SILVA FENNICA

Silva Fennica 41(4) research articles

www.metla.fi/silvafennica · ISSN 0037-5330
The Finnish Society of Forest Science · The Finnish Forest Research Institute

Incidence of Butt Rot at Final Felling and at First Thinning of the Subsequent Rotation of Norway Spruce Stands in South-Western Sweden

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Rönnberg, J., Berglund, M. & Johansson, U. 2007. Incidence of butt rot at final felling and at first thinning of the subsequent rotation of Norway spruce stands in south-western Sweden. Silva Fennica 41(4): 639–647.

The incidence of butt rot in Norway spruce stands at final felling and at first thinning of the subsequent rotation was investigated at 20 sites in south-western Sweden. There was a negative correlation between the incidence at first thinning and the basal area of decayed trees at final felling. Using incidence of decay or basal area of decayed trees to predict disease transfer between rotations is difficult and requires the inclusion of several factors, making predictions uncertain. The level of infection found at final felling in this study varied between 7 and 71.8%, indicating that the risk of spore infection transfer to the next rotation was probably quite low. Long-term experiments are required to reveal the effect of stump treatment on disease transmission between rotations.

Keywords consecutive rotations, disease transmission, *Heterobasidion annosum*, *Heterobasidion parviporum*, *Picea abies*, stump treatment
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Received 29 June 2006 **Revised** 12 February 2007 **Accepted** 24 August 2007
Available at http://www.metla.fi/silvafennica/full/sf41/sf414639.pdf

1 Introduction

Root and butt rot in Norway spruce (*Picea abies* (L.) Karst.) results in severe economic losses to forestry in Scandinavia (Holmsgaard et al. 1968). *Heterobasidion annosum* s.s (Fr.) Bref and *H. parviporum* Niemelä and Korhonen is mainly responsible for the decay and the complex epidemiology of *Heterobasidion* involves many factors. *Heterobasidion* establishes in fresh wounds or on fresh stump surfaces through infection by basidiospores (Rishbeth 1951a, Isomäki and Kallio 1974). The mycelium subsequently spreads to healthy trees via grafts or through loose contact between infected and uninfected roots (Rishbeth 1951b) and can survive in stumps for over 30 years (Schönhar 1973, Piri 1996). Stenlid (1987) and Piri (1996) have shown transmission of genets of *Heterobasidion* between consecutive rotations of Norway spruce and the possibility of infection build-up in subsequent rotations has been reported by several others (e.g. Jørgensen et al. 1939, Low 1958, Yde-Andersen 1978, and Schönhar 1997). Prior to the first thinning, the incidence of butt rot in a stand is mainly dependent on the vegetative growth of *Heterobasidion* on stumps and roots from the previous rotation (Schönhar 1973, 1995). Consequently, the incidence of butt rot at first thinning should be correlated to the incidence of butt rot at final felling of the previous rotation.

A study by Rönnberg and Jørgensen (2000) in Denmark revealed that there was no correlation between the incidence of butt rot at final felling and the incidence at first thinning of the subsequent Norway spruce rotation. In that study, however, butt rot incidence was estimated by visual examination of stump surfaces. It is possible that (non-visible) spore infections on healthy stumps at final felling could have contributed to the transmission of the disease, explaining the lack of correlation. On most of the study sites however, the final felling was carried out in February, a time of year when the spore load of *Heterobasidion* has been shown to be low in Denmark (Yde-Andersen 1962). In addition, many of the second rotation stands were young (10–15 years) and *Heterobasidion* infection probably had not yet developed, since young Norway spruce trees are fairly resistant to the disease (Dimitri 1994).

Stump treatment to prevent *Heterobasidion* infection, during seasons when spore loads are high, is a common forestry practice in many European countries (Thor 2001). The treatment is most often applied in thinnings, but in some countries it is also applied in final fellings (Thor 2001). Based on model simulations, Thor et al. (2006) recommended stump treatment at final felling in pure and mixed Norway spruce stands in southern Sweden. Nevertheless, experimental evidence that stump treatment at final felling reduces the incidence of disease in the subsequent rotation is scarce (Korhonen et al. 1998) and existing data are contradictory (Yde-Andersen 1971, Gibbs et al. 2002).

