Heterobasidion spp presence in young pine plantations in southern Sweden

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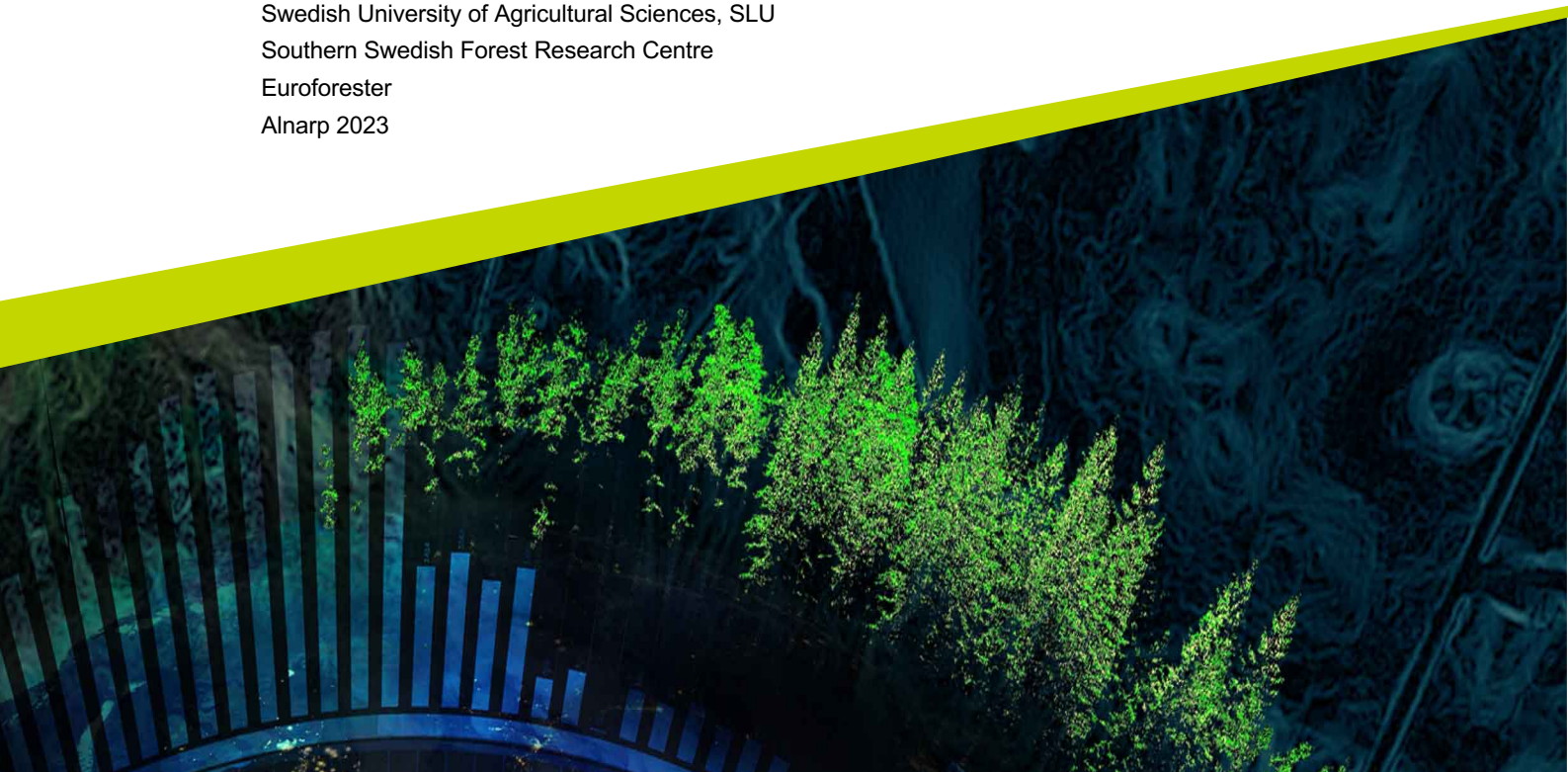

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Abstract

Heterobasidion species cause great economic loss the forest industry in the northern hemisphere. The spread of infection takes two forms, the first is an airborne infection and the second is a vegetative infection from infected root to healthy root. Much research has been done concerning the *Heterobasidion* pathogen. Little research has however been done on young pine stands with a previous generation of pine. Therefore the presence of *Heterobasidion spp* in such stands without a known history of infection is unknown. 30 sites, between 4 and 6 years after planting in southern Sweden were sampled. Using a transect and circular plots as proxies for the whole stand. Discs were taken from all dead pine trees found in the transect and 6 randomly taken live trees from two circular plots per stand. Results showed that 6.5% of the live tree samples were infected with *Heterobasidion spp*, and 6.2% of dead trees sampled were infected. There was no significance in relation to age, density, DBH or height to infection. Although infection presence is a small proportion of these young stands now, with many years until harvest there is much vegetative and airborne infection that could spread through the sites, potentially causing significant damage. The use of control methods such as urea, Rotstop and silvicultural controls could be a way to reduce negative effects of the *Heterobasidion spp* infection. Especially in a changing climate, it may be prudent to include *Heterobasidion* spp. controls in forest planning.

