Small birches are of large importance for beetle diversity in burned boreal forests

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Abstract

Forest fires create substrates and habitats many species are dependent on in boreal forests. Since forest fires have been mitigated since the 20th century these substrates and habitats have decreased and pyrophilous species are declining. The role of the fire favoured pine (*Pinus sylvestris*) in burned forests has been frequently covered when it comes to its post-fire connection to beetles, while the role of the similarly fire favoured birch (*Betula pendula*/*pubescens*) has not been equally covered. As birch has a generally high regenerative ability in Swedish forests, while it is not a particularly favoured tree species in the industry, the occurrence of birch is dominated by relatively small dimensions in Swedish forests. We sampled beetles after prescribed burnings in boreal forests of Sweden, to compare beetle abundance, diversity and species compositions on birches and pines after fire. We also registered trap tree diameters and local deadwood to compare beetle responses in relation to the amount of burned substrate surface area.

The results show higher species richness and a higher number of associated species on burned birches compared to burned pines. Beetle species richness was slightly lower on larger diameters on pines, while no responses differed in relation to diameters on birch. This could possibly be caused by the narrow range of diameters in this study, reflecting commonly occurring birch diameter distributions in Swedish productive forests. Species compositions did not differ with any leverage between diameters regardless of tree species. A positive relationship between local deadwood volume and beetle diversity along with distinct species compositions was found, regardless of trap tree species. Local deadwood richness related to distinct species compositions only on pines. No relationships with beetle abundances were found.

These results show that in the context of the common diameter distribution of the tree species in Swedish forests, birches can contribute to an overall higher beetle diversity in fire affected environments, side by side with pine, even when small. A high level of preference-driven attraction could be a possible explanation, as opposed to a larger surface area resulting in higher probabilities of more beetle individuals landing on a substrate. Since larger trees than sampled in this study could show other patterns, as earlier studies have indicated, beetle responses on burned birches of wider diameter ranges is necessary to keep investigating in future studies. Nevertheless, this study shows that smaller birches should not be overlooked when restoring values created by forest fire.

Keywords: prescribed burning, beetles, *Coleoptera*, pyrophilous, *Betula pendula*, *Betula pubescens*, *Pinus sylvestris*, diameter, species richness, abundance, diversity, species composition

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Abbreviations

Abbreviation	Description
GLMM	Generalized linear mixed model
NMDS	Non-metric multidimensional scaling

1. Introduction

1.1 Forest fire

Natural forests in boreal Fennoscandia have historically been shaped by fire (Zackrisson 1977; Niklasson & Granström 2000), killing groups of trees and creating sun-exposed open areas (Kuuluvainen & Aakala 2011), or forests consisting of large, old fire-resistant pines intermixed with fire-favoured deciduous species (Östlund et al. 1997; Linder et al. 1998). Climatic processes have resulted in a proneness to natural fires occurring in Fennoscandia throughout the Holocene time period (Drobyshev et al. 2016). The use of burning as a means of land management by humans have also been speculated as a possible reason for a high frequency of fires before today's use of active mitigation operations, along with droughts and lightning induced fires (Zackrisson 1977). Scots pine (*Pinus sylvestris* (L.)) and birch (*Betula pendula* (Roth)/*B. pubescens* (Ehrh.)) are resilient tree species able to regenerate effectively after fire, while Norway spruce (*Picea abies* ((L.) H. Karst.)) is not (Adámek et al. 2016), and would without fire be able to outcompete the former two during late successional stages (Zackrisson 1977). Forest areas in northern Sweden with the highest rates of fire occurrences have historically, as a result, become dominated by deciduous species such as birch and aspen (*Populus tremula* (L.)) (Esseen et al. 1997). Active suppression of fire results in a threat to this early successional, post-disturbance dynamic, resulting in the risk of competition of late successional species like Norway spruce, and a lack of these natural forests and habitats (Linder et al. 1998).

Forests in Sweden house many species dependent on the occurrence of fire (Roberge et al. 2020) as this creates specific habitats with structures and substrates they have evolved to utilize. Especially the early stage after fire has been shown to strongly favour beetle diversity (Langor et al. 2008; Hekkala et al. 2014) and particularly threatened species (Similä et al. 2002). Many organism groups and their substrates are physically destroyed during fire leading to their decrease, however beetles have shown swift increases in diversity (Vanha-Majamaa et al. 2007) as well as shifts in species composition shortly after fire (Hyvärinen et al. 2006; Hjältén et al. 2017). Forest fires create burned substrates needed by pyrophilous saproxylic species (Stokland et al. 2012), but also large amounts of dead and wounded trees (Hyvärinen et al. 2009) beneficial for other saproxylic species.

1.2 Deciduous trees, deadwood and saproxylic beetles

1.2.1 Deciduous trees

The vast majority of the Swedish forest is made up of homogeneous conifer forests managed for silvicultural purposes (Felton et al. 2020), leaving only thirteen percent with some form of protection (Roberge et al. 2020). Deciduous species have not been of economic interest resulting in historical removal, and are now mostly occurring in post-disturbance successions in boreal forests of Sweden, otherwise dominated by coniferous pine or spruce (Roberge et al. 2020). Today, the most common deciduous tree species in Sweden, birch, is especially overrepresented in the form of small diameters (Roberge et al. 2024).

1.2.2 Deadwood

Management has also created a disparity in deadwood amounts, as the volume of deadwood in natural boreal forests has been reported to be around 60-80 m^3 per hectare, while only 4-10 m^3 per hectare in managed forests (Stokland et al. 2012). These managed environments provide habitats favouring only some species, while other species are unable to thrive in productive forests, being left with fragments of past habitat cover.

A relatively large proportion of diverse forest species utilize deadwood as habitat in the forests of northern Europe (Siitonen 2001; Stokland et al. 2012) partly because of its many possible states and diverse microhabitats (Thorn et al. 2020). The connection between large amounts of deadwood and the presence of species of conservation concern showcase the importance of the substrate, as the amount of deadwood has shown to be an important indicator for such species (Hekkala et al. 2023). These deadwood dependent (saproxylic) species have been negatively affected as the amount of deadwood in many productively managed forests has decreased (Siitonen 2001; Löfroth et al. 2023).

1.2.3 Saproxylic beetles

Saproxylic species include those directly dependent on dead or dying trees, or indirectly dependent via carnivory or fungivory of said species, and many other insects utilize dead or dying trees while not exclusively dependent (Ulyshen & Šobotník 2018). One of the most species-rich organism groups in the world are beetles (Gimmel & Ferro 2018), and the majority of them are saproxylic (Stokland et al. 2012). This large variety of saproxylic beetle species have a large variety of needs (Jonsell et al. 1998) ranging from specifics in diameter (Jonsell et al. 2007; Zumr et al. 2023) to tree species of the deadwood (Tikkanen et al. 2006; Müller et al. 2015). Of all beetle species in Sweden, 21% are red-listed, and one of the most detrimental reasons for this is old continuous forests with high nature values still being harvested (Eide et al. 2020).

1.3 Host specificity

There is no one perfect substrate archetype able to encompass the needs of all saproxylic species (Jonsson et al. 2005). Therefore, variety is essential. For example, many beetles are not only dependent on deadwood, but on deadwood of specific tree species (Tikkanen et al. 2006), resulting in distinct species compositions found on coniferous as compared to deciduous tree species (Hägglund & Hjältén 2018; Vogel et al. 2021). A negative relationship has even been identified between the amount of coniferous deadwood in an area and the prevalence of deciduous-preferring beetle species (Bergmark et al. 2024). A high proportion of threatened invertebrates have been associated with deciduous forests (Berg et al. 1994), and beetle species associated with deciduous trees are among the most threatened (Seibold et al. 2015). Although, some beetles utilizing deciduous species are somewhat generalist, and are able to survive on multiple tree species, making the commonly occurring birch a possible substitute for these beetles, of which there are many (Milberg et al. 2014). Birch high-stumps have also shown to be able to house a higher number of beetle-species than spruce, regardless of being in a productive forest or forests of conservation value (Lindbladh et al. 2007). The relatively common interspersion of birch within otherwise conifer-dominated forests across Sweden (Hynynen et al. 2010), could therefore be an excellent provision of habitat and substrate for many beetle species dependent on deciduous deadwood. Although, while birch is the most commonly occurring deciduous tree species in Fennoscandia, old and large diameter birches are not common (Roberge et al. 2024).

1.4 The effect of diameter

Large diameter trunks of both living and dead trees has previously been recognized as one of the most important substrates for beetle diversity (Zumr et al. 2023; Cizek et al. 2025). The importance of a larger substrate could partly be explained by the target area hypothesis, where larger surfaces of a habitat could lead to a higher level of colonisation, and subsequently a higher species richness (Lomolino 1990). As such, the relative overabundance of small-diameter birch would perhaps not favour a high diversity of saproxylic deciduous-dependent species. However, there are studies showing similar species richness of saproxylic species when comparing small diameters (1-15 centimeters) of deciduous tree species, although showing differences in species composition (Jonsell et al. 2007). Larger diameters (21-65 centimeters) of birch high-stumps have also shown similar abundances, species richness, and even species compositions (Lindhe et al. 2005; Lindbladh et al. 2007). Perhaps this might signify diameters of deciduous tree species lacking importance for saproxylic beetles. Conversely, higher beetle species richness on beech high stumps above 35 centimeters have also been

found, along with unique beetle species associated with diameter classes (Zumr et al. 2023). Nonetheless, if small-diameter birch could support specialised communities, there is an unknown high ecological value inherent to this comparatively abundant tree in the boreal forest. Even though birch regenerates easily post fire, and is among the dominating tree species in past high frequency fire affected areas of northern Sweden, its role in fire shaped forests is not covered as thoroughly when compared to pine. The relationships between fire-favoured organisms evolved to thrive in these environments and the burned birch has, subsequently, also not been nearly as covered. Unveiling potential beetle diversity associated with the smaller birches within the fire-shaped forest could aid practitioners in seeking out suitable environments for prescribed burning, making the most of restoration efforts when performed.

