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Original article

Stem cracks in Norway spruce in southern Scandinavia: causes and consequences

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Summary — Stem cracks in Norway spruce (*Picea abies* L, Karst) have been recognized as a problem in southern Sweden since 1980. Stands 15–20 years of age that had been planted at a wide spacing on fertile sites were mostly unaffected. Damage was most severe on the larger trees with wide annual rings and a low basic density. Cracking frequency, which is partly under genetic control, varied between provenances as well as clones. Microscopy revealed that most cracks developed during the period of latewood formation. Hot, dry weather, which started in July, promoted cracking. To prevent cracking, it is recommended that suitable provenances be planted on fertile sites at square spacings not more than 1.5 m. Furthermore, clones prone to cracking should be excluded from breeding programmes.

stem crack / basic density / annual ring / stress-grading / *Picea abies*

Résumé — Les fentes du tronc chez l'épicéa commun en Scandinavie méridionale : causes et conséquences. *En Suède méridionale, les fentes du tronc d'épicéa commun (*Picea abies* (L) Karst) ont été identifiées pour la première fois comme un problème technologique vers 1980. Les peuplements âgés de 15-20 ans plantés à grands espacements sur des sols fertiles ont été les plus abîmés, et c'est surtout sur les plus gros arbres présentant des cernes larges et une densité de bois faible que l'on a trouvé les plus gros dégâts. La fréquence des fentes du tronc peut être contrôlée génétiquement, au moins en partie. Des variations ont été trouvées entre différentes provenances et clones. Des études au microscope ont montré que la plupart des fentes sont apparues pendant la saison de formation de bois final. Une période de temps chaud et sec au mois de juillet a également influencé l'apparition de fentes du tronc. Les conseils suivants sont donnés aux sylviculteurs : plantations de provenances convenables sur des sols fertiles en carrés ne dépassant pas 1,5 m ; les clones présentant une tendance à se fendre doivent être éliminés.*

***fente du tronc / densité du bois / cerne /* «stress-grading» / Picea abies**

INTRODUCTION

Background

During this century, the widespread cracking of Norway spruce (*Picea abies* L Karst) has occurred on a number of occasions. Flander (1913) reported cracks occurring in 1911 in Germany, and cracks developing the same year were also discussed by Knuchel (1947). Cracking in 1947 was reported from Sweden by Anon (1948), from Denmark by Buchwald (1948) and from Britain by Day (1954). Between 1980 and 1983 a marked increase in stem cracking in Norway spruce was observed in southern Sweden. During the same period, stem cracking was also observed in Denmark and southern Norway. However, since 1983 hardly any stem cracking has been noted.

The problem became apparent when selecting candidates for plus trees as a base for further tree breeding. Stem cracks often led to the rejection of otherwise well-suited trees, and already selected candidates had to be rejected when cracks were found during later inspections.

Stands affected

Most commonly, cracked trees were found in plantations on abandoned pasture/agricultural land in southern Sweden, up to about latitude 60° N, planted with a spacing of 2 m or wider. The extensive areas of abandoned agricultural land planted with spruce in the early 1960s were often affected. Although less common and severe, cracking also occurred in naturally regenerated stands, especially where early and heavy precommercial thinnings had been carried out.

Appearance

The cracks were usually 0.5–6 m long, occasionally longer, and frequently extended from the cambium into the pith. Most cracks showed a slight bend to the left, although virtually straight cracks also occurred. During dry periods cracks reached a width of up to 20 mm, whereas during moist periods they closed again. Most cracks that were wide during the dry summers of 1982 and 1983 remained closed during the moist summer of 1984. The cracks eventually closed and were only visible as a scar in the bark in early 1992.

Internal cracks, not visible on the surface of the stems, were observed sporadically. In most cases they were found on trees that had been felled and crosscut because they also had visible cracks. Figures 1 and 2 show logs with external cracks and a cross-section of a stem with both external and internal cracks.

Earlier studies

Various attempts have been made to determine why cracking occurs. Flander (1913) and Knuchel (1947) described stem cracks formed in connection with the dry year of 1911 and ascribed cracking to drought and heat respectively.

