for the earlier years into the longer term context. The Private Sector and Forest Enterprise data have been brought together and are published here on behalf of the Forestry Commission's Advisory Panel. However it is worth noting that the Forest Enterprise forecast and the Private Sector forecast data presented in this article have been arrived at through two quite separate processes, and therefore represent very different types of estimate.

Forest Enterprise Forecast

The Forest Enterprise has based its forecast on the detailed information on growing stock in each Forest District, together with harvesting prescriptions from the current forest design plans and crop management regimes. The output is therefore built up from the stand/felling coupe level and represents a production plan for the first five years and thereafter an indicative forecast of production.

Private Sector Forecast

The Private Sector forecast, on the other hand, is based on the much broader information about crops obtained from the National Inventory of Woodland & Trees (NIWT), together with a set of assumptions provided by a survey of Timber Growers Association members. The woodland is in a multiplicity of ownerships and the input assumptions do not include firm individual or collective plans to harvest timber at a particular time. The output for the Private Sector therefore represents a forecast of availability rather than a forecast of production.

The fundamental methodology of the Private Sector forecast (Morris, 1991) has not been changed significantly for this assessment. However, the results presented below were arrived at through a process of discussion and the modelling of various scenarios – to give more information on the background to the Private Sector forecast the FC will publish a Technical Paper (currently in prep.). A list of the key parameters used in the Private Sector forecast is given below.

The NIWT provided the basic Private Sector crop data. The overall area of conifer woodland was 87K ha more than that used in the 1995 forecast - this includes some new planting, and some FC disposals, but it also indicates that the updating of 1980 Census data was becoming less reliable. The NIWT showed there to be some 10.6% open space within woodland for the Private Sector in Scotland. The forecast then used productive net areas, which meant that the 'standard' 15% reduction used in 1995 did not have to be applied.

Some account of the timber potential of each stand was taken in the NIWT, with crops being assessed to be in one of 4 classes. The better two classes, considered capable of producing sawlogs, were included as normal in the forecast. The third class, defined as being good for small roundwood only, has also been included in the forecast, but the poorest class, defined as firewood only, has not been included (it may be presented as a potential biofuel resource at another time). The third class represented 3.5% of the woodland area, including over 5,000 ha of Lodgepole pine crops in North Scotland, while the poorest class represented only 1.5% of the woodland area.

Woodland that is currently already older than the assumed rotation lengths is defined as being 'over-mature'. For the 1995 forecast it was estimated that 45% of the over-mature timber would be felled over the next 20 years. For this forecast the percentages were adjusted for each geographic zone, with the differences taking into account factors such as the fact that many of the over-mature crops in North Scotland will be Caledonian pine.

In the 1995 forecast volume was reduced by a nominal figure of 5% to account for 'under-stocked and/or non-productive crops'. The NIWT gathered information on both stocking and on whether there were physical factors which would impede extraction. This information was used to formulate the more objective volume reduction factors of 5%, 3% and 4% for North, Mid and South Scotland respectively.

The 1994 TGA survey of the larger management companies and private estates was repeated to gain up to date information including yield class distribution, windthrow risk, thin/non thin intentions, and proposed rotation lengths. All the previous respondents were included plus an extra four management/consulting companies. Results for Sitka spruce, compared with 1994, showed a slight upward movement in the yield class distribution, a slight overall increase in the percentage to be thinned (although a decrease in South Scotland), while the rotation lengths stayed much as before. The main modification to these assumptions has been the spreading of the rotation lengths for species/yield class combinations to reflect the influence of forest design and restructuring.

The new set of yield models produced by the FC's Mensuration Branch were used. Compared with the previous set the effect has been to increase slightly the overall volume, and, more significantly, to increase the proportion of smaller top-diameter material – e.g. in Mid Scotland the amount of material in the 7-14cm class increased by over 25% when the new set of models was used.