1.5 Research questions and hypotheses

As birch commonly occurs in early-post-disturbance environments, while fire creates substrates for many saproxylic beetle species, and different diameters can house distinct species compositions – this study investigates what importance burned birch of different diameters hold for saproxylic beetle species. The purpose was to answer these three questions:

Q1. Are there any differences in beetle species richness, diversity and/or composition between **tree species**, after being exposed to fire?

Q2. Are there any differences in beetle species richness, diversity and/or composition between **diameter** of birch or pine after being exposed to fire?

Q3. Are there any differences in beetle abundance, species richness, diversity, and/or composition related to the **local deadwood** volume and diversity?

I have the following five hypotheses:

1.5.1 Tree species

H1. Burned birch will show a higher substrate-level species richness compared to burned pine - in accordance with a study showing higher species richness in birch deadwood, in comparison to spruce (Lindbladh et al. 2007).

H2. Burned birch and burned pine will show differences in species composition - in accordance with studies showing such differences in species compositions based on host tree species (Tikkanen et al. 2006; Jonsell et al. 2007).

1.5.2 Diameter

H3. Diameter of both species will show a positive relationship with species richness - in accordance with studies showing larger diameters correlating with higher species richness of saproxylic beetles beetles (Zumr et al. 2023), and also with target area hypothesis (Lomolino 1990).

H4. Diameters of both tree species will show differences in species compositions - in accordance with studies showing differing dimensions of fine wood housing distinct species compositions (Jonsell et al. 2007), specific beetle species preferences of larger diameters (Platek et al. 2019; Cizek et al. 2025) and overall beetle species compositions specializing on certain diameter dimensions (Stokland et al. 2012).

1.5.3 Local deadwood as an accumulated surface area

H5. In accordance with target area hypothesis larger diameter trap trees will house higher abundances, and subsequent species richness. The relationship is also expected to be indicated via a higher local volume of deadwood, acting as an accumulated surface area of suitable substrate in the vicinity of the trap tree.

2. Method

2.1 Study area

The study took place in Sweden in the county Dalarna, in ecopark Ejheden established in 2007 by the forest company Sveaskog AB. The ecopark plan (Moberg 2007) describes the area as spanning across a total of 6900 hectares. The majority of the area is considered to be productive forest land, of which 9.2% was intended to be restored through some kind of treatment with the aim of fortifying and increasing the coverage of the nature type in question. Parts of the landscape was intended to still be productively managed at some level of intensity; 40% mainly productively (PG), and 13.6% productively but with enhanced consideration of nature values and varying levels of retention (PF). Of the area intended to be restored 1.7% is described as natural deciduous-coniferous forest, while 1.8% is described as natural deciduous forest and 5.6 % as natural coniferous forest. This landscape has historical remnants indicating repeated fire occurrences, described as older pines intermixed with between 10-50% fire-favoured deciduous species. Birch represented 89% of these. The ecopark is described as a core area in Europe specifically for fire-dependent insects, and a known and especially large forest fire stretched across most of the ecopark during the late 1800's. The forest company's plan includes restoring these historically fire affected areas through prescribed burning to maintain the structures. A large portion of the landscape is reported to be older than harvest mature age, which usually lies between 80-100 years. A large portion of the landscape (72%) has some amount of pine, at the time estimated to be around 150 years old, and a slightly smaller portion (65%) with some amount of birch around 100 years old in the historically fire affected areas. The amount of deadwood is reported to have been highly varied, but with a total of 4 975 standing dead pines per 100 hectare with a diameter above 15 centimeters at breast height, and 9185 pieces of pine logs per 100 hectare above 15 centimeters at breast height. Standing dead birches above 15 centimeters in breast height are reported to be at 690 pieces per 100 hectare, and birch logs at 685 pieces per 100 hectare, although this description was written almost twenty year ago (Moberg 2007).

2.2 Experimental design

The selection of areas to undergo prescribed burning was done by the forest company Sveaskog. The areas were selected to not only encompass completely management-exempt stands, but also stands undergoing productive management (Moberg 2007). Three large areas of 30-50 hectare each were selected for the study (Figure 1). One of the three sampled areas was burned each consecutive

year since 2022: one stand in 2022, one in 2023 and one in 2024. Using QGIS (QGIS Development Team 2023) 10 survey plots each were randomly placed with a minimum distance of 100 meter between points and 50 meter from the edge of the stand, resulting in a total of 30 survey plots. The aim was to choose two standing pines and two standing birches, one with diameter below 20 centimeters and one above 25 centimeters, if possible, within a 20 meter radius of the center points. The aim was also to choose dead trees based on tree species and diameter difference within the 20 meter radius circle plots. However, there were seldom dead trees living up to the criteria in each sample plot. Because of this many trap trees still alive or of reduced vitality had to be chosen (Appendix A; Figure 7).

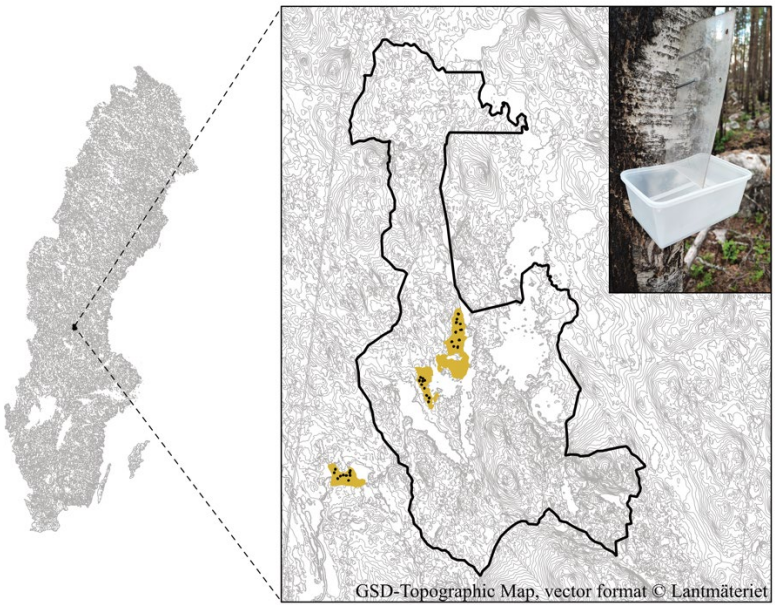

Figure 1. A map of the ecopark location using GSD-Topographic Map, vector format © Lantmäteriet, showing burned areas and trap setup.

2.3 Sampling and measurements

The beetles were sampled with small trunk-attached flight intercept traps (Bergmark et al. 2024). The traps were built using Plexiglas attached vertically unto the trunk of the trap trees, with 1000ml plastic tubs attached directly underneath at breast height, directed southwards as a standardization of possible sun exposure. A mixture of 60 percent Propylene glycol and water along with a small amount of detergent was poured into the traps to kill and preserve any organisms on or flying around the snags until emptying of the traps. All traps were placed during late May- early June. They were emptied and samples collected twice, once during July and once during late August. After collecting, beetles were sorted out of the samples on a basis of order (*Coleoptera*) and sent for taxonomic identification.

The height, diameter at breast height and species of each trap tree was registered. The fire intensity was estimated by measuring the flame height via visible charring. Broken or not broken tops was noted, vitality was estimated visually by presence or absence, and color, of leaves or needles: green leaves were considered alive, yellowing leaves as reduced vitality, and no leaves as dead.

Deadwood was measured with a 20-, 15- or 10-meter radius from the center point depending on the amount of deadwood and accessibility. If topography did not affect accessibility of the plot area and the deadwood amount was subjectively low with a minimum of 10 pieces, a radius of 20 meter was used. Otherwise, a 10–15-meter radius was used. All deadwood above the minimum diameter of 10 centimeters at the widest part, 5 centimeters at the thinnest and a minimum height of 1.3 meters was measured as long as its base, or if the base was missing its widest part, was within the plot. Measurements consisted of height, the smallest and largest diameter along with length for volume calculations, tree species, and if the piece was a log or snag. Decay stage of coniferous logs was estimated by sticking a knife repeatedly along the length of the wood. The depth of the knife sinking in was noted and visual disintegration level was determined to classes between 1-6 (Siitonen & Saaristo 2000). For coniferous snags decay stage was determined to classes 1-9, 1-3 representing states of vitality (1 = alive, 2 = reduced, 3 = recently dead) and 4-9 stages of decay (Thomas 1979). For deciduous logs and snags the decay stage was also estimated using a knife, but classified as either hard or soft (Gibb et al. 2006). Percentage of burn cover was estimated by visual charring.

2.4 Calculations – local deadwood volume and richness

Local deadwood volume was calculated for logs based on widest and smallest diameter and length using the formula for a truncated cone. For snags volume was calculated using taper formulas (Näslund 1947), one for deciduous tree species (1) and another for coniferous tree species (2), where D represents the diameter of the tree at breast height in centimeters, and H the height in meters:

$$1)\ 0.03715 \times D^2 + 0.02892 \times D^2 + 0.004983 \times D \times H^2$$
$$2)\ 0.09314 \times D^2 + 0.03069 \times D^2 + 0.002818 \times D \times H^2$$

For broken snags their theoretical heights before breaking were calculated from whole standing dead trees measured in our data using a linear regression line. The theoretical heights were then used in the same taper formula mentioned above for whole snags before their volume was reduced based on the proportion of height reduction as per Ollas (1980);

If proportion is < 0.1, do nothing
If proportion is >= 0.1 and < 0.3, reduce volume by 0.3
If proportion is >= 0.3 and < 0.5, reduce volume by 0.5
If proportion is >= 0.5 and < 0.7, reduce volume by 0.75
If proportion is >= 0.7, reduce volume by 0.9

Local deadwood diversity was represented by the deadwood richness and abundance in the surrounding area within each plot. It was measured and calculated to control for potential additional effects on response variables. This was done by categorizing the dead wood based on tree species, log/snag, decay stage, bark cover and burn cover into one of three categories (Appendix B; Table 9). The number of deadwood pieces per each established category was counted for abundance and calculated for diversity using the Shannon diversity index and species richness.