Keywords - *Heterobasidion*, Scots pine, *Pinus Sylvestris*. Sweden

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1. Introduction

Heterobasidion species cause root rot disease in trees in the northern hemisphere. In commercial forestry, *Heterobasidion spp* are responsible for much economic loss and has even been described as "the most important disease in conifers in the northern temperate regions" (Woodward 1998). In numerical values it has been estimated that *Heterobasidion annonsum* alone costs forest sector in the European Union 790 million euros per year (Woodward 1998). Infection cause reduction in growth, wood quality, mortality and an increased risk of windthrow (Woodward et al., 1998, Garbelotto & Gonthier 2013, Wang 2014). In an effort to try to combat these economic losses much research is conducted on this pathogen. With *Heterobasidion annonsum* being the first of this kind of pathogen to have its genome sequenced and having over 1700 published papers on the subject (Garbelotto & Gonthier 2013)

1.1 Biology

The two most economically important conifer species in Sweden, Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris)*, are impacted by *Heterobasidion* species. The two *Heterobasidion* species present in Swedish forests are *H. parviporum* and *H. annonsum*. *Heterobasidion parviporum* prefers Norway spruce and is found throughout Sweden. *Heterobasidion annosum* is found only in the southern half of Sweden and prefers Scots pine but can also infect other conifer and broadleaf trees (Garbelotto & Gonthier 2013). In general, broadleaf trees are less susceptible to the infection of *Heterobasidion* species than conifers (Swedjemark &Stenlid 1995). Due to the location of sample sites and the host species sampled, it is likely that the pathogen studied will be *H. annonsum.* Unfortunately, we cannot be sure of this without genetic analysis so from this point on "*Heterobasidon spp"* will be used to describe the possible presence of both species.

Heterobasidion spp. infect, in the first place, fresh exposed dead wood such as stumps or wounds via airborne basidiospores. If this initial stage of infection is successful, the pathogen can then infect healthy trees via a secondary infection method that involves vegetative growth of the mycelium through root-to-root contact (Garbelotto & Gonthier, 2013, Stenlid and Redfern 1998). Once the

infection has taken hold in a healthy tree it can cause a loss in vigour, growth and even mortality (Woodward 1998). The Infection can be gradual and often is not identified until the later stages of the infection as the pathogen is hard to identify using visual cues only (Vollbrecht & Agestam 1995, Garbelotto & Gonthier 2013).

Although infection cannot be identified visually with certainty, there are some visual indications of *Heterobasidion spp* infection, such as an enlarged buttress. As shown by Pitkänen et al (2021) who investigated the ability of remote sensing equipment to identify root rot in pine stands in Finland where buttresses of infected pine trees were swelled in comparison to pine trees with no *Heterobasidion spp.* infection.

Due to the nature of infection and spread of *Heterobasidion spp,* silvicultural practices in the stand can influence the infection potential from *Heterobasidion spp* as was shown by Blomquist et al in 2020 in spruce trees. Management practises such as pre commercial thinning and harvest (Cleary et al., 2013) can increase the incidence and spread of *Heterobasidion spp* in the stand by creating wounds and fresh stumps open to infection. Contrary to popular belief, *Heterobasidion spp* can spread early in the life of a stand (Bendz-Hellgren and Stenlid, 1998). Infection after pre commercial thinning can have repercussions to stand health in the future and importantly economically for the forest industry, at the time of harvest.

1.2 *Heterobasidion spp.* Control

There are two methods of control used to prevent or reduce infection by *Heterobasidion spp* , i.e., silviculture and stump treatment (Asiegbu et al., 2005). Silvicultural methods include for example wider spacing when planting to avoid a management regime including many thinnings or only thinning broadleaves or thinning in winter (Rönnberg et al., 2013, Lygis et al., 2004). A radical method to reduce the inoculum is to remove the stumps at final felling (Vasaitis et al., 2008). Planting mixed stands with broadleaved and conifer species can also reduce *Heterobasidion spp* infection due to the natural resistance to infection found in broadleaf trees (Piri et al., 1990, Swedjemark & Stenlid 1995, Delatour et al., 1998 (Lindén and Vollbrecht, 2002).

Stump treatment occurs in two different forms, chemical or biological. Chemical control uses compounds that work to prevent the spread of the *Heterobasidion spp* pathogen. They are sprayed on the stump directly after harvesting or thinning takes place. These compounds are easy to manufacture, handle and use so they have become widely applied (Asiegbu et al., 2005). An example of one such chemical control is urea. This compound works to increase the pH of the stump surface so as to render it unsuitable for colonisation of the *Heterobasidion spp* pathogen (Johansson et al., 2002). Urea treatment effectiveness has been shown to increase in higher temperatures (Johansson et al., 2002).

Biological control intends to use a more competitive, and less deleterious pathogen to out-compete *Heterobasidion spp* (Asiegbu et al., 2005). One such biological control is Rotstop, a treatment consisting of the spores of the fungus *Phlebiopsis gigantea*, a natural enemy of *Heterobasidion spp* which is used commercially with mixed results. Effectiveness of Rotstop has been found to be greater on pine stands than on spruce stands (Kenigsvalde et al., 2016). Notably, pine stands in Sweden are rarely treated for *Heterobasidion spp* infection at thinning or harvest.