The aim of this study was to investigate the incidence of butt rot in two consecutive rotations of Norway spruce stands in south-western Sweden, in order to refine the recommendations to forest owners, based on predictions of disease transfer from one rotation to the next.

2 Material and Methods

2.1 Study Sites and Data Collection

The study included 20 sites located in the Tönnersjöheden Experimental Forest, in south-western Sweden (56°40’N, 13°10’E, 60–125 m a.s.l.) on former forest or *Calluna* heath land (Table 1). The sites, ranging from 0.41 to 7.11 ha in size, were afforested with Norway spruce and Scots pine (*Pinus sylvestris* L.) during the late 19th and early 20th centuries. At all sites, Scots pine was gradually removed through thinnings, leaving Norway spruce as the dominating tree species at final felling (Table 1). Soil textures at the sites were either sandy loamy till or gravel, which are typical for Norway spruce stands in this geographical area. The incidence of butt rot was estimated in two consecutive rotations of Norway spruce. The first rotation stands were clear-felled, without stump treatment, during the period 1961 to 1979 (Table 1). At final felling, the basal area at breast height (1.3 m) varied between 16 and 35.2 m^2 per hectare. The time between clear felling and planting of the subsequent rotation stands varied between zero and four years (Table 1). On some sites, scarification was carried out by disc trenching or patch treatment, prior to planting and the number of planted Norway spruce seedlings varied between 2500 and 4500 per hectare (Table 1). Most sites were regenerated with a local provenance of spruce, but with central European origin (T-sjo) (Table 1). At first thinning, the stands were between 24–39 years and site index (estimated top height of the stand at an age of 100 years (Hägglund 1973)) varied between 28 and 35 m, indicating highly productive sites (Table 1).

Table 1. Stand and butt rot data from two subsequent rotations of Norway spruce in south-western Sweden.

Stand	SI[a]	Land-use[b]	Previous rotation at final felling						Subsequent rotation						
	(m)		Scots pine share (%)	Time of clear felling	Prob. spore inf. (%)	Sporophores[c] (nos.)	Butt rot incidence (%)	Butt rot BA[d] (m^2ha^{-1})	Delay[e] (yrs)	Soil treat	Seedling density (nos.×ha^{-1})	Provenance	Age[g] (yrs)	Butt rott incidence (%)	$H.$[h] (%)
50	35	F	0	Jan–Apr 1962	12.5		7.0	1.8	0	no	3000[f]	T-sjo	32	18.0	
299	32	F	0	Jan–Apr 1968	21.0		15.0	5.2	1	no	3300	T-sjo	26	14.0	50
292	33	F	0	Apr–June 1966	69.2		32.0	11.3	0	no	3300	T-sjo	27	14.0	87
293	33	F	0	Apr–June 1966	69.2		32.0	11.3	3	no	4500	T-sjo	27	10.0	86
294–295	33	F	0	Oct–Dec 1966	26.1		32.0	11.2	0	no	2500	T-sjo	28	8.0	73
725	32	H	20	Nov–Dec 1961	11.5		44.8	9.6	0	no	4500	T-sjo	26	9.7	86
52;1	30	H	0	Jan–Apr 1968	21.0	0	31.0	5.0	0	no	3300	T-sjo	36	16.3	79
52;2	30	H	0	Jan–Apr 1968	21.0	10	27.8	4.4	0	no	3300	T-sjo	36	27.5	84
52;3	30	H	0	Jan–Apr 1968	21.0	10	38.3	6.1	1	no	2500	T-sjo	35	31.0	100
71;11	30	H	20	Jan–May 1965	30.5	0	71.8	14.4	1	no	3500	T-sjo	39	16.2	67
71;12	30	H	20	Jan–May 1965	30.5	0	71.8	14.4	1	no	3500	T-sjo	39	22.9	88
71;14a	30	H	20	Jan–Apr 1967	15.0	0	45.8	8.9	1	no	3500	T-sjo	37	18.0	64
71;14b	30	H	20	Jan–Apr 1967	15.0	0	52.8	10.2	1	no	3700	Istebna	37	23.0	77
71;15	28	H	20	Jan–Apr 1967	15.0	0	70.6	13.7	1	no	3500	T-sjo	37	18.3	80
13;159	34	F	0	Oct–Dec 1976	38.0		9.2	3.0	4	trench	3300	T-sjo	24	16.8	63
13;161	34	F	0	Oct–Dec 1976	38.0		9.2	3.0	4	trench	3300	T-sjo	24	8.9	
79:1–3	30	H	10	Jan 1976	0.0		34.1	8.8	1	trench	3500	Karsholm	29	14.3	85
77:5–9	28	H	40	Nov–Apr 1978–79	14.4		42.0	12.0	1	trench	3200	Maglehem, Minsk, Kosta	26	8.7	
70:8	30	H	20	Nov 1973	20.0		34.6	7.2	1	trench	3100	Christinehof	32	15.6	
32A:T103	32	H	0	Feb 1975	0.0		29.1	7.0	1	patch	3300	Kosice	30	29.7	

