Stem Straightness and Compression Wood in a 22-Year-Old Stand of Container-Grown Scots Pine Trees

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The distribution of compression wood in relation to eccentric growth and development of stem straightness was studied in a 22-year-old Scots pine (*Pinus sylvestris* L.) stand in central Sweden that was established with container-grown seedlings. Stem straightness was measured on the same 440 trees in 1986 and 1997. The number of stems with straight base sections increased from 60% in 1986 to 89% in 1997. Measurements of 72 sample trees in 2001 showed that 96% of the trees had developed straight stem bases. External geometry data of the logs was obtained with a Rema 3D log scanner. A sub-sample of 16 trees was randomly selected for analysis of compression wood distribution and eccentricity measurements. From each tree, 11 discs were cut at every 60 cm along the stem. All discs, except one, contained compression wood. Compression wood and pith eccentricity was most pronounced near the stem base but not significantly correlated to basal sweep. Severe compression wood content was correlated to pith eccentricity and bow height. In general, correlations were better for the basal sections of the logs. Even though most trees were straight, they contained large amounts of compression wood. It is evident that eccentric growth and compression wood formation play major roles in the development of stem straightness. In several stems, a spiral compression wood distribution pattern was found. Reasons for this are discussed.

Keywords *Pinus sylvestris*, stem form, eccentricity, reaction wood
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1 Introduction

Tilting a conifer stem from its normal vertical orientation is known to inhibit the growth of the current-year terminal shoot and to induce the formation of compression wood on the lower side of the stem (Cremer 1998). According to the Swedish grading system for saw logs (Regulations… 1999), compression wood is considered as a severe defect that causes downgrading.

Compression wood has many properties that can cause problems in wood utilisation. The high longitudinal shrinkage associated with the large microfibril angle, cause distortions such as bow and crook in sawn timber (Timell 1986, Warensjö and Lundgren 1998, Öhman 2002). The brittle fracture and the relatively high density make compression wood more difficult to use in structures and the high level of hardness makes it difficult to handle when sawing, drilling and nailing (Timell 1986, Johansson 2002). Mechanical properties such as tensile strength and impact bending strength are lower in compression wood compared to in normal wood at air dry condition (Timell 1986). Moreover, its high lignin content, together with its relatively low cellulose content decreases the pulp yield.

The relationship between external geometry of stems and the distribution of compression wood have e.g. been discussed by Low (1964), Rune and Warensjö (2002) and Warensjö (2003). According to Lundgren (2000), the external geometry of a trunk is a rather good indicator of the log quality. Öhman (2001) found that external geometry features such as the largest sweep and ovality in log ends, did not explain the variation of compression wood content. Warensjö (2003) studied the compression wood distribution in boles of Norway spruce (*Picea abies* (L.) Karst.), and concluded that bow height and compression wood content in log ends together are a good measure of compression wood content of entire logs. However, according to Öhman (2001), the compression wood content in the butt end of saw logs is a rather poor indicator of the quality of sawn products.

Kärkkäinen and Uusvaara (1982), Uusvaara (1985) and Agestam et al. (1998) found that naturally regenerated Scots pine trees were significantly more straight than those that were planted. Strand et al. (1997) found that basal sweep was more common in planted than in naturally regenerated Scots pine trees. However, many parameters of commercial wood quality, such as number and diameter of branches, wood density, annual ring width and amount of juvenile wood, are correlated with growth rate and level of competition (Persson 1975, 1976). Therefore, they can to some extent be controlled by the silvicultural treatments.

Since the mid-seventies, most plantations of Scots pine stands in Sweden have been established with seedlings cultivated in containers (Lindström 1978). However, these early types of containers have been found to increase the risk of instability in young trees, due to container-induced root deformities (Lindström and Rune 1999, Rune 2003). From now on, forests produced from the early types of containers will be a source of increasing importance to the forest industry. Therefore, it is important to study the effect of juvenile instability on future timber quality with the emphasis on compression wood formation.

The objectives of this study were; (i) to determine if young trees with basal sweep become straighter over time and if this process is associated with eccentric growth and compression wood formation; (ii) to study the distribution of compression wood in relation to external geometry.

