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Consequences of Injury Caused by Timber Harvesting Machines on the Growth and Decay of Spruce *(Picea abies* (L.) Karst.)

Puunkorjuukoneiden aiheuttamien vaurioiden vaikutus kuusen lahoamiseen ja kasvuun

Antti Isomäki and Tauno Kallio

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CONSEQUENCES OF INJURY CAUSED BY TIMBER HARVESTING MACHINES ON THE GROWTH AND DECAY OF SPRUCE (PICEA ABIES (L.) KARST.)

ANTTI ISOMÄKI and TAUNO KALLIO

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PREFACE

The present study was part of the study project handled by the Project Group for Studying the Mechanization of Thinnings the so-called HAKO Commission, financed by the Fund for the Festival Year of Finnish Independence (SITRA). The project was launched under the supervision of Professor Kalle Putkisto at the Department of Logging and Utilization of Forest Products, University of Helsinki, in 1970.

A pilot study based on small material had been made by Matti Kärkkäinen, Dr of Forestry. It was on the basis of this pilot study that the present study was conceived and programmed, a year later.

The study was carried out in cooperation between the Helsinki University Institutes of Forest Technology and Plant Pathology. The material was collected and computerized by the Institute of Forest Technology, while the Institute of Plant Pathology undertook responsibility for identifying decay agents and estimating the incidence of decay microbes.

Though the HAKO Commission finished its work in 1972 the study was extended thanks so allocations granted by the Society of Forestry in Finland and the Ministry of Education. In addition, the study was materially supported by the National board of forestry, Enso-Gutzeit Oy, Kymin Oy, Oy W. Rosenlew AB, G. A. Serlachius Oy and Yhtyneet Paperitehtaat Oy, all of whom — often free of charge — placed skilled personnel at the researchers' disposal for the selection of sample plots and collection of study material. It was also of very great value that, in the treatment of all trees selected for the study, the needs of the research could always be met. This of course often caused the forest owners a noticeable reduction in the useful value of the trees besides extra harvesting expenses.

Valuable advice throughout the study was given by Professors Kalle Putkisto and Matti Kärkkäinen. Other help was given by Risto Haarlaa, Heikki Iisalo and Kari Mutka in collecting the material. The major part of the laboratory work necessary for the study was carried out by Miss Ulla Hartikainen, who also drew the figures and diagrams for the text.

We wish to extend our warmest thanks to all the persons and corporations who contributed towards the completion of the study.

Helsinki, November 10, 1973

Antti Isomäki　　　　Tauno Kallio

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INTRODUCTION

Mechanized harvesting of wood after thinnings damages the remaining growing stock more than earlier harvesting methods used to do. This is due to the mass and consequent need of space of crawler and wheel tractors, and to the fact that cross-country haulage in the snowless seasons has become general for stands marked for thinning. Even in intermediate cuttings of spruce stands mechanical harvesting probably involves a risk for the growing stock expected to ensure the full growth and yield of the stand after cutting. This is the basic problem that must be solved before mechanization of thinning cuttings can be started (VUOKILA 1969).

Timber harvesting machines injure the stems and roots of the remaining trees left to grow. The incidence of injured stems in thinning cuttings is c. 20 per cent (WEBBER et al. 1969, PAWSEY 1971). According to a Swedish estimate (HYPPEL 1973), in connection with the harvesting of thinned trees 17–25 million spruce trees left to grow after annual cuttings are perceptibly injured, while according to another Swedish study (ÅGREN 1968) production loss from remaining growing stock is c. 30 per cent of the current increment. In the USA (HINDS & HAWKSWORTH 1966), as a result of mechanical harvesting, some 18 per cent of the quantity logged next had been cull. Yield losses were mainly due to infection by decay fungi of the damage sustained by the trees following mechanical harvesting, thus reducing the yield of the later loggings (SHEA 1960, 1961, 1970).

Studies of the consequences of haulage damage have only recently been started in Finland (KÄRKKÄINEN 1969, 1971 a, 1971 b, 1973, ISOMÄKI 1973, ISOMÄKI & KÄRKKÄINEN 1972). These studies tried to ascertain, among other thigs, the extent to which a knowledge of the site, area and depth of the injury, and of the tree growth, affected prediction of the consequences of the injury, primarily the spread of the decay. No valid predictive equation could be developed. The reports listed paid no attention to the fungal species infecting the injuries.

The purpose of the present study was:

1. to find parameters per stand, per tree and per site of damage to help predict the rate of increase in decay initiated by damage to the tree,
2. to study the increment changes produced by the damage,
3. to investigate the infection by *Fomes annosus* (Fr.) Cooke, and
4. to identify the fungi from all decay that advanced at a rate exceeding 30 cm/year.

I MATERIAL

The material was collected from practical work sites. The unit of observation was the individual injury. Data were collected from several injuries per tree. From the point of view of the assortment of timber yield it is important to know especially the rate of increase in decay upward from the injury, and the fungi found in the decay. For this reason the study was mainly confined to this particular area.

The material was collected in June—November 1971 and September-November 1972. Sample plots were selected from spruce stands damaged by timber harvesting machines. Crushing by vehicles was the most typical injury (Figs. 1 and 2), where the wood bark and also wood material had often been scraped off. The type of damage incurred was classified as follows: 1. injuries above the felling cut as trunk injuries, 2. those between soil level and felling cut as root collar injuries, and 3. those underneath soil level, in the root, as root injuries. Three groups were also formed on the basis of the season in which damage had been sustained: the early summer (before July 15), the late summer (after July 15), and the winter (while the ground was covered by snow). The location of sample plots is shown in Fig. 3. The material comprised ten South Finnish spruce sample plots, specified in Table 1. The 1971 sample plots (1—8) represented a total of 22 working sites, the total of damaged trunks was 525 and the individual injuries 615. The 1972 sample plots (9—10) covered 12 working sites, 291 damaged trunks and 363 individual injuries. The total of working sites studied was 34, damaged trunks 816 and individual injuries 968. The age of the stands studied ranged from 45 to 115 years and that of the damage incurred from 3 to v. 50 years.

Fig. 1. A typical injury.
Kuva 1. Tyypillinen vaurio.

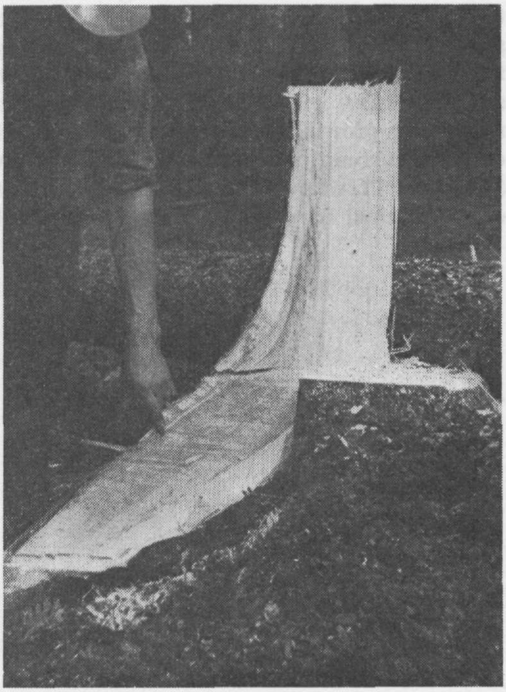

Fig. 2. Decay starting from the injury.
Kuva 2. Vauriosta alkanut laho.

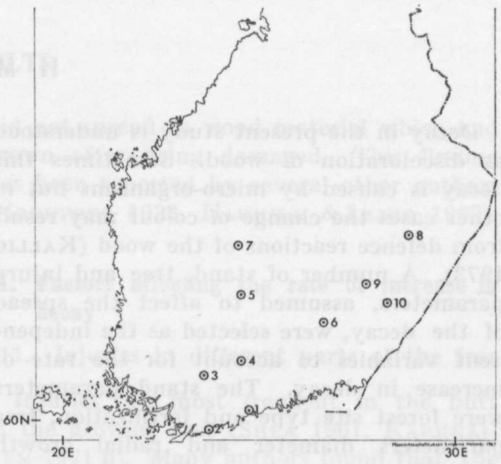

Fig. 3. Location of sample plots.
Kuva 3. Koealojen sijainti.

