Biodiversity analysis of Swedish FSC certified forests

Changes in occurrence of forest species, habitats and structures

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Greensway

Greensway AB
Ulls väg 24 A, 756 51 Uppsala
Epost: info@greensway.se

Document title: Biodiversity analysis of Swedish FSC certified forests
Authors: Diana Rubene, Teresa Montràs-Janer
Images: Greensway AB
Quality check: Adam Ekholm
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Summary

This study uses biodiversity data analyses to evaluate the contribution of FSC certified forest management to forest biodiversity conservation. The analysis investigates temporal trends of a set of forest indicator species and red listed species occurring in boreal forests of Sweden. The selected species are associated with habitats and structures promoted by FSC certified forest management, such as old forests, deciduous trees and dead wood.

Changes in probability to find species over time and across space were estimated from open species data using a modelling approach. Time trends were also estimated for six habitat/structural variables from systematic survey data of the National Forest Inventory (NFI). NFI data was also used to visualise spatial variation of habitats and structures across the assessed forest area. All analyses were performed for three regions separately, covering large, certified forest areas in central and northern Sweden.

The occurrence of most species has been stable over the last 15-20 years. A couple of species of wood-decaying fungi showed increasing trends in the regions of central and south-northern Sweden. None of the species displayed significant changes in their occurrence in northern Sweden.

The total amount of dead wood increased in all regions over the last 15-20 years and this increase was mainly due to a rapid increase in the amount of hard wood. Decayed wood only showed an increasing trend in central Sweden and was decreasing in the north. The total area of old forest was stable or slightly increasing (central Sweden), while the area with deciduous-rich forests showed a decline in all regions.

Several significant correlations between habitat occurrence and species occurrence were observed. In the central region, most of the associations were positive, while in the northern region mainly negative associations were present. Negative associations could be due to opposite patterns caused by time lags or specific events that affect both the species and the habitat, but in different directions.

Spatial variation of important habitats and structures shows that higher concentration of old and deciduous-rich forests, as well as dead wood, are found in the north-western part of Sweden. The highest habitat values were observed in the south-northern study region. The northern region had clearly lower habitat abundance, even though it is part of the same sub-alpine landscape with known high conservation values. Lower habitat abundance in the very north might indicate higher harvesting pressure and expansion of forest management into natural forest areas.

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1. Part 1 – Occurrence of species and habitats

The goal of this study is to assess the changes in occurrence of selected forest species across space and over time in FSC certified forests, as well as changes in availability of habitats and structures important for the boreal forest biodiversity. This report describes complementary analyses to the original species occurrence assessment presented in the report “FSC Biodiversity Conservation – final report”. The background and methodology are described in more detail in the previous report.

Boreal forest biodiversity is linked to its structural characteristics, disturbance regimes and ecological processes, as well as management history. Threats to biodiversity are therefore often associated with intensive forest management, which reduces the structural and ecological elements that forest species depend on (Paillet et al. 2009). The FSC forest management standard specifically targets many of these important elements, to ensure that habitats and structures are maintained in managed forests that can support native forest species.

Our qualitative analysis of FSC potential added value for biodiversity identified several aspects where FSC was expected to have a positive contribution compared to national legislation. Among these, several structural characteristics were identified, including dead wood and deciduous trees. The present analysis aims to provide a quantitative evaluation of these key identified habitat characteristics, together with occurrence analysis of forest indicator species known to depend on these habitats.

Figure 2. Old pine forests are characterised by an open structure, dead wood and lichen-dominated ground layer. The characteristic structures provide habitat for many red-listed forest species.

The selected habitat variables used in the analysis include **old forest**, **deciduous forest**, and **dead wood** (Table 1). The selected species include a set of **forest indicator and red-listed species** that are known to be associated with these habitats (Table 2). The analysis estimates changes in probability of occurrence for i) forest species, and ii) habitats and structures important for biodