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Decay of spruce (*Picea abies* (L.) Karst.) in the Åland Islands.

Ahvenanmaan kuusien lahovikaisuus.

Tauno Kallio and Pekka Tamminen

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DECAY OF SPRUCE (PICEA ABIES (L.) KARST.) IN THE ÅLAND ISLANDS

TAUNO KALLIO and PEKKA TAMMINEN

SELOSTE:

AHVENANMAAN KUUSIEN LAHOVIKAISUUS

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PREFACE

It has long known that trees growing in the forests of Åland have a poor stem form, and that site qualities on forest land are more difficult to classify than elsewhere in Finland. A high incidence of decay in spruce has also been discovered in connection with cuttings. Åland is a separate region, with a type of nature different from that of the rest of Finland, but for just separation it has advantages to offer the research work.

The present study was started with the support of the Forest Division of the Provincial Administration in Åland (Ålands lanskapsstyrelses Skogsbyrå). The Administration kindly placed manpower and material at the research workers' disposal. The authors received valuable help especially from Mr. Bo Högnäs, Bachelor of Forestry. Private forest owners permitted the felling of trees in their forests everywhere in the study area. The Administration undertook to refund the forest owners for the trees felled.

The study would not have been possible without the valuable assistance of the Forest Research Institute. The Insitute made available the map material and the unpublished results of the Sixth National Forest Inventory. Professor Kullervo Kuusela, of the Department of Forest Inventory and Yield, gave the authors his support and was generous in giving advice and instruction in the different phases of the work. The authors also received valuable help from Dr. Paavo Tiihonen, Mr. Sakari Salminen and Mr. Jouko Laasasenaho, Bachelors of Forestry.

The personnel of the Department of Plant Pathology of Helsinki University, assisted the authors in many ways. Mr. Arvi Salonen identified a number of fungi from the cultures. Miss Ulla Hartikainen undertook the responsibility for most of the laboratory work connected with the fungal cultures, and she also drew the diagrams for this report.

During the course of the work, Professor Aarne Nyyssönen, the Head of the Department of Forest Mensuration and Management of Helsinki University, has on several occasions discussed the details of the study and with his advice contributed towards its completion.

The authors wish to extend their very cordial thanks to all those mentioned above.

Helsinki, December 19, 1973

Tauno Kallio Pekka Tamminen

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I INTRODUCTION AND STUDY OUTLINE

Spruce is highly susceptible to decay. Furthermore, decay is difficult to detect in growing spruce. Butt rot may cause an unexpectedly steep fall in the realisable value of the final cuttings. Economic losses in infected forests may be considerable, and come as a complete surprise.

According to a German study (ZYCHA 1964b), the butt rot of spruce is responsible for the fact that c. 10 per cent of the spruce wood annually harvested in Europe is damaged by partial rot. In terms of money, the loss in Central and Western Europe annually amounts to something like 15—30 million dollars (DIMITRI 1973). According to a study on a limited material in Finland (KALLIO 1972), the loss caused by butt rot of spruce in South Finland was c. 10 million dollars a year.

Interest in the butt rot of spruce is widespread. Forest industry planning needs reliable and detailed estimates as to the timber assortments obtainable from a given area in the next few decades. Forest owners are worried about the high taxes they have to pay decaying spruce stands. They are also interested to know whether it would be an economic proposition to allow the further growth of a mature spruce stand, i.e. whether the decay will reduce the value of timber more than increment and price development will be able to increase it. Regeneration of decayed spruce stands is a silvicultural problem. Forest mensuration needs information on the frequency of decayed trees, and on the changes in stem form and increment.

Estimation of the decay in spruce stands in association with the growing stock mensuration of forest tree stands has so far been given little attention. The results of the national forest inventories in Finland (ILVESSALO 1927, KUUSELA 1972, KUUSELA and SALMINEN 1969) afford a possibility of comparing the results of spruce butt rot studies with those of growing stock mensuration over extensive forest areas. For the time being, this possibility exists only in those countries in which detailed data on the growing stock of the forests is available. For Finland this data has been available for some decades (ILVESSALO 1927, 1942, 1956).

According to the results of several studies the butt rot of spruce occurs in patches (KANGAS 1952, KALLIO 1961). The present study attempted to investigate this patchy occurrence by using the spruce trees of the increment sample plots of the Sixth National Forest Inventory (ANON. 1971) as study material. The main island of the Åland Archipelago and the islands connected with it by bridges were chosen as the study area. The principal objective of the study was to ascertain the incidence of spruce decay in Åland. In addition, the parameters of decay, decay microbes, appraisal of the decay in standing trees, and the consequential effects of decay were also investigated.

II MATERIAL

The material was collected from the volume sample tree and increment plots of the Sixth National Forest Inventory (ANON. 1971) on the main island of Åland and the islands connected with it by bridges. The Åland forests were surveyed in the summer of 1971 by the Forest Research Institute. The Forest Division of the Provincial Administration in Åland quadrupled the density of the sampling units (tracts) to improve the accuracy of the inventory. The distance between corresponding points in adjacent tracts was then four kilometres (Fig. 1). Each tract had four volume sample tree and increment plots. The study comprised all spruce trees of these sample

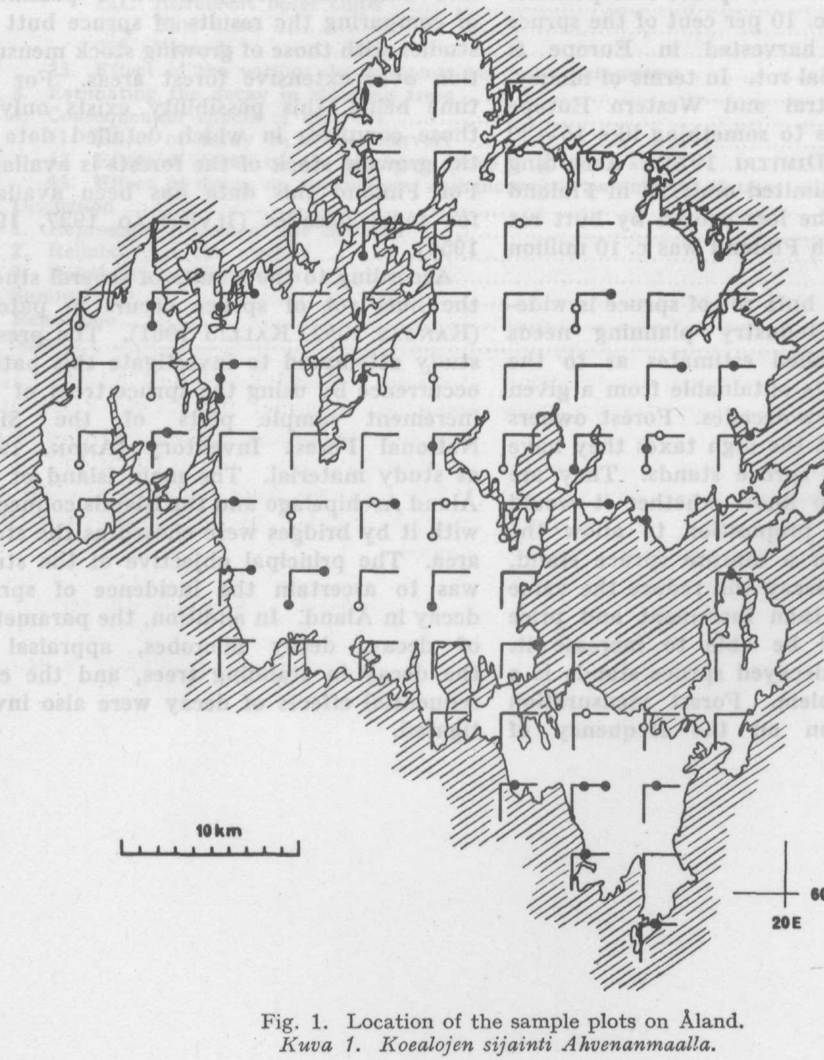

Fig. 1. Location of the sample plots on Åland.
Kuva 1. Koealojen sijainti Ahvenanmaalla.

┌ tract, *lohko*
○ sample plot without decay, *koealalla vain terveitä koepuita*
● sample plot with decay, *koealalla myös lahoja koepuita*

Table 1. Sample trees by forest site types and development classes.
Taulukko 1. Koepuut metsätyypeittäin ja kehitysluokittain.

Development class *Kehitysluokka*[1])	Forest site type — *Metsätyyppi* Lh	OMT	MT	VT	CT	Poorly productive land *Kitumaa*	Total *Yht.*
Small seedling stand .... *Pieni taimisto*			3	5			8
Large seedling stand .... *Iso taimisto*		9					9
Thinning stand .... *Nuori kasv. metsikkö*	6	10	22	12	3		53
Accretion stand .... *Varttunut kasv. metsikkö*		21	32	6			59
Mature stand .... *Uudistuskypsä metsikkö*		64	30	8	2		104
Low yielding stand .... *Vajaatuottoinen metsikkö*		24	28	5			57
No. — *kpl*	6	128	115	36	5	5	(295)
Total — *Yht.* %	2	43	39	12	2	2	100

[1]) See — *Ks.* ANON. 1971

plots with a minimum diameter of 7 cm at breast height. The 7 cm limit was chosen because the agreed minimum diameter for coniferous pulpwood was 6 cm excluding bark.

The Sixth National Forest Inventory used the relascope plot technique (KUUSELA 1966). Every tallied tree represented a basal area of 2 sq.m./ha. This sampling method strongly emphasizes the large trees which are important from the point of view of volume and increment calculation. For example, a tree 10 cm in diameter is included in the relascope sample plot at a distance of c. 3.5 metres, and one 30 cm in diameter at a distance of c. 10.6 metres from the centre.

From the point of view of decay detection, the relascope plot technique appears to be favourable, for some studies report that decay increases as the diameter of the growing stock increases (HOLMSGAARD et al. 1968). It is therefore justifiable to study a greater number of large than small trees. Of all sample plots, 92 per cent (59 out of 64) and of all sample trees, 90 per cent (295 out of 327) of which five were stumps, were traced The sample plots were relatively evenly distributed over the study area (Fig. 1). The majority (84 per cent) of the sample trees were found on typical spruce soils (Table 1), 12 per cent grew on VT (Forest site types see CAJANDER 1949) and only 4 per cent on poorer soils. All sample plots were situated on mineral soils.

The stem distribution series of the sample trees was approximately normal, as can be seen from Fig. 2. The smallest diameter class was 7 cm, the largest 53 cm, the mode diameter class 15—19 cm. Timber trees in the material numbered 131 (44 per cent), including the decayed. The parameters per stand and per tree of the sample are given in Table 2.

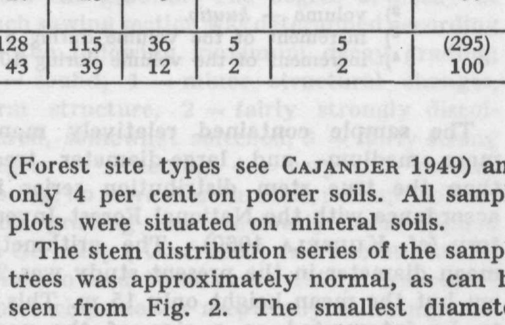

Fig. 2. Stem distribution series for spruce in Åland 1) according to the Sixth National Forest Inventory (Forest Research Institute, unpublished), and 2) in the study material.
Kuva 2. Kuusten runkolukusarjat Ahvenanmaalla 1) VI valtakunnan metsien inventoinnin mukaan, 2) tutkimusaineiston mukaan.

Table 2. Mean values of parameters per stand and per tree, weighted by the number of trees.
Taulukko 2. Metsikkö- ja puukohtaisten tunnusten puuluvulla painotetut keskiarvot.

Parameter — *Tunnus*	Mean value *Keskiarvo*	Standard deviation *Keskihajonta*
Forest site type — *Metsätyyppi*	2.7	(2.7 = MT+)
Tax class — *Veroluokka*	1.1	(1.1 = IB)
Age class — *Ikäluokka*	8.5	(8.5=76—85 yrs/*v*)
Basal area — *Pohjapinta-ala* m²/ha	26.1	
Age, yrs — *Ikä, v*	95.9	34.1
Height — *Korkeus*, m	14.98	4.28
D 1.3 m, cm¹)	21.2	7.9
D 1.3 — D 6.0, cm	5.1	2.1
V, cu.dm, incl, bark — *kuorineen* dm³ ²)	306	273
pV 5 v %³)	13.7	11.1
pV 10 v %⁴)	27.6	18.1

¹) diameter at breast height incl. bark — *läpimitta rinnankorkeudelta kuorineen.*
²) volume — *kuutio.*
³) increment of the volume during 5 yrs — *5 vuoden kuutiokasvu.*
⁴) increment of the volume during 10 yrs — *10 vuoden kuutiokasvu.*

The sample contained relatively many more medium- and large-diameter trees than the true stem distribution series in accordance with the National Forest Inventory (cf. Kuusela 1960). The arithmetic mean diameter in the present study was 21 cm but the mean height only 15 m. This is to be interpreted as a sign of the poor stem form, on average, in the growing stock of Åland (cf. Högnäs 1966). The material was numerically small, taking into account the wide variation in the incidence of butt rot (Kangas 1952, Kallio 1961). Probably, however, the sampling method used considerably increased the serviceability of the material. The sample plots of the Sixth National Forest Inventory apparently represent the studied forest area very well. The results of tree tally, volume sample tree and increment plots can perhaps, with certain reservations, be considered regression estimates for the results obtained from all sample plots of the inventory and further for the entire forest area studied (cf. Nyyssönen 1967).

