Presence of *Heterobasidion annosum* and the need for stump treatment in monocultures of Scots pine in southern Sweden

Eglė Petrylaitė
Supervisors: Jonas Rönnberg
Mattias Berglund

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ABSTRACT

The incidence of *Heterobasidion* spp. in the roots of Scots pine (*Pinus sylvestris* L.) was investigated in fifteen monocultures of Scots pine in southern Sweden. On the basis of crown condition, all trees were divided into four classes from healthy to dead trees on a number of sample plots at each site. The root systems were excavated and sample discs were taken from two healthy looking trees and two defoliated trees in each stand. All samples were analysed for the presence of *Heterobasidion* spp. The data was used to create a probability model for trees getting infected. Estimated volume losses were then compared to the costs for treating stumps.

Heterobasidion spp. was found in root samples from pines at fourteen of the fifteen stands. A total of 44 of the 60 sampled trees were infected by *Heterobasidion* spp. in the root systems. Of the infected pines 20 trees were assessed as healthy looking and 24 as defoliated trees. Previous land use, thinning season and crown condition class had significant effects on the percentage of root discs infected by *Heterobasidion* spp. Accordingly, highest probability of finding an infected tree was among the defoliated trees in stands on former agricultural land with thinnings carried out during season of spore spread.

The results show that at three percent interest rate stump treatment to prevent spore infection of *Heterobasidion* spp. in monocultures of Scots pine in southern Sweden is clearly beneficial, especially in stands established on former arable land.

SAMMANFATTNING

Förekomsten av rotticka (*Heterobasidion* spp.) i rötterna av tall (*Pinus sylvestris* L.) undersöktes i 15 tallmonokulturer på sandig mark i södra Sverige. Baserat på kronutglesningen delades alla träd in i fyra klasser, från friska till döda, på ett antal provytor i varje bestånd. På två till utseendet friska respektive kronutglesade individer i varje bestånd grävdes rotsystemen fram och prover togs. Döda träd provtogs ej. Alla prover analyserades med avseende på förekomsten av rotticka. Det erhållna materialet användes sedan för att skapa en modell för att prediktera sannolikheten att ett träd i ett bestånd var infekterat av rotticka. Estimerade volymsförluster till följd av angrepp av rottickan jämfördes sedan med kostnaden för en stubbehandling vid gallring.

Rotticka återfanns i 14 av 15 undersökta bestånd. I 44 av totalt 60 fall hade provtagna tallar infektion av rottickan i någon rot. Av de undersökta tallarna var 20 visuellt bedömda som friska och 24 som kronutglesade. Tidigare markanvändning, säsong för gallring och kronutglesningsklass hade en signifikant effekt på frekvensen infekterade rotprover. Följaktligen var risken störst att stöta på ett infekterat träd bland de kronutglesade tallarna i bestånd på tidigare åkermark med gallringar utförda under tiden för rottickans sporspridning.

Vid en treprocentig internränta visar resultatet av denna studie att stubbehandling för att undvika sporinfektioner av rotticka i monokulturer av tall i södra Sverige är klart lönsam, speciellt i bestånd etablerade på tidigare jordbruksmark.

SANTRAUKA

Šakninės pinties paplitimas ištirtas penkiolikoje paprastosios pušies želdiniuose pietinėje Švedijoje. Kiekviename medyne išskirti tyrimo bareliai, kuriuose visos pušys pagal lajos defoliacijos laipsnį suskirstytos į keturias grupes: nuo vizualiai visiškai sveikų iki nudžiūvusių. Dviejuose tyrimo bareliuose pagal vizualinį įvertinimą atrinkta po dvi sąlyginai sveikas ir po dvi akivaizdžiai pažeistas pušis. Atkasus jų šaknis paimti šaknų medienos pavyzdžiai, kurie vizualiai ir laboratoriniu metodu įvertinti šakninės pinties pažeidimo požiūriu. Medynų duomenys ir laboratoriniai rezultatai panaudoti pušies pažeidžiamumo šaknine pintimi tikimybės modelio sukūrimui. Apskaičiuoti medienos tūrio nuostoliai palyginti su kelmų apsaugos priemonių išlaidomis.

Beveik visuose tirtuose medynuose (keturiolikoje iš penkiolikos) buvo rasta pušų su daugiau ar mažiau šakninės pinties pažeistomis šaknimis. Iš viso 60 detaliau tirtų pušų net 44 pušų šaknų mediena buvo pažeista šakninės pinties. Iš infekuotų pušų 20 medžių buvo įvertinti kaip vizualiai sveiki ir 24 buvo pripažinti pažeistais. Didžiausia tikimybė rasti infekuotą pušį buvo tarpe akivaizdžiai pažeistų pušų įveistų žemės ūkio naudmenose ir tuose želdiniuose, kuriuose kirtimai buvo vykdyti ne žiemos metu.