A thorough analysis of stem cracking in conifers was carried out by Day (1954). His study was based on the numerous cracks that appeared in various parts of Britain during the latter part of 1947. The author concluded that cracking was caused by an abnormal drought, which was most severe during August 1947.

Eriksson *et al* (1975) studied a combined clonal and seedling seed orchard in Sweden. About 4% of the stems showed cracks, and no difference in cracking frequency was

Fig 1. Three bottom logs of Norway spruce that developed stem cracks while growing on a fertile site. (Photo: Kurt-Arne Öh.)

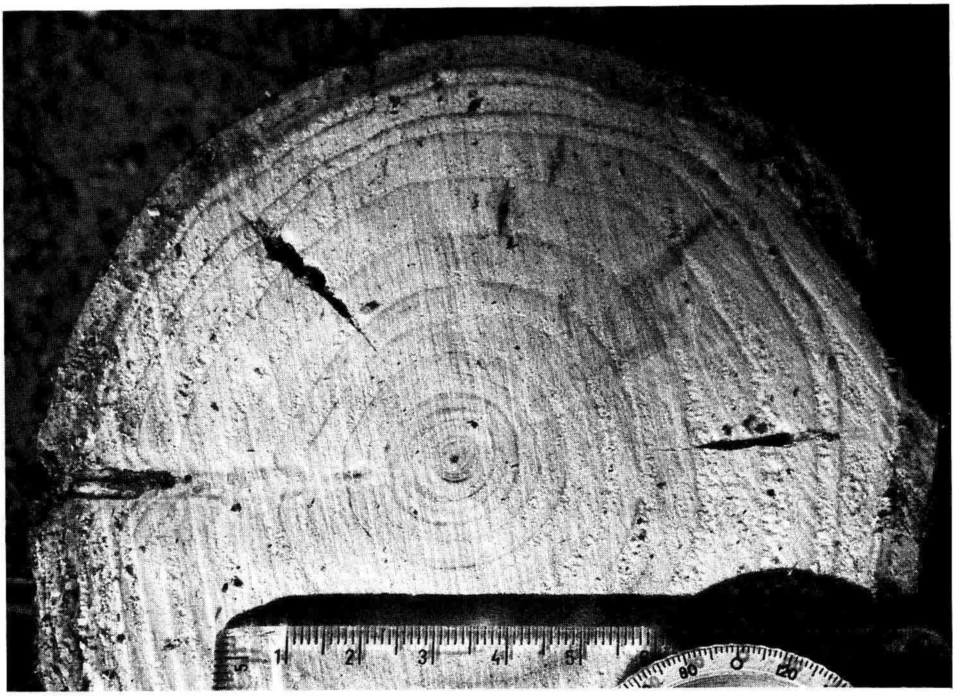

Fig 2. Crosscut stem with 1 externally visible crack and 2 internal cracks. (Photo: the author.)

found between provenances. In an extensive Norwegian study (Dietrichson *et al* 1985), carried out during approximately the same period as the present study, late summer drought was considered to be the most likely triggering factor for many of the cracks.

Objectives

The increase in the frequency of cracking during the early 1980s caused forest owners to question the suitability of the seedlings recommended and supplied by the nurseries of the Swedish Board of Forestry, the main supplier for private forest owners in Sweden. Mainly for this reason, a research programme was initiated in 1984 with the objectives of determining the causes and consequences of the stem cracking. Some of the findings of the studies involved have been reported (Persson, 1985a, 1985b; Persson *et al*, 1987).

MATERIALS AND METHODS

Trials and stands examined

To assess the general importance of the problem, observations were made within the trials listed in table I. All these had known provenance, origin and treatment history. Through an enquiry to forest owners, 150 stands with cracked spruce were reported, out of which about 100 were inspected during 1984.

Table I. Trials in which occurrence of stem cracks has been studied.