Table 1. Sample plot stands — *Taulukko 1. Koealametsiköt*

Sample plot year of selection number and locality *Koealan ottamisvuosi numero ja paikkakunta*	Forest site type *Metsätyyppi*	Age of growing stock, years *Puuston ikä, v.*	Season of injury *Vaurioitumisajankohta*	Damaged stems, no. *Vaurioituneita runkoja kpl*	Injuries, no. *Vaurioita kpl*
1971 1. Vantaa	MT	c. 75	Winter — *Talvi*	93	110
2. Snappertuna	OMT,MT	65—75	Winter, late summer *Talvi, loppukesä*	47	57
3. Tammela	MT,VT	95—105	Late summer *Loppukesä*	38	50
4. Janakkala	OMT,MT	45—115	Winter, early summer late summer *Talvi, alkukesä, loppukesä*	64	73
5. Längelmäki	MT	80—95	Early summer, late summer *Alkukesä, loppukesä*	72	82
6. Mäntyharju	MT	85—90	Early summer *Alkukesä*	47	54
7. Keuruu	OMT,MT	c. 75	Winter, late summer *Talvi, loppukesä*	70	79
8. Savonranta—Heinävesi	OMT,MT	45—85	Winter, early summer late summer *Talvi, alkukesä, loppukesä*	94	110
Total 1971 — *Yhteensä 1971*				525	615
1972 9. Juva	OMT,MT	35—95	Winter, early summer late summer *Talvi, alkukesä, loppukesä*	220	271
10 Puumala	MT	c. 65	Winter, late summer *Talvi, loppukesä*	71	92
Total 1972 — *Yhteensä 1972*				291	363
Total material — *Kaikki yhteensä*				816	978

II METHOD

Decay in the present study is understood as discoloration of wood. Sometimes this decay is caused by micro-organisms but in other cases the change of colour may result from defence reactions of the wood (Kallio 1973). A number of stand, tree and injury parameters, assumed to affect the spread of the decay, were selected as the independent variables to account for the rate of increase in decay. The stand parameters were forest site type and fertilization, tree parameters diameter and radial growth of the tree, and injury parameters were the site, size and season of damage.

From the material collected in 1972 (291 trees, 363 injuries) height and radial growth (at breast height) were determined in a five-year period before and after the damage. The ratio between pre-injury and post-injury growth was then calculated.

All the trees were felled. Tree and injury parameters were measured from the felled trees. The highest point of the decay advancing upwards visible to the naked eye was located by cutting the trunk into lengths by power saw. A piece of wood was taken from this point for culture and identification of fungi.

Identification of the fungal species was carried out by the Department of Plant Pathology, University of Helsinki. Two methods were used. Every specimen of decay was examined for conidiophores of *Fomes annosus* (Fr.) Cooke. The fungi of all the specimens in which decay had advanced at a rate of over 30 cm/year, were cultured on malt agar for identification. Determination of *F. annosus* thus comprised the total material, but for the other fungi only a small part thereof.

III RESULTS

1. Rate of increase in decay, and its variation

The incidence of decay in spruce injuries is very high (Pawsey & Gladman 1965), and the rate of spread in the spruce seems to be remarkably higher than in a few other tree species (Pawsey 1971).

In Sweden it has been estimated (Schotte 1922) that the spread of decay from the tops of dominant spruce trees broken by snow advances at a rate of some 50 cm/year in trees aged 50—60 years and some 25 cm/year in those aged 45—50 years. From axe marks on spruce trees, according to another study made in Sweden (Nordfors 1923), the decay began to grow in the direction of the radius, tangent and tree height in ratios 1: 3: 70, while according to a Finnish study (Hakkila & Laiho 1967) decay starting from axe marks increased in the spruce at a maximum rate of c. 50 cm/year in height direction. In Scotland, *Stereum sanguinolentum* (Alb. & Schw.) Fr. was found to advance in the spruce at a rate of c. 40 cm/year (Pawsey & Gladman 1965).

In the present study, the rate of increase in decay in the total material, from the injury upward, was 21 cm/year, while the maximum rate was 135 cm/year. Decay spread upward from the injury about three times as fast as downward. It was also confirmed by Kallio (1973) that discoloration advanced far more rapidly upward than downward. In the present study the decay did not spread to wood material which had grown after being damaged. This finding has been reported by several other authors (Nordfors 1923, Hakkila & Laiho 1967).

11. Factors affecting the rate of increase in decay

111. Injuries in different parts of the tree

Injuries are most frequent in the butt of the growing tree (Shea 1961, Kärkkäinen 1971 b). Many authors found that the location of the initial damage affects the incidence and spread of decay (Haufe 1938, Wright & Isaac 1956, Nilsson 1967, Pawsey & Gladman 1965). Injuries at soil level are almost always infected by decay fungi, whereas trunk injuries escape this infection the higher their location on the trunk (Parker & Johnson 1960, Shea 1970). Swedish authors have reported (Nilsson 1967, Nilsson & Hyppel 1968) that injuries in spruce roots at a distance of 0.7—1.0 m from the felling cut produced only local decay not affecting the useful value of the wood.

The present study divided damage into three groups on the basis of their location: root injuries, root collar injuries and trunk injuries. Table 2 quotes the mean advance rates of the decay.

Tested by the F value, differences in advance rates between these groups were highly significant (p = 0.001). It can be

Table 2. Mean rates (cm/year) of the advance in decay according to injury location.
Taulukko 2. Lahon etenemisnopeuden keskiarvot (cm/v) vaurion sijainnin mukaan.

	Root injuries *Juurivauriot*	Root collar injuries *Juurenniska-vauriot*	Trunk injuries *Runko-vauriot*	Total *Yhteensä*
Mean value .... *Keskiarvo*	19.9	28.4	18.3	21.1
Standard deviation .... *Standardipoikkeama*	20.3	19.1	16.1	17.8
No. of observations .... *Havaintojen lukumäärä*	70	263	645	978

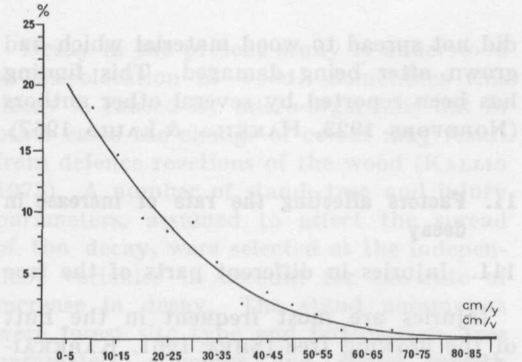

Fig. 4. Relative frequency of the observations according to the rate of increase in decay.
Kuva 4. Havaintojen suhteellinen jakautuminen lahon etenemisnopeuden mukaan.

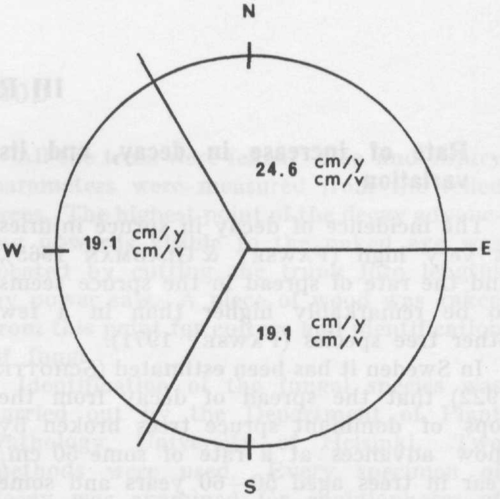

Fig. 5. Locations of the advance in decay resulting from damage on different sides of stem.
Kuva 5. Lahon etenemisnopeus eri ilmansuunnissa illeissa vaurioissa.

assumed that the injuries in roots and root collars are, on average, more severe than on the trunk (KÄRKKÄINEN 1969). For this reason the material was also analysed according to the width of the injuries. The findings in Table 2 show that root collar injuries offer favourable starting points for the onset and spread of decay. This may be due e.g. to variations in the water content in the different parts of trees (HAUFE 1938, NILSSON & HYPPEL 1968).