Rezultatai rodo, kad esant trijų procentų palūkanų normai yra tikslinga taikyti kelmų apsaugos priemones pušies medynuose pietinėje Švedijoje. Ypač tai akivaizdu pušynuose, įveistuose žemės ūkio naudmenose.

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1. INTRODUCTION

The fungal pathogen *Heterobasidion* spp. causes considerable losses to conifer stands in the northern temperate zone (Hodges 1969, Laine 1976). Annual losses on a European level due to growth reduction and degradation of wood have been estimated to €790 million, of which Sweden accounts for about €80 million (Woodward et al. 1998).

Heterobasidion annosum (Fr.) Bref. s.l. is divided into several taxonomic species (Niemelä and Korhonen 1998). In Sweden two species are present, *Heterobasidion annosum* (Fr.) Bref. s.s. and *Heterobasidion parviporum* Niemelä & Korhonen. The former, *H. annosum* s.s., is often found on pine trees. Other coniferous species, primarily larch, spruce and some broadleaved trees may also be attacked, particularly when they grow in mixed stands with pine or on sites where pine was present in the previous rotation (Korhonen et al. 1992). The latter, *H. parviporum*, mainly infects Norway spruce (*Picea abies* (L.) Karst.) and occasionally also young Scots pine (*Pinus sylvestris* L.) trees (Korhonen 1978). In Sweden, *H. annosum* s.s. is present only in the southern part up to Mälardalen whereas *H. parviporum* is present in most of the country (Karlsson 1993). Root and butt rot, caused by *Heterobasidion* spp., is traditionally regarded as most serious on Norway spruce in Sweden. In areas where *H. annosum* s.s. is present, though, damage to Scots pine might be substantial (Bendz-Hellgren et al. 1998, Nilsson 2002).

The spores of *Heterobasidion* spp. enter Scots pine stands mainly through the stumps created during thinnings (Rishbeth 1951a) when the temperature is above 0ºC (Brandtberg et al. 1996). The fungus grows from stump roots to roots of neighbouring living trees via root contacts and grafts (Rishbeth 1951b). Once established in the root system, *Heterobasidion* spp. can remain active up to 62 years (Greig & Pratt 1976). In Scots pine, attack by *Heterobasidion* spp. is different from that in Norway spruce. Usually the fungus destroys only the roots of pine resulting in sudden death of the tree or windthrow. Consequently, while in Norway spruce the decay may extend several metres up in the stem, decay is seldom visible at the cut surface of the pine stumps (Laine 1976). This leads to less obvious economic losses to pine. However, according to Nilsson (2002) it is possible that *Heterobasidion* spp. damage is underestimated in Sweden, i.e. it is present in the tree, but the damage or death is referred to other causes.

The level of *Heterobasidion* spp. infection in the stand is associated with edaphic factors. Heavy attacks on Scots pine usually occur on dry, sandy soils with high pH (Rishbeth 1951b). Another factor which influences the intensity of root rot infection is the previous land use. Stands established on former agricultural land are more subjected to *Heterobasidion* spp. infection compared to stands on old forest land (Fiodorov 1998, Rishbeth 1950, 1957).

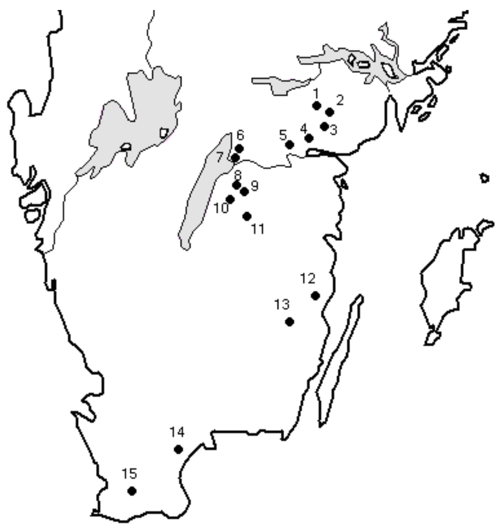
It has been shown that pine stumps generally are more susceptible to spore infection than stumps of other conifer species (Redfern 1982). The spread of *Heterobasidion* spp. can be reduced if freshly cut stump surfaces are treated (Rishbeth 1952, 1957). By using e.g. *Phlebiopsis gigantea* (Fr.) Jül, the amount of spore infection on the stumps can be significantly reduced (Gibbs et al. 2002, Greig 1976, Rishbeth 1963). Stump treatment is regularly used in many countries and in Sweden on Norway spruce (Thor 2001). However, Scots pine is not treated in Sweden and the reason for that is unclear.