III METHODS

The material was collected in October—December 1972, i.e. 1—2 growing seasons after the field work for the Sixth Inventory. The diameters and bark thicknesses of the sample trees were measured, and a number of increment borings were made: at stump height, 0.5 m above the stump, and at the heights of 1.3 m, 3.5 m and 6.0 m from the ground, and also at a height that equalled 70 per cent of the total height of the tree. Furthermore, measurement was made of the height of the sample tree, the lengths of the last 10 leading shoots, the height of the lower edge of the crown from the ground, the crown class and age (= the number of the annual rings of the stump plus 5—7 years, cf. NYYSSÖNEN 1954). For the 5 stump sample trees, these measurements were estimated. The soundness of the trees was determined on the basis of butt swelling, resin flow, amount and colour of needles, and the decay noted in increment borer chips taken at stump and breast height. Aseptically bored chips were immediately placed in sealed test tubes into which a modification of the Hagem agar had been poured as the culture medium (MIKOLA 1955). The sample trees were marked into lengths when felled. The tree was considered decayed if the decay affected the assorting into lengths. The decayed trees were marked into lengths twice, first disregarding the decay (assorting regardless of decay) and then according to quality requirements (assorting according to decay). This method has previously been used by several authors (PETRINI 1944, ARVIDSON 1954, KALLIO 1972). The assortment of timber followed the recommendations and minimum measurements applied to Åland by the forest industry. The minimum measurements were: pulpwood 6 cm excluding bark, butt log 49 dm × 17 cm, 46 × 21 and 43 × 23, middle and top log 43 × 17, 40 × 19, and 37 × 21. The log lengths were measured without extra length, and the top diameter with a 2-cm classification was measured inside the bark. Pulpwood volumes were calculated on the basis of the middle diameter of the log, in solid cubic meters including bark.

For the decayed sample trees, sample sections were sawn at stump height and at the highest point where decay could be seen by the naked eye. The highest point of decay was determined with the greatest possible accuracy by cutting the stem into lengths. The decay diameters were measured at stump height and upward from the stump at 0.5 m, and at 1.3, 2.0, 4.0 m . . . from the ground. The degree of decay at each sawing section was determined according to the following maximum decay grading: 0 = sound, 1 = minor structural changes, firm structure, 2 = fairly strongly discoloured, somewhat softened, 3 = fairly strong degree of softening, 4 = very soft, decomposing, no more structure left, perhaps hollow. This grading has previously been applied in Germany (KATÓ 1967) and also in Finland (KALLIO and NOROKORPI 1972). Increment borer chips taken aseptically at stump and breast heights from every sample tree were sent for laboratory studies. From decayed trees, moreover, sample sections at stump height and the greatest height of the decay, and in cases of wound decay, from the upper and lower ends of the decay were submitted to laboratory studies.

Immediately on the arrival of the stump sections in the laboratory small sample pieces were taken from the different parts of the decay. Fungi from these pieces were cultured on malt agar substrate, pure-cultured and identified. After a ten-day storage in the laboratory at room temperature, both the borer chips and the sections were examined by stereomicroscope to identify the *Fomes annosus* (Fr.) Cooke fungus on the basis of its conidiophores. The decay fungi were then determined in two ways: e.g. *F. annosus* by stereomicroscope from increment borer chips and sample sections on the basis of its conidiophores, and most other fungi from pure cultures grown from the pieces of the sample sections.

The sample tree volumes were calculated by means of the spruce volume equation developed by LAASASENAHO for the national forest inventories (personal communication); there was one equation for trees under 6 m high and another for those over 6 m high. The diameter including bark 5 and 10 years ago was estimated with the equation used by MIELIKÄINEN (1972). The sample tree volumes at the time of measurement, and 5 and 10 years earlier were calculated. Increments were obtained by subtraction as differences between the volumes including bark. The decay per stem distribution series was analysed by 5 cm diameter classes. The unit stem number per hectare represented by each of the sample trees was calculated by the method used by KUUSELA (1966).

No diameter class grading was applied to the study of changes in stumpage prices due to decay (cf. LAASASENAHO and SEVOLA 1971), and fixed volume unit values were used instead: saw timber = 100, sulphite pulpwood = 59 and sulphate pulpwood = 53. The relative values were calculated from the mean stumpage prices for felling seasons 1970/71 and 1971/72 in the forestry board districts of Helsinki, Lounais-Suomi and Satakunta (ANON. 1973). Owing to the use of fixed unit prices, the estimates of the financial loss possibly caused by the butt rot are slightly too low or at least very conservative.

Calculations were carried out at the Helsinki University Computing Centre.

IV RESULTS

1. Butt rot in Åland

Earlier butt rot studies used stand sample plots on the basis of which the decay percentages were calculated (PETRINI 1944, KANGAS 1952, ARVIDSON 1954, HÖGNÄS 1966, HOLMSGAARD et al. 1968). Of these, the study by KANGAS was systematical and comprised the stumps along a line cleared for electric pylons. The material for the present study, by contrast, was collected from small sample plots selected by the relascope plot technique, mathematically evenly distributed over the area studied. The decay percentages of the growing stock were determined for the whole stem distribution series on the basis of the results per hectare.

11. Decay by diameter classes

Five-cm diameter classes were used for calculation. This sparse classification was used e.g. owing to the small number of observations (cf. KULOKARI 1970) and because the same classification is used for calculating the results of national forest inventories.

Butt rot has in some earlier investigations been reported to increase as the diameter of the growing stock increased (PETRINI 1944, BJÖRKMAN et al. 1949). Reports from Denmark claim that trees of average diameter are the most heavily affected with decay (HOLMSGAARD 1957, MORVILLE 1958).

The mean butt rot percentage of Åland spruce was c. 23, and if wound decay is included, the percentage was around 26. The results (Table 3) agree fairly well with those reported from Denmark. The relative share of trees with butt rot increased sharply up to the diameter class of 30–34 cm but began to decline subsequently. The lower percentages for the classes exceeding 35 cm perhaps illustrate the true situation as regards the decay, but owing to the small sample tree numbers the percentages are uncertain. When trees exceeding 35 cm are combined into one class, the butt rot percentage obtained for them is c. 38 per cent.

The results of Table 3 fall between those reported by two Swedish authors, PETRINI (1944) and BJÖRKMAN et al. (1949). The former quoted a decay incidence of c. 45 per cent of the number of stems, the latter c. 5 per cent. In the latter study the decay percentages were determined on the basis of borings at breast height, and therefore the frequency is probably too low (cf. DIMITRI 1968, KALLIO 1972). Also the

Table 3. Spruce decay in Åland by diameter classes.
Taulukko 3. Kuusen lahoisuus Ahvenanmaalla läpimittaluokittain.

Sample trees *Koepuita*	Diameter class, cm *Läpimittaluokka, cm* –10	10–14	15–19	20–24	25–29	30–34	35–39	40–	Total *Yht.*
Total No. .... *Kaikkiaan, kpl.*	12	48	71	65	54	28	7	6	291
Butt rot, No. .... *Tyvilahoja, kpl.*	1	9	22	20	20	12	3	2	89
Butt rot, % .... *Tyvilahoja, %*	7.0	17.5	30.4	31.5	37.3	44.5	42.7	33.8	23.1
Decayed, total %¹) .... *Lahoja, yht. %¹)*	7.0	19.3	37.1	31.5	41.4	44.5	57.1	33.8	25.7

¹) Including trees affected with wound decay. — *Myös haavalahoiset puut.*

Table 4. Decayed wood in relation to stem volume (%), by diameter classes.
Taulukko 4. Lahon puuaineen osuus rungon tilavuudesta (%) läpimittaluokittain.

	Diameter class, cm *Läpimittaluokka, cm*								Total *Yht.*
	−10	10−14	15−19	20−24	25−29	30−34	35−39	40−	
Butt rot .... *Tyvilahoa*	0.2	3.3	5.2	5.0	4.7	6.6	6.8	7.8	4.9
Wound decay .... *Haavalahoa*	—	0.3	0.3	0.7	0.3	—	0.2	—	0.3
Decayed, mean .... *Lahoa, keskim.*	0.2	3.5	5.5	5.8	5.0	6.6	6.9	7.8	5.3

decay percentage of 12 quoted by Kangas (1952) suggests that the result of c. 5 per cent, obtained in the Gävleborg district in Sweden, is too low. The decay percentage of 23 obtained for the spruce in Åland agrees well with several studies (Rennerfelt 1946, Perttula 1960, Kallio and Norokorpi 1972).

The proportion of trees affected with wound decay ranged from 0 to 14 per cent of the stem number, average 2.6 per cent. These relatively low percentages are probably partly due e.g. to the fact that, apart from one or two, the stands studied had not been logged at all in the last few years.

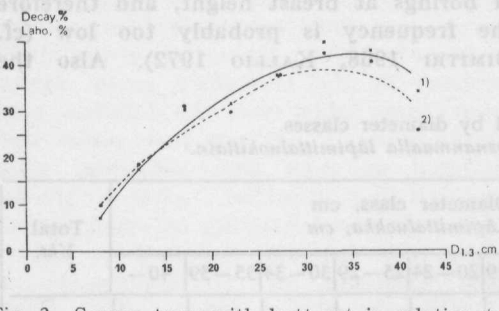

Fig. 3. Spruce trees with butt rot in relation to the total number of stems 1) and to total volume 2), by diameter classes.
Kuva 3. Tyvilahoisten kuusien osuus runkoluvusta 1) ja kuutiomäärästä 2) läpimittaluokittain.

The decayed trees' proportion of the volume was approximately that of the number of stems (Fig. 3). Fig. 3 also shows the difference between these two percentage series, decay as a percentage of the number of stems and as a percentage of the volume. In the small-diameter classes the proportion of decayed trees in the volume exceeded that in the number of stems, and in the large-diameter classes the case was the opposite. The calculation method weighted the small trees so heavily that the mean percentage climbed from 23 to 31.

Decayed wood in relation to the total volume of the stems is shown in Table 4. The proportion was very low. However, its location in the butt, the most valuable part of the stem, may lead to losses many times as great as the volume of the decayed part would provide. In the North Finnish spruce stands studied by Tikka (1934) the proportion of decayed wood material was only 1−3 per cent, although 10−40 per cent of the number of stems were decayed. According to Norokorpi (1973), 13 per cent of the volume of growing spruce in a North Finnish natural stand was spoiled by decay. About half the number of spruce stems in the stand were affected by decay.

12. Decay by forest site types, tax, development and age classes

The spruce trees of the best and poorest sites were most affected by decay (Table 5). The six trees of a very rich site (in this paper Lh) are combined in the table with OMT, and the ten trees of CT and poorly productive land with VT. According to Table 5, there was no correlation between

Table 5. Decay, of the number of stems, by forest site types.
Taulukko 5. Lahoisuus runkolovusta metsätyypeittäin.

Forest site type *Metsätyyppi*	Sample trees, No. *Koepuita yht., kpl*	Butt rot *Tyvilahoja*		Decayed, total *Lahoja, yht.*	
		No. *kpl.*	%	No. *kpl.*	%
Lh + OMT	132	44	27.1	45	28.7
MT	113	32	19.8	36	21.6
VT + poorer	46	13	22.0	16	27.9
Total — *Yht.*	291	89	23.1	97	25.7

decay and forest site type. This is a problem that has already been very much studied, and the results reported are highly contradictory. Many authors have found that decay frequency increases as the soil type improves (Falck 1930). Numerous results to the contrary have also been reported (Kangas 1952, Rehfuess 1969). The problem can be approached, as it was by Rennerfelt (1946), by trying to find correlations between decay on the one hand and the hydrogen ion concentration, moisture and physical properties of the soil on the other.

These soil factors and many other component factors affect the growth of different fungi in different ways, and this leads us to the conclusion, recently drawn very often, that antagonistic microbes and the conditions necessary for their development strongly affect the butt rot (Zycha 1964 a, Laatsch 1970). The decay percentages obtained from Åland by forest site types (Table 5) and by tax classes (Table 6) confirm the opinion that butt rot varies very much. This again seems to suggest that the forest site classification used in Finland does not necessarily illustrate e.g. the number and type of fungi and bacteria antagonistic to the causative factors of butt rot in the soil (cf. Svinhufvud 1937).

The determination of forest site types and tax classes in Åland is less certain than in South Finland on the whole, since the adverse effect e.g. of a maritime climate and the nearness of primary rock on the development of the growing stock is not always visible in the ground vegetation (cf. Nyyssönen 1954, Högnäs 1966). In Czechoslovakia (Červinková 1973) a thin soil layer has been found to increase the butt rot caused by *F. annosus*.

Table 6. Decay, of the number of stems, by tax classes.
Taulukko 6. Lahoisuus runkoluvusta veroluokittain.

Tax class *Veroluokka*	Sample trees, No. *Koepuita yht., kpl.*	Butt rot *Tyvilahoja*		Decayed, total *Lahoja, yht.*	
		No. *kpl.*	%	No. *kpl.*	%
IA	94	27	18.0	29	20.7
IB	121	41	26.9	45	29.6
II	44	10	16.6	12	20.1
III + IV	27	9	25.5	10	28.4
Total — *Yht.*	291	89		97	

By development classes (Table 7), the more mature stands showed an increase in butt rot. A similar result has been reported e.g. by HOLMSGAARD et al. (1968), KATÓ (1967), and ČERVINKOVÁ (1973). Almost one-third of the spruce trees in mature forests were affected with butt rot. This is a very high frequency of decay, bearing in mind the extent of the area represented by the results.

