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BUTT-ROT IN NORWAY SPRUCE IN SOUTHERN FINLAND

PEKKA TAMMINEN

SELOSTE

KUUSEN TYVILAHOISUUS ETELÄ-SUOMESSA

HELSINKI 1985

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Cover (front & back): Scots pine (*Pinus sylvestris* L.) is the most important tree species in Finland. Pine dominated forest covers about 60 per cent of forest land and its total volume is nearly 700 mil. cu.m. The front cover shows a young Scots pine and the back cover a 30-metre-high, 140-year-old tree.

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The abundance of butt-rot was estimated during the period 1974—82 with the help of 146 spruce-dominated clear-cutting stands and spruce sample trees from the 7th National Forest Inventory. The clear-cutting stands were situated in seven forestry board districts in south-west Finland. The sample trees from the NFI represented the whole of southern Finland. Butt-rot defectiveness was determined on spruce stumps in clear-cutting stands and on NFI sample trees by means of boring. Stand characteristics of the clear-cutting areas were converted from stump measurements with the help of the respective equations.

The volume proportion of the most common butt-rot agent, *Heterobasidion annosum,* out of the total rot volume was 90 % and 47 % in the felled sample trees and the NFI sample trees respectively. Butt-rot was most abundant in the southern parts of the study area, on sites which were close to sea level, fertile, non-paludified and covered with old spruce stands. The relative rot frequency weighted by the stem volume was 18,5 % in the clear-cutting material and 8,6 % in the NFI material. In the clear-cutting stands the loss in saw-timber yield due to butt-rot was 8,5 % and the loss in stumpage value at the same time 2,9. . .4,8 % depending on the price relationships of the timber assortments.

Spruces affected by butt-rot had, on the average, poorer growth and stem form than healthy ones. Identifying butt-rot trees according to these characteristics was not successful, apart from those spruces severely affected by rot. Taking increment cores at stump height appeared to be a rather reliable method of detecting rot defects: the proportion of butt-rot cases detected was 80 %, these cases accounting for almost 100 % of the total rot volume.

Kuusen tyvilahon määrää arvioitiin vuosina 1974—82 146 kuusivaltaisen avohakkuuleimikon ja valtakunnan metsien 7. inventoinnin kuusikoepuiden avulla. Leimikoita tutkittiin Helsingin, Lounais-Suomen, Satakunnan, Uudenmaan-Hämeen, Pirkka-Hämeen, Itä-Hämeen ja Vaasan piirimetsälautakuntien alueelta. Inventoinnin koepuut edustivat koko Etelä-Suomea. Tyvilahoisuus määritettiin leimikoissa kantojen perusteella ja VMI-koepuiden osalta kairauksin. Leimikoiden puustotunnukset arvioitiin kantotietojen ja laadittujen yhtälöiden avulla.

Yleisimmän lahottajan, juurikäävän, osuus lahojen kokonaistilavuudesta oli kaatokoepuuaineistossa 90 % ja VMI-koepuuaineistossa 47 %. Tyvilaho oli yleisintä tutkimusalueen eteläosissa, lähellä merenpinnan tasoa, viljavien ja soistumattomien kasvupaikkojen vanhoissa kuusikoissa. Kuusten runkotilavuudella painotettu tyvilahofrekvenssi oli avohakkuuaineistossa 18,5 % ja VMI-aineistossa 8,6 %. Leimikkoaineistossa tyvilaho alensi sahapuun saantoa keskimäärin 8,5 %. Samalla kuusten kantoarvo aleni 2,9. . .4,8 % puutavaralajien hintasuhteista riippuen. Tyvilahokuuset olivat kasvaneet huonommin kuin terveet kuuset, ja lahopuilla oli myös huonompi runkomuoto. Lahojen runkojen yksilöinti onnistui näiden ominaisuuksien perusteella vain lahoimmasta päästä. Sen sijaan kairaamalla kuuset tyveltä pystyttiin löytämään 80 % lahojen lukumäärästä. Nämä lahot edustivat lähes 100 % lahon puuaineksen kokonaistilavuudesta.

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ABBREVIATIONS

tree:

d_s = diameter at stump height, cm
d = diameter at breast height (1,3 m above ground level), cm
d_6 = diameter at 6 m, cm
h = height, m
g = basal area at 1,3 m, cm^2
v = volume, dm^3

t = age, a
id = diameter increment at 1,3 m, mm/5 a
id_{1-10} = diameter increment at 1,3 m, 1—10 yrs ago, mm/10 a
id_{11-20} = diameter increment at 1,3 m, 11—20 yrs ago, mm/10 a
id_6 = diameter increment at 6 m, mm/5 a
pg = basal area increment percentage at 1,3 m, %/a
pg_{1-10}, pg_{11-20} = as for id's above
pg_6 = basal area increment percentage at 6 m, %/a
pv = volume increment percentage, %/a

butt-rot column:

DC = maximum stage of decay at stump height: 0 = stained or incipiently-decayed, 1 = soft decay or cavity
DD = decay diameter at stump height, cm
$DD_{1,3}$ = decay diameter at 1,3 m, cm
DH = height of the butt-rot above stump level, dm
DV = volume of the butt-rot above stump level, dm^3

sample plot or clear-cutting area:

D_g = mean diameter weighted by basal area (g), cm
G = basal area, m^2/ha
H = mean height, m
T = mean age, a
BON1 = if site type is OMaT, FT or OMT then 1, else 0 (site types, see Cajander 1949)
TAX1 = if tax class is IA then 1, else 0
TAX2 = if tax class is II—IV then 1, else 0 (Tax class is a productivity class determined by site type (see Cajander 1949), stoniness and paludification or drainage. Tax classes are called in the descending order of productivity IA, IB, II, III and IV)
H_{100} = site index, m/100 a
STONES = stoniness, 0 = few stones, 1 = abundant
PALUD = paludified, 0/1 or proportion of the plots paludified
LAT = latitude, 10 km (Finnish general map coordinates)
ELEV = elevation, 10 m
SLOPE = steepness of the slope, %
TEMP = effective cumulative temperature, d.d.
NP = relative frequency of decayed spruces, %
VP = relative frequency of decayed spruces weighted by stem volume = proportion of butt-rot spruces of the volume of all the spruces, % (referred as 'butt-rot frequency')
DP = $100\Sigma DD/\Sigma d_s$, relative decay diameter at stump height weighted by stump diameter, %

Other symbols:

SAW = proportion of saw-timber, %
SAWLOSS = loss in the saw-timber yield due to butt-rot, %
PULP = proportion of decay-affected pulpwood, %
VAL1 = relative stumpage value with relative prices: saw-timber = 100/m^3, pulpwood (sound) = 40/m^3
VAL2 = relative stumpage value with relative prices: saw-timber = 100/m^3, pulpwood (sound) = 60/m^3
VALLOSS1 = loss in stumpage value with relative prices: saw-timber = 100, sound pulpwood = 40, decayed pulpwood = 36, %
VALLOSS2 = loss in stumpage value with relative prices: saw-timber = 100, sound pulpwood = 60, decayed pulpwood = 60, %
NFI = National Forest Inventory, NFI-6: 1971—76, NFI-7: 1977—84
VMI = Valtakunnan metsien inventointi, VMI-6: 1971—76, VMI-7: 1977—84
s_f = residual standard deviation
$s_{est} = \sqrt{\dfrac{\Sigma(100(\hat{y}_i - y_i)/\hat{y}_i)^2}{n-1}}$, relative standard error of the estimate, %
FBD = forestry board district

PREFACE

The idea for the present study was suggested by Professor Tauno Kallio in 1974. The Foundation for the Research of Natural Resources in Finland provided financial support for this work during 1974—79. The Departments of Forest Pathology, Forest Inventory and Soil Science, all in the Finnish Forest Research Institute, also contributed to the study in many ways.

Mr. Matti Kaivos and my wife Marjatta Tamminen assisted in the collection of the study material. Mrs. Anna-Maija Hallaksela, Lic. of For., identified the microbes for her own study, already published, and kindly let the results be used in this study. Dr. Bruno Lönnberg, Keskuslaboratorio Oy (the Finnish Pulp and Paper Research Institute) analyzed the decayed wood samples. Professors Tauno Kallio, Pekka Kilkki, Aarne Nyyssönen and Simo Poso, Dr. Timo Kurkela and Lic. Anna-Maija Hallaksela read the manuscript and made valuable comments. The manuscript was translated into English by Mr. John Derome, and the final manuscript was completed with the help of the personnel of the Department of Soil Science, the Finnish Forest Research Institute.

I wish to express my thanks to all the persons and institutions mentioned above.

Pekka Tamminen

1. INTRODUCTION

11. The concept of butt-rot

Butt-rot refers to rot which spreads up the stem of trees from the roots. In Norway spruce *(Picea abies* (L.) Karst.) the rot mainly spreads in the inner parts of both the stem and the roots, i.e. in the dead heartwood. Thus the term heart-rot rather well describes real butt-rot. Wound decay refers to rot which has usually originated from injuries to the above-ground parts of the tree. This type of rot also usually spreads in the heartwood. In addition to defining the point at which the rot has commenced, or the direction in which it has spread, there are also mycological grounds for distinguishing butt-rot and wound decay from each other: many microbes are common to both types of rot, but these two forms of rot differ markedly from each other as regards the most important causal agent. In addition, butt-rot has been found to occur more regularly as regards the type of site or age of the trees than wound decay (e.g. Schlenker 1976, Norokorpi 1979). This is natural when we consider that wound decay mainly occurs in commercial forests as a result of harvesting operations. Different harvesting methods and seasonal variation easily obscure the effects of site and tree stand on the abundance of injuries and wound decay in such cases (cf. Kärkkäinen 1973, Kyttälä 1980). The occurrence of butt-rot, on the other hand, is more closely related to the soil, the properties of which remain relatively stable and can be estimated at the time when the decay inventory is carried out. The conditions prevailing at the ground surface and below it are more stable and generally more favourable for the rot organisms than those above the ground.

When iventorying the abundance of butt-rot, it would be useful to be able to distinguish butt-rot caused by human activities (anthropogenic rot) from so-called natural rots. Man's activities produce variation which is difficult to control when studying e.g. the significance of climate, site or stand characteristics on the occurrence of butt-rot. Since it is not possible in practice to distinguish anthropogenic butt-rot from other types of rot, the former type is included as an essential but disturbing component in the group of butt-rots.

It is often difficult, when examining stumps, to decide whether a case of rot is wound decay or butt-rot (see Fig. 4). This being the case, the term "butt-rot" has to be expanded to a vague term "decay on the stump surface". Some cases of real butt-rot may, on the other hand, not yet have reached stump height (Basham 1973), and are thus not visible although they may already affect the growth of the tree or its ability to withstand storms in almost the same way as rot which is in fact visible in the stump.

12. Susceptibility of spruce to butt-rot

Butt-rot occurs on spruce throughout its range of distribution. Rot damage appears to be most common in old spruce stands in an almost natural state growing at the edge of spruce's distribution range in the north (Tikka 1934, Norokorpi 1979), and in spruce plantations in the temperate, deciduous vegetation zone (Rohmeder 1937, Low and Gladman 1960, Holmsgaard et al. 1968). The geographical differences in the distribution of butt-rot may be partly explained by the properties of the tree stand, and partly by the distribution of the rot microbes: spruce stands in the north have a high rot frequency because of their greater age (Norokorpi 1979), and in the south the main reason is probably the abundance of aggressive *Heterobasidion annosum* (Fr.) Bref. (Zycha 1976). Although butt-rot probably occurs throughout the whole of Finland, it is known to be especially common along the coasts of southern Finland and in the old spruce stands of the far north (Kangas 1952, Kallio 1961, Kallio and Tamminen 1974, Norokorpi 1979).

Earlier site usage can affect the abundance of butt-rot. According to Werner (1971, 1973), areas previously used as fields or for grazing are especially susceptible to rot. There are many references to this in the literature (cf. Johansson 1980), but very little actual data. It has been suggested that the structure, pH, nutrient status and microflora of old agricultural land would be unfavourable for spruce and favourable for the root pathogens (Evers 1973, Haas 1979). No general observations have been made in Finland about the greater abundance of rot in spruce stands planted on abandoned fields. Growing more than one generation of spruce on the same site has also been found to increase the incidence of butt-rott (Holmsgaard et al. 1961), although contradictory experiences have been reported (Werner 1971). Kallio (1961) compared his map of the distribution of butt-rot in Finland with Blomqvist's (a silviculturist) travel reports from 1867—1869. Kallio found "that those districts which a hundred years ago were the most spruce-dominated in our country, are nowadays the ones most affected by *H. annosum*" (see also Norokorpi 1979).

Thinnings carried out in a stand are important from the point of view of the incidence of rot (Kärkkäinen 1973). Many of the remaining trees are damaged (see Kyttälä 1980), and in many cases the rot defects originate from these wounds (Nilsson and Hyppel 1968, Isomäki and Kallio 1974). In addition, the most important causal agent of butt-rot, *H. annosum,* has been found to spread, via the freshly-cut surface of stumps, to the roots of felled trees and from there via the root contacts to healthy trees (Molin 1957, Dimitri 1963, Kallio 1971a, b).

The significance of site properties as regards the abundance of butt-rot has been studied especially in Germany (Zycha 1976, Schlenker and Mühlhäusser 1978) and in Denmark (Holmsgaard et al. 1968), where the conditions are however rather different from those in Finland. In addition, the type of site classification system has varied in different studies. Of the physical properties of the soil, the particle size distribution has been found to be correlated relatively rarely with the frequency of butt-rot (Paludan 1959, Enerstvedt and Venn 1979). On the other hand, many researchers have found correlation between soil moisture and the incidence of butt-rot. In Falck's (1930) material, butt-rot was least common on both wet and dry soils, while in Rohmeder's (1937) material it was quite the opposite. In the Nordic Countries Rennerfelt (1946), Kangas (1952), Enerstvedt and Venn (1979) and Huse (1983), and in Canada Basham (1973), have shown that spruces growing on moist upland sites, and especially on peatlands, are more healthy than those on dry upland sites. Heikinheimo (1920) and Saarnijoki (1939) have put forward quite the opposite claims. Data concerning topographical aspects have been published which support the notion that trees growing on slopes are more susceptible to rot (Falck 1930, Huse 1983). The butt-rot frequency has not been found to correlate with the shallowness of the soil (Huse 1983), apart from a few exceptions (Werner 1973). On the other hand, slight correlation has been found with respect to the soil type (Rehfuess 1969, Huse 1983).

Of the chemical properties of the soil, the pH and the nitrogen and calcium content of the soil have been found to be positively correlated with the butt-rot frequency (Laatsch et al. 1968, Rehfuess 1969, Evers 1973). The nutrient parameters mentioned here are also known to be indicators of the site productivity (e.g. Ilvessalo 1925, Viro 1961, Urvas and Erviö 1974). Holmsgaard et al. (1968) found a slight correlation between the butt-rot frequency and the potassium, magnesium and manganese content in the humus. The soil in the stands suffering from butt-rot presented by Salonen and Päivinen (1974) contained abundant nutrients apart from boron. German researchers (Laatsch et al. 1968) have put forward the hypothesis that spruce stands are especially susceptible if the roots grow near to the surface and the ground dries out periodically, if the top soil contains much calcium, if water containing bicarbonate ions is present in the soil near to the roots, or if the soil is rich in nitrogen — e.g. abandoned farmland — or especially if there is a combination of the above factors. According to Schlenker and Mülhäusser (1978, p. 63), "all the observations indicate that the site conditions and stand history have an indirect effect on the butt-rot frequency by affecting the composition of the fungal and bacterial populations". Furthermore, they found that there is a susceptibility to butt-rot under all conditions in South-West Germany if the pH is high, while the other site factors — shallow soil, stoniness, susceptibility to drought, periodical wetness or dryness, poor aeration in the soil etc. — become decisive factors only in the case of certain combinations. The hypotheses presented here are rather general, and are only partly applicable in Finland.

Results supporting almost all possible combinations have been presented with respect to the dependence between site productivity and butt-rot frequency. The materials of e.g. Rohmeder (1937), Tikka (1938) and Kangas (1952), indicate negative correlation, those of e.g. Falck (1930), Basham (1973) and Enerstvedt and Venn (1979) positive correlation, while those of e.g. Zycha (1967), Kallio and Tamminen (1974) and Huse (1983) show curvilinear correlation or none at all. Although there would be no generalized correlation between site productivity and the butt-rot frequency, it has been found that fast-growing wood of generally lower density rots much quicker than slow-growing, dense wood (Curtois 1970). Isomäki and Kallio (1974) found that site fertility and nitrogen fertilization promoted the spread of logging-wound decay. The results of Basham (1973) and Laiho (1983) also support the theory that there is positive correlation between tree growth and the rate of spread of decay. It seems that although the site fertility would not affect the type or incidence of rot infection, the amount of wood that will become affected within a certain length of time is greatest on the most fertile sites. In general, the amount of rot found in trees is at least partly a function of the growth rate of the trees. In practice, however, it is difficult to verify the above connection since a number of rot agents may be involved, their rotting capacity varies considerably and, in addition, it is usually impossible to take the time factor into account.

The abundance of butt-rot is also considered to be dependent on the proportion of different tree species in a stand: the greater the admixture of different tree species, the less butt-rot there is (cf. Johansson 1980). The observations of Falck (1930) and Werner (1971) (cf. also Kangas 1952), however, even support quite the opposite conclusion. It has been suggested that the better health of mixed stands is due to the fact that the root contacts between the spruce trees which spread the rot are less common, to the favourable depth distribution of the roots of spruce trees, and to the diverse microflora which is antagonistic to *H. annosum* (Rennerfelt 1946).

On the other hand, since the surface layer of the soil in pure spruce stands is usually more acidic than that in mixed stands (Mikola 1965), spruce should be more susceptible to butt-rot in mixed stands than in pure stands (Schlenker 1976). Establishment of a mixed stand on sites where a number of spruce generations have been grown might even increase the incidence of butt-rot. Up till now it has not been possible to find any concrete evidence concerning the effect of the composition or proportion of different trees in a mixed stand on the butt-rot frequency under Finnish conditions, although some indirect evidence has been presented (cf. Kallio 1973).

Of the properties of the tree stand, age has been almost always correlated with the butt-rot frequency (Rohmeder 1937, Holmsgaard et al. 1968, Basham 1973, Kallio and Tamminen 1974). The dependence is usually curvilinear (Werner 1971, 1973, Norokorpi 1979). Among others, Basham (1973, p. 103) mentions that the effect of the site can obscure the effect of age on the butt-rot frequency. One reason for this may be the different age distributions of different sites: the stands on infertile sites are usually older, and on the more fertile ones younger (Gustavsen 1980). German researchers have studied the relationship between stand age and butt-rot frequency by restricting their study to narrow, uniform sites and to stands whose history is known (Rehfuess 1969, 1973, Werner 1971, 1973). In Norokorpi's (1979) study, the dependence of the rot volume and frequency on age was very fixed in Norway spruce stands in northern Finland. The age dependence generally appears to be weaker further to the south (Holmsgaard et al. 1968, Kallio and Tamminen 1974).

It has not been possible to show, with any degree of certainty, a dependence between stand density and the butt-rott frequency (Kangas 1952, Kato 1967). In theory, trees growing in a dense stand might be more resistant to rot owing to the fact that they are slow growing, and the absence of thinnings does not give *H. annosum* the chance to infect the stand, nor root damage to occur. On the other hand, when thinning dense spruce stands a lot of injuries and subsequent decays may be caused (Kärkkäinen 1969, 1973), and infection and reproduction material for rot fungi is produced at the same time (Yde-Andersen 1970, Kallio 1971a, b). The size of the trees in the stand has been found to be positively correlated with the rot frequency (Rohmeder 1937, Kallio and Tamminen 1974, Huse 1983). The dependence with respect to diameter, as is the case with age, is rather loose and usually curvilinear (Basham 1973, Norokorpi 1979), or almost completely lacking (Holmsgaard et al. 1968).

13. The consequences of butt-rot

Arvidson (1954) divided the consequences of butt-rot into primary and secondary ones. The former are the losses in stumpage income caused by the deterioration in the timber assortment distribution, and the latter are the theoretical stumpage income losses calculated on the basis of the poorer stem form and lower level of growth. The causal chain of primary losses can be roughly presented as follows:

> Decay — Properties of the wood (density, strength, chemical composition) — Dimension and quality norms of timber assortments — Yield of timber assortments — Stumpage income

Kärkkäinen (1973) has, for instance, made a rather extensive review of the significance of rot defects for timber and products based on wood. Rot reduces the strength characteristics of wood, the impact bending strength decreasing the fastest. The deterioration in the strength is relatively the greatest at the beginning of the rot process. The effect of mild cases of rot and especially blue stain on the density and the strength is, however, only slight (cf. e.g. Kärkkäinen 1977, Wilcox 1978, Pratt 1979b). Poorer quality pulp with a smaller yield per unit volume is obtained from rot-affected spruce wood. In addition, more chemicals are required in bleaching pulp made from wood affected by rot (see e.g. Björkman et al. 1949, 1964, Henningsson 1964, Lönnberg and Varhimo 1981). According to the Finnish quality norms (Kärkkäinen 1983a), rot is not allowed in sawlogs, not even blue stain, and rot is allowed only in limited amounts in spruce pulpwood. In practice, however, the norms may be less stringent.