The aim of this study was to investigate the importance of *Heterobasidion* spp. in monocultures of Scots pine in southern Sweden and to find out if it is reasonable to start treating pine stumps in order to reduce the future levels of infection, thereby minimizing the economic losses in stands of Scots pine.

2. MATERIALS AND METHODS

2.1 Description of the stands

The study was carried out in fifteen monocultures of Scots pine in southern Sweden (Fig. 1). High risk sites, i.e. well-drained sandy soils with high pH, were the main criteria in selecting the stands. Some of the sites were known to have damages possibly caused by *Heterobasidion* spp.



No.	Site	Location (Lat/Long)
1.	Katrineholm	60º00'53"N/16º15'10"E
2.	Katrineholm	58º57'52"N/16º23'30"E
3.	Katrineholm	58º53'15"N/16º18'10"E
4.	Norköping	58º47'9"N/16º22'10"E
5.	Norköping	58º41'33"N/15º44'30"E
6.	Motala	58º38'40"N/14º57'30"E
7.	Motala	58º38'35"N/14º57'10"E
8.	Mjölby	58º19'20"N/15º4'20"E
9.	Mjölby	58º18'40"N/15º4'10"E
10.	Ekeby	58º14'9"N/14º59'30"E
11.	Melaxander	58º2'N/14º16'E
12.	Fårbo	57º23'12"N/16º28'40"E
13.	Högsby	57º12'45"N/15º55'16"E
14.	Degeberga	55º50'2"N/14º5'50"E
15.	Genarp	55º36'3"N/13º26'36"E

Fig. 1. Location of the study sites in southern Sweden.

The size of the stands varied between 0.7 and 11 hectares (Table 1). The age of the stands was 21 to 65 years. All stands were even-aged and single-storied. Site index ranged from 22 to 30 m, measured for the dominant tree species (Scots pine) as the top height at a total age of 100 years (Table 1). The information about the stand history i.e. previous land use and number of thinnings was obtained from the forest owners. Three investigated stands were situated on old forest soils, eight stands had been used for agricultural purposes and the rest were pasture lands before being afforested (Table 1). All stands were thinned at least one time. In five stands thinnings were carried out exclusively during wintertime. For the rest of the stands one or all thinnings were performed during summer, autumn or spring. Stand density varied between 390 and 2197 trees/ha (Table 1).

2.2 Design of the experiment

At the stand level symptoms that might indicate the presence of root rot caused by *Heterobasidion* spp. in Scots pine stands were registered. The symptoms used were: (i) uneven stand density, (ii) pines dying in groups, (iii) windthrown pines with decay in root system, (iv) dead junipers (*Juniperus communis* L.) in the undergrowth and (v) basidiocarps of *Heterobasidion* spp. (Laine 1976).

Table 1. Description of the surveyed stands. In cases where exact month of the thinning is not known only the season is noted. "Size" is the stand size. "Age" is the stand age. "SI" is the site index, i.e. dominant height at 100 years of age. "DBH" is the mean diameter at breast height. "Land use" is the previous land use. "F" is forest soils, "A" agriculture land and "P" pasture land. "N" is the number of pines per ha. "Plots" is the number of sample plots. "Pines" is the number of pines per plot, and "Total" the number of assessed pines

Site	Size (ha)	Age (yrs)	SI (m)	DBH (cm)	Land use	Thinnings (no., year, season (month))	N (ha^{-1})	Plots (nos.)	Pines ($plot^{-1}$)	Total (nos.)
1.	2.8	25	T26	14.0	F	1. 2000-2001 winter (Dec-Jan)	1033	10	12-19	160
2.	0.7	31	T26	15.3	F	1. 2000 summer (July)	991	4	15-21	73
3.	2.0	38	T28	16.0	F	1. 1983 winter 2. 2003 autumn (Sept)	767	10	9-15	119
4.	1.1	43	T27	24.7	A	1. 1990 autumn (Sept) 2. 2000 spring (Apr)	511	7	7-11	68
5.	1.1	37	T27	22.6	P	1. 1990 autumn (Aug)	808	7	11-17	98
6.	3.5	46	T28	23.1	A	1. thinning 2. thinning	747	10	7-16	116
7.	0.8	21	T26	12.6	P	0. precommercial thinning	2197	5	35-39	186
8.	0.9	40	T30	23.2	A	1. 1982 winter 2. 1988 summer/autumn 3. 2001 winter	574	6	8-13	59
9.	1.2	50	T28	26.6	A	1. 1978 winter 2. 1990 winter 3. 2001 winter	577	8	7-12	71
10.	0.8	35	T26	24.8	A	1. winter 2. winter	481	5	7-10	41
11.	4.2	40	T26	25.5	A	self thinning 1. 1990 winter	637	10	7-12	98
12.	1.0	30	T28	20.6	A	1. thinning 2. 2002 winter	704	6	9-15	70
13.	1.6	35	T22	17.6	A	1. 1999 autumn (Aug-Sept)	1092	10	13-23	180
14.	11.0	29	T24	17.7	P	1. 1996 summer (May) 2. 2001 summer (June)	929	10	12-20	149
15.	0.9	65	T28	33.4	P	1. winter 2. winter 3. winter 4. 1997 winter	390	6	5-7	36