It must be noted that Rotstop was originally developed in Finland and uses therefore, the Finish strain of *Phlebiopsis gigantean.* In Sweden the control agent is called RotstopS and uses the Swedish strain of *Phlebiopsis gigantean* (Berglund et al., 2005).

1.3 Young stands and subsequent pine generations

Heterobasidion spp can remain in a diseased tree or stump for decades and so increasing the chance of infection over time if not over space. Leaving the next planted generation at risk. Little is known about how *Heterobasidion spp* develops through different pine generations and what the prevalence of *Heterobasidion spp* infection looks like in second generation young pine stands. In a study conducted by (Piri et al., 2021) the stand level infection between pine generations was investigated. They looked in detail at a harvested stand of 1.2 ha that had slight signs of *Heterobasidion spp* infection before harvesting occurred. The actual infection rate of the old stand and then the infection rate of the subsequent generation were studied in detail to try to elucidate on current biological and pathological knowledge of *Heterobasidion spp* over two generations. The first generation had a 40% presence of *Heterobasidion spp* in what were observed as “healthy trees” . While the second generation 15 to 18% of seedlings killed by *Heterobasidion spp* over 9 years. The first dead seedlings were found 5 years after planting. This level of infection, argued Piri, means that more attention should be given to the vegetative stage of infection, so as to reduce the damage in Pine stands. This argument is backed up by other research and in other tree species (Oliva et al., 2011, Tubby et al., 2008, Piri, 1996).

1.4 Climate change

Heterobasidion spp spore infection takes place when temperatures reach 0˚C and over (Korhonen and Stenlid, 1998). Climate change predictions estimate that world temperatures and temperatures in Sweden will increase (IPCC 2021, Lind &

Kjellström 2008). *Heterobasidion spp* infections could, therefore, take a firmer hold in more northern regions and stay active for a larger part of the year in Sweden (Korhonen and Stenlid, 1998). Indirect climate change factors such as snow and ice, droughts, wind, fire, insects and pathogens are also set to increase in many climate change scenarios These disturbances could amplify fresh dead wood and so compound the spread of pathogens such as *Heterobasidion spp* (Seidl et al., 2017, La Porta et al., 2008, Terhonen et al., 2019)

With this knowledge it is important to improve management techniques in Swedish forestry to prevent the spread of such disease and protect forests from the consequent economic loss. To do this, more investigation into the disease and its prevalence is needed. Especially in pine trees which are underrepresented in *Heterobasidion spp* reseach in Sweden today. Allowing a potential shift in management, perhaps also treating stumps in pine stands when they are thinned and harvested (Vasaitis et al., 2008). *Heterobasidion spp* also reduce a stand's resilience to storm damage and with climate change comes an increase in storm severity and frequency in Sweden (Schütz et al., 2006). *Heterobasidion spp* therefore increases risk factors and potential economic loss in the future for forest owners in more than one way and as these factors combine the problems could multiply.

1.5 Hypothesis

Hence, in this study we want to quantify the presence of *Heterobasidion spp* in pine stands where the previous stand consisted of pine. The infection history will be unknown and therefore the sample will be unbiased to infection history. In the hope that the sample will be representative of southern Sweden. This way we can look at the effect of *Heterobasidion spp* on pine stands, independently of any connection to historical spruce infections. This study will investigate what is termed "young pine trees". Here "young" refers to trees of 4 to 6 years after planting.

The hypotheses are:

1. *Heterobasidion spp* is present in young pine stands where the previous stand consisted of pine.
2. *Heterobasidion spp* fruiting bodies will be present in stands studied
3. *Heterobasidion spp* infection is related to tree density, height, diameter at breast height (DBH) and or age.

2. Methods

2.1 Study sites

During August and September of 2022, 30 pine stands planted between 2016 to 2018 were selected in southern Sweden for the field study. In all sites the previous tree generation was also pine, years after planting were between 4 and 6 years. A gross list of sites was provided by Sveaskog, Boxholms skogar AB and Trolle Ljugby estate. Permission to take disc samples from these forest owners stands was requested and granted before fieldwork began. From this list sites were selected largely via random number generator but within certain parameters. These were to gain a roughly even number of ages and site index (SI).