Rot has been found to reduce the amount of merchantable wood (e.g. Falck 1930, Tikka 1938), deteriorate the timber assortment distribution (Petrini 1944, Arvidson 1954) and to reduce the quality and value of sawn timber (Hakkila and Laiho 1967, Pratt 1979c). Since sawlogs and sound pulpwood are lost, or they are scaled as rot-affected pulpwood of lower value, the stumpage value of the spruce stand is reduced. However, it is usually very difficult to compare the results of different studies on the timber yield and value, owing to the large variation in the quality norms, minimum dimensions and price ratios of timber assortments. However, a few of the studies carried out in Finland are worth mentioning.

The significance of rot defects in spruce stands in northern Finland has been studied by Tikka (1938, 1947) and more recently by Hyppönen and Norokorpi (1979). In the latter extensive study, rot reduced the proportion of spruce saw timber by 41 %, the value of spruce stems falling by 18 %. The effects of butt-rot have been studied in southern Finland by, e.g. Salo (1954), Kallio (1972), Kallio and Tamminen (1974), Pasanen (1974), Tuimala (1979) and Örnmark (1979). In these studies the amount of sawtimber fell by 2,5. . .30 % as a result of rot, and the value of the tree stand by 1. . .30 %.

As far as the secondary consequences of butt-rot are concerned, it appears that advanced butt-rot reduces the growth of spruce (Henriksen and Jörgensen 1952, Arvidson 1954, Kallio and Tamminen 1974). This is also the case with wounds and the decays that develop from wounds (Isomäki and Kallio 1974, Kardell 1978). The stem form may also deteriorate as a consequence of rot, i.e. radial growth is concentrated more in the butt part of a tree affected by rot than a healthy one (Arvidson 1954, Kallio and Tamminen 1974). The growth reduction in trees affected by rot is presumably due to the destruction of the roots (Bradford et al. 1978). On the other hand, the reason why radial growth is concentrated in the butt section of butt-rot trees has still not been elucidated. Increasing the growing space of the tree, e.g. by thinning, usually shifts the point of maximum growth in the stem down towards the butt (Nyyssönen

1952, Sirén 1952, Vuokila 1965). In some cases fertilization can have a similar effect (Saramäki 1980). The deterioration in the stem form of trees affected by rot may be at least partly connected with the increase in the growing space and the weakening of the butt of the tree caused by rot. Butt-rot does not directly kill spruce trees, but increases the incidence of windthrow, which in turn increases the growing space of the remaining trees. As butt-rot tends to affect trees in groups (Zycha 1967, Kurkela et al. 1978, Thies 1983), the growing space in the vicinity of butt-rot trees may be greater than that around healthy ones. On the other hand, the strengthening of the butt part of the stem already weakened by rot, and subsequent deterioration in the stem form, would be in agreement with the mechanical stem form theory presented by e.g. Ylinen (1952). There may, however, be other explanations for this phenomenon (see Larson 1963).

In addition to the points discussed above, the consequences of rot which are difficult to estimate in monetary terms include the increase in storm damage, the problems involved in managing infected stands, the need to shorten the rotation period of spruce stands and the additional harvesting costs caused by rot.

The magnitude of storm damage has been found to depend, among other things, on the butt-rot frequency: Persson (1975) has shown that windthrow increases as the rot frequency rises. He has presented a cause-effect chain, partly based on Hintikka's (1972) study: the effect of wind movements of the roots — root damage and death of part of the root system — butt-rot — windthrow (see also Bazzigher and Schmid 1969). The high butt-rot frequency along the coasts of Finland (Kallio 1961, Kallio and Tamminen 1974, Örnmark 1979) could be explained by the above theory.

Measures recommended for curing spruce stands infected by butt-rot include clear-cutting, prescribed burning and a change of tree species. There are some tentative results concerning the effectiveness of measures designed to decrease rot or fungal damage (e.g. Kallio 1965). In any case, the most common curative measure has been the clear-cutting of spruce stands affected by butt-rot, followed by planting with pine, even though the most important butt-rot fungus, *H. annosum,* may also kill pine seedlings (Laine 1976, Jokinen and Tamminen 1979). Treating the freshly-cut surface of the stumps of spruces, exposed during the thinning of young spruce stands in southern Finland, with compounds which inhibit infection by *H. annosum* might also become necessary (Kallio 1971b).

Already at the beginning of the 20th century, Wagner considered that butt-rot was an important factor affecting the rotation period of spruce (Tikka 1938). Arvidson (1954) also estimated that butt-rot drastically reduces the economic viability of growing spruce. However, no general results have yet been presented which could be applied to Finnish conditions.

In addition to the consequences of butt-rot mentioned above, butt-rot also increases the harvesting costs. For instance, decayed bolts have to be remeasured after cuttings are made in marked stands which have been measured beforehand. The costs of carrying out the bucking, piling and transportation of decayed bolts separately are difficult to estimate.

14. Methods of inventorying rot defects

Most of the material used in butt-rot studies has been collected by judgement sampling. The quality of the material has varied from large, representative materials (e.g. Holmsgaard et al. 1968, Enerstvedt and Venn 1979) to quite small ones, so-called typical cases (e.g. Saarnijoki 1939, Petrini 1944, Kallio 1972). On the other hand, probability sampling (e.g. Liedes and Manninen 1974) has been used to pick the material for a few rot studies only, the largest of which appear to be the materials of the Swedish and Norwegian national forest inventories (Bengtsson 1975, Huse 1983). Corresponding materials have been studied in Finland in great detail, although only in restricted areas (Kallio and Tamminen 1974, Örnmark 1979).

The materials used in rot studies have in many cases been small, and the sample size has not been determined using statistical principles. However, Norokorpi (1979) has estimated the number of sample plots needed per study area in a pilot study. The optimum size of the sampling unit, e.g. a sample plot, has not been treated in rot studies at all (cf. Nyyssönen et al. 1967).

The most unreliable yet quickest and cheapest of the material collection methods used in rot studies, are questionnaires and the use of ready-prepared cutting statistics. Decay survey methods based on field observations are usually more accurate but expensive. The last-mentioned methods utilize site or stand parameters, or the external appearance or internal characteristics of the trees. Some of the methods are listed in the following:

- Site or stand parameters: history, soil moisture, windthrows, fruiting bodies, age (e.g. Laine 1976, Arlauskas and Tyabera 1979)
- External appearance of the trees: wounds, scars, branch swellings, resin flow, sparse crown (e.g. Hornibrook 1950, Aho 1966, 1971, Kallio and Tamminen 1974)
- Internal characteristics of the trees:
  - Felling sample trees (e.g. Tikka 1934, Basham 1973, Norokorpi 1979)
  - Increment cores (e.g. Rennerfelt 1946, Dimitri 1968, Kallio and Tamminen 1974, Lachance 1979, Nilsen 1980)
  - Stump estimation (e.g. Kangas 1952, Bengtsson 1975, Enerstvedt and Venn 1979)
  - Radioactive labelling (Eslyn 1959)
  - Needle pushed into the tree (Zycha and Dimitri 1962)
  - Wood resistance (Skutt et al. 1972, Martin 1978)
  - Tomography (Habermehl et al. 1978)
  - X-ray fluorescence and neutron activation methods (Jartti 1978, Raunemaa et al. 1979)

The most frequently used methods are the taking of increment cores, stump estimation and the felling of sample trees. When cores are being used to detect rot defects, minor cases in particular may remain undetected, and estimating the volume of the rot-affected wood by this method is unreliable, although the size of the stem and the injured area can be determined. Inventorying the rot defects on the basis of stumps is a rather fast method. However, all the rots will perhaps not be recorded because of resin formation and discolouration of the stump surface (see Nyyssönen 1955, Tiihonen 1963). Furthermore, it is not always possible to distinguish between butt-rot and wound decay, nor to measure characteristics of the stem and rot above the stump. The most reliable method is to fell and cut up sample trees since the dimensions of the stem and the rot can then be measured accurately, although it is difficult and expensive to procure a sufficiently large and representative material.

Up to now, analytical methods have not been used very much in rot studies for estimating the stem volume and amount of timber assortments in individual trees and stands (Stage et al. 1969, Hyppönen and Norokorpi 1979, Pratt 1979c). In earlier rot studies, the volume parameters of the sample trees have usually been measured in the field and the stems scaled at the same time into timber assortments (Tikka 1938, Petrini 1944, Aho 1966, Kallio and Tamminen 1974). Analytical methods are especially suitable for rot studies in which the material is rather small, and the affected trees have to be scaled into timber assortments according to more than one quality criteria. On the other hand, it is easier to take into account all the factors affecting the timber yield *in situ* in the forest.

15. The aim of the study

As the wide range of literature referred to in the earlier sections shows, butt-rot in spruce has been extensively studied. However, there is no generalized data available for southern Finland (see Fig. 1), which is the region where most of the spruce resources in Finland are concentrated — about 80 % of the stem volume and about 90 % of the growth. This study is intended to clarify the situation in southern Finland as regards the following points:

- The properties of butt-rot
- The abundance of butt-rot
- The effect of butt-rot on the timber yield and the value of spruce
- Butt-rot and stem growth
- How to detect butt-rot in living spruces.

2. MATERIAL AND METHODS

21. Material

The material consists of the following items: 146 spruce-dominated stands marked for clear-cutting, about 20 000 spruce sample trees from the 7th National Forest Inventory (NFI) in southern Finland (see Fig. 1), the remeasured part (1 226) of these sample trees, and four separate spruce stands in the research forests of the Finnish Forest Research Institute.

The spruce stands marked for clear-cutting were situated in the seven forestry board districts that were considered to include the main part of the volume of butt-rot affected spruces in southern Finland (Kangas 1952, Kallio 1961, Kuusela and Salovaara 1969, 1974, Kallio and Tamminen 1974) (see Fig. 2). The marked clear-cutting areas were allocated to the individual forestry board districts (see Table 1) on the basis of the total spruce stem volume weighted by the proportion of spruce. The location of the areas within the forestry board districts was determined by selecting the target communes by means of PPS sampling using the above-mentioned sampling variate. The stem volume of the spruces was estimated on the basis of the cartographic outputs of the 5th NFI (Salminen 1973) and the land area of each commune (Suomen . . . 1973) The sampling variate in question was assumed to be better correlated with the abundance, or the effects of butt-rot, than the total stem volume. The spruce stands included in the study were selected from among those suggested by local forest officers. The final selection was done subjectively, although an attempt was made to make the selection as random as possible as far as the abundance of butt-rot was concerned. Despite this subjectivity, selection of the stands was considered to conform approximately to the criteria of stratified cluster sampling (Sukhatme and Sukhatme 1970, see Section 321).

Most of the 1 167 spruce sample trees felled in half of the stands were measured before harvesting on subjectively delineated sample plots (300 m^2). The rest of the sample trees, in this case primarily stems affected by butt-rot, were measured during or after harvesting. The size of the marked spruce stands varied from 0,5 to 5 hectares. Between 10 to 25 circular sample plots (300 m^2) were located systematically in each clear-cutting stand. The total number of sample plots was 2 915 (see Table 1). All the stumps with a diameter of at least 10 cm were measured, the number of spruce stumps totalling 29 900.

The original NFI material comprised all the spruce sample trees with a breast-height diameter of at least 5 cm growing on forest land in southern Finland during 1977—82. The occurrence of rot defects was estimated in conjunction with the ordinary field work on the basis of increment and age cores taken at breast height, as well as visual observations of possible stem wounds (Valtakunnan . . . 1977).

A total of 1 226 spruce sample trees were remeasured on 139 sample tree plots in six forestry board districts in autumn 1977 and 1978 (see Fig. 2 and Table 1). The plots were selected from the inventory field forms using systematic PPS sampling. The sampling variate was the spruce basal area for 1977 and the basal area weighted by the mean diameter for 1978. No information was available about the stem volume of the sample trees at the time when sampling was carried out.

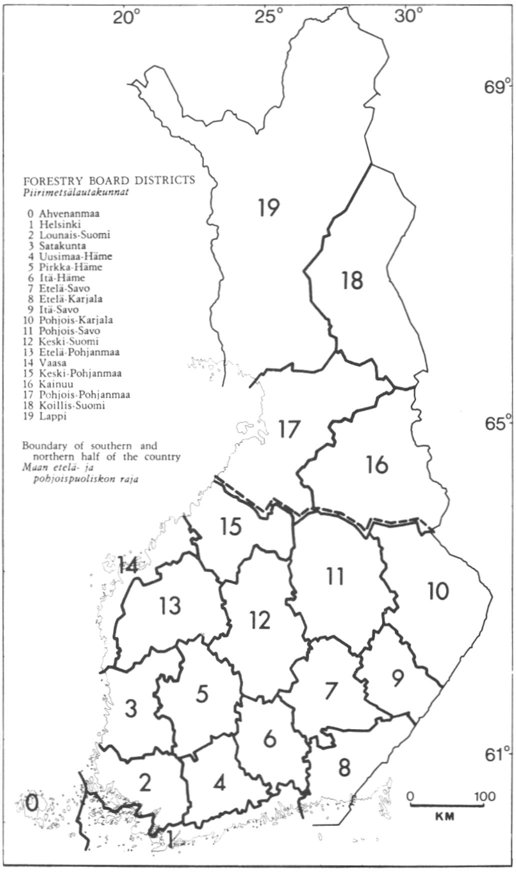


Fig. 1. Forestry board districts.
Kuva 1. Piirimetsälautakunnat.

Table 1. Distribution of the clear-cutting area and remeasured NFI[1]) material according to forestry board districts and tax classes.

Taulukko 1. Avohakkuuleimikko- ja uudestaan mitattu VMI[1]) -aineisto piirimetsälautakunnittain ja veroluokittain.

Material *Aineisto*	Forestry board district[2]) *Piirimetsälautakunta*[2])	Tax class[1]) — *Veroluokka* IA	IB	II	III—IV	Total *Yht.*	No. of clear-cutting areas *Leimikoita, kpl*
		No. of sample plots *Koealoja, kpl*					
Clear-cutting areas *Avohakkuuleimikot*	1 Helsinki	67	104	55	0	226	12
	2 Lounais-Suomi	31	237	48	0	316	16
	3 Satakunta	21	246	142	4	413	21
	4 Uusimaa-Häme	148	359	142	1	650	32
	5 Pirkka-Häme	94	397	148	1	640	32
	6 Itä-Häme	142	200	63	0	405	20
	14 Vaasa	32	142	82	9	265	13
Total — *Yht.*		535	1 685	680	15	2 915	146

		No. of spruce sample trees *Kuusikoepuita, kpl*					No. of sample plots *Koealoja, kpl*
NFI sample trees *VMI-koepuut*	1 Helsinki	46	25	5	8	84	11
	2 Lounais-Suomi	34	47	34	12	127	16
	3 Satakunta	47	98	32	0	177	21
	4 Uusimaa-Häme	59	90	34	2	185	23
	5 Pirkka-Häme	136	191	85	7	419	44
	8 Etelä-Karjala	102	106	23	3	234	24
Total — *Yht.*		424	557	213	32	1 226	139

[1]) See Abbreviations
[2]) See Fig. 1.

218 sample trees were measured in four spruce stands in the Ruotsinkylä and Lapinjärvi Research Forests in order to study how butt-rot affects the stem growth of spruce trees, and to determine whether butt-rot can be detected in standing trees. These sample plots were delineated subjectively. In addition, ten spruces suffering from butt-rot caused by *H. annosum* were felled in Lapinjärvi as material for studying the effect of butt-rot on the wood density and pulp quality.

Samples were taken of the decay in 404 butt-rots and 43 wound-rots in the marked clear-cutting stands, and from 157 sample trees in the remeasured NFI material, in order to identify the rotting agent (see Hallaksela 1984).

22. Methods

221. Measurements

All the spruce sample trees in the clear-cutting stands were felled and the following parameters measured: stump height (5 cm), age at stump and breast height (a), stump diameter (cm), stem diameter (mm) at heights of 0,5, 1, 2, 4, 6... m above the stump and 2 m below the top, stem length (0,1 m), and bark thickness (mm) at stump and breast height, at 6 m and at 2 m below the top. Height growth (0,1 m/5 a) and diameter growth (0,1 mm/5 a) at breast height and at a height of 6 m were measured on 362 of the sample trees. The dimensions of the butt-rot were estimated as follows: The height (dm) and the diameter (cm) at stump height and, whenever possible, one more diameter at a higher level (2, 4 or 6 m) were measured on all 643 cases of butt-rot. All the diameters at 2 m intervals were measured on 371 out of the 643 cases of butt-rot in order to study the form of the rot column. The rot diameter referred to a circle of the same area as the irregular-shaped band of rotten wood. The length of the rot column was estimated by making small cuts in the stem at half-meter intervals. The stage of decay was estimated using the classes: 1 = stain, 2 = hard rot, 3 = soft rot or cavity (cf. Kallio and Tamminen 1974).

The diameter of all the over 10 cm-thick stumps on the stump sample plots were measured in a random direction. In cases where the surface of the stump was discoloured or there was abundant resin flow, a cut was made with a small axe so as to reveal any possible rot defects. The rot diameter was estimated in the same way as for the sample trees. The site type, stoniness or existance of palu-

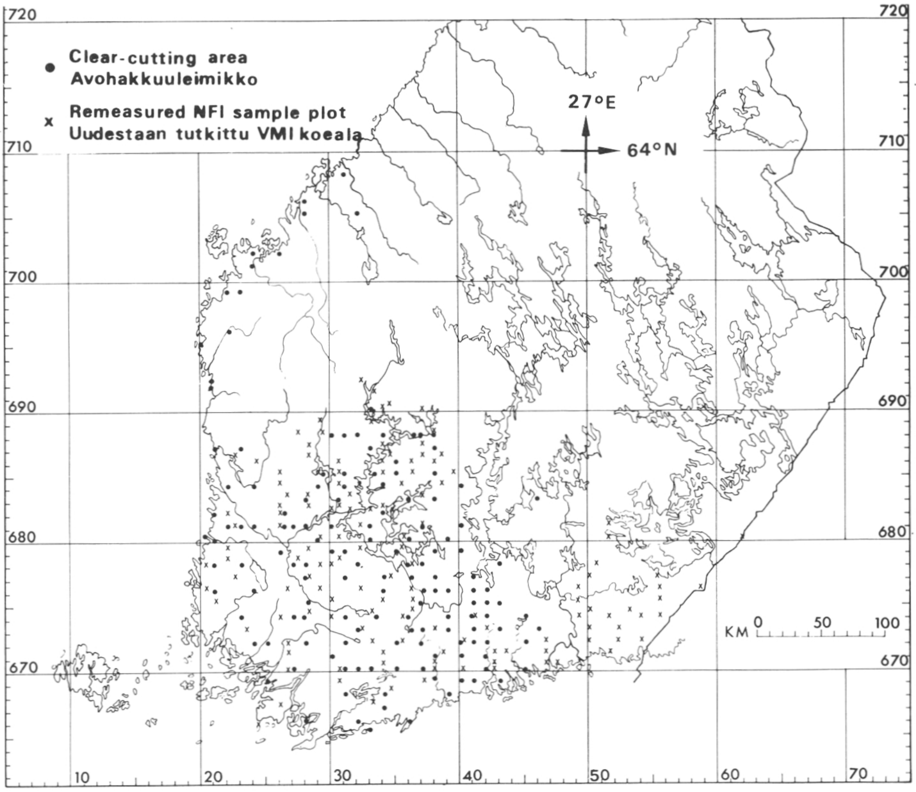


Fig. 2. Geographical distribution of the clear-cutting areas and the remeasured NFI sample plots.
Kuva 2. Avohakkuuleimikoiden ja uudestaan tutkittujen VMI-koealojen sijainti.

dification, tax class, approximate soil type, topography, steepness and direction of slope, and age class, were all determined on each sample plot.

The NFI sample plots to be remeasured were located using the inventory maps and field forms — only 1 out of 140 was not found. The spruce sample trees were identified and core samples then taken at stump and breast height in order to test for possible rot defects. In addition, core samples were taken aseptically from the spruces affected by butt-rot in order to identify the microbes. Notes were also made of possible injuries (cf. Valtakunnan . . . 1977). The cores were taken from opposite sides of the butts of sample trees with a stump diameter of more than 24 cm. All the cores were taken down to the pith at least. The diameter of the decay column and the decay stage (hard or soft) were determined at stump and breast height on the basis of the wood cores.

The spruces growing on the four stand sample plots were studied before and after felling. The following parameters were measured on the sample trees: diameter (mm) at stump and breast height and 6 m, tree height (0,1 m), diameter growth at breast height and 6 m (0,1 mm) during the periods 1—5, 6—10 and 11—20 years ago. The butt-rot infection of standing trees was first estimated from the butt cores (2 per stem). After felling, rot defectiveness was checked at the stump, and the dimensions of any rots present were measured.

222. Calculations

In addition to the diameters actually measured in the clear-cutting material, the diameters over bark were estimated for the felled sample trees at 1 m intervals using the second degree parabola. The thickness of the bark at 1 m intervals was estimated linearily, and the under-bark diameters then calculated. The volume of the sample trees was determined from stump height to a height of one meter using Simpson's formula (with three diameters) and from a height of one meter upwards using Smalian's formula (with two diameters).

