Crown Condition as an Indicator of the Incidence of Root Rot Caused by *Heterobasidion annosum* in Scots Pine Stands

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Trees in three Scots pine stands seriously infected by *Heterobasidion annosum* were classified according to their crown condition into four classes, from healthy to dead trees. After cutting the stands, the classification was compared with the symptoms of annosum root rot on stump surfaces (pitched area) and with the extension of decay in the roots of excavated stumps. When dead trees were included, the average crown condition on the survey plots correlated with disease incidence. Without dead trees the correlation was not significant. Slightly infected trees could not be distinguished from healthy trees on the basis of crown condition. It was concluded that only the proportion of dead and dying trees in a stand is a reliable indication of the disease incidence for making decisions about the future management.

Keywords *Pinus sylvestris*, *Heterobasidion annosum*, root rot, symptoms, disease incidence
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1 Introduction

Annosum root rot caused by *Heterobasidion annosum* (Fr.) Bref. is a serious problem in Scots pine stands in southeastern Finland (Laine 1976). The assessment of the incidence of annosum root rot in pine or spruce forests is often a difficult task. Basidiocarps found on butts of trees or in the root systems are most reliable signs for the presence of root rot. However, basidiocarps are rare on living trees and may occur sparsely also on dead trees. In the absence of basidiocarps a safe identification of annosum root rot in an individual tree may require culturing of the fungus from samples of infected wood. Some external symptoms as crown density and colour, butt swelling and exudation of resin on stem or roots can be used for assessment purposes (Greig 1998), but other diseases or disturbances can as well cause similar symptoms.

In an attempt to identify butt rot in growing Norway spruces, Kallio and Tamminen (1974) classified Norway spruce trees to healthy and diseased on the basis of external appearance of the trees. Only 49% of the diseased trees and 73% of the healthy trees were correctly classified. Vollbrecht and Agestam (1995) analysed the connection between butt rot and external signs, such as butt swelling, resin exudation and decreasing crown density in standing spruces. They found the connection quite inconsistent, and even professional foresters could not predict the butt rot incidence reliably. The estimation of butt rot incidence in standing spruces can be made more successfully using the butt rot incidence in the stumps of thinned stands (Vollbrecht and Agestam 1995).

Same type of studies have not been made in pine stands where several symptoms and signs may indicate the presence of root rot caused by *H. annosum*. Uneven stand density, pines dying in groups, wind-thrown pines with decayed root system, dead junipers in the undergrowth, and basidiocarps on roots and butts of these trees are the most important signs for diagnosing the cause of root rot infection in Scots pine stands in northern Europe (Rennerfelt 1952, Laine 1976). Colour change of foliage, crown thinning or transparency, crown reduction, and decline of shoot growth may indicate the disease in individual trees. However, most of this kind of external signs are not specific for any particular disease but they can be induced by different biotic causes and abiotic environmental problems (Innes 1993, Kandler and Innes 1995). The use of these secondary signs as diagnostic indices requires that the main primary cause in a specific case is known. Otherwise, conclusions could be biased. Once the diagnosis has been made one may ask how extensive the infection is in the stand and what is more profitable: continue growing or harvest the stand.

In this work the external condition of trees in Scots pine stands was compared to the incidence of root rot caused by *H. annosum*, determined after cutting the trees. The aim was to assess the usefulness of the external symptoms in predicting the incidence of root rot in the stand. The knowledge of this would help in planning optimal stand management.

Table 1. Description of the surveyed stands.

Stand	1. Ristiina	2. Ruoko-lahti	3. Suomen-niemi
Age, years	75	79	73
Height, m	21.2	19.4	20.4
$D_{1.3}$, cm	23.8	24.1	24.6
Volume, m^3ha^{-1}	238	151	214
Number of trees ha^{-1}			
Pines	439	321	424
Other trees	126	3	33
Pines in the plots	421	308	280
Number of pines per plot	5–24	2–22	10–17
Dead pines	63	31	10

2 Materials and Methods

The crown condition of trees was surveyed in three Scots pine stands in 1976 and 1977. The stands were affected by P type of *H. annosum* identified by Kari Korhonen (Korhonen 1978, see also Niemelä and Korhonen 1998). Stand 1 located in Ristiina (61°27'N, 27°35'E), stand 2 in Ruokolahti (61°21'N, 28°37'E), and stand 3 in Suomenniemi (61°19'N, 27°18'E) in southeastern Finland. In stand 1 and stand 2, the surveyed area was 0.96 ha (32 circular plots of 300 m^2) and in stand 3 it was 0.66 ha (22 plots). The plot centres formed a 20×20 m perpendicular net. In stand 1, site type according to the Finnish classification (Cajander 1949) was mostly dry pine forest: *Vaccinium* type (VT) or *Calluna* type (CT). Nine plots represented fresh sites: eight *Myrtillus* type (MT) and one *Oxalis-Myrtillus* type (OMT). In stands 2 and 3, all plots belonged to VT. (Table 1).