2 Material and Methods

Sample trees were selected from a 22-year-old experiment of Scots pine in central Sweden (lat. 60°35´N, long. 16°10´E). Elevation was 180 m a.s.l. with a northern aspect of the slope varying between 0° and 10°. The stand was established in May 1979 with 1-year-old Scots pine seedlings of identical origin (Hedesunda, lat. 56°32´N, long. 03°32´E, 160 m a.s.l.). Seedlings were reared in containers of different design, regarding root guidance, and they were planted out at 1.5 m × 2.5 m spacing (Håkansson and Lindström 1989). Container types were not taken into consideration in this study. The total number of planted seedlings was 720. Of these, 440 trees remained after 7 growing seasons. According to a description system developed by Hägglund and Lundmark (1982), the site index was T 24 (dominant height

Table 1. Classification of 22-year-old Scots pine trees into four categories based on the basal curvature measurements made in 1986 and 1997. Sweep categories (1986, 1997) within brackets.

Category	Stem base 1986	Stem base 1997
1	Straight (0–5°)	Straight (<5°)
2	Straight (0–5°)	Basal sweep (>5°)
3	Basal sweep (6–30°)	Basal sweep (>5°)
4	Basal sweep (6–30°)	Straight (<5°)

of Scots pine at a total age of 100 years). The soil texture was a sandy-loam till and the soil type was a podzol. Soil preparation was carried out by a disc trencher before planting in autumn 1976 (cf. Sutton 1993).

The angle of basal sweep within the lower 50 cm section of the 440 Scots pine trees was measured and assigned into four categories according to Hultén and Jansson (1978) in August 1986. Categories were: straight (0–5°), slightly crooked (6–30°), crooked (31–45°) and very crooked (>46°). Measurements were repeated in September 1997 on the same trees and in 2001 on 72 sample trees by using a digital protractor (Lucas Anglestar, model DP 45, USA).

The 440 Scots pine trees were classified into four categories according to their history of basal curvature in 1997 compared to that of 1986 (Table 1). From these four categories, a total of 72 trees with a diameter exceeding 10 cm at breast height (1.3 m above ground) were randomly selected. Means for height and diameter at breast height were calculated for trees in each category and in total (Table 2). A sub-sample of 16 trees, four trees per category, was randomly selected for compression wood distribution measurements. These trees were felled and cross-cut at a height of 6 m above stump height.

The logs were transported to a sawmill where a Rema Log 3D scanner was used to determine the external geometry. After log scanning, 10 cm thick discs were cut at approximately every 60 cm of the log length, producing a total of 176 discs (11 per tree). To avoid discs containing branch-induced compression wood, discs positioned closer than 10 cm below a branch or branch scar were avoided by shifting the position of the disc. The northern and western aspect was marked on all discs. From each disc, a thin cross-section with a thickness of 2.5 mm was sawn using a circular saw.

Prior to compression wood analysis, the cross-sections were wetted and placed on a light box in order to view the discs in transmitted light. The procedure is based on the observations that compression wood is opaque to transmitted light while normal wood is translucent (Pillow 1941). According to Andersson and Walter (1995) mild compression wood appears light orange to red in colour and severe compression wood appears dark brown to black when exposed to transmitted light. Images were registered with a digital camera (JVC 3-CCD KY-F55).

COMPRESSION WOOD ANALYSIS 1.0 software (Dianthus, Boden, Sweden) was used to assess the compression wood content and its position in each disc. The software uses supervised multivariate classification for dividing the image of the disc into normal wood, mild and severe compression wood. Output data was used to calculate the geometric variables pith eccentricity

Table 2. Number of trees, average height (m) and average diameter (mm) measured at breast height (1.3 m) in 2001 for sweep categories and in total. Categories 1: trees with straight stem base 1986 and straight stem base 1997, 2: straight 1986 and basal sweep 1997, 3: basal sweep 1986 and basal sweep 1997, 4: basal sweep 1986 and straight 1997.