After the volume under bark had been calculated, the cumulative sum of the relative volume was calculated at 1 m intervals starting from the butt — butt = 0, and top of the stem = 100 (Nisula 1967, Laasasenaho 1975). When the timber assortment volumes were being calculated, these relative volumes were used to estimate the volume of the bolts and stem parts. The volume of the NFI sample trees and sample trees measured on the stand sample plots were determined using Laasasenaho's (1976) formulae.

The treatment of the clear-cutting material as a whole was as follows:

I Sample tree and stump measurements
II Volume, timber assortment and value estimates of the sample trees

III Regression equations used in converting the stump data into sample tree data:

— all sample trees: $d=f(d_s)$
$v=f(d_s)$
probability $(SAW>0)=f(d_s)$

— saw-timber trees: $SAW=f(d_s)$
$VAL=f(d_s)$

— pulpwood trees: $VAL=f(d_s)$

— butt-rot trees: $DH=f(d_s, DD, DC)$
$DV=f(d_s, DD, DC)$
$PULP=f(d_s, DD, DC)$

— saw-timber trees affected by butt-rot:
$SAWLOSS=f(d_s, DD, DC)$
$VALLOSS=f(d_s, DD, DC)$

— pulpwood trees affected by butt-rot:
$VALLOSS=f(d_s, DD, DC)$

IV Sample tree data for stumps with regression equations
V Sample plot characteristics by means of the sample tree data of the stumps
VI Clear-cutting area characteristics by means of the sample plot data.

Equations were prepared for predicting the breast-height diameter (22.1) and the stem volume (22.2) using all the sample trees in the clear-cutting material. The dependence between the breast-height diameter and the stump diameter of spruce stems has been shown to be linear (Nyyssönen 1955, Hakkila 1972, Laasasenaho 1975). Approximately the same result was obtained in this study. However, logarithmic transformations clearly evened-out the residual deviation.

(22.1) $y = \ln d$

Variable	*Coefficient*	*t-value*	
Constant[1]	—1,0037	—36***	$R^2=0{,}95$
$(\ln d_s)^{0,8}$	1,559	150***	$s_{est}=6{,}3$ %
			n=1 167

(22.2) $y = \ln v$

Variable	*Coefficient*	*t-value*	
Constant[1]	—5,9609	—10,8***	$R^2=0{,}92$
$\ln d_s$	4,7335	14,4***	$s_{est}=19$ %
$(\ln d_s)^2$	—3,5177	—7,2***	n=1 167
TAX2	—0,07328	—5,3***	
$\arctan(DD/d_s)$	—0,20464	—9,6***	

1) $s_f^2/2$ added (see Meyer 1941, Kilkki 1979a, pp. 374—375)

Estimation of the stem volume of trees removed in cuttings is a routine task in inventories, and it can be performed in many different ways (Nyyssönen 1955, Kilkki 1979a). In this study, the volume was predicted directly on the basis of the stump diameter (Hakkila 1972). The tax class variable in Eq. (22.2) indicates that a particular stump diameter corresponds to a smaller stem volume on the most infertile sites (cf. Nyyssönen 1955, Hakkila 1972). The relative butt-rot diameter at the stump, DD/d_s, was also correlated with the stem volume. The rot variable depicts the secondary effect of butt-rot mentioned by Arvidson (1954). Entering the rot variable in the equation was mainly dependent on the high butt-rot frequency of the sample trees (55 %), and did not depict the general situation except with respect to the direction of the trend. Eqs. (22.1) and (22.2) were fairly reliable in the calculation material (cf. Laasasenaho 1982, p. 41).

The height and relative volume of the theoretical proportion of saw-timber and merchantable timber (minimum diameters under bark 15 and 6 cm respectively) were calculated for the sample trees before timber scaling. The proportion of the part of the stem containing rot was also calculated for rot-affected trees, as well as the relative volume and total length per stem of decayed pulpwood bolts (á 2 m). The volume of the rot columns was calculated using Smalian's formula and the cone formula (cf. Roeder 1970, Kallio and Tamminen 1974).

All the spruce sample trees were first scaled on the basis of the external dimensions without taking into account possible rot defects (Ist timber scaling). Only the stems suffering from butt-rot were included in the IInd timber scaling — the rot defects being taken into account according to the quality norms (Petrini 1944). No rot was permitted in saw-timber logs — maximum rot diameter 2 cm — although in practice minor cases of rot or slight colour defects are not very uncommon in saw-timber logs. On the other hand, there was no limit set on the amount of rot allowed in decayed pulpwood, no rot at all being permitted in the sound pulpwood (cf. Kärkkäinen 1983a). The number of logs in saw-timber stems was determined on the basis of the following limits:

Length of the theoretical saw-timber section, dm	Number of logs/stem
49— 82	1
83—122	2
123—162	3
163—202	4
203—	5

The lengths of the individual saw-timber logs were 40, 43, 46. . .61 dm (see Kärkkäinen 1983b). The theoretical proportion of saw-timber was divided mechanically into sawlogs (see Heiskanen 1976, also Laasasenaho and Sevola 1971, Kuusela and Salminen 1980). Pulpwood was taken right upto the minimum diameter, the minimum length of the pulpwood bolts being 2 m. The following values depict the timber scaling for the saw-timber logs:

	Ist timber scaling	
	Sound stems	Butt-rot stems
Mean length, dm	47,8	48,8
Mean volume, dm³	211	218
Number of logs	1 139	1 227

The mean length of all the saw-timber logs, 48,3 dm, was close to the target mean length of 49 dm (Kärkkäinen 1983b). The stemwise saw-timber percentages closely corresponded to the calculated values of Laasasenaho and Sevola (1971).

The minimum stump diameter of the saw-timber stems had to be solved when estimating the sample tree characteristics of the stumps. In general, a certain limiting diameter, e.g. 24 cm, is used (Valtakunnan . . . 1977). However, the decision was made in this study to use a more flexible method since the effect of rot on the yield of saw-timber logs was very strong, especially in the case of small saw-timber trees (see Fig. 12). A model was constructed for determining the probability that the stump represented the saw-timber stem (Eq. 22.3, see Fig. 3). The probability was calculated for each stump, and the probability then summed from stump to stump. Those stumps where the sum exceeded the integer were taken as saw-timber stumps (cf. Laasasenaho 1973).

The discriminating power of Eq. (22.3) was rather good. The following values illustrate this:

Observed	Estimated using the equation Pulpwood	 Saw-timber	 Total
Pulpwood	156	51	207
Saw-timber	51	909	960
Total	207	960	1 167

Equation (22.4) was prepared for predicting the stemwise proportion of saw-timber. It was fairly reliable for stump diameters over 23 cm, but gave an underestimate for smaller trees — the inflection point in the curve for the proportion of saw-timber was located at around 25 cm. The bias was not even completely removed when a correction term was included.

(22.4) $y = \ln(100\text{-SAW})$

Variable	*Coefficient*	*t-value*	
Constant[1])	—8,607	—41,3***	$R^2=0,82$
$1/\ln d_s$	39,75	53,3***	$s_{est}=8,3$ %
$\arctan(DD/d_s)^2$	0,3004	7,0***	n=960
$\left(\dfrac{1/\ln d_s - 0,2395}{0,089}\right)^8$	—0,5504	—3,7***	

1) $s_f^2/2$ added

As was the case for the volume (see Eq. 22.2), the proportion of saw-timber in butt-rot stems was smaller than in the case of sound stems. The effect of rot on the value of spruce was investigated using relative unit prices. The following relative prices were considered to cover an essential part of the range of the price relations (Uusitalo 1981).

	Relative price/m³ VAL1	 VAL2
Saw-timber	100	100
Sound pulpwood	40	60
Decay-affected pulpwood	36	60

The price-size relationship was ignored (cf. Laasasenaho and Sevola 1971, Kilkki and Siitonen 1975, Nyyssönen and Ojansuu 1982) because it was considered to be of no importance in this work (cf. Heiskanen 1976). Equations (22.5) to (22.8) were made for predicting the stemwise relative stumpage value.

Saw-timber stems:

(22.5) $y = \ln \text{VAL1}$

Variable	*Coefficient*	*t-value*	
Constant[1])	—4,893	—8,9***	$R^2=0,85$
d_s	—0,1117	—7,3***	$s_{est}=21$ %
$\sqrt{d_s}$	2,169	11,8***	n=960
TAX2	—0,0995	—5,8***	
$\arctan(DD/d_s)$	—0,2007	—8,0***	

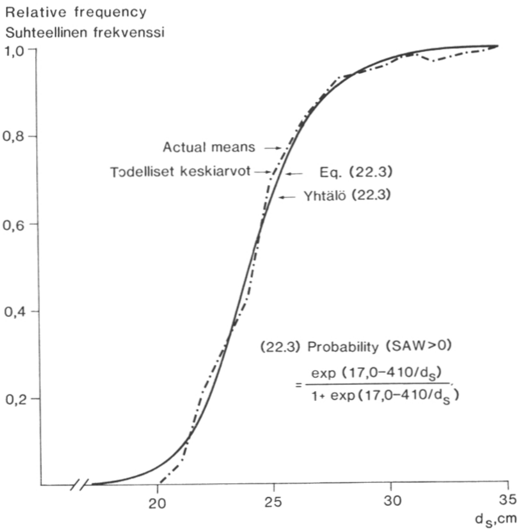


Fig. 3. Relative frequency of saw-timber stems as a function of stump diameter.
Kuva 3. Tukkirunkojen suhteellinen frekvenssi kantoläpimitan funktiona.

(22.6) $y = \ln \text{VAL2}$

Variable	*Coefficient*	*t-value*	
Constant[1])	—3,732	—7,3***	$R^2=0,85$
d_s	—0,08702	—6,0***	$s_{est}=20$ %
$\sqrt{d_s}$	1,831	10,5***	n=960
TAX2	—0,0959	—5,9***	
$\arctan(DD/d_s)$	—0,1919	—8,0***	

Pulpwood stems:

(22.7) $y = \ln \text{VAL1}$

Variable	*Coefficient*	*t-value*	
Constant[1])	—24,56	—11,2***	$R^2=0,85$
$\ln d_s$	15,32	10,3***	$s_{est}=22$ %
$(\ln d_s)^2$	—2,186	—8,8***	n=207

(22.8) $y=\ln \text{VAL2}$

Variable	*Coefficient*	*t-value*	
Constant[1])	—24,13	—11,0***	$R^2=0,85$
$\ln d_s$	15,31	10,3***	$s_{est}=22$ %
$(\ln d_s)^2$	—2,185	—8,8***	n=207

1) $s_f^2/2$ added

The value equations (22.5) and (22.6) for saw-timber trees corresponded, as regards their variable composition, to volume equation (22.2). The fact that the equations for pulpwood were different is presumably due to the smaller material and the narrower variation intervals of the variables. Equations (22.5) to (22.8) were fairly reliable and unbiased in the calculation material.

3. RESULTS

31. Properties of the butt-rot

Heterobasidion annosum (Fr.) Bref. was the most common decay agent in the butt-rots. It accounted for 60 % of the cases of butt-rot in the clear-cutting stands, and 38 % in the NFI material (see Hallaksela 1984).

In the clear-cutting area material the butt-rots were divided on the basis of the occurrence of *H. annosum* into two groups (Table 2). Annosum-rots were larger in every respect than the other types of decay. They accounted for almost 90 % of the volume of the rots. The mean length of butt-rot in northern Finland was 11 dm, and the ratio between the length of the rot and the diameter of the rot was 1,2 (Norokorpi 1979). It thus appears that the butt-rot in southern Finland is larger than that in northern Finland, even when Annosum-rots are not taken into account (cf. Kallio and Tamminen 1974). The size of the rots appeared to vary considerably from area to area (Table 3). According to the analysis of covariance — the covariates were the absolute and relative diameter of the rot and the stage of decay — the length of the rot and the ratio between the length and the diameter were different by forestry board districts. However, this result can only be taken as indicative since the sample was small.

Ten 60-year-old spruces suffering from Annosum-rot were felled in the Lapinjärvi Research Forest. Thin sections were cut from the sound wood and from parts of the stem affected by soft and hard rot. The density of these samples, as well as the characteristics of the pulp prepared from the wood, were determined at Keskuslaboratorio Oy. Part of the results are presented in the following set-up. The effect of decay on the wood density and on the yield and quality of the pulp could clearly be demonstrated only in the case of the advanced stage of decay, although the quality of the pulp made from hard rot seemed to be already poorer in every respect.

	Sound wood	Hard rot	Soft rot
Density of wood, kg/m^3	329	323	257
Density of pulp, kg/m^3	798	804	829
Yield, %	54	53	47
Ash, %	0,3	0,6	2,4
Tensile strength, Nm/g	125	112	97
Tear index, mNm^2/g	6,2	5,5	4,3

Table 2. Annosum-rots compared to other types of butt-rot.
Taulukko 2. Juurikääpälahot verrattuna muihin tyvilahoihin.

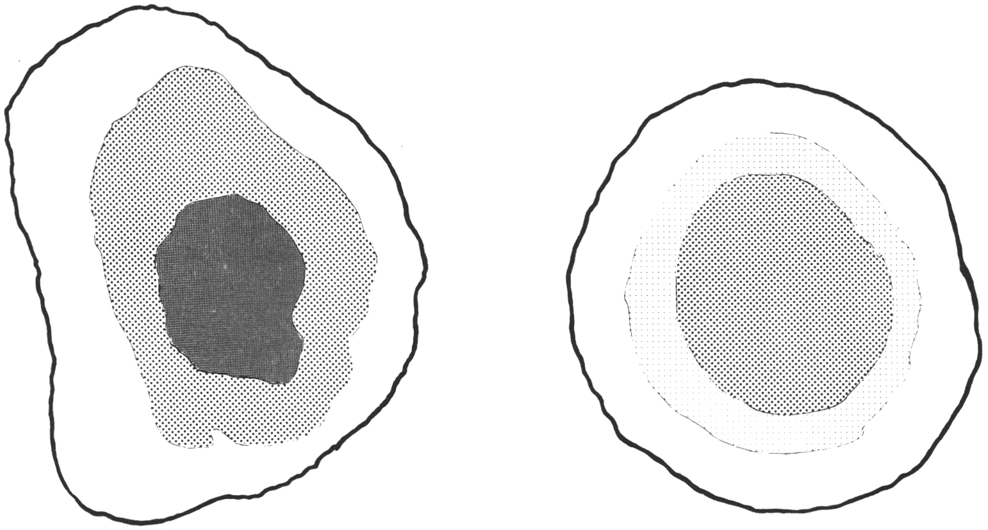
Characteristic *Tunnus*	Annosum-rots *Juurikääpälahot*	Other types of butt-rot *Muut tyvilahot*	Total *Yhteensä*
Number	244	160	404
DD, cm	20,7	11,1	16,9
DH, dm	42,5	16,8	32,3
DV, dm^3	66,4	12,0	44,8
DD/d$_s$	0,654	0,342	0,530
DH/h	0,231	0,086	0,174
DV/v	0,152	0,026	0,102
DH/DD, dm/cm	2,06	1,53	1,85
Relative frequency, % *Suht. frekvenssi, %*	60,4	39,6	100,0
Proportion of volume, % *Tilavuusosuus, %*	89,4	10,6	100,0

Table 3. The butt-rot characteristics according to forestry board districts.
Taulukko 3. Tyvilahojen tunnuksia piirimetsälautakunnittain.

Forestry board district *Piirimetsälautakunta*	Number of butt-rots *Tyvilahoja, kpl*	DD cm	DH dm	DH/DD dm/cm	DD/d$_s$
1 Helsinki	89	16	32	1,8	0,51
2 Lounais-Suomi	50	18	33	1,9	0,61
3 Satakunta	70	21	45	2,2	0,64
4 Uusimaa-Häme	132	16	26	1,6	0,49
5 Pirkka-Häme	121	20	44	2,2	0,61
6 Itä-Häme	106	18	33	1,8	0,50
14 Vaasa	75	16	35	2,2	0,58
Total — *Yhteensä*	643	17,8	35,0	1,94	0,552

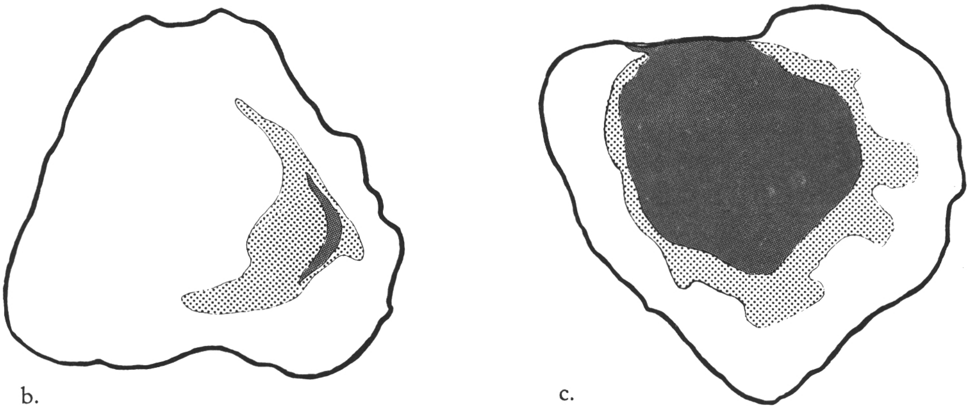
The mildest form of rot, i.e. stain, was not included in the comparison, but its properties are apparently very similar to those of sound wood (Wilcox 1978, Pratt 1979b). Although the rot degree was determined subjectively, it appears to be rather suitable for estimating the overall effects of rot since the strength properties of the wood deteriorate in approximately the same way as the properties of the pulp (Pratt 1979b).

The shape of the rot column is usually rather irregular in comparison to the shape of the stem (Mercer 1979, Pratt 1979a). The tissues of the stem determine the absolute limits of the rot, and far-advanced cases of rot are hence rather regular. On the other hand, short, minor cases of rot are frequently crescent-shaped or eccentric in cross-section (Fig. 4). The rot spreads through the heartwood, sometimes as a ring around the pith. When the dimensions of the rot column were determined, the end of the column was assumed to have the form of a cone or a parabola.



a. stump

a. 2 m



b.

c.

Fig. 4. The cross-sections of a) a regular, advanced butt-rot at stump and two-meter height, b) a minor, eccentric butt-rot, and c) a decay arising from a root-collar injury.
Kuva 4. Lahoumien poikkileikkauksia: a) säännöllinen, pitkälle edennyt tyvilaho kannosta ja kahden metrin korkeudelta b) pieni, epäkeskinen tyvilaho ja c) juurenniskan vauriosta alkunsa saanut laho.

The diameters of 371 butt-rots were estimated at intervals of 0,3—1,0 m depending on the length of the rot. The volume of the rot column was determined using Simpson's formula with three diameters and a cone formula. The form factors at stump and breast height were then calculated for the rot column —

f_{stump} = DV/(DG DH), and
$f_{1,3}$ = DV/($DG_{1,3}$DH), where

DG and $DG_{1,3}$ are the basal areas of the rot column at the stump resp. 1,3 m height.

According to Table 4, the mean stump form factor lies between a cone (0,33) and a parabola (0,5). The volume of small cases of rot, i.e. under two meters in length, was determined using a cone formula only. The concavity of a neloid (0,25) was apparent in the larger rots. The breast-height stem factor, $f_{1,3}$, which was calculated for rot columns higher than 1,3 m, fell on the average between a parabola (0,5) and a cylinder (1,0). The short rots increased the mean value. Although the rot form factors do not depict the rot column nearly as well as e.g. the stem form factors do the stem, they do provide us with some analytical information about the shape of different-sized rots.

The distributions of the diameter, length and especially the volume of the butt-rots were skewed to the right and not very suitable for regression analysis (see Fig. 5). This is even more apparent when we consider the rather high degree of error involved in determining the length and volume of small-sized rots.

Characteristic	$\bar{x}$	s	Range
DV, dm^3	66,2	93,3	0,03. . .760,11
DD, cm	17,8	9,1	2. . .50
DD/d_s	0,552	0,223	0,047. . .0,938
DH, dm	35,1	24,9	2. . .110

Equations (31.1) and (31.2) were prepared for predicting the length and volume of the butt-rots. The equations were unbiased in the calculation material, although not very accurate. For instance, the mean error of the volume equation was 78 %. It does not seem possible to attain a much higher degree of accuracy in predicting the rot length and volume in southern Finland than with Eqs. (31.1) and (31.2), unless the microbes causing the rot are taken into account (cf. Table 2). In addition, the rot equations appear to be very specific for each material (Kallio and Tamminen 1974, Norokorpi 1979).

(31.1) $y = \sqrt{DH}$

Variable	*Coefficient*	*t-value*	
Constant	1,10	7,6***	R^2=0,64
DC	0,730	5,7***	s_{est}=55 %
DD	—0,0649	—3,1**	
DD/$\sqrt{d_s}$	1,624	11,1***	n=643

$\hat{DH} = \hat{y}^2 + s_f^2 = \hat{y}^2 + 1{,}80$ dm
(see Kilkki 1979 a, pp. 374—375)

(31.2) y = ln DV

Variable	*Coefficient*	*t-value*	
Constant[1])	—6,742	—23,1***	R^2=0,91
DD/$\sqrt{d_s}$	2,780	16,4***	s_{est}=78 %
DD	—0,1754	—9,5***	
arctan(DD/d_s)	2,629	9,0***	n=643
DC	0,3200	5,3***	

[1]) $s_f^2/2$ added.