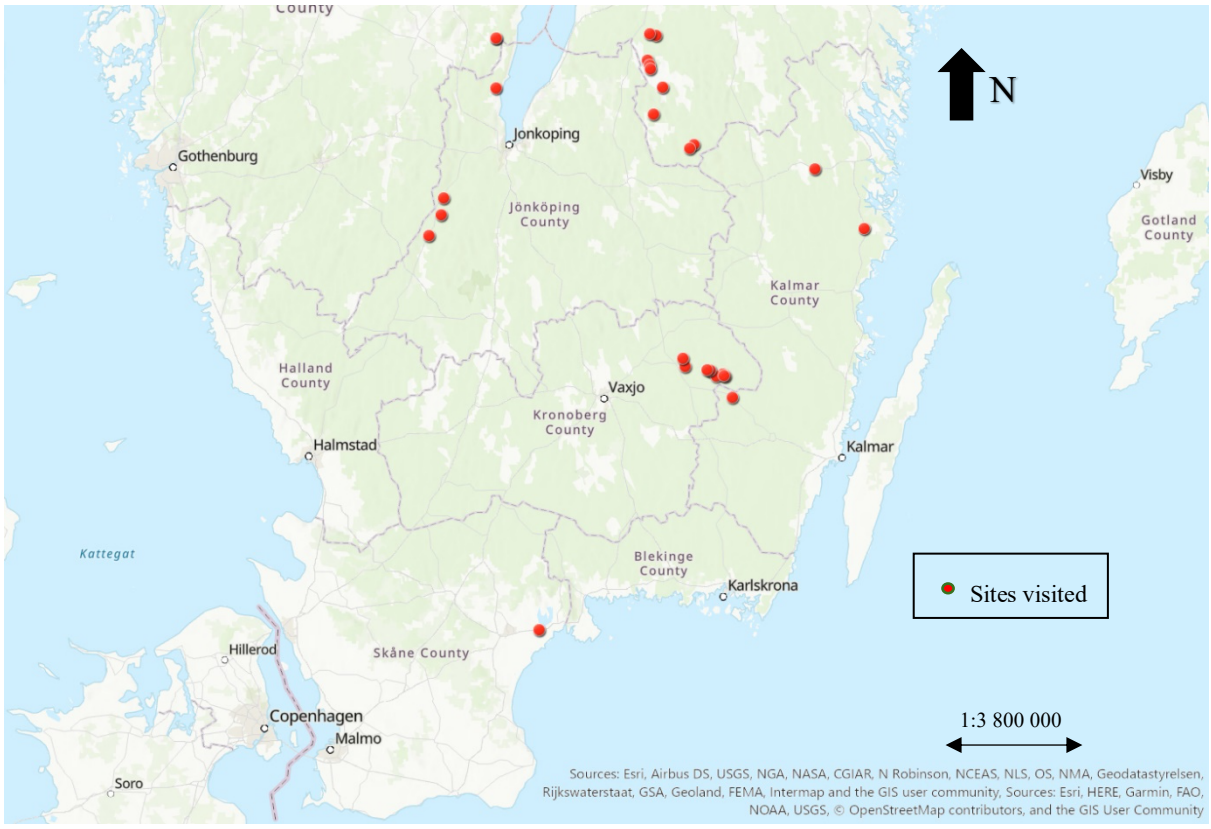

Figure 1 Location of the 30 sites sampled in southern Sweden

2.2 In the field

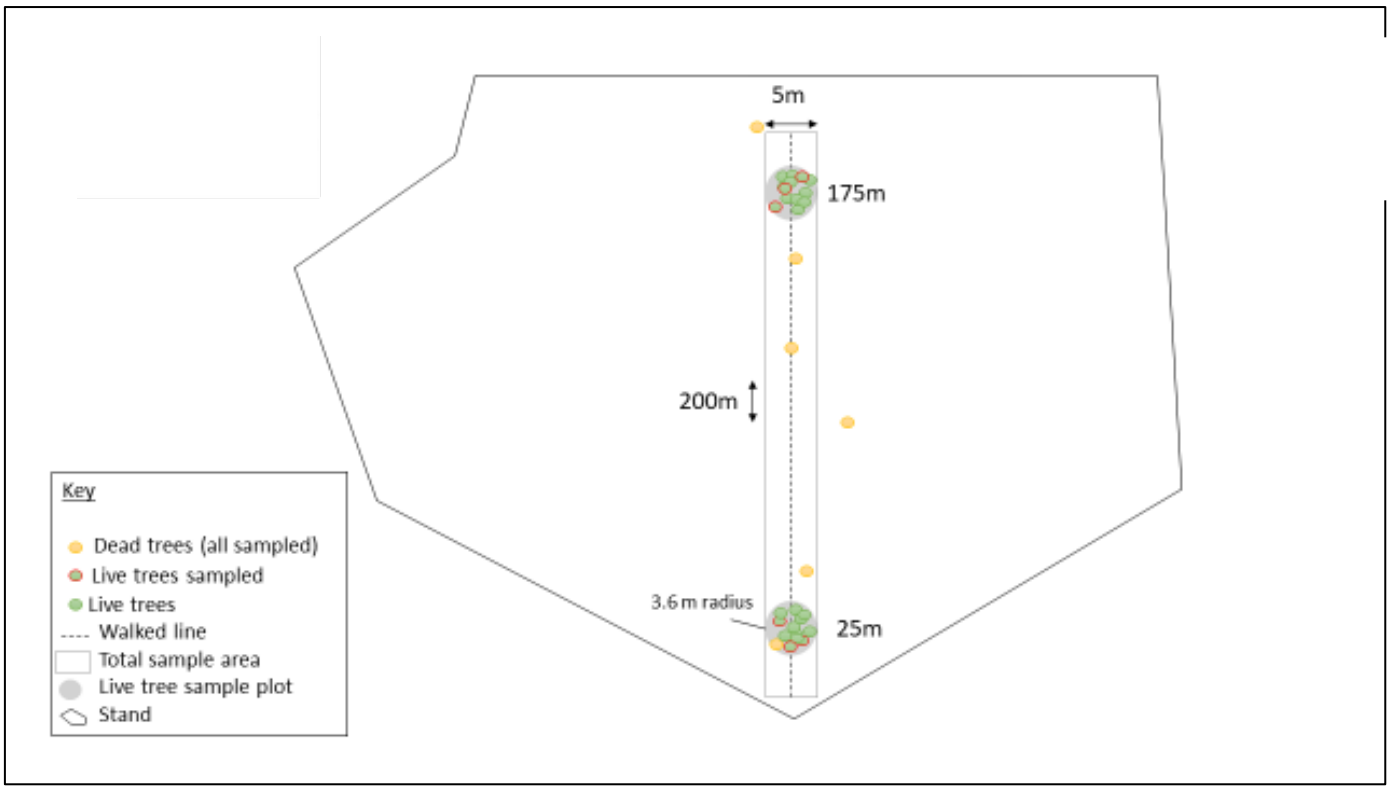

Figure 2. Schematic of fieldwork methods

At each site a transect of 200 meters in length and 5 meters in width was used as a sample for the whole stand. The transect was placed by finding the most southern point of each stand and then going north from this point 200m using a compass. If the transect did not fit in this direction, the transect was placed by going in a clockwise direction from north until the transect fit into the site parameters.

Once the transect was placed, any dead trees (planted in the current generation) found were sampled by taking a disc. This was done by first uprooting the tree, and then cleaning and disinfecting the root collar using a brush and 70% ethanol. At this point the disc sample could be taken using a saw, the sample was then placed in a labelled plastic bag and loosely tied (Figure 3).

Figure 3 Method of obtaining a disc sample after uprooting the sample tree. A Brush off soil from root collar. B clean sample C spray clean samples with 70% ethanol, D spray the saw, E label a plastic bag with the sample name, F after sawing a disc sample place in plastic bag and tie.

Along the transect two 3.6m (radius) circular sample plots were placed arbitrarily at 25m and 175m. In these sample plots the height and diameter at breast height of all pine trees were measured along with 3 healthy tree disc samples taken in the same method as for the dead trees planted in the current generation. Healthy young pine trees for sampling were selected using a random number generator at each circular plot.

It must also be stated that the number of sites sampled 6 years since planted was n=9, 5 years since planted was n=12 and 4 years since planted was n=9.

Disc samples were stored in a fridge until 10 days before they were analysed under the microscope to give any *Heterobasidion spp.* time to develop fruiting bodies that can be detected under the microscope. After this time, they were incubated in a black bag at room temperature.

2.3 Under the Microscope

Figure 4 Heterobasidion spp conidiophores in 20 magnification and 45 respectively on a pine sample analysed in this study.

After the 10-day incubation period samples were analysed using a stereo microscope at 20 to 45 times magnification to determine the presence of *Heterobasidion spp* conidiophores. On pine disc samples *Heterobasidion* spp. conidiophores are found most frequently at the cambium layer, under the bark (Otrosina and Cobb Jr., 1989). This area was a focus but the whole disc was studied as conidiphores can be found anywhere over the disc sample. Samples found to be positive and negative for *Heterobasidion spp.* were noted down and stored in a 5C fridge.

Some samples were suspected to have *Heterobasidion spp* but without certainty. These samples were left to incubate again at room temp for another 3 to 5 days to allow more time for any possible *Heterobasidion spp* conidiophores to develop. If after this time the disc sample was still inconclusive it was left as a suspect sample. This occurred due to heavy mould infestation or uncertainty. There are methods which could provide conclusive evidence of *Heterobasidion spp*. but unfortunately this was not possible due to time constraints.

An example of a positive sample can be seen in figure 3. Conidiophores can clearly be seen in the cambium. It is likely that the *Heterobasidion* species in this study will be *Heterobasidion* annonsum. However no genetic verification took place (Greig, 1998).

2.4 Statistical analysis

Statistical analysis of Welch T-test (used instead of a t- test due to unequal sample sizes between negative/positive and live/dead disc samples) and Chi squared were carried out in R statistical program.

Density measurements were calculated per circular plot to give a micro perspective of the growing conditions at each circular sample plot. For each site the average DBH and height was calculated from all trees present in the circular sample plots.

3. Results

3.1 *Presence of Heterobasidion spp*

Out of 65 dead young pine tree samples, 4 samples were positive for *Heterobasidion spp.* (6.2% *Heterobasidion spp.* precence). Live trees had a 6.5% *Heterobasidion spp.* presence, 10 out of 155 young pine tree samples were infected with the pathogen. 9 samples were catagorised as suspect and subsequently left out of anaylsis. All young pine trees sampled were sampled 4 to 6 years after planting, on stands that have been previously planted with pine. I have labled these trees as being aged 4 to 6 for simplicity but it must be noted that they are 4 to 6 years from when they were planted.

3.2 Live tree samples

Live trees (n= 833) had height and DBH recorded. 173 of the live trees were sampled in the form of a disc and analysed further. Out of the 173 discs analysed 8 discs could not be positively identified as *Heterobasidion spp.* and were omitted form this analysis giving 155 negative and 10 positive live tree samples from the circular sample plots

Density in the form of number of stems per circular plot was measured. In total there were 60 circular plots, 52 of which were had no *Heterobasidion* precense and 8 had *Heterobasidion spp.* precense.

3.3 Fruiting bodies

No fruiting bodies were found in any of the sites on any tree.

Table 1 Summary data of live tree circular plots. Age is prepresentative of the number of years after planting. There were 60 circular plots over 30 sites.

	Negative				*Positive*			
	Density	*Height (m)*	*DBH(cm)*	*Age*	*Density*	*Height(m)*	*DBH (cm)*	*Age*
Mean	14	0.97	1.18	4.96	13	1.43	1.6	5.1
Standard Error	1.09	0.05	0.05	0.06	1.57	0.36	0.43	0.28
Standard Deviation	7.83	0.57	0.58	0.77	4.44	1.15	1.35	0.88
Minimum	1	0.1	1	4	9	0.3	1	4
Maximum	37	2.7	4	6	19	4	5	6
Confidence Level(95.0%)	2.18	0.09	0.09	0.12	3.71	0.82	0.97	0.63
Number of plots	52				8			

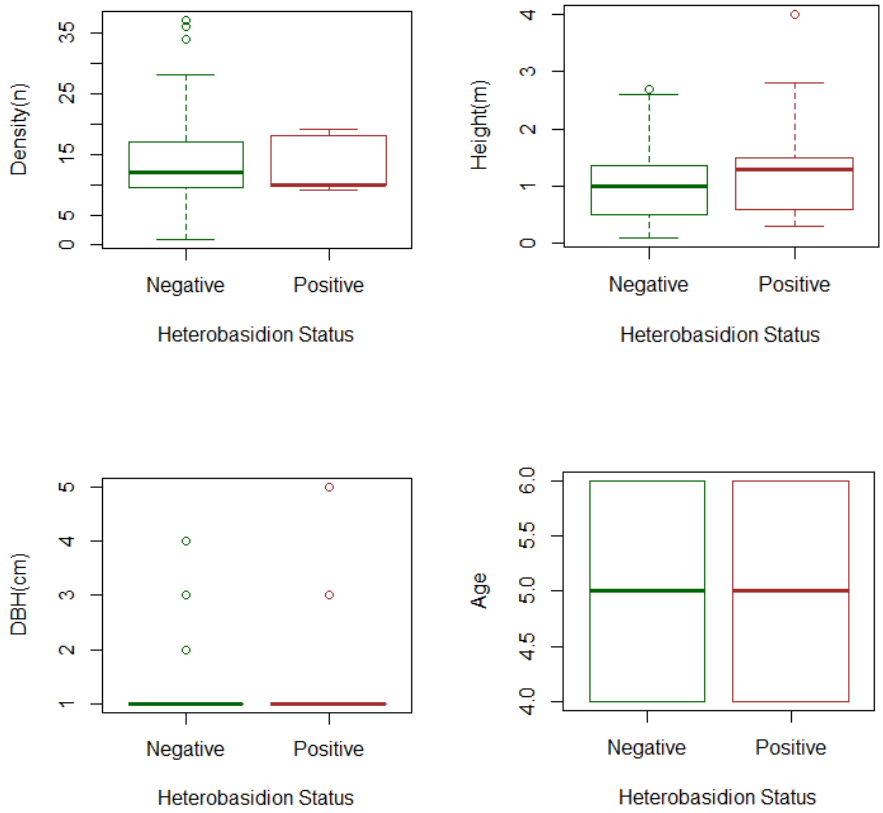

Figure 5 Box plots displaying circular sample plots where Heterobasidion was found (Positive) and circular plots where Heterobasidion was not found (negative). Circular sample plots were then compared with density, height, DBH and age

3.4 Density per circular sample plot.

Box plots show circular plots with no *Heterobasidion spp.* precence (negative) have a higher mean density compared to circular plots with *Heterobasidion spp. present.* However there is much variation around the mean. Welch sample T-test analysis found that no significant difference between density in positive circular plot samples and density of negative circular samples (P= 0.2374).

3.5 Height

Box plot of height and infection presence (figure 5) show little difference . The positive samples have a slightly higher mean that the negative samples and perhaps with a larger sample size this effect could be seen with a significance as well. On the other hand, the positive samples have one data point which has a much higher value than the rest of the population and so could be skewing the mean. Welch sample T-test analysis found that no significant difference between height of positive samples and height of negative samples (P= 0.2374).

3.6 DBH

Due to the age of the seedlings in this study, the DBH of the majority of the samples is just 1 cm. As the DBH measurements were rounded up to the nearest whole number this also has increased the count of 1 DBH as both smaller and larger DBHs are included in this category. Therefore, the box plot doesn't give much extra dimension to analysis. Only to emphasise that these seedlings are young. Welch sample T-test analysis found that no significant difference between DBH of positive samples and DBH of negative samples (P=0.3537).

3.7 Age

A chi square analysis was done in R to assess if sapling age was related to infection rate. When comparing different ages after planting with potential infection it is not statistically significant (p=0.7701). Due to only having 3 different ages the box plot isn't useful. The welch T-test showed no significant difference between the means of positive and negative samples circular plot samples when compared to their ages after planting (P=0.6356). The means were different with the positive sample mean being 4.96 and the negative mean 5.10 but only slightly so again a larger sample of positive trees would be interesting to look into further.

