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Control Efficacy of Stump Treatment and Influence of Stump Height on Natural Spore Infection by *Heterobasidion* spp. of Precommercial Thinning Stumps of Norway Spruce and Birch

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An alternative precommercial thinning technique results in trees being cut higher up the stem compared to the normal method using a brush saw. The aims of this study were to investigate if primary infection of *Heterobasidion* spp. on precommercial thinning stumps of Norway spruce and birch is influenced by stump height and to test the control efficacy of stump treatment with *Phlebiopsis gigantea* on precommercial thinning stumps of Norway spruce. Small Norway spruce and birch trees were felled on five sites in southern Sweden and their stumps subjected to natural spore infection. For each species, two treatments of stump height were created: 15 and 100 cm. Half of the Norway spruce stumps were treated with *P. gigantea*. After two months, 896 stumps were sampled and infection by *Heterobasidion* spp. was quantified. The height of stumps did not significantly influence infection frequency or size of infection on either tree species. Untreated Norway spruce stumps had an infection frequency of 55% while 31% of the treated stumps were infected. The control efficacy of stump treatment in terms of reduced relative infected area was 61–65%. The area occupied by *Heterobasidion* spp. on birch stumps was generally small, on average 0.4 cm^2 per infected stump, although 15% of the stumps were infected. The risk of primary infection in Norway spruce dominated stands should be considered when precommercial thinning is conducted but the control efficacy and economy of stump treatment warrants further investigation before practical recommendations can be made.

Keywords *Heterobasidion* spp., *Picea abies, Betula* spp., *Phlebiopsis gigantea*, precommercial thinning, stump height, stump treatment
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1 Introduction

Root and butt rot caused by *Heterobasidion* spp. results in severe economic losses for the forest industry in the Nordic countries (Bendz-Hellgren et al. 1998). Two species of the genus are known to exist here, *Heterobasidion parviporum* Niemelä & Korhonen and *Heterobasidion annosum* sensu stricto (Fr.) Bref. (Korhonen et al. 1998). While *H. parviporum* mainly infects Norway spruce (*Picea abies* (L.) Karst.) and occasionally saplings of Scots pine (*Pinus sylvestris* L.), *H. annosum* s.s. has a broader range of hosts, for example Norway spruce, Scots pine and several broadleaved tree species including birch (*Betula* spp. L.) (Korhonen 1978).

Infection starts with airborne basidiospores of *Heterobasidion* spp. germinating on and colonizing freshly created stump surfaces and wounds (Rishbeth 1951a, Isomäki and Kallio 1974). Trees surrounding a diseased tree or stump can become infected through secondary spread of fungal mycelia that grows across root grafts and contacts (Rishbeth 1951b). Infections on the stumps can be prevented by the application of chemical or biological control agents as stump treatment directly after felling (Holdenrieder and Greig 1998, Pratt et al. 1998). In the Nordic countries the most widespread treatment method is to spray with *Phlebiopsis gigantea* (Fr.) Jül. and Norway spruce is the most common species to be treated (Thor 2003). Stump treatment is frequently applied during commercial thinnings but not during precommercial thinnings (Berglund et al. 2007). While several studies have evaluated the effect of treating Norway spruce commercial thinning stumps with *P. gigantea* (Berglund and Rönnberg 2004, Nicolotti and Gonthier 2005, Thor and Stenlid 2005), the effect on precommercial thinning stumps is still unknown.