[a] Site index based on Hägglund (1973) for Norway spruce of the subsequent stand
[b] The previous land-use where "F" means old forest site (broadleaved, coniferous or mixed) and "H" *Calluna* heath land
[c] Frequency of old stumps with fruit bodies of *Heterobasidion*
[d] Basal area at breast height of decayed trees
[e] Delay is the time between final felling and planting
[f] Mean value, since the number of planted seedlings per hectare varied between 1600 and 4500 within the site
[g] Tree age at assessment of the subsequent rotation
[h] The frequency of infection caused by *Heterobasidion* at assessment of the present rotation (through stump discs and core samples)

Estimating the Incidence of Butt Rot

After the clear felling and first thinning, the incidence of butt rot was estimated by visual examination of stump surfaces. Stumps with discolouration, i.e. initial and advanced decay, were regarded as infected. Stumps with discolouration due to secondary factors, such as compression wood, were not included. Decay in the roots, that was not visible at stump height, was assumed to be of little importance (Rönnberg and Jørgensen 2000). All stumps within five-meter wide strips placed along systematic transects through the stands were sampled (one strip per transect) (Persson 1975). Prior to felling, distance between transects was adjusted to stand density and area, so that approximately 100 stumps were examined within each stand. Since the distance between transects was consistently ≥25 m, fewer than 100 stumps were assessed in small stands. Due to miscalculations of the number of felled trees, more than 100 stumps were observed in some cases. As it is difficult to identify standing trees damaged by root and butt rot from external signs (Kallio and Tamminen 1974, Vollbrecht and Agestam 1995), and since there is little or no difference in the incidence of butt rot in different tree height classes (Werner 1971, Vollbrecht and Agestam 1995), the butt rot frequency among the stumps left by the thinning operation within a stand was assumed to be representative of the butt rot frequency in the remaining stand (Holmsgaard et al. 1968, Bryndum 1969, Vollbrecht and Agestam 1995). Since the different sites had different numbers of trees and differences in basal area at final felling the incidence of butt rot at final felling was also transformed to basal area of decayed trees per ha in the calculations. The basal area of decayed trees better reflects the actual amounts of inoculum at final felling at the different sites.

Identifying the Cause of Butt Rot

Identification of the decay-causing fungi was not carried out at the time of the clear felling operation. To get a rough idea about the possible presence of *Heterobasidion* and *Armillaria* spp., the presence or absence of *Heterobasidion* sporophores and *Armillaria* spp. rhizomorphs was confirmed by examining stumps created in clear felling of the previous stands (stands 52 (1–3) and 71 (11, 12, 14a,b, 15)). In each of these stands, ten randomly selected stumps were examined during the first thinning.