Results

The data for Scotland in Table (1) is presented by three geographic zones corresponding to the old North, Mid and South FC Conservancies. These were retained to enable comparison with previous forecasts, and because they provide a reasonable broad-brush breakdown of marketing areas. Volume is given, as in previous forecasts, in cubic metres measured overbark and standing. A break from convention is the presentation by top-diameter classes – previous forecasts have used a fairly arbitrary ‘sawlog/small roundwood’ split, while Table (1) shows 4 classes leaving consumers to decide the split depending on their technical requirements.

Annual softwood availability is set to almost double over the next 20 years from the current 5.3 million m^3 to 10.4 million m^3 in the period 2017-2021. It is worth emphasising again here that the overall forecast is an estimate of *availability* rather than of *production*, because of the reasons mentioned earlier, especially in relation to the Private Sector.

The longer term trend, shown in Figure (1), indicates that over the following 25 years beyond the peak softwood availability will fall back almost to current levels. Figure (1) also shows that the FE production in the log term is less variable than the Private Sector availability line. Various scenarios were run for the Private Sector and while the value of the peak and trough could be moved up or down a little, and the timing could be moved back and forth a little, the general shape of the trend line was quite robust. Restocking is taken into account, but no allowance was made for new planting. However, production from new planting would really only begin to have an effect beyond the trough.

Figures (2) and (3) show the long term forecast breakdown by species and top-diameter class. Sitka spruce is the dominant species overall, and is even more so in Mid and South Scotland. In North Scotland the pines are equally important. The top-diameter class chart illustrates that the ‘small roundwood’ element varies much less than the ‘sawlog’ element in the long term, with ‘sawlogs’ rising from 51% in 1999-2001 to 66% in 2017-2021.

Comparison with previous forecasts

The FE forecast, as shown in Table (2), is very similar to the 1995 FE forecast. The Private Sector forecast, in keeping with previous trends (*Rothnie and Selmes*, 1995, and *Thompson*, 1991), shows an increase in the volumes forecast. In this case the reasons include; an increased area of conifer woodland, the new set of yield models, less open space allowed for, and slightly less taken off as an arbitrary reduction. In the past few years the actual production levels in the Private Sector have been higher than the previous forecasts, as shown in Figure (4).

Over the period of the detailed forecast up to the period 2027-2031 the new Private Sector forecast shows 18% more volume available when compared to the 1995 forecast. The situation for the overall forecast for the same period is an increase of 10% in volume compared to 1995.

The robust nature of the long term trend can be illustrated again by Figure (5). This shows that despite a completely new crop dataset for the Private Sector from the NIWT, and despite a new set of assumptions being applied to the Private Sector, the overall line shows a peak and a trough at around the same level and in the same period as shown by the 1995 forecast.

Future Developments

Timber quality is not taken account of in the current forecast, but is obviously of crucial importance to the forest industry. The FC’s Forest Research agency has a project ongoing, one aim of which is to develop a method for incorporating timber quality into production forecasts. The project is moving ahead through a timber quality survey in South Scotland this summer, and an attempt to model stem straightness in relation to crop and site parameters.

In some areas timber included in this forecast may not be harvested because of roading or transport issues. The scale of these issues has not yet been quantified, although investigations are ongoing, led by the FC National Office in Scotland. A pilot project starting soon in Strathclyde will develop a GIS-based methodology which will hopefully be applicable to the rest of the country.

Acknowledgements

We would like to acknowledge the considerable effort put into data collection and development by the Timber Grower's Association and the Supply & Demand Sub-committee of the Forestry Commission's Advisory Panel. Thanks especially to Guy Watt for collecting and compiling the TGA data, and to Robin Adam, George Webb, Andrew Smith and Chris Cloy for considering every stage of the private sector modelling. We would also like to thank Roger Coppock for providing the Forest Enterprise data in a suitable format.

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Data and key assumptions used in the Private Sector model for Scotland

Crop data: Crop areas by species and age class from the 1995 National Inventory of Woodland and Trees (NIWT), updated from FC records. All types of conifer woodland including the conifer element of mixed woodland were included.

Unproductive area: The NIWT showed there to be 10.6% open space within Private Sector woodland in Scotland.