The trees on each plot were numbered and mapped, and the crown condition classes were determined visually. Before the next growing season after the surveyings the stands were clear cut and stem infection on the stump surface and root rot in excavated roots were rated. The crown condition, stem infection and root infection were classified as follows:

– *Crown condition* (CC): CC_1 – healthy-looking trees with a dense crown and the foliage with intensive green colour, CC_2 – trees with increased crown transparency and retarded shoot growth, CC_3 – trees with yellowish or partially brown foliage, CC_4 – dead trees with brown foliage or needles already fallen, the trees apparently killed in earlier growing seasons.

Table 2. The range of each stem infection class (SI_{1-5}) as the percentages of the diameter of resinous area (RD) from the stump diameter, and the upper limit of each class when expressed as the relation of their areas (stem infection = SI).

Stem infection classes (SI_{1-5})	RD %	Upper limit in SI %
1	0	0
2	0.01–25	< 6.25
3	25.01–50	< 25.00
4	50.01–75	< 56.25
5	75.01–100	< 100

– *Stem infection* (SI) indicates the relative extension of the resin-soaked (pitched) area on the stump surface. It was defined as (diameter of resin-soaked area/stump diameter)^2 in percentages. For further statistical analyses, the trees were divided into five stem infection classes, SI_{1-5} (Table 2).
– *Root infection* (RI). The extension of decay in the roots was estimated using a 10% classification. The roots were examined from stumps lifted with a tractor excavator. Broken resinous or decayed roots and lack of fine roots were used as main criteria for root rot rating. Stumps were lifted in 18 plots in Ristiina and Ruokolahti, and in 12 plots in Suomenniemi.

Moreover, *relative length of the living part of the crown*, RLC (as percentage of tree height) was defined as an additional phenological variable possibly connected with infection, although it might merely be connected with previous stand density and the trees' social position. The length of pines and the length of their green crown were measured when trees were cut down.

Number of pines per plot of 300 m^2 (NP) was also used in regression analyses as well as the basal area (BA) of trees. These variables represented the survey plots, and therefore, the regression models for root rot infection were computed using plot averages also for CC and RLC (i.e. plot level). Each variable expressed as percentages was transformed according to the equation $2 \times \arcsin \sqrt{p}$ for statistical treatments using SYSTAT® 8.0 software. The pines having *Cronartium* cankers in the stem were excluded from the material, since the rust may also change the appearance of the crowns.

Table 3. Pearson correlation of average crown condition with stem infection (SI) and root infection (RI) at the plot level in each stand and total material. For SI and RI percentages arcsin transformations were used. N = number of plots.

Stand	SI N	SI r	RI N	RI r
All pines				
1	32	0.81***	16	0.78***
2	32	0.43	16	0.69**
3	22	0.51*	11	0.49
Total material	86	0.62***	43	0.66***
Living pines				
1	32	0.41	16	0.51
2	32	0.40	16	0.71**
3	22	0.22	11	0.51
Total material	86	0.38**	43	0.45*

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

3 Results

The frequency of pines infected by root rot was significantly higher ($p<0.01$) in stand 1 than in stands 2 and 3; between the latter two stands the difference was not significant. Correlation between the stem infection (SI) and root infection (RI) was 0.74 ($p<0.001$) when computed with the plot averages.

In stand 1, site type did not affect the frequency distribution of healthy and diseased trees according to the crown condition classification. In stands 2 and 3, all plots belonged to one site type (VT).

3.1 Crown Condition and Stem Infection

At plot level, the average crown condition (CC_{1-4}) of trees could be handled as continuous variable having values from 1 to 4. Pearson correlation between the average crown condition and stem infection (SI) was significant in stand 1, stand 3, and in the total material but not in stand 2. Without yellowish and dead trees (classes CC_3 and CC_4) the correlation was significant only in the total material (Table 3).

When the frequency distribution of trees in different crown condition classes was compared against the stem infection classes (SI_{1-5}), the dif-

Table 4. Mean SI, RI, and RLC in percentages according to the crown condition classes (CC). Different letters with numbers show statistical difference at the level of p < 0.05. N = number of pines.