Type of trial	*No of trials*	*Denomination*	*Management*	*Reference*
Provenance	10	1969 series	ISF	Werner and Karlsson, 1983
Provenance	2	704, 715	ISF	–
Provenance	1	IUFRO 1964/68, Abild	SUAS	Persson and Persson, 1992
Provenance	3	IUFRO 1938	SUAS	Krutzsch, 1975
Seed orchard	2	Aspanäs, Slogstorp	ISF	–
Seed orchard	1	Marma	–	Eriksson *et al*, 1975
Increment plot	4	–	Forest service	–
Spacing trial	1	Fagerhult	Forest service	–
Spacing trial	1	Tjurvallshult	Sparresäter school of forestry	–
Pre-commercial thinning	7	–	SUAS	–
Total				

Abbreviations: ISF = The Institute for Forest Improvement; SUAS = Swedish University of Agricultural Sciences.

Methods

Inventory

Inventory methods varied, the most thorough being used in the experiments listed in table I. To do the inventory in the stands, temporary sample plots were established in some of them. But once some experience had been gained, most data were observed without using instruments.

Sample collection

In 54 of the 100 stands discs or 12-mm-diameter increment cores were taken from cracked stems. The crack was included in the core. Samples were also collected from the undamaged side of cracked stems with a standard size (4.5 mm diameter) increment borer. In addition, a corresponding core was taken from an equally thick nearby stem, free from external cracks.

Microscopic studies

Cut wood surfaces were studied under a light microscope. Both transparent and non-transparent specimens were examined. The time at which cracking had occurred could be determined because abnormal cell formation is initiated in the cambium once the crack opens. The stage of development at that moment could be deterined, *eg*, earlywood in the 6th–8th cell line, initial stage of latewood formation or after the cell formation had ended. Year of cracking and time of the year of cracking were determined on 160 samples.

Wood density and annual-ring width

The basic density of the 4.5-mm-thick increment cores was determined using the mercury immersion method (Ericson, 1959). At the same time, the widths of the annual rings were determined. In some cases the basic density of complete stem discs was also determined. While still green, their volume was measured by submerging them into water. After drying them in a drying cabinet at 80°C to constant weight, which normally took 48–72 h, they were weighed.

Weather

Weather data for the years 1975–1983 were obtained from official Swedish statistics. Maximum day-time temperature and daily precipitation for the period May to September were the variables of greatest interest.

Timber strength and fibre dimensions

When studying the seed orchard described by Eriksson *et al* (1975), test sawings and fiber-size determinations were carried out in addition to the methods used for other trials and stands. After sawing and drying, the timber was machine stress-graded according to methods described by Brundin (1981).

RESULTS

Which trees crack?

Cracks were most frequent in trees between 18 and 30 years of age with a diameter at breast height of at least 100 mm. Crack width varied between 2 and 20 mm. The average annual diameter growth during the 5-yr period prior to cracking had been at least 8 mm. Trees facing gaps and those along forest edge tended to crack more frequently than trees deeper in the stand.

Time of cracking

The microscopic studies revealed that most cracks had developed during latewood formation; in a few cases they developed during earlywood formation and in other cases during the period when no new cells were being formed. The number of cracks per year and their time of occurrence in relation to cell division are presented in table II.

Importance of various factors

Weather conditions

A study of the relationship between cracking frequency and weather data was carried out between 1975 and 1983. During each of the years in which many cracks formed during the cell division period (1975, 1982 and 1983, table II), a period with hot and dry weather started in July. No similar hot, dry spell occurred in any of the other years during the study period, nor did cracks form during cell division during any of these years, except 1981. The hot and dry weather during 1982 and 1983 continued into August and may have caused the cracks dated to the period without cell division. Occasional cracking occurred during years with no remarkable weather features. On the other hand, a high frequency of cracking was reported from 1969, which had a remarkably hot summer.

Table II. Number of sites where cracking had occurred in a certain year.

Period of cracking	*Year of cracking*									
	1969	*1971*	*1973*	*1974*	*1975*	*1979*	*1980*	*1981*	*1982*	*1983*
During cell-division	4	1	2	2	3	–	–	2	22	12
Between cell-division	1	2	5	2	1	2	4	3	5	3

Only years during which at least 2 sites with cracking were observed are included. Sites at which cracking had occurred between cell division periods were considered to have cracked during the year of the preceding growth period.