Category	1	2	3	4	Total
N	4	4	4	4	16
Height, m	10.7 ± 0.2	10.5 ± 0.2	10.6 ± 0.2	10.4 ± 0.2	10.5 ± 0.1
Diameter, mm	153.9 ± 2.3	152.2 ± 3.9	149.6 ± 4.1	144.5 ± 4.3	149.4 ± 2.1

Data are means ± standard error of the mean

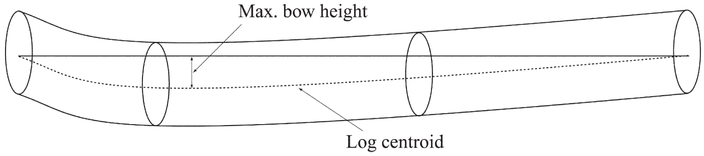

Fig. 1. Description of variable bow height.

and out-of-roundness of the discs. Pith eccentricity was calculated as the distance between the position of the pith and the geometric centre of the cross section divided with the mean diameter of the disc. Out-of-roundness was calculated according to formula 1.

$$\text{Out-of-roundness} = \frac{(\text{max diameter}) - (\text{min diameter})}{((\text{max diameter} + \text{min diameter})/2)} \quad (1)$$

Compression wood (CW) content per disc was calculated by dividing the CW area with the disc area. Total CW content per disc was calculated by dividing the sum of severe and the mild compression wood areas with the disc area. Weighted CW content per disc was calculated according to formula 2.

$$\text{Weighted CW content} = \frac{(\text{Severe CW area} + 0.5 \text{ X Mild CW area})}{\text{DISCArea}} \quad (2)$$

The basal five discs from each of the 16 sample logs were used for growth ring analyses using WINDENDRO software (Instruments Régent Inc., Québec, Canada). Growth ring width was registered from pith to bark in eight directions. Data was used for calculations of temporal variation in pith eccentricity.

The software VIRTUAL MILL 1.0 (Dianthus, Boden, Sweden) makes it possible to visualise and combine 3D log data sets into whole tree data sets as well as virtually simulate crosscuts. The software was used for the analysis of external log geometry data obtained from the 3D scanner and simulation of log lengths. From the basal part of each log, two log sections (lengths 240 cm and 420 cm respectively) with known external geometry and compression wood content were simulated.

For each log and simulated log section, mild, severe, total and weighted compression wood content (CW_{LOG}) was calculated according to formula 3.

$$CW_{LOG} = \frac{\sum_{i=1}^{n} \text{CWArea}_i}{\sum_{i=1}^{n} \text{DiscArea}_i} \quad (3)$$

Pith eccentricity and out-of-roundness for logs and log sections were calculated as mean values of the discs. Bow height was extracted from the raw data obtained from the 3D-scanner. The bow height describes the maximum deviation between a straight line joining both log end centres and the centroid of the log (Fig. 1).

Spearman rank correlation coefficients (r_s) were used to measure and calculate the association between the variables compression wood content, out-of-roundness, pith eccentricity and maximum bow height (Bluman 1997). Analysis of variances (one-way) was used to reveal differences in the compression wood distribution between categories, and to reveal differences between stems with straight and crooked stem bases. Prior to the analyses, data was tested for homogeneity of variances. Analysis of variance with repeated measures was used to determine the differences in development of temporal pith eccentricity for trees in the four categories.

During the analysis, one of the sample trees (11 discs) was excluded because it had been tested mechanically for stability in 1986. In addition, 13 discs were excluded from the analysis since they obviously contained branch induced compression wood.

3 Results

After 7 growing seasons (1986), 60% of the 440 Scots pine trees had straight stem bases and by 1997, this proportion had increased to almost 89% ($p=0.005$). Measurements in 2001 showed that 96% of the 72 sample trees had developed straight stem bases, but the improvement in straightness was not significant ($p=0.238$).

Analyses of butt end discs showed that formation of single-sided compression wood started within the fourth to seventh growth ring from the pith for all trees that had a basal sweep in 1986. All examined discs, except one, contained compression wood. The total compression wood content in the discs ranged from 0 to 26.6% and most compression wood was found in the basal discs. Further up the stems the amounts decreased. Compression wood content in the basal 60 cm part of the 15 stems was not significantly correlated to basal sweep in 2001 ($p=0.164$).

Severe compression wood was found in all stems, but the stem height with registered compression wood varied among the four categories (defined in Table 1) (Table 3).

Table 3. Average and maximum stem height (cm) with registered severe compression wood (CW) for stems in category 1 to 4 (n=15).