2.5 Statistical analysis

To test the initial hypotheses, statistical analyses were conducted using R 4.2.3 (*R Core Team* 2023). Alpha diversity was tested via response variables set to beetle abundance, species richness and the Shannon diversity index. Explanatory variables were set to trap tree species as a binomial variable and trap tree diameter as a continuous variable for linear analysis of beetle species responses. Diameters were divided into categorical variables (small = 7-16 centimeters, medium = 17-26 centimeters and large = 27-37 centimeters) for permutational analysis of Bray-Curtis dissimilarity indices calculated from sample level beetle species compositions. Analyses were focused on comparisons of response variables within treatments of prescribed burning, between tree species and along the diameter gradient. Sampled data were grouped as all identified *Coleoptera* per plot and type of trap tree, resulting in four groups per plot; beetles collected from a large pine, from a small pine, from a large birch or from a small birch. The aim was to detect any possible differences in species diversity and species composition between each of these trap tree-types within each plot. Before the testing of the hypotheses the explanatory variables were tested for possible collinearity using the performance package (Lüdecke et al. 2025).

Hypothesis H1 and H3

Differences in species richness between the chosen explanatory variables per each research question were analysed using generalized linear mixed models (GLMM). As trap tree species and diameters correlated, possibly because of an overrepresentation of larger diameters of pines (Appendix A; Figure 7) resulting from the previous even-age management operations, two models per beetle response were made; one with the variable tree species, and one with the variable diameter of the trap tree. Vitality was added in the models to not confuse possible

differences in beetle response related to alive or dead trees as relating to other variables. ‘Year’ of each prescribed burning was included in each model to account for several variables: time passed since burning, environmental location/landscape differences and variation in fire intensity, as differences was detected when plotting height of charring, indicating a higher fire intensity year 2023 (Figure 1). Lastly, plot ID was included as random effect to control for potential unknown environmental differences between plot locations, along with the nested nature of the sampling, as four trees were sampled within the same plot thus making variables of the four sampled trees dependent. The fit of the models were determined via diagnostic plotting of residuals using the DHARMa R package (Hartig et al. 2024) and non-continuous response variable models were assigned either poisson or negative binomial family distributions based on residual deviations. Abundance on pines was log-transformed because of residual deviations, potentially caused by outliers in the form of a deviate amount of *Nicrophorus* species sampled in two plots. Variance explained by the models were derived in the form of marginal and conditional R^2 using the MuMIn package (Bartoń 2025).

Hypothesis H2 and H3

Potential differences in species composition between tree species and diameters were represented by calculated Bray-Curtis dissimilarity distances, and analysed using a permutational multivariate analysis of variance (PERMANOVA), set at 999 permutations. Explanatory variables tree species, diameter and ‘year’ was included in three separate PERMANOVAs, while plot ID was set as strata using the vegan package (Oksanen et al. 2025), more specifically the adonis2-function, to account for the previously mentioned nested nature of the study design. The source of any possible significance was revealed using betadisper, a test of homogeneity of dispersion (Oksanen et al. 2025). If the betadisper was not significant then any potentially significant differences in the PERMANOVA result would not be caused by differences between groups, but more explained by differences within groups. To further explore the differences in a potentially significant PERMANOVA, a non-metric multi-dimensional scaling (NMDS), also using the vegan package, was created. Differences in tree species association on an individual species level were tested via an indicator species analysis using the indicspecies package (Cáceres et al. 2025). Local deadwood variables were analysed using an envfit (Oksanen et al. 2025), set at 999 permutations. As the local deadwood variables were continuous, they were not part of the NMDS formulation, but instead superimposed on the plotted NMDS as vectors resulting from the envfit. Sample coverage was tested via rarefaction curves illustrating sample completeness of species richness found on each diameter category, using the iNEXT package (Hsieh & Chao 2024).

Hypothesis H5

Any indicative relationships between beetle abundance or richness and diameters were tested for in previously described GLMM's. Additionally, local deadwood volume and richness were modelled together, to reveal possible relationships between an accumulatively increased area of suitable substrate in the local area and beetle abundance as per the target area hypothesis, resulting in a possible increase in beetle richness as per the energy hypothesis. These models also included the variable 'year' as fixed effect and plot ID as random effect.

3. Results

A total of 120 trees were sampled within the 30 plots, resulting in a total catch of 5040 beetle individuals and 260 unique species caught in the window traps. On birches 2463 individuals were caught and on pines 2577, of which 195 and 187, respectively, were unique species. There were 186 individuals that are red-listed (Appendix A; Table 5) according to the Swedish red-list of 2020 (Eide et al. 2020), of which 15 were unique species. All are near threatened (NT), except for one individual of *Corticeus longulus*, which is vulnerable (VU). The redlisted species were dominated by 151 individuals of *Sphaeriestes stockmanni*, eleven individuals of *Stephanopachys linearis* and six individuals of *Acmaeops septentrionis*.

Fire intensity and trap tree vitality

Few trees had died after the burning, only one of the pines and thirteen of the birches were dead, while many were of reduced vitality, or alive and seemingly unscathed besides bark scorching (Appendix A; Figure 7). Despite this, species richness did not differ between vitality levels of birch (Appendix B; Table 3). Since there was only one dead pine, any conclusions based on statistical analyses regarding species richness related to vitality on dead pines would be unreliable. The stand burned in 2023 had an overall observationally higher fire intensity, by proxy of flame height, compared to the stands burned in 2022 and 2024 (Appendix A; Figure 8).

3.1 Tree Species

H1: Beetle responses between birch and pine

Beetle species richness and Shannon diversity index were shown to be higher on birches than on pines, along with patterns of the same relationship for beetle abundance, although not significant (Figure 2, Table 1). As variance explained by models were in the form of marginal and conditional R^2, each variable could not be determined as the main contributor to the variance found. Both models with tree species explained a low proportion of variance in species richness and Shannon diversity (Table 1). Although, considering the difference in marginal and conditional R^2, ie the explained variance when including the random factor plot ID, a relatively high proportion of the total variance explained by the model lies in the fixed effects.

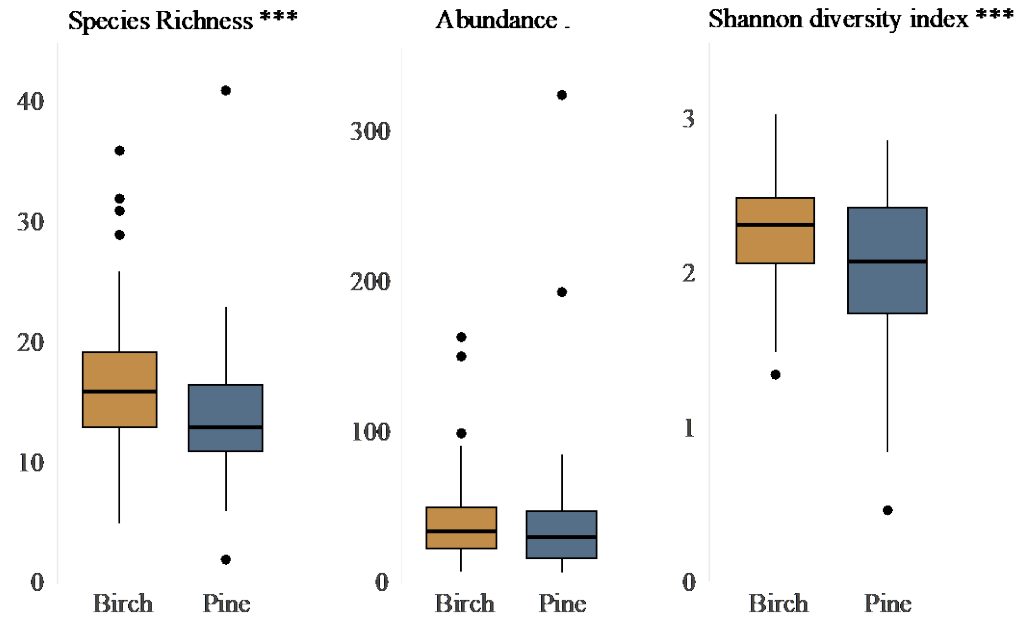

*Figure 2. Boxplots illustrating beetle responses (species richness, abundance and Shannon diversity index) between tree species (birch and pine). "***" indicate significant results with p<0.001, while "." indicate close to significant results (model results can be found in Table 1).*

Table 1. Model coefficients: beetle response variables (species richness, abundance and Shannon diversity index), estimates of each predictor (tree species and year), p-values, and marginal and conditional R^2. Values in bold indicate significant results.

Predictors	Estimate	*p*	Marginal R^2 / Conditional R^2
Species richness ~ tree species + year + (1 | plot ID)			
Tree species [Pine - Birch]	**-0.185**	**0.001**	0.183 / 0.378
Year [2023]	**0.281**	**0.006**	
Year [2024]	-0.021	0.840	
log(Abundance) ~ tree species + year + (1 | plot ID)			
Tree species [Pine - Birch]	**-0.16**	**0.066**	0.376 / 0.508
Year [2023]	**0.97**	**<0.001**	
Year [2024]	**0.50**	**0.001**	
Shannon index ~ tree species + year + (1 | plot ID)			
Tree species [Pine - Birch]	**-0.22**	**0.001**	0.170 / 0.339
Year [2023]	**-0.29**	**0.010**	
Year [2024]	**-0.31**	**0.006**	

H2: Beetle species compositions between birch and pine

Pine and birch had significantly different species compositions according to the PERMANOVA results, along with non-significant dispersions within each group according to the betadisper (Appendix B; Table 6). Thereby, the difference was revealed to be between groups, rather than between samples within groups.