To estimate in how many cases *Heterobasidion* was the decay-causing organism at the time of first thinning, discs were cut immediately after felling from the stumps of 20 randomly selected thinned trees with incipient or advanced decay in each of the following stands; 13 (159), 52 (1–3), 71 (11; 12; 14a; 14b and 15), 79 and 293. In stands 299, 292, 294–295 and 725, examining the decay-causing organism was not possible, as thinnings had been carried out 2–9 years prior to this study. Therefore in these stands, an increment borer was used to take core samples at stump height, from 50 randomly selected trees per stand, to identify the decay-causing organism. The core was directed towards the pith of the tree (Stenlid and Wästerlund 1986), using 2.6-dichlorophenolindophenol to assist in the detection of incipient decay (Johansson and Stenlid 1985). If a core was found to be decayed by the use of 2.6-dichlorophenolindophenol, a new bore core was taken. Stem discs and cores with initial or advanced decay were immediately transferred to plastic bags and incubated at 20°C for 10 days. *Heterobasidion* was regarded as the cause of the decay if conidiophores corresponding to those of *Heterobasidion* could be seen on the wood surface using a dissecting microscope. Classification of other possible butt rot causing agents was not carried out. In the remaining stands (50; 13 (161); 77 (5–9); 70 (8) and 32A (T103)) no investigation of the decay-causing fungus could be carried out.

2.2 Probability of Spore Infection at Final Felling

The probability that stumps may have become infected by air-borne *Heterobasidion* spores at clear felling was estimated using daily climate data from a climate station in Simlångsdalen (56°71’N, 13°12’E, 75 m a.s.l.) during the period 1961–1979 (Swedish Meteorological and Hydrological Institute). Each day was assigned a risk infection value of either ‘1’ (i.e. risk of spore infection) or ‘0’ (i.e. no risk of spore infection), according to five rules: i) mean daily air temperature <5°C = 0, mean daily air temperature ≥5°C = 1 (Korhonen and Stenlid 1998). If the air temperature exceeded 5°C, then; ii) daily precipitation <10 mm = 1; iii) daily precipitation between 10 and 15 mm = 0 for that day; iv) daily precipitation between 15 and 25 mm = 0 for that and the following day; v) daily precipitation ≥25 mm = 0 for that and the two following days (Yde-Andersen 1962, Sinclair 1964). The probability of *Heterobasidion* spore infection was calculated for each site as the percentage of days with infection risk in relation to the total number of days during the period when the stand was clear-felled (Table 1). The data for precipitation in February and March 1968 were missing. This had however little influence on the analysis since the air temperature during this period was <5°C nearly the whole time.

2.3 Data Analyses and Statistics

Spearman's rank-order correlation was used (SAS Institute Inc., Cary, NC, USA) to investigate the strength of the relationship between the incidence of butt rot at first thinning in the subsequent rotation stands and the basal area at breast height of decayed trees at final felling of the previous rotation. Since several other factors may affect the build-up of infection in the subsequent rotation, a partial statement was included in the above correlation, i.e. the strength of the above relationship was investigated while controlling the following variables:

- site index; SI
- probability of spore infection at final felling; P(Spore)
- time between final felling and planting of the present rotation; Time
- number of planted seedlings per hectare; Seedlings
- stand age at first thinning; Age
- relative frequency of infection caused by *Heterobasidion* in the subsequent rotation; RelFreq

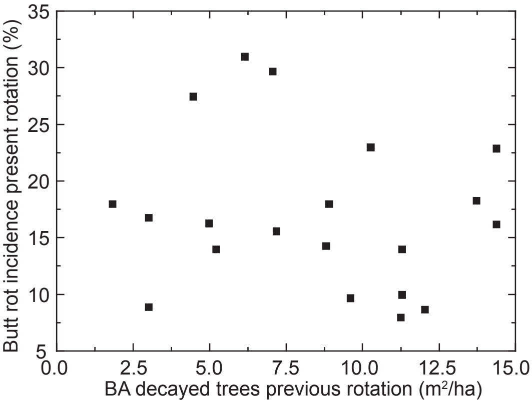

Fig. 1. The incidence of butt rot at first thinning of the subsequent rotation in relation to basal area at breast height of decayed trees at final felling of the previous rotation.