Fig. 4 shows the distribution of all observations studied into groups according to the rate of discoloration. A total of 182 observations (18.6 per cent of the material) showed discoloration advancing upward from the injury at a rate below 5 cm/year. A similar result was also obtained in Finland for decay starting from axe marks (HAKKILA & LAIHO 1967).

112. Location of injury

The location of every observed injury was also determined according to the points of compass. The material was trisected within the compass circle. As can be seen from Fig. 5 the quickest rate of discoloration started from injuries in a northwest to east direction. The cause may be sought in greater air humidity, lack of sunlight or different wood material.

113. Size of the injury

Many authors have found that the extent of the damaged surface area affects the infection and spread of decay originating from the initial injury (EKBOM 1928, PARKER & JOHNSON 1960, HUNT & KRUEGER 1962, KÄRKKÄINEN 1973). The parameters chosen in the present study to illustrate the injury size were width, surface area and depth.

a. *Width of the injury.* The coefficient obtained for the correlation between the width of injury and rate of decay was +0.344 (Table 3). KÄRKKÄINEN (1973) came to the conclusion that the width of the injury best illustrates its consequences. Fig. 6 shows the relationship between the increase in decay and the width of the injury. The effect of differences in the width classes on the rate of decay proved highly significant even though standard deviation of observations within the classes was relatively great. In England (PAWSEY 1971) the rate of decay in individual spruce trees related to the width of the injury but no general relationship between the size of injuries and incidence of decay could be shown.

b. *Surface area of the injury.* The coefficient obtained for the correlation between the surface area of the injury and the rate

Table 3. Correlation coefficients between the advance in decay and the parameters illustrating the injury size.

Taulukko 3. Lahon etenemisnopeuden ja vaurion kokoa kuvaavien tunnusten keskeiset korrelaatiokertoimet.

Location of tree injury *Vaurion sijainti puussa*	Width *Vaurion leveys*	Surface area *Vaurion pinta-ala*	Depth *Vaurion syvyys*
Root — *Juuri*	0.022	−0.182	0.214
Root collar — *Juurenniska*	0.356	0.325	0.276
Trunk — *Runko*	0.392	0.445	0.275
All injuries — *Kaikki vauriot*	0.334	0.385	0.324

of decay originating from it was +0.385, and for trunk injuries +0.445 (Fig. 7). Consequently the surface area of the injury explains the rate of increase in decay better than any other of the variables selected. The result is similar to that of certain other studies (HEPTING 1941, KÄRKKÄINEN 1971 a, 1973) In the present study, according to variance analysis, the surface area of the injury does not illustrate effectively the rate of the decay emanating from root injuries, whereas for root collar injuries the correlation is highly significant (p = 0.001). For trunk injuries too, the relationship was highly significant (p = 0.001).

c. *Depth of the injury*. Superficial damage in all site groups produced a decay advancing at a mean rate of 13.5 cm/year (Fig. 8). Decay starting from deep injuries increased in roots and trunk c. 21 cm/year, and from those in the root collar at a mean rate of

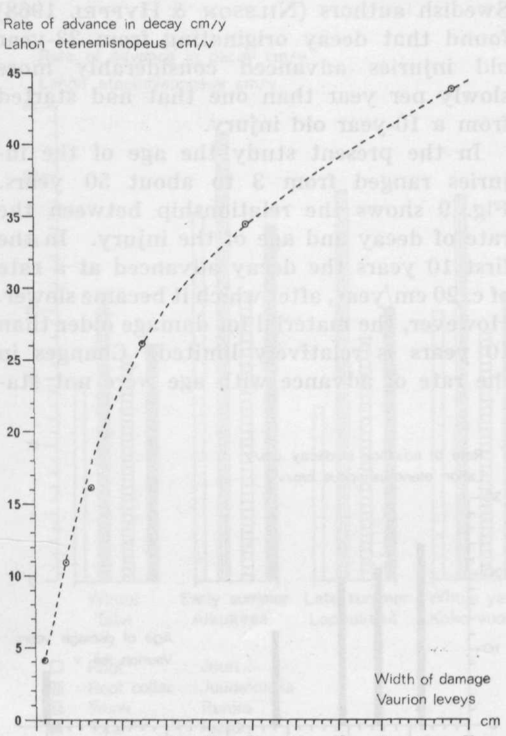

Fig. 6. Relationship between the advance in decay and the width of damage.
Kuva 6. Lahon etenemisnopeuden riippuvuus vaurion leveydestä.

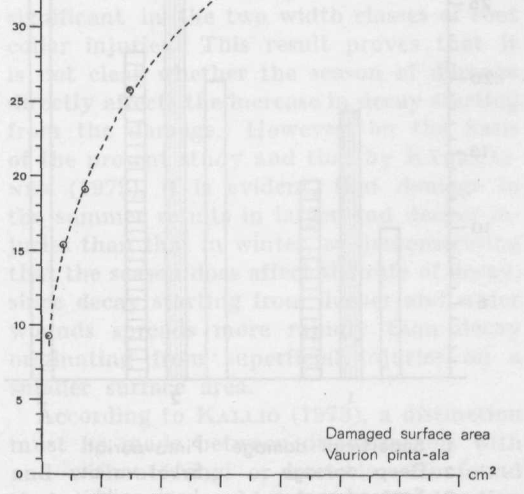

Fig. 7. Relationship between the advance in decay and the damaged surface area.
Kuva 7. Lahon etenemisnopeuden riippuvuus vaurion pinta-alasta.

28 cm/year. Decay originating from severed roots advanced on average c. 32 cm/year. The deep injuries at the root collar are apparently even deeper than elsewhere. Both exposed parts of roots and the root collar are highly susceptible to haulage damage. Wheels and crawler tracks usually exert their weight several times on the same site deepening but not necessarily widening the damage. In England the decay has been found more often to infect deep than superficial injuries of spruce (Pawsey & Gladman 1965).

The rate of decay originating from an injury can be predicted on the basis of the width, depth and surface area of the injury. The surface area is the most reliable of the three parameters. It explained 22.2 per cent of the total variance in the rate of the decay, while the width explained only 16.2 and the depth 10.5 per cent.

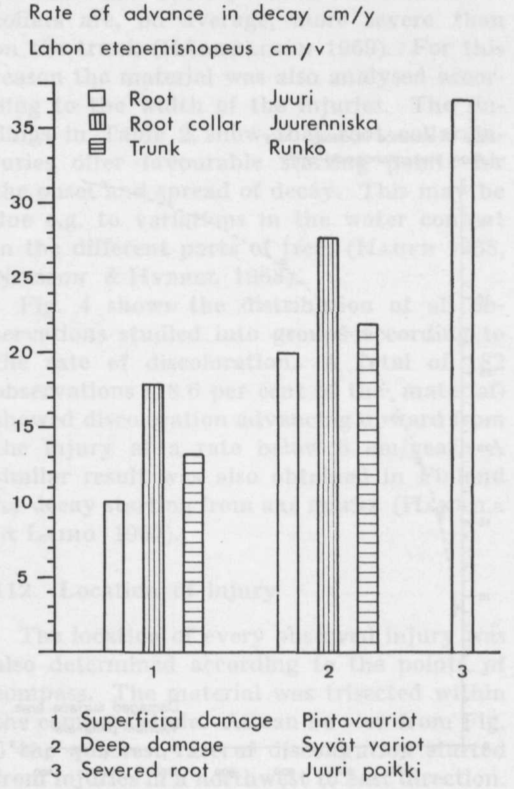

Fig. 8. Relationship between the advance in decay and the depth of damage.
Kuva 8. Lahon etenemisnopeuden riippuvuus vaurion syvyydestä.