Table 4. Stump and breast-height form factors of the butt-rot columns.
Taulukko 4. Tyvilahojen kanto- ja rinnankorkeusmuotoluku.

	Rot diameter at stump height, cm *Lahon kantoläpimitta, cm*									Total *Yht.*
	2—5	—10	—15	—20	—25	—30	—35	—40	—50	
No. of rots *Lahoja, kpl*	10	41	66	77	82	49	24	13	9	371
f_{stump}	0,33	0,38	0,44	0,44	0,43	0,39	0,40	0,36	0,36	0,41
	Rot diameter at stump height, cm *Lahon kantoläpimitta, cm*									Total *Yht.*
	1—5	—10	—15	—20	—25	—30	—35	—45		
No. of rots *Lahoja, kpl*	18	38	73	87	50	29	7	10		312
$f_{1,3}$	3,90	1,26	0,71	0,64	0,63	0,59	0,51	0,56		0,91

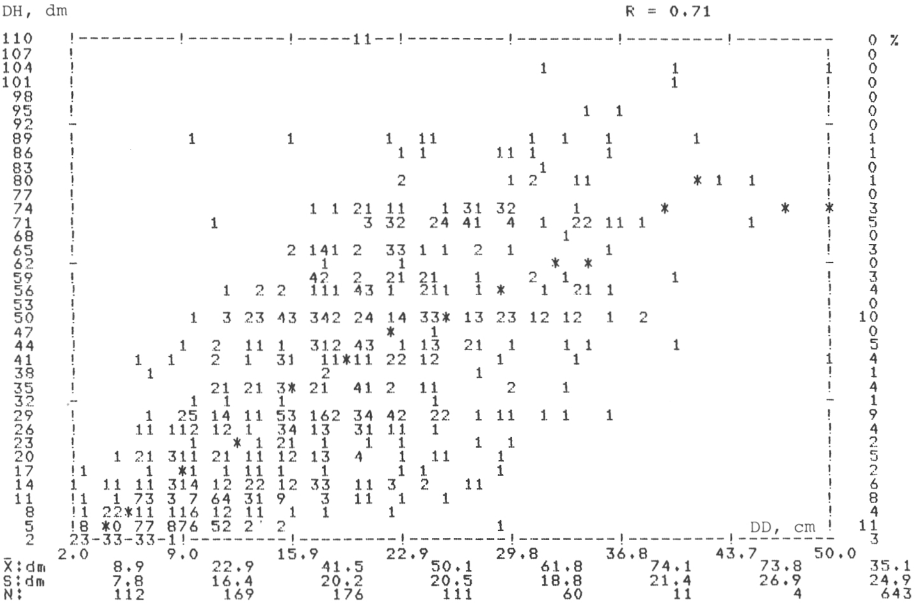


Fig. 5. Correlation between the diameter and the height of butt-rot.
Kuva 5. Tyvilahon kantoläpimitan ja pituuden korrelaatio.

32. The occurrence and frequency of butt-rot

321. The clear-cutting material

The data from the stump sample plots were transformed, using regression equations based on the sample tree information, into standing tree data for the sample plots and the whole clear-cutting areas (see Section 222). The butt-rot frequency, i.e. the proportion (in %) of spruces affected by butt-rot, is presented in the following, unless otherwise stated, as the proportion of butt-rot spruces out of the total stem volume of the spruces. The proportion of butt-rot spruces out of the stem number for spruce is presented in Table 5.

The proportion of butt-rot spruces increased along with increasing diameter on the average. The rot frequency was highest in the Helsinki Forestry Board District, being almost twice the level elsewhere. The proportion of rot was smallest in the Pirkka-Häme Forestry Board District. The data presented in Table 5 are straight data which have not been weighted. The rot figures in Table 6, on the other hand, were weighted with the spruce stem volume — the weights being estimated on the basis of the results of the 7th NFI. An attempt was also made to remove the effect of possible skewness of the tax class distribution on the values presented in Table 6. According to the analysis of covariance — the covariates being T, Dg, G and the dependent variable $\ln(y+1)$ — there were highly significant differences between the forestry board districts and the tax classes, although there was significant interaction between the classifying variables.

It can be seen that stratification considerably increased the mean values in the Satakunta Forestry Board District area. The clear-cutting stands were situated, especially in the case of Satakunta, on less fertile sites. One reason for this may be that the natural regeneration of spruce is most common on the more fertile sites and hence their proportion in the clear-cutting areas remains rather small. On the other hand, the best sites — Tax class IA — were, according to Table 6, the most infected ones. It would thus appear that the decay agents thrive well on those sites where spruce grows well (Laatsch et al. 1968, Isomäki and Kallio 1974).

The proportion of butt-rot spruces out of the stem volume, VP, better describes the

Table 5. Relative frequency of butt-rot spruces by forestry board district and diameter class in the clear-cutting material.
Taulukko 5. Tyvilahokuusten suhteellinen frekvenssi piirimetsälautakunnittain ja läpimittaluokittain leimikkoaineistossa.

Forestry board district *Piirimetsä-lautakunta*	d, cm —10	—15	—20	—25	—30	—35	—40	41—	
	Relative butt-rot frequency, % *Suhteellinen tyvilahofrekvenssi, %*								Mean *Keskim.*
1 Helsinki	18	22	23	31	31	38	42	70	30,2
2 Lounais-Suomi	10	12	17	18	16	23	22	27	16,4
3 Satakunta	10	16	16	21	20	21	17	14	18,1
4 Uusimaa-Häme	10	13	14	18	19	20	24	27	16,6
5 Pirkka-Häme	8	10	10	11	14	16	17	24	12,1
6 Itä-Häme	12	14	19	18	16	20	20	32	17,3
14 Vaasa	10	14	18	19	22	37	37	17	16,9
Mean — *Keskim.*	10,4	13,7	15,5	17,9	18,3	21,5	23,5	33,9	17,0

Table 6. Butt-rot frequency of spruces (VP) and relative stump diameter of butt-rot (DP) by forestry board district and by tax class: stratification by tax class and without stratification.
Taulukko 6. Kuusten tyvilahoisuus (VP) ja lahon suhteellinen kantoläpimitta (DP) piirimetsälautakunnittain ja veroluokittain: ositettuna veroluokittain ja osittamatta.

Forestry board district *Piirimetsä-lautakunta*		Tax class *Veroluokka* IA	IB	II + III	Total *Yht.*	Without stratification *Osittamatta* Sample plots *Koealat*	Clear-cutting areas *Leimikot*
1 Helsinki	n	67	104	55	226	226	12
	VP, %	44,4	31,1	23,8	35,4	34,2	37,6
	DP, %	22,0	16,4	10,1	17,6	16,4	18,5
2 Lounais-Suomi	n	31	237	48	316	316	16
	VP, %	19,3	16,0	16,1	16,9	16,3	16,3
	DP, %	11,3	7,6	7,6	8,6	7,9	7,6
3 Satakunta	n	21	246	146	413	413	21
	VP, %	45,5	19,1	13,5	23,7	18,4	18,8
	DP, %	25,2	9,0	5,7	11,8	8,8	8,9
4 Uusimaa-Häme	n	148	359	143	650	650	32
	VP, %	23,4	17,0	14,7	19,4	18,2	18,5
	DP, %	9,8	7,1	5,5	8,1	7,5	7,2
5 Pirkka-Häme	n	94	397	149	640	640	32
	VP, %	17,5	13,0	11,5	13,9	13,4	13,4
	DP, %	8,1	4,6	4,1	5,4	5,0	4,5
6 Itä-Häme	n	142	200	63	405	405	20
	VP, %	19,7	16,8	13,2	17,5	17,4	17,5
	DP, %	7,9	7,7	4,4	7,5	7,3	6,6
14 Vaasa	n	32	142	91	265	265	13
	VP, %	21,3	20,7	12,6	17,0	18,9	19,0
	DP, %	9,3	10,1	5,2	7,8	8,5	8,3
Total *Yhteensä*	n	535	1 685	695	695	2 915	146
	VP, %	24,4	16,7	13,9	18,5	18,3	18,8
	DP, %	12,5	7,7	6,0	8,3	8,0	7,9

significance of the butt-rot than the relative frequency, NP. Furthermore, the relative rot diameter, DP, even better describes the butt-rot defectiveness because it contains essential information about the size of the rot (see Eqs. 31.1 and 31.2), and because its sample plot means have been calculated by weighting with the stump diameter —

$$DP = 100\Sigma d_s \frac{DD}{d_s} / \Sigma d_s = 100\Sigma DD/\Sigma d_s.$$

This means that the economically important, large trees have a higher representation.

In addition to the rot variables presented in Table 6, the stem volume of butt-rot spruces and its sampling error were also estimated. Precise stratification was done afterwards on the basis of the results of the 7th NFI. The first stage stratification was made by forestry board districts, and the second stage by tax classes. Each cluster was composed of sample plots of a certain tax class in each clear-cutting area, and the sampling unit was a single sample plot. The following formulae were selected (Sukhatme and Sukhatme 1970):

Whole material (TOT):

$$(32.1)\quad \bar{y}_{TOT} = \sum_{FBD}^{7} w_{FBD}\, \bar{y}_{FBD}$$

$$(32.2)\quad \mathrm{Var}(\bar{y}_{TOT}) = \sum_{FBD}^{7} w^2_{FBD}\, \mathrm{Var}(\bar{y}_{FBD})$$

where w_{FBD}, $\bar{y}_{FBD}$ and $\mathrm{Var}(\bar{y}_{FBD})$ are the area-based weight, mean and its variance of the forestry board district FBD.

Forestry board district (FBD):

$$(32.3)\quad \bar{y}_{FBD} = \sum_{TC}^{3} w_{TC}\, \bar{y}_{TC}$$

$$(32.4)\quad \mathrm{Var}(\bar{y}_{FBD}) = \sum_{TC}^{3} w^2_{TC}\, \mathrm{Var}(\bar{y}_{TC}),$$

where w_{TC}, $\bar{y}_{TC}$ and $\mathrm{Var}(\bar{y}_{TC})$ are the area-based weight, mean and its variance of the tax class TC.

Tax class (TC):

$$(32.5)\quad \bar{y}_{TC} = \frac{\sum_{i}^{n_{TC}} m_i \bar{y}_i}{\sum_{i}^{n_{TC}} m_i}$$

$$(32.6)\quad \mathrm{Var}(\bar{y}_{TC}) = \left(1 - \frac{n_{TC}}{N_{TC}}\right) \frac{\sum_{i}^{n_{TC}} \frac{m_i^2}{\bar{m}^2_{TC}} (\bar{y}_i - \bar{y}_{TC})^2}{n_{TC}(n_{TC} - 1)} + \frac{\sum_{i}^{n_{TC}} \frac{m_i^2}{\bar{m}^2_{TC}} \left(1 - \frac{m_i}{M_i}\right) \frac{\sum_{j}^{m_i} (y_{ij} - \bar{y}_i)^2}{m_i(m_i - 1)}}{n_{TC} N_{TC}},$$

where N_{TC} and n_{TC} are the total number and sampled number of the clusters of the tax class TC,

$$\bar{m}_{TC} = \frac{\sum_{i}^{n_{TC}} m_i}{n_{TC}} \quad \text{is the mean size of the clusters,}$$

M_i and m_i are the total number and sampled number of the elements of cluster i,

$$\bar{y}_i = \frac{\sum_{j}^{m_i} y_{ij}}{m_i} \quad \text{is the mean of cluster i, and}$$

y_{ij} is the value of element j (i.e. sample plot j) in the cluster i.

The last term on the right-hand side of Formula (32.6), the variance within the clusters, was not taken into account since it only accounted for a very small amount of the total variance.

The variance of the mean of the tax class TC was estimated using the following reduced formula:

$$(32.7)\quad \mathrm{Var}(\bar{y}_{TC}) = \frac{\sum_{i}^{n_{TC}} \left(\frac{m_i}{\bar{m}_{TC}}\right)^2 (\bar{y}_i - \bar{y}_{TC})^2}{n_{TC}(n_{TC} - 1)}$$

which does not include the correction term of the finite population $1\text{-}n_{TC}/N_{TC}$.

Some idea of the sampling error of the clear-cutting material can be obtained from Table 7. The sampling error of the estimated mean and the total stem volume of the butt-rot spruces were, on the average, quite low, but in single cells the error was 10. . .30 % of the respective mean. In addition, the mean values were biased because Formula (32.7) was used in the estimation (see Sukhatme and Sukhatme 1970, p. 289). The errors by forestry board district were obviously too low since the weights of the various strata already contained a considerable sampling error (see Kuusela and Salminen 1980, 1983). An attempt was made to take the error in the area estimates of the various forestry board districts into consideration when the error of the estimated totals were being calculated. The relative error was estimated using figures presented by Salminen (1973) and Kuusela and Salminen (1980, 1983). Despite this, the mean errors in Table 7 remained relatively low compared to the figures from the 7th NFI (Kuusela and Salminen 1980, 1983).

Table 7. Mean and total values and respective sampling errors of the stem volume of butt-rot spruces in mature spruce stands by forestry board district and tax class according to the clear-cutting material.
Taulukko 7. Tyvilahokuusten runkotilavuuden keskiarvo, kokonaismäärä ja vastaavat keskivirheet uudistuskypsissä kuusikoissa piirimetsälautakunnittain ja veroluokittain leimikkoaineiston mukaan.

Forestry board district *Piirimetsä-lautakunta*	Tax-class — *Veroluokka* IA		IB		II—IV		Average *Keskim.*		Total volume *Kokonaismäärä*	
	$\bar{y}_{TC}$	$s_{\bar{y}_{TC}}$	$\bar{y}_{TC}$	$s_{\bar{y}_{TC}}$	$\bar{y}_{TC}$	$s_{\bar{y}_{TC}}$	$\bar{y}_{FBD}$	$s_{\bar{y}_{FBD}}$	Σy	$s_{\Sigma y}$ 1)
	m³/ha								1 000 m³	
1 Helsinki	85	26	54	6	32	11	61	10,9	1 220	293
2 Lounais-Suomi	25	6	23	4	19	5	23	2,8	875	149
3 Satakunta	53	9	31	6	18	2	32	4,1	1 414	226
4 Uusimaa-Häme	42	6	27	2	19	3	32	2,5	1 909	229
5 Pirkka-Häme	29	8	22	2	15	2	22	2,2	1 985	238
6 Itä-Häme	33	5	27	3	18	3	28	2,4	1 464	190
14 Vaasa	41	5	30	5	11	3	21	2,3	729	117
Average — *Keskim.*	40	3,5	27	1,4	17	1,4	28	1,2	9 596	499

1) $s_{\Sigma y} = \frac{r_{\Sigma y} \cdot \Sigma y}{100}$, where $r_{\Sigma y} = \sqrt{r_{\bar{y}}^2 + r_A^2}$ is the relative error of the total stem volume of butt-rot spruces, $r_{\bar{y}} = \frac{100 s_{\bar{y}}}{\bar{y}}$ is the relative error of the mean volume estimate and r_A is the relative error of the area estimate of the mature spruce stands (see Salminen 1973, Kuusela and Salminen 1980, 1983).

In order to check the estimation procedure used in preparing Table 7, the mean errors for the whole material were calculated without stratification using the formula for simple random sampling, single sample plots and whole clear-cutting stands being used as the sampling units. In addition, the variance associated with cluster sampling was estimated according to the formula:

$$(32.8) \quad Var_{CS} \cong [1 + (m - 1)\omega]\, Var_{SRS}, \text{ where}$$

$Var_{SRS} = 0{,}63$ = the variance of simple random sampling, $m = 20$ = the cluster size (sample plots/clear-cutting area), $\omega = 0{,}3$ = the intra-class correlation (Liedes and Manninen 1974, p. 192, see also Table 13).

The following values were obtained:

	$s_{\bar{y}_{TOT}}$ m³/ha	n
Sample plots	0,6	2 915
Clear-cutting stands	1,8	146
Formula (32.8)	1,6	(2 915)

The sampling error based on single sample plots was clearly lower than the ones based on the clear-cutting stands or Formula (32.8). However, the last-mentioned were higher than that presented in Table 7. Although the variation in cluster size (1. . .20) increased the variance of all the means in Table 7 (see Formula 32.7), according to these figures stratification decreased the variance to some extent.

Table 8. Butt-rot frequency of spruces by forest site type in the clear-cutting material.
Taulukko 8. Kuusten tyvilahoisuus metsätyypeittäin leimikkoaineistossa.

Site type *Metsätyyppi*	Non-stony *Vähäkivinen* n 1)	VP, %	Stony *Kivinen* n	VP, %	Paludified *Soistunut* n	VP, %	Total *Yhteensä* n	VP, %
OMaT/FT	8	28	0	—	14	20	22	22,6
OMT	413	27	122	23	137	16	672	23,9
MT	1 276	17	511	15	364	14	2 151	16,4
VT	53	13	0	—	17	8	70	11,9
Total	1 750	19,7	633	16,8	532	14,7	2 915	18,3

1) Number of sample plots — *Koealoja, kpl*

The increasing effect of site fertility, and the decreasing effect of stoniness and especially paludification on the butt-rot frequency, can be seen in Table 8. According to the analysis of covariance — the covariates were LAT, ELEV, T and G and the dependent variable ln(VP+1) — site type, stoniness and paludification had a highly significant effect on the butt-rot frequency, without any interaction. The differences as regards the relative butt-rot diameter were even more distinct.

According to Table 9, only the stand mean diameter and not age appeared to be correlated with the butt-rot frequency.

The map in Fig. 6 is based on moving averages, each of which represent 3 to 14 clear-cutting areas, apart from two individual cases, calculated for each 50 km × 50 km general map coordinate square. The most important feature in the map is the higher butt-rot frequency in the coastal areas. When the map is compared to the tax class distribution for the area (see Salminen 1981), there is also further evidence for the positive correlation between the butt-rot frequency and site fertility.

322. The sample trees of the 7th National Forest Inventory

Equation (33.12) was calculated on the basis of the remeasured NFI spruce sample trees. The rot estimates for all the NFI sample trees were adjusted using this equation. The butt-rot frequency of both materials is presented in Table 10.

The NFI data confirmed the picture already given by the clear-cutting material about the higher butt-rot frequency in the Helsinki Forestry Board District. The butt-rot frequencies of the remeasured NFI sample trees were higher, on the average, than those in the original NFI material. This is presumably mainly due to the method used (see Section 36). When the butt-rot frequencies for the clear-cutting material were compared with the corresponding adjusted NFI frequencies, the latter frequencies were on the average clearly lower, by 7 %-units, as can be seen in the following set-up.

Forestry board district		Clear-cutting areas	NFI sample trees
1	Helsinki	35,4	36,6
2	Lounais-Suomi	16,9	17,3
3	Satakunta	23,7	10,1
4	Uusimaa-Häme	19,4	14,5
5	Pirkka-Häme	13,9	11,9
6	Itä-Häme	17,5	11,4
14	Vaasa	17,0	11,1
Average		18,5	11,6

The difference is presumably due to both the materials and the methods. However, the NFI values appear to be underestimates (cf. Kallio and Tamminen 1974).

Table 9. Butt-rot frequency of spruces according to sample plot means for diameter and age in the clear-cutting material.

Taulukko 9. Kuusten tyvilahoisuus koealoittaisen keskiläpimitan ja keski-iän mukaan leimikkoaineistossa.

Mean diameter, cm *Keskiläpimitta, cm*	Mean age, a — *Keski-ikä, a* -40	 -60	VP, % -80	 -120	 -160	Mean *Keskim.*
—15	1	0	3	7	—	5,1
—20	15	16	12	12	15	14,0
—25	19	18	15	14	13	16,0
—30	13	17	17	17	17	17,1
—35	60	19	21	22	23	20,4
—40	—	24	31	36	24	29,0
40,1—	—	31	45	37	28	35,1
Mean - *Keskim.*	18,2	18,0	18,1	19,2	19,0	18,3

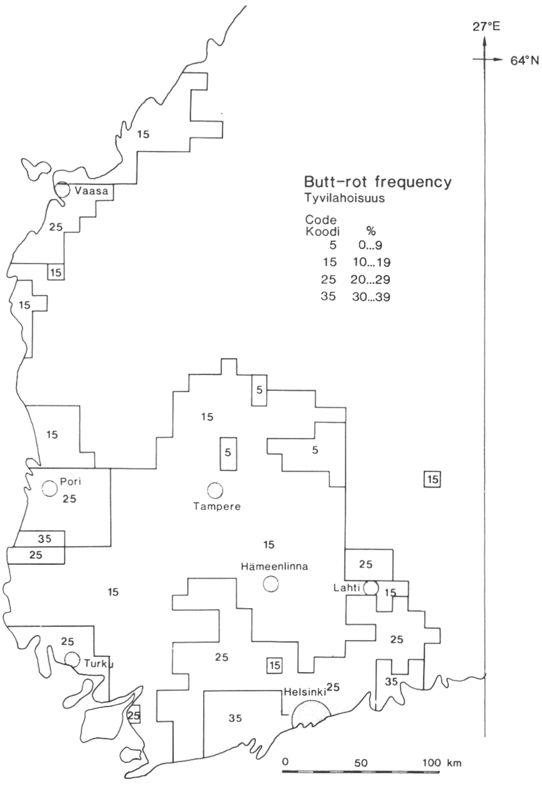


Fig. 6. Butt-rot frequency of spruces according to the clear-cutting material. The map is based on moving averages calculated on 50 km × 50 km squares.