4. Discussion

Young live pine trees of 4 to 6 years after planting, having been previously planted with pine, have a 6.5% incidence of *Heterobasidion spp* infection. Dead young pine trees in the same stand had a 6.2% incidence of *Heterobasidion spp.* incidence. No fruiting bodies were found in any of the sites investigated. There was no significant relationship between age, DBH, density and height of the live trees and their chance of infection in this data set. Out of 30 sites 65 dead trees were found in the sample area. As there are few studies to directly compare these results give us an idea of the incidence of *Heterobasidion spp* infection in pine stands in southern Sweden.

In southern Finland Piri et al (2021) found that fruiting bodies were "abundant" in their experimental site. Piri's study did have some differences to the study conducted here in a few ways. The first being that this study looked at multiple locations and with less detail, only using 2 circular plots to represent the whole stand while the study by Piri looked at one site in great detail with a larger sample area and broader age range. The second big difference is that the present study looked at sites that had an unknown history of *Heterobasidion spp* presence. Whereas the Piri study, selected for a study site that had previously had *Heterobasidion spp* infection in order to track the infection over subsequent generations. Even more specifically the study looked at seedlings that were in the geographical range of potential infections from known infected stumps of the previous generation. All this means that while we can compare the two studies with age and species, we must also note that Piri selected for trees that had a potential to be infected with *Heterobasidion spp* while this study was indiscriminate in site and seedling selection.

It would be interesting to compare the method of Piri et al (2021) to random or non-infected sites so as to get a picture on the stand scale of *Heterobasidion spp* instances. On the other hand, for the results to be viable there would need to be multiple sites and with this level of detail it would be a huge task to undertake. The method in the present study does allow us to get a snapshot of a range of sites with unknown *Heterobasidion spp* infection history. If it was to be scaled up even further to include more sites and more detail, results could be more robust. Even selecting sites with *Heterobasidion spp* infection histories and without so that a good positive and negative *Heterobasidion spp* samples can be expected.

While there was only 6.2% and 6.5% dead and live trees with *Heterobasidion spp* present on average in the 30 stands sampled. It is still possible that there was an even higher actual infection rate if root samples would also have been taken. As was found in a study by Wang et al (2014) when an extensive investigation on the root system of sampled trees was done it was discovered that in a sample plot with no known *Heterobasidion spp*, 75% of the trees were positively identified as having *Heterobasidion spp* despite no sign of infection above ground. No live trees in this study had any outward sign of infection but it is possible that they would be infected if the root system was investigated. It would be a good comparison to also look at sites with a history of *Heterobasidion spp* vs no history to make direct comparisons.

The results show no age relationship to infection status, despite some studies that have found this result in Scots pine (Müller et al., 2018). The age range in the studies was however much larger, in some cases with a range of 160 years. In this case there is more chance of having a significant difference in infection as the range and so the difference in chemical processes and life stages would be much more pronounced than the 3-year range found in this study. It is however interesting to look at this range with a larger sample size or in sites that have a known *Heterobasidion spp* infection to understand in more detail the relationship between age and infection risk.

Although the relationship between age and infection was not statistically significant in this study it must be observed that more of the infections were found in the stands 6 years after planting compared to 4 years after planting. If there was a larger sample size it may be possible to correlate the two variables but not with this sample size.

Gibbs et al (2002) looked at young pine stands of 10 years of age. These stands were planted on previous pine plantations which had had positive *Heterobasidion spp* infection. On these second-generation sites there was between a 20% and 30 % stand mortality at 10 years depending on the pH of the soil and therefore the favourability of the stand to *Heterobasidion spp*. In some of the sites looked at in this study there was no dead trees at all in the sample area. It is hard to find research on pine sites without a history of *Heterobasidion spp* in the previous generation. In spruce stands there is some estimation of *Heterobasidion spp* presence. In 1987 Stenlid compared stands with no infection to stands with known infection history. He did this by removal of stumps from the previous generation and even sifted the soil to avoid infected root debris. The results showed that the subsequent generation in the stump removal stands had a *Heterobasidion spp* presence of 1 and 2% at 25 and 28 years respectively. This is in comparison to the control stands which had no stump removal which had a 17% and 12% infection presence at the same ages. This stud infection presence being somewhere in the middle of these two conditions. Stenlid's (1987) study was however on spruce stands, so the two studies cannot be compared directly.

In general, for pine stands younger trees have a decreased mortality rate compared to older trees (Siipilehto et al., 2020). So, it would follow that as the stand increases in age then the potential mortality from the infected *Heterobasidion spp* trees would also increase. With increased chance of mortality comes also increased chance of primary infection by *Heterobasidion spp* due to damage to surrounding trees and increase of fresh deadwood in the stand. This is of course not considering the pre commercial thinnings in the stands which will provide many stumps for colonisation of the *Heterobasidion spp* pathogen.