For other measurements in the stands sample plots were used. The number of sample plots was adjusted to represent approximately 10 % of the stand area, up to a number of maximum 10 plots, i.e. for stands bigger than 1.5 ha the number of plots was 10 irrespective of the stand size (Table 1). The sample plots, with a radius of seven metres, were evenly distributed in each stand with a randomized starting point. The diameter at breast height, 1.3 m above ground, was measured for each tree in each plot. The trees were classified according to their crown condition into one of four classes (Kurkela 2002): 1) healthy looking trees with a dense crown and the foliage with intensive green colour, 2) trees with increased crown transparency and retarded shoot growth, 3) trees with yellowish or partially brown foliage, 4) dead trees with brown foliage or needles already fallen, the trees apparently killed during earlier growing seasons.

After visual assessment of the trees on each plot, two plots were randomly chosen in each stand. In each of these plots one healthy looking tree and one tree with signs of dying off, i.e. trees in crown condition class two or three, were selected for root excavation. Dead pines were not sampled. Sample discs, two cm thick, were taken from three to four main lateral roots at a distance of 10, 50 and 100 cm from the butt of the tree. The cut samples from the roots were immediately transferred into plastic bags and incubated at 22ºC for 10 days. *Heterobasidion* spp. was detected by the presence of its conidial stage. No attempt was made to identify other decay-causing organisms. Isolations were made from conidiophores taken from root discs. Mating tests were carried out on isolations made from one randomly selected sample disc for each pine to assign isolated strains to *H. parviporum* and *H. annosum* s.s. The tests were based on the isolated strain's ability to heterokaryotize homokaryotic tester strains of *H. parviporum* and *H. annosum* s.s. (Korhonen 1978). The presence of clamp connections in the tester strains after mating, morphological changes in the tester strains, and the shape of the border line between the two mated isolates were used to assign the unknown sample to either *H. annosum* s.s. or *H. parviporum* (Korhonen 1978).

2.3 Statistics

The statistical analyses were performed using the SAS computer program (SAS Institute, Cary, NC). Stand number 7 was excluded from the statistical analysis since it was only precommercially thinned, and none of the sampled roots had *Heterobasidion* spp. infection. Simple linear regression analysis was used to determine the relationship between the dependent variable (percentage of infected root discs per tree) and the independent variables (previous land use, site index, stand age, number of thinnings, season of thinnings and crown condition class).

2.4 Modelling infection probability

To calculate the probability (P) of a tree being infected a logistic model was applied;

$$P = 1/(1 + e^{a + b\,\mathrm{CCgood} + c\,\mathrm{Agric} + d\,\mathrm{Winter}})$$

where e is the base of the natural logarithm, a, b, c, d are the parameters and CCgood, Agric, and Winter are the independent variables, i.e. the independent variables most suitable to use according to the regression analysis (see above).

Following values for independent variables were used:

CCgood	= 1	for healthy trees (the trees with 0 or 1 infected root disc were regarded as healthy)
CCgood	= 0	for infected trees, with more than 1 root disc infected
Agric	= 1	for agriculture land
Agric	= 0	for other land use
Winter	= 1	for the stands thinned only during winter season
Winter	= 0	when thinnings were performed not in winter or thinning seasons were mixed

The results from the logistic regression model were used to estimate the volumes that may be rescued by treating the stumps for each investigated stand. This was done by multiplying the probability (P) of a tree being infected with the total volume per hectare in each stand. The approximate volume per hectare was calculated from $V_{ha} = V \times N$, where "V" is the volume for an individual tree according to Näslund (1947) ($V = 0.1072d^2 + 0.0247d^2h + 0.007315dh^2$), and "N" the number of trees per hectare. Due to the available data collected in field the mean diameter at breast height on bark for all plots at a site was used for "d", and the average height of the dominant trees for all plots at a site was used for "h".