Kuva 6. Kuusen tyvilahoisuus avohakkuuleimikoiden perusteella. Kartta perustuu 50 km × 50 km:n ruuduille laskettuihin liukuviin keskiarvoihin.

Table 10. Butt-rot frequency of spruce sample trees in the 7th NFI by forestry board district and tax class.
Taulukko 10. VMI-7:n kuusikoepuiden tyvilahoisuus piirimetsälautakunnittain ja veroluokittain.

Forestry board district *Piirimetsä-lautakunta*	Tax class — *Veroluokka* IA n	 IA VP, %	 IB n	 IB VP, %	 II n	 II VP, %	 III+IV n	 III+IV VP, %	Total *Yht.* n	 VP, %	Remeasured *Uudestaan mitatut* VP, %
0 Ahvenanmaa	18[1]	18[2] 25[3]	33	14 18	14	9 31	1	0 100	66	14,1 23,3	
1 Helsinki	327	22 29	184	20 28	161	10 15	51	6 18	723	18,3 25,4	32,4
2 Lounais-Suomi	332	8 14	421	7 12	155	7 15	41	3 10	949	7,3 13,3	17,7
3 Satakunta	213	4 7	584	5 9	246	5 11	25	0 4	1 068	4,8 9,2	6,1
4 Uusimaa-Häme	524	8 12	527	7 11	161	4 10	58	11 15	1 270	6,9 11,5	18,4
5 Pirkka-Häme	612	6 9	882	8 11	333	6 10	45	0 2	1 872	6,8 10,0	10,4
6 Itä-Häme	636	5 10	519	5 10	143	4 10	62	7 7	1 360	4,8 10,1	
7 Etelä-Savo	358	3 7	545	3 6	233	3 6	70	1 8	1 206	2,7 6,5	
8 Etelä-Karjala	349	6 13	595	3 8	155	6 15	27	3 25	1 126	4,2 10,8	9,7
9 Itä-Savo	171	1 4	403	2 5	89	2 8	15	0 8	678	1,7 5,5	
10 Pohjois-Karjala	214	1 4	1 025	2 4	420	3 6	132	3 6	1 791	2,4 4,7	
11 Pohjois-Savo	751	3 5	1 239	3 7	514	3 5	230	3 7	2 734	2,9 5,8	
12 Keski-Suomi	542	2 4	1 233	2 4	399	2 4	48	0 4	2 222	2,0 4,3	
13 Etelä-Pohjanmaa	88	2 3	453	3 7	282	3 6	118	3 5	941	3,0 6,2	
14 Vaasa	105	20 24	234	7 10	322	5 9	136	7 12	797	7,9 11,9	
15 Keski-Pohjanmaa	59	0 2	317	1 4	171	5 9	33	6 6	580	2,3 5,2	
Total *Yht.*	5 299	5,9 9,9	9 194	4,2 7,9	3 798	4,1 8,4	1 092	3,9 8,4	19 383	4,7 8,6	13,2

[1] Number of spruce sample trees — *Kuusikoepuita, kpl*
[2] The original NFI-rot frequency estimate — *Alkuperäinen VMI-lahoisuusarvio*
[3] The adjusted NFI-rot frequency estimate — *Korjattu VMI-lahoisuusarvio*

According to the results in Table 11, age was slightly better correlated with the butt-rot frequency than diameter in the NFI material. However, both dependences were weak, as was the case in the more restricted clear-cutting material (Table 9).

The original and adjusted butt-rot frequencies of the NFI sample trees are presented in Fig. 7 on the basis of the moving averages of 7 × 7 inventory blocks (56 km × 56 km). The areas which stand out the most with respect to the butt-rot frequency are the southern and south-western coasts, and the part of the west coast around Vaasa. The data in Fig. 7 agree rather well with the map made on the basis of the clear-cutting material (Fig. 6). The NFI material differs from the clear-cutting material in that it indicates that there is rather a lot of butt-rot inland, close to the city of Tampere. The butt-rot frequency in the rest of southern Finland is low.

323. Equations describing the butt-rot frequency

The butt-rot frequency is depicted in Tables 5. . .11 and Figs. 6 and 7 with respect to some variables. However, the butt-rot frequency could only be expressed in this way with respect to a maximum of two variables. For this reason, regression equations were also calculated using the values for the individual clear-cutting areas and the individual sample plots in the clear-cutting material, and the values for the individual sample trees in the remeasured NFI material.

The rot variables for the individual clear-cutting areas and the sample plots were mean values. Their distributions were skewed to the right.

	Clear-cutting areas (n=146) $\bar{x}$	s	Range
VP, %	18,36	11,22	3,8 . . .76,4
DP, %	8,25	6,68	0,98. . .38,2

Sample plots (n=2915)

$\bar{x}$	s	Range
17,98	19,88	0. . .100
7,93	10,61	0. . .65

Logistic models were calculated for both VP and DP after they had been divided by 100. The variables describing the tree stand were not included in the clear-cutting area equations (32.8) and (32.9). On the other hand, the clear-cutting areas were especially suitable for examining the relationship between the butt-rot frequency and the geographical location. The term degree of paludification used in the clear-cutting equations refers to the proportion of paludified sample plots, and the site index to the mean of the sample plots, when in the tax class IA H100 = 27 m, in IB H100 = 24 m, in II H100 = 21 m and in III H100 = 18 m.

(32.8) VP/100 = f/(1+f), where

$$\begin{array}{lll} f = \exp(7{,}15 & & \mathit{coeff./s.e.}^{1)} \\ & -0{,}0173\ \mathrm{LAT} & -6{,}7 \\ & -0{,}0666\ \mathrm{ELEV} & -13{,}1 \\ & -0{,}925\ \ \mathrm{PALUD} & -7{,}7 \\ & +0{,}159\ \ \mathrm{H100)} & 9{,}8 \end{array}$$

Table 11. Butt-rot frequency of the NFI spruce sample trees by diameter and age classes.
Taulukko 11. VMI-kuusikoepuiden tyvilahoisuus läpimitta- ja ikäluokittain.

Diameter of sample tree, cm *Koepuun läpimitta, cm*	Age of sample tree, a *Koepuun ikä, a* -40	-60	-80	-100	-120	121-	Mean *Keskim.*
	VP, %						
—10	1,3[1])	2,1	2,8	1,4	1,8	6,9	1,9
	2,9[2])	4,0	5,8	2,1	5,0	20,1	3,9
—15	1,1	4,1	3,8	2,1	1,5	3,4	3,3
	4,0	6,2	6,3	7,6	5,1	12,8	6,2
—20	3,0	4,2	4,6	4,4	3,8	3,7	4,2
	4,8	5,7	7,1	7,9	10,8	12,7	7,2
—25	3,4	4,0	5,0	4,8	3,9	6,4	4,7
	5,4	7,5	8,6	9,0	9,4	15,0	8,9
—30	3,2	3,9	5,1	5,1	6,3	7,1	5,2
	3,2	7,6	9,3	10,3	10,2	17,4	10,1
—35	0,0	4,6	7,2	6,9	7,3	10,9	7,0
	0,0	5,7	10,6	11,8	12,0	22,5	11,5
35,1—	0,0	2,3	3,7	7,3	7,3	11,3	6,0
	0,0	6,3	6,4	12,5	12,9	23,7	10,9
Mean	1,7	3,8	4,9	5,3	5,3	7,0	4,7
Keskim.	3,7	6,3	8,2	9,9	10,4	17,1	8,6

[1]) The original NFI rot frequency estimate — *Alkuperäinen VMI-lahoisuusarvio*

[2]) The adjusted NFI rot frequency estimate — *Korjattu VMI-lahoisuusarvio*

(32.9) DP/100 = f/(1+f), where

$$\begin{array}{lll} f = \exp(6{,}57 & & \mathit{coeff./s.e.}^{1)} \\ & -0{,}0179\ \mathrm{LAT} & -5{,}0 \\ & -0{,}0855\ \mathrm{ELEV} & -11{,}8 \\ & -1{,}06\ \ \ \mathrm{PALUD} & -6{,}2 \\ & +0{,}167\ \ \mathrm{H100)} & 7{,}5 \end{array}$$

n = 146

[1]) coefficient/standard error

The most important independent variable in both equations was the elevation above sea level (see Fig. 8). According to Eq. (32.8), the butt-rot frequency decreases on average by 13 %-units on moving from sea level to a height of 100 m. The second most important independent variable was the tax class, represented here by H100. The difference between the tax classes in the butt-rot frequency was 6. . .9 %-units. According to these equations, butt-rot was most common in the southern parts of the study area, close to sea level on fertile and non-paludified sites.

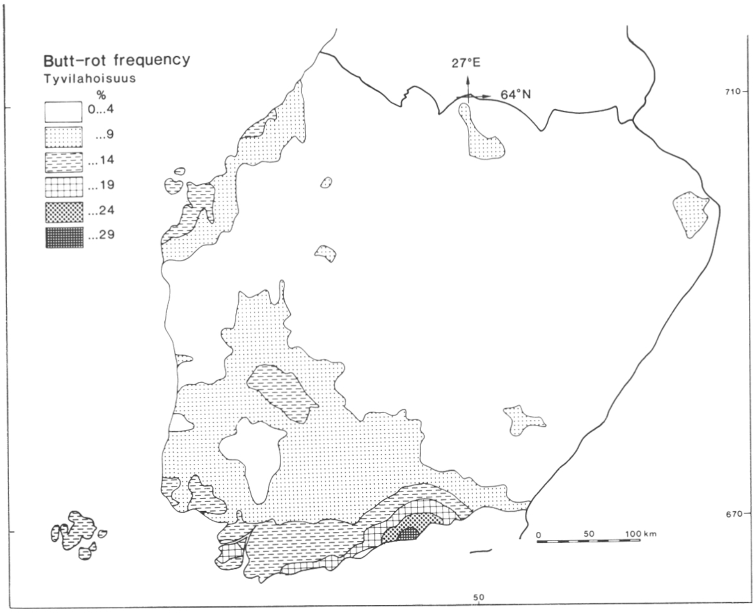


Fig. 7a. Butt-rot frequency of spruces according to the original NFI data. The map is based on moving averages of the spruce sample trees in 7×7 inventory blocks (56 km × 56 km).

Kuva 7a. Kuusen tyvilahoisuus alkuperäisten VMI-havaintojen mukaan. Kartta perustuu liukuviin keskiarvoihin, jotka on laskettu 7×7 inventointilohkon (56 km × 56 km) kuusikoepuiden perusteella.

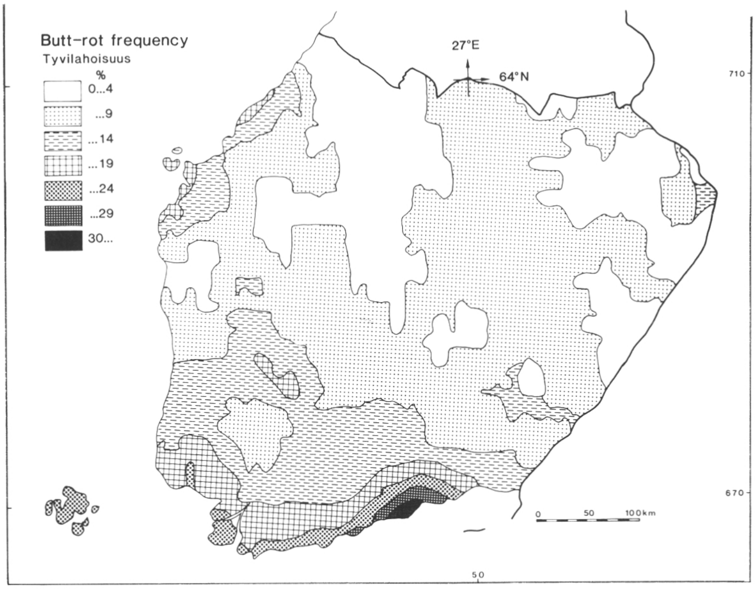


Fig. 7b. Butt-rot frequency of spruces according to the adjusted NFI data. The map is based on moving averages of the spruce sample trees in 7×7 inventory blocks. The butt-rot frequency has been corrected with the help of Eq. (32.12).

Kuva 7b. Kuusen tyvilahoisuus muunnettujen VMI-havaintojen mukaan. Kartta perustuu liukuviin keskiarvoihin, jotka on laskettu 7×7 inventointilohkon kuusikoepuiden perusteella. Lahofrekvenssiä on korjattu yhtälön (32.12) avulla.

As can be seen from Fig. 9, for instance, Eqs. (32.8) and (32.9) were not very reliable. The equations appeared to give overestimates for stands with a low rot frequency, and underestimates for stands with a high rot frequency. One reason for this might be the poor distributions of the predicting variables (see e.g. Fig. 2), and another the pure inadequacy of the models.

Equations (32.10) and (32.11) prepared for the individual sample plots explained less than 10 % of the variance of the butt-rot variables. However, the equations also indicated the increasing effect of site fertility on the abundance of butt-rot, and the decreasing effect of stoniness and paludification (cf. Table 8). In addition, the steepness of the slope also seemed to be positively correlated with the rot abundance.

(32.10) VP/100 = f/(1+f), where

f = exp (12,0		*coeff./s.e.*
—0,0199	LAT	—34,5
—0,0644	ELEV	—56,5
+0,229	SLOPE	26,4
+0,340	BON1	30,3
—0,418	PALUD	—29,1
—0,238	STONES	—18,8
+0,0508	T	15,9
+0,00392	G)	4,2

(32.11) DP/100 = f/(1+f), where

f = exp (11,3		*coeff./s.e.*
—0,0197	LAT	—24,4
—0,0795	ELEV	—48,6
+0,253	SLOPE	21,5
+0,312	BON1	20,2
—0,500	PALUD	—23,6
—0,290	STONES	—16,1
+0,0196	T)	4,4

n = 2 915

Interpretation of the regression coefficients for the stand characteristics was difficult because of the strong intercorrelations. However, the basal area of the spruces was clearly the best variable. The mean diameter alone did not explain the butt-rot frequency at all, and together with the basal-area the regression coefficient of the mean diameter was negative (Basham 1973, Norokorpi 1979, cf. Table 9).

The equation (32.12) mentioned earlier was calculated on the basis of the remeasured NFI sample trees. The butt-rot defectiveness of the sample trees (0 or 1) was used as the dependent variable. The ability of the equation to distinguish between sound trees and those affected by rot is described in Section 36. Only the regression coefficients of this logistic model are presented here.

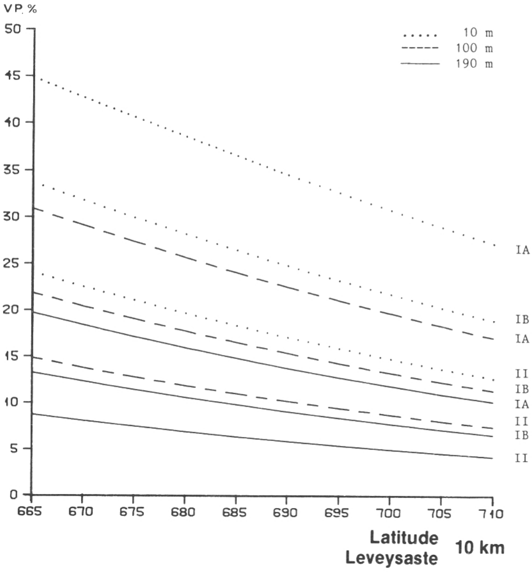


Fig. 8. Butt-rot frequency of spruces in the clear-cutting areas as a function of latitude, elevation and tax class according to Eq. (32.8).
Kuva 8. Kuusen tyvilahoisuus avohakkuuleimikoissa leveysasteen, korkeuden ja veroluokan funktiona yhtälön (32.8) mukaan.

(32.12) Probability (DD>0) = f/(1+f), where

f = exp (—4,20		*coeff./s.e.*
+0,0527	TEMP	3,75
—0,482	PALUD	—1,77
+0,244	TAX1	1,30
+0,0244	t	5,90
—8,11	d/d_s)	—5,23

n = 1 226

The graph of Eq. (32.12) has been plotted as a function of age, effective cumulative temperature and paludification in Fig. 10. The figure gives only an approximate picture of the real situation as the equation was rather unreliable. The butt-rot probability appears to increase sharply after the trees have reached the age of 100 years (cf. Norokorpi 1979). Of the sample tree characteristics in addition to age, only the diameter ratio d/d_s explained the butt-rot frequency to a significant degree. As was to be expected, its regression coefficient was negative (cf. Arvidson 1954).

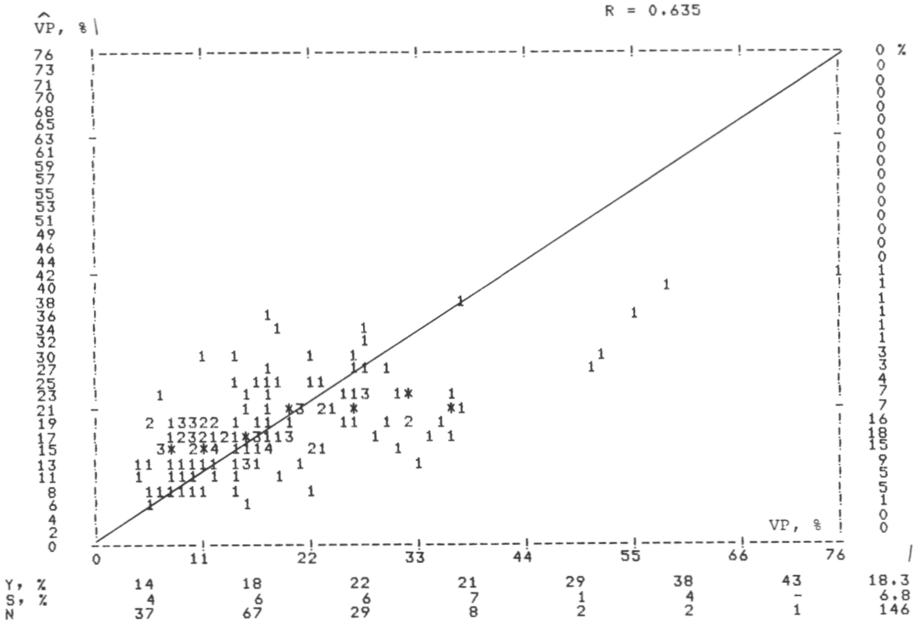


Fig. 9. Correlation between the observed and estimated (Eq. 32.8) butt-rot frequencies for clear-cutting stands.

Kuva 9. Havaittujen ja yhtälöllä (32.8) ennustettujen leimikkokohtaisten tyvilahofrekvenssien korrelaatio.

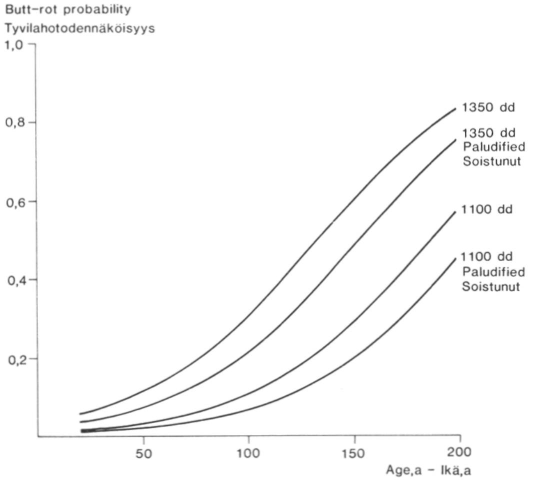


Fig. 10. Butt-rot probability of spruces as a function of age, effective cumulative temperature and paludification according to Eq. (32.12) in the NFI material.

Kuva 10. Kuusten tyvilahotodennäköisyys iän, lämpösumman ja soistuneisuuden funktiona yhtälön (32.12) mukaan VMI-aineistossa.

324. The spatial arrangement of the butt-rot spruces

Butt-rot has been found to occur in a clusterwise fashion (Kangas 1952, Zycha 1967), in the same way as, for instance, *H. annosum* damage in Scots pine stands (Laine 1976). As cluster sampling was applied in this study, it was considered to be worth estimating the spatial arrangement of the butt-rot spruces and the distribution of the variance of the rot parameters in the components within and between the clusters.

The spatial arrangement can be described by a parameter $s^2/\bar{x}$, i.e. by the ratio of the variance and the mean value of the number of individual trees per sample plot. If this ratio is 1, the distribution is random, i.e. a Poisson distribution. If the ratio is greater than 1, the individual trees are distributed in a clusterwise fashion, and the greater the degree of clustering, the larger is the value of the ratio (Greig-Smith 1964). All the spruces in the clear-cutting area material occurred clusterwise, the ratio $s^2/\bar{x}$ being 1,9,

Table 12. Randomness of the spatial distribution of butt-rot spruces in the clear-cutting material.
Taulukko 12. Tyvilahokuusien tilajärjestyksen satunnaisuus leimikkoaineistossa.