Samples seemingly cluster regardless of tree species in the NMDS (Figure 3), paired with a low explanatory value (R^2) of tree species, thus explaining low percentage of the variation (Appendix B; Table 6, Figure 3). In contrast to tree species, the variable 'year', while significant in its relation to beetle compositional differences, also showed a significant betadisper result, indicating the differences found being between samples within each year (Appendix B; Table 6). A higher amount of species was found to be associated with birch, a lower amount was associated with pine, while there was overall low numbers of "strong indicators" (Dufrene & Legendre 1997) (Table 2). The value of specificity represents the proportion of the beetles' occurrences being found on a type of substrate. Fidelity represents the proportion of a type of substrate the beetle is found on. For example, the redlisted *Stephanopachys linearis* has a significant permutation test p-value, indicating its association with pine, while its IndVal value, a composite value of specificity and fidelity, is below 0.5, thereby not considered a "strong indicator".

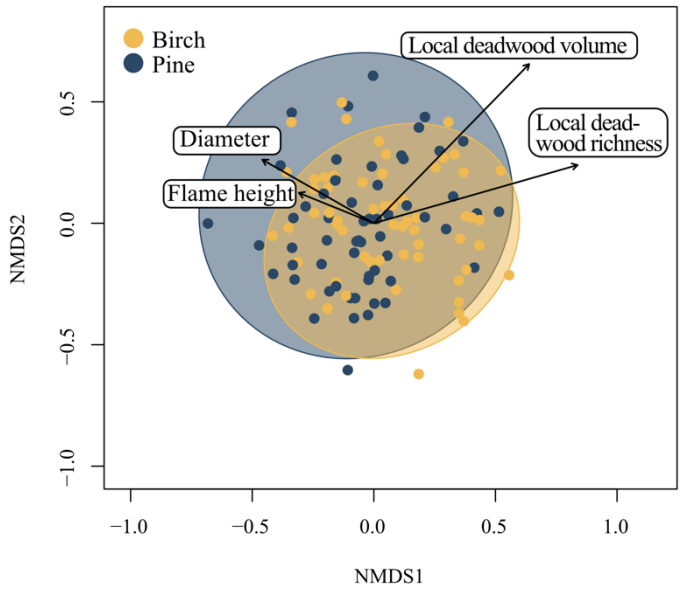

Figure 3. Non-Metric MultiDimensional Scaling (NMDS) illustrating beetle species composition dissimilarity distances (Bray Curtis dissimilarity index) between tree species, with envfit vectors of environmental continuous variables relating to the distances (envfit results are found in Appendix B; Table 8).

Table 2. Significant indicator species analysis results for beetle species between tree species (birch and pine). Values in bold indicate "strong" indicator species (Dufrene & Legendre 1997). "NT" signify the status "near threatened" as of the Swedish redlist 2020.

Species	Specificity	Fidelity	IndVal	*p*
Birch				
Epuraea rufomarginata	**0.8605**	**0.3667**	**0.562**	0.001
Rhizophagus fenestralis	**0.9904**	**0.3167**	**0.560**	0.001

Phloeopora corticalis	0.8421	0.2500	0.459	0.003
Litargus connexus	1.0000	0.2000	0.447	0.001
Atheta vaga	0.8077	0.2333	0.434	0.023
Glischrochilus quadripunctatus	0.9000	0.1833	0.406	0.010
Placusa atrata	0.8261	0.1833	0.389	0.023
Rhagium inquisitor	0.8462	0.1500	0.356	0.036
Paranopleta inhabilis	1.0000	0.1167	0.342	0.015
Soronia punctatissima	0.9000	0.1167	0.324	0.047
Scolytus ratzeburgii	1.0000	0.1000	0.316	0.032
Pine				
Hylastes brunneus	**0.9111**	**0.3833**	**0.591**	0.001
Tomicus piniperda	1.0000	0.2000	0.447	0.001
Stephanopachys linearis (NT)	0.9091	0.1333	0.348	0.031

3.2 Diameter

H3: Beetle species responses to tree diameter

Beetle species richness was found to be lower on larger diameters of pine (Figure 4), although the complete model explained relatively low proportion of variance explained (Table 3). No differences were found between diameters on birch, while Shannon diversity related positively to vitality status, specifically alive compared to dead birch trap trees (Table 3). As there were only one dead pine, vitality was only included in models based on birch trap tree data, as the unevenness of the vitality distribution of pine could otherwise return misleading results.

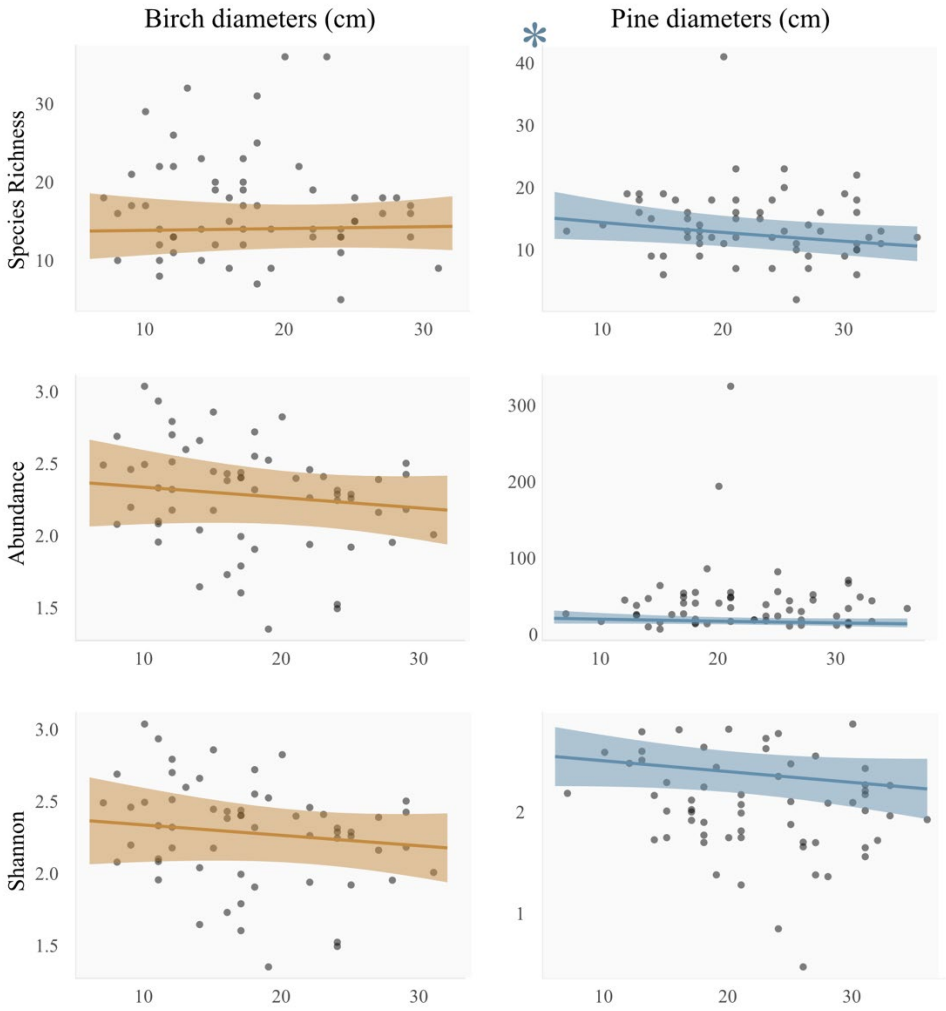

Figure 4. Linear predicted estimates of models and sample points of beetle responses (species richness, abundance and Shannon diversity index) from models of birch- and pine diameters. Significant results are indicated by a star in the upper left corner (model results can be found in Table 3).

Table 3. Model coefficients: beetle response variables (species richness, abundance and Shannon diversity index), estimates of each predictor (birch- or pine diameter, year 2022 compared to 2023 or 2024, and vitality status alive compared to reduced or dead) p-values, and marginal and conditional R^2. Values in bold indicate significant results.

Predictors	**Estimate**	***p***	**Marginal R^2 / Conditional R^2**
Species richness ~ diameter + vitality + year + (1 | plot ID)			
Diameter (cm) [Birch]	0.002	0.820	0.273 / 0.507
Vitality [Reduced]	0.031	0.761	
Vitality [Dead]	0.225	0.106	
Year [2023]	**0.316**	**0.005**	
Year [2024]	0.035	0.806	
Abundance ~ diameter + vitality + year + (1 | plot ID)			
Diameter (cm) [Birch]	0.007	0.250	0.505 / 0.918
Vitality [Reduced]	0.027	0.757	
Vitality [Dead]	0.084	0.509	
Year [2023]	**0.906**	**<0.001**	

Year [2024]	**0.354**	**0.038**	
Shannon index ~ diameter + vitality + year + (1 | plot ID)			
Diameter (cm) [Birch]	-0.02	0.349	0.197 / 0.197
Vitality [Reduced]	-0.005	0.966	
Vitality [Dead]	**0.293**	**0.040**	
Year [2023]	-0.086	0.409	
Year [2024]	-0.113	0.315	
Species richness ~ diameter + year + (1 | plot ID)			
Diameter (cm) [Pine]	**-0.012**	**0.042**	0.126 / 0.494
Year [2023]	0.238	0.077	
Year [2024]	-0.001	0.994	
log(Abundance) ~ diameter + year + (1 | plot ID)			
Diameter (cm) [Pine]	-0.014	0.173	0.391 / 0.516
Year [2023]	**1.065**	**<0.001**	
Year [2024]	**0.714**	**<0.001**	
Shannon index ~ diameter + year + (1 | plot ID)			
Diameter (cm) [Pine]	-0.011	0.143	0.269 / 0.459
Year [2023]	**-0.512**	**<0.001**	
Year [2024]	**-0.433**	**0.003**	

H4: Beetle species compositions between diameters

Beetle species compositions did not differ between any diameter categories according to the PERMANOVA, regardless of tree species (Appendix B; Table 7, Figure 5). However, the additional envfit analysis showed some pattern of differing species composition between diameters on pine, while no such patterns were found on birch (Appendix B; Table 8). The number of trap trees in each diameter category varied, as pines were more uniformly sized and larger than birches, resulting in a lower sample coverage regarding the total species richness of medium and large birches, and of small and large pines (Appendix B; Figure 9). There were beetle species associated with each diameter category on pine according to the indicator species analysis, none with IndVal value indicating a "strong indicator", while there were no species associated with any diameter category on birch (Appendix B; Table 10).