2.5 Possible benefits from stump treatment

The volume needed to be rescued from *Heterobasidion* spp. infection, in order to cover up the cost for stump treatments, was calculated based on growth and yield tables for Scots pine in southern Sweden (Persson 1992). In the example used, four thinnings were carried out in a stand with the site index of T28.

The benefits from stump treatment were estimated by comparing two different management scenarios: With or without stump treatment in thinnings performed during the season of spore spread. The incomes from volumes possibly being rescued by treating stumps were compared with the costs associated. It was assumed that in the absence of stump treatment the infected volumes would have no commercial value. It was also assumed that the positive effect from the stump treatment was seen only at second and third thinning (Table 7).

The costs for treating the stumps with Rotstop® were calculated according to the prices presented by Thor (1996) (Table 2). The share of timber and pulpwood at each thinning was calculated according to Lendrup et al. (1977). In estimations the average prices were used for timber and pulpwood (SÖDRA 1999/2000) (Table 2). All costs and benefits were discounted to the first thinning using interest rate of three percent.

The lowest volume to be rescued to cover the expenses from doing a treatment was then compared to the volumes calculated from the logistic model output described under *2.4*, i.e. the volumes likely to be rescued from *Heterobasidion* spp. death in real stands.

Table 2. Prices for pine wood and stump treatment with Rotstop

	Harvested volume		Prices		
	Pulpwood m³ fub/ha	Timber m³ to/ha	Pulpwood[1] SEK/m³ fub	Timber[1] SEK/m³ to	Treatment cost[2] SEK/m³ fub
1st thinning	23	1	240	200	9.80
2nd thinning	26	14	240	380	7.35
3rd thinning	26	31	240	460	11.00
4th thinning	22	51	240	600	6.60
Final felling	16	313	240	700	3.31

[1]Södra 1999; [2]Thor 1996

3. Results

3.1 General

Heterobasidion spp. was present in root samples from trees in fourteen of the fifteen stands (Fig. 2). A total of 44 (73 %) of the 60 sampled pines had *Heterobasidion* spp. infection in the sampled roots. Of the infected pines 20 trees (45 %) were assessed as visually healthy looking and 24 (55 %) as diseased trees. In five stands all four sampled pines were infected by *Heterobasidion* spp. (Fig. 2).

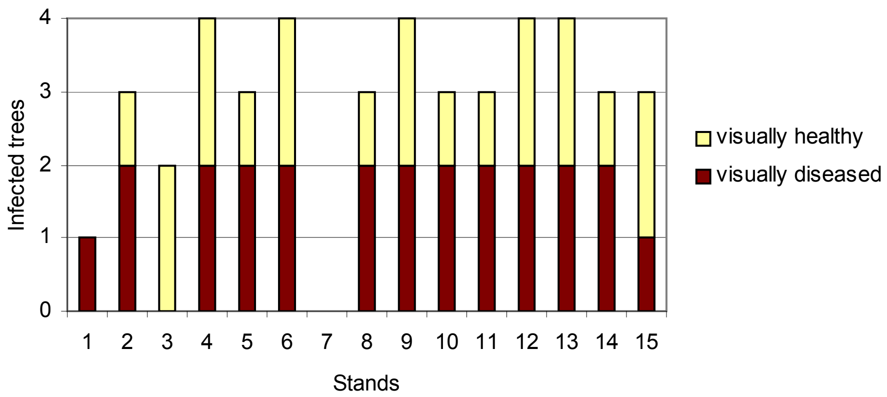


Fig. 2. Number of stands and trees infected by *Heterobasidion* spp. The stands are presented in the direction from the north (stand no.1) to the south (stand no. 15).

A significantly higher proportion of discs from the diseased looking trees (48 %) were infected by *Heterobasidion* spp. than for the healthy looking trees (14 %) (p<0.001) (Table 3). The incidence of *Heterobasidion* spp. in the sampled roots was significantly higher (p<0.001) in the stands established on former arable land, compared to stands on pasture land or old forest soils (Fig. 3). Thinnings during winter time also had a significant effect (p<0.05) on the disease incidence, while site index, stand age and number of thinnings had no effect (p>0.05).