No. of spruces/sample plot *Kuusia/koeala*		No. of butt-rot spruces/sample plot *Tyvilahokuusia/koeala* 0	1	2	3	4	5	6	7+	Tot. *Yht.*	χ^2
5	obs. *hav.*	92	62	25	12	10				201	
($\bar{x}$ = 0,936)	exp. *od.*	78,9	73,8	34,5	10,8	3,0				201,0	23,1***
10	obs. *hav.*	70	86	50	32	10	9	6		263	
($\bar{x}$ = 1,54	exp. *od.*	56,2	86,7	66,9	34,5	13,3	4,1	1,3		263,0	31,5***
15	obs. *hav.*	18	23	22	11	12	5	3	9	103	
($\bar{x}$ = 2,57)	exp. *od.*	7,9	20,2	26,0	22,3	14,3	7,4	3,2	1,7	103,0	52,2***
19+20+21	obs. *hav.*	10	23	20	8	4	2	3	11	81	
($\bar{x}$ = 2,94)	exp. *od.*	4,3	12,6	18,5	18,1	13,3	7,9	3,9	2,4	81,0	63,8***

Expected frequency
Odotettu frekvenssi $= n\frac{(\bar{x})^k}{k!}e^{-\bar{x}}$,

where n = number of sample plots — *koealoja, kpl*
missä k = number of butt-rot spruces/sample plot — *tyvilahokuusia/koeala*
$\bar{x}$ = mean number of butt-rot spruces/sample plot
tyvilahokuusia keskimäärin koealaa kohti

and the butt-rot spruces even more so, $s^2/\bar{x}$ being 2,2. The distribution of the spruces on the individual sample plots was also skewed to the right, the mean being 10,2, the mode 8 spruces/sample and the range 1. . .38 spruces/sample plot. There was slight, negative correlation between the number of spruces and the butt-rot frequency, although it was not significant according to Equations (32.10) and (32.11). The randomness of the distribution of the butt-rot spruces was tested on sample plots where there were 5, 10, 15 or 20 spruces (Table 12).

The distribution of the butt-rot spruces digressed, independently of the stand density, from a random distribution, and especially at the beginning and end of the distribution. In addition, it appeared that the degree of clustering increased as the stand density increased.

The distribution of the variance of some variables depicting the abundance of butt-rot in different components was estimated on the basis of the clear-cutting material (Table 13). A cluster comprised 20 sample plots in a clear-cutting stand.

Table 13. The variances between and within the clear-cutting areas and the intra-class correlation of some butt-rot variables.
Taulukko 13. Eräiden lahomuuttujien leimikoiden välinen ja sisäinen varianssi ja sisäkorrelaatio.

Variable *Muuttuja*		Mean *Keski-arvo*	Variance *Varianssi* s_b^2	s_w^2	Intra-class correlation *Sisä-korrelaatio* ω
Decayed wood *Lahoa puuta*	m³/ha	2,03	7,2	13,9	0,306
DP, %		7,93	37,6	74,9	0,299
VP, %		18,0	115	280	0,253
NP, %		17,7	105	243	0,266

$$\omega = \frac{s_b^2 - s_w^2 / (m-1)}{s^2},$$ where
missä

s_b^2 = variance between clusters — *rypäiden välinen varianssi*

s_w^2 = variance within clusters — *rypäiden sisäinen varianssi*

$s^2 = s_b^2 + s_w^2$ and
ja

m = cluster size, i.e. number of sampling units/cluster

ryväskoko, ts. otosyksiköitä/ryväs

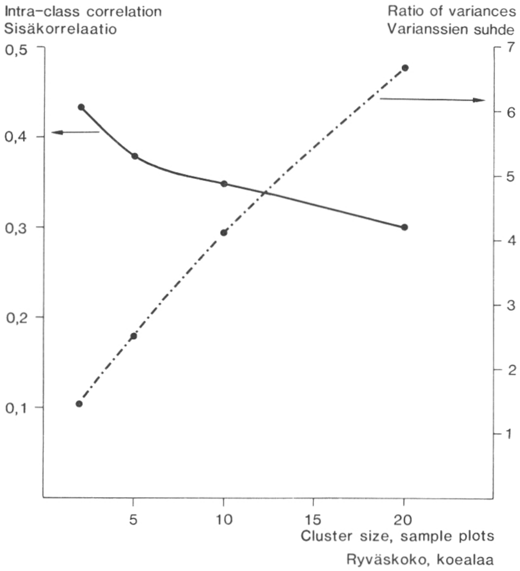


Fig. 11. The intra-class correlation of the relative butt-rot diameter, DP, and the ratio between the variances of cluster and simple random sampling, $\mathrm{Var}_{CS}/\mathrm{Var}_{SRS} = 1 + (m\text{-}1)\ \omega$, as a function of cluster size.

Kuva 11. Tyvilahon suhteellisen läpimitan, DP, sisäkorrelaatio ja ryväsotannan ja yksinkertaisen satunnaisotannan varianssien suhde, $Var_{CS}/Var_{SRS} = 1 + (m\text{-}1)\ \omega$, *ryväskoon funktiona.*

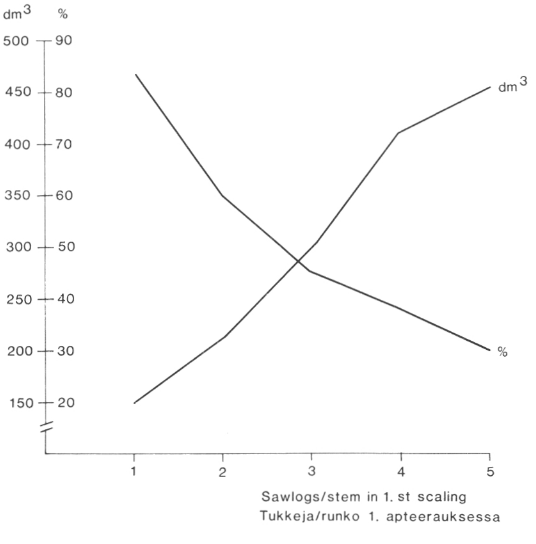


Fig. 12. Loss in saw-timber yield as a function of theoretical log number in the rot-defected saw-timber stems.

Kuva 12. Tukkipuun väheneminen teoreettisen tukkiluvun funktiona lahoilla tukkipuilla.

The intra-class correlations were quite high — the possible range in this case —0,05. . .+1, i.e. the clear-cutting areas were internally relatively homogeneous, the conditions favouring a small cluster size, i.e. only a few sample plots/cluster. The situation was examined in more detail using the relative rot diameter. The intra-class correlation of the variable DP was calculated on the basis of a few cluster sizes, and the variance ratio $\mathrm{Var}_{CR}/\mathrm{Var}_{SRS} \cong 1+(m—1)\ \omega$ was calculated using Formula (32.8) (see Fig. 11). As the intra-class correlation decreased slowly with respect to the increase in the cluster size, the variance of cluster sampling in comparison to that of simple random sampling increased very strongly as the cluster size increased (cf. Seppälä 1971).

The number of sample plots on each clear-cutting area varied from 10. . .25, the average being 20 sample plots. A slight negative correlation was found between the variables depicting the abundance of butt-rot and the number of sample plots in the clear-cutting area. The small clear-cutting areas, as well as being more infected with butt-rot, were also more fertile sites.

33. Butt-rot and the yield of timber assortments

The felled sample trees in the clear-cutting material were scaled analytically into timber assortments. The proportions of timber assortments were estimated for the stumps using Eqs. (22.3) and (22.4). The reduction in the saw-timber yield resulting from butt-rot was the largest in absolute terms in the case of large sample trees. In relative terms, however, the greatest loss occurred in the case of the small sample trees (Fig. 12), since in many cases the loss was 100 %. On the other hand, it was usually possible to obtain logs from larger stems, despite decay, although the absolute loss was large. Equations (33.1) and (33.2) were used in estimating the saw-timber reduction for the stumps in the clear-cutting material. Equation (33.1) was used in an attempt to distinguish those decayed saw-timber stumps which, after taking the decay into account, did not yield any logs, i.e. those trees whose reduction in saw-timber was 100 %. The saw-timber reduction of the other saw-timber trees was estimated using Eq. (33.2). The

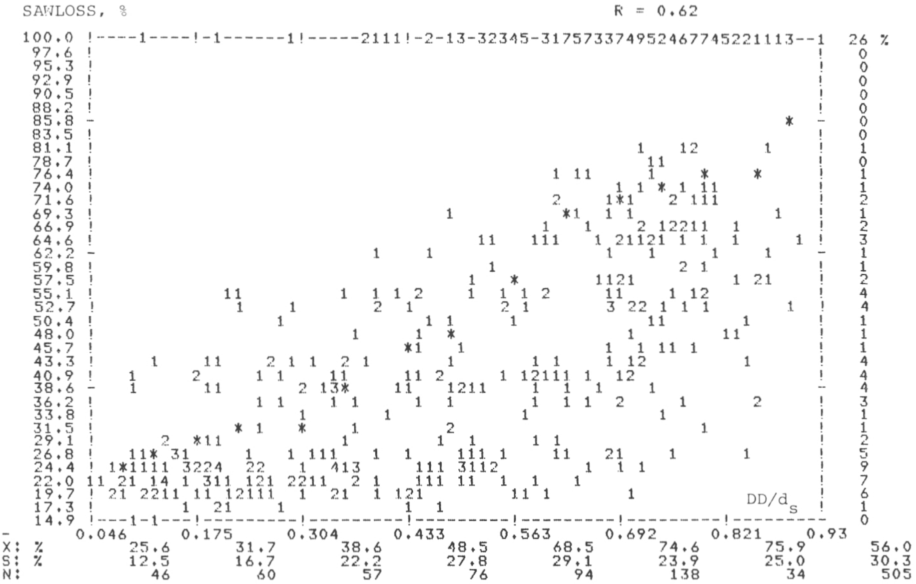


Fig. 13. Correlation between the relative rot diameter and the loss in saw-timber yield.
Kuva 13. Lahon suhteellisen läpimitan ja tukkipuun vähenemisen korrelaatio.

model prepared for all the decayed saw-timber trees gave illogical reduction percentages of over 100 %, or reduction percentages which did not occur in the material — 83. . .99 % (see Fig. 13). These cases were eliminated using the logistic model (33.1) and the reduction model proper (33.2).

(33.1) Probability (SAWLOSS = 100 %) = f/(1+f), where

	coeff./s.e.
f = exp (—11,06	
+4853/d_s	9,10
+6,88 DD/d_s	7,22
+1,69 DC)	4,45
n = 505	

As the enclosed values show, Equation (33.1) was relatively reliable. The classification was successful in 80 % of the cases.

Observed	Estimated with equation 0	1	Total
0	323	51	374
1	51	80	131
Total	374	131	505

where 0 = loss in saw-timber < 100 %
1 = loss in saw-timber = 100 %

Equation (33.1) was used cumulatively in the same way as the earlier presented equations (22.3) and (32.12).

(33.2) y = ln SAWLOSS

Variable	*Coefficient*	*t-value*	
Constant¹)	2,354	11,0***	R^2=0,50
DC	0,1687	4,6***	
$1/\sqrt{d_s}$	3,845	3,3***	s_{est}=31 %
$DD/\sqrt{d_s}$	0,1920	15,4***	n = 374

¹) $s_f^2/2$ added

Equation (33.3) was prepared for estimating the proportion of rot-affected pulpwood in individual stems.

(33.3) y = ln PULP

Variable	*Coefficient*	*t-value*	
Constant¹)	2,832	63,6***	R^2=0,61
DC	0,1884	6,4***	
$1/d_s$	5,247	4,9***	s_{est}=30 %
$(DD/d_s)^2$	2,923	3,4***	
arctan $(DD/d_s)^2$	4,981	5,0***	n = 643

¹) $s_f^2/2$ added

The rather large residual variance of Eq. (33.3) was presumably due to both the va-

Table 14. Loss in saw-timber yield and the proportion of decay-affected pulpwood by forestry board district and by tax class in the clear-cutting material.

Taulukko 14. Tukkipuun väheneminen ja lahokuitupuun osuus piirimetsälautakunnittain ja veroluokittain leimikkoaineistossa.

Forestry board district *Piirimetsälautakunta*	Characteristic *Tunnus*	Tax class — *Veroluokka* IA	IB	II+III	Mean *Keskim.*
1 Helsinki	SAWLOSS, %	20,6	15,5	12,3	17,0
	PULP, %	17,1	12,3	8,7	13,7
2 Lounais-Suomi	SAWLOSS, %	8,2	7,9	9,1	8,2
	PULP, %	7,6	6,1	6,4	6,6
3 Satakunta	SAWLOSS, %	30,1	8,9	5,9	12,8
	PULP, %	21,3	7,1	4,6	9,7
4 Uusimaa-Häme	SAWLOSS, %	9,8	7,2	5,8	8,1
	PULP, %	8,1	5,8	4,7	6,6
5 Pirkka-Häme	SAWLOSS, %	8,1	5,0	4,9	5,7
	PULP, %	6,4	4,1	3,6	4,6
6 Itä-Häme	SAWLOSS, %	8,4	7,6	4,7	7,6
	PULP, %	6,6	5,9	4,0	5,9
14 Vaasa	SAWLOSS, %	9,7	10,6	7,4	9,0
	PULP, %	7,6	8,0	4,8	6,5
Mean — *Keskim.*	SAWLOSS, %	11,6	7,4	6,6	8,5
	PULP, %	9,7	6,2	5,0	6,7

riation in the height of the rot column and the steps caused by two-meter- long butt logs in the dependent variable.

The timber assortment characteristics were estimated for all the stumps using Eqs. (22.4) and (33.1) — (33.3), and after that for the individual sample plots and clear-cutting areas. Owing to the uncertain nature of the method used, only the most important characteristics were treated: the loss in the saw-timber yield and the proportion of decay-affected pulpwood (Table 14).

The loss in saw-timber and the proportion of decay-affected pulpwood was calculated in the same way as the values in Table 6 for different tax classes and forestry board districts. According to Table 14, the greatest loss in saw-timber caused by butt-rot occurred in the Helsinki Forestry Board District. The next highest loss, in Satakunta, was partly due to the high butt-rot frequency, and partly to the small mean diameter, especially in Tax class IA. Equations (33.4) and (33.5) were calculated for the clear-cutting stands in order to predict the loss in saw-timber yield as a function of the mean diameter and the abundance of the butt-rot.

(33.4) $y = \mathrm{SAWLOSS}/\mathrm{VP}$

Variable	*Coefficient*	*t-value*	
Constant	0,682	16,9***	$R^2=0{,}53$
D_g	—0,01577	—10,7***	$s_{est}=15$ %
$\sqrt{\mathrm{VP}}$	0,04375	9,4***	$n = 145$

$\widehat{\mathrm{SAWLOSS}} = \hat{y}\ \mathrm{VP}$

(33.5) $y = \mathrm{SAWLOSS}/\sqrt{\mathrm{DP}}$

Variable	*Coefficient*	*t-value*	
Constant	0,843	6,0***	$R^2=0{,}83$
$\sqrt{\mathrm{DP}/D_g}$	3,675	11,4***	$s_{est}=15$ %
$(\mathrm{DP}/D_g)^2$	0,5665	2,4*	$n = 145$

$\widehat{\mathrm{SAWLOSS}} = \hat{y}\ \sqrt{\mathrm{DP}}$

Equations (33.4) and (33.5) were rather reliable in their own data. One clear-cutting area which differed from the others was omitted. The mean diameter of the spruces in this clear-cutting area was 14 cm, the butt-rot frequency 5 %, and the loss in saw-timber 14 %. Estimation of the effect of butt-rot was clearly less certain in small-diameter spruce stands than in the case of spruce stands comprising larger-sized trees (cf. Nyyssönen and Ojansuu 1982). According to Fig. 14, the loss in saw-timber

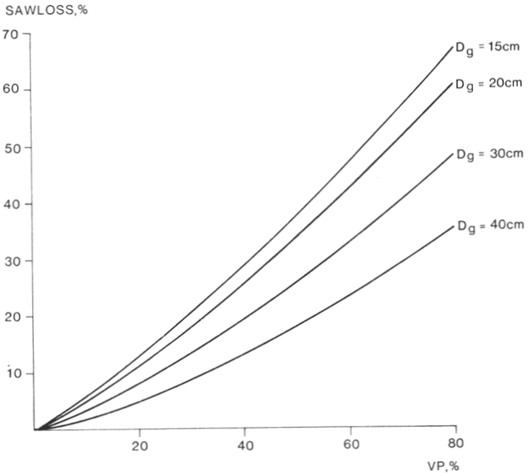


Fig. 14. Loss in saw-timber yield as a function of the butt-rot frequency and the mean diameter of spruces according to Eq. (33.4) in the clear-cutting material.
Kuva 14. Tukkipuun väheneminen kuusten lahofrekvenssin ja keskiläpimitan funktiona yhtälön (33.4) mukaan leimikkoaineistossa.

was relatively the smaller, the larger was the diameter. However, the absolute loss was largest in spruce stands containing large trees (see also Fig. 12).

The following values were obtained when the loss in saw-timber yield in each forestry board district was estimated using Eqs. (33.4) and (33.5) on the basis of the butt-rot frequencies presented in Table 6 and the mean diameters obtained from the 7th National Forest Inventory:

	Forestry Board District 1	2	3	4	5	6	14
	Loss in saw-timber due to butt-rot, %						
Table 14	17,0	8,2	12,8	8,1	5,7	7,6	9,0
Eq. (33.4)	18,6	8,0	12,1	8,6	6,0	7,6	9,0
Eq. (33.5)	17,2	9,0	12,2	8,2	5,9	7,7	8,8
Mean diameter, cm[1])	26,4	24,7	24,3	27,3	26,3	27,2	21,2

[1]) Kuusela and Salminen 1980, 1983.

These estimates probably better represent all the mature spruce stands in the study area than the values given in Table 14, even though the differences are small.

34. Butt-rot and the stumpage value of spruce

The effect of butt-rot on the stumpage value of spruce was studied using two different price ratios (see Section 222). The rot variable which showed the form of rot-affected spruces to be worse than that of sound trees was included already in the value equations (22.5) and (22.6). The effect of butt-rot proper on the value for individual stems was estimated using Eqs. (34.1) — (34.3). The equations for rot-affected saw-timber stems were less reliable than the pulpwood equation. On the other hand, the prediction error of the saw-timber equations was greatest as regards small-sized saw-timber stems.

(34.1) $y = \ln \text{VALLOSS1}$

Variable	*Coefficient*	*t-value*	
Constant[1])	1,574	14,1***	$R^2=0{,}54$
$1/d_s$	30,95	10,0***	
$DD/\sqrt{d_s}$	0,2398	18,0***	$s_{est}=35\ \%$
DC	0,2525	6,5***	n = 505 rot-affected saw-timber stems

(34.2) $y = \ln \text{VALLOSS2}$

Variable	*Coefficient*	*t-value*	
Constant[1])	1,202	10,5***	$R^2=0{,}53$
$1/d_s$	26,55	8,5***	
$DD/\sqrt{d_s}$	0,2381	17,7***	$s_{est}=35\ \%$
DC	0,2512	6,3***	n = 505 rot-affected saw-timber stems

[1]) $s_f^2/2$ added

(34.3) $y = \sqrt{\text{VALLOSS1}}$

Variable	*Coefficient*	*t-value*	
Constant	0,867	6,1***	$R^2=0{,}46$
$1/d_s^2$	207	8,7***	$s_{est}=28\ \%$
DD	0,0709	10,4***	n = 138 rot-affected pulpwood stems

$\widehat{\text{VALLOSS1}} = \hat{y}^2 + 0{,}11.$

The average loss in the stumpage value caused by butt-rot was 32 % (100:40:36) and 19 % (100:60:60) in the case of rot-affected saw-timber stems. The mean loss in value for pulpwood trees was only 5 % (40:36). The loss in the stumpage value of pulpwood trees was very small, both in relative and absolute terms. The loss in the stumpage value of the spruces caused by butt-rot can be almost completely explained on the basis of the saw-timber trees.

The loss in the stumpage value of spruces caused by butt-rot was estimated for each forestry board district and tax class (Table 15). The value of spruce appeared to de-

Table 15. Loss in stumpage value of the spruces as a consequence of butt-rot by forestry board district and tax class in the clear-cutting material.
Taulukko 15. Kuusten kantoarvon aleneminen tyvilahon takia piirimetsälautakunnittain ja veroluokittain leimikkoaineistossa.