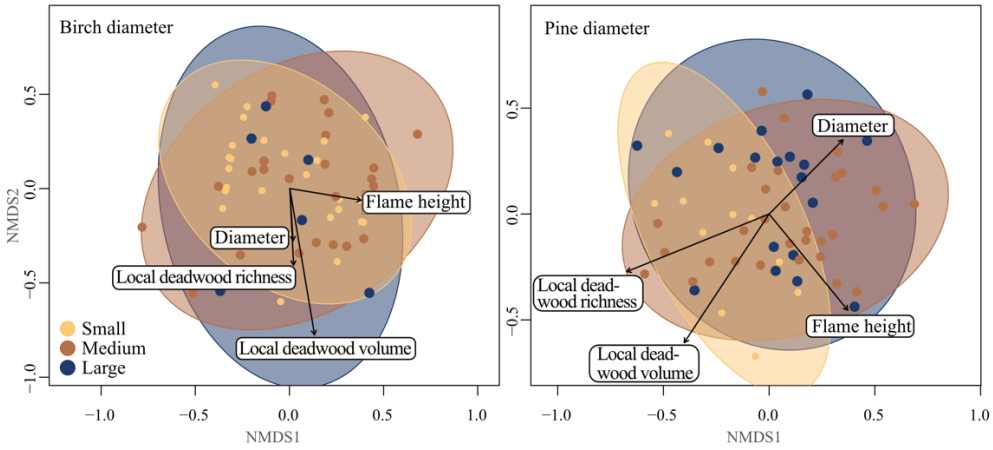

Figure 5. NMDS illustrating beetle species composition Bray Curtis dissimilarity distances between diameter categories, with envfit vectors of environmental continuous variables relating to the distances where long vectors indicate significant results (envfit results are found in Appendix B; Table 8). Diameter categories consist of small (7-16 cm), medium (17-26 cm) and large (27-37 cm).

3.3 Local deadwood variables

H5: Local deadwood as an accumulated surface area

With higher local deadwood volume, beetle species richness and Shannon diversity index showed to be higher (Table 4) while abundance did not differ with local deadwood volume. Variance explained by models was relatively low. No beetle response differed with differences in deadwood richness. Species compositions differed along local deadwood volume gradients in the envfit results on both pines and birches. The same was found for local deadwood richness, but only on pines (Appendix B; Table 8). The envfit results also showed beetle responses relating to flame height, and some patterns of differences related to diameters, but only on pine (Appendix B; Table 8).

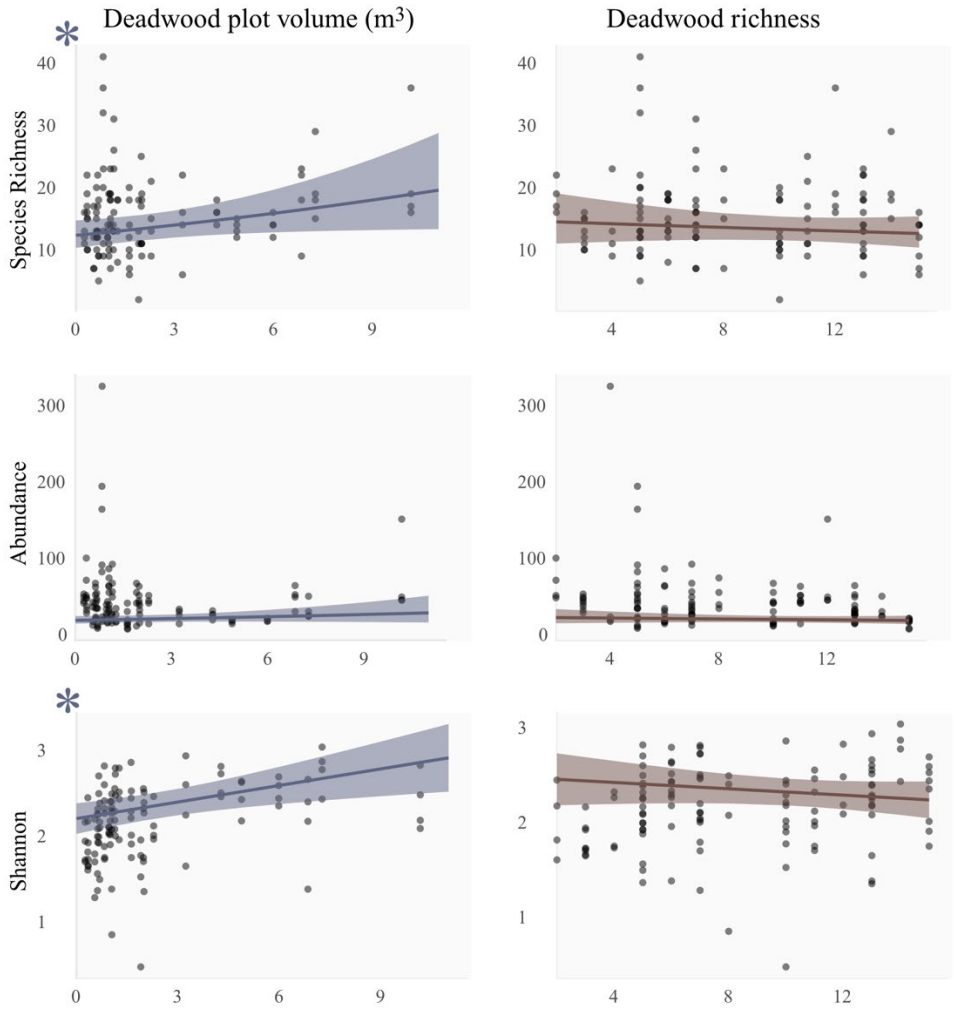

Figure 6. Linear predicted estimates of models and sample points of beetle responses (species richness, abundance and Shannon diversity index) from models of local deadwood volume (m)^{3}and richness. Significant results are indicated by a star in the upper left corner (model results can be found in Table 4).

Table 4. Model coefficients: beetle response variables (species richness, abundance and Shannon diversity index), estimates of each predictor (local deadwood volume, local deadwood richness and year), p-values, and marginal and conditional R^2. Values in bold indicate significant results.

Predictors	**Estimate**	***p***	**Marginal R^2 / Conditional R^2**
Species richness ~ local deadwood volume + local deadwood richness + year + (1 | plot ID)			
Local deadwood volume (m^3)	**0.04209**	**0.042**	0.170 / 0.307
Local deadwood richness	-0.011	0.467	
Year [2023]	**0.110**	**0.011**	
Year [2024]	0.110	0.798	
log(Abundance) ~ local deadwood volume + local deadwood richness + year + (1 | plot ID)			
Local deadwood volume (m^3)	0.038	0.226	0.374 / 0.490
Local deadwood richness	-0.014	0.509	
Year [2023]	**0.949**	**<0.001**	

Year [2024]	**0.525**	**0.001**	
Shannon index ~ local deadwood volume + local deadwood richness + year + (1 | plot ID)			
Local deadwood volume (m^3)	**0.064**	**0.002**	0.188 / 0.256
Local deadwood richness	-0.017	0.249	
Year [2023]	**-0.299**	**0.008**	
Year [2024]	**-0.241**	**0.029**	

4. Discussion

The study was initiated with research questions regarding how beetle species richness, diversity and composition relate to burned birches compared to burned pines (Q1), their diameter (Q2), as well as local deadwood amounts and diversity in burned forest environments (Q3). I expected a higher species richness (H1) and distinct species composition on burned birches (H2), higher species richness (H3) and distinct species compositions on larger diameter trap trees (H4), and a higher abundance and species richness in relation to higher local deadwood volumes (H5).

4.1 Tree Species

H1 and H2: Beetle responses, species composition and tree species

For Q1 I found that there were differences in beetle species richness, although not in Shannon diversity or species composition between tree species after being exposed to fire. H1 is supported by these results, as a higher diversity was expected to be found on burned birches compared to burned pines. As expected, beetle species richness and Shannon diversity was revealed to be higher on burned birches. This is in line with an earlier study by Lindbladh (2007) showing higher species richness on birch, where dead birches hosted more species than dead spruces. Also Wikars (2002) found a higher diversity of beetle species on birch logs when burned compared to when unburned, and interpreted this as a result of historical co-evolution shaped by fire as a disturbance. Although similar comparisons between burned and unburned birches cannot be made in this study, the favourability of birches within the pine forest is supported – choosing birch-rich areas to conduct prescribed burning would as such be advantageous when intending to provide for beetle diversity. Additionally, the contextual vulnerability to fire connected to tree species and size could have been a probable component as to why the birches could hold a higher species richness, as deadwood has been found to house higher beetle species richness compared to living threes (Graf et al. 2022). However, in this case the species richness found on the total amount of birch trap trees did not differ in relation to vitality level, and as such the differences found can be attributed to tree species.

As for the species composition, distinct differences between tree species were initially expected. H2 is supported in the case of individual beetle species, however when measuring the complete composition, tree species explained a very low proportion of variance found. This contrasts previous studies showing distinct species compositions found on different host tree species (Tikkanen et al. 2006; Zuo et al. 2016). The higher number of species associated with burned birches

could be in accordance with previous studies showing beetle species on deciduous tree species having generalistic host-species tendencies (Milberg et al. 2014), also shown for beetles found on birch (Volodchenko & Selenzev 2022). Perhaps this is a result of beetle species preferring deciduous species overall having a refuge in the occurrence of birch. However, these studies cover dead birch-wood, leaving room for the possibility of specialist tendencies in species associated with earlier successional stages, as has previously been seen for bark beetles (Zuo et al. 2016). Nonetheless, the results do suggest a contribution in providing for these species in otherwise pine-dominated forests.