Site

All sites in the study where cracking had occurred were of high fertility.

Provenance

In the 3 IUFRO 1938 provenance experiments no tree had cracks, although all were planted on fertile sites. The dense initial spacing, *ca* 1.2 x 1.2 m, was certainly important in this respect. Trees in the 10 experiments comprising the 1969 series established by the Institute for Forest Improvement were planted with a 2.0 m spacing. Only 3 experiments had a noticeable amount of cracks, but the frequency was too low to allow detailed analyses.

Two experimental sites belonging to the IUFRO 1964/68 series were more thoroughly studied: Abild in Sweden at latitude 56° 57' N, longitude 12° 44' E, altitude 65 m; Bjerkøy in Norway at latitude 59° 12' N, longitude 10° 28' E, altitude 10 m. These data were collected and used by Dietrichson *et al* (1985) and thereafter by courtesy made available also to this project.

The results from the 2 experiments are shown in figure 3. To get enough material, the provenances have been assembled into zonal groups. Mean diameter at breast height was higher in the Bjerkøy than in the Abild experiment as was the crack frequency (about 7 and 2%, respectively).

On average, the frequency of cracked trees was higher among provenances with rapid diameter growth than among slow-growing ones. Two zonal groups had a cracking frequency higher than expected based on their diameter growth, namely Slovakia and, to a lesser extent, Romania. Three zonal groups had a cracking frequency that was lower than expected based on their diameter growth, namely Finland, northern Poland and a group containing the Baltic states, Belorussia and western Russia.

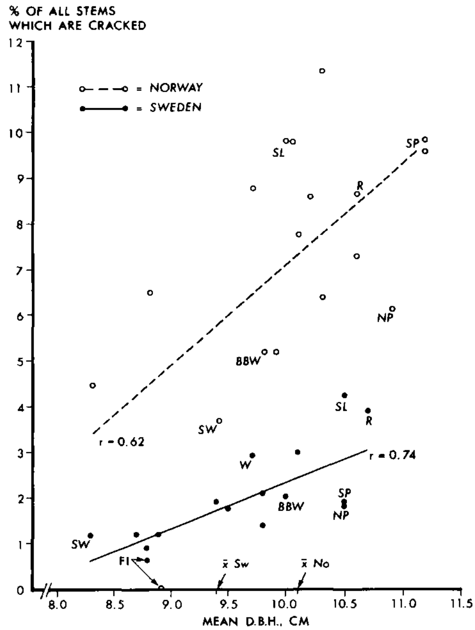

Fig 3. Mean crack frequency of Norway spruce from various provenance zones that had been grown at 2 different sites, Bjerkøy in Norway and Abild in Sweden. The symbols for provenance regions mean: FI = Finland; SL = Slovakia; NP = northern Poland; SP = southern Poland; R = Romania; SW = Sweden; BBW = the Baltic states; Belorussia and western Russia; W = Westerhof, western Germany. *x* Sw and *x* No represent the mean diameter of the material at the Swedish and Norwegian sites respectively. The Norwegian material has been made available courtesy of T Skrøppa, NISK, Norway. (Modified version of figure in Persson, 1985a.)

Genotypes of individual trees

Studies in 2 clonal seed orchards have revealed considerable differences in disposition to cracking between clones. Although not an experiment by design, a seed orchard has the various clones intermixed in an efficient way, thereby eliminating most site differences. Furthermore, conditions in seed orchards are conducive to the formation of cracks since the spacing is wide and the soil is well fertilized.

In one of the seed orchards, Slogstorp in southern Sweden (Scania), clones of pure Swedish origin (S, 25 clones), clones from Swedish stands of continental European origin (C, 10 clones) and clones of Polish origin (P, 10 clones) can be compared. From each of the 45 clones, about 150 grafts (ramets) were planted. Only 5 clones had more than 2 cracked ramets, distributed as follows:

Provenance	*Origin*	*Cracked (%)*
Vevik	S	15
Holkastorp	S	8
Nordanå	C	30
Białowieża	P	4
Rycerka Zwardon	P	71

All the mentioned provenances except Holkastorp (which had only one clone) contained other clones in which not a single ramet had cracked.