Timber potential: The NIWT defined crops into 4 classes of timber potential. The better two classes are considered capable of producing sawlogs and small roundwood. The third class was considered capable of producing small roundwood only; the volume from these crops has been incorporated into the forecast in the 7-14cm size class, disregarding the forecast assortment. The lowest class of timber potential has not been incorporated into the forecast.

Volume adjustment: Details on under-stocking were collected for the NIWT. This information was used to reduce the volumes in North, Mid and South Scotland by 2%. In addition the NIWT defined some crops as being ‘un-extractable’ (for physical, rather than transport, economic or conservation reasons). This gave further volume reductions of 3%, 1% and 2% for North, Mid and South Scotland respectively.

Yield Class: The YC distribution for each species was based on the TGA survey data.

Thin/Non Thin: The proportion of thin/non thin was provided by the TGA survey.

Windthrow hazard: The TGA survey incorporated information on windthrow hazard class, which was used in setting rotations for SS and LP.

Rotation length: The TGA survey supplied a set of basic rotation lengths by species and YC. After discussion these were amended to reflect the influence of forest design and restructuring: fell 25% 5 years earlier, 25% as per basic assumption, 25% 5 years later, and 25% 10 years later.

Over-mature: Crops already older than rotation age amounted to 15.6 million cubic metres. It was assumed that a proportion of this will be felled during the first 20 years of the forecast, with the rest being retained indefinitely. The proportions assumed to be felled in North, Mid and South Scotland were 35%, 40% and 45% respectively.

Yield models: The full set of new Yield Models were supplied by Mensuration Branch, Forest Research.

Volume assortment: The assortment is calculated in 4 top-diameter classes: 7-14cm, 14-16cm, 16-18cm and over 18cm as an overbark standing volume.

****
***

Period	**North**				**Mid**				**South**				**Scotland**			
Top-diam Class	FE	PS	Total	% Spruce	FE	PS	Total	% Spruce	FE	PS	Total	% Spruce	FE	PS	Total	% Spruce
1999-2001 (3 years)																
7-14cm	330	366	696	35	245	216	461	73	363	462	825	81	938	1044	1982	63
14-16cm	99	100	199	49	92	69	161	79	128	155	282	85	319	324	643	72
16-18cm	93	93	186	52	90	60	150	80	115	133	248	84	298	286	584	73
to 18cm	374	408	783	53	349	202	551	77	371	397	768	77	1094	1008	2102	68
Total	**897**	**967**	**1863**	**46**	**775**	**548**	**1323**	**76**	**978**	**1147**	**2124**	**81**	**2649**	**2661**	**5310**	**67**
2002-2006																
7-14cm	305	394	699	35	245	273	518	74	334	508	842	83	884	1174	2058	65
14-16cm	100	119	219	47	95	97	192	79	125	188	313	88	320	404	724	73
16-18cm	96	112	207	50	95	87	182	80	115	177	292	88	306	375	682	74
to 18cm	411	507	918	52	412	317	729	80	378	638	1016	84	1201	1462	2663	72
Total	**912**	**1131**	**2043**	**46**	**847**	**774**	**1621**	**78**	**953**	**1511**	**2463**	**85**	**2712**	**3415**	**6127**	**70**
2007-2011																
7-14cm	309	478	787	35	310	323	633	77	398	542	940	84	1017	1343	2360	66
14-16cm	114	156	269	43	131	125	257	81	163	219	382	88	408	500	908	73
16-18cm	113	150	263	45	135	117	253	82	159	219	378	89	407	486	893	74
to 18cm	540	673	1213	49	615	482	1097	83	587	960	1547	86	1743	2114	3857	74
Total	**1076**	**1456**	**2532**	**44**	**1192**	**1047**	**2239**	**81**	**1308**	**1939**	**3247**	**86**	**3575**	**4443**	**8018**	**71**
2012-2016																
7-14cm	303	544	847	35	287	325	612	79	408	562	970	84	998	1431	2429	65
14-16cm	124	187	311	43	129	143	272	82	180	236	415	89	432	566	998	73
16-18cm	128	186	313	44	138	143	280	83	183	249	433	90	449	578	1026	74
to 18cm	633	846	1479	49	691	660	1351	85	756	1271	2027	89	2081	2776	4857	76
Total	**1188**	**1763**	**2950**	**44**	**1245**	**1270**	**2515**	**83**	**1527**	**2318**	**3845**	**88**	**3959**	**5351**	**9310**	**73**
2017-2021																
7-14cm	344	527	871	39	356	327	683	78	375	516	891	84	1075	1369	2444	66
14-16cm	145	201	346	45	165	158	323	82	174	223	397	90	485	581	1066	73
16-18cm	152	212	364	45	178	167	345	83	185	245	430	91	515	623	1138	74
to 18cm	782	987	1768	48	955	804	1760	85	878	1349	2227	90	2615	3140	5755	75
Total	**1423**	**1926**	**3349**	**45**	**1655**	**1455**	**3110**	**83**	**1612**	**2332**	**3944**	**89**	**4690**	**5713**	**10403**	**73**
2022-2026																
7-14cm	315	535	850	42	323	338	661	81	264	489	753	84	902	1362	2264	68
14-16cm	147	214	361	45	151	166	317	85	122	204	326	91	420	584	1004	73
16-18cm	156	237	393	45	162	185	346	86	131	226	357	92	449	648	1097	73
to 18cm	801	1166	1968	46	835	971	1806	88	607	1377	1985	90	2244	3514	5758	75
Total	**1420**	**2152**	**3572**	**45**	**1471**	**1659**	**3130**	**86**	**1124**	**2297**	**3421**	**89**	**4015**	**6108**	**10123**	**73**
2027-2031																