3 Results

The incidence of butt rot at final felling of the previous rotation varied between 7 and 72% and between 8.7 and 31% at first thinning of the subsequent rotation. The basal area (at breast height) of decayed trees at final felling of the previous rotation ranged from 1.8 to 14.4 m^2 per hectare. There was no correlation between the incidence of butt rot at first thinning of the subsequent rotation and the basal area at breast height of decayed trees at final felling of the previous rotation (r = –0.17, p = 0.47) (Fig. 1). When controlling the variables SI, Time, Seedlings, Age and RelFreq, the incidence of butt rot at first thinning of the subsequent rotation was negatively correlated to the basal area at breast height of decayed trees at final felling of the previous rotation (r = –0.76, p = 0.019).

In all stands from which information was available, *Heterobasidion* were the dominating decay-causing fungi (50–100%) at first thinning. *Heterobasidion* sporophores were found on old stumps of the previous rotation in two of the eight stands investigated (Table 1). *Armillaria* spp. rhizomorphs were not found in any of the sites investigated.

3.1 Probability for Spore Infection at Final Felling

From analysis of the climate data, the probability that *Heterobasidion* spore infections may have occurred at final felling (P(Spore)) varied between 0 and 69.2%, with a mean value of 24.6% (Table 1). Including the P(Spore) variable with the other variables did not have any major impact on the correlation between the incidence of butt rot at first thinning of the subsequent rotation and the basal area at breast height of decayed trees at final felling of the previous rotation ($r = -0.75$, $p = 0.032$).

4 Discussion

There was a negative correlation between the incidence of butt rot at first thinning of the subsequent rotation and the basal area at breast height of decayed trees at final felling of the previous rotation, when the effect from other variables (SI, Time, Seedlings, Age and RelFreq) were controlled (Table 1, Fig. 1). Considering the mechanism of *Heterobasidion* disease transmission, it seems likely that disease severity should progress from one rotation to the next (Schönhar 1990). Through transmission of the disease from infected old stumps to new young trees, this progression should become evident during the first thinning of the following rotation. Neither the present study, nor studies by Bornebusch and Holm (1934), Piri (1996), and Rönnberg and Jørgensen (2000), support this theory. Infact, no correlation or even a negative correlation was found in disease severity between the rotations. Consequently, it is very difficult to use the amount of decay at final felling, of the previous rotation, to predict the amount of decay in the subsequent rotation.

It is also noteworthy that results from the analysis differed when including or excluding the variables SI, Time, Seedlings, Age and RelFreq. No correlation was found when these variables were excluded from the analysis. In order to predict the amount of decay in subsequent rotations reliably, the inclusion of these variables, as well as others, may be essential.

The negative correlation in disease severity between rotations in this study is rather perplexing. The more healthy stumps there were at final felling, the larger was the risk for infection in the next rotation (given similar conditions). It is possible that stumps from healthy trees from the previous rotation may contribute to the transfer of infection of *Heterobasidion* to the consecutive rotation, if infected by spores at final felling (Bendz-Hellgren and Stenlid 1998, Yde-Andersen 1978). Although climate data was not used in the analysis, this possibility was discussed by Rönnberg and Jørgensen (2000) as the most probable explanation for the lack of correlation between butt rot already within the stumps at final felling and butt rot then observed in the first thinning of the subsequent rotation. When including the probability of spore infection at final felling in the partial correlation analysis in the present study, there was no major difference to the result, i.e. when controlling the variable P(Spore), there was still a negative correlation. In addition, climate data, provided by the Danish Meteorological Institute (DMI) and applied on the data in the study by Rönnberg and Jørgensen (2000), indicated that spore infection at final felling was probably not the major reason for the lack of correlation in that study. The present study is however based on limited material, with the probability only roughly indicating the likelihood of spore infection. Furthermore, only few stands had low amounts of butt rot infections at final felling.