Silviculture

In this context main emphasis was placed on the influence of initial spacing in planted stands. Unfortunately, no well-designed spacing trials in which cracks had occurred were available in Sweden.

At Løvenholm, Denmark, stem cracking had occurred in one spacing experiment. Most of the cracks had apparently been formed during summer 1982. The assessments were carried out during 1984, when the trees were 24 years old. Although not replicated, the experiment had the advantage that as many as 11 different spacings, from 0.75 to 3.25 m, were included and thus equalizing of the trend was possible. Summaries of assessment data have been made available by courtesy of H Bryndum, Statens Forstlige Forsøgsvæsen, Denmark. The provenance used was Rycerka, from southern Poland, and the site index was G32–34, which means that the dominant height at age 100 years was assumed to be 32–34 m. This is a high (but not an extreme) value. Many of the Swedish spruce plantations on abandoned agricultural land have a higher site index.

Figure 4 (modified from Persson, 1985a) is based on the Løvenholm data and shows that cracks first appeared at 1.75 m spacing. Cracking frequency then increased with spacing, reaching 17% (equalized) at the widest spacing (3.25 m). It is also evident that the mean diameter at breast height was greater for cracked stems than for the stand as a whole.

In the 2 Swedish unreplicated spacing trials at Tjurvallshult (3 spacings) and at Fagerhult (5 spacings), the cracking frequency generally increased with increasing spacing. The major difference between the spacings was, however, that the yield-reducing gaps resulting from the removal of cracked stems were larger in the treatments with wider initial spacings than in those with narrower spacings.

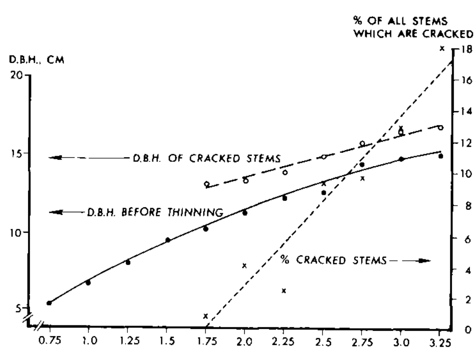

Fig 4. Mean diameters at breast height (• and o) and proportion of trees with cracks *(x)* in a 24-year-old spacing trial with Norway spruce at Løvenholm, Denmark. Data were provided by H Bryndrum, Statens Forstlige Forsøgsvæsen, Denmark.

Basic density

In stands where trees had cracked during 1981–1983, increment cores were taken in autumn 1984 from 30 cracked trees and 30 uncracked trees with the same diameter. Basic density was determined and was compared for the 5 annual rings formed during 1980–1984. On average the basic density for all trees was 275 kg per m^3, and the width of the corresponding annual rings 5.2 mm. Although the variation was large, on average, the cracked stems had 7% wider annual rings and a 6% lower basic density than their uncracked counterparts.

A study including test-sawing (see below) was carried out in the combined clonal and seedling seed orchard described by Eriksson *et al* (1975) (Persson *et al,* 1987). It is situated at Marma in Uppsala County, latitude 60° 28', altitude 35 m; thus it is considerably more northerly than most of the other sites at which cracks have been registered. The orchard was established on abandoned agricultural land in spring 1958, and by summer 1974 it was found that 4.4% of the trees had developed stem cracks. A renewed crack assessment in autumn 1985 revealed that 11.7% of the trees had cracks.

Various provenances from Poland, Czechoslovakia, Austria and Germany were included. Since none of these provenances are recommended today in Swedish forestry, for reasons unrelated to their propensity for cracking, and since no provenance-related differences in cracking frequency were found, the orchard is treated as one stand in this analysis. The grafts had either died or were hopelessly suppressed. The spacing of the seedlings was 1.6 x 8.0 m, corresponding to a square spacing of 3.6 m. The site index was very high (G 37). In late 1985, at an age of 32 yr, 4-m-long bottom logs from each of 51 trees with visible cracks and 25 trees without cracks were analysed. The arithmetic mean DBH for the sample trees was 239 mm ob, and the top diameter ub of the logs was 206 and 211 mm from cracked and uncracked trees, respectively. Results from the measurements are shown in table III.