Table (1)
Scotland: 1999 Forecast of Softwood Availability - Forest Enterprise and Private Sector
(Average annual standing volume in thousands of cubic metres overbark)

PRIVATE SECTOR									
	Small Roundwood			Sawlogs			Total		
Period	1995	1999	% Change	1995	1999	% Change	1995	1999	% Change
1999-2001	891	1368	35%	931	1294	28%	1822	2661	46%
2002-2006	1174	1578	26%	1538	1837	16%	2712	3415	26%
2007-2011	1333	1843	28%	2132	2600	18%	3466	4443	28%
2012-2016	1523	1997	24%	2994	3354	11%	4517	5351	18%

FOREST ENTERPRISE									
	Small Roundwood			Sawlogs			Total		
Period	1995	1999	% Change	1995	1999	% Change	1995	1999	% Change
1999-2001	1074	1257	17%	1285	1392	8%	2359	2649	12%
2002-2006	1144	1204	5%	1480	1507	2%	2623	2712	3%
2007-2011	1326	1425	7%	2043	2150	5%	3369	3575	6%
2012-2016	1447	1430	-1%	2501	2530	1%	3948	3959	0%

TOTAL									
	Small Roundwood			Sawlogs			Total		
Period	1995	1999	% Change	1995	1999	% Change	1995	1999	% Change
1999-2001	1965	2625	34%	2216	2868	29%	4181	5310	27%
2002-2006	2318	2782	20%	3018	3345	11%	5336	6127	15%
2007-2011	2659	3268	23%	4175	4750	14%	6835	8018	17%
2012-2016	2970	3427	15%	5495	5883	7%	8465	9310	10%

Notes:

The 1995 forecast split the 14-18cm top-diameter class 50/50 between sawlogs and small roundwood

The 1999 forecast has:

- grouped the 7-14cm and 14-16cm classes as small roundwood
- grouped the 16-18cm and >18cm classes as sawlogs

Table (2)
Comparison of 1995 and 1999 Softwood Availability Forecasts for Scotland
(Average annual standing volume in thousands of cubic metres overbark)

Figure 1 Longer Term Trends in Softwood Availability for Scotland
Forest Enterprise and Private Sector

