Variation of Density and Growth Ring Width in Stems of Sitka and Norway Spruce

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SUMMARY

The variation with height and radial distance from the pith of basic density and ring width has been determined in stems of 48-year-old Sitka and Norway spruce planted at two spacings at Durris, Kincardineshire. The pattern of radial variation of density was broadly similar at all heights: high near the pith, falling to a minimum and then a gradual increase. The mean whole-stem densities were significantly different at the two spacings in Sitka but not in Norway spruce. Density at breast height was inversely correlated with ring width, strongly in Sitka but weakly in Norway spruce. The density/ring width regression equation for outer wood in Sitka spruce at age 48 differed from that at age 31. In Norway spruce a high correlation was found between whole-stem density and the density of rings 16–25 at breast height.

INTRODUCTION

The density of the wood of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) is known to decrease in response to increased growth rate (Brazier, 1970a,

1970b; Gardiner and O'Sullivan, 1978; Savill and Sandels, 1983). The initial diameter growth rate of individual trees may be increased by increasing the initial spacing of the crop, but since most strength properties of wood are proportional to density this may contribute to an unacceptable loss of strength in the timber produced (Brazier *et al.*, 1985). Brazier (1977) has reviewed the influence of silvicultural practice on wood properties, including density, and Elliott (1970) has reviewed the subject of wood density in general.

Brazier (1970b) used samples from the Forestry Commission's Durris spruce spacing experiment, planted in 1935. This experiment, already depleted by wind damage, was recently clearfelled. The opportunity was taken to sample the Sitka spruce to see whether the relation between growth rate and density up to age 31 years found by Brazier (1970b) still obtained up to age 48. He used only breast height samples, and a further aim of the present work was to examine the variation of these quantities at other heights in the stem. Subsequently, as a result of a separate investigation of growth rate and branch size in Norway spruce (*Picea abies* (L.) Karst.), wood

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samples of this species were also obtained from the same spacing experiment for a similar investigation of growth rate and density. Less is known of the relationship between these quantities in home grown Norway spruce, although Klem (1952) has investigated this subject in Norway, as have Harvald and Olesen (1987) in Denmark.

MATERIALS AND METHODS

Sample trees were cut in 1983 from the Forestry Commission spruce spacing experiment planted in 1935 at Durris Forest, Kincardineshire. Norway and Sitka spruce were each planted in four adjacent square plots of 0.13 ha, separated by narrow unplanted strips, at spacings of 2.4 × 2.4, 1.8 × 1.8, 1.4 × 1.4 and 0.9 × 0.9 m. The trees had received a 'Q' thinning treatment, designed to maintain the growth difference apparent at the time of the first thinning: very light thinning at the narrowest spacing and very heavy at the widest spacing, equivalent to almost open growth conditions. Details of the Forestry Commission spacing experiments planted in 1935–36 and their thinning treatments are given by Hamilton and Christie (1974). Some trees were pruned, other than at 0.9 × 0.9 m, but this had no direct effect on sampling since internodal discs were used. The pruning seems unlikely to have had an appreciable effect on diameter growth (Brazier, 1977).

Six Sitka spruce trees were selected randomly from the narrowest spacing. Twelve trees remained at the widest spacing, and the six trees nearest the plot centre were used to avoid edge trees. The two intermediate spacings of Sitka spruce were destroyed by a gale in 1974.

Ten Norway spruce sample trees were cut from each of the 1.4 and 2.4 m spacing plots. They were the trees of greatest diameter, excluding edge trees. These trees were originally sampled as part of an investigation of branch development, and the opportunity was later taken to examine their growth rates and density.

Transverse, internodal sample discs about 30 mm thick were cut from each sample tree at 10, 30, 50, 70 and 90 per cent of the measured distance from stump to the point of 7 cm diameter. A further disc was cut at breast height. From each disc a strip approximately 15 mm wide was cut along the north–south axis through the pith. This direction was chosen arbitrarily, but it probably minimized the occurrence of compression wood in the samples, since the prevailing winds are westerly. This strip was oven dried to constant weight and sanded to produce a smooth transverse surface for the measurement of ring widths. Working outwards from pith, the widths of successive groups of five growth rings were measured using a ruler graduated to 0.5 mm and a hand lens. With a typical ring width of 5 mm this gives a margin of error of ± 1 per cent for the combined width of five rings.

The strips were split, using a chisel, into blocks containing five growth rings as measured above. These were then oven dried to a recorded constant weight and immersed in water for at least 36 h. Their water-swollen volumes were then determined by measuring the apparent weight gain caused by immersion in a beaker of water on a top pan balance reading to an accuracy of 0.01 g. The basic density of each block was calculated by dividing dry weight by water-swollen volume. It is possible the blocks did not quite regain their green dimensions (Panshin and de Zeeuw, 1980) so that the densities may be slightly greater than the true basic densities.