Precommercial thinning aims at promoting the desired trees by removing trees with non-desirable characters. This is a common practice in Swedish forestry and is normally carried out motor-manually with a brush saw (Fahlvik 2005). In most cases precommercial thinning in a monoculture Norway spruce stand is conducted when trees reach two to three meters in height (Fahlvik 2005). In an attempt to decrease time consumption and increase timber quality in the remaining stand an alternative precommercial thinning technique has been investigated (Fällman et al. 2003, Ligné et al. 2005). Instead of cutting the precommercial thinning trees at a normal low height, the new technique suggests they are cut higher up the stem, approximately 70–120 cm above ground (Karlsson and Albrektson 2000). Precommercial thinning stumps have previously not been considered to be of importance for the introduction of *Heterobasidion* spp. infection into a stand (Vollbrecht et al. 1995a). But since small Norway spruce stumps can get infected by spores of *Heterobasidion* spp. (Paludan 1966, Solheim 1994, Berglund et al. 2007) and Gunulf et al. (2013) showed that they also have the ability to spread *H. parviporum* to surrounding trees it is possible that precommercial thinning stumps can be an entry point for *Heterobasidion* spp. into the stand. Spore abundance of *Heterobasidion* spp. varies with the height above ground (Kallio 1970), and the microclimate on the stump surface, affecting spore germination and growth, might also be influenced by stump height. Furthermore, the tapering of trees could lead to smaller stump area being exposed to basidiospores if trees are cut higher up the stem. The risk of infection by basidiospores of *Heterobasidion* spp. could therefore be influenced by the height of the stump and consequently also by the precommercial thinning technique used during the operation.

The majority of seedlings in young forests in Sweden are naturally regenerated birch (*Betula* spp.) (Skogsdata: aktuella uppgifter… 2004). When the aim of management is a Norway spruce-dominated stand the birch will often be felled during precommercial thinnings. Although birch can get infected (Korhonen 1978), deciduous trees are regarded as less susceptible to *Heterobasidion* spp. infection compared to conifers (Korhonen and Stenlid 1998). Dead birch wood can on the other hand be substantially degraded by *H. annosum* s.s. (Daniel et al. 1998). Transfer of *Heterobasidion* spp. between stump and tree belonging to different tree species has also been reported (Vollbrecht et al. 1995b, Piri 1996). It is therefore possible that birch stumps act as entry points for *Heterobasidion* spp. into Norway spruce stands if they get infected. Consequently it is of interest to investigate primary stump infection on birch stumps created at precommercial thinning.

Hence the aims of this study were to i) investigate the influence of stump height of precommercial thinning stumps on natural spore infection by *Heterobasidion* spp., ii) test the control efficacy of *P. gigantea* as a control agent against natural spore infection of *Heterobasidion* spp. on precommercial thinning stumps of Norway spruce, and iii) investigate the susceptibility of precommercial thinning stumps of birch to natural spore infection by *Heterobasidion* spp.

2 Materials and Methods

2.1 Research Design

The experiment was established in five Norway spruce-dominated precommercial thinning sites in southern Sweden during ten days in June 2010. The stand age varied between 8 and 15 years with site indices (dominant height at age 100 years in Norway spruce) between 26 and 32 (Table 1). The previous land use was forest on all sites. Six different stump types were created by felling trees with a chainsaw: low cut spruce (15 cm above ground), low cut spruce treated with *P. gigantea* (see below), high cut spruce (100 cm above ground), high cut spruce treated with *P. gigantea*, low cut birch and high cut birch. Trees were crossed callipered 15 cm and 100 cm above ground and diameters ranged between 2.4 and 14.5 cm at 15 cm height (Table 2). Trees were felled along a path, mimicking a normal precommercial thinning operation, starting at a random spot in each stand. To ensure similar spore densities on all stump types, trees were felled repetitively in the following order; high cut untreated spruce, low cut untreated spruce, high cut treated spruce, low cut treated spruce, high cut birch and low cut birch, i.e. stumps belonging to the same stump type were created five stumps apart. For every stand 30 stumps belonging to each stump type were created. The sampling path followed the shape of the stand and turned around when it reached a stand edge. All stumps were situated at least ten meters from all edges. Green branches were generally removed while the smallest that were difficult to cut with the chainsaw were left.