Table 7. Decay, of the number of stems, by development classes.
Taulukko 7. Lahoisuus runkoluvusta kehitysluokittain.

Development class *Kehitysluokka*[1])	Sample trees, No. *Koepuita yht., kpl.*	Butt rot *Tyvilahoja* No. *kpl.*	%
2–4	69	10	8.5
5	59	19	25.9
6	101	41	31.4
8	57	17	33.8
Total – *Yht.*	286	87	

[1]) 2–4 = small seedling stand – thinning stand – *pieni taimisto – nuori kasv. metsikkö*
5 = accretion stand – *varttunut kasv. metsikkö*
6 = mature stand – *uudistuskypsä metsikkö*
8 = low yielding stand – *vajaatuottoinen metsikkö*

Decay percentages by age classes showed an increase with age (Table 8). The only exception was the age class 101–120 years. A similar result has been reported by many authors (ROHMEDER 1937, KATÓ 1967, ČERVINKOVÁ 1973). In the Åland forests decay seemed to remain approximately unchanged from the age of 80–100 years onwards (cf. ROHMEDER 1937, HOLMSGAARD 1957).

Table 8. Decay, of the number of stems, by age classes.
Taulukko 8. Lahoisuus runkoluvusta ikäluokittain.

Age class *Ikäluokka*	Sample trees, No. *Koepuita yht., kpl.*	Butt rot *Tyvilahoja* No. *kpl.*	%
1– 40	16	1	2.9
41– 60	50	6	9.5
61– 80	73	15	14.2
81–100	88	48	52.2
101–120	42	8	10.3
121–	17	9	52.8
Total – *Yht.*	286	87	

2. Parameters of decay

21. Degree and dimensions of decay

A total of 12 sample trees were affected by wound decay, and four of these additionally by butt rot. The degree of the decay extending from the wound was on average 2.1, i.e. the wood was discoloured and somewhat softened. The lower end of the decay was on average at a height of 2.9 m from the ground, and the upper end at 6.9 m. The mean length of the decay was 4.0 m and the mean volume 19.2 cu. dm. (range 2.2—84.2 cu.dm.). The proportion of wound decay in the stems of decayed trees was, on average, 12.1 per cent (range 0.4—47.7 per cent).

Table 9 shows the mean values of butt rot parameters by degrees of decay and the test results of a two-way variance analysis. The means by degrees of decay differ distinctly. The degree of decay seems to explain the dimensions of the other parameters to some extent. Table 10 illustrates the mutual correlation of decay parameters. The correlation coefficients of this table were used to build up the regression models for estimation of the height and volume of butt rot with the aid of other parameters.

Table 9. Butt rot parameters by degrees of decay.
Taulukko 9. Tyvilahon tunnukset lahoasteittain.

Parameter *Tunnus*		Degree of decay[1]) *Lahoaste*[1]) 1	2	3	4	Mean *Keskim.* 2.8	F-value *F-arvo*
Diameter, cm[3]) ... *Läpimitta, cm*	M[2])	10.1	17.6	17.5	25.0	19.2	***
	D	7.9	9.8	8.2	11.3	11.2	9.0314
Height, dm .... *Korkeus, dm*	M	11.9	27.8	43.6	41.7	32.8	***
	D	9.6	13.5	31.2	31.2	27.3	6.1658
Volume, cu. dm. *Tilavuus, dm³*	M	7.0	34.2	57.8	84.4	53.6	**
	D	17.1	45.6	59.5	101.3	78.4	4.7438
Share of decay in stem .... *Lahon osuus rungosta*	M	0.021	0.117	0.255	0.215	0.161	***
	D	0.037	0.106	0.196	0.176	0.167	8.5885
Trees, No. .... *Puita yht., kpl.*		17	21	14	37	89	

[1]) see Methods, p. 9 — *ks. Menetelmät, s. 9.*
[2]) M = mean value, D = standard deviation — *M = keskiarvo, D = keskihajonta*
[3]) Diameter of decay in stump section — *Lahon läpimitta kantoleikkauksessa*

Table 10. Intercorrelations of decay parameters.
Taulukko 10. Lahotunnusten keskinäiset korrelaatiot.

	Lpm	ln Lpm	H_1	Q
Lpm[1])	1.000			
ln[2]) Lpm	0.530	1.000		
H_1[3])	0.544	0.287	1.000	
Q[4])	0.464	0.284	0.411	1.000
v[5])	0.775	0.344	0.757	0.384

[1]) Decay diameter in stump section. — *Lahon läpimitta kantoleikkauksessa.*
[2]) Natural logarithm. — *Luonnollinen logaritmi*
[3]) Height of decay. — *Lahon korkeus.*
[4]) Degree of decay. — *Lahoaste.*
[5]) Volume of decay. — *Lahon tilavuus.*

The diameter and height of the decay show a strong positive correlation with volume, whereas the correlations of the degree of decay were relatively weak. The seemingly slightly illogical change of the means in Table 9 also strengthens the impression gained from Table 10 that the degree of decay in the applied form does not give a particularly good overall picture of the butt rot (Fig. 4).

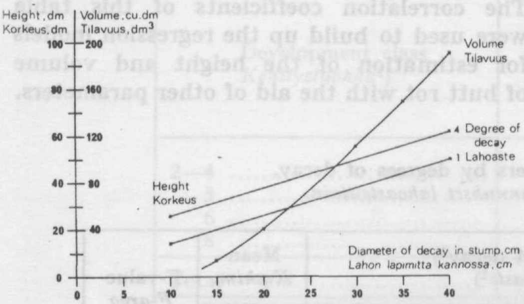

Fig. 4. Estimates of the height and volume of butt rot according to the equations 1 and 2.
Kuva 4. Tyvilahon korkeuden ja tilavuuden estimaatit yhtälöiden 1 ja 2 mukaan.

The following equations were formed to estimate the height and volume of butt rot with the aid of the other decay parameters:

(1) $H_1 = -1.58404 + 1.188046 \cdot \mathrm{Lpm} + 3.965871 \cdot Q \; (R^2 = 0.355)$

(2) $v = 83.65842 + 10.549034 \cdot \mathrm{Lpm} - 84.491577 \cdot \ln \mathrm{Lpm} \; (R^2 = 0.744)$

R^2 = coefficient of determination

The 95 % reliability limits of the mean are:

H_1 : 32.79 ± 23.58 dm
v : 53.58 ± 42.73 cu. dm

22. Decay microbes

Determinations of the decay microbes were carried out at the Helsinki University Institute of Plant Pathology. Increment borer chips and sample discs from the butt and tip of the decay were examined by stereomicroscope. After the fungi had been pure cultured, species determinations were carried out from the upper and lower ends of both the butt rot and wound decay.

221. Increment borer chips

Fomes annosus, *Armillaria mellea* (Vahl ex Fr.) Quél. and *Odontia bicolor* (Alb. & Schw. ex Fr.) Quél. were identified from the fungi.

Table 11. Decay microbes in increment borer chips.
Taulukko 11. Lahottajat kairanlastuissa.

Decay microbe *Lahottaja*	Butt chips *Tyvilastut* No. *kpl.*	%	Chips at 1.3 m *1.3 m-lastut* No. kpl.	%
F. annosus	19	7	22	8
A. mellea	6	2	4	1
O. bicolor	1	1		
Unidentified — *Tunnistamatta*	22	7	42	15
No microbe — *Ei mikrobia*	242	83	223	76
Total — *Yhteensä*	290	100	291	100

On 18 occasions the decay microbe identified from the upper and the lower chip was the same, i.e. in c. 38 per cent of the cases. Both *F. annosus* and *A. mellea* were found together in one chip. On the basis of the butt chips, the proportions of *F. annosus* and *A. mellea* were approximately 40 and 13 per cent, respective, of all the fungi.

56 per cent of the chips from decayed trees were sterile, while a decay microbe was found in c. 5 per cent of the chips from sound trees (Table 12). The success achieved by one aseptical boring in tracing the decaying agents in decayed trees was therefore relatively poor (cf. Dimitri 1968, Kallio 1972).

Table 12. Success of microbial determination by butt boring.
Taulukko 12. Lahottajamäärityksen onnistuminen tyvikairauksella.

Condition of the sample tree *Koepuun terveydentila*	Decay agent in butt chip *Lahottaja tyvilastussa* — No./*kpl.*	— %	+ No./*kpl.*	+ %	Total *Yht.* No./*kpl.*
Sound — *Terve*	192	95	9	5	201
Decayed — *Laho*	50	56	39	44	89
Total — *Yhteensä*	242		48		290

222. Butt discs

A total of 97 butt discs were examined, including one sawn from the stump of a previously felled sample tree. 95 samples of the tip of the decay were studied. Four fungi were identified from these discs by means of the stereomicroscope (Table 13).

Table 13. Decay microbes in discs examined by stereomicroscope.
Taulukko 13. Lahottajat stereomikroskoopilla tutkituissa kiekoissa.

Decay microbe *Lahottaja*	Butt disc *Tyvikiekko* No. *kpl.*	%	Topmost disc *Kärkikiekko* No. *kpl.*	%
F. annosus	45	44	35	36
A. mellea	15	15	2	2
O. bicolor	2	2	1	1
Ceratocystis spp.	1	1	1	1

F. annosus occurred in 44 per cent and *A. mellea* in 15 per cent of the 97 butt discs studied. *F. annosus* was definitely the most common and *A. mellea* the second most common of the identified decay fungi. In 52 per cent of the decayed trees, the decay microbe was the same in both the butt and the tip. *F. annosus*, compared with the other decay microbes, was common also in the specimens of the tip. *A. mellea* was identified from only two topmost discs, and in only one case was it found both in the butt and the tip specimens.

Fungal mycelia were cultured from 96 butt discs and 95 topmost discs. A total of 23 fungal species (families) and bacteria were identified from them (Table 14).

Fomes annosus was very common in the cultures. It was found alone in 13.6 per cent of the butt discs, and altogether it occurred in 36.5 per cent of the butt discs. Of the topmost discs, it was alone in 31.2 per cent and altogether present in 34.3 per cent. Bacteria were also very common: alone in 12.5 per cent and altogether in 50.0 per cent of the butt discs, and altogether in 9.5 per cent of the topmost discs. *F. annosus* and bacteria occurred together in 15.6 per cent of the butt discs. The following fungi were identified from more than five specimens: *Coryne cylichnium* (13.6 per cent), *Phialophora* spp. (10.4 per cent), *Penicillium* spp. (9.4 per cent), *Cephalosporium* spp. (6.3 per cent). Butt discs in which only one decay microbe was found numbered 48; this was equal to the number of butt discs with several decay microbes. The proportion of the three most common decay

Table 14. Decay microbes in the butt and topmost discs.
Taulukko 14. Lahottajien esiintyminen tyvi- ja kärkikiekoissa.

a. Decay microbes alone: *a. Lahottajat yksin:*	Butt disc *Tyvikiekko* No. *kpl*	 %	Topmost disc *Kärkikiekko* No. *kpl*	 %
Armillaria mellea (Vahl ex Fr.) Quél.	1	1	1	1
Bacteria, Bakteerit	12	13	9	10
Cephalosporium spp.	1	1	5	6
Coryne cylichnium (Tul.) Bound.	3	3	4	4
Fomes annosus (Fr.) Cooke	13	14	30	31
Grandinia farinaceae Pers.			1	1
Graphium sp.			1	1
Yeast, *Hiiva*	1	1		
Penicillium spp.	4	4	2	2
Peniophora pithya (Pers.) Eriksson			1	1
Phialophora spp.	1	1	4	4
Stereum purpureum (Pers.) Fr.			1	1
» » *sanguinolentum* (Alb. & Schw.) Fr.	1	1	2	2
Torula sp.			1	1
Trametes abietis Karst.			4	5
Odontia bicolor (Alb. & Schw. ex Fr.) Quél.	2	2		
Unidentified — *Tunnistamatta*	9	9	21	23
Total alone — *Yksin yhteensä*	48	50	88	93

b. Combinations of decay agents in butt disc: *b. Tyvikiekon lahottajayhdistelmät:*	No. *kpl*	%
Fomes annosus + Bacterium, *Bakteeri*	11	12
F.a. + *Phialophora* spp.	3	3
» + Bacterium, *Bakteeri* + *Penicillium sp.*	1	1
» » » + unidentified fungus, *tunnistamaton sieni*	3	3
» + *Graphium sp.*	1	1
» + *Coryne cylichnium*	1	1
» » » + *Cephalosporium sp.* + *Cordana pauciseptata* Preuss	1	1
F.a. + *Polyporus abietinus* Dicks. ex Fr.	1	1
Armillaria mellea + Bacterium, *Bakteeri* + *Cephalosporium sp.*	1	1
Bacterium, *Bakteeri* + *Phialophora spp.*	4	5
» » + *Coryne cylichnium*	2	2
» » » » + *Phialophora sp.*	1	1
» » » » + unidentified fungus, *tunnistamaton sieni*	1	1
» » + *Graphium spp.*	2	2
» » + *Penicillium sp.*	1	1
Bacterium, *Bakteeri* + unidentified fungus, *tunnistamaton sieni*	2	2
Cephalosporium sp. + *Phialophora sp.*	1	1
» » + *Stereum sanguinolentum*	1	1
» » » + *Torula sp.*	1	1
Coryne cylichnium + *Penicillium sp.*	1	1
» » + *Stereum purpureum*	2	2
» » + unidentified fungus, *tunnistamaton sieni*	1	1
Peniophora gigantea (Fr.) Massee[1]) + *Stereum sanguinolentum*	1	1
Trametes abietis + unidentified fungus, *tunnistamaton sieni*	1	1
» » + *Lenzites sepiaria* Wulf. ex Fr. + unidentified fungus, *tunnistamaton sieni*	1	1
Combinations in butt disc, total *Tyvikiekon yhdistelmät, yhteensä*	48	50
Butt discs, total *Tyvikiekkoja kaikkiaan*	96	100

[1]) stump sample tree — *kantokoepuu*

microbes of the butt discs was 72.9 per cent.