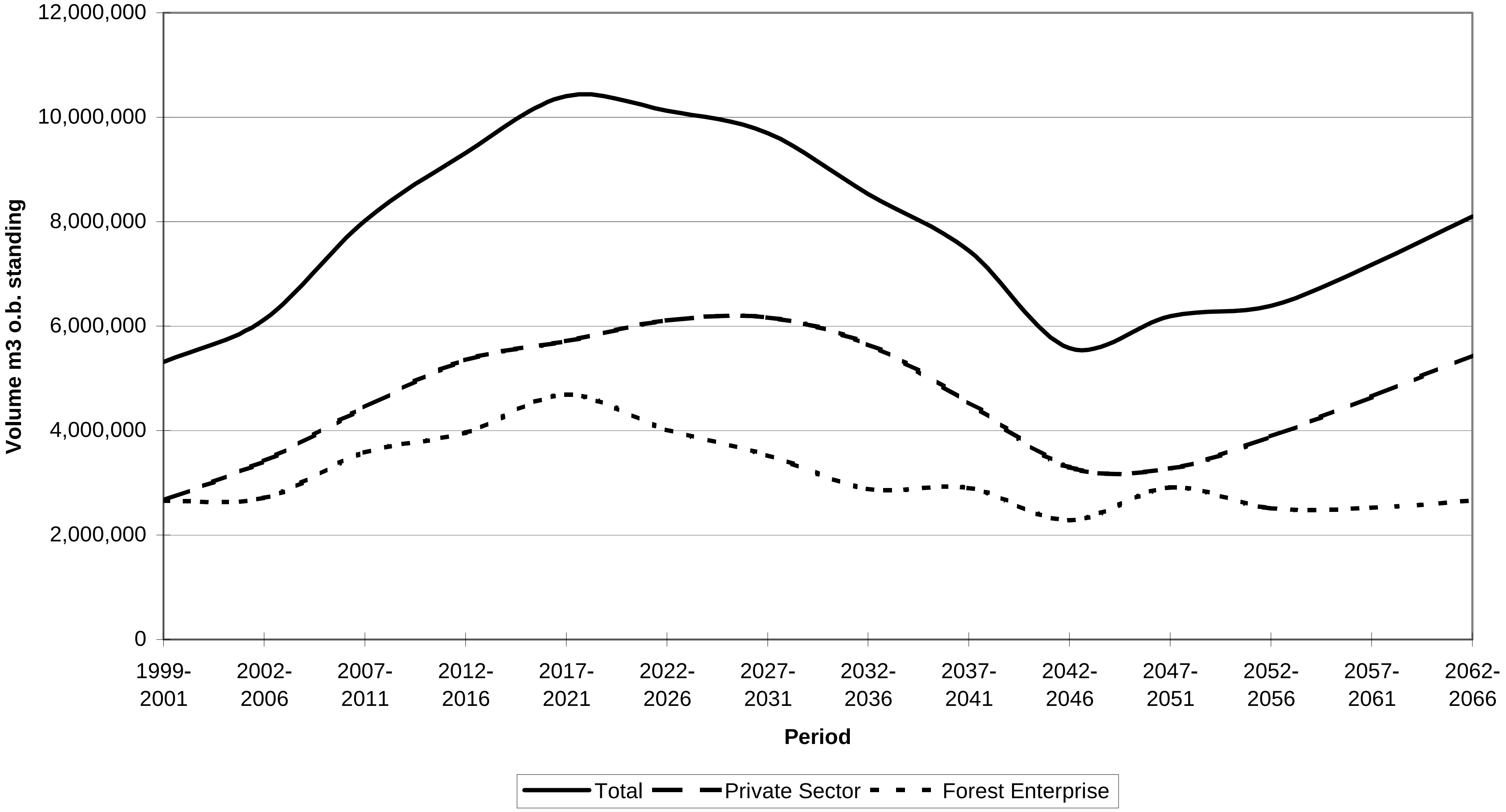

Figure 2 Longer Term Forecast of Softwood for Scotland by Tree Species