Average values for corresponding pairs of blocks from north and south of the pith were calculated for both density and ring width.

RESULTS

Table 1 shows the variation of density in the Sitka spruce sample trees. At both spacings the general pattern at all heights is for density to be relatively high near the pith, falling to a minimum further out and then a gradual increase with increasing distance from the pith.

The whole-stem density of each sample tree was calculated by an adaptation of the method of Brazier (1970a). This consists of first calculating the total weight of the stem by summing the products of the total cross-sectional area of each group of five growth rings multiplied by their density, multiplied by one fifth of the length of stem to 7 cm diameter. The volume of the stem is then calculated by applying Huber's formula to each of the five logs from the mid-points of which the sample discs were cut. Whole-stem density is then obtained by dividing total weight by total volume. The mean whole-stem density was 321.9 ± standard error of 9.4 kg m^{-3} for the wide spacing and 364.3 ± 14.3 kg m^{-3} for the narrow spacing. The two values are significantly different at the 95 per cent probability level.

Table 2 shows the variation of ring width in the same sample trees. It will be seen that the patterns differ somewhat at the two spacings, with the wide spacing showing an initial increase followed by decreasing ring width outwards from the pith, whereas the narrow spacing shows a gradual decline in ring width until about 25 rings from the pith. As might be expected the rings are much narrower at the closer spacing.

Table 3 shows the variation of density in the Norway spruce sample trees. Both spacings show high density near the pith, but the narrow spacing possesses a minimum density at around 10–20 rings from the pith while the wide spacing shows much less tendency for density to increase at greater distances from the pith.

The mean whole-stem densities were 325.0 ± 9.4 kg m^{-3} for the wide spacing and 316.4 ± 6.4 kg m^{-3} for the narrow spacing. These two values are not significantly different at the 95 per cent probability level, in contrast to the results for Sitka spruce.

Table 4 shows the variation of ring width in Norway spruce. There is a sharp increase in ring width in the first few rings from the pith, followed by a gradual decrease in width which is more pronounced at the narrow spacing. As with density, the patterns of variation are very similar at all heights.

TABLE 1. *Variation of basic density with fractional height and distance from the pith in stems of Sitka spruce planted at two spacings*

fractional height	spacing (m)	basic density ($kg\ m^{-3}$) at stated number of rings from pith							
		1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40
0.9	2.4	431	370	365					
	0.9	407	381	413					
0.7	2.4	390	316	341	368				
	0.9	386	345	381	407				
0.5	2.4	362	299	300	331	353			
	0.9	390	327	336	387	424			
0.3	2.4	347	285	280	308	341	366		
	0.9	383	310	332	352	410	419		
0.1	2.4	388	311	308	282	302	330	363	385
	0.9	407	336	338	367	360	394	418	428

TABLE 2. *Variation of growth ring width with fractional height and distance from the pith in stems of Sitka spruce planted at two spacings*

fractional height	spacing (m)	ring width (mm) at stated number of rings from pith							
		1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40
0.9	2.4	5.4	4.9	5.8					
	0.9	4.2	4.5	2.6					
0.7	2.4	6.7	8.3	5.2	5.8				
	0.9	4.8	4.4	2.6	2.4				
0.5	2.4	6.9	9.1	7.3	4.6	4.0			
	0.9	4.8	5.0	3.2	2.0	1.8			
0.3	2.4	6.5	8.5	8.4	6.2	3.8	2.9		
	0.9	5.4	4.6	2.9	2.2	1.8	1.8		
0.1	2.4	5.6	7.7	5.4	6.2	6.3	4.9	3.0	4.0
	0.9	4.7	4.1	2.8	2.5	2.4	1.7	1.8	2.0

TABLE 3. *Variation of basic density with fractional height and distance from the pith in stems of Norway spruce planted at two spacings*

fractional height	spacing (m)	basic density ($kg\ m^{-3}$) at stated number of rings from pith							
		1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40
0.9	2.4	381	332	340					
	1.4	364	324	319					
0.7	2.4	373	324	325	325				
	1.4	384	307	299	298				
0.5	2.4	363	338	322	323	332	341		
	1.4	341	313	295	300	314	340		
0.3	2.4	379	329	332	319	314	331	353	
	1.4	347	308	318	308	323	339	341	
0.1	2.4	361	340	332	335	317	305	330	327
	1.4	358	325	315	315	312	320	333	359