Category	Average stem height with severe CW (cm)	Maximum stem height with severe CW (cm)
1	120 ± 0	120
2	165 ± 38	240
3	195 ± 51	300
4	150 ± 71	300

Data are means ± standard error of the mean

Severe compression wood content in the discs was significantly correlated to pith eccentricity ($p=0.003$–0.038) for all 30 log sections' lengths but not to out-of-roundness ($p=0.459$–0.909). Weighted compression wood was significantly correlated to pith eccentricity for all log sections ($p=0.005$–0.032). Severe and weighted compression wood content was significantly correlated to bow height for the 2.4 m sections ($p=0.018$ vs. $p=0.026$) (Table 4).

The majority of the cross sections, 80%, were almost circular (out-of-roundness <5%) even though they had an eccentric pith position. For the basal 2.4 m part of the sample logs, out-of-roundness was significantly correlated to pith eccentricity ($r=0.51$, $p=0.05$) but not to severe compression wood content ($r=0.19$, $p=0.51$). If discs from all stem heights were considered there was no significant correlation between out-of-roundness and any of the tested variables.

In general the correlations were stronger for short sections than for longer sections and logs. Compression wood in top and butt end discs was significantly correlated to compression wood within the logs (Table 5).

Temporal pith eccentricity was most expressed in the basal part of the 15 sample trees. Further up the stems the discs were circular with almost no offset of the pith. Analyses of temporal pith

Table 4. Non-parametric correlation matrix (Spearman rank) for mean values per log and log section (n=15) for 22-year-old Scots pine trees. Significance levels: ns=not significant, *p≤0.05, **p≤0.01.

	Length of log sections, m	Mean values of compression wood content per log section			
		Severe	Mild	Total	Weighted
Pith eccentricity (%)	2.4 m	0.71 **	0.70 **	0.69 **	0.68 **
	4.2 m	0.68 **	0.64 *	0.64 *	0.66 **
	6.0 m	0.54 *	0.47 ns	0.50 ns	0.55 *
Out-of-roundness (%)	2.4 m	0.21 ns	0.10 ns	0.05 ns	0.11 ns
	4.2 m	0.08 ns	–0.01 ns	–0.06 ns	–0.05 ns
	6.0 m	0.03 ns	–0.01 ns	0.05 ns	–0.01 ns
Maximum bow height (%)	2.4 m	0.60 *	0.30 ns	0.47 ns	0.57 *
	4.2 m	0.47 ns	0.24 ns	0.44 ns	0.48 ns
	6.0 m	0.49 ns	0.13 ns	0.30 ns	0.37 ns

Table 5. Non-parametric correlation matrix (Spearman rank) for mean values per log and log section (n = 15) and variables obtained from top and butt end discs for 22-year-old Scots pine trees. Significance levels: ns = not significant, *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001.

	Length of log sections, m	Mean values of compression wood content per log section			
		Severe	Mild	Total	Weighted
Data obtained from log ends					
Severe CW content (%)	2.4	0.94 ***	0.71 **	0.86 ***	0.91 ***
	4.2	0.94 ***	0.75 ***	0.89 ***	0.90 ***
	6.0	0.94 ***	0.65 **	0.82 ***	0.86 ***
Total CW content (%)	2.4	0.84 ***	0.84 ***	0.90 ***	0.90 ***
	4.2	0.87 ***	0.84 ***	0.87 ***	0.88 ***
	6.0	0.81 ***	0.79 ***	0.89 ***	0.88 ***
Weighted CW content (%)	2.4	0.89 ***	0.75 ***	0.88 ***	0.90 ***
	4.2	0.90 ***	0.77 ***	0.89 ***	0.91 ***
	6.0	0.88 ***	0.74 **	0.86 ***	0.89 ***
Pith eccentricity (%)	2.4	0.15 ns	0.10 ns	0.05 ns	0.10 ns
	4.2	0.03 ns	0.01 ns	0.01 ns	0.03 ns
	6.0	0.01 ns	–0.18 ns	–0.05 ns	–0.01 ns

eccentricity in the basal 1.2 m part of stems showed no significant differences between trees in the four categories in 1985 (p = 0.199–0.605) (Fig 2). Trees with straight stem bases in 1997 showed a constant eccentricity during the period 1995–2000, whereas trees with basal sweep in 1997 increased their pith eccentricity during this period. Trees with straight stem bases in 1986 and 1997 had a more centric pith position after 22 growing seasons compared to trees with basal sweep in 1986 and 1997 (p = 0.02). Differences in pith eccentricity for trees with basal sweep 1986 and straight stem base 1997 respective trees with straight stem base 1986 and basal sweep 1997 was smaller (p = 0.05–0.123).