P. gigantea (Rotstop®S) was used for stump treatment. Each morning, 2 g of Rotstop®S was suspended in 2000 ml of tap water resulting in a concentration of 1000–10 000 oidiospores/ml. To ensure full coverage of treatment on stump surfaces, a dye (Becker-Underwood, Inc., Ames, IA, USA) was added to the solution approximately corresponding to the manufacturer's recommendations of one tablet dissolved in 25 l. Immedi-

Table 1. Description of experimental sites.

Site	North coord. a)	East coord. a)	Stand age (years)	Site index	Stems/ha
Tönnersjö	6285271	384438	15	32	2500
Åryd 497	6296802	499919	8	26	2700
Åryd 200	6301369	499067	8	26	4100
Åryd 268	6299245	499503	13	28	3120
Kullaskogen 65	6238835	453084	11	28	4750

a) Coordinates according to SWEREF99 TM

Table 2. Properties of sampled stumps.

Species	Stump type	N	Diameter at 15 cm height (cm)		
			Mean (St. dev)	Min	Max
Norway spruce	Low cut Treated	150	6.53 (2.12)	2.6	12.9
	High cut Treated	150	6.62 (2.14)	2.5	14.5
	Low cut Untreated	148	6.55 (2.22)	2.7	14.5
	High cut Untreated	150	6.95 (2.20)	2.7	13.4
Birch	Low cut	148	5.74 (2.03)	2.4	12.1
	High cut	150	6.23 (2.10)	2.6	13.8

ately after felling, the treatment was applied to the stumps using a hand spraying nozzle. The volume of the suspension applied was adjusted according to the diameter of the stump surface so that the solution covered the surface with a thickness of about 1 mm, corresponding to approximately 100–1000 oidiospores/cm^2. To avoid any preexisting infection in stumps, only stumps without discoloration were included.

2.2 Sampling and Infection Assessment

Stumps were sampled two months after establishment. A 5 cm thick disc was cut with a handsaw after discarding the top 1 cm thick disc. Prior to cutting the discs, the bark and the blade of the saw were disinfected by spraying with 70% ethanol. All cut discs were immediately put in plastic bags and stored in a cold-store room (≈4 °C) within 36 hours. After three to eight weeks in cold storage, discs were incubated at room temperature (≈20 °C) for 7–10 days. Both sides of discs were scanned for *Heterobasidion* spp. colonies using a dissecting microscope. *Heterobasidion* spp. was recognized by the presence of conidiophores. All colonies of *Heterobasidion* spp. were marked, the number of discrete colonies counted and the total area occupied on each side of the disc was measured to an accuracy of 0.5 cm^2. Three stumps could not be located and one stump showed signs of previous infection, i.e. discoloration on the underside of the disc, and were therefore not included (Table 2). If conidia of *Heterobasidion* spp. were found on either side of the disc it was considered infected. Infected area and number of colonies were calculated for each infected disc as the average of the two sides. Relative infected area was determined by dividing infected area by the total disc area.