TABLE 4. *Variation of growth ring width with fractional height and distance from the pith in stems of Norway spruce planted at two spacings*

fractional height	spacing (m)	ring width (mm) at stated number of rings from pith							
		1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40
0.9	2.4	2.5	5.5	4.9					
	1.4	2.5	4.8	4.4					
0.7	2.4	2.6	6.1	5.9	5.2				
	1.4	2.4	5.6	4.6	4.1				
0.5	2.4	2.5	5.5	6.2	5.7	4.7	4.7		
	1.4	2.5	5.0	5.1	4.0	3.5	3.5		
0.3	2.4	2.8	5.7	5.2	6.1	5.3	4.0	3.2	
	1.4	2.5	5.3	4.2	4.4	3.9	2.8	2.9	
0.1	2.4	2.6	6.4	4.6	4.5	5.3	5.6	4.6	3.7
	1.4	2.5	5.0	3.8	4.1	4.2	3.8	3.0	2.5

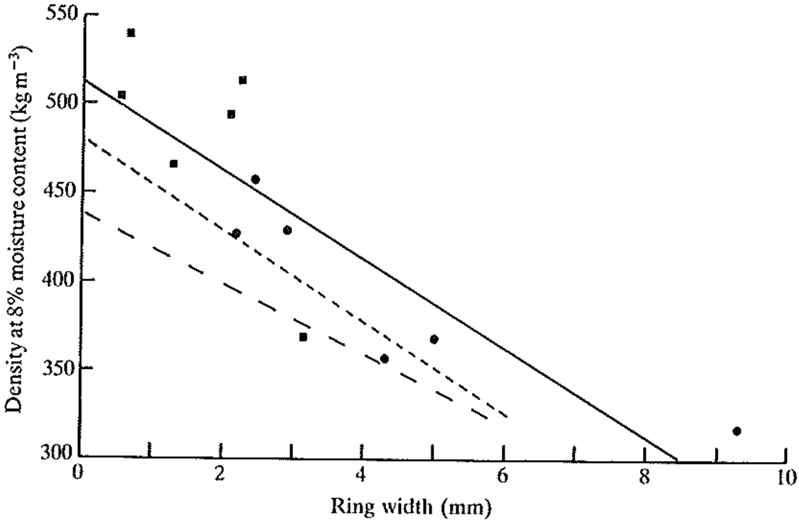

Figure 1. Ring width and density values for the outer five growth rings at breast height in Sitka spruce at narrow (■) and wide (●) spacing together with the fitted regression line ——— ($Y = 512 - 25.0X$, $r = -0.84$). Also shown is Brazier's (1970b) regression line — — — ($Y = 439 - 21.5X$, $r = -0.84$) and the line for the corresponding rings in the present work ---- ($Y = 480 - 27.3X$, $r = -0.89$).

The relation between density and ring width for Sitka spruce at breast height is examined in Figure 1. The density values are given here for 8 per cent moisture content (m.c.) for comparison with the regression line found by Brazier (1970b), who used the rings formed in 1963–65 inclusive. Also shown are the regression lines for the outermost five growth rings at breast height for the Sitka spruce trees sampled in the present work and for rings 21–23 from the pith, which were judged to be equivalent to those used by Brazier. All three lines were found to differ significantly ($P = 0.05$). The line for rings 21–23 is nearer to Brazier's than that for the outermost rings. However, the latter regression line is greatly influenced by one extreme point which may have been caused by nearness to a knot. If this point is omitted the regression equation becomes:

density at 8 per cent m.c. (kg m^{-3}) = 542 – 37.7 (ring width in mm) and $r = -0.85$

The relation between basic density and ring width for all 298 Sitka spruce wood blocks used in this work was found to be significant ($P = 0.05$) with $r = -0.52$:

basic density (kg m^{-3}) = 414 – 12.5 (ring width in mm)

In contrast, density and ring width at breast height in Norway spruce were found to be rather weakly correlated. For all blocks at breast height from all the sample trees the regression equation is:

basic density (kg m^{-3}) = 357 − 6.95 (ring width in mm)

This is a significant relationship ($P = 0.05$) with $r = -0.27$. Figure 2 shows the relation between density and ring width at 8 per cent moisture content for the outer five growth rings at breast height. The regression equation is:

density at 8 per cent m.c. (kg m^{-3}) = 407 − 16.3 (ring width in mm)

with $r = -0.44$. This relationship is significant ($P = 0.05$), and may be compared with the somewhat similar equation with a much higher correlation coefficient obtained for Sitka spruce (Figure 1).