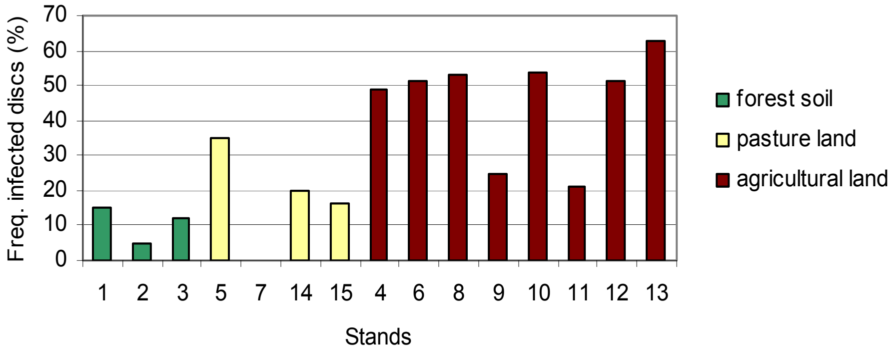


Fig. 3. Frequency of the root discs infected by *Heterobasidion* spp. on sites with different stand history. The stands are presented in the direction from the north (stand no.1) to the south (stand no. 15).

In 11 stands all four crown condition classes were distinguished (Table 4). In two stands (number 1 and 15) yellowish pines (i.e. pines of the third crown condition class) were not found. Dead trees (crown condition class 4) were not registered in three stands (number 9, 11 and 15) (Table 4).

At the stand level the most commonly registered signs of *Heterobasidion* spp. infection were uneven stand density and pines dying in groups (Table 5). There were no symptoms characteristic for *Heterobasidion* spp. in two stands (number 3 and 7) (Table 5).

Three isolates (7 %) of *Heterobasidion* spp., two from stand number 2 and one from stand number 1, were assigned to *H. parviporum*. All other isolates (93 %) were of *H. annosum* s.s.

Table 3. Frequency of root discs infected by *Heterobasidion* spp. in sampled trees. All visually healthy pines are of the first crown condition class

Stand	Visually healthy pines (%)	Visually diseased pines (%)
1.	0,0	4,5 [2]
2.	4,2	25,0 [3]
3.	12,5	0,0 [2, 3]
4.	16,7	82,6 [3]
5.	8,3	62,5 [2]
6.	42,9	61,1 [3]
7.	0,0	0,0 [2]
8.	20,8	87,0 [3]
9.	8,7	42,9 [2]
10.	21,7	90,5 [3]
11.	4,3	33,3 [2, 3]
12.	14,3	86,4 [2, 3]
13.	25,0	100,0 [3]
14.	9,1	31,8 [3]
15.	22,7	9,5 [2]
Mean	14,1	47,8

[2] Both pines from crown condition class 2.
[3] Both pines from crown condition class 3.
[2, 3] Pines from crown condition classes 2 and 3.

Table 4. Frequency of assessed pine trees in different crown condition classes

	Crown condition classes			
Stand	1 (%)	2 (%)	3 (%)	4 (%)
1.	63	34	-	1
2.	47	19	18	16
3.	63	35	1	1
4.	30	41	10	19
5.	51	34	4	11
6.	21	49	29	1
7.	43	33	15	9
8.	17	41	32	10
9.	45	44	11	-
10.	39	32	19	10
11.	57	33	10	-
12.	49	38	6	7
13.	51	34	8	7
14.	51	37	8	4
15.	78	22	-	-
Mean	47	35,1	11,4	6,4

Table 5. Registered signs of *Heterobasidion* spp. at the stand level

Stand	Stand density	Groups of dying pines	Windthrown pines with decay in roots	Basidiocarps of *Heterobasidion* spp.	Dead junipers (*J. communis* L.)
1.	uniform	no	a few	not found	no junipers
2.	uneven	yes	no	not found	no junipers
3.	uniform	no	no	not found	no junipers
4.	uneven	yes	only one	not found	no junipers
5.	uneven	yes	no	not found	not all
6.	uneven	yes	stumps of windthrown pines	on old pine stumps	no junipers
7.	uniform	no	no	not found	yes
8.	uneven	yes	no	not found	no junipers
9.	uneven	no	a few	on the roots of windthrown pines	no junipers
10.	uneven	yes	no	not found	yes
11.	uneven	yes	yes	on the roots of windthrown pines	no junipers
12.	uneven	yes	no	not found	no junipers
13.	uneven	yes	a few	on the roots of windthrown pine	no junipers
14.	uneven	yes	no	on the stumps	no junipers
15.	uniform	no	stumps of windthrown pines	on the roots of windthrown pines	no junipers

3.2 Modelling infection probability

The probability (P) of a tree being infected was best described by the model:

$$P = 1/(1 + e^{0.2634 + 2.4937\ \text{CCgood} - 2.3958\ \text{Agric} + 0.9078\ \text{Winter}}),$$

where the likelihood (max-rescaled R-square) for P is 0.4610. The probability of a tree being infected ranged from 0.22 to 0.89 for stands established on former arable land and from 0.03 to 0.43 for stands with other former land use, i.e. forest and pasture, depending on tree health (CCgood) and season for thinning (Winter) (Table 6).