The distributions of the examined factors divided into stems with straight stem bases and crooked stem bases, are shown in Table 6. Significant differences between trees with straight and crooked stem bases for basal 2.4 m sections were found for all tested variables (p = 0.002–0.014), except for out-of roundness (p = 0.371).

Most of the logs and log sections had a limited bow height. The bow height of the 15 original six-metre logs varied between 0.2% and 1.5%. If only the basal 2.4 m and the basal 4.2 m sections were considered the relative size of the bow height increased to a maximum value of 3.8%. Only three of the basal 2.4 m sections had a bow height exceeding 2%.

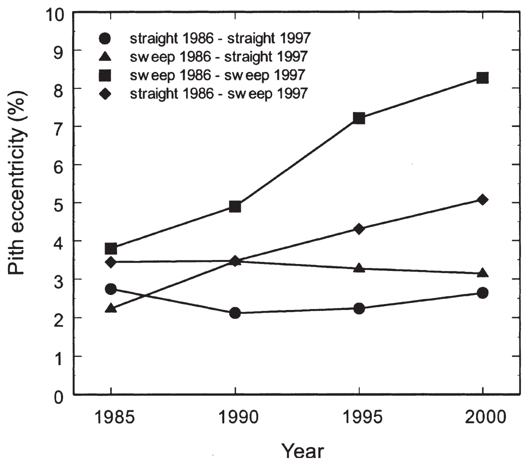

Fig. 2. Temporal pith eccentricity (%) for 22-year-old Scots pine trees (n = 15) expressed as mean values in 1985, 1990, 1995 and in 2000 for discs taken from 0, 0.6 and 1.2 m height (n = 45). The trees were classified into four categories based on basal curvature measurements made in 1986 and 1997.

In five of the 15 examined stems, an obvious spiral compression wood distribution pattern was

Table 6. One-way variance analyses on the examined variables for the basal 2.4 m part of straight (n = 7) and crooked (n = 8) stems of Scots pine (mean values per stem). Straight stems = trees with straight stem base 1986 and straight stem base 1997 (category 1), trees with basal sweep 1986 and straight stem base 1997 (category 4). Crooked stems = trees with straight stem base 1986 and basal sweep 1997 (category 2) and trees with basal sweep in both 1986 and 1997 (category 3).

Variable	Curvature	Mean	Max.	Min.	SD	P
Volume severe CW	Straight	1.5	3.9	0.3	1.2	0.001
	Crooked	5.3	7.9	1.7	2.2	
Volume mild CW	Straight	5.9	10.9	3.3	2.8	0.008
	Crooked	9.7	12.5	6.3	1.9	
Volume Total CW [a)]	Straight	7.4	12.8	3.9	3.6	0.002
	Crooked	15.0	20.4	10.0	3.9	
Volume weighted CW [b)]	Straight	4.4	8.0	2.1	2.3	0.001
	Crooked	10.1	14.1	6.2	3.0	
Pith eccentricity [c)] (%)	Straight	3.2	4.6	1.9	1.1	0.009
	Crooked	4.8	6.4	3.2	1.2	
Out-of-roundness [d)] (%)	Straight	3.5	4.9	2.2	1.0	0.371
	Crooked	4.5	8.6	2.5	2.0	
Max. bow-height (mm)	Straight	20.5	37.5	10.5	11.2	0.014
	Crooked	47.8	91.1	22.4	22.5	

Compression wood (CW) expressed in % of total volume.
a) Total CW = severe + mild CW
b) Weighted CW = severe CW + 0.5 × mild CW
c) Pith eccentricity = distance between pith position and geometric centre of cross section / mean diameter
d) Out-of-roundness = (max. diameter – min. diameter) / ((max. diameter + min. diameter) / 2)