114. Age of the injury

Decay infecting the wood from spruce tops broken by snow is assumed to increase more slowly in the course of time (Schotte 1922). On the other hand, decay fungi are known to infect the wood relatively soon after the injury has been inflicted (Ekbom 1928, Kallio 1973). Within one year of the injury, discoloration of spruce in Finland has been found to advance upward by 50 cm in the suppressed and 30 cm in the dominant crown layer (Kallio 1973). The advance of decay, according to Ekbom, was most rapid in the few years after the injury. Its rate diminished subsequently but its spread continued throughout the remaining life-time of the tree, while according to another study (Wright & Isaac 1956) the advance was becoming slower within three years of the injury. However, the decreasing rate has also been reported to take place 10–15 years after the injury (Parker & Johnson 1956). Swedish authors (Nilsson & Hyppel 1968) found that decay originating from 33-year old injuries advanced considerably more slowly per year than one that had started from a 10-year old injury.

In the present study the age of the injuries ranged from 3 to about 50 years. Fig. 9 shows the relationship between the rate of decay and age of the injury. In the first 10 years the decay advanced at a rate of c. 20 cm/year, after which it became slower. However, the material for damage older than 10 years is relatively limited. Changes in the rate of advance with age were not sta-

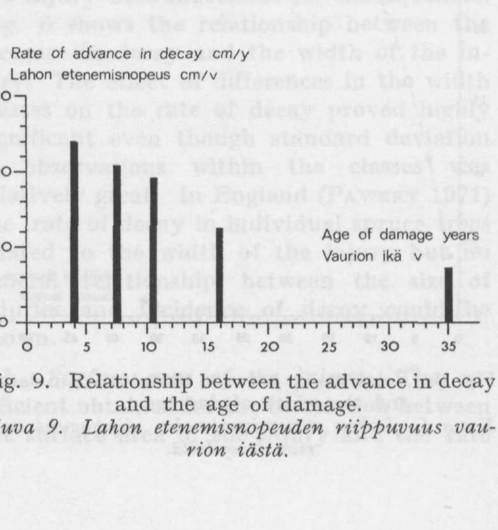

Fig. 9. Relationship between the advance in decay and the age of damage.
Kuva 9. Lahon etenemisnopeuden riippuvuus vaurion iästä.

tistically significant for the root and root collar injuries, but for trunk injuries the slowing of the advance was statistically significant. A similar result has been recorded on oak species concerning decay that started from damage caused by forest fires (Hepting 1941). On the other hand, Hunt & Kreuger (1962), in their material of 82 injuries in *Tsuga heterophylla* (Raf.) Sarg., found no relationship between the age of the injury and the amount of decay.

115. Season of injury

Snow and freezing of the soil protect roots against injuries in the winter. The frozen soil cover is usually firmly attached to the tree. Consequently winter injuries are apparently smaller than summer injuries. According to a study (Hakkila & Laiho 1967) trees axe-marked for felling in May were less frequently infected by decay than those marked in the summer or early autumn.

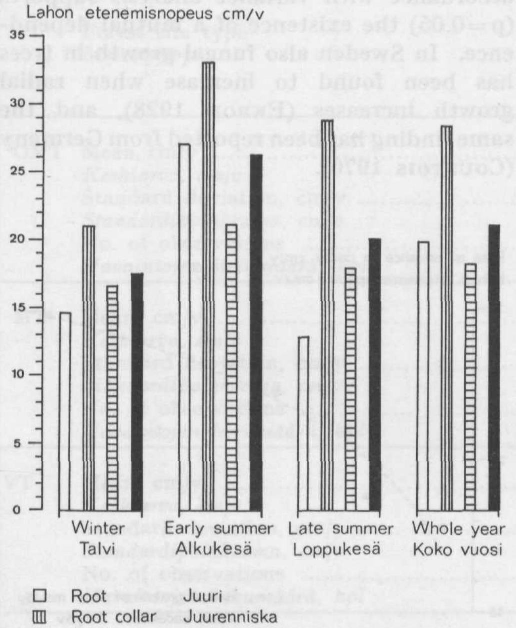

Fig. 10. Relationship between the advance in decay and season of damage.
Kuva 10. Lahon etenemisnopeuden riippuvuus varioitumisen ajankohdasta.

The present material was distributed into three groups according to the season of injury: 1. damage sustained in the winter (=while the snow cover was on), 2. damage sustained in the early summer (=before July 15), and 3. damage sustained in the late summer (= after July 15).

Fig. 10 shows that damage in the early summer caused, on average, a decay advancing at a faster rate than that in the winter ($p = 0.001$). The effect of the season of damage in the present material was most clearly discernible in the rate of increase in decay starting from root collar damage. Variance analysis showed that significant differences existed between the seasons only in the cases of root collar damage and the total material.

The indirect effect of the season on root collar and trunk damage was also investigated. The size of the injuries in different seasons was analysed, in an effort to ascertain the indirect effect. The injuries were divided into two groups: the 4—8 cm wide and the 8—16 cm wide. This analysis suggested that the season of injury apparently affected the width of the damage and hence also the rate of the increase in decay. In trees injured in the winter the decay advanced more slowly than in those injured in the summer. No difference was discernible between early and late summer. Nor were the differences between winter and summer significant in the two width classes of root collar injuries. This result proves that it is not clear whether the season of damage directly affects the increase in decay starting from the damage. However, on the basis of the present study and that by Kärkkäinen (1973), it is evident, that damage in the summer results in larger and deeper injuries than that in winter, so demonstrating that the season does affect the rate of decay, since decay starting from deeper and wider wounds spreads more rapidly than decay originating from superficial injuries on a smaller surface area.

According to Kallio (1973), a distinction must be made between discolorations with and without fungi or bacteria. He found that in one-year old injuries discoloration with no fungi or bacteria advanced upward more quickly in spruce trees injured in January-March, whereas discoloration with microbes advanced upward at the fastest rate from injuries produced in October-December. The diaspore deposition of fungi growing on trees is greater in October-December in South Finland than perhaps in any other quarter of the calendar year (cf. Kallio 1970).

116. Tree-related factors

a. *Tree diameter.* Decay has been found to infect stem wounds more often the larger the stem size (Kuenzel & Sutton 1937, Parker & Johnson 1960). Also, with a larger root diameter, the increase in decay infecting the roots has been found to be more rapid (Hagner et al. 1964). Large trees are more frequently affected by butt rot than small trees (Saarnijoki 1939). According to Kató (1967), as the diameter of the growing spruce increases the decayed area in the section of the butt of the stem becomes larger. In spruce trees growing in the same soil type a correlation was found between the diameter of decay in the section and the stem diameter, whereas in different soil types the proportion of stem sections covered by decay was different (Zycha 1967). Studies in Finland (Kallio & Norokorpi 1972) revealed no relationship between the degree of decay of spruce discoloration and the area of the felling cut section. Nor was any relationship noted between breast height diameter and decay (Kallio 1972).

In the present study, a distinct positive correlation existed between the tree diameter and the rate at which decay increased (Fig. 11). For root collar damage, the correlation was also positive but weaker. In subsoil injuries to roots, on the other hand, variance analysis disclosed no correlation between diameter and the rate at which decay advanced. The DBH of the tree alone does not affect the rate at which decay increases. The quicker spread of decay in the larger stems probably depends on the larger damage of the large trees, their wood structure, moisture of wood material its chemical composition and the changes of this composition with age.

b. *Radial growth of the tree.* Fig. 12 classifies the results into four groups according to the radial growth prior to damage. According to the picture, the spread of decay depends on the radial growth of the tree. The t-test reveals statistically significant differences between the mean values; these differences, however, are not very reliable ($p = 0.10 - 0.20$). The F value in accordance with variance analysis supports ($p = 0.05$) the existence of a mutual dependence. In Sweden also fungal growth in trees has been found to increase when radial growth increases (Ekbom 1928), and the same finding has been reported from Germany (Courtois 1970).