F. annosus was found in butt discs and increment borer chips of the butt as follows: borer chips 39.6, butt discs with stereomicroscope 46.4, and butt disc cultures, 36.5 per cent. According to several earlier studies, the proportion of *Fomes annosus* has been greater than in the Åland material (cf. RENNERFELT 1946, RATTSJÖ and RENNERFELT 1955, SCHÖNHAR 1969, KALLIO and NOROKORPI 1972).

c. Combinations of decay agents in topmost disc: *c. Kärkikiekon lahottajayhdistelmät:*	No. *kpl*	%
Coryne cylichnium + *Odontia bicolor*	1	1
» » + unidentified fungus, *tunnistamaton sieni*	1	1
» *sarcoides* (Jacquin ex Fr.) Tul. + *Penicillium sp.*	1	1
F. annosus + *Penicillium sp.*	1	1
» + unidentified fungus, *tunnistamaton sieni*	1	1
» + *Trametes abietis* + unidentified fungus, *tunnistamaton sieni*	1	1
Stereum sanguinolentum + unidentified fungus, *tunnistamaton sieni*	1	1
Combinations in topmost disc, total *Kärkikiekon yhdistelmät, yhteensä*	7	7
Topmost discs, total *Kärkikiekkoja kaikkiaan*	95	100

223. Wounds

The causative agents of wound decay were determined from pure cultures. Altogether eight fungal species (families) and a number of bacteria could be identified. The unidentified were grouped together separately. Table 15 lists the decay agents found, specimens from the lower end of the decay separately from those of the upper end.

Upper and lower end specimens were cultured from a total of 10 decayed sites in the stem. Of the identified agents *Cephalosporium* spp. and *S. sanguinolentum* were each discovered twice in both the lower and the upper end. The latter has been found to be a very common causative agent in wound decay (e.g., HAKKILA and LAIHO 1967, KALLIO 1973).

Table 15. Causative agents of wound decay.
Taulukko 15. Haavalahon aiheuttajat.

Decay agent *Lahottaja*	Lower end *Alapää*		Upper end *Yläpää*	
	No. *kpl*	%	No. *kpl*	%
Acremonium spp.	1	8	1	8
Bacterium — *Bakteeri*			1	8
Cephalosporium spp.	2	17	2	15
Coryne cylichnium	1	8		
Graphium sp.	1	8		
Penicillium spp.	2	17		
Phialophora sp.	1	8		
Stereum sanguinolentum	2	17	2	15
Trametes abietis			1	8
Unidentified — *Tunnistamatta*	2	17	6	46
Total — *Yhteensä*	12	100	13	100

23. Effect of the various decay agents on decay parameters

F.annosus was found to be the most common fungus in the decayed spruce. Since earlier studies have also shown *F. annosus* to be the most dangerous and most common decay fungus (KANGAS 1952, KALLIO and NOROKORPI 1972), it was considered useful to distinguish the decay caused by it from that caused by other agents. Mean values were calculated separately from the material for these two groups of decay. By degrees of decay, *F. annosus* occurred as follows: 1) 11.8 per cent, 2) 52.4 per cent, 3) 50.0 per cent, and 4) 35.1 per cent. The fungus grew more often in hard than in already softened wood material, which emphasizes its character as a primary cause of infection.

The division made in the present study between the decay producing agents appears appropriate on the basis of Table 16. The means of the decay parameters of the groups differ distinctly from one another, but the average site types, age of trees and stem volumes of the groups hardly differ at all. The decay parameters, without exception, were more pronounced in the *F. annosus* group. The decay volume is significantly, and the other parameters highly significantly higher than the corresponding parameters of the other group. The diameter of *F. annosus* decay is 1.5 times, the height almost twice, the volume 2.2 times, proportion of decay in relation to the stem 2.4 times and the length of the butt rot 1.4 times that of the other group. The great height of the *F. annosus* decay and its relative proportion of the stem volume probably express the effective decaying action of this fungus (cf. BJÖRKMAN et al. 1949). The proportions of decayed patches in relation to stump sections were not calculated but according to Table 16 the diameter of the decay was highly significantly larger in the *F. annosus* decay than with the other decay agents. The result, therefore, is on the same lines as that reported earlier from Finland (KALLIO and NOROKORPI 1972). In the last mentioned study it was noted, furthermore, that *F. annosus* alone produced a smaller decayed patch in the stump than when together with *A. mellea*.

Table 16. Parameters of the decay formations produced by *F. annosus* and the other decay agents.
Taulukko 16. Maannousemasienen ja muiden lahottajien aiheuttamien lahopatsaiden tunnukset.

Parameter *Tunnus*		*F. annosus* *Maan-nousemasieni*	Others *Muut lahot*	F-value *F-arvo*
Forest site type …………………… *Metsätyyppi*	M	2.4 (=OMT−)	2.9 (=MT+)	
Age of tree, yrs …………………… *Puun ikä, v*	M	103	111	1.8401
Stem volume, cu. dm …………… *Rungon tilavuus, dm³*	M	337.2	338.4	0.0075
Decay diameter, cm …………… *Lahon lpm, cm*	M D	24.4 9.6	16.1 11.0	*** 13.7618
Height, dm …………………………… *Korkeus, dm*	M D	46.4 21.9	24.8 27.1	*** 13.0395
Volume, cu. dm …………………… *Tilavuus, dm³*	M D	80.6 74.2	37.6 77.1	* 6.1065
Percentage of stem …………… *Osuus rungosta, %*	M D	25.3 14.4	10.7 15.7	*** 17.2047
Degree of decay ……………… *Lahoaste*	M D	2.9 1.0	2.7 3.1	
Length of butting off, dm ……… *Tyveyksen pituus, dm*	M D	35.3 16.4	25.8 25.3	0.4186
Number of trees …………………… *Puita yht., kpl*		33	56	

3. Estimating the decay in standing trees

An attempt to ascertain the decay in standing trees before increment boring and felling, was made by studying the butt swelling, resin flow, and the colour and amount of needles. A two-value grading was used for every property: yes or no. The probability with which the soundness of the tree could be successfully determined with the aid of these symptoms is given in Table 17.

Table 17. Estimation of the decay in a standing tree with the aid of external characteristics.
Taulukko 17. Pystypuun lahoisuuden arvioiminen ulkoisten tuntomerkkien avulla.

Characteristic *Tuntomerkki*	Probability of success *Onnistumistodennäköisyys*	
	Butt rot *Tyvilaho*	Soundness *Terveys*
Butt swelling *Tyvilaajentuma*	0.07	0.70
Resin flow *Pihkavuoto*	0.25	0.73
Needles *Neulasisto*	0.49	0.73

Estimation of butt rot on the basis of external charecteristics failed. The best characteristic in this study was the needles, but even then only half the cases were discovered. Resin flow revealed only a quarter of the decayed trees. Russian authors (Semenkova 1971) managed to determine the butt rot by this method in 50 per cent of the cases. Decay in Åland spruce could be determined on the basis of the butt swelling in only 7 per cent of the cases. Neither do the Russians find that butt swelling is a reliable indication of decay (Semenkova 1971). Many other authors also have had little success in trying to detect decayed trees on the basis of external characteristics (Rennerfelt 1946, Dimitri 1968, Kallio 1973).

All the examined spruce trees were bored at butt and breast height as aseptically as possible. Decay in the chips was estimated immediately after boring and before the tree was felled. They were classified as either sound or decayed. Decay of the tree was finally determined after felling in connection with cutting into lengths. Table 18 presents the results of the estimation based on increment borer chips.

Boring at the butt revealed 82 per cent of the decay, while 4 per cent of the sound trees were estimated as decayed. On the basis of boring at the butt the condition of the tree could be correctly estimated in 91 per cent of the cases (cf. Semenkova 1971). Boring at breast height was considerably less reliable. Only 48 per cent of the decayed trees were detected, and 1 per cent of the sound trees were estimated as decayed.

Table 18. Estimation of the condition of standing tree by increment borer chips.
Taulukko 18. Pystypuun terveydentilan arvioiminen kairauksin.

True condition of standing tree *Pystypuun todellinen terveydentila*	Estimated condition *Arvioitu terveydentila*							
	Decayed *Laho*				Sound *Terve*			
	Butt *Tyvi*		1.3 m		Butt *Tyvi*		1.3 m	
	No. *kpl*	%	No. *kpl*	%	No. *kpl*	%	No. *kpl*	%
Decayed *Laho*	72	82	42	48	16	18	46	52
Sound *Terve*	9	4	2	1	193	96	200	99
Total—*Yhteensä*	81		44		209		246	

The estimate of the condition was correct in 83 per cent.

The variation in the reliability between the borings was probably due to the fact that the decay did not in all cases extend to the 1.3 m height, or else was at this height small, irregular and possibly only faintly discoloured. Boring at the 1.3 m height has been found a poor indicator of decay by many other authors as well (Rennerfelt 1946, Dimitri 1968, Kallio 1972).

4. Consequential effects of butt rot

41. Effect of decay on timber harvest

On the basis of the results of earlier studies (Petrini 1944, Arvidson 1954, Kallio 1972), two different measurements for cutting into lengths were used in the study of timber losses caused by butt rot. However, the method is probably not particularly exact in small materials. In the material of the present study the harvest of timber, including decay, totalled about 85 solid cu.m. incl.bark. C. 49 solid cu.m. of this volume was sawn timber logs. The material is relatively small to permit the calculation of reliable results. The trend and magnitude of the effect of butt rot can, however, be investigated even from such a small material (cf. Arvidson 1954).

The mean values of the timber assortments can be seen from Table 19. The mean volume of the logs was not calculated, only their mean length.

Table 19. Results of cutting into lengths by timber assortments.
Taulukko 19. Apteeraustulokset puutavaralajeittain.

		1st cutting *1. apteeraus*		2nd cutting *2. apteeraus*	
		Volume *Tilavuus*	Trees, No. *Puita, kpl*	Volume *Tilavuus*	Trees, No. *Puita, kpl*
Log, cu.dm .... *Tukki, dm³*	M D	375 270	131	348 278	112
Sulphite pulpwood, cu.dm .... *Sulfiittipuu, dm³*	M D	121 78	291	115 79	282
Sulphate pulpwood, cu.dm .... *Sulfaattipuu, dm³*	M D	91 111	10	98 76	90
Butting off, dm .... *Tyveys, dm*	M D			29.8 21.1	48
Length of logs, dm .... *Tukkien pituus, dm*		47.8		47.8	

Table 20. Timber assortment percentages of the total volume according to the 1st cutting into lengths.
Taulukko 20. Puutavaralajisadannekset kokonaiskuutiosta 1. apteerauksen mukaan.

	Diameter class, cm *Läpimittaluokka, cm*								Mean *Keskim.*
	–10	10–14	15–19	20–24	25–29	30–34	35–39	40–	
Log — *Tukki*			1.4	42.9	66.4	73.0	70.8	79.4	37.2
Sulphite pulpwood ... *Sulfiittipuu*	55.8	82.9	91.6	53.2	29.3	23.6	17.7	15.4	55.2
Sulphate pulpwood ... *Sulfaattipuu*		2.2	0.6	0.8	0.9		6.2		1.0
Total — *yht.*	55.8	85.1	93.6	96.9	96.6	96.6	94.7	94.8	93.4

The number of trees suitable for saw timber decreased by 14.5 per cent, and for sulphite pulpwood by 3.1 per cent, but the number suitable for sulphate pulpwood increased from 10 to 90. The volume of logs and sulphite pulp per tree also decreased, whereas that of sulphate pulp increased. Tables 20 and 21 show the timber assortment percentages of total volumes. The calculation was based on the equation derived by KUUSELA (1966). The percentages are estimated for the whole stem distribution series by 5 cm diameter classes.

The picture given by Tables 20 and 21 is complemented by Table 22, which shows the changes in the yield of timber assortments, excluding sulphate pulpwood, and in the total yield compared with the timber cut into sound lengths.

Table 21. Timber assortment percentages of the total volume according to the 2nd cutting into lengths.
Taulukko 21. Puutavaralajisadannekset kokonaiskuutiosta 2. apteerauksen mukaan.

	Diameter class, cm *Läpimittaluokka, cm*								Mean *Keskim.*
	−10	10−14	15−19	20−24	25−29	30−34	35−39	40−	
Log .... *Tukki*			1.4	33.5	52.2	56.9	51.8	67.0	29.2
Sulphite pulpwood .... *Sulfiittipuu*	51.8	71.3	74.0	47.7	28.9	23.3	24.3	15.4	48.5
Sulphate pulpwood ... *Sulfaattipuu*	4.0	9.3	10.1	8.9	11.7	10.1	15.3	5.1	9.9
Total − *yht.*	55.8	80.6	85.5	90.1	92.8	90.3	91.4	87.5	87.6

Table 22. Effect of butt rot on the yield of timber assortments.
Taulukko 22. Tyvilahon vaikutus puutavaralajisaantoon.