2.3 Statistical Analyses

The influence of stump height and treatment on *Heterobasidion* spp. infection on Norway spruce stumps was investigated with a factor analysis in GLM with sites as random blocks in Minitab 16 (Minitab Inc., State college, PA, USA). For the infection parameters relative infected area, infected area and number of colonies on infected stumps, averages for each stump type and site were used in the factor analysis. Due to unequal variances among stump types, the difference of infection parameters on birch stumps, treated Norway spruce stumps and untreated Norway spruce stumps was analyzed with Friedman's test with the sites as blocks in Minitab 16. Further pair wise comparisons were also performed with Friedman's test. The average for every site and stump type of relative infected area, infected area and number of colonies on infected stumps were used in the analysis. The influence of stump height on infection on birch stumps was analyzed with sites as random blocks in GLM in Minitab 16. The average for every site and stump type of relative infected area, infected area and number of colonies on infected stumps were used in the analysis. Also, the difference of exposed stump area, calculated from the diameter, depending on the height of stumps was analyzed with sites as random blocks in GLM. Stumps from Norway spruce and birch were analyzed separately and the averages for each site and stump type were used. For each site, control efficacy (Berglund and Rönnberg 2004) was determined for infection frequency and relative infected area on high cut untreated, high cut treated and low cut treated Norway spruce stumps using low cut untreated Norway spruce stumps, i.e. the typical stump left after a precommercial thinning, as the control. Control efficacy is defined as the reduction of relative infected area or infection frequency on a specific stump type in relation to the relative infected area or infection frequency of the control stump. The control efficacy was analyzed with sites as random blocks in GLM and further analyzed with Tukey's test in Minitab 16. The relationship between stump size and the probability of infection was investigated with PROC GLIMMIX in SAS 9.2 (SAS Institute Inc., Cary, NC, USA) with binomial distribution and logit as link. Treated and untreated Norway spruce stumps were analyzed separately. The model included the random factor "Site", i.e. the dependence of stumps in the same site was taken into account.

Table 3. The effect of precommercial thinning stump height and stump treatment with *P. gigantea* on infection by *Heterobasidion* spp. of Norway spruce stumps.

Factor	Stump type	N	Infection frequency (%)		Relative infected area of infected stumps (%)		Infected area of infected stumps (cm^2)		No. of colonies on infected stumps	
			Mean	p-value	Mean	p-value	Mean	p-value	Mean	p-value
Height of stump	High cut	10	40.3	0.214	9.8	0.144	2.39	0.824	1.73	0.116
	Low cut	10	46.1		6.1		2.20		2.34	
Treatment	Untreated	10	55.1	<0.001	11.7	0.008	3.49	0.015	2.51	0.021
	Treated	10	31.3		4.2		1.09		1.55	

Table 4. Control efficacy [y] of different stump types of Norway spruce on reducing infection frequency and relative infected area compared to low cut untreated Norway spruce stumps. Means within columns that do not share a letter are significantly different at significance level 0.05.

Stump type	Efficacy on infection frequency (%) (95% CI) [z]		Efficacy on relative infected area (all stumps included) (%) (95% CI) [z]	
High cut Untreated	11.1b	(–2.5; 24.7)	–51.3b	(–97.4; –5.2)
Low cut Treated	44.8a	(31.2; 58.4)	65.3a	(19.2; 111.4)
High cut Treated	60.0a	(46.4; 73.6)	61.2a	(15.1; 107.3)

[y] Control efficacy is defined as the reduction of relative infected area or infection frequency on a specific stump type in relation to the relative infected area or infection frequency of the control stump.
[z] CI, confidence interval. All confidence intervals that do not cover 0 are significantly different from the control, i.e. low cut untreated Norway spruce stumps.

3 Results

3.1 Norway Spruce Stump Height and Treatment

Stump height of Norway spruce did not significantly influence infection frequency nor any of the other infection parameters. Stumps treated with *P. gigantea* had lower infection frequency as well as smaller mean infected area, relative infected area and fewer mean number of colonies on infected stumps compared to untreated stumps (Table 3). There was no significant interaction between height and stump treatment when analyzing any of the infection parameters, i.e. treated stumps had lower values for infection parameters compared to untreated irrespective of stump height. Exposed stump area was on average 37.2 cm^2 for the low cut stumps and smaller, 26.8 cm^2, for the high cut stumps ($p = 0.004$).

The control efficacy differed among stump types with respect to infection frequency ($p = 0.002$) and relative infected area ($p = 0.005$). High- and low cut stumps treated with *P. gigantea* had significantly higher control efficacy in reducing infection frequency as well as relative infected area compared to the high cut untreated stumps. As the confidence intervals for the means of the treated stumps did not cover zero they were also significantly different from the control (i.e. the low cut untreated stumps). The control efficacy of high cut untreated stumps differed significantly from the control in terms of the relative infected area, but not for infection frequency (Table 4).