Specific beetle species

A surprising result is the association between birch and the beetle species *Rhagium inquisitor* (NT), more commonly associated with conifers (*SLU Artdatabanken* 2025a). This result could be interpreted as the species being overall attracted to fire affected areas, but not necessarily differentiating between burned substrates when swarming on site, as seen for some beetle species (Graf et al. 2022). Wikars (2002) found similar species compositions regardless of tree species early on after burning, possibly suggesting homogenization of substrates when burned. Considering this finding, alongside Palm (1951) describing *Rhagium inquisitor* as able to utilize deciduous species after they're burned, the notion of homogenization after burning could also be supported in this study.

A pyrophilous species, *Acmaeops septentrionis* (NT), was the third most abundant redlisted beetle species found in this study, mostly on pines. According to Ehnström and Holmer (2007) it is associated with burned conifers and dry spruce snags. The same species was also found in the study by Wikars (2002), but linked to non-burned substrates. As such, *Acmaeops septentrionis* could be an example of species otherwise associated with burned sites not necessarily using the burned trees for colonization, perhaps because of its need of specifically dead burned substrates (*SLU Artdatabanken* 2025b), but attracted to the site none the less. Perhaps birch when burned, and as such possibly homogenized, constitutes a contributing addition for some species in the otherwise pine dominated forests, while also providing resources for some species with preference toward birch over pine, resulting in an addition to beetle diversity compared to a hypothetical exclusively pine-comprising forest.

The red-listed species *Stephanopachys linearis* (NT) was found to be associated with burned pines, although occurrences were quite rare. A common issue when analysing the occurrences of redlisted species is the rarity in and of itself inhibiting the possibility of robust analysis (Martikainen & Kouki 2003). However, in this case, the association is supported by earlier studies of the same species. Ranius et al. (2014) describe the species as utilizing mainly burned pines

that are still alive, showcasing an importance of a variety of tree vitality status post-fire.

4.2 Diameter

H3 and H4: Beetle responses, species composition and diameters

For Q2 there were no differences in beetle species richness, Shannon diversity nor species compositions between diameters of birch and pine after being exposed to fire. A higher diversity and distinct species compositions on larger diameter trap trees was initially expected, but not found. As such, H3 and H4 cannot be supported. Instead, the diameter-relationships found were negative, and species compositions between small, medium and large trap trees did not differ with any leverage in explained variance. Not a single species was associated with birch diameter categories, which could be an indication of species attracted to burned birches not having any preference between diameters. On pines we found a surprising negative relationship between diameter and species richness, and contrary to birches, the few species found associated with pine diameter-categories indicates a few species' preference of each diameter category, even though no beetle composition differences were found. Perhaps these few distinguishing species were not enough of a difference in the context of the complete species composition. Conversely, Zumr et al. (2023) found higher beetle species richness and diversity on beech snags once diameters reached above 35 centimeters using a similar trapping method, while Lindhe et al. (2005) found beetle abundances on dead birch snags to increase along diameters between 23-65 centimeters, although when using emergence traps. Trap trees in my study ranged between 7-36 centimeters, limiting any conclusion regarding larger diameters. As such, there is a considerable range left unanalysed, and any potential thresholds where patterns might shift along higher diameters would be left unnoticed. However, this pattern is not surprising given the management history of the area, as pine diameters most often range between 20-30 centimeters and rarely exceeding 45 centimeters, while birch mostly range between 10-20 centimeters, rarely exceeding 30 centimeters in the managed forest landscape of the region (Roberge et al. 2024). Additionally, there was a discrepant number of trap trees within diameter categories. The following diameter analyses were subsequently separated by tree species to represent the importance of diameters of each tree species, decreasing the interconnection between diameter distribution and tree species. The separation resulted in a low number of trap trees and sample coverage in some of the diameter categories, namely large birches, small pines and large pines. Although, the differences happen to be found between the two categories with relatively robust sample coverage, which instead could hint at the existence of more differences being left unnoticed for birch diameters above the

threshold set between the medium and large diameter category. As such, the importance of larger diameters cannot be dismissed, while the importance of smaller birch diameters can be supported.

Smaller diameters have previously been shown to carry a high diversity (Korhonen et al. 2024) and unique beetle species compositions (Jonsell et al. 2007), while certain beetle species have been shown to be specifically associated with larger deciduous trees (Platek et al. 2019; Cizek et al. 2025). However, the results of this study ultimately do not support the initial hypotheses, that abundance and species richness would increase with diameter, as the relationships found were negative, and species compositions did not differ between diameters. Possibly unnoticed thresholds above the sampled diameter range warrants future studies seeking out areas with diameters not covered in this study, as well as larger sample sizes of both small and large trees than was able to be sampled here. It is also possible that the trapping method resulted in the sampled beetles representing only early successional attracting capabilities of the trap trees, not the utility of them. The use of flight intercept traps does not ensure catches representing beetles successfully colonizing the substrates and successfully reproducing. This would instead require emergence traps. For example, a difference in species composition on diameters of pine and oak between 1-40 centimeters have previously been found based on beetle body size, although on downed deadwood, where larger pieces of deadwood hosted larger beetles (Brin et al. 2011). The importance of larger diameters could perhaps be revealed within this context, where larger diameters could become more important as succession proceeds (Lindhe et al. 2005).

Vitality of the trap trees

The diameter distribution is further connected to the vulnerability and resulting vitality of the trees during and after the fire. Neither abundance nor species richness on birches differed in relation to vitality level, although Shannon diversity was higher on dead compared to alive birches. This indicates the possibility of species having low abundances on living birches, having comparatively higher abundances on dead birches. Perhaps species associated with deadwood, although occurring on both alive and dead birches, were more attracted to and therefore more abundant on dead birches, while the total amount of species did not differ.

The higher number of dead birches compared to pines in this study could be linked to traits of the tree species, but also to tree size. Small pines are very vulnerable to fire, becoming more resilient as they grow larger and their bark thickens (Linder et al. 1998), while birches are inherently more vulnerable to fire overall compared to pines (Adámek et al. 2016). As tree species and size are connected to fire-vulnerability, one cannot completely disconnect these traits from

beetle responses, as some habitat-types only occur once the tree is dead (Stokland et al. 2012).

There are also interesting beetle species in need of trees surviving fire, such as the aforementioned *Stephanopachys linearis*. Most studies focus on saproxylic species on deadwood, when the term 'saproxylic' has been defined to not only include species depending solely on deadwood, but to also encompass species utilizing living trees, as these can carry various decaying tissues (Alexander 2008; Kašák & Foit 2018), and beetle species partly being the trees' cause of death (Stokland et al. 2012). Bark beetles (*Scolytidae*) colonizing and killing stressed trees have been shown to enable the colonization of following saproxylic taxa dependent on deadwood specifically (Zuo et al. 2016). It is therefore probable that species paving the way for deadwood-specialist species also are a part of these results, and further studies beyond this successional stage is needed. The comparison, in the end, becomes one of beetle populations on smaller birches versus larger and uniformly sized pines, all of varying vitality status, but mostly still alive after fire. With this context in mind the relationships found reflect an early part of beetle succession after a relatively intermediate intensity fire. Within the complicated interconnections of these ecological variables, the study has shown small birches carrying a contributing role in providing for beetle diversity in fire shaped boreal forests in Sweden.

The variable 'year'

Shannon diversity related negatively to areas burned earlier years, suggesting lower evenness and fewer species dominating the species compositions even one or two years after fire. Perhaps this pattern could be a reflection of pyrophilous species leaving the area when smoke- and fire-induced volatiles diminish. Then again, species compositions did not differ between 'years'. It is possible that the differences in rarity between species were not distinct enough to translate into the complete species setup. Restoration measures are only one part of what influences the ability of an area to provide for saproxylic insects needs - surrounding landscape characteristics and human induced measures apart from restoration will have an additional effect (Hjältén et al. 2017). 'Year' has in this case been a composite variable of time since burning, fire intensity, location in the surrounding landscape mosaic and possible differences in management history. Whether the variance explained by 'year' can be accounted to differences regarding each of these composites is not further investigated in this study. Nevertheless, a higher fire intensity was observed in the sites burned in 2023 compared to year 2022 and 2024, which could be part of the explanation for the higher beetle responses in 2023 compared to 2022. Time since burning is overall short relative to the previously shown time-sensitive effect of fire on pyrophilous insect species (Hyvärinen et al. 2006; Ranius et al. 2014; Heikkala et al. 2016),

but could nonetheless also partly explain the increased beetle responses on sites burned 2023 and 2024.

4.3 Local deadwood as an accumulated surface area

H5: Beetle responses and local deadwood

For the final study question, Q3, there were differences in beetle species richness, diversity and species composition related to the local deadwood volume, although not in beetle abundance. In H5 a higher abundance was expected in areas with higher local deadwood volumes. This would, in combination with a higher abundance and species richness on larger trap trees, concur with the previously mentioned target area hypothesis. As no substantial relation to size was found, nor between beetle abundances and local deadwood volume, this reasoning could not be validated. The differences found is instead a higher species richness in environments with higher local volumes or richness of deadwood. As such, a relationship between higher abundances and higher species richness is not supported. Perhaps the higher species richness in areas with higher local deadwood volume and richness is instead a sign of more preferences being fulfilled, as a result of the higher deadwood diversity. The association of beetle species with certain pine-diameters is additional signs of preferences, although only for a small number of them.

The target area hypothesis as written (Lomolino 1990) does not cover the foundational causation of said relationship, other than substrate size and shape, more so focusing on the higher probability of populations' colonization and evasion of extinction based on area resources. Rather than the larger area of the substrates in and of themselves resulting in a higher probability of landing and subsequent successful colonization, specific characteristics of substrates could be driving the relationship between abundance, richness and size of substrates – as opposed to a large target being successfully hit more often.

Species-specific chemical volatiles are released from stressed (Ranger et al. 2010; Gitau et al. 2013) and burning trees, attracting beetles (Schütz et al. 1999; Paczkowski et al. 2013) who in response swarm the area. Some pyrophilous beetle species even use a unique set of organs to sense heat from substrates, aiding them in their pursuit of burnt substrates safe to use soon after fire (Mainz et al. 2004). These previous studies would suggest conscious weighing of which substrates to land on and/or colonize in the swarmed area. Saproxylic beetles have specifically been suggested to actively select their substrates (Graf et al. 2022), and the primary attraction hypothesis suggests beetles being able to sense the suitability of substrates even before landing through semiochemical and olfactory sensing (Saint-Germain et al. 2007). An example of this is during colonization by bark beetles, other swarming beetles are made aware of this via secondary

attraction pheromones, communicating that the tree is already occupied - something that can be picked up even between species (Gitau et al. 2013). Perhaps the size of the substrate does not translate in this communication within the diameter range in this study.