The results agree fairly well with studies from ordinary stands with cracked trees, *ie* at breast height cracked trees had about 5% wider annual rings and a 5% lower basic density than uncracked ones. It is worth noting that at 4 m height there was no difference in ring width, but the cracked trees had a 7% lower basic density.

Quality assessment

Rot is a serious defect for sawn timber as well as for pulpwood. An open crack automatically provides an entrance court for spores of rot fungi. Rot in connection with cracks was registered frequently, although never in annual rings formed after the last cracking.

Test-sawing and subsequent determination of strength by stress-grading of 138 central yields from bottom logs of the seed orchard at Marma, as described in the previous section, resulted in the following. Among yields from cracked trees, 21% qualified for the lowest grade of structural timber (T 18), whereas the corresponding value for yields from uncracked trees was 24%. On average, yields from the cracked trees were estimated to have 6% less strength than those from uncracked trees when the comparison was based on unclassified machine values.

Fibre dimensions

Cracked and uncracked test-sawn trees from the Marma seed orchard were similar in terms of their measured fibre dimensions, *ie* length and width (total, cell-wall thickness and diameter of lumen).

Table III. Annual-ring width and basic density for cracked and uncracked trees from the seed orchard at Marma.

	Annual-ring width			*Basic density*		
	Cracked (mm)	*Uncracked (mm)*	*Cracked/uncracked (%)*	*Cracked (kg per m³)*	*Uncracked (kg per m³)*	*Cracked/uncracked (%)*
Top discs	6.0	6.0	100	327	350	93
Breast height						
Year 1–5	3.6	3.4	106	282	298	94
Year 6–10	4.9	4.9	100	265	279	95
Year 11–15	6.7	6.5	103	260	267	97
Year 16–20	6.6	6.2	106	287	306	94

The top discs were taken at 4 m height; breast height values are means for groups of 5 annual rings starting from the cambium.

DISCUSSION

Causes

Drought or frost?

Drought and frost have been proposed to be the 2 most important direct causes of stem cracking. Day (1954) based his study on the assumption that cracking was caused by frost or lightning, but ended up concluding that drought was the main reason. Kubler (1983) evaluated the possibility that water movement in the stem in connection with frost will cause cracking, which also led Hellström *et al* (1984) to suggest frost as the most likely reason for cracking in Norway spruce. Dietrichson *et al* (1985) concluded that many of the cracks had developed in the late part of the growing season, which would exclude frost as a triggering factor. This result is well in line with the findings of the present study. The importance of water stress and high temperature was also recognized by Monchaux and Nepveu (1986).

Wood density and latewood content

These 2 traits are related and difficult to distinguish from each other. It is well known that annual ring width in Norway spruce is negatively correlated with basic density. This is a natural result of the fact that an increase in annual-ring width normally is associated with an increase in the amount of the less dense earlywood, whereas the amount of the denser latewood is less affected.

Day (1954) showed that cracked trees had light wood of poor structure that lacked well-thickened latewood, whereas uncracked trees had denser, more structurally sound wood with a larger latewood component. Dietrichson *et al* (1985) concluded that the latewood content of cracked wood is very low, its cell walls thin and its lignification delayed in the autumn. These conclusions are in accordance with findings in the present study. Also Caspari (1990) showed that cracked trees had wider annual rings than had uncracked ones, in spite of having narrower latewood. Studies in which cracked trees and uncracked control trees of approximately the same diameter have been compared in terms of basic density, *ie* Monchaux and Nepveu (1986), Boulet-Gercourt and Nepveu (1988, refers to *Abies grandis*) and the present study, yielded similar results. In all 3 studies the average basic density of cracked trees was 5–6% lower than that of uncracked trees. It is worth noting that even uncracked trees can have a basic density so low that the wood is unsuitable for many uses.