In view of the useful correlation between breast height density and whole-stem density found by Brazier and Howell (1979) for Sitka spruce it seemed of interest to examine the corresponding relationship for Norway spruce. The whole-stem density was found to be significantly ($P = 0.05$) correlated with the mean density of the diameter strip cut from the breast height disc, with $r = 0.71$. A higher correlation ($r = 0.83$) was found between whole-stem density and the density of the wood in rings at 16–25 at breast height, the regression equation being:

whole-stem density (kg m^{-3}) = 58.4 + 0.81 (density of rings 16–25 in kg m^{-3})

The coefficient of variation of the basic density values from individual trees which were averaged to give each entry in Tables 1 and 3 was typically 10 per cent. This corresponds to standard errors of 13 and 10 kg m^{-3} for Sitka and Norway spruce respectively for a man value of 325 kg m^{-3}. The standard error for the ring width values in Tables 2 and 4 was approximately 0.4 mm.

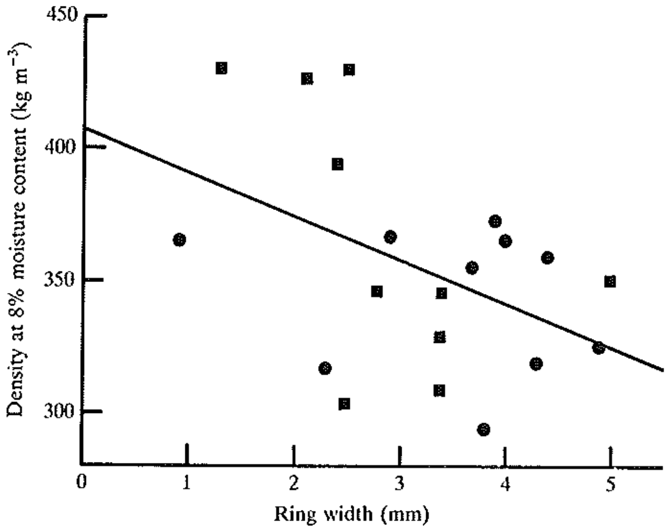

Figure 2. Ring width and density values for the outer five growth rings at breast height in Norway spruce at narrow (■) and wide (●) spacing.

DISCUSSION

The observed patterns of horizontal variation of density and ring width are reported to occur commonly in plantation grown conifers including the two spruces used here (Panshin and de Zeeuw, 1980). Savill and Sandels (1983) found similar patterns at breast height in a Sitka spruce spacing experiment in Northern Ireland. Harvald and Olesen (1987) also found similar patterns at several heights in both thinned and unthinned stands of Sitka spruce in Denmark. However, their results for Norway spruce differ in that they did not find a high density zone near the pith. They used material grown on several different sites. Gardiner and O'Sullivan (1978), however, found less horizontal variation in density at five heights in a spacing experiment in Eire. It appears that broadly similar patterns exist at all heights.

Tables 1 and 3 show that there is apparently less variation of density within stems of Norway spruce than in Sitka spruce. Furthermore rate of diameter growth has less effect on density in Norway spruce, to the extent that there is no significant difference in average whole-stem density between the two spacings. In supplementary work it was found that there was also no significant difference in percentage of latewood at breast height for wood located between 6 and 25 rings from the pith. These observations agree with those of Klem (1952) who found that in 46–52 years old Norway spruce in Norway there was very little difference in density between trees grown at spacings of 1.5 m (423 kg m^{-3}) and 2.0 m (419 kg m^{-3}). It is interesting that in the present work the whole stem densities of Sitka and Norway spruce at the common spacing of 2.4 m are very similar – 322 and 325 kg m^{-3} respectively.

Oven dry dimensions are used in the calculation of whole stem density, whereas the basic density involves water swollen volume. However, since dry dimensions are used in calculating both total weight and total volume the resulting error in whole stem density is negligible.

The close inverse relationship between density and ring width found by Brazier (1970b) in the Sitka spruce at Durris has been found to continue to age 48 years. However, the numerical relation has changed somewhat. The slight difference in regression lines obtained for what should be the same group of three growth rings could be a consequence of the techniques used: Brazier used an indirect β-ray method, while the present results were obtained by direct measurement of weight and volume. Surprisingly a low correlation between density and ring width was found in Norway spruce. This work has shown that the density of this timber is much less influenced by spacing, and hence rate of diameter growth, than that of Sitka spruce.

The good correlation between breast height density and whole tree density found in Norway spruce is similar to that found in Sitka spruce by Brazier and Howell (1979). It appears that the average density of rings 16–25 from the pith obtained from an increment boring could be used to give a good indication of whole tree density. This could prove useful in the selection of trees for superior wood properties at an early stage in their life.

Although density is an important factor in determining the strength of a piece of timber it must be remembered that other factors, such as the size and number of knots, also have a major effect (Brazier, 1977). In practical terms this work has demonstrated that wider spacing not only produces wider growth rings but also wood of lower density and therefore lower strength. This effect will be exacerbated by a tendency to produce larger knots at wider spacings. Thus, especially for Sitka spruce, there is a risk of wider spacings resulting in the production of timber that fails to meet desirable stress grade or strength class criteria.

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