Larger pieces of deadwood have been described as having specific characteristics resulting from its size, such as a more stable microclimate (Lindman et al. 2022), old tree structures favouring some specialists (Ranius et al. 2014), and a slower decay rate perhaps providing resources for specialists of certain decay stages for a relatively prolonged period of time, allowing successful colonization and reproduction. Regardless, the results of this study reveal a higher number of species with a preference for burned birch over pines, while no difference in abundance, species richness nor species-specific preferences between birch-diameters was revealed. Hypothesis number five could as such not be supported.

4.4 Conclusion

This study shows that birches contribute to beetle diversity in the early successional post-fire stage. This is the case even with birches of smaller diameters, and in comparison to the co-occurring and fire favoured pines. Although more could be revealed with a higher variation of diameters, the sampled diameters are reflective of the common distribution of the tree species and diameter relationship in Swedish boreal forests. Based on the results of this study, the importance of larger diameters cannot be dismissed, while the importance of smaller diameter birches can be validated. As such, smaller birches should not be overlooked or removed when aiming to restore or retain the values created by forest fire. This is motivation to protect and preserve a high percentage of birch alongside the otherwise pine dominated fire shaped forests, regardless of sizes present throughout landscape. For prescribed burning, practitioners should consider areas rich in birch even if they are of small diameters, as they too support diversity of beetles when burned.

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Popular science summary

During the relatively short time the management of Swedish forests have changed, the forests themselves have also changed as a result. Many environments do not occur as often as they once did. Just like a bumblebee needs flowering plants to survive, other insects like beetles need trees that are weakened or have already died – which is actually something the bumblebee also needs during their winter slumber. The systematic and widespread change in forest management, with the aim of creating forests with vigurous trees able to be harvested, has lead to a lack of environment shaping mechanisms creating these important structures. These mechanisms can be natural events such as storms, floods and fires, resulting in trees falling over and leaving gaps of sunlight hitting the dead log, some surviving and growing old, developing coarse bark and stem-hollows after branches dying of with age, and so much more. The pine forests commonly seen today is most often created via clear-cut forestry management, creating homogeneous stands, continuously kept young as harvest is planned along a consistent timeline. However, before modern forestry, pine forests were created and maintained through continually occurring fires. Vegetation not able to survive fires would be removed, pioneer tree species would spring up, and pines allowed to stay old could survive the fires, resulting in the possibility of natural regeneration on the disturbed ground. As living organisms co-evolve side by side, adapting to changes and environments within which they are existing, many organisms' traits and characteristics have developed to be able to survive these fires – which as a result have become a necessity for them. One such organism-group are the wood-inhabiting beetles.

The intention of this study has been to look at some characteristics of fire-affected wood that beetles could be attracted to. The two characteristics studied are the size and species of the tree, which have been shown to harbor their own unique beetle species compositions in previous studies. Pine, as mentioned, is commonly known to be fire-favoured itself, and harboring special beetle species when they are burned – but there is actually another tree species also favoured by fire; the commonly occurring birch. As such, the birch could also harbor special beetle species when burned. The question arising here is: what role does the birch have in the otherwise pine dominated fire shaped forests?

Birch has not been an equally popular tree species in the industry, resulting in the systematic removal of its natural regeneration. Because of this it is often times very young and small when found in forested areas. Would this fact make a difference for the importance of the tree for beetles? Or do we have a great opportunity to create meaningful burned wood for fire-dependent beetle species, without even noticing. The context of the state of birch in Swedish forests today has brought about the second question: what role does the size of birch have in the

fire shaped forests? If we can answer these questions, we would be able to aid future restoration efforts in making use of the environments we already have, and hopefully providing for species not otherwise favoured by modern forestry.

To answer these questions beetles have been caught on large birches, small birches, large pines and small pines after a prescribed burning. This was done in an area previously known to have burned, in a Sveaskog Ecopark called Ejheden in Dalarna Sweden. The study showed that beetle species do differ between pines and birches when they are burned, and a higher number of species were directly associated to birches compared to the number associated with pines. Furthermore, there were no identifiable differences in beetle species on different sizes of birch. This led to the conclusion that there are beetles that prefer burned birches over burned pines, making birches an important factor in forests that are being burned as a restoration measure – even if they are small. Large sized birches can still hold very meaningful benefits for beetles, this study has not included them as they are often hard to come by in Swedish forests otherwise dominated by pine. Because of this, one should not disregard the importance and need for birches allowed to grow old and large. What has been shown here is that even small birches, still, can hold a large importance for beetles in fire shaped forests of Sweden.

Appendix A – Descriptive figures

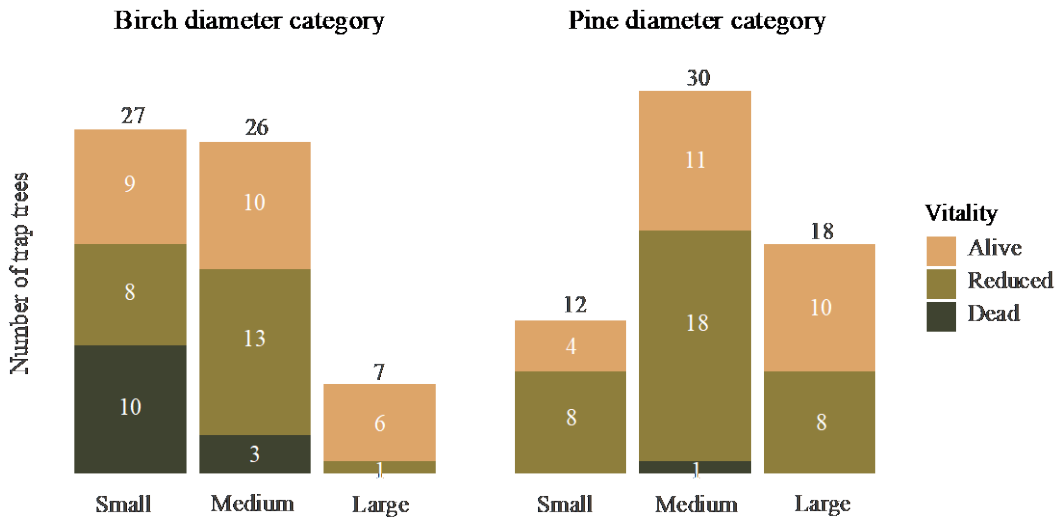

Figure 7. Stacked barplots showing the amount of sampled trees in each vitality level, per the amount of sampled trees in each diameter category.

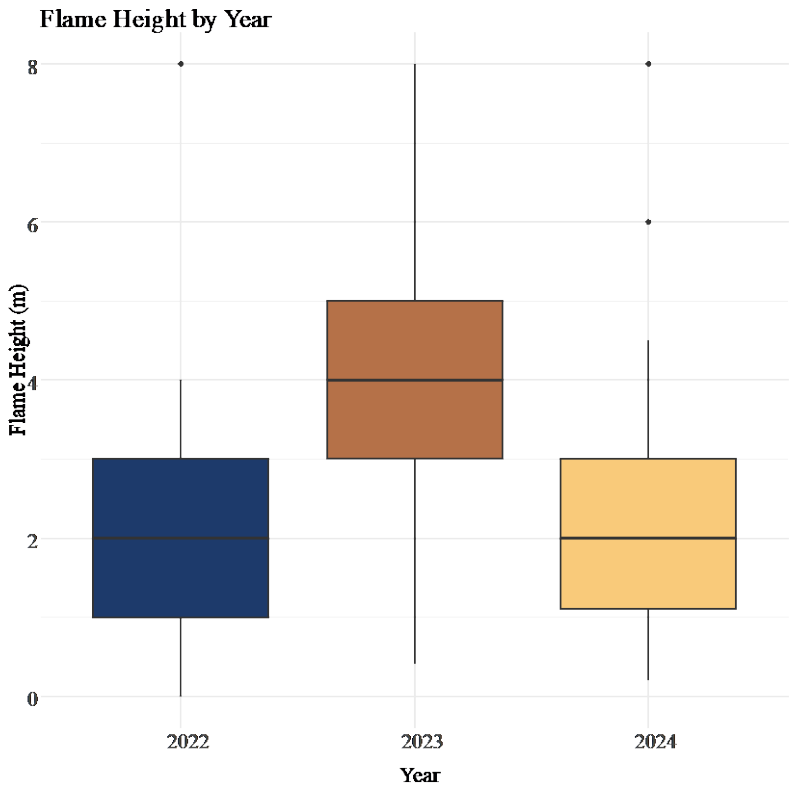

Figure 8. Flame height in meters as a proxy for fire intensity, per each year of burning, also representing stand location.

Table 5. Redlisted beetle species sampled; the tree species they were found on, the trap tree vitality status, diameter category, diameter in centimeters, flame height in meters, abundance of the beetle species per trap tree, the total abundance of the beetle species, and the category of redlisting as of the Swedish redlist 2020.