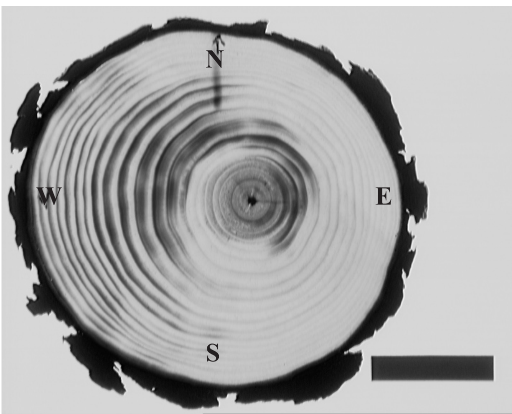

Fig. 3. Spiral compression wood pattern in a cross section of a 22-year-old Scots pine tree. The bar in the figure represents an interval of 5 cm. Compression wood is present in the third to the fifth growth ring from the pith in eastern direction (E), in growth rings 6 to 9 in northern direction (N) and in rings 10 to 22 in western direction (W).

found within discs (Fig. 3). This pattern was apparent in the discs cut at tree heights ranging from 70 cm to 310 cm. The direction of the spiral in the discs was clockwise in one tree and anti-clockwise in four trees. In six of the other trees the direction of the compression wood changed between discs forming a spiral pattern along the stem. Among these six trees, four had anti-clockwise and two had clockwise distributed compression wood along the stem. Significant for the five trees with the spiral pattern within discs were the large amounts of single-sided severe compression wood and absence of spiral compression wood in the basal disc (height 10 cm). Only four of the examined trees did not show any spiral pattern. One of these trees had also large amounts of single-sided compression wood in the basal disc.

4 Discussion

Measurements made in 1986, 1997 and 2001, showed that trees with basal sweep are able to develop a normal straight-appearing bole over time. Lindström and Rune (1999) also demonstrated this by comparing young and old trees from different stands. In this study, however, all measurements were performed on the same trees over a longer period of time, 22 years.

Although eight of the 15 sampled trees had a straight stem base in 2001, compression wood was found in all stems and in almost all discs. This is in accordance with Boone and Chudnoff (1972) and Koch et al. (1990), who examined pine trees and found that virtually all stems contained compression wood. Compression wood formation was most pronounced in the basal part of the stem. With increased stem height, compression wood content decreased. Burdon (1975), Nicholls (1982) and Rune and Warensjö (2002) have reported similar results. Rune and Warensjö (2002) found a significant correlation between degree of basal sweep and severe compression wood content for 6-year-old Scots pine trees. In contrast, this study showed no correlation between basal sweep and compression wood content. The absence of correlation between basal sweep and compression wood content is probably an effect of the concealment of the juvenile basal sweep by eccentric growth, which leads to straight trees that contain large amounts of compression wood. This was also confirmed in the analysis of the temporal pith eccentricity, which showed that trees with straight stem bases 1986 and 1997 had a more centric pith position after 22 growing seasons compared to trees with basal sweep in 1986 and 1997.

If a tree loses its anchorage in the soil and starts to lean, the stem size at this time is crucial for the recovery process. For example, during the first years after planting, a small tree will be able to recover from a leaning position rather quickly (Little and Mergen 1966, Cremer 1998). As a consequence, limited compression wood formation can be expected. If the tree is larger, the process will take longer, thus leading to more compression wood formation. According to Mason (1985), a young established tree leaning more than 45 degrees will never be able to conceal the basal sweep. Similarly, if a tree with a large diameter becomes inclined, the tree will never be able to conceal the basal part of the stem by eccentric growth. As a consequence the basal part of the stem will continue to produce compression wood even though the upper part of the stem may have reached a stable vertical position, leading to over-correction (Cremer 1998). Two of the examined stems in this study showed a compression wood pattern that is typical for an over-corrected tree.

The trees with a basal sweep in 1986 had produced single-sided compression wood in growth rings five to eight from the pith, indicating that trees were inclined during the period 1983 to 1986. This was also in accordance to the observations of the temporal pith eccentricity that showed that all trees had similar pith eccentricity in 1985. However, from this study it is impossible to estimate any limits for tree size or size of basal sweep that can be concealed by eccentric growth.