	Diameter class *Läpimittaluokka*								Mean *Keskim.*
	−10	10−14	15−19	20−24	25−29	30−34	35−39	40−	
Log .... *Tukki*				−21.8	−21.4	−22.2	−26.9	−15.7	−21.5
Sulphite pulpwood .... *Sulfiittipuu*	−7.2	−14.0	−19.2	−10.3	−1.2	−1.4	+36.9	−0.1	−12.2
Total yield[1]) .... *Kokon. saanto*[1])		−5.2	−8.6	−7.0	−4.0	−6.6	−3.6	−7.8	−6.3

1) Total yield = logs + sulphite pulp + sulphate pulp
1) *Kokonaissaanto = tukki + sulfiittipuu + sulfaattipuu*

The proportion of timber logs was reduced by 21.5 per cent because of decay. The reduction was greatest in diameter class 35−39 cm, viz. by 26.9 per cent (cf. Table 3). The mean reduction in sulphite pulpwood was 12.2 per cent. The share of sulphate pulpwood (Tables 20 and 21) increased from 1 to 10 per cent of the total. The total timber yield fell by 6.3 per cent. This is the amount consumed by butting of owing to decay (cf. RATTSJÖ and RENNERFELT 1955). The figure, however, is hardly exact since two measurements, the 1st and 2nd cutting into lengths, are slightly different when carried out in practice, and the volume calculation of any one part of the stem in the different timber assortments, e.g. logs or sulphate pulpwood, may lead to quantitatively different results (cf. RATTSJÖ and RENNERFELT 1955).

The loss of saw timber due to decay was greatest in tax class IB (Table 23) and the total yield also fell more than it did on average.

Table 23. Effect of butt rot on the yield of timber assortments by tax classes.
Taulukko 23. Tyvilahon vaikutus puutavaralajisaantoon veroluokittain.

	Tax class — *Veroluokka*				
	I A	I B	II	III + IV	Mean-*Keskim.*
Log — *tukki*	−23.0	−25.0	−8.8		−21.5
Sulphite pulpwood .... *Sulfiittipuu*	−6.8	−12.1	−8.1	−24.9	−12.2
Total yield — *Kokonaissaanto*	−6.5	−7.8	−0.3	−10.2	−6.3

Earlier studies have usually led to slightly higher timber losses. In Sweden (RATTSJÖ and RENNERFELT 1955) it was found that 34 per cent of the timber logs were lost. The total loss of timber spoiled by decay was 14.6 per cent. According to a study in the far north of Finland (TIKKA 1938), 13.5 per cent of the usable wood volume of spruce was lost, primarily owing to butt rot. In a South Finnish spruce stand infected by *F. annosus* the proportion of logs decreased by c. 30 per cent (KALLIO 1972), that of sulphite pulpwood increased a little, but sulphate pulpwood showed an increase that was about equal to the quantity by which the logs were decreased.

In Åland the loss of timber due to decay was approximately the same as the proportion of decayed wood material in the total volume (cf. Table 4).

Figs. 5 and 6 show the timber assortment percentages and the changes due to decay in the shares of saw timber, sulphite pulpwood and usable wood.

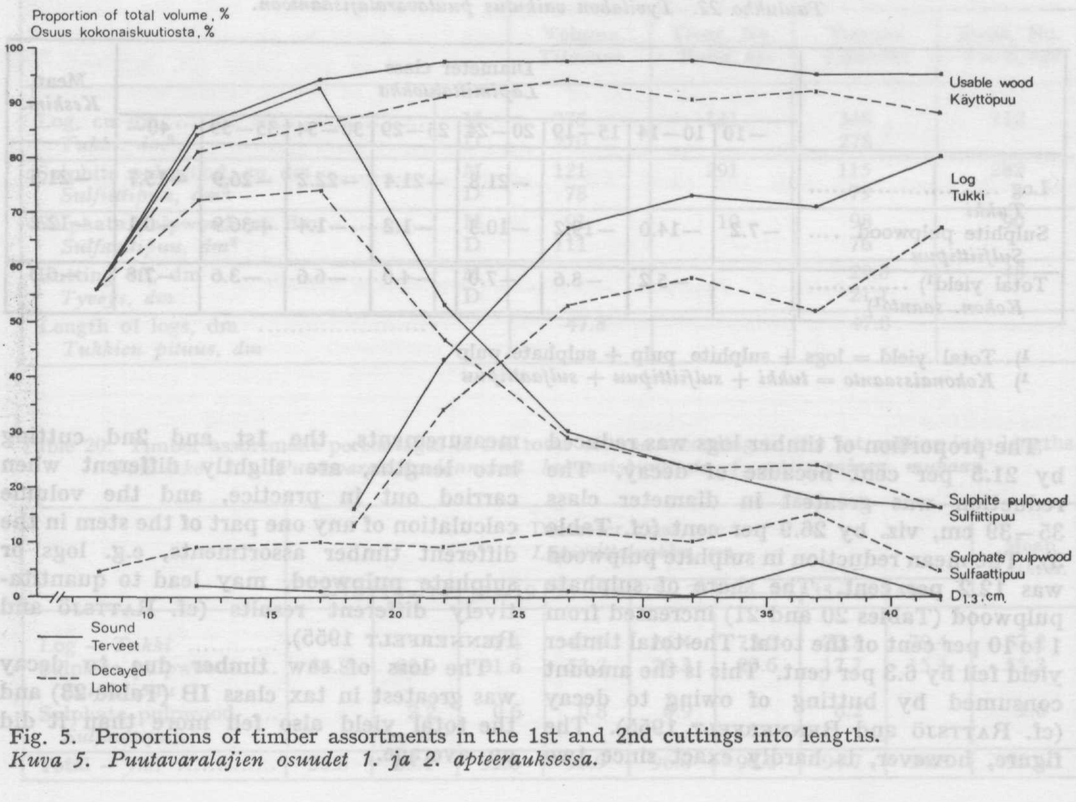

Fig. 5. Proportions of timber assortments in the 1st and 2nd cuttings into lengths.
Kuva 5. Puutavaralajien osuudet 1. ja 2. apteerauksessa.

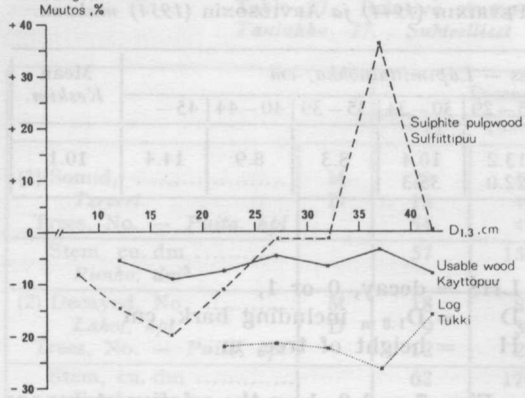

Fig. 6. Decay-induced changes of timber assortments.
Kuva 6. Puutavaralajien muutokset lahon takia.

42. Effect of decay on the stumpage price of growing stock

Studies of the financial losses were based on fixed unit prices of the timber assortments. The method led to a slight underestimation of the losses (cf. LAASASENAHO and SEVOLA 1971). The relative unit prices of the timber assortments were: logs 100, sulphite pulpwood 59 and sulphate pulpwood 53.

Due to decay, the relative stumpage price fell by 10.3 per cent, on average (Table 24). The relative reduction in stumpage value increased as the forest site type improved (Table 25). The reduction was heaviest in stands approaching full maturity, ready for regeneration. The fall in stumpage price was greatest in age class 71 – 100 years.

Table 24. Reduction in stumpage price due to decay.
Taulukko 24. Kantoarvon aleneminen lahon vuoksi.

	Diameter class — *Läpimittaluokka, cm*								Mean *Keskim.*
	–10	10–14	15–19	20–24	25–29	30–34	35–39	40–	
Reduction, % .... *Vähennys, %*	0.7	6.1	9.6	11.1	10.4	12.7	12.3	11.0	10.3

Table 25. Effect of butt rot on the stumpage price by forest site types, tax, development and age classes.
Taulukko 25. Tyvilahon vaikutus kantoarvoon metsätyypeittäin, vero-, kehitys- ja ikäluokittain.

Forest site type *Metsätyyppi*	Trees No. *Puita kpl*	Reduction, % *Vähennys, %*
Lh + OMT	132	12.7
MT	113	8.7
VT + others	46	5.8
	291	10.3

Tax class *Veroluokka*	Trees No. *Puita kpl*	Reduction, % *Vähennys, %*
I A	99	11.4
I B	121	12.1
II	44	2.6
III + IV	27	10.7

Age class *Ikäluokka*	Trees No. *Puita kpl*	Reduction, % *Vähennys, %*
– 40 yrs	16	0.5
41–70 »	66	4.3
71–100 »	145	13.3
101– »	59	10.4

Development class *Kehitysluokka*	Trees No. *Puita kpl*	Reduction, % *Vähennys, %*
(2) Small seedling stand ... *Pieni taimisto* (3) Large seedling stand *Iso taimisto* (4) Thinning stand........... *Nuori kasv.metsikkö*	69	4.2
(5) Accretion stand .... *Vartt. kasv. metsikkö* ...	59	9.8
(6) Mature stand .... *Uudistuskypsä metsikkö*	101	13.9
(8) Low yielding stand ...... *Vajaatuottoinen metsikkö*	57	10.1

Table 26. Reduction in stumpage price due to decay according to PETRINI (1944) and ARVIDSON (1954).
Taulukko 26. Kantoarvon aleneminen lahon vuoksi PETRINIn *(1944) ja* ARVIDSONin *(1954) mukaan.*

	Diameter class — *Läpimittaluokka, cm*								Mean *Keskim.*
	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–	
PETRINI	1.6	12.2	12.3	13.2	10.4	8.3	8.9	14.4	10.1
ARVIDSON	20.0	25.5	24.7	22.0	35.3				

The figures of Table 26 are the study results reported by PETRINI (1944) and ARVIDSON (1954). According to ARVIDSON, the smaller percentages quoted by PETRINI are due to different timber prices, measurement standards and wages. The low percentages of the Åland material were due, in part, to a method of calculation different from the earlier studies, and in part to fixed unit prices. The most important cause of the low percentages for the Åland material was, however, the smaller amount of decay compared with the Swedish materials mentioned. In the study by RATTSJÖ and RENNERFELT (1955), the loss in value was 22.9 per cent. In their material not less than 50 per cent of the total stem number were decayed trees. According to KALLIO (1972), the loss was 13 per cent.

The stumpage price of the Åland material was also studied with the aid of regression models. For sound trees, the equation arrived at was Y = (ln D, d-d6, D6), which had a coefficient of determination of 0.728 (ln = natural logarithm; $D = D_{1.3\,m}$ including bark, cm; $d = d_{1.3\,m}$ excluding bark, cm; $d\,6 = d_{6.0\,m}$ exluding bark, cm; $D\,6 = D_{6.0\,m}$ including bark, cm.). The values of the decayed trees could not be explained even passably, and the coefficient of determination remained at 0.203. The final equation chosen was the following:

$$(3)\quad Y = -259.8447 - 56.730561 \cdot LHS + 11.274153 \cdot D6 + 11.560746 \cdot H + 5.798451 \cdot D,$$

with a coefficient of determination of 0.680, the 95 % reliability limits of the mean value of 200.4 ±22.0, and the variables:

Y = the relative stumpage price of tree
LHS = decay, 0 or 1,
D = $D_{1.3\,m}$ including bark, cm
H = height of tree, m

Figs. 7 and 8 show the relative stumpage prices, the true and those obtained from the above equation, as a function of diameter.

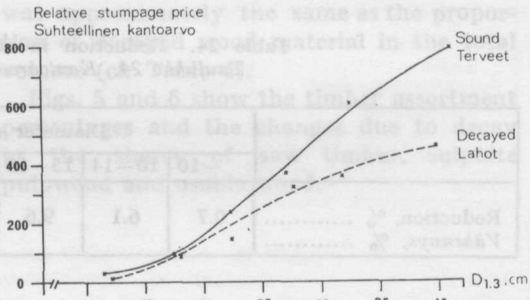

Fig. 7. Relative stumpage prices by diameter classes.
Kuva 7. Suhteelliset kantoarvot läpimittaluokittain.

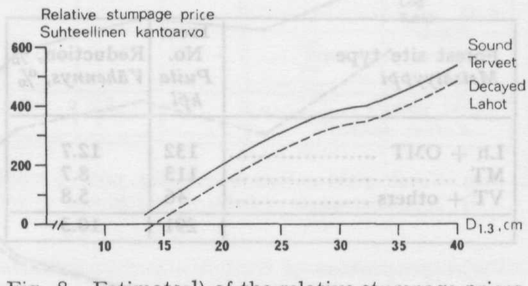

Fig. 8. Estimates[1]) of the relative stumpage prices by diameter classes.
Kuva 8. Suhteellisten kantoarvojen estimaatit [1]) läpimittaluokittain.

[1]) according to the equation 3.