Pathogen damage and potential to cause mortality in the stand isn't even considered as a major or minor contributor in some general tree or stand mortality models directly. Although indirectly site index and pH is considered in these models to increase likelihood of pathogen damage such as *Heterobasidion spp* (Siipilehto et al., 2020, Salas-Eljatib & Weiskittel 2020). Conversely, we see in this study and in others (Stenlid, 1987, Piri, 2021, Wang, 2014), the infection rate in commercial stands by *Heterobasidion spp* alone is not insignificant and especially when in combination with other mortality factors such as storms and insect outbreaks (Woodword et al., 1998) it is a factor that perhaps needs to be included in mortality models.

Another factor that could explain the presence of *Heterobasidion spp* in this present study is that these seedlings were planted on forest land as part of the site selection process so that the second plus generation pine plantation could be explored. This selection therefore excludes plantations on any former agricultural sites where *Heterobasidion spp* on pine infection rate is of particular abundance in the literature (Woodword et al., 1998).

With a presence of just 6.5% and 6.2% live and dead trees respectively, infection in these stands it is perhaps not economically viable to use biological or chemical treatment on these stands during thinnings and harvest. In wangs study from 2014, the economic viability of treating spruce stumps in commercial and precommercial thinnings was modelled using RotStand model. This model showed that at low infection rates it may not be economically viable to use treatment because of the cost of the treatment itself. Perhaps silvicultural control methods such as timing of thinnings and pre commercial thinnings could be more useful for pine stands in this study.

Having said that, Wangs 2014 paper also points to the potential mortality caused by *Heterobasidion spp* within the stand at varying amounts of infection in the previous rotation. With stands that had no infection presence in the previous stand there was still a potential for 22.8 % of the stand to be decayed at harvest. Although it has to be said that these results are both from a model and are modelled on spruce stands. It is clear however that *Heterobasidion spp* infection can cause considerable damage to stands with no previous history of *Heterobasidion spp* infection. Thor et

al in 2005 found that in spruce stands they studied, approximately 14% of trees were infected with *Heterobasidion spp*.

Rönnberg and Cleary (2012) also make the point that even a small amount of infection early in the rotation can persist in the stand and cause damage to previously "healthy trees" at harvest. It was found that after 3 months of inoculation by Rotstop up to 70% of spruce stumps had infection from *Heterobasidion spp*, although many of these infections were not present when sampled again 1 and 6 years later. This point being backed up also by Oliva in 2008, Tubby in 2008 and Morrison and Redfern in 1994 who looked at Sitka spruce infection and found that *Heterobasidion spp* passed clearly from one infected tree to neighbouring trees. An incidence that is exacerbated by thinning and pre commercial thinning regimes as found by Morrison and Johnson, in 1978 when their experiment in North America found that the number of infected trees in their sample area doubled after being thinned.

This study has a large sample size of 30 stands and number of disc samples 242. On the other hand, like in every study, there are some limitations that must be stated. The age after planting, 4 to 6 years was a small range and therefore difficult to find any significance in. As young trees are less likely to be infected by *Heterobasidion spp* in the first place it would be interesting to track how this infection rate changes over time and with increasing tree age. Comparing these results to stands after pre commercial thinning, and with or without stump treatment, would also be informative. Studying other species in the stand such as birch or spruce (if found) could also have been interesting. Due to time and resources this was not possible but could be achived in future research.

4.1 Conclusion

In young pine in stands previously planted with pine in this study there is 6.5% *Heterobasidion spp* presence in live young pine trees and 6.2% presence in yound dead pine trees.. A minor incidence of *Heterobasidion spp*? Or something more incidious? 6.5% live and 6.2% dead young pine trees infected in a stand are just that. This result is not describing mortality, only infection Any *Heterobasidion spp* infection is arguably enough reason to recommend management changes when it comes to stump spraying on pine stands. As *Heterobasidion spp* is persistent over time and can move, even if fairly slowly, through space and can persist through time. Recommendations to increase defences against this pathogen could be a successful management strategy. Especially with the onset of climate change, predictions estimate an increase in disturbance factors such as droughts, fire, snow, storms, pathogens, and insect outbreaks (Seidl et al., 2017). Factors which could create plentiful fresh dead wood and increase the spread of *Heterobasidion spp* through increased host material. For now, this infection rate in young pine stands

of the *Heterobasidion spp* pathogen could be viewed as negligible. Conversely, should risks be taken in such an uncertain future with a pathogen which is already responsible for considerable economic loss in the forestry sector? This question can only be answered with more research, especially on pine and *Heterobasidion spp* infection.

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6. Popular science summary

Root rot in the young pine forests of southern Sweden

Sarah Louise Gore

Root rot disease causes economic loss in the forest industry in Sweden. This effect is found mostly in spruce forests and pine forests to a lesser but extent. It slows growth of trees, creates ugly tree trunks and sometimes even kills trees. It is extremely infectious, spreading via the wind to freshly cut tree truks or stumps. Because forestry practices, such as cutting trees at harvest, leave many freshly cut tree stumps, root rot can spread quickly within and between forest stands.

However little is known about how much root rot disease is found in young pine forests as, today, pine trees are not so badly effected by the disease as spruce trees. In the light of climate change our environment will be different in unknown ways in the future. It is important, therefore, to understand everything we can about root rot so that we can try to reduce its cost to forest owners now and in the future.

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