Redlisted species	Tree species	Vitality level	Diameter category	Diameter (cm)	Flame height (m)	Abundance	Sum	Redlist category
Sphaeriestes stockmanni	Birch	Alive	A	9	0.70	2	151	NT
				10	1.50	5		
				12	2.00	2		
			B	17	2.50	1		
				18	4.00	2		
				22	4.00	1		
			C	28	8.00	2		
		Reduced	A	14	2.00	1		
				15	3.00	5		
			B	17	2.00	3		
				17	7.00	2		
				18	2.00	9		
				21	4.00	2		
				23	7.00	4		
				25	3.00	3		
			C	29	7.00	2		
		Dead	A	7	0.41	2		
				9	3.00	1		
				12	3.00	8		
				13	1.00	4		
				14	3.00	7		
				16	3.00	1		
			B	17	8.00	4		
				20	6.00	4		
	Pine	Alive	A	12	4.00	7		
				13	1.20	3		
				14	4.00	5		
			B	17	1.00	1		
				18	2.50	1		
				21	4.00	6		
				25	0.20	2		
				26	4.00	4		
			C	31	7.00	4		
				33	4.00	1		
		Reduced	A	10	0.50	1		
				15	2.00	1		
				15	3.00	1		
			B	17	2.00	1		
				17	3.00	5		
				20	2.50	1		
				21	4.00	8		
				24	2.00	3		
				25	3.00	1		
				25	5.00	2		
			C	27	3.00	3		
				28	2.00	2		
				28	4.00	2		

				30	2.00	2		
				31	5.00	5		
		Dead	B	20	4.00	2		
Stephanopachys linearis	Birch	Dead	A	9	3.00	1	11	NT
	Pine	Alive		14	4.00	1		
			C	31	7.00	1		
		Reduced	A	15	1.00	1		
				16	1.00	2		
			B	23	2.00	1		
				25	3.00	2		
				25	5.00	1		
			C	32	2.20	1		
Acmaeops septentrionis	Birch	Reduced	B	17	7.00	1	6	NT
	Pine	Alive	A	14	4.00	1		
		Reduced		14	2.00	1		
			B	19	5.00	1		
				25	5.00	1		
			C	28	2.00	1		
Enicmus planipennis	Birch	Alive	B	17	2.50	1	2	NT
	Pine	Reduced	A	16	1.00	1		
Stagetus borealis	Birch	Dead	A	7	0.41	1	2	NT
	Pine	Alive	C	31	7.00	1		
Corticaria crenicollis	Birch	Alive	C	29	4.00	1	-	NT
Corticaria polypori	Pine	Alive	B	21	1.00	1	-	NT
Corticeus longulus	Pine	Dead	B	20	4.00	1	-	VU
Danosoma fasciatum	Pine	Reduced	B	17	2.00	1	-	NT
Denticollis borealis	Birch	Reduced	A	16	1.00	1	-	NT
Dropephylla clavigera	Pine	Reduced	C	27	4.00	1	-	NT
Mycetophagus fulvicollis	Pine	Alive	C	27	0.00	1	-	NT
Orchesia minor	Pine	Reduced	A	13	1.50	1	-	NT
Pachyta lamed	Pine	Alive	C	33	4.00	1	-	NT
Platysoma lineare	Pine	Dead	B	20	4.00	5	-	NT

Appendix B – Statistical Analysis methods and results

Table 6. Beetle species composition PERMANOVA results (p-value of PERMANOVA and betadisper, R^2 of PEMANOVA and NMDS stress) and following betadisper results, comparing groups tree species (birch / pine). Values in bold denotes significant results.

Variables	*p* (PERMANOVA)	R^2 (PERMANOVA)	*p* (Betadisper)	NMDS stress
Tree Species	**0.001**	**0.019**	0.603	0.233
Year	**0.001**	**0.114**	**0.001**	

Table 7. Beetle species composition PERMANOVA results (p-value of PERMANOVA and betadisper, R^2 of PEMANOVA and NMDS stress) and following betadisper results, comparing categories of diameter per tree species. Diameter categories consist of small (7-16 cm), medium (17-26 cm) and large (27-37 cm). Values in bold indicate significant results.

Variables/Levels	*p* (PERMANOVA)	R^2 (PERMANOVA)	*p* (Betadisper)	NMDS stress
Birch diameter	0.192	0.042	0.969	0.209
Year	0.074	0.12	**0.001**	
Pine diameter	0.606	0.048	0.278	0.214
Year	0.363	0.12	**0.001**	

Table 8. Envfit results of beetle species compositions' relation to local deadwood richness, volume and abundance, flame height, and trap tree diameter, illustrated as vectors on Figure 3 and Figure 5. Values in bold indicate significant results.

Variable	*p*	R^2
Birch		
Local deadwood richness	0.180	0.0596
Local deadwood volume	**0.002**	**0.2231**
Diameter	0.460	0.0278
Flame height	0.221	0.0530
Pine		
Local deadwood richness	**0.004**	**0.1943**
Local deadwood volume	**0.001**	**0.1949**
Diameter	0.062	0.0901
Flame height (m)	**0.023**	**0.1268**

*Table 9. Deadwood categories for diversity calculation and analysis of effect on beetle response variables. * (divided into two to keep deciduous and coniferous trees having equal weighting)*

Deadwood category	*Tree species (birch/pine)*	*Type (log/snag)*	*Decay class deciduous log (hard/soft)*	*Decay class coniferous log (1-3 / 4-6)**	*Decay class deciduous snag (hard/soft)*	*Decay class coniferous snag (4-6 / 7-9)**	*Diameter class (10/20/30/40 cm)*	*Degree of burn (none/medium/high)*
1	*birch*	*log*	*hard*	*-*	*-*	*-*	*10*	*none*
2	*birch*	*log*	*hard*	*-*	*-*	*-*	*20*	*none*
3	*birch*	*log*	*hard*	*-*	*-*	*-*	*30*	*none*
4	*birch*	*log*	*hard*	*-*	*-*	*-*	*40*	*none*
5	*birch*	*log*	*hard*	*-*	*-*	*-*	*10*	*medium*
6	*birch*	*log*	*hard*	*-*	*-*	*-*	*20*	*medium*

and so on…

Table 10. Indicator species analysis results for beetle species on diameter categories small, medium and large of birch or pine.

Category	**Specificity**	**Fidelity**	**IndVal**	**p**	**Descript.**
Small birch					
			-		
Medium birch					
			-		
Large birch					
			-		
Small pine					
Mycetochara obscura	1.00	0.2500	**0.500**	0.008 **	
Cortinicara gibbosa	0.7895	0.2500	0.444	0.020 *	
Medium pine					

Hadreule elongatula	1.00	0.2	0.447	0.047 *
Large pine				
Atheta vaga	0.8696	0.2222	0.44	0.046 *

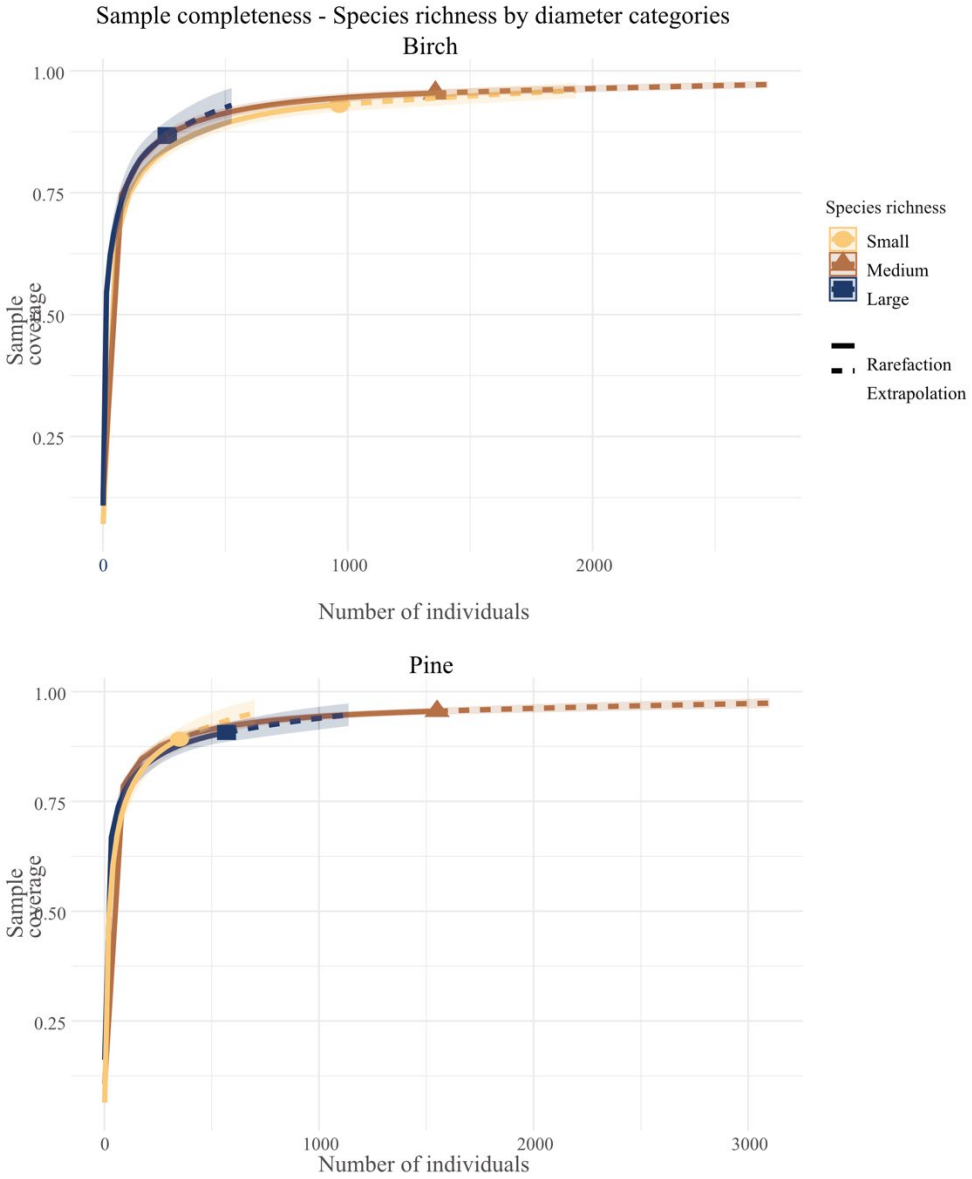

Figure 9. Rarefaction curves: species richness between diameter categories found on birch (top) and pine (bottom) is shown. Diameter categories consist of small (7-16 cm),

medium (17-26 cm) and large (27-37 cm). The confidence interval of 0.95 is represented by a shaded area around the rarefaction- and extrapolation lines.

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