By two-way variance analysis (Table 27), the relative price of decayed trees was found to be statistically highly significantly lower than that of the sound trees. According to

Table 27. Relative stumpage prices by diameter classes.
Taulukko 27. Suhteelliset kantoarvot läpimittaluokittain.

		Diameter class — *Läpimittaluokka, cm*						Mean *Keskim.*
		–14	15–19	20–24	25–29	30–34	35–	
(1) Sound, ... *Terveet*	M	28	91	235	370	602	790	205
	D	18	43	81	114	226	193	211
Trees, No. — *Puita, kpl*		54	49	43	33	14	5	198
Stem, cu. dm .... *Runko, dm³*		57	158	304	449	709	1220	293
(2) Decayed, No. .... *Lahot, kpl*	M	18	81	145	321	359	460	190
	D	9	36	83	131	174	292	175
Trees, No. — *Puita, kpl*		12	22	19	21	7	5	86
Stem, cu. dm .... *Runko, dm³*		62	170	296	494	592	904	338
Difference, % .... *Ero, %* (1–2)		36	11	38	13	40	42	

the equation 3, the difference between the stumpage prices of sound and decayed trees remains constant, with a difference of c. 57 units. The picture given by Table 24, however, is probably more correct, in other words, the relative difference between the prices of sound and decayed trees remained constant, at c. 10 per cent.

43. Effect of decay on the volume and increment parameters of trees

The study of the differences between the volume and increment parameters of sound trees and trees with butt rot was considerably restricted by the size of the material and the way in which it had been collected. A total of 202 sound and 89 decayed sample trees had been collected from 59 sample plots representing very different stands. A few stand sample plots would perhaps have been a better starting point. On the other hand, the main objective of the study was to ascertain the incidence of butt rot of spruce in Åland, while the consequential effects of the decay were of secondary importance to the main study.

The mean values of stand parameters of the compared groups — sound and decayed — weighted with the number of sample trees can be seen from Table 28.

Table 28. Parameters of the stands represented by sound and decayed trees.
Taulukko 28. Terveiden ja lahojen puiden edustamien metsiköiden tunnukset.

Parameter *Tunnus*	Sound *Terveet*	Decayed *Lahot*
Forest site type — *Metsätyyppi*	2.8 (MT)	2.7 (MT)
Development class¹) — *Kehitysluokka*¹)	5.5	5.9
Tax class — *Veroluokka*	1.1 (IB)	1.0 (IB)
Age class — *Ikäluokka*	73–82 yrs/v	85–94 yrs/v
Basal area — *Pohjapinta-ala m²/ha*	25.0	28.7
Trees, No. — *Puita, kpl.*	206	89

¹) See Table 7 — *Ks. taulukko 7.*

The stands represented by the decayed trees were, on average, 12 years older and, per hectare of basal area, 3.7 sq.m. denser than the stands represented by the sound trees. The other parameters were approximately the same.

Differences in the stem form and increment characteristics of the groups are presented in Table 29. To start with, differences between the parameters of sound trees and trees representing various degrees of decay were examined by means of the t-tests. According to the tests, the trees representing degrees 2 and 4 of decay were, on average, older and larger than the trees of the other groups. Furthermore, the increment percentages of the sound trees and trees with decay of degree 1 differed at least almost significantly (p = 0.05) from those of the trees with decay of degree 2—4. The results of the tests are to be interpreted conservatively; they are rather approximative.

Table 29. Volume parameters of the sample trees by diameter classes.
Taulukko 29. Koepuiden kuutiotunnukset läpimittaluokittain.

Parameter *Tunnus*		Sound *Terveet*	Decayed *Lahot*	F-value *F-arvo*
Age, yrs .... *Ikä, v*	M	90.7	107.9	***
	D	34.9	29.2	12.1963
H, m	M	14.63	15.80	
	D	4.30	4.17	0.1486
D 1.3 m, cm	M	20.5	22.9	
	D	8.0	7.3	1.4772
d 1.3 — d 6.0, cm	M	4.9	5.7	*
	D	1.9	2.7	4.7684
V, cu.dm, dm³	M	292.7	337.8	
	D	288.6	238.7	0.9965
Trees. No. ...... *Puita, kpl*		202	89	

Table 30. Increment parameters of sound and decayed trees by age classes.
Taulukko 30. Terveiden ja lahojen puiden kasvutunnukset ikäluokittain.

Parameter *Tunnus*		Sound *Terveet*	Decayed *Lahot*	F-value *F-arvo*
Age, yrs *Ikä, v* ..	M	90.7	107.9	
	D	34.9	29.2	0.1396
D 1.3 m, cm	M	20.5	22.9	
	D	8.0	7.3	0.7324
IH 10 v¹), m	M	1.96	1.26	*
	D	1.27	0.73	4.97
ID 10 v²), cm	M	2.4	1.5	
	D	1.8	1.1	3.6164
ID6 m 10 v, cm ...	M	2.6	1.5	**
	D	2.0	1.1	6.7023
pV 5 v, %	M	15.8	8.7	**
	D	12.1	6.5	7.3741
pV 10 v, %	M	31.5	18.6	***
	D	19.6	10.5	12.0211
Trees. No. .... *Puita, kpl*		201	87	

[1]) Height increment of the last 10 years
[1]) *10 viimeisen vuoden pituuskasvu*
[2]) Diameter increment at 1.3 m of the last 10 years
[2]) *10 viimeisen vuoden läpimitan kasvu 1.3 m korkeudella*
Other explanations see Table 2 — *ks. taulukko 2 selitykset.*

By contrast, the tests of Tables 29 and 30, carried out by diameter and age classes, probably give relatively reliable results.

The wide deviations in the parameters of the sound trees — the group comprises trees over the total range of the stem distribution series — distinctly affect the testing. Partly for this reason, the group of sound trees has been excluded from Table 31. An effort has been made to divide the sample tree parameters between Tables 29 and 30 so that the classifications concerned would reduce the residual variances to a minimum in order to improve the reliability of test results. The two-way variance analysis was used in the study.

Of the volume parameters (Table 29), only the tapering of stems excluding bark, d1.3–d6.0, is statistically almost significantly (at the level 0.05) greater in decayed than in sound trees. According to Arvidson (1954), the tapering of the trees of decay class 3 — the decay of more than 75 per cent of the stump diameter — was statistically highly significantly greater than in sound trees. According to his study decayed trees often had a larger breast height diameter, smaller height and lower yield than the sound trees. According to Kallio (1972), tapering of decayed trees in the lower part of the stem (d 1.3 – d 3.5) was 4 per cent, in the middle part (d 1.3 – d 6.0) 22 per cent and in the top part (d 3.5 – d 6.0) 54 per cent greater than in sound trees. Tapering shown in Table 29 supports the results reported by Arvidson and Kallio. Growth parameters are larger throughout in sound than in decayed trees.

Table 31. Parameters of decayed trees by degrees of decay.
Taulukko 31. Lahopuiden tunnuksia lahoasteittain.

Parameter *Tunnus*		Degree of decay *Lahoaste* 1	2	3	4	F-value *F-arvo*
Age, yrs *Ikä, v*	M	105	111	99	111	
	D	34.7	35.7	25.9	23.6	0.7695
D 1.3 m, cm	M	20.6	22.0	20.6	25.2	
	D	6.5	7.7	6.8	7.2	2.4562
d1.3—d6.0, cm ..	M	5.0	5.6	5.4	6.1	
	D	2.2	2.3	3.5	2.8	0.8142
V, cu.dm, dm³	M	274.2	328.3	260.3	401.8	
	D	197.0	284.3	181.0	238.2	1.8226
pV 5 v, % ...	M	13.5	7.7	8.7	7.0	*
	D	8.0	5.3	9.0	3.9	3.6706
pV 10 v, % ...	M	27.3	16.3	16.9	16.4	**
	D	12.4	8.9	11.0	8.0	4.5277
Trees, No. .... *Puita, kpl*		17	21	14	37	

M = mean value, D = standard deviation
M = *keskiarvo*, D = *keskihajonta*
Explanations see Table 2 — *ks. taulukko 2 selitykset.*

The series of figures in Table 30 more or less correspond to the results reported by Arvidson. In their study of the effect on growth of decay starting from damage caused to spruce by timber harvesting machines, Isomäki and Kallio (1974) came to the conclusion that the radial growth at breast height was up to 50 per cent smaller in the decayed and damaged than in the sound trees. In these cases, however, the heavy timber harvesting machines probably had also severed some of the tree roots and so had a weakening effect on the growth of the trees. Zycha (1967), in Germany, noticed no difference between sound and decayed spruce trees in relation to tapering, height or crown height.

Statistically significant differences in the degrees of decay were recorded for growth parameters only. The age differences between the groups, however, impaired the reliability of the differences. Reliable points of comparison, from the point of view of occasional variations in growth, are probably the growth percentages over a lengthy period, say 10 years (NYYSSÖNEN 1954). On the other hand, age differences between groups do not affect the percentages of the shorter and later 5-year period so much as they do the 10-year percentages, when the connection between growth percentages and age, and the high age of the sample trees are taken into consideration. On this basis, the difference between the growth percentages of the last five years, which was statistically significant, is probably correct (Table 30).

Regression models were made to confirm the difference seen from Tables 29 and 30 in the tapering and volume increment percentages of sound and decayed trees. The following were chosen:

(4) $K = 5.634137 + 0.477349 \cdot LHS + 0.391128 \cdot D - 0.594389 \cdot H;$

(5) $pV = -39.58799 - 4.016595 \cdot LHS + 0.132741 \cdot T + 2.721487 \cdot \ln D + 3987.216007/T.$

The variables of the equations are:

K = tapering excluding bark d 1.3 — d 6.0, cm
LHS = butt rot of the tree, 0 = sound, 1 = decayed
H = height of tree, m
pV = volume increment percentage of the last 10 years
T = age of tree, years

The coefficient of determination of the equation 4 in the material was 0.685, and the 95 % reliability limits of the mean were: 5.16 cm ± 2.35 cm (2.81—7.51). The coefficient of determination of the equation 5 was 0.719, and the 95 % reliability limits of the mean of the volume increment percentage were: 27.61 ± 18.87 (8.74—46.48). From the equation 4 it was seen that the

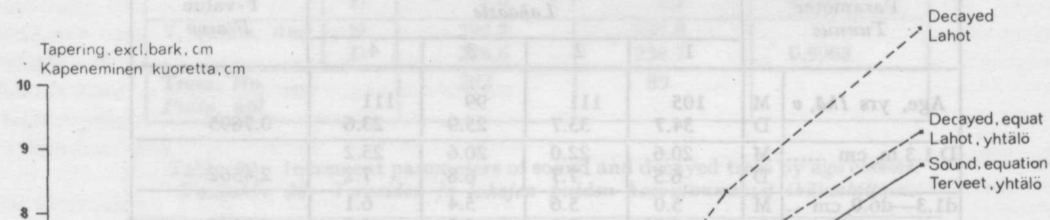

Fig. 9. Tapering by diameter classes according to the equation 4 and the true observations.
Kuva 9. Kapeneminen läpimittaluokittain yhtälön 4 ja todellisten havaintojen mukaan.

tapering estimate of a tree with butt rot exceeded that of a sound tree of the same size by c. 0.5 cm. The difference is small, the standard error is about 5 times as great. However, it should be borne in mind that tree height and diameter determine tapering rather exactly (cf. TIIHONEN 1961) and that the decayed trees of the study generally grew in denser stands, the difference being 3.7 sq.m./ha (cf. NYYSSÖNEN 1954). For these reasons, it can be concluded that the decayed trees of the present material have tapered more than the sound. A similar finding has earlier been reported by e.g. ARVIDSON (1954) and KALLIO (1972). The volume increment of decayed trees is smaller than that of sound trees also according to the equation 5 (cf. Table 30). Decay is found to have reduced the 10-year increment percentage by 4 units. A study of the increment percentages by age classes revealed that the percentages of sound and decayed trees differed most in the lower age classes. Towards the older age classes the difference diminished until, in the oldest groups, it disappeared completely.

Figs. 9 and 10, in addition to the values according to the equations 4 and 5, present the true mean values, calculated from the material, for tapering by diameter classes and the volume increment percentage by age classes.