Table 6. Probability of a tree getting infected in different scenarios. "CCgood 1" for healthy trees with 0 or 1 infected root disc, "CCgood 0" for infected trees with more than 1 infected root disc, "winter 1" stands thinned only during winter, "winter 0" stands thinned not in winter or thinning seasons are mixed, "agric 1" is agriculture land, "agric 0" is other land use

	CCgood 1		CCgood 0	
	Winter 1	Winter 0	Winter 1	Winter 0
Agric 1	0,22	0,41	0,77	0,89
Agric 0	0,03	0,06	0,24	0,43

3.3 Possible benefits from stump treatment

Based on the probability model the volumes which might be rescued by doing a stump treatment varied from 24.7 up to 43.1 m^3/ha for the stands on former arable land and from 8.8 up to 25.2 m^3/ha for the stands with other previous land use (Table 7).

According to the cost estimation for treating the stumps the minimal volumes needed to be saved in order to cover the cost of treatment in all thinnings and in final felling were estimated to be 2.7 m^3/ha in the second thinning and 3.9 m^3/ha in the third thinning, i.e. in total 6.6 m^3/ha (Table 8) (Fig. 4).

Table 7. Calculated volumes that may be saved from doing stump treatment for different former land uses. Stand 7 was excluded from calculations since it was only precommercially thinned and none of sampled root discs had *Heterobasidion* spp. infection. “Agric 1” indicates stands established on former arable land, “Agric 0” indicates stands on former pasture land and old forest soils

	Volumes saved m^3/ha	
Stand	Agric 1	Agric 0
1.		8,76
2.		12,72
3.		10,85
4.	31,47	
5.		26,04
6.	41,58	
8.	24,67	
9.	47,59	
10.	25,5	
11.	43,13	
12.	27,77	
13.	27,96	
14.		19,61
15.		25,24
Mean	38,52	17,2

Table 8. The costs and incomes during the rotation for two management scenarios: With or without stump treatment in thinnings carried out during season of spore spread

	Thinning time (years)	Harvested volume (m^3sk/ha)	Cost (SEK/ha)	Income (SEK/ha)
With stump treatment:				
1st thinning	24	35	8810	5735
2nd thinning	33	54	6761	11447
3rd thinning	45	77	7986	20448
4th thinning	60	101	8937	35911
Final felling	84	467	23156	222832
Without stump treatment:				
1st thinning	24	35	8566	5735
2nd thinning	33	51,3	6479	10834
3rd thinning	45	73,1	7291	18909
4th thinning	60	101	8370	35911
Final felling	84	467	21842	222832

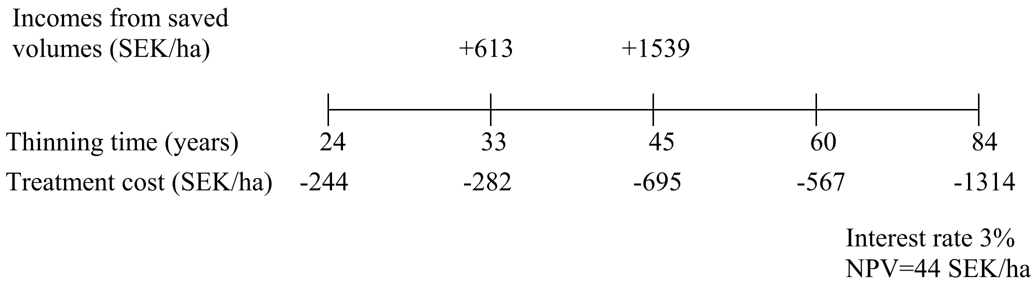


Fig. 4. Net present value (NPV) of costs and incomes associated with stump treatment over the rotation period.

4. DISCUSSION

The results of this study clearly show that *Heterobasidion* spp. is widespread in monocultures of Scots pine in southern Sweden. *Heterobasidion* spp. damage in pine stands in southern Sweden has already been recognized in earlier studies by Molin (1957) and Rennerfelt (1962). However, no attempts have been made to protect Scots pine stumps from spore infections. According to Nilsson (2002), stumps of pine trees in southern Sweden are frequently infected by *Heterobasidion* spp., therefore, with the additional results of the present study in mind, it seems important to treat stump surfaces against spore infections.

The present estimations show that stump treatment is beneficial in pine monocultures in southern Sweden. The volumes that may be saved from infection by treating stumps were higher than estimated minimal volumes needed to be saved in order to cover the cost for treatments in all stands. It was however most evident in stands established on former arable land. This may be explained by the fact that pine stands growing on former arable land are particularly susceptible to *Heterobasidion* spp. damage (Vasiliauskas 1989).