Physiology

Both Day (1954) and Dietrichson *et al* (1985) could only speculate as to the physiological basis of cracking, as was also the case in the present study.

In Caspari (1990) and Caspari and Sachsse (1990), descriptions and analyses of the formation of stem cracks are given. The explanation was that during dry and hot periods the normal sucking tension between the crown and the root increases to such an extent that cell collapse occurs. This develops into xylem cracks and when wood strength proves be insufficient, fully developed stem cracks are formed. It was shown that this was not due to tension through shrinkage, because spruces under water stress crack although the wood moisture content is higher than the fibre saturation point.

Winter damage

An interesting comparison that leads to further conclusions was made by Skrøppa and Dietrichson (1986). In their study of discolouration and needle loss in various provenances in the IUFRO 1964/68 provenance experiment, they attributed these problems to winter damage that occurred because the shoots had not become sufficiently winter-hardy the preceding autumn. The correlation between degree of winter damage and frequency of cracked trees was high when the comparison was based on zonal mean values with the 1 100 provenances grouped into 20 zones, whereas it was weaker when based on provenances, and nonexistent when based on individual trees. They concluded that "winter damage and stem cracks have acted independently on individual trees within provenances, even though similar provenance effects are observed for the 2 types of damages".

The most severly affected trees were those from the central European zones, which tend to harden late (Dietrichson, 1964). It has been shown previously that late hardening can lead to needle discolouration and subsequent needle loss (Skrøppa and Dietrichson, 1986). Furthermore, in the same study they showed that such damage reduced height increment. Evidence that needle loss also causes reduction in diameter growth was demonstrated by Björkdahl and Eriksson (1989).

The apparent contradiction between results obtained with provenances and those obtained with individual trees can be attributed to the fact that cracks and discolouration have a common cause. Late hardening results in needles that are sensitive to harsh winter conditions and poorly developed latewood. Individuals subjected to heavy needle damage, which may have been repeated, show reduced diameter growth, which in turn makes them less prone to stem cracking. Furthermore sucking tension between the crown and the root is probably lower, owing to the reduced needle mass.

In conclusion, hardiness must be given high priority when recommending Norway spruce provenances. If insufficiently hardy provenances are used, needle loss and/or stem cracking may result, depending on the site. This is one of the major reasons why Fottland and Skrøppa (1989) and Persson and Persson (1992) warn against using Romanian and Slovakian provenances in Norway and Sweden.

Consequences

Some consequences of cracking have already been mentioned, *eg,* the crack provides an entry point for rot fungi, and removal of cracked trees may create unwanted openings in the stand. Cracking constitutes a very serious problem when it affects a large proportion of the stand. For instance, in some cases up to 60% of the number of stems can be cracked, and in terms of basal area, the proportion is even higher since mainly the large trees crack. The economic consequences of rot has become more serious during recent years as the pulp industry has shown increasing reluctance to accept wood with even the least sign of rot.

However, it should be kept in mind that low basic density rather than cracking itself is the major cause of economic losses in cracking-susceptible stands. Thus, even if cracking does not occur in such stands (because of no dry spell occurred, *etc*) the timber may nevertheless be unsuitable for structural purposes, and contain too little dry matter to be marketable as raw material for chemical pulp.

MANAGEMENT IMPLICATIONS

From the above discussion it becomes clear that the major task of foresters is not to avoid the cracking as such, but to avoid producing trees with cracking-susceptible wood. Thus one basic rule should be to avoid planting at a wide spacing on very fertile sites.

Based on the knowledge gained, more specific recommendations and generalizations can be made with regard to Swedish conditions:

– Avoid planting Romanian and Slovakian provenances on fertile sites;

– North Polish and Belorussian provenances should be planted at a spacing of not more than 1.5 m to give a high yield; the wood produced is of resonable quality;

– Clones used in clonal forestry should be tested with respect to disposition to cracking; however, methods for such testing must be developed first;

– Clones with a high predisposition to cracking should be removed from seed orchards;

– Spruce plantations between 15 and 30 yr of age should be inspected in connection with prolonged dry spells, thereby permitting cracked trees to be removed without unnecessary loss of value because of rot.

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