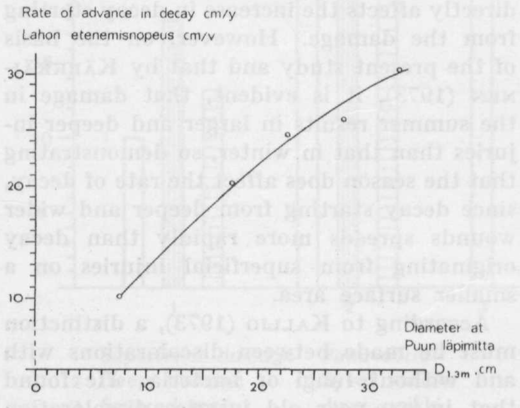

Fig. 11. Relationship between the advance in decay and tree diameter.

Kuva 11. Lahon etenemisnopeuden riippuvuus puun läpimitasta.

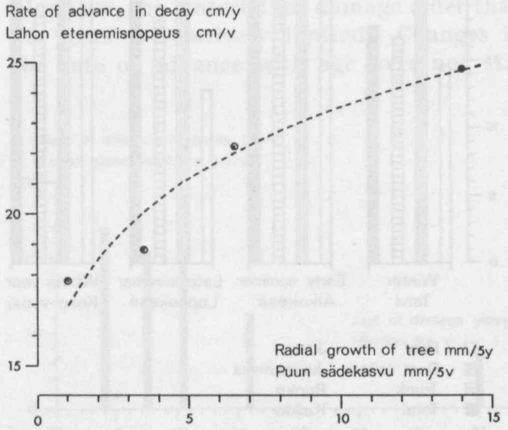

Fig. 12. Relationship between the advance in decay and the radial growth of the tree.

Kuva 12. Lahon etenemisnopeuden riippuvuus puun sädekasvusta.

117. Forest site type

Reports on the incidence of decayed trees growing in different soil types are contradictory. According to Saarnijoki (1939), the number of decayed trees was lower in Myrtillus type (MT) soil and increased in the poorer soils. Decay was most frequent on Oxalis-Myrtillus type (OMT) soil. On the other hand, according to his study, the incidence of decay is affected more by the humidity than the nutritional content of the soil type. According to Kangas (1952), decayed trees are more numerous on MT than OMT soil, while the soundest growing stock could be found on the Vaccinium type (VT) soil. Nordfors (1923) reported that decay is more pronounced the better the growth of the forest in question. According to American studies (Cowling & Merrill 1966), an increased nitrogen content in the wood material accelerated the rate of decay in laboratory tests. On the other hand, it has not been shown that urea fertilization will increase the tendency of spruce to decay (Cowling et al. 1969). When the effect of forest fertilization on decay of the growing stock is studied, distinction must be made between the infection in growing trees by decaying microbes and the rate of the decay caused by them. So far there are hardly any study results available on the rate of infection, whereas findings have been reported on the rate of spread of decay in the wood material in trees growing in fertilized forests (Cowling et al. 1969). In principle, it may be assumed that a fertile soil type has the same effect as fertilization. In the present study, however, the effect of soil type and fertilization are studied separately.

Table 4. Relationship between the advance in decay and fertilization of soil.
Taulukko 4. Lahon etenemisnopeuden riippuvuus kasvualustan lannoituksesta.

Forest site type *Metsätyyppi*		Advance in decay, cm/year *Lahon etenemisnopeus, cm/v*		
		Unfertilized *Lannoittamaton*	Fertilized *Lannoitttu*	Total *Kaikki*
OMT	Mean, cm/y *Keskiarvo, cm/v*	22.5	31.71	26.3
	Standard deviation, cm/y *Standardipoikkeama, cm/v*	15.2	23.8	19.7
	No. of observations *Havaintojen lukumäärä, kpl*	118	83	201
MT	Mean, cm/y *Keskiarvo, cm/v*	16.9	25.8	20.0
	Standard deviation, cm/y *Standardipoikkeama, cm/v*	16.0	17.8	17.2
	No. of observations *Havaintojen lukumäärä, kpl*	487	263	750
VT	Mean, cm/y *Keskiarvo, cm/v*	13.1	—	13.1
	Standard deviation, cm/y *Standardipoikkeama, cm/v*	11.3	—	11.3
	No. of observations *Havaintojen lukumäärä, kpl*	27	—	27
Total *Kaikki*	Mean, cm/y *Keskiarvo, cm/v*	17.8	27.2	21.1
	Standard deviation, cm/y *Standardipoikkeama, cm/v*	15.9	19.5	17.8
	No. of observations *Havaintojen lukumäärä, kpl*	632	346	978

a. *Forest site type.* On the basis of the nutritional content of the soil type, macroscopically determined, the material was divided into three groups:

— groves, OMT and the like

— MT and the like, and

— VT and the like.

Fig. 13 shows the correlation between the rate of the decay and the soil type. Where the soil type became more fertile the rate of decay increased. The increase in decay in the OMT spruce stand was twice as fast as in the VT spruce stand.

b. *Fertilization.* The results concerning the effect of fertilization on the rate of the spread of decay are incomplete and contradictory. Acid soils, however, have been shown to carry less decay than alkaline soils (Kató 1967). Decayed trees are more frequently found in afforested fields (Rehfuess 1969). Table 4 shows the relationship between the increase in decay and the fertilization of the soil.

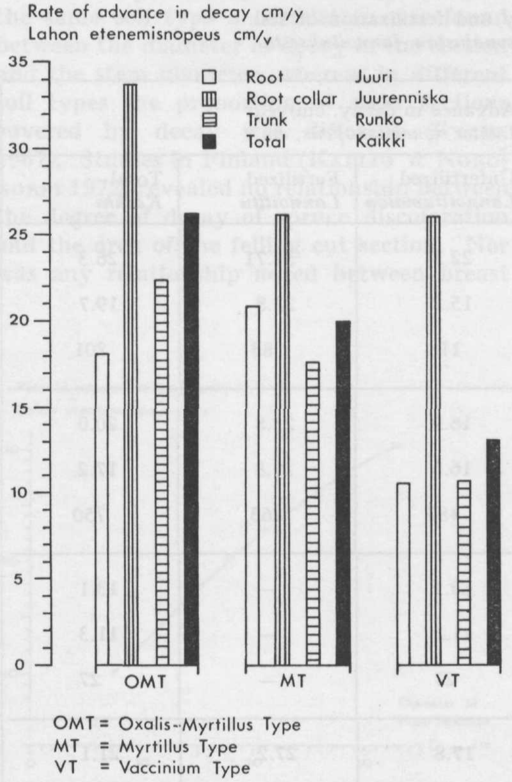

Fig. 13. Relationship between the advance in decay and forest site type.
Kuva 13. Lahon etenemisnopeuden riippuvuus metsätyypistä.

According to variance analyses the differences in the rate of growth of decay between trees growing in unfertilized and fertilized spruce forests were highly significant ($p = 0.001$). No reliable data is available on the type and quantities of fertilizers used. However, all fertilizers contained nitrogen.

On the basis of material used in the present study the soil type affects the rate of increase in decay to the extent that the more fertile the soil type the quicker the growth of decay (Figs. 13 and 14). Fertilization improves the growth substrate and therefore accelerates rate of decay.

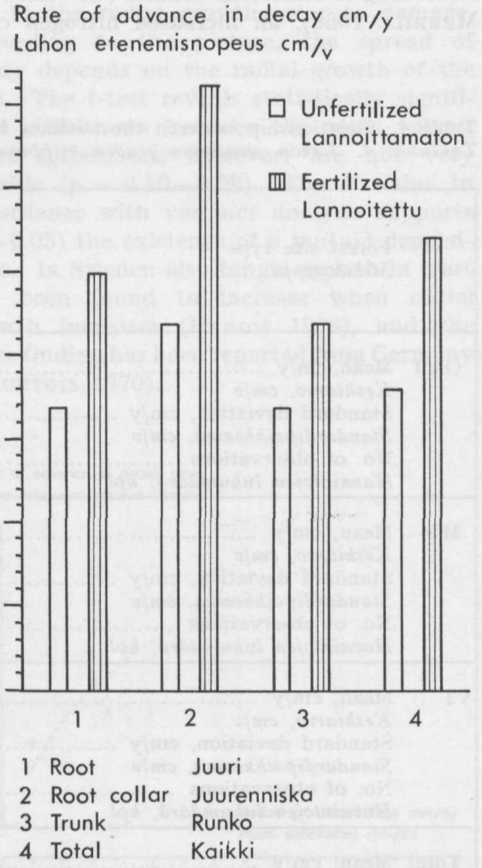

Fig. 14. Relationship between the advance in decay, fertilization and injury location.
Kuva 14. Lahon etenemisnopeuden riippuvuus kasvualustan lannoituksesta ja vaurion sijainnista.