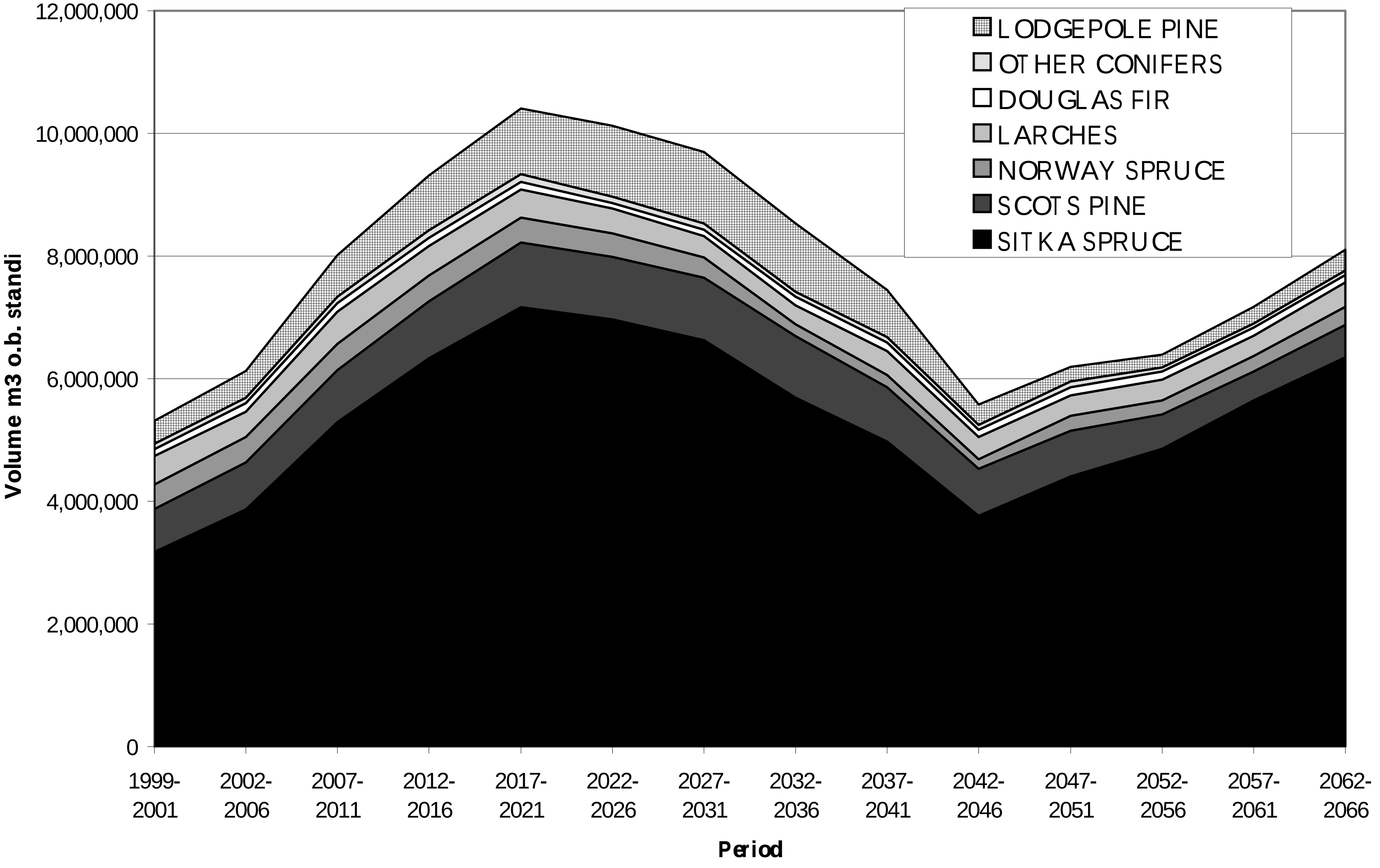

Figure 3 Longer Term Forecast of Softwood for Scotland by Top-diameter Class