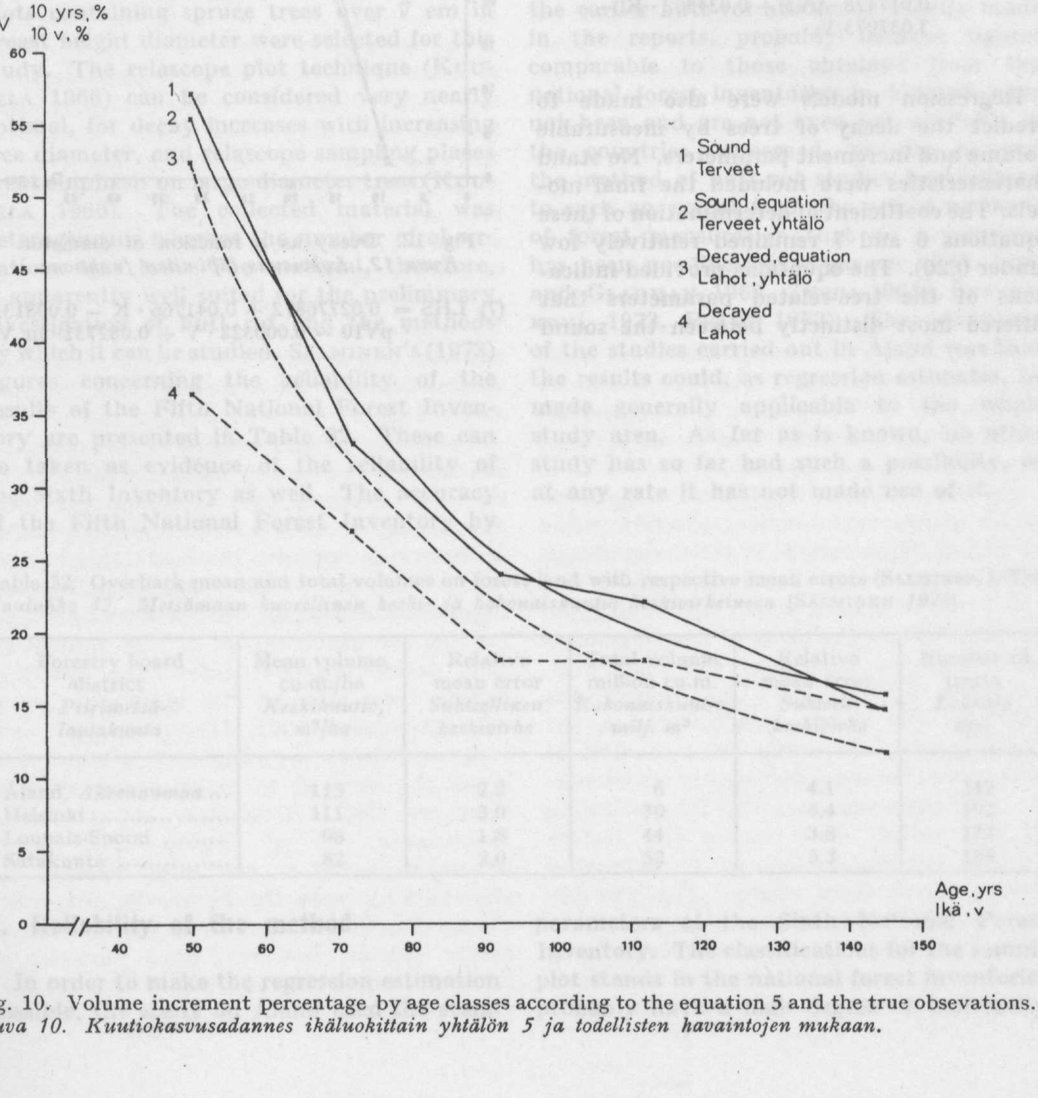

Fig. 10. Volume increment percentage by age classes according to the equation 5 and the true obsevations.
Kuva 10. Kuutiokasvusadannes ikäluokittain yhtälön 5 ja todellisten havaintojen mukaan.

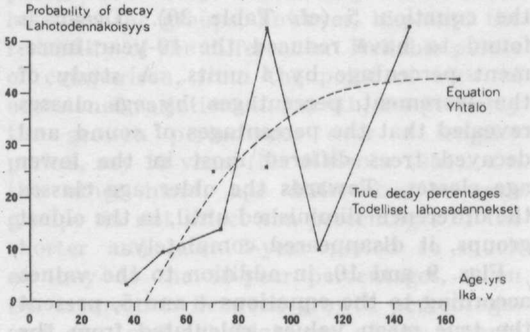

Fig. 11. Decay as a function of age.
Kuva 11. Lahoisuus iän funktiona.

(6) $LHS = 0.4124628 - 0.018177 \cdot pV10 + 0.017478 \cdot pV5 + 0.034302 \cdot K - 3.037973/V;$

Regression models were also made to predict the decay of trees by measurable volume and increment parameters. No stand characteristics were included the final models. The coefficient of determination of these equations 6 and 7 remained relatively low (under 0.20). The equations provided indications of the tree-related parameters that differed most distinctly between the sound and decayed trees. The best independent variable was the age class of the trees (Fig. 11). In most studies the diameter class also has been found to be a reliable parameter (Fig. 12).

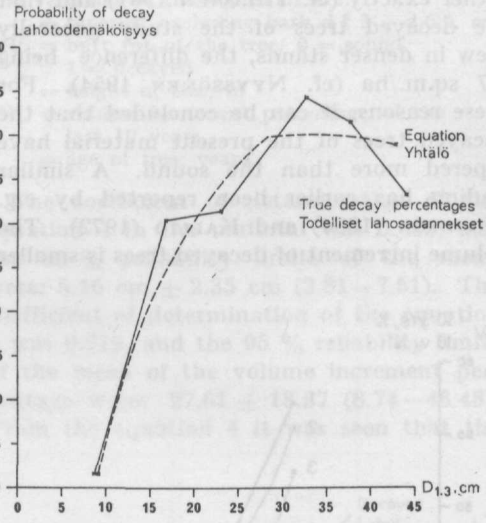

Fig. 12. Decay as a function of diameter.
Kuva 12. Lahoisuus läpimitan funktiona.

(7) $LHS = 0.02776872 + 0.041766 \cdot K - 0.008135 \cdot pV10 - 0.000322 \cdot V + 0.082731 \cdot \ln V$

V DISCUSSION

1. Representativeness of the material

The material of the present study can be said to be small by absolute standards but representative by relative standards. The 59 sample plots and 295 sample trees were fairly evenly divided over the spruce-growing forest land studied in Åland. The selection of samples was made in two stages. In the summer of 1971, the tracts of the Sixth National Forest Inventory were measured at 4 km intervals, and from these tracts all volume and increment sample plots containing spruce trees over 7 cm in breast height diameter were selected for this study. The relascope plot technique (KUUSELA 1966) can be considered very nearly optimal, for decay increases with increasing tree diameter, and relascope sampling places great emphasis on large-diameter trees (KUUSELA 1960). The collected material was heterogeneous whereas the number of observations was low. The material, therefore, is apparently well suited for the preliminary investigation of butt rot and the methods by which it can be studied. SALMINEN'S (1973) figures concerning the reliability of the results of the Fifth National Forest Inventory are presented in Table 32. These can be taken as evidence of the reliability of the Sixth Inventory as well. The accuracy of the Fifth National Forest Inventory by forestry board districts was excellent as far as volumes were concerned. If the results are calculated by smaller subregions the accuracy falls very steeply at a certain point as the area diminishes (SALMINEN 1973). No parameters to reflect the accuracy were calculated for the butt rot estimate of spruce trees in Åland since the sample was so small. For economic reasons it is obviously not worth while to strive for very small standard errors in butt rot parameters.

No mention concerning the accuracy of the earlier butt rot studies is usually made in the reports, probably because figures comparable to those obtained from the national forest inventories in Finland have not been and are not even yet available in the countries concerned, or else because the method of butt rot studies has differed to such an extent from the actual methods of forest mensuration that no comparison has been possible (RENNERFELT 1946, LOW and GLADMAN 1962, ZYCHA 1964a, ČERVINKOVÁ 1973, PRATT 1973). The advantage of the studies carried out in Åland was that the results could, as regression estimates, be made generally applicable to the whole study area. As far as is known, no other study has so far had such a possibility, or at any rate it has not made use of it.

Table 32. Overbark mean and total volumes on forest land with respective mean errors (SALMINEN 1973).
Taulukko 32. Metsämaan kuorellinen keski- ja kokonaiskuutio keskivirheineen (SALMINEN *1973*).

Forestry board district *Piirimetsälautakunta*	Mean volume, cu.m./ha *Keskikuutio, m³/ha*	Relative mean error *Suhteellinen keskivirhe*	Total volume, million cu.m. *Kokonaiskuutio, milj. m³*	Relative mean error *Suhteell. keskivirhe*	Number of tracts *Lohkoja kpl.*
Åland, *Ahvenanmaa* ...	115	2.2	6	4.1	347
Helsinki	111	3.0	39	4.4	192
Lounais-Suomi	98	1.8	44	3.8	174
Satakunta	82	2.0	52	3.3	184

2. Reliability of the method

In order to make the regression estimation possible, the study on Åland used the stand parameters of the Sixth National Forest Inventory. The classifications for the sample plot stands in the national forest inventories probably have a high degree of uniformity since the group leaders have the same training, but e.g. the determination of forest site type could be particularly difficult in Åland (Nyyssönen 1954, Högnäs 1966). For this reason the results obtained on the correlation of butt rot with forest site types were perhaps not absolutely accurate. The other stand parameters are probably more reliable than those conserning site type classification. The estimates made by the naked eye in the study were primarily related to the condition of the trees. Since they were made by the same person these estimates are probably mutually comparable.

The measurement results in the present study are probably relatively accurate (cf. Nyyssönen 1954), since felled sample trees were used. The sample tree volumes were calculated by means of equations with good accuracy (Laasasenaho and Sevola 1971). The volume calculation of timber assortments may have been less accurate. The absolute and relative volume increments were probably also determined very reliably. The volumes of the decayed parts of the stems were calculated as if they had been cones. The accuracy would therefore not equal that of the stem volume estimate owing to the asymmetry and diffuse contours of the decay. The decay diameters were cross-measured in such a way that the mean value would have equalled a round patch. A surface area determination would perhaps have been more accurate.

The sample was so small that wide classes had to be formed for testing the differences between the parameters of the decayed and sound trees. Some classes comprised less than 10 observations, which is probably too small considering the range of the parameters tested and the extent of the classes (cf. Kulokari 1970). For this reason the results for the larger diameter classes, the most important from the point of view of decay, are perhaps not sufficiently representative. The regression equations for confirming the test results and tracing the factors affecting the parameters to be estimated were not particularly reliable. This was due to the small number of observations and the wide range. The regression equations, however, perhaps provide a better idea than that given by tests per class, since the equations could be made to contain simultaneously several factors affecting the issue. The reliability of the final models was not studied any more exactly than by mean values and their reliability limits. The smoothing capacity of the equations was illustrated by graphs and diagrams (cf. Laasasenaho and Sevola 1971). Both tests and regression analyses were adversely affected by the difference in the diameter distribution of the decayed and sound trees, the former being of relatively greater diameter than the latter.

The stumpage prices of the trees were surveyed by way of an example only.

3. Reliability of the results

The parameter values of the decay formations can hardly be generalized beyond the actual material studied. A feature typical of the decay dimensions seems to be the very great variation which is only to a minor extent explained by e.g. the degree of decay. The fungal species also explained only relatively little of this variation. The degree of decay, in the form used in this study, is probably not particularly reliable. The proportion of decay in stump diameter (Arvidson 1954) or fewer grades of decay would possibly have been better (Norokorpi 1973).

According to the present study, estimation of the decay of standing trees on the basis of external characteristics was not particularly successful. Many earlier results confirm the present finding (Rohmeder 1937, Dimitri 1968). Determination of decay by butt borings was relatively successful but the disadvantage of this method is that decay microbes infect the growing spruce trees through the increment borer holes (Schöpfer 1961, Jaeger 1970).

Spruce decay by diameter classes was much the same as in many earlier studies (Petrini 1944, Björkman et al. 1949, Holmsgaard et al. 1968). The most uncertain, owing to the small number of observations, were the figures for diameter classes 35—39 cm and over 40 cm. Some earlier studies, however, have reported a lower incidence of butt rot in the largest trees (Petrini 1944, Morville 1958), and therefore the results obtained can be equally reliable throughout the stem distribution series. By development and age classes, the decay showed a definite trend, with slight exceptions. Earlier studies (ROHMEDER 1937), in the main, support the present results. The difficulty of determining the forest site type in Åland must be borne in mind when results relating to forest site type and tax class are reviewed. The results obtained support many earlier findings, according to which butt rot shows considerable local variations.

The smaller tapering and greater increment of sound trees is clearly seen in the present study. ARVIDSON (1954) reported exactly the same finding whereas ZYCHA (1967) found no difference between sound and decayed trees on this point. However, it seems obvious that the decay advancing in the roots and trunk must before long affect the physiology of the tree and reduce its growth (cf. ARVIDSON 1954, ISOMÄKI and KALLIO 1974). The Åland material was somewhat small and even qualitatively rather poor for a study of stem form and increment, since it was selected from an extremely heterogeneous population of stands. The increment variation produced by the difference in stand characteristics may have been a contributory factor (cf. KUUSELA and KILKKI 1963). Sufficiently large stand sample plots would have been considerably better for the purpose than the inventory sample plots used. The main purpose of the study, however, was to investigate the amount and incidence of decay, and the study material was well suited for this purpose.

The analysis of the decay-induced changes in timber assortments seems to have been successful. The results were parallel to those of many earlier studies (TIKKA 1938, PETRINI 1944, ARVIDSON 1954, RATTSJÖ and RENNERFELT 1955, HOLMSGAARD et. al. 1968). Owing to different quality and measurement standards the results of the studies of this type are not usually fully comparable. The Åland material was relatively small for the purpose, which also has been the case in most earlier studies. An advantage that can be attributed to the Åland study is perhaps that the result of the measurements for cutting into lengths could be checked by means of the total volume of the stem involved, since timber volume was also calculated as true solid cubic metres including bark. It must be borne in mind that the effect of the decay was considered with due application of certain minimum measurement and quality standards whose modifications might considerably affect the final results of the study. On the whole, minimum measurements and quality standards vary considerably depending on the demand- supply ratio for timber.

The effect of butt rot on the stumpage price was only illustrated by examples. Since the material was small and stumpage prices vary annually and regionally, detailed studies were not found justifiable (cf. LAASASENAHO and SEVOLA 1971). Fixed unit prices resulted in an underestimation of the loss. However, the results obtained apparently were approximately correct. Several earlier butt rot studies support the present results (cf. PETRINI 1944, RATTSJÖ and RENNERFELT 1955, HOLMSGAARD et al. 1968, KALLIO 1972).