2. Growth changes produced by the injuries

The growth observations were derived from stands where, at the time of the damage, the growing stock was being thinned and often the forest fertilized. The damaged trees left to grow had, according to the study, reacted to these measures by an average increase of about 20 per cent in the radial growth at breast height and an average decrease of about 25 per cent in the height growth compared with the pre-injury growth figures (cf. Vuokila 1960).

Tree growth reaction to more extensive living area and to fertilization was eliminated for the purposes of the study by calculating, for each observation, the ratio of post-injury height and radial growth to the corresponding pre-injury growth (see p. 8). The values obtained for the observations were then classified solely on the basis of injury-related parameters. Separate classifications were made according to the site, depth and width of the injury. The underlying assumption was that equal ratios in all of the growth factors occurred in the resulting groups. The ratios indicating growth reactions, disregarding the effect of the injuries, should be equal on average in the different injury groups. Where statistically significant differences were noted between the groups, they were considered to have arisen exclusively from the fact that the classification variable used to illustrate the injury correlated with the growth reaction of the tree.

The control material used consisted of the values illustrating the growth change of the trees (a total of 36 observations) with the smallest injuries (width 0—4 cm). The mean growth reaction of these trees is indicated as 100 in Figs. 15—16, while for

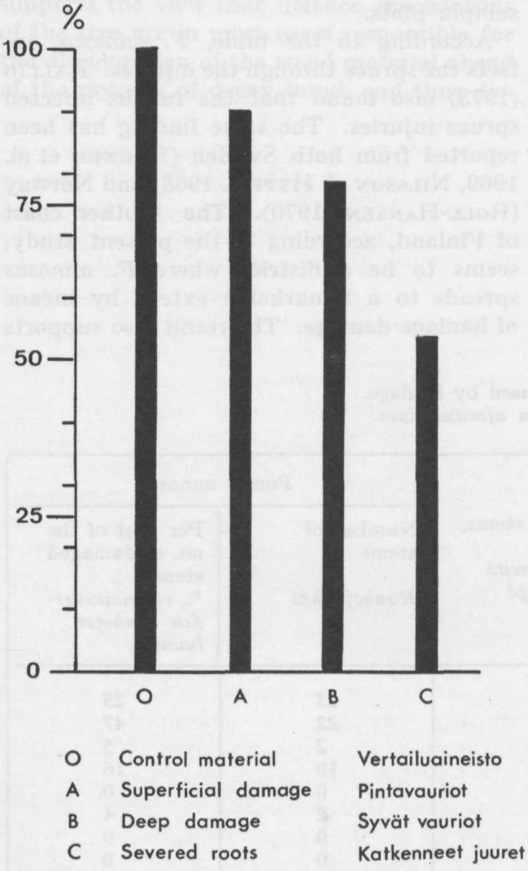

Fig. 15. Relative influence of the depth of damage on the radial growth spruce

Kuva 15. Vaurion syvyyden suhteellinen vaikutus kuusen sädekasvuun.

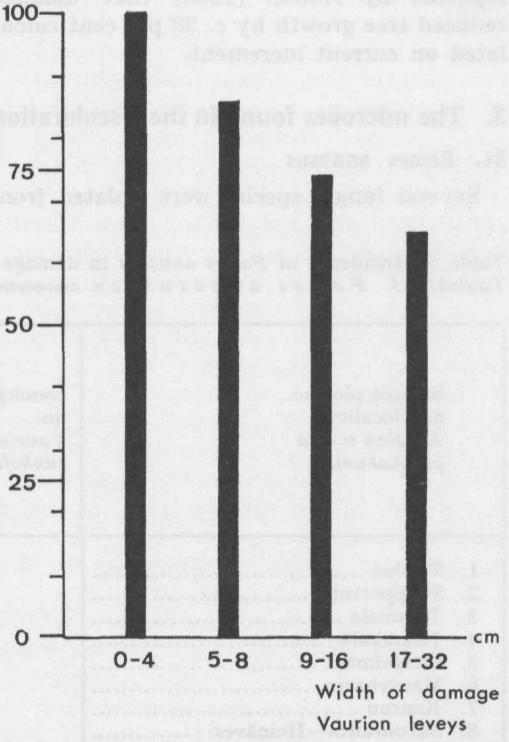

Fig. 16. Relative influence of the width of damage on the radial growth of spruce.

Kuva 16. Vaurion leveyden suhteellinen vaikutus kuusen sädekasvuun.

the other injury groups the relative growth changes have been calculated as percentages of these ratios.

The damage reduced the height and radial growth of the trees. Radial growth was reduced most by the depth of the injury (Fig. 15). Superficial injuries reduced radial growth by c. 10 per cent, deep injuries and severed roots by nearly 50 per cent. All these differences were mutually highly significant ($p = 0.001$). Trunk damage reduced both radial and height growth by c. 15 per cent. Root collar damage reduced height growth by c. 40 per cent, subsoil root damage by c. 25 per cent. The radial growth in both of the latter groups of damage was reduced by c. 35 per cent.

The effect of the width of the injury on the radial growth of tree (Fig. 16) was also considerable. The widest injuries (17–32 cm) reduced radial growth by almost 35 per cent. Height growth also weakened as the width of the injury increased.

These results support the observation reported by Ågren (1968) that damage reduced tree growth by c. 30 per cent calculated on current increment.

3. The microbes found in the discoloration

31. Fomes annosus

Several fungal species were isolated from discolorations originating from damage produced by haulage operations (Hagner et al. 1964, Nilsson & Hyppel 1968, Pawsey 1971, Pechmann & Aufsess 1971). On the other hand, haulage damage hardly constitued any exceptional group of injuries. They supply a growth substrate for decay microbes like any other injury. Usually the decay starts from the injuries as a result of microbial population (Roll-Hansen 1970, Kallio 1973).

The present study tried to ascertain the extent to which *F. annosus* infects haulage damage in spruce. This was done by keeping a piece of wood damaged by decay initiated by an injury caused by haulage for about 10 days wrapped up in plastic, after which the possible presence of *F. annosus* was verified by stereomicroscope. Table 5 shows the incidence of *F. annosus* in the different sample plots.

According to the table, *F. annosus*, infects the spruce through the injuries. Kallio (1973) also found that the fungus infected spruce injuries. The same finding has been reported from both Sweden (Hagner et al. 1969, Nilsson & Hyppel 1968) and Norway (Roll-Hansen 1970). The souther coast of Finland, according to the present study, seems to be a district where *F. annosus* spreads to a remarkable extent by means of haulage damage. The result also supports

Table 5. Incidence of *Fomes annosus* in damage caused by haulage.
Taulukko 5. Fomes annosuksen esiintyminen ajovaurioissa.

Sample plot no. and locality *Koealan n:o ja paikkakunta*	Damaged stems, no. *Vaurioituneita runkoja, kpl*	Fomes annosus	
		Number of stems *Runkoja kpl*	Per cent of the no. of damaged stems *% vaurioitunei-den runkojen luvusta*
1. Vantaa	93	23	25
2. Snappertuna	47	22	47
3. Tammela	38	2	5
4. Janakkala	64	10	16
5. Längelmäki	72	0	0
6. Mäntyharju	47	2	4
7. Keuruu	70	0	0
8. Savonranta–Heinävesi	94	0	0
9. Juva	220	62	28
10. Puumala	71	0	0
Total — *Yht.*	816	121	15

the view that *F. annosus* occurs by patches all over Finland (Kallio 1961).

F. annosus was isolated from a total of 121 injuries. It had infected trunk injuries 14 per cent (91 times), root collar injuries 10 per cent (25 times), and root injuries 7 per cent (t5 times). It has been reported from Germany that *F. annosus* infection of spruce was more successful the more serious was the damage to the tree (Dimitri 1969).