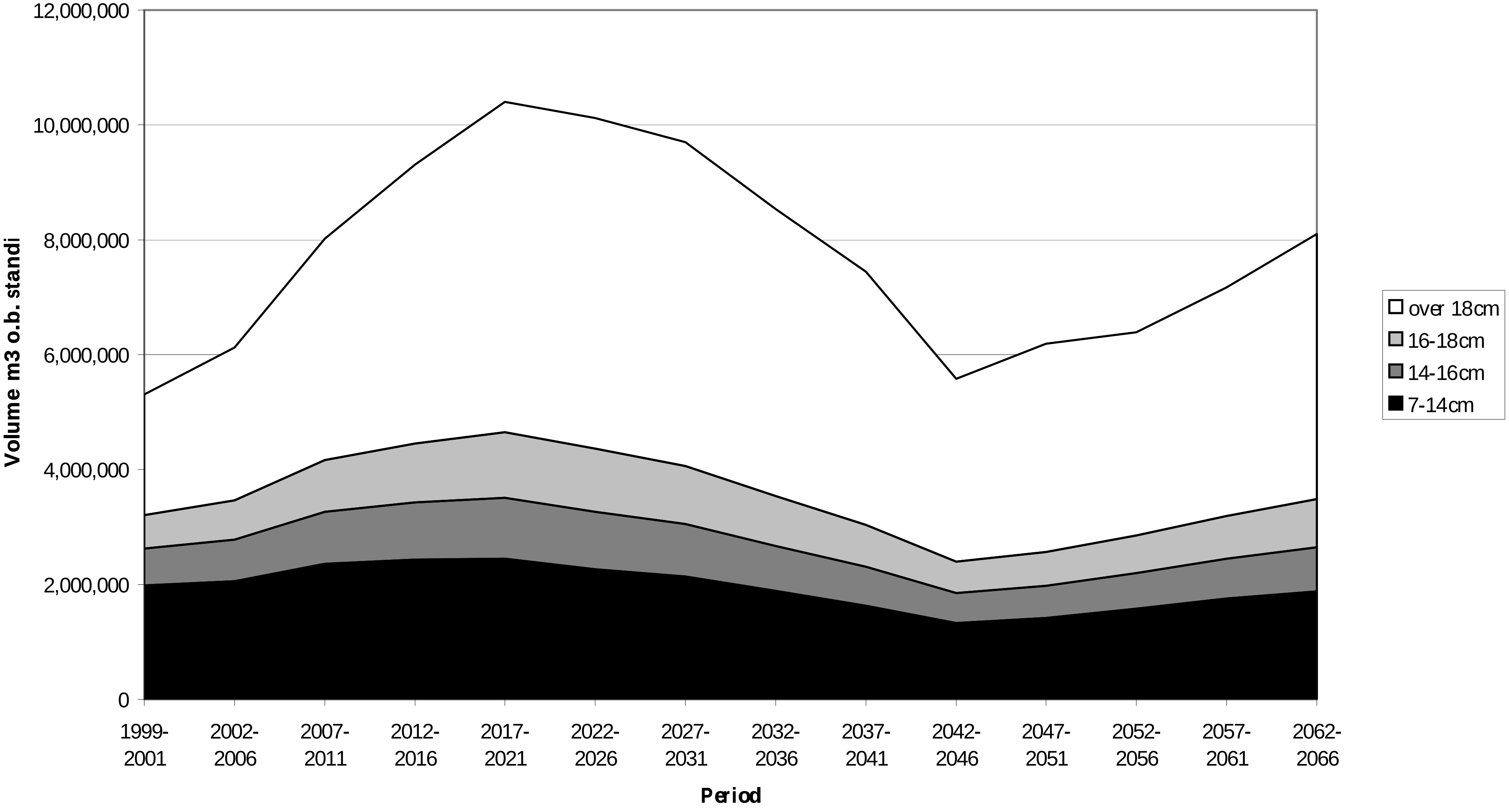

Figure 4 Comparison of Private Sector Timber Production in Scotland
Forecast vs. Actual