In the estimations of the minimal volumes needed to save, stump treatment was included for all thinnings and for final felling. Since *Heterobasidion* spp. damage to pine trees tends to decrease with increasing stand age (Rishbeth 1951b), it may seem less important to apply stump treatment in later thinnings and in final felling. However, according to Rönnberg et al. (1999) *Heterobasidion* spp. is able to spread not only into the same tree species but also into other susceptible tree species of the next rotation. Consequently, if conifers are being planted in the subsequent rotation, it may still be important to protect stumps also in later thinnings.

There are several factors of which the exact effect is not clearly shown. Some of the may be positive and some may be negative for the beneficiary of treating the pine stumps. In this study the benefits from stump treatment were estimated only by volumes that may escape mortality, not taking into account the losses due to growth reduction or increased risk of windthrow (Pratt 1998). Consequently, the benefits from treatment may be even greater. On the other hand, the volumes possible to rescue from infection may have been overestimated due to the use of the average height of the dominant trees instead of the height of individual trees. Moreover, since also trees with only one infected root disc were regarded as healthy in the modeling this might have led to an underestimation of the volumes possible to rescue from infection. However, the future of the trees in each crown condition class is unknown. It is possible the some of the slightly infected trees might survive the infection.

In the present study, sampled pines frequently contained *Heterobasidion* spp. infection in the root system. Because the majority of the stands was thinned during the season of spore spreading without applying stump treatment, the infection could easily spread within the stand. However, *Heterobasidion* spp. was also found in the stands that had been thinned only during winter when the risk for spore infection is low (Brandtberg et al. 1996). Since there were no data on the temperatures during thinnings, it can not be excluded that some winters may have been warm enough to allow for spore infections. Still winter thinnings gave a significantly lower infection level in the investigated stands.

In one stand *Heterobasidion* spp was absent. This stand had been only precommercially thinned. According to Vollbrecht et al. (1995), precommercial thinnings do not appear to pose a significant risk for stand infection in Norway spruce in southern Sweden. If this can be applied also for Scots pine, it might explain why the pathogen was not found in this stand. Furthermore, the root samples were taken from a limited number of lateral roots. It is possible that *Heterobasidion* spp. was present in the roots not being sampled, including the tap root. The tap root is very often found to be infected by *Heterobasidion* spp. (A. Vasiliauskas personal communication). Consequently, it is possible that the actual number of pines containing the pathogen is greater for the precommercially thinned stand and also for the other stands.

There was no significant difference between the number of healthy and diseased looking pines with *Heterobasidion* spp. infection in the roots. This may be due to the fact that slightly infected trees can not be distinguished from healthy trees on the basis of the crown condition (Kurkela 2002). However, defoliated pines were found to have a significantly higher proportion of infected root discs than healthy looking trees, especially in stands established on former arable land.

The majority of isolates were ascribed to *H. annosum* s.s. However, three isolates were of *H. parviporum*. According to Korhonen (1978) pine trees may be attacked also by *H. parviporum*. Usually, though, this species does not cause any considerable damage to older pines (Rishbeth 1951b). Since the isolations were made only from one randomly selected root disc for each tree, it can be argued that the other roots may have been infected by *H. annosum* s.s. (Slaughter et al. 1994). Consequently the importance of the three isolates of *H. parviporum* should not be overemphasized.

Mixed stands of Norway spruce and Scots pine have been suggested as a measure to reduce the spread of *Heterobasidion* spp. due to less intraspecific root contacts (Lindén et al. 2002, Piri et al. 1990). In mixed stands commonly only spruce stumps are treated against spore infection of *Heterobasidion* spp. (J. Rönnberg personal communication). According to Stenlid (1987), in southern Sweden *H. annosum* s.s. is more common on Norway spruce that *H. parviporum*. Since transfer of infection between tree species has been shown occasionally (Rishbeth 1957), it is possible that *H. annosum* s.s. may spread from spore infection of untreated pine stumps to the neighbouring Norway spruce trees (Lindén et al. 2002, Pratt et al. 1988). In this context, it seems important to treat also pine stumps in mixed stands with Norway spruce to prevent *H. annosum* s.s. from spreading to the Norway spruce trees. However, further studies are recommended to be able to economically justify this recommendation.

Conclusively the present study shows that Scots pine is often heavily attacted by *H. annosum* s.s. in southern Sweden. In order to reduce the incidence of *H. annosum* s.s. in monocultures of Scots pine, stump treatment during spore spread should be applied. With normal costs for the treatment this measure should also be economically beneficial.

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