32. Other microbes

Small pieces of wood from the topmost macroscopically visible point of discoloration advancing at a rate exceeding 30 cm/year, were transferred onto malt agar for growth, pure culture and identification for microbes. A total of 301 samples were cultured. 170, i.e. c. 57 per cent, remained sterile. This supports the view that defence mechanisms of the tree are in most cases responsible for the discoloration of the wood material ahead of the mycelia of decay fungi, and thus discoloured wood material does not always grow microbes (Kallio 1973). On the other hand, the malt agar substrate does not necessarily ensure all bacterial growth. Only 17 cultures (c. 6 per cent) grew bacteria. The most common decay fungus of the discoloured wood material was *Stereum sanguinolentum* (Alb. & Schw.), identified in 50 specimens (c. 17 per cent). *Penicillium* spp. were isolated from 21 samples (c. 7 per cent), and *Cephalosporium* spp. from 16 samples (c. 5 per cent). Fifteen fungi (c. 5 per cent) remained unidentified. Additionally, eight different species of *Fungi imperfecti* and *Ascomycetes* were idetified. The identified *Basidiomycetes* fungi included e.g. *Fomes pinicola* (Sw.) Gillet, *Peniophora cinerea* (Fr.) Massee, *Merulius* sp., and *Trametes heleromorpha* (Fr.) Bres. The results obtained are similar to those previously reported from Finland (Kallio 1973) and elsewhere in Scandinavia (Nilsson & Hyppel 1968, Roll-Hansen 1970).

IV DISCUSSION

Year-round logging of timber and the damage produced by heavy timber-harvesting machines have given rise to concern about the yield capacity of growing stock remaining after intermediate cutting (Vuokila 1969). Mechanical timber harvesting, has, however, reduced the cost of timber harvesting so strikingly that return to the former practices of winter logging and horse haulage has hardly been considered seriously again.

The concern about the state of health of the remaining growing stock has, however, prompted a large number of studies in America and Europe, including Finland (Kärkkäinen 1969, 1971 a, 1971 b, 1973, Isomäki & Kärkkäinen 1972). A simple but at the same time relatively incomplete method of studying the problem is to investigate the spread of discoloration (in the present study = decay), starting from the site of the injury, in the damaged trees. But it must be remembered that a macroscopically visible discoloration in the wood material may be due to several causative factors, e.g. temperature variations and defence mechanisms of the tree. The discoloration may have also been produced by microbes (mostly bacteria or fungi). On the other hand, e.g. fungal mycelia may grow in the wood even though discoloration is invisible to the naked eye (Kallio 1971, 1973). The present results also showed that the very topmost parts of discoloration advancing upward from an injury in stems of growing spruce trees in most cases contained no microbes. The method used in the present study did not reveal the cases in which microbes may have grown on a site where discoloration visible to the naked eye was not present (cf. Kallio 1973).

The adverse effects of damage produced by haulage manifest themselves primarily in two ways. Decay originating from the injury destroys valuable stemwood, or the timber harvesting machines cut the roots of trees while compacting the soil around them thus reducing tree growth. Weakening of tree vitality probably reduces the effectiveness of the defence reactions of trees, thus aggravating the destruction by decay microbes. In the present study the surface area of the injury was the parameter which best predicted the rate of advance in decay. A similar result has been reported from an earlier study in Finland (Kärkkäinen 1973).

The present material was collected from actual forest work sites. For this reason it is impossible in retrospect to define the time of damage. Exact definition of the time of damage would be of primary importance since it would enable e.g. determination of the weather at that moment, the weather playing an important part from the point of view of fungal species infecting the injury (Webber et al. 1969, Kallio 1970). The infecting fungal species probably determine to a great extent the destruction which finally results from haulage injuries in the form of stemwood decay (Pechmann & Aufsess 1971). If the infecting fungal flora is ignored, the predictive equations illustrating the sequelae of the injury do not lead to a particularly high degree of determination (Kärkkäinen 1971). On the other hand, long periods of drought, for example, may considerably reduce the vitality of trees and at the same time their defence reactions (Alcubilla et al. 1971). In any case, the fungal flora growing in wood material is rich an varied in the decayed parts as well due to damage by haulage operations (Nilsson & Hyppel 1968, Roll-Hansen 1970, Pechmann & Aufsess 1971). A very varied and rich fungal flora was also obtained in the present study, even though fungi were only cultured from a number of the damaged sites and just one growth substrate — developed expressly for fungal cultures — was used. This culture medium has such a low hydrogen ion concentration that bacteria very often do not grow on it (cf. Kallio 1973).

The principal damage after haulage injury to stems is caused by the decay fungi proper. *Fomes annosus* is one of the most dangerous decay fungi for spruce stands.

This is the reason why haulage damage in particular was studied for possible infection. The fungus was found to infect profusely the coastal forests in the south of Finland. This infection through haulage damage (or damage in general) has previously been ascertained in Sweden (NILSSON & HYPPEL 1968) and Norway (ROLL-HANSEN 1970), as well as in Finland (KALLIO 1973). Infection by *F. annosus* through haulage damage to such a great extent as seen in the present study probably means that the yield capacity of the remaining growing stock is perhaps fatally weakened. A parallel effect produced is the reduction in the growth of remaining growing stock. These results are worth considering in the future when revenues and costs of timber harvesting are estimated (KÄRKKÄINEN 1973).

The influence of forest site type and fertilization on the rate of increase in decay initiated by damage is interesting. Laboratory studies have shown that wood decays more rapidly the higher its nitrogen content (COWLING & MERRILL 1966). When the amount of nitrogen increases in the growth substrate the nitrogen content of the wood material in trees growing on the site also increases (TAMM 1968). On the other hand, information on the interaction of mycorrhizal fungi and decay fungi in the soil is incomplete (cf. ORLOS & DOMINIK 1960, HYPPEL 1970 a, 1970 b, HESTERBERG & JURGENSEN 1972). If a wood-decaying fungus once has the chance of infecting nitrogen-containing wood material, its growth in it is faster and the decaying action more effective than in wood poor in nitrogen. The defence reactions of a living tree may, however, be much more effective, e.g. owing to balanced fertilization, than they are in unfertilized forest (JAROSEVSKAJA 1970). When the vitality of a tree (*Pinus contorta* Loud) is improved its resistance to decay fungi also becomes stronger (HORNIBROOK 1950). Many other factors, however, are simultaneously active (HAUFE 1938). Studies of infection and spread of decay should therefore also consider abiotic factors (e.g. temperature and moisture conditions). This results in a problem complex common to forest pathology, which the present study made no effort to solve. Although the proportion of fertilized trees in the present study was relatively small (346 observations), it should be noted that decay in these trees advanced at a much faster rate than in the spruce trees of unfertilized forests. The type and quantities of fertilizers used were not known. In today's forestry in Finland, fertilization holds such an important position that extensive and through studies should soon be started to ascertain its possible disadvantages, especially since collection of material for any significant evidence requires plenty of time and trained personnel. Studies of how to combat decay spreading from damage caused to trees by haulage operations also require urgent attention (cf. LAIRD & NEWTON 1973).

The present study showed that year-round timber harvesting with heavy machinery may weaken the yield of our future forests. Logging of spruce stands during the summer has already been shown (KALLIO 1970, 1971) to dangerously increase the *F. annosus* infection. Among the control methods that can be recommended for the time being are shortening the rotation of spruce stands (HUNT & KREUGER 1962, WEBBER et al. 1969), removal of damaged trees by thinning cuttings (NILSSON & HYPPEL 1968), and treatment of the felling cuts of stumps with *Peniophora gigantea* fungus after summer fellings of spruce stands in South Finland (KALLIO 1971, 1973).

SUMMARY

The present study is a part of the project handled by the HAKO Commission (Project Group for Studying the Mechanization of Thinnings). The study was carried out in 1970—72 in the Helsinki University Institutes of Forest Technology and Plant Pathology. Some of the study results have been published in the Commission's final report, entitled Harvesting of Thinned Wood (ISOMÄKI & KÄRKKÄINEN 1972).