The stage of decay is another important factor to consider. Stumps with decay that has been present for a long time may have a lower transfer potential than stumps with early decay, due to decomposition of the root system. The age of the genets of *Heterobasidion* may affect the pathogenicity of the fungus favouring the younger genets, as suggested by Rönnberg and Jørgensen (2000). Former land-use may also have an effect on the age of genets and consequently the transfer between rotations, i.e. stands on former forest land may host older genets than stands on former heath-land. The material in the present study, however, is rather heterogeneous making it difficult to draw any further conclusions on this matter.

Coexistence of *Heterobasidion* and *Armillaria* spp. in stumps has been reported for spruce, fir and pine (Greig 1962). *Armillaria ostoyae* (Romagn.)

Herink usually occupies outer tissue at lower parts of the stumps, while *Heterobasidion* occupies the inner tissue. Possibly *Armillaria ostoyae* thereby diminishes the spread of *Heterobasidion* to adjacent healthy trees via root contacts (Greig 1962). In this study, only *Heterobasidion* was identified on the stump discs but while *Heterobasidion* was dominating, approximately 23% of the decay remained unidentified. Given this, the presence of *Armillaria* spp. in the lower parts of the stumps or on roots cannot be excluded and the fact that no rhizomorphs of *Armillaria* spp. were found on stumps of the previous rotation in some of the stands does not exclude the possibility that it had affected the transmission of *Heterobasidion* between rotations. However, since the previous land-use was not only broad-leaved tree dominated forest, and to a great extent heath land, the probability of presence of *Armillaria* spp. and its importance in the disease transmission should be low (Greig 1962, Rehfuess 1973). The frequent occurrence of *Heterobasidion* at the time of sampling in the present rotation would also add confusion if *Armillaria* spp. had prevented *Heterobasidion* infections in the stumps of the previous rotation to spread to the subsequent rotation stands, if not other means of spread are important. The presence of *Armillaria* spp. can also affect the efficacy of stump treatment at final felling.

Although generally regarded to be of little importance, sometimes *Heterobasidion* enters trees by means other than root-to-root contact, with stumps from the previous rotation. Roll-Hansen and Roll-Hansen (1981) and Schönhar (1995) have demonstrated that *Heterobasidion* spores may infect the roots of standing live trees directly, probably through associations with wounds on the roots. Rönnberg and Jørgensen (2000) suggest, however, that infection via this route has a low significance.

The practical implication of this study restricts the use of the incidence of decay or basal area of decayed trees for making predictions on disease transfer between rotations of Norway spruce. Several other factors need to be included, making predictions of this kind difficult. Stump treatment at final felling has been suggested and, when tested in simulations, believed to be profitable (Thor et al. 2006). The results from this study do not support the recommendation to treat stumps at final fellings, however it does not provide any indisputable proof for the opposite either. It seems necessary to sound a cautionary note to those who believe that treating stumps at final felling is the solution to every situation. In stands with infection already present at final felling, treating stumps can be questionable, but in stands that are more or less free of infection, stump treatment may be a way of reducing the build-up of infection in subsequent rotations. The amount of decay needed in order to regard the stand as 'healthy' still, however, needs to be defined.

Acknowledgements

"Granprogrammet" at SLU kindly provided financial support for the study. Thanks also to Dr. Tuula Piri and Kari Korhonen at Metla, Finland, for discussions about the results. We are also grateful to Katherine Tubby at Forestry Commission, UK, for revising the language and providing helpful comments to the manuscript.

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