Stand	CC	N	SI%	N	RI%	N	RLC%
1. Ristiina							
	1	128	6.1a	56	9.9a	128	46.4a
	2	191	9.9b	103	25.6b	181	42.7b
	3	21	52.2c	13	96.7c	12	36.1b
	4	37	60.5c	19	100.0c		–
2. Ruokolahti							
	1	131	1.9a	58	8.4a	131	48.6a
	2	140	7.0b	44	26.4b	140	44.3b
	3	5	65.3c	4	85.0c	5	44.6b
	4	8	61.4c	2	70.0bc		–
3. Suomenniemi							
	1	83	4.3a	33	8.5a	83	43.6a
	2	179	8.4a	115	12.8a	178	40.9b
	3	2	96.6b	2	75.0b	2	35.2ab
	4	10	100.0b	2	55.0b		–
Total material							
	1	342	4.0a	150	9.0a	342	46.5a
	2	510	8.6b	279	20.0b	499	42.5b
	3	28	57.7c	20	92.5c	18	37.8c
	4	55	63.6c	29	94.1c		–

ferences between classes were highly significant (Pearson Chi-square test, $p<0.001$). Most of the trees in crown condition classes 1 and 2 belonged to stem infection classes 1, 2 or 3 in each stand. Detecting the difference between crown condition classes 1 and 2 was difficult, since the limit between them could be really floating when making ocular surveys.

In stand 1, 20% of the pines with healthy crown (CC_1) took the place in stem infection class SI_1 (healthy), but even 5.4% of them fell into SI_4 where the diameter of the resinous area on stump surface was between 51 and 75%. Stand 3 was healthiest; here 75% of the trees with healthy crown fell into SI_1, but still 2.4% of healthy trees showed extensive resinous area at the stump surface, falling into class SI_5. Trees with healthy crown were especially abundant in stem infection class SI_2, which means that slight root infection was not visible in crown phenology, and *vice versa*, a lot of trees being slightly weakened according to their crown phenology were ranked healthy in SI. However, the difference in the frequency of trees in crown condition classes CC_1 and CC_2 was statistically significant within stem infection classes ($p<0.05$) in each stand. As regards crown condition classes CC_3 and CC_4, the difference was not significant. Same was also seen in ANOVA where the SI was significantly different ($p<0.001$) between classes CC_1, CC_2 (except in stand 3) and CC_3 but not between classes CC_3 and CC_4 (Table 4).

3.2 Crown Condition and the Extent of Root Infection

The evaluation of the extent of root infection (RI) was made in excavated stumps turned upside down. RI correlated (Spearman) significantly with the crown condition class of individual trees in all three stands. At the plot level, Pearson correlation was significant only in stand 2 and in the total material (Table 3). The average RI in crown condition class CC_1 (healthy trees) in total material was 9%, and in the classes CC_3 and CC_4 it was more than 90% (Table 4).

Table 5. Correlation of RLC with stem infection (SI) and root infection (RI) without the pines of CC_4 in each surveyed stand.

Stand	SI N	SI r	RI N	RI r
1. Ristiina	323	–0.26***	164	–0.26**
2. Ruokolahti	275	–0.03	106	–0.09
3. Suomenniemi	263	–0.15*	151	–0.12
Total	861	–0.14***	421	–0.13**

***) p < 0.001, **), p < 0.01, *), p < 0.05

3.3 Crown Length and Disease Incidence

Dead trees (CC_4) were not included in the relative crown length (RLC) data. RLC was significantly (ANOVA, $p<0.01$) shorter in the crown condition classes CC_2 and CC_3 than in class CC_1 (Table 4). RLC correlated significantly negatively with stem infection (SI) in stands 1 and 3 and in the total material. Correlation between RLC and root infection (RI) was negative and significant in the total material and in stand 1 (Table 5).

3.4 Regression Models of Stem Infection

The significance of the phenological variables was tested in estimating disease incidence in stem and roots (SI and RI) at stand level using data for plot averages of each variable in multiple regression analysis. It was shown above, that two variables, crown condition (CC) and relative crown length (RLC), had connection with disease incidence (Tables 4 and 5). Number of pines per plot (NP) was tested as an alternative for RLC, since it correlated significantly ($p<0.05$) with RLC in the plot average data, and decreases while root rot is killing pines. Basal area (BA) was also included in the model since it is an expression for stand density and is easily obtained in the forest with a relascope.

When regression analysis was computed stepwise with four independent variables, CC, RLC, NP, and basal area, CC was significant in each case ($p<0.001$), regardless if the analysis was computed separately for each stand or for the total material. RLC was significant in stand 1 and in the total material but not in stands 2 and 3. Similarly, NP and BA were significant in some of the cases but not systematically. In the total material arcsin-transformed stem infection (SI) got the following model:

$$SI = 0.715 \times CC - 0.010 \times BA - 0.445$$

or without constant,

$$SI = 0.667 \times CC - 0.011 \times BA - 0.229 \times RLC$$

In these equations all terms were statistically significant. Rejecting the constant term increased the explanation degree of the model from about 45% to 80–90%. RLC, NP, and basal area increased only slightly the explanation degree of the model.