Forestry board district *Piirimetsä-lautakunta*	Relative prices *Suht. hinnat*[1]	Tax class — *Veroluokka* IA	IB	II—IV	Mean *Keskim.*
		Loss in value *Arvon aleneminen* %			
1 Helsinki	1	12,5	9,1	6,7	10,1
	2	7,7	5,5	3,9	6,1
2 Lounais-Suomi	1	5,0	4,5	4,9	4,7
	2	2,9	2,7	2,9	2,8
3 Satakunta	1	15,4	5,2	3,5	7,1
	2	8,7	3,1	2,1	4,1
4 Uusimaa-Häme	1	5,8	4,2	3,4	4,5
	2	3,5	2,5	2,0	2,7
5 Pirkka-Häme	1	4,8	2,9	2,6	3,4
	2	2,9	1,8	1,5	2,0
6 Itä-Häme	1	4,9	4,3	2,8	4,4
	2	3,0	2,6	1,7	2,6
14 Vaasa	1	5,7	5,7	3,4	4,7
	2	3,4	3,3	1,8	2,6
Mean - *Keskim.*	1	6,9	4,5	3,7	4,8
	2	4,2	2,7	2,1	2,9

[1] 1 = 100:40:36
2 = 100:60:60

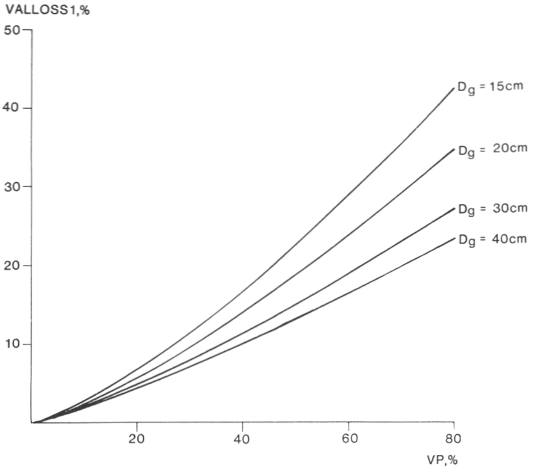


Fig. 15. Loss in stumpage value of spruces as a function of butt-rot frequency and mean diameter according to Eq. (34.4) in the clear-cutting material.
Kuva 15. Kuusten kantoarvon aleneminen tyvilahofrekvenssin ja keskiläpimitan funktiona yhtälön (34.4) mukaan leimikkoaineistossa.

crease rather slightly as a result of butt-rot. As, in addition, there was a large admixture of other tree species — on average 14 % — in the clear-cutting areas, the value of the whole stand decreased to a relatively smaller degree than that of the spruces. However, the tree species mixture did not alleviate the absolute loss in value. Although the relative loss in value was on the average slight, the loss in individual cases exceeded 20 % which, especially in the case of large-dimensioned stands, means a marked absolute loss.

Equations (34.4) and (34.5), which were calculated using the values for the individual clear-cutting areas, can be used to predict the loss in the stumpage value of spruces in a stand when the mean diameter and butt-rot frequency of the spruces are known.

(34.4) $y = \mathrm{VALLOSS1}/\sqrt{\mathrm{VP}}$

Variable	*Coefficient*	*t-value*	
$\sqrt{\mathrm{VP}}$	0,1478	12,6***	$R^2=0{,}87$
$\sqrt{\mathrm{VP}/D_g}$	0,6448	10,1***	$s_{est}=16$ %
			n = 146

(34.5) $y = \mathrm{VALLOSS2}/\sqrt{\mathrm{VP}}$

Variable	*Coefficient*	*t-value*	
$\sqrt{D_g}$	—0,05413	—9,1***	$R^2=0{,}87$
$\sqrt{\mathrm{VP}}$	0,2183	30,5***	$s_{est}=18$ %
			n = 146

Fig. 15 was drawn on the basis of Equation (34.4). The effect of the mean diameter was relatively small, although statistically significant. In addition to the butt-rot frequency, the mean diameter and the price ratio of the timber assortments, the loss in value also depends on the amount of rot per tree and on the scaling norms of the timber assortments. However, the relative rot diameter, DP, was only a slightly better predicting variable than the butt-rot frequency — the relative standard error of the equation in question was 14,4 %. An attempt was made to adjust the values in Table 15 with respect to the mean diameter of the 7th NFI using Table 6 and Eqs. (34.4) and (34.5). However the changes were small, as can be seen in the following set-up.

		Forestry board district 1	2	3	4	5	6	14
VALLOSS1, %	Table 15	10,1	4,7	7,1	4,5	3,4	4,4	4,7
	Eq. (34.4)	9,7	4,7	6,6	5,3	3,8	4,8	4,9
VALLOSS2, %	Table 15	6,1	2,8	4,1	2,7	2,0	2,6	2,6
	Eq. (34.5)	6,1	2,6	3,9	3,0	2,0	2,6	2,7

35. Butt-rot and the growth of the spruce stems

The relationship between butt-rot and the growth of the spruce stems was studied by measuring sample trees on circular sample plots in the clear-cutting areas and in four separate spruce stands.

An attempt was made to find pairs of sound and rot-affected spruces of similar age and size. However, too few of these "matched pairs" were obtained, and therefore the sound and rot-affected trees were compared as groups.

There were 160 butt-rot affected and 202 sound sample trees in the heterogeneous clear-cutting material. According to the analysis of covariance, the groups differed most clearly from each other as regards the relative volume increment and the stem form characteristic, d_6/d. The average dependence of the relative volume increment percentage and the relative diameter at six meters on the relative rot diameter is shown in Fig. 16.

Butt-rot appeared to be associated with decreased growth, especially in the upper part of the stem. The stand sample plots, being more homogeneous as regards age and size of the spruces, were used in order to confirm this observation. According to the t-test, the sound and rot-affected sample trees differed from each other only with respect to the diameter ratios d/d_s and d_6/d in the following set-up.

	Sound		Rot-affected	
n	138		80	
d, cm	24,7		24,9	
h, m	20,7		20,4	
t, a	90		89	
d/d_s	0,797	$>$	0,776	t=3,45***
d_6/d	0,846	$>$	0,830	t=2,85**

Regression models (35.3) — (35.6) were used to estimate the effect of butt-rot on the growth and form of the stem (see Fig. 17).

(35.3) $y = d$

Variable	*Coefficient*	*t-value*	
Constant	0,597		$R^2 = 0,97$
d_s	0,777	77,7***	n = 218
DD/d_s	—0,0131	—4,8***	

(35.4) $y = d_6$

Variable	*Coefficient*	*t-value*	
Constant	—1,11		$R^2 = 0,98$
d	0,895	107***	n = 218
$(DD/d_s)^2$	—0,0135	—5,4***	

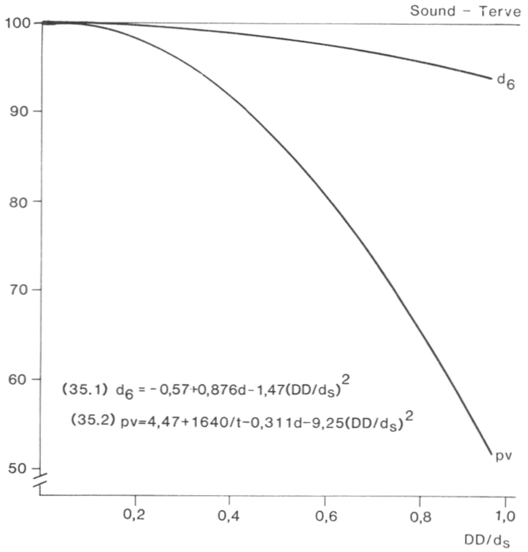


Fig. 16. The stem diameter d_6 and the volume increment percentage expressed in relative values as a function of the relative decay diameter according to Eqs. (35.1) and (35.2) in the clear-cutting material (n=362).

Kuva 16. Läpimitta d_6 ja tilavuuskasvuprosentti suhteellisina arvoina lahon suhteellisen läpimitan funktiona yhtälöiden (35.1) ja (35.2) mukaan leimikkoaineistossa (n=362).

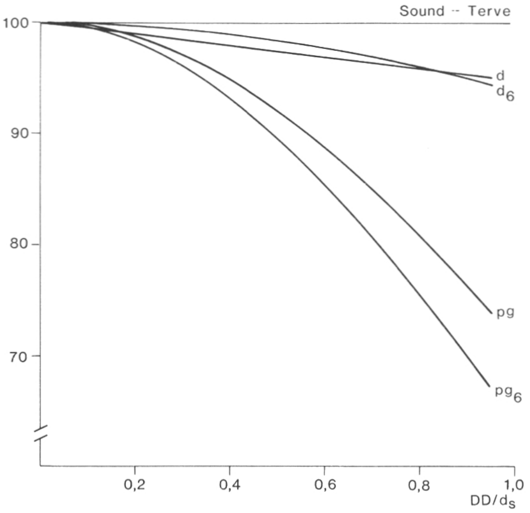


Fig. 17. The stem diameters d and d_6 and the basal-area increment percentages pg and pg_6 expressed in relative values as a function of the relative decay diameter according to Eqs. (35.3) ... (35.6) on the stand sample plots.

Kuva 17. Läpimitat d ja d_6 ja pohjapinta-alan kasvuprosentit pg ja pg_6 suhteellisina arvoina lahon suhteellisen läpimitan funktiona yhtälöiden (35.3) ... (35.6) mukaan metsikkökoealoilla.

For illustrative purposes, the diameters were chosen as the dependent variables in Eqs. (35.3) and (35.4), and not the diameter ratios d/d_s or d_6/d which are approximately independent of the diameters of the stem. In this case the same rot variables would have been the best predictors.

(35.5) $y = \ln pg$

Variable	*Coefficient*	*t-value*	
Constant¹)	0,262		
$\ln pg_{11-20}$	0,630	15,5***	$R^2 = 0,60$
$(DD/d_s)^2$	—0,334	—3,7***	$n = 218$
g	—0,000292	—4,0***	

(35.6) $y = \ln pg_6$

Variable	*Coefficient*	*t-value*	
Constant¹)	0,483		
$\ln pg_{11-20}$	0,583	13,2***	$R^2 = 0,55$
$(DD/d_s)^2$	—0,444	—4,6***	$n = 218$
g_6	—0,000459	—4,4***	

¹) $s_f^2/2$ added.

Although the important variables which depict the environment around the trees were not included in Eqs. (35.5) and (35.6) (cf. Thies 1983), it appeared that butt-rot reduced the growth of spruce approximately in proportion to the relative rot area at the stump, and that growth in rot-affected spruces was concentrated more in the butt part of the stem than it is in sound trees.

36. Detecting butt-rot in standing spruces

361. The stand sample plots

An attempt was also made to distinguish butt-rot spruces from sound ones, without having to fell them, on four stand sample plots and on 139 NFI sample plots.

The stand sample plots contained quite a lot of butt-rot, 37 %. On the other hand, the sound and rot-affected trees were quite similar as regards age and size (see Section 35).

In the discriminant analysis which was used, linear combinations of the original variables are determined that maximize the ratio of the between groups sum of squares to the within groups sum of squares in the analysis of variance of an arbitary linear combination. Discriminant analysis was first carried out with the variables describing the form and growth of the stem of the sample trees (Eq. 36.1).

(36.1)

Variable	Coefficient	Coefficient of the standardized variable
$d\text{-}d_6$	—1,20	—1,27
d/d_s	23,4	0,978
$d_s\text{-}d$	0,351	0,772
d_6/d	—16,9	—0,683
id_6/id	3,82	0,597
h/H	3,73	0,436
id	0,828	0,293
d	0,0414	0,268
h/d	2,55	0,254
id_{1-10}/id_{11-20}	0,794	0,215

Eigenvalue = 0,201
$\chi^2 = 38,8$***

The eigenvalue was low, although the discriminating power of the function was statistically highly significant. The variables describing the form of the stem appeared to be the most important. Classification using Function (36.1) succeeded as follows:

Actual classification¹)	Function classification Sound	Butt-rot	Total
Sound	100	38	138
Butt-rot	31	49	80
Total	131	87	218

¹) Classification from the face of the stump after felling

The success rate was 68 %, and a butt-rot frequency of 40 % was obtained instead of the correct value of 37 %. The success of classification is depicted in the light of the number of butt-rot cases detected using Eq. (36.1) in Table 16.

Table 16. Characteristics of the butt-rot columns detected and undetected with the help of Eq. (36.1).
Taulukko 16. Yhtälöllä (36.1) havaittujen ja havaitsematta jääneiden tyvilahoumien tunnuksia.

Butt-rot category *Tyvilahoryhmä*	Relative frequency *Suht. frekvenssi* %	Mean height *Keskipituus* dm	Height proportion *Pituusosuus* %	Mean volume *Keskitilavuus* dm³	Volume proportion *Tilavuusosuus* %
Detected *Havaitut*	61	39	78	79	79
Undetected *Ei-havaitut*	39	17	22	33	21
Total *Yhteensä*	100	31	100	61	100

The proportion of cases of butt-rot detected using the discriminant function (36.1) out of the total number of rots was 61 %. However, the proportion of the volume detected was 79 %. It was thus possible, using standard inventory measures, to detect a high proportion of the total number of rots (cf. Kallio and Tamminen 1974, p. 21). The sound trees which were incorrectly classified as being rot-affected ones were in most cases slower-growing trees or those of poorer form.

The second discriminant function (36.2) was calculated taking into account the increment cores.

(36.2)

Variable	Coefficient	Coefficient of the standardized variable
Butt core 1)	—3,64	—0,984
id_6/id	1,05	0,164
h/d	1,47	0,147
$d-d_6$	0,122	0,130
d_6/d	2,68	0,108
id_{1-10}/id_{11-20}	0,208	0,057
h/H	0,358	0,042
d/d_s	—0,602	—0,025

Eigenvalue = 2,02

$\chi^2 = 235^{***}$

1) sound = 0, butt-rot = 1

Function (36.2) was clearly better than Function (36.1). The butt core alone almost completely solved the problem of which group the tree belonged to. Application of discriminant function (36.2) succeeded as follows:

Actual classification 1)	Function classification Sound	Butt-rot	Total
Sound	135	3	138
Butt-rot	16	64	80
Total	151	67	218

1) Classification from the face of the stump after felling

The success rate was 91 %, and 31 % of the trees were estimated as being rot-affected using Function (36.2), the correct value being 37 %. This result is in agreement with those presented earlier (e.g. Dimitri 1968, Kallio and Tamminen 1974). The amount of butt-rot which was detected can be seen from Table 17.

80 % of the rot number was detected using discriminant function (36.2), and almost 100 % of the rot volume. However, it should be pointed out that even a smallish band of rot in a saw-timber stem usually results in the bucking of a two-meter-long bolt of pulpwood. In other words, the amount of rot does not have a smooth effect in individual cases, but instead has a strong stepwise effect e.g. on the saw-timber and stumpage yield. Taking increment cores proved to be a very effective technique for determining the butt-rot frequency in standing trees in this material. One important point, however, is that the field workers who carried out the work were very experienced.

Table 17. Characteristics of the butt-rot columns detected and undetected with the help of Eq. (36.2).

Taulukko 17. Yhtälöllä (36.2) havaittujen ja havaitsematta jääneiden tyvilahoumien tunnuksia.

Butt-rot category *Tyvilahoryhmä*	Relative frequency *Suht. frekvenssi* %	Mean height *Keskipituus* dm	Height proportion *Pituusosuus* %	Mean volume *Keskitilavuus* dm^3	Volume proportion *Tilavuusosuus* %
Detected *Havaitut*	80	37	96	76	99,5
Undetected *Ei-havaitut*	20	6	4	2	0,5
Total *Yhteensä*	100	31	100	61	100,0

362. The NFI sample trees

Rot defects in the NFI sample trees were determined by observing possible stem injuries and decay in the increment/age cores taken at breast height. New observations were made of injuries at the time when the 1 226 spruce sample trees were being inventoried. The stems were bored at breast and stump height, twice if the stump diameter was over 24 cm. The correspondence between the rot estimates of the inventory and those of the control measurements are shown in Table 18.

55 % of the butt-rot trees were detected in the inventory. According to the original NFI observations, the butt-rot frequency was 8,6 %, the correct value being 14,1 %. However, the original butt-rot trees accounted for 87 % of the amount of rot-affected wood in the inventory. In other words, the smallest rots were not detected during the inventory. On the other hand, the

Table 18. Reliability of the original NFI rot estimates in the light of the control estimates.
Taulukko 18. Alkuperäisten VMI-lahoarvioiden luotettavuus kontrolliarvioiden valossa.

Original NFI estimate *Alkuperäinen VMI-arvio*	Control estimate — *Kontrolliarvio*				
	Sound *Terve*	Injury+ decay *Vaurio+ lahoa*	Decay, no injuries *Lahoa, ei vauriota*	Injury, no decay *Vaurio, ei lahoa*	Total *Yhteensä*
	No. of observations — *Havaintoja, kpl*				
Sound *Terve*	973	20	54	37	1 084
Injury + decay *Vaurio + lahoa*	0	17	1	1	19
Decay, no injuries *Lahoa, ei vauriota*	8	13	64	1	86
Injury, no decay *Vaurio, ei lahoa*	2	2	0	22	26
Other defect *Muu tuho*	2	0	0	0	2
Possible butt-rot *Mahdollinen tyvilaho*	4	2	0	3	9
Total *Yhteensä*	989	54	119	64	1 226

control measurements were also done on the basis of the increment cores and part of the rots were not presumably detected either. Estimation of the volume of the rots done on the basis of the increment cores was quite unreliable and might give too good a picture of the precision of the NFI observations.

Equation (32.12) depicting the butt-rot frequency was prepared using those NFI sample trees where rot was detected in the butt (see Section 323). The discriminating ability of the equation can be seen from the following set-up.

Actual classification[1]	Function classification Sound	Rot	Total
Sound	943	125	1 068
Rot	125	33	158
Total	1 068	158	1 226

$\chi^2 = 10{,}3^{***}$

[1] Based on butt cores.

About 21 % of the number of rots were found using Eq. (32.12), and these trees accounted for 30 % of the total volume of decayed wood. Identification of the butt-rots was thus less successful when done without taking increment cores (cf. Eq. 36.1). Both the original inventory observations and Eq. (32.12) were utilized in estimating the rot frequency of all the NFI spruce sample trees. In addition to the spruces classified as being rot-affected in the inventory, the proportion of rots not detected in the inventory was estimated using Eq. (32.12). The constant of the equation was adjusted to yield the correct number of rots in the control material. The rot frequencies outside the control material are thus rough extrapolations as regards the remainder: total minus inventory rots. The use of the equation, independent of the inventory field observations, was regarded as being better than constant ratio correction, since the inventory classification of rot defects did not seem to be very homogeneous. In the control material, on the other hand, only 4. . .7 butt-rot affected spruces could be detected out of the 53 cases not detected in the inventory — totalling 1 121 spruces.

4. DISCUSSION

41. Methodology

The main material used in the study, the spruce-dominated clear-cutting areas, was selected subjectively. An attempt was made to improve their representativeness by means of stratification. Owing to the small number of clear-cutting areas, however, the accuracy of the results is not very high, especially with respect to the sub-areas. Despite this, a satisfactory overall picture was probably obtained about the occurrence of butt-rot (see Fig. 2). Comparison of the clear-cutting material and the NFI material gave support for the evaluation of the results. The number of sample plots measured in each clear-cutting area can be considered to be sufficient, bearing in mind the size of the clear-cutting areas. The small sample plots were homogeneous as regards the tree stand and site factors, and in practice were easy to delineate. Owing to the high variation and clusterwise distribution of the butt-rot, however, the use of fewer but larger sample plots would perhaps have been more effective. This view was substantiated when the regression models depicting the butt-rot frequency were being prepared (see Section 323).

Butt-rot trees were emphasized in the selection of the sample trees in the clear-cutting material. For this reason, rot variables which in a more representative material would hardly have been of any significance were included in the sample tree equations. On the other hand, inclusion of the rot variables perhaps reduced the systematic bias. There were only a few cases of large, economically most significant rots. Sampling with respect to the diameter or the predicted volume of the rot (Laasasenaho 1973, Kuusela 1979) would have produced a more representative sample with respect to the significance of the rots. The estimate of the relative frequency of the most important butt-rot fungus, *H. annosum,* would at the same time have become more accurate.

Although the NFI material was as a whole representative and fulfilled the requirements of probability sampling, there were, from the point of view of the regression analysis in the control material, far too few old and large-dimensioned trees. In the light of the results, furthermore, the stratification of the sample trees among the different forestry board districts was not effective.

The problems as regards the use of stumps in the butt-rot inventory became clearly apparent during the course of the study. In addition, it is highly likely that not all the spruce stumps covered by logging waste were found. Another problem was that owing to the variation in the height of the stumps, the stump diameter and the diameter of the rot had sometimes to be measured at different heights. Since the measurements were made on the stumps, it appears highly likely that the stem volume of the spruces and the amount of rot were underestimated.

The missing sample tree data were supplemented and the taper curves and volumes of the stem portions of the sample trees were determined using methods which at present are considered to be clumsy (cf. Päivinen 1978, Kilkki and Varmola 1981, Laasasenaho 1982). However, as far the aims of the study are concerned, the methods used here seemed to be sufficient. Analytical scaling of the sample trees is well suited to the study of rot. However, it did not take into account any other defects which affect the yield of timber (see Kärkkäinen 1983a). Since it is difficult, owing to the varying scaling norms, to compare the estimates of different timber assortments obtained in various decay inventories, the use of some commensurable parameter which depicts the size and location of the rot would be beneficial. The proportion of decayed pulpwood or the part of the stem containing rot-affected wood could be recommended as such a parameter.

The effect of butt-rot on the stumpage value of spruce was studied on the basis of the relative unit prices and changes in the timber assortments. Price scaling according to timber dimensions would perhaps have slightly increased the effect of butt-rot. From the point of view of those who buy and use wood as a raw-material, however, butt-rot in practice reduces the value of wood raw-material more than was estimated in this study. In this work it was examined from the point of view of the stumpage price paid to the forest owner. Additional work stages caused by decay, such as butting-off, the bunching and marking of decay-affected bolts, the possible off-road haulage of timber assortments separately and the separate measuring of decay-affected bolts after harvesting, increase the actual price of wood raw-material. If the user of pulpwood pays the same unit price for rot-affected and sound spruce pulpwood, this cannot be justified at least as regards the properties of the raw-material or the harvesting costs (see also Lönnberg and Varhimo 1981).