The spiral compression wood pattern observed in some of the trees indicated that the tree or stem segment previously had been leaning in several directions (Timell 1986). Rune and Warensjö (2002) reported a similar spiral-pattern of compression wood distribution for young Scots pine trees with basal sweep. According to our findings, the spiral develops when the tree starts to lean in a direction that is offset from the direction of the basal sweep. The direction of the spiral is probably caused by chance since both clockwise and anti-clockwise directions are present. Telewski (1988) suggested that spiral compression wood formation produced in the southern hemisphere might be counter-clockwise due to the east to west movement of the sun. This suggestion contradicts our observations of the predominant direction of the spiral. The large amounts of single-sided severe compression wood found in the basal disc of the trees with the most obvious spiral pattern indicated a large basal sweep formation. The absence of spiral compression wood in the basal discs of these trees indicated that the anchorage of the root in the soil had improved over time and that only upper parts of the stem had been moving. This was supported by Lindström and Rune (1999) who found that mechanical stability of young trees with deformed root systems would be improved after a certain time. However, the trees with spiral compression wood were probably still unstable.

Most of the cross sections were almost circular even though they had an eccentric pith position.

Often, discs with an eccentric pith position have an elliptic or oval appearance (Timell 1986, Rune and Warensjö 2002). In this study out-of-roundness was significantly correlated to pith eccentricity but not to severe compression wood content, for the basal 2.4 m part of the stems. However, if discs representing all heights were considered there was no correlation between out-of-roundness and pith eccentricity. This was probably an effect of centric discs with limited amounts of compression wood in upper parts of the stems.

The external geometry of the log was explained by the variables bow height and out-of-roundness. For most of the trees, the maximum bow height was found within the basal 1.5 m part, but even then, it was not very large. According to the Swedish grading system for saw logs (Regulations… 1999), a bow height of 1 % of the log length is allowed in the better grades of saw logs. The maximum bow height that is accepted for saw logs is 2% of the log length (Regulations… 1999). In this study, only one of the 15 log sections of 4.2 m length and three of the 15 log sections of 2.4 m length had a bow height exceeding 2%. In practice, the 2.4 m sections can be ignored since they are too short to be representative of Scots pine saw logs. Also the limited dimension of the sample trees used in this study need to be considered. Due to the ongoing concealment by radial growth these trees would probably have become even straighter before time of harvest. Bow height was only significantly correlated to the severe and weighted compression wood content for the 2.4 m log sections. Consequently the bow height was not a good measure of the compression wood content in the sample trees. The weak correlation between bow height and compression wood content in this study can probably be explained by the limited bow heights. However, most literature report that curved logs contains compression wood (cf. Timell 1986). Compression wood in straight trees has earlier been reported by others (e.g. Low 1964, Timell 1986, Warensjö 2003). However by combing data describing the external geometry of logs with information obtained from log ends predictions of compression wood can probably be improved.

In this study, severe and weighted compression wood content in log ends was significantly correlated to the compression wood content within the trees. This is also in accordance to Warensjö (2003) who found that compression wood in log ends was a good measure of the compression wood distribution within the stem. In general, the correlations in this study were stronger for short log sections (2.4 m) than for longer log sections. Since most of the top end discs did not contain compression wood the correlations were even stronger if only the butt end discs were considered.

The large amounts of compression wood in the basal parts of the sample trees are a result of instability of the young trees resulting in basal sweep (Rune and Warensjö 2002, Rune 2003). This will probably increase the risk for compression wood formation in future saw timber.

Due to the fact that the straightening process still was ongoing at the time of cross cutting it is difficult to forecast the future wood quality if only the external geometry is considered. With knowledge of the history of basal sweep, predictions of compression wood content in older trees can be improved.

4.1 Conclusions

It is evident that eccentric growth and compression wood formation play a major role in the development of stem straightness, and young trees with basal sweep will be more straight over time. As a consequence also straight trees can contain large amounts of compression wood. Therefore, the straightness of a log is not a reliable measure of occurrence of compression wood in such trees. By combing data describing the external geometry of logs with information obtained from log ends predictions of compression wood can probably be improved.

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