The correlation between the observed and computed values of stem infection (SI) was 0.69 ($p<0.001$) in stand 1, 0.58 ($p<0.01$) in stand 2, and 0.56 ($p<0.05$) in stand 3. In the total material the corresponding correlation was 0.62. Without dead trees correlation was significant only in stand 2 and in the total material.

3.5 Predicting the Extent of Root Infection

Same kind of equations as above described better root infection than SI in stands 1 and 2 but in stand 3 there was no correlation. In the total material the observed root infection (RI) correlated significantly with predicted root infection $r = 0.77$ for all pines and 0.71 for living pines ($p<0.001$). The models describing the incidence of root infection were:

$$RI = 0.914 \times CC - 0.019 \times BA - 0.262$$

(in which constant term was not significant),

or without constant,

$$RI = 0.855 \times CC - 0.048 \times NP$$

4 Discussion

Several foliage and shoot diseases can also cause crown thinning or discoloration, e.g. *Gremmeniella abietina* infection (Aalto-Kallonen and Kurkela 1985). Natural needle fall and foliage diseases may cause variation in color and amount of needle mass within and between growing seasons (Jalkanen et al. 1995). Because of extensive root rot, the condition of the studied stands was monitored already in some previous years, but no needle or shoot disease epidemics were observed. Thus, relative differences in the crown condition between the trees were caused mainly by root rot infection. Sources of error in surveying the condition of trees were apparently in the personal interpretation, different weather during the work, and different season of surveying. Stand 1 was surveyed in autumn 1976 and stands 2 and 3 in spring 1977.

The external condition of pines was ranked into four categorical classes. The limits between each class may be floating and the criteria used to differentiate classes may lack commensurability. For example, it is not possible to solve objectively how far in the used scale (intensive green → light green → yellow → brown → total loss of needles) a dead tree should be from a tree having normal foliage colour but increased crown transparency.

In each stand of this study, *H. annosum* had killed pines patchwise. Around the gaps caused by the fungus, pines were in a various condition, from dead trees to slight crown thinning and to normal healthy-looking condition, as also Rennerfelt (1952) and Laine (1976) have described. The condition of trees may change quickly in one or two years (Rennerfelt 1952). Often in younger stands and in more temperate environments the diseased trees may turn brown without a gradual change in the crown appearance (Hodges 1974). Some variation in the condition of the trees may occur also outside the patches because of single tree infections, as shown e.g. by Hodges (1974).

In the present study it was possible to predict the disease incidence in stands before cutting using the crown condition of trees and some other variables related to stand density. The observed and computed disease incidence values correlated significantly in each stand when dead trees were included. Without them the correlation was also significant in total material (Table 3), but the prediction at stand level was not reliable. Root rot infection in living trees was probably underestimated in each stand. One reason for that could be that sticking fine textured soil caused often difficulties in the observation of the condition of fine roots. Because the distinction of healthy trees from slightly infected ones was not very clear, attempts to separate such cases in practice are not reliable. There could be also some other factors than root rot causing differences in crown transparency among living trees, e.g., male flowering and needle retention as response to weather conditions. For the practical forestry, it is safer to count the trees with green foliage into one group and to form another group of dead trees and trees with discoloured foliage. If dead trees are not present, one can count also the stumps of the trees removed from the gaps e.g. during last five years.

In case the volume of annually dying trees exceeds the annual volume increment, the stand is not profitable for the future growing. In reality, the zero limit of profitability will be reached earlier, since volume increment of infected trees may start to retard as early as ten years before dying (Kurkela et al. 1978), although such a retardation has not been seen in more temperate conditions (Webb et al. 1981) or in young pines (Laine 1976). Most seriously infected trees usually surround the gaps or they are close to dying trees (Rennerfelt 1952). Therefore, the remaining living trees in an infected stand can hardly benefit the gaps and thus compensate the growth loss caused by root rot.

In stands 1 and 2, the volume loss caused by annual mortality (class CC_3) exceeded clearly the average annual volume increment according to the volume and increment tables by Vuokila (1967). Because of progressive growth retardation, the only reasonable economic decision for such infected stands could be clear cutting. Stand 3 was still acceptable for growing since the annual mortality was less than one percent and the number of trees per hectare exceeded the lowest recommended one.

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