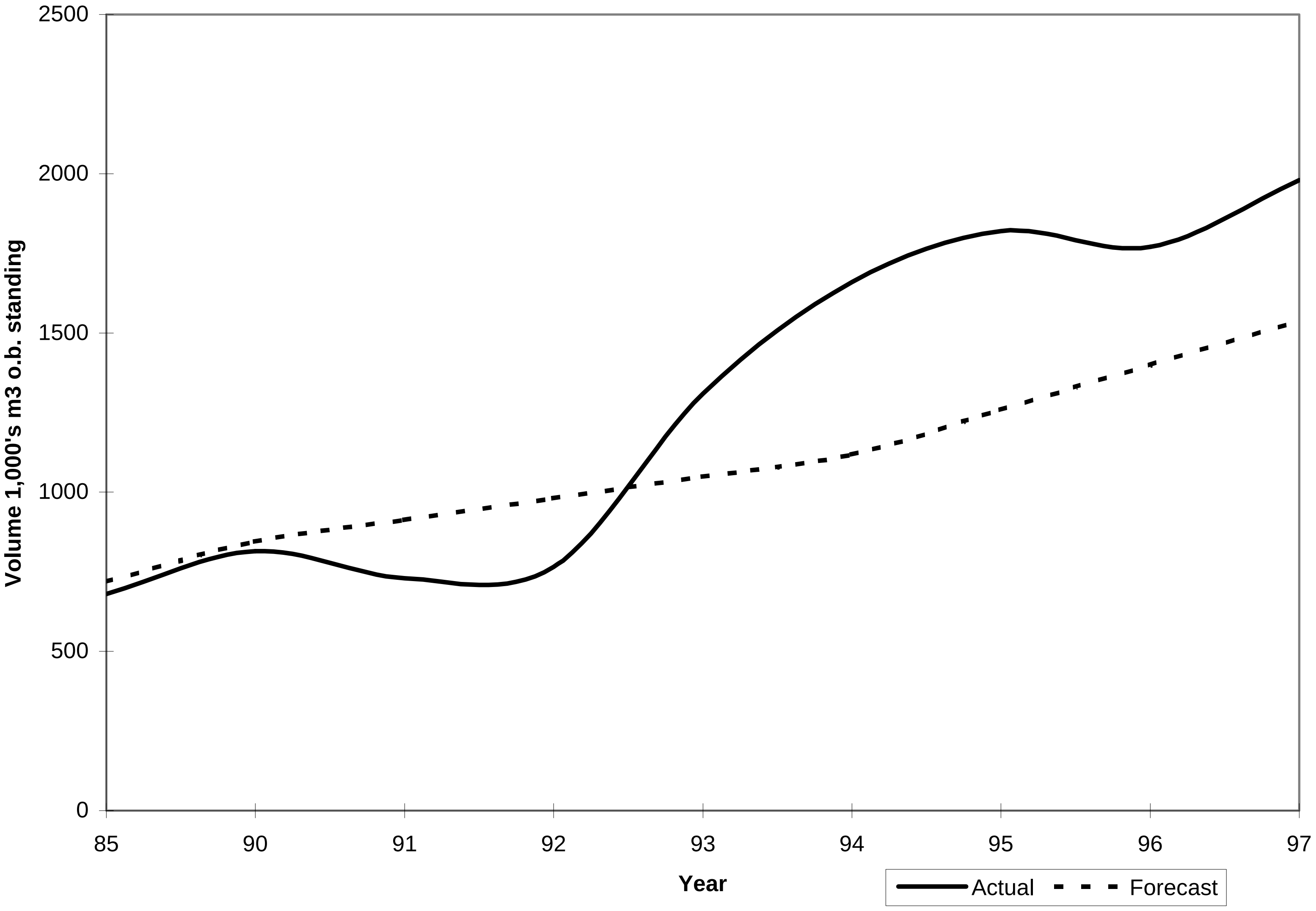

Figure 5 Comparison of 1995 and 1999 Softwood Availability Forecasts for Scotland