The material was collected from spruce stands damaged by timber harvesting machines. The most typical injury was crushing by these machines. The injuries were distributed into trunk, root collar and root injuries. Three groups were formed according to the season when the damage had occurred: early summer, late summer, and winter. The location of the sample plots is seen from Fig. 1.

The purpose of the study was to find stand-related, tree-related or injury-related parameters that would help predict the rate of advance in the tree of decay originating from the damaged areas. The growth changes caused by the injuries, and the fungal flora infecting the damaged areas were also studied.

Effect of injuries on the rate of increase in decay. The decay advanced upward from the damaged areas about three times as fast as downward. The rate of upward advance averaged 21 cm/year. The maximum rate of advance recorded was 135 cm/year. Decay with the quickest spread started from above-ground root injuries, i.e. root collar injuries. This was perhaps mainly due to the fact that the damage to large above-ground roots and root collar is usually wider and deeper than in other parts of the tree. Injuries in the northwest -to-east sector of the trees produced decay advancing more rapidly than those in other sectors. The size of the damaged area (surface area, width and depth) distinctly correlated positively with the rate of decay starting from the damaged spot. The larger or deeper the injury, the faster the spread of the decay to be expected. The mean annual distance of advance by the decay in the first 10 years was largely the same. After this the advance became slower but did not cease. Damage sustained in the early summer caused, on average, a more rapid advance in decay than that sustained in the late summer or winter. The rate of increase in decay was the greater the larger the stem involved. Decay initiating from stem damage advanced at a greater rate the larger the radial growth of the tree. The rate of increase in decay was greater the richer in nutrients the substrate on which the tree grew. Fertilization also increased the rate of advance in decay.

The effect of damage on increment was manifested in both height and thickness increment, in the latter more distinctly than the former. Root injuries reduced growth more markedly than trunk injuries. The widest injuries reduced the radial growth of trees by about one-third, while severed roots reduced nearly half of the radial growth of tree with small, i.e. 0—4 cm wide injuries.

The *Fomes annosus* fungus infected spruce damage especially along the southern coast of Finland. The majority of cultures made from the farthest tip of decay were found to be sterile. This may have been because the defence reactions of the tree here had effected the change of colour. The fungus most frequently isolated from discoloured wood material was *Stereum sanguinolentum*. A number of bacteria, and other fungi were isolated from the farthest part of the discoloration.

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Seloste:

PUUNKORJUUKONEIDEN AIHEUTTAMIEN VAURIOIDEN VAIKUTUS KUUSEN LAHOAMISEEN JA KASVUUN

Tutkimus kuului osana SITRAn rahoittamiin Harvennuspuun Korjuun Koneellistamistoimikunnan selvityksiin. Tutkimus suoritettiin 1970—1972 Helsingin yliopiston metsäteknologian ja kasvipatologian laitoksessa. Osa tutkimustuloksista on julkaistu HAKO-toimikunnan loppuraportissa.

Aineisto kerättiin puunkorjuukoneiden vioittamista kuusimetsiköistä. Tyypillisimmät vauriot olivat ruhjoutumia. Vauriot ryhmiteltiin runko-, juurenniska- ja juurivaurioihin. Syntymisajankohdan perusteella muodostettiin kolme ryhmää: alkukesällä, loppukesällä ja talvella syntyneet vauriot. Koealojen sijainti näkyy kuvasta 1.

Tutkimuksen tarkoituksena oli löytää metsikkö-puu- tai vauriokohtaisia tunnuksia, joiden perusteella voitaisiin ennustaa vaurioiden kautta alkunsa saaneen lahon puussa etenemisen nopeus. Tutkimuksessa selvitettiin myös vaurioiden aiheuttamia kasvun muutoksia ja tutkittiin vaurioihin iskeytynyttä sienilajistoa.

Vaurioiden vaikutus lahon etenemisnopeuteen. Laho (= värivika) eteni vaurioista ylöspäin n. kolme kertaa nopeammin kuin alaspäin. Etenemisnopeus ylöspäin oli keskimäärin 21 cm/v. Suurin todettu etenemisnopeus oli 135 cm/v. Nopeimmin edenneet lahot alkoivat maanpäällisistä juurivaurioista eli juurenniskavaurioista. Tämä johtunee pääasiassa siitä, että suurten pintajuurien ja juurenniskan vauriot ovat tavallisesti suurempia ja syvempiä kuin puun muiden osien vauriot. Puiden luoteis-itäsektorilla sijainneet vauriot aiheuttivat nopeimmin edenneet lahot. Vaurion koko (pinta-ala, leveys ja syvyys) korreloitui selvästi positiivisesti vauriosta alkunsa saaneen lahon etenemisnopeuteen. Mitä suurempi tai syvempi vaurio oli, sitä nopeammin siitä alkanut laho eteni. Lahon keskimääräinen vuosittainen etenemismatka oli kymmenenä ensimmäisenä vuotena suurin piirtein sama. Sen jälkeen tapahtui lahon etenemisessä hidastumista, mutta ei pysähtymistä. Alkukesällä syntyneet vauriot aiheuttivat nopeammin edenneet lahot kuin loppukesällä ja talvella syntyneet vauriot. Lahon etenemisnopeus oli sitä suurempi, mitä järeämmästä rungosta oli kysymys. Runkovauriosta alkunsa saaneen lahon etenemisnopeus oli sitä suurempi, mitä suurempi puun sädekasvu oli ollut. Lahon etenemisnopeus lisääntyi kasvualustan parantuessa. Lannoitus lisäsi lahon etenemisnopeutta.

Vaurioiden vaikutus puiden kasvuun ilmeni sekä pituus- että paksuuskasvussa, paksuuskasvussa kuitenkin selvemmin kuin pituuskasvussa. Juurivauriot heikensivät puiden kasvua voimakkaammin kuin runkovauriot. Leveimmät vauriot vähensivät puiden sädekasvua noin kolmanneksella ja katkenneet juuret lähes puoleen verrattuna niiden puiden kasvuun, joissa vauriot olivat leveydeltään 0—4 cm.

Fomes annosus-sieni iskeytyi kuusen vaurioihin erityisesti eteläisellä rannikkoalueella. Lahon uloimmasta kärjestä tehdyistä viljelmistä todettiin pääosa steriileiksi. Tämä saattoi johtua siitä, että puun puolustusreaktiot olivat tässä värivian osassa värin muutoksen aiheuttajina. Tavallisin sieni, joka värjäytyneestä puuaineksesta eristettiin, oli *Stereum sanguinolentum.* Lahon uloimmasta osasta eristettiin myös joukko muita sieniä ja bakteereita.

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ISOMÄKI, ANTTI & KALLIO, TAUNO O.D.C. 481: 443: 582.1

1974 Consequences of injury caused by timber harvesting machines
on the growth and decay of spruce (*Picea abies* (L.) Karst.
ACTA FORESTALIA FENNICA 136. 25 p. Helsinki.

The study material was collected from 10 localities in South Finland in 1971—72. Altogether, the material comprised 616 damaged spruce trees with a total of 978 injuries.
Decay (= discoloration) spread upward from the damaged site about three times as fast as downward. The mean rate of advance upward was 21 cm/year. The decay spreading at the quickest rate started from above-ground root collar injuries. The size of the damaged area (surface area, width and depth) correlated positively with the rate of increase in decay initiated by the injury. For the first 10 years the decay advanced at the same rate after which the advance became slower though not ceasing. Damage produced in the early summer caused a faster spread of decay than that produced in the late summer or winter. The rate of advance was the greater the larger the stem involved. When decay started from trunk damage the rate of advance was greater the faster the growth of the trees. With a better soil type, the rate of advance in decay increased. Fertilization increased the rate of advance.
The widest stem injuries reduced tree growth by about one-third, and severed roots by nearly half of the growth of trees where the width of the injuries was 0—4 cm. *Fomes annosus* infected spruce injuries especially in the southern coastal district. The farthest tips of discoloration proved in most cases to be sterile. The most common fungus isolated from these sites was *Stereum sanguinolentum*.

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