3.2 Birch Stumps

The height of birch stumps did not significantly influence infection frequency or any of the other infection parameters (Table 5). Exposed stump area of low cut stumps was on average larger compared to that of the high cut stumps ($p = 0.001$); 29.0 cm^2 compared to 16.2 cm^2. Birch stumps had significantly lower infection frequency than untreated Norway spruce stumps; 14.8% compared to 55.0%. The mean infected area and relative infected area on the infected stumps

Table 5. The effect of precommercial thinning stump height on infection by *Heterobasidion* spp. on birch stumps and the difference between infection on birch, untreated Norway spruce and treated Norway spruce stumps. The influence of height was analyzed with GLM and differences among birch, untreated Norway spruce and treated Norway spruce were analyzed with Friedman's test. Values that do not share a letter are significantly different at significance level 0.05.

Stump type	N	Infection frequency (%)		Relative infected area of infected stumps (%)		Infected area of infected stumps (cm^2)		No. of colonies on infected stumps	
		Mean	p-value	Mean	p-value	Mean	p-value	Mean	p-value
High cut Birch	5	17.3	0.077	2.2	0.144	0.36	0.579	0.91	0.493
Low cut Birch	5	12.2		1.5		0.49		1.53	
Birch	5	14.8b		1.9c		0.37c		0.98a	
Treated spruce	5	31.3b	0.022	4.3b	0.007	1.18b	0.007	1.66a	0.074
Untreated spruce	5	55.0a		11.3a		3.46a		2.52a	

were more than twice as large for Norway spruce stumps, irrespective of treatment, compared to birch stumps (p=0.007) (Table 5).

3.3 Probability of Infection and Stump Diameter

On Norway spruce stumps, the probability of infection increased with increasing stump diameter for untreated stumps (p=0.002). For the treated stumps no relationship could be detected (p=0.412), i.e. the probability of a treated Norway spruce stump being infected was not influenced by the diameter of the cut surface (Fig. 1).

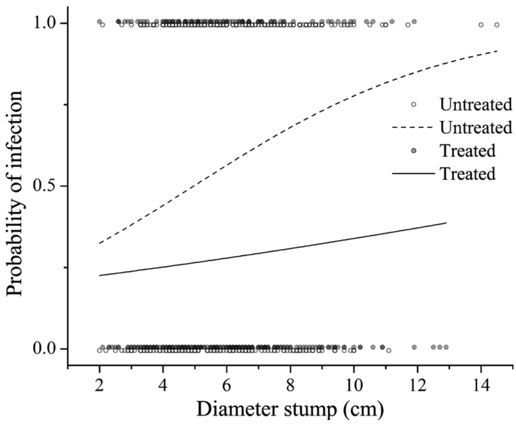

Fig. 1. Probability of infection by Heterobasidion spp. on Norway spruce stumps depending on the diameter of the stump surface for untreated stumps (p=0.002) and treated stumps (p=0.412). Circles represent sampled stumps while lines represent the predicted probability based on the sampled stumps. Circles representing infected stumps are placed at probability 1 and uninfected at probability 0. The probability of infection depending on size was predicted by PROC GLIMMIX. Overlapping data points are indicated by darkening color of circles.