42. The reliability of the results

The proportion of the most common rot agent, *H. annosum,* was estimated to be 60 % in the clear-cutting material, which can be regarded in this respect as being more reliable than the NFI material. The approximate value of the 95 % confidence interval of the proportion of Annosum-rot is 50... 70 % (cf. Kallio and Norokorpi 1972, Kallio and Tamminen 1974). The corresponding confidence intervals for the mean length and mean volume of all the cases of butt-rot are 33 ... 37 dm and 57 ... 75 dm^3. The equations (31.1) and (31.2) predicting the length and volume of the butt-rot are examples only, and have not been tested on other material. The equations may rapidly become useless when moving inland and to the north of the study area (cf. Norokorpi 1979). In any case, it was possible using a number of simple parameters to explain a considerable amount of the variation in the length and volume of the rot (cf. Johansson 1980).

The 95 % confidence interval of the relative proportion of the butt-rot spruces was approximately 16...21 % in the clear-cutting material and 7...10 % in the adjusted NFI material. According to both part materials, butt-rot was clearly most common along the south coast, in the Helsinki Forestry Board District, while it was the least common on infertile sites inland. Earlier observations (e.g. Kangas 1952, Kallio 1961, Kallio and Tamminen 1974) support the results obtained here in this respect.

The opinion concerning the usefulness of the NFI material was strengthened by the results of this study. However, the field teams should be given better training and guidance, and estimation of the damage should be based on easily measurable variables and measurement of the rot column (cf. Huse 1983). A sufficient number of sample trees, the number being in proportion to the estimated total amount of butt-rot spruces, should be picked for remeasurement. In addition, the second stage research should be done with greater precision than was done in this study, perhaps partly with the help of felled sample trees.

The dependence of the butt-rot frequency on the site and stand parameters was poor in Equations (32.8) — (32.12). However, the equations may depict quite general trends in the conditions prevailing in southern Finland. The best variables were:

— geographical location: latitude, elevation, temperature sum
— site: paludification, fertility (site type, tax class)
— stand: age

The poor correlation between rot frequency and the tree diameter differed from earlier observations (e.g. Bengtsson 1975, Norokorpi 1979). Variables describing the history of the stand, such as the number of spruce generations (Werner 1971, 1973) or information about thinnings, were not available when the equations were being prepared. Without doubt, quantitative information about the distribution of *H. annosum* would have explained part of the variation. The butt-rot frequency in southern Finland appears to be of a different type to that in northern Finland. In southern Finland age explained only a very small part of the variation in the frequency of butt-rot, which was quite the opposite to the situation in northern Finland (Norokorpi

1979). On the other hand, site factors and probably also the high frequency of *H. annosum* (cf. Laine 1976) appeared to be a relatively good predictor. The abundance of butt-rot in southern Finland is more in the nature of a local epidemic than a phenomenon associated merely with the deterioration of the tree stand.

The effect of butt-rot on the yield of timber assortments was rather small (Table 14) and was in good agreement with the estimates made by Tuimala (1979). The loss in saw-timber yield in the materials of Kallio (1972), Kallio and Tamminen (1974) and Örnmark (1979) was much larger. On the other hand, the variation in this study was rather large. The reduction in saw-timber caused by rot varied in the different clear-cutting areas by 1. . .37 % (0. . .76 m^3/ha) and the proportion of rot-affected pulpwood out of the stem volume was 1. . .28 % (1. . .71 m^3/ha). Butt-rot reduced the stumpage value of spruce on the average only slightly by 3 % (100:60:60) or by 5 % (100:40:36) (cf. Tuimala 1979). The range was 1. . .20 % or 0. . .13 %, so that in individual cases the reduction in the absolute value caused by rot might thus have been considerable.

The correlation between butt-rot and the growth of spruce was in good agreement with some of the results reported earlier (Arvidson 1954, Kallio and Tamminen 1974, Lachance 1978, Thies 1983). The lower growth of butt-rot spruces was most clearly evident in stems with far-advanced rot. The growth was concentrated more in the lower part of the stem than in sound trees (see Fig. 17). The rot frequency in this study was determined on the basis of the cut face of the stumps. Basham (1973) found that out of a group of 80 black spruces, 24 showed signs of rot at stump height and 59 at ground level. Thus the butt-rot defectiveness estimated at stump height only for scaling should be replaced with a more physiological butt-rot classification at a lower level, e.g. at ground level or on the roots (see also Bradford et al. 1978). It would also have been necessary to know, when examining the dependence of growth on the amount of rot, how long the tree in question had been affected by rot. This is essential in selecting a reliable reference growth period, i.e. the period of normal (sound) growth. The lack of such information may increase the amount of unexplained variation in inventory studies such as this. Inventory studies should be replaced in a number of respects by more reliably designed experiments if one wants to determine more precisely the effect of rot on the stem growth.

According to Arvidson (1954), half or even more of the total effects of butt-rot comprise growth losses, deterioration in the stem form and other secondary effects of rot (cf. Eqs. 22.2, 22.4—22.6). He considered that a butt-rot incidence of only 7 % could result in a situation where further growing of the stand might be endangered. Although it is not possible on the basis of the results of this study to confirm the above-mentioned estimate, butt-rot does appear to have effects which can cause a shortening of both the biological and economical rotation period, e.g. due to the reduction in growth, increased susceptibility to storm damage and especially to changes in the timber assortments.

The detection of rot defects in standing trees was studied using both conventional tree measurement data and increment cores. Increment cores and other methods have been tried earlier. However, external stem dimensions and growth do not appear to have been used in the systematic detection of rot-affected trees. In this study, 218 sample trees were classified as being either sound or rot-affected on the basis of the earlier-mentioned stem parameters. The final result was a slightly too high rot incidence, and the identification of rot-affected trees did not succeed very well. However, these trials showed that the rot-affected trees differed statistically from sound ones as regards their dimensions. The clearest distinguishing feature was the strong tapering of the butt part of rot-affected trees (see Eq. 36.1). On the other hand, distinguishing between sound and rot-affected trees was not as successful in the NFI material (see Eq. 32.12). However, taking increment cores revealed the presence of rot defects to a satisfactory accuracy. The use of increment cores was least successful when the NFI field teams with little experience took the cores at breast height in conjunction with their normal inventory work (see Table 18). The best result was obtained when experienced personnel took increment cores from the butt of the trees (see Table 17). The advantages of estimating rot defects by taking cores can be considered to be as follows:

- identification of rot-affected trees is sufficiently accurate
- large, economically most important rots are identified relatively the most accurately
- it is especially suited to inventory work where the age of the stand is determined from increment cores
- causes only slight damage in relation to its importance, and possible damage can be prevented by applying wound ointment

and the disadvantages:

- underestimates the butt-rot frequency
- still rather laborious
- requires training
- causes colour and rot defects, almost without exception, to deciduous trees (Schöpfer 1962, Lenz and Oswald 1971, Vuokila 1976, Laiho 1983).

Despite its drawbacks, boring appears to be the best technique so far developed for detecting rot defects in standing trees.

A survey of this sort involving the quantification of biological damage can be useful, for instance when planning new rot studies or new silvicultural measures, but especially in modern comprehensive management planning systems for forest resources (Kilkki 1979b, Siitonen 1983). Such systems can, on the other hand, also reveal the overall significance of this or any other study dealing with forest damage.

SUMMARY

The extent of butt-rot infection in southern Finland during the period 1974—82 was determined in the study. In addition, the properties and subsequent effects of butt-rot, and methods for detecting rot-affected trees, were also examined. The material comprised 146 spruce-dominated clear-cutting stands containing 2 915 stump sample plots (à 300 m^2) and 1 167 felled spruce sample trees, about 20 000 spruce sample trees measured in the 7th National Forest Inventory during 1977—82, 1 226 remeasured NFI spruce sample trees and 218 felled sample trees on four stand sample plots. The clear-cutting areas were selected subjectively, and allocated into forestry board districts and communes with respect to the spruce stem volume weighted by the proportion of spruce. The NFI sample plots — determined by relascope — and trees were selected systematically.

The effect of butt-rot on the timber yield was determined by scaling the rot-affected stems into timber assortments in two ways — first, not taking rot defects into consideration, and secondly taking rot defects into account according to the quality norms. The regression equations used for transforming the stump data into stem data were calculated on the basis of the felled sample trees. The rot frequency, the proportion of rotten pulpwood and the changes in the amount of saw-timber and the stumpage price caused by rot were determined as observation units both for the individual sample plots and for the cutting areas. In the 7th NFI the increment cores for detecting rot defects were taken from the sample trees at breast height only, but when they were reinventoried increment cores were taken at both breast height and stump height.

Heterobasidion annosum (Fr.) Bref. was the most important causal agent of butt-rot. It accounted for 60 % of the cases of rot found in the felled sample trees, and 38 % of those in the NFI sample trees. The volume proportion of rotten wood destroyed by this fungus was greater, i.e. 90 % and 47 % respectively. The proportion of *H. annosum* was also great in areas where there was a high incidence of butt-rot. The mean diameter of the butt-rot (643 cases) was 18 cm at stump height, with a mean length of 35 dm and mean volume of 66 dm^3. The regression equation explained 64 % of the variation in the height, and 91 % of the variation in the volume. However, the equations were unreliable since the relative standard errors were 55 and 78 % respectively. The effect of rot on the wood density, cellulose yield and pulp quality was studied using 10 rot-affected trees. Significantly less cellulose of poorer quality was only obtained after the rot had progressed to a rather advanced stage.

Butt-rot was most abundant in the southern parts of the study area, mainly on sites which were close to sea level, fertile, non-paludified, and in old spruce stands. The picture given by the results from the NFI sample trees was approximately the same as regards the prevalence of rot, although the relative rot frequency was lower. The relative rot frequency — weighted with the stem volume — of the butt-rot spruces was 18,5 % according to the clear-cutting material, and 8,6 % in the adjusted NFI material. The NFI value corresponding to the clear-cutting material — mature spruce stands — was 11,6 %. The difference, 7 %-units, was presumably due to the nature of the materials and especially to the methods used.

The amount of saw-timber decreased in the clear-cutting areas as a result of butt-rot by 0. . .37 %, on the average 8,5 %, the amount of rot-affected pulpwood out of the stem volume being 6,7 %. The stumpage prices of the spruce stems fell on the average by 4,8 % or 2,9 % — the relative unit prices were saw-timber = 100, sound pulpwood = 40, and rot-affected pulpwood = 36 or 100, 60 and 60. The effect of butt-rot

was relatively the greatest in the case of small-sized saw-timber trees.

Spruces affected by butt-rot had poorer growth and stem form than healthy ones. An attempt was made, using discriminant analysis, to identify standing rot-affected trees on the basis of conventional sample tree measurements. Identifying individual trees by this method was not successful, apart from those spruces severely affected by rot. The most effective variables were those describing the taper of the butt part of the stem. Taking increment cores at stump height appeared to be a rather reliable method of detecting rot defects: the number of butt-rot cases detected was 80 %, these cases accounting for almost 100 % of the volume of rot.

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SELOSTE

Kuusen tyvilahoisuus Etelä-Suomessa

Tutkimuksessa selvitettiin kuusen tyvilahon runsautta, lahon ominaisuuksia, seurauksia ja havaitsemismenetelmiä vuosina 1974—82 Etelä-Suomessa. Aineisto koostui 146 kuusivaltaisesta avohakkuuleimikosta, joista mitattiin 2 915 koealaa ja 1 167 kaadettua kuusikoepuuta, n. 20 000 valtakunnan metsien 7. inventoinnin vuosina 1977—82 mitatusta kuusikoepuusta, joista 1 226 tutkittiin lahovikojen osalta uudestaan, ja neljältä metsikkökoealalta kaadetusta 218 kuusikoepuusta. Avohakkuuleimikot valittiin subjektiivisesti ja ositettiin piirimetsälautakunnittain ja kunnittain kuusen osuudella painotetun kuusen runkotilavuuden suhteessa. VMI-koealat ja -koepuut valittiin systemaattisesti.

Leimikoista kaadetut koepuut kuutioitiin ja apteerattiin analyyttisesti. Tyvilahon vaikutusta puutavarasaantoon selvitettiin apteeraamalla lahot koepuut kahdesti, ensin ottamatta lahovikaa huomioon ja sitten ottamalla laho huomioon laatuvaatimusten mukaan. Kaatokoepuiden perusteella laadittiin regressioyhtälöt, joilla kantotiedot muunnettiin puustotiedoiksi. Lahofrekvenssiä, lahon kuitupuun osuutta ja lahon aiheuttamaa tukkipuumäärän ja kantoarvon muutoksia selvitettiin laskentayksikköinä sekä yksittäiset koealat, a 300 m^2, että leimikot. VMI-koepuut kairattiin inventoinnissa vain rinnankorkeudelta, uusintatutkimuksessa sekä rinnankorkeudelta että tyveltä.

Tärkein tyvilahon aiheuttaja oli juurikääpä (Heterobasidion annosum (Fr.) Bref.). Sen osuus kaatokoepuista tutkituista lahoista oli 60 % ja valtakunnan metsien inventoinnin koepuista todetuista lahoista vastaavasti 38 %. Sienen osuus lahojen tilavuudesta oli suurempi eli 90 % ja 47 %. Alueilla, joilla oli runsaasti tyvilahoa, oli myös juurikäävän osuus suuri. Tyvilahojen, 643 kpl, keskimääräinen läpimitta kannon korkeudelta oli 18 cm, keskipituus 35 dm ja keskitilavuus 66 dm^3. Regressioyhtälöllä pystyttiin selittämään lahon pituuden vaihtelusta 64 ja tilavuuden vaihtelusta 91 %. Yhtälöt olivat kuitenkin epäluotettavia, sillä suhteelliset keskivirheet olivat 55 ja 78 %. Lahon vaikutusta puun ominaispainoon, selluloosasaantoon ja massan laatuun tutkittiin 10 lahopuulla. Voitiin todeta, että vasta pitkälle lahonneesta puusta saatiin merkittävästi vähemmän ja heikompaa selluloosaa kuin terveestä tai lievästi lahosta puusta.

Tyvilahoa oli eniten tutkimusalueen eteläosissa, lähellä merenpinnan tasoa, parhailla, soistumattomilla kasvupaikoilla ja vanhoissa kuusikoissa. Valtakunnan metsien inventoinnin kuusikoepuiden perusteella saatiin likimain sama kuva lahon yleisyydestä, joskin lahon suhteellinen frekvenssi oli alhaisempi. Tyvilahoisten kuusten osuus kuusten runkotilavuudesta oli leimikkoaineistossa 18,5 % ja valtakunnan metsien inventoinnin aineistossa 8,6 %. Leimikkoaineistoa vastaava VMI-arvio oli 11,6 %. Ero, 7 %-yksikköä, johtui luultavasti sekä aineistoista että erityisesti menetelmistä.

Tukkipuun määrä väheni tyvilahon vuoksi leimikoittain 0. . .37 %, keskimäärin 8,5 %, jolloin lahoa kuitupuuta saatiin 6,7 % runkotilavuudesta. Kuusten kantoarvo aleni lahon vuoksi keskimäärin 4,8 tai 2,9 %, kun puutavaralajien suhteelliset yksikköhinnat olivat tukkipuu = 100, terve kuitupuu = 40 ja laho kuitupuu = 36 tai vastaavasti 100, 60 ja 60. Tyvilahon vaikutus oli suhteellisesti suurin pienten tukkipuiden kohdalla.

Tyvilahoiset kuuset olivat kasvaneet vähemmän ja olivat runkomuodoltaan huonompia kuin terveet kuuset. Tavanomaisten koepuutunnusten perusteella yritettiin erotteluanalyysin avulla tunnistaa lahopuut pystyssä. Näiden yksilöinti onnistui melko huonosti ja lähinnä lahoimmasta päästä. Tehokkaimpia muuttujia olivat rungon tyviosan kapenemista kuvaavat muuttujat. Tyvikairaus osoittautui varsin luotettavaksi lahovikojen määrityskeinoksi: tyvilahojen lukumäärästä havaittiin jopa 80 %, ja nämä tapaukset edustivat liki 100 %:a lahojen tilavuudesta.

TAMMINEN, P. 1985. Butt-rot in Norway spruce in southern Finland. Seloste: Kuusen tyvilahoisuus Etelä-Suomessa. Commun. Inst. For. Fenn. 127: 1—52.

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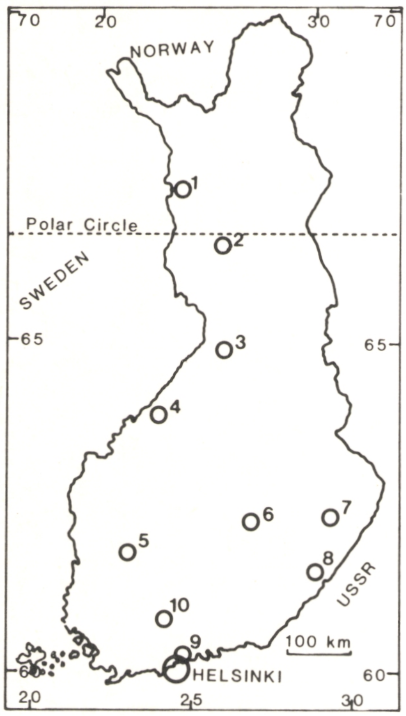

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FACTS ABOUT FINLAND

Total land area: 304 642 km^2 of which 60—70 per cent is forest land.

Mean temperature, °C:	Helsinki	Joensuu	Rovaniemi
January	-6,8	-10,2	-11,0
July	17,1	17,1	15,3
annual	4,4	2,9	0,8
Thermal winter (mean temp. < 0°C):	20.11.—4.4.	5.11.—10.4.	18.10.—21.4.

Most common tree species: Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens

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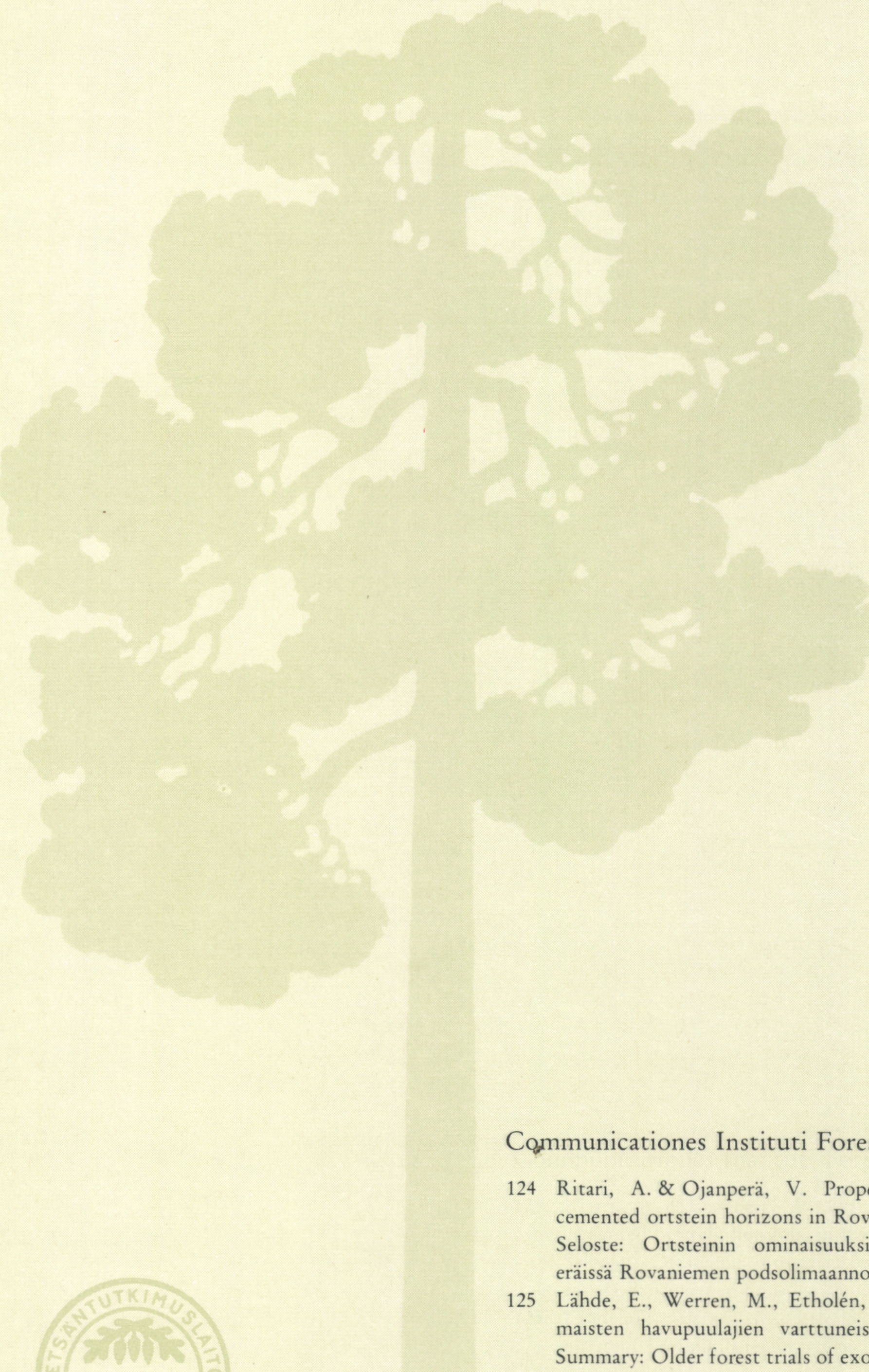

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