VI SUMMARY

In the autumn of 1972, all spruce trees of a minimum breast height diameter of 7 cm, total number 295, on the 59 Sixth National Forest Inventory sample plots on the mainland of Åland were examined. The soundness of the standing sample trees was estimated by their external characteristics and by borings. The trees were then felled and measured after felling. Decay was determined in connection with the cutting into lengths, and its type and dimensions were also studied. Increment borer chips at butt and at breast height were taken as aseptically as possible from all sample trees. These chips were examined in the laboratory to ascertain the incidence of the *Fomes annosus* fungus. Discs were cut from the butt of the decayed trees and from the highest point of the decay and were cultured in the laboratory, in the attempt to identify the causative factors. The decayed trees were classified into those affected by butt rot and those decayed through wound infection.

Tree volumes were calculated by means of the equations of the Sixth National Forest Inventory to obtain the volume at the time of measurement, and by means of increment measurements to obtain the volumes of 5 and 10 years earlier.

Once felled, the trees were cut into timber assortments according to the quality standards applied in practice. True solid cubic metres including bark were used in measuring. Decay formations — discoloured wood was considered decayed — were cubed as cones. Four degrees of decay were applied. The wood of the first degree was slightly discoloured, and that of the fourth degree was very soft, it had lost its structure, and the tree was perhaps hollow.

Trees with decay caused by wound infection numbered 12. On average, the decay was 4.0 m long and constituted 12 per cent of the stem volume. Eighty-nine trees had butt rot, i.e 30 per cent of the trees studied. The mean diameter of butt rot in the felling section was 19 cm, height 4.2 m and volume 84 cu.dm. Its average proportion of the stem volume was 16 per cent. The variety of the parameters measured was very great. When the degree of decay increased, the dimensions of the decay also increased. *Fomes annosus*, on average, produced a distinctly more extensive decay than the other agents.

Decay could not be predicted on the basis of the external characteristics of growing trees, whereas boring at the butt revealed the decay in 82 per cent of the decayed trees. In 91 per cent of all the trees, the degree of soundness was correctly estimated by butt boring. Boring at breast height was found to be unreliable.

Comparing the present material with the results of the Sixth National Forest Inventory, it can be estimated that 23 per cent of the Åland spruce trees exceeding 7 cm in diameter are affected with butt rot. The large-diameter and aged trees were relatively the most decayed. The proportion of decayed trees in the volume was 31 per cent, which is much higher than their proportion of the stem number. The mean proportion of decayed wood material was 5 per cent of the volume including bark. The richest and the poorest forest lands were more infected than the average sites. No consistent features by tax classes could be distinguished in the decay; tax class IB had the highest decay percentage (27 per cent of the number of stems). By development classes, butt rot increased towards the more mature stands. The decay percentage of forests ready for regeneration was 31 per cent of the number of stems.

The timber obtained from the sample trees totalled c. 85 solid cu.m. Timber trees totalled 131, but subtraction of the decayed trees leaves a total of 112. Decay reduced the number of saw timber trees by 14.5 per cent. Similarly, decay reduced the volume of saw timber by 21.5 and sulphite pulpwood volume by 12 per cent, whereas it increased the sulphate pulpwood volume from 1 to 10 per cent. The total reduction in the proportion of usable wood was 6.3 per cent. In tax classes I A and I B decay

reduced the proportion of saw timber by 23 and 25 per cent, respectively, and the volume of total timber by 6.5 and 7.8 per cent, respectively.

The effect of decay on stumpage price was studied by means of fixed relative unit prices. The stumpage price fell on average by 10.3 per cent. In the largest diameter classes the price reduction was most pronounced. The relative value of the tree was estimated by means of regression model Y = f (lnD, d-d6, D6), with a coefficient of determination of 0.728 for sound trees. For the price variations of decayed trees the coefficient of determination was only c. 20 per cent.

The volume increment percentages of the sound and decayed trees differed distinctly. As the degree of decay increased the percentages decreased. The increment percentages of the decayed trees, especially in young trees, were lower than those of sound trees.

The most common causative factor for butt rot was *F. annosus*, which was identified from cultured discs in 46 per cent of the number of decayed trees. *Armillaria mellea* was identified from 16 per cent of the butt discs of decayed trees. Bacteria were isolated from 50 per cent of the butt discs. The third most common decay fungus was *Coryne cylichnium.*

The small size of the material reduces the reliability of the results and the possibility of their generalization. On the other hand, the relascope plot technique and the use of the tree sample plots of the inventory improve the informative value of the results, for the results obtained from the sample tree plots of the national forest inventory can probably be taken as regression estimates for results obtainable from all the sample plots of the inventory.

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Seloste:

AHVENANMAAN KUUSIEN LAHOVIKAISUUS

Nyt esiteltävän tutkimuksen tarkoituksena oli selvittää kuusen tyvilahon yleisyys Ahvenanmaalla. Sen lisäksi tutkittiin lahon tunnuksia, lahottajamikrobistoa, pystypuiden lahoisuuden arvioimista ja lahon seurausvaikutuksia.

Tutkimusaineisto käsitti valtakunnan metsien VI inventoinnin kuutiointi- ja kasvukoealojen kuuset, jotka olivat rinnankorkeudelta 7 cm tai sitä paksumpia. Ahvenanmaan maakuntahallituksen toimesta lohkoverkosto oli tihennetty nelinkertaiseksi, joten vastinpisteiden etäisyys oli 4 km. Koepuiden runkolukusarja oli likimain normaali. Tukkipuita oli aineistossa 131 kpl (44 %), kun lahoa ei otettu huomioon. Aritmeettinen keskiläpimitta oli aineistossa 21 cm, mutta keskipituus vain 15 m. Tämä lienee osoitus Ahvenanmaan kuusien huonosta runkomuodosta. Aineistoa on pidettävä lukumääräisesti suppeana, mutta käytetty otantamenetelmä lisännee aineiston käyttökelpoisuutta merkittävästi.

Kaikki koepuut kaadettiin. Ennen kaatamista koepuista suoritettiin joukko mittauksia sekä arvioitiin puiden terveydentila ulkoisten tuntomerkkien perusteella. Samoin suoritettiin mahdollisimman aseptiset kairaukset kannon- ja rinnankorkeudelta. Kaatamisen jälkeen koepuut mitattiin ja apteerattiin. Puu tulkittiin lahoksi, jos lahovika vaikutti apteeraukseen. Lahot puut apteerattiin kahdesti, ensin ottamatta lahoa huomioon (apteeraus terveenä) ja sitten laatuvaatimusten mukaan (apteeraus lahona). Puutavaralajien laatuvaatimukset olivat samat, joita metsäteollisuus Ahvenanmaalla käytti.

Lahoista koepuista sahattiin näytekiekot kannon korkeudelta ja paljain silmin havaittavissa olleen lahon ylimmästä kohdasta. Lahon ylin kohta määrättiin puuta katkoen mahdollisimman tarkasti. Näytekiekoista viljeltiin ja tunnistettiin lahottajamikrobit. Maannousemasieni tunnistettiin kiekoista myös stereomikroskoopilla.

Kantoarvojen muutoksia tutkittiin käyttäen suhteellisia kiinteitä kuutioyksikköarvoja: tukkipuu 100, sulfiittipuu 59 ja sulfaattipuu 53. Suhteelliset arvot laskettiin hakkuuvuosina 1970/71 ja 1971/72 Helsingin, Lounais-Suomen ja Satakunnan piirimetsälautakunnan alueella käytetyistä keskimääräisistä kuutiohinnoista.

Tutkituista puista oli 31 % tyvilahoisia. Tyvilahon läpimitta kaatoleikkauksessa oli keskimäärin 19 cm, korkeus 4.2 m ja tilavuus 84 dm^3. Osuus rungon tilavuudesta oli keskimäärin 16 %. Mitattujen tunnusten hajonta oli voimakasta. Haavasta lahoutuneiden puiden osuus runkoluvusta oli keskimäärin 2.6 %. Haavasta alkaneen lahon pituus oli keskimäärin 4.0 m. Lahon alapään korkeus maasta oli keskimäärin 2.9 m ja yläpään 6.9 m. Haavalahon tilavuuden keskiarvo oli 19 dm^3. Haavalahon osuus rungon tilavuudesta oli keskimäärin 12 %. Lahoasteen noustessa suurenivat myös lahon ulottuvuudet. Vertaamalla Ahvenanmaan aineistoa valtakunnan metsien VI inventoinnin tuloksiin voidaan arvioida 23 % Ahvenanmaan yli 7 cm:n kuusista olevan tyvilahoja. Suuriläpimittaiset ja iäkkäät puut olivat suhteellisesti lahoimpia. Lahojen puiden osuus kuutiomäärästä oli 31 % eli paljon suurempi kuin niiden osuus runkoluvusta. Lahon puuaineen osuus oli keskimäärin 5 % kuorellisesta kuutiomäärästä. Parhaimpien ja huonoimpien kasvupaikkojen kuuset olivat lahoimpia. Selvää riippuvuutta lahovikaisuuden ja boniteetin kesken ei voitu osoittaa. Ahvenanmaalta saadut metsätyypittäiset ja veroluokittaiset lahosadannekset vahvistavat sitä käsitystä, että tyvilahoisuus vaihtelee suuresti.

Kehitysluokittain tyvilahoisuus kasvoi varttuneempiin metsiköihin siirryttäessä. Uudistuskypsyyden saavuttaneista metsiköistä oli lähes kolmannes tyvilahoisia. Ikäluokittaiset lahosadannekset kasvoivat yleensä iän myötä ikäluokkaan 81—100 v. saakka.

Kasvavien puiden ulkoisten tunnuksien avulla ei lahoisuutta pystytty ennustamaan. Sen sijaan tyvestä suoritetulla kairauksella kyettiin paljastamaan 82 % lahopuista. Rinnankorkeudelta tehty kairaus todettiin epäluotettavaksi.

Fomes annosus oli tavallisin lahoista tunnistettu sieni. Se kasvoi useammin kovassa kuin pehmeässä puuaineksessa. Aineisto jaettiin kahteen ryhmään: lahot, joissa *F. annosus* esiintyi, ja lahot, joissa sitä ei esiintynyt. Lahotunnukset olivat poikkeuksetta suuremmat maannousemaryhmässä. Lahon tilavuus oli merkittävästi, muut tunnukset erittäin merkittävästi suuremmat kuin toisessa ryhmässä. Maannousemalahon läpimitta kannossa oli 1.5-

kertainen, korkeus lähes kaksinkertainen, tilavuus 2.2-kertainen, lahon osuus rungosta 2.4-kertainen toiseen ryhmään verrattuna. Maannousemalahon suuri korkeus ja osuus rungon tilavuudesta kuvannevat maannousemasienen tehokasta lahottamiskykyä.

Tukkipuiden määrä väheni lahon vuoksi 14.5 % ja sulfiittipuiden 3.1 %. Tukkipuun osuus väheni lahon vuoksi 21.5 %. Eniten se väheni läpimittaluokassa 35–39 cm. Väheneminen oli n. 27 %. Sulfiittipuun määrä väheni keskimäärin 12 %. Koko puutavarasaanto väheni 6.3 %. Veroluokassa I B menetettiin eniten tukkipuuta lahon takia (25 %).

Puuston kantoarvo väheni lahon vuoksi keskimäärin 10.3 %. Kantoarvon suhteellinen aleneminen suureni metsätyypin parantuessa. Uudistuskypsyyttä lähentelevissä metsiköissä kantoarvo aleni eniten.

Runkojen kuoreton kapeneminen oli suurempi lahoilla kuin terveillä puilla. Kasvutunnukset olivat terveillä puilla suurempia kuin lahoilla. Lahoasteen kasvaessa kasvusadannes pieneni.

F. annosus tunnistettiin kannon korkeudelta 46 %:sta lahoja puita. *Armillaria mellea* tunnistettiin 16 %:sta lahojen puiden tyvikiekkoja. Bakteereita eristettiin 50 %:sta tyvikiekkoja. Kolmanneksi tavallisin lahottajasieni on *Coryne cylichnium*.

KALLIO, TAUNO & TAMMINEN, PEKKA O.D.C. 443.3: 174.7 *Picea abies*

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Thirty per cent of the number of trees examined was affected by butt rot, c. 3 per cent by wound decay. A comparison of the results with those of the Sixth National Forest Inventory justifies the estimate that in Åland 23 per cent of the stem number of spruce trees exceeding 7 cm in diameter at 1.3 m had butt rot. The proportion of decayed trees in the cubic volume was 31 per cent. Decayed wood material accounted for 5 per cent of the volume including bark. Butt rot increased towards the mature stands. The reduction in the number of timber trees due to decay was 14.5 per cent, in their volume 21.5 per cent, and in the volume of sulphite pulpwood 12 per cent. The share of sulphate pulpwood increased from 1 to 10 per cent. The total reduction in usable wood was 6.3 per cent. The stumpage price of the trees fell by 10.3 per cent. As the degree of decay increased, the increment percentage of the trees decreased. The most common cause of butt rot was *Fomes annosus*, found in 46 per cent of the number of decayed trees. *Armillaria mellea* was found in 16 per cent. Bacteria were found in 50 per cent of the decayed trees.

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