4 Discussion

The height of precommercial thinning birch stumps did not significantly influence any of the infection parameters. For the Norway spruce stumps, no differences between high- and low cut stumps could be detected regarding infection frequency, actual infected area, relative infected area, number of colonies or control efficacy on the reduction of infection frequency, while high cut untreated stumps were found to have lower control efficacy on reducing relative infected area compared to low cut untreated stumps. Considering all parameters combined, it seems that the height of the stump is of minor importance for *Heterobasidion* spp. infection on Norway spruce as well as birch precommercial thinning stumps. Thus it seems likely that the alternative precommercial thinning technique, resulting in taller stumps, would not influence primary infection on birch or Norway spruce to any greater extent. The result can seem unexpected considering the report of higher abundance of spores close to the ground (Kallio 1970). We should however bear in mind that Kallio (1970) only measured at two levels, on the ground and 10 m above, thus spore loads 1 m from the ground perhaps do not differ all that much from those at ground level. Several studies have shown a positive relationship between stump size and infection frequency (Rishbeth 1951a, Paludan 1966, Solheim 1994, Morrison and Johnson 1999). Although high cut Norway spruce stumps had approximately 30%, and birch stumps 40%, smaller exposed area than low cut stumps in the present study it seems that this difference was not large enough to have any significant effect on primary infection. Still, there is a possibility that precommercial thinning technique could influence the amount of *Heterobasidion* spp. infection entering the remaining stand. High cut stumps entails a longer distance for the fungus to grow before reaching adjacent trees which could reduce the risk of secondary infection. On the other hand, the larger volume of woody material associated with high cut stumps could increase the amount and potential of inoculum which could increase the risk to the remaining stand compared to if low cut stumps were created. Thus, further studies are needed to elucidate the influence of stump height on secondary spread.

Almost one-third of the treated Norway spruce stumps were infected by *Heterobasidion* spp. two months after treatment. The infections were however considerably smaller on the treated stumps compared to the untreated stumps. Although the impact of infection size at stump height on infection probability in the adjacent trees is basically unknown, Morrison and Redfern (1994) found on Sitka spruce (*Picea sitchensis* (Bong) Carrière) a positive correlation between stump area colonized two years after felling and root volume colonized six years later suggesting a greater impact from larger infections. Therefore it is likely that merely considering the infection frequency will lead to an underestimation of the impact of stump treatment on the remaining stand.

The relative infected area was reduced by 61–65% on the precommercial thinning stumps treated with Rotstop®S. Previous studies dealing with commercial thinning stumps of Norway spruce have reported control efficacies ranging between 50–100% for Rotstop® (the original strain presently used in Finland) (Korhonen et al. 1994, Thor and Stenlid 1998, Berglund and Rönnberg 2004, Berglund et al. 2005, Nicolotti and Gonthier 2005, Rönnberg et al. 2006) and 63–94% for Rotstop®S (the strain presently used in Sweden) (Berglund et al. 2005, Rönnberg et al. 2006). Although the control efficacy found in the present study could be considered low, it is not exceptionally different from studies on commercial thinning stumps. Still, the tendency of stump treatment being more effective for the larger stumps (Fig. 1) gives rise to the question if control efficacy of *P. gigantea* as stump treatment is influenced by the size of stump. Perhaps environmental differences on precommercial thinning stumps compared to that of commercial thinning stumps, e.g. moisture content (Bendz-Hellgren and Stenlid 1998), inhibits colonization by *P. gigantea* and its overall treatment effect to some degree. Vasiliauskas et al. (2002) found fewer sporocarps of *P. gigantea* on smaller stumps of Norway spruce compared to larger stumps, possibly indicating a preferred habitat of the fungus. The present study was not designed to investigate the effect of stump size on treatment and therefore further conclusions should not be drawn at this point.

The previous land use of forest on the experimental sites could also have had some influence on the apparent low control efficacy as well as the high infection frequency of treated stumps; i.e. it is possible that residual stumps from the previous rotation infected the precommercial thinning stumps thru secondary infection (Piri 2003). Measures were taken to reduce this risk as only stumps without any discoloration were included in the study, but since mycelia can be found before visible decay (Piri 2003) it is possible that some of the stumps nevertheless were infected. Still, it is not likely that the majority of the detected infections were present before cutting the trees as infection frequency is positively correlated with tree age (Piri and Korhonen 2001). Infection frequencies in Norway spruce trees of similar ages as in the present study have been reported to range between 2–13% despite heavy infection in the previous rotation (Rönnberg and Jørgensen 2000, Piri 2003).

Although the probability of primary infection by *Heterobasidion* spp. increases with increasing stump diameter (Paludan 1966), half of the untreated precommercial thinning stumps in the present study were infected two months after stumps were created. This result is in accordance with Berglund et al. (2007) who found approximately 40% of Norway spruce stumps with diameters between 5–6.9 cm, and almost 60% sized between 7–8.9 cm, infected by *Heterobasidion* spp. Consequently, we must conclude that there is a substantial risk of infection on the stumps created during precommercial thinning of Norway spruce. The future of these newly established infections is unknown and it is possible that the rapid drying of precommercial stumps (Bendz-Hellgren and Stenlid 1998) could hamper further spread into the stand. However Paludan (1966) sampled small Norway spruce stumps four years after the trees were felled and found approximately 50% of the stumps with diameters between 4–7 cm to be infected. With a growth rate of 0.5 m/year in stump roots (Pettersson et al. 2003) infection of *Heterobasidion* spp. could reach the closest trees during those four years if planted with 2 by 2 meters spacing as long as the substrate for fungal growth, i.e. roots, extends long enough. Since 15-year-old spruce trees can have roots extending more than 3 m (Kalliokoski et al. 2008) it is highly probable that root contacts are established and secondary spread from precommercial thinning stumps can occur. Furthermore, since Gunulf et al. (2013) showed the ability of small infected Norway spruce stumps to spread the disease to adjacent small trees we therefore must conclude that there is a risk of infection from *Heterobasidion* spp. entering the stand during precommercial thinning. That risk is most likely, due to lower probability of both primary and secondary infection (Paludan 1966, Gunulf et al. 2013), lower compared to the risk during commercial thinnings. Since the magnitude of the risk is not known it is uncertain at this point if stump treatment of precommercial thinning stumps would be economically justified. However conducting precommercial thinning during the winter when the risk of primary infection is low (Solheim 1994) could, where applicable, be an option to reduce the risk of *Heterobasidion* spp. infection.

Considering that deciduous trees are less susceptible to infection by *Heterobasidion* spp. (Korhonen and Stenlid 1998) it can seem surprising that almost 15% of the birch stumps in the present study were infected. However, the infections were small which could, as discussed above, suggest lower probability of infections getting established in the stump. Furthermore, if the infections found in birch stumps were *H. parviporum* they would, due to host preferences (Korhonen 1978), probably not be vigorous in the long run. Therefore it seems unlikely that birch stumps created during precommercial thinnings would contribute to any greater extent to the spread of infection into the remaining Norway spruce stand. However since many birch stumps can be created during precommercial thinnings and a substantial proportion of them can get infected, it would be advantageous to monitor the development of these small infections in birch stumps before they are discarded.

As infection frequency for birch was low, the individual infected birch stump on some sites had a large impact on the analysis of infected area, relative infected area and number of colonies on infected stumps. Excluding sites with less than five infected stumps in any category from the analysis, thus omitting two sites from the height analysis and one site from the comparison between Norway spruce and birch, gave the same general result as when all sites were included. The only difference was that in the comparison between birch and Norway spruce the differences in number of colonies were significant with the omission of one site.

In conclusion, the height of precommercial thinning stumps of Norway spruce and birch does not significantly influence primary infection by *Heterobasidion* spp. Thus from a management perspective equal amount of spore infections can be expected on the precommercial thinning stumps irrespective of whether the conventional or the alternative technique, where trees are cut higher up, is used. The choice of technique might however affect the future of those infections since the risk of secondary spread could be influenced by the height of stumps. A substantial amount of small Norway spruce stumps can get infected and the risk of infection in Norway spruce dominated stands should be considered when precommercial thinning is conducted. Control efficacy and economical consequences of stump treatment need further investigation before practical recommendations can be made. Conducting precommercial thinning during the winter, when applicable, is one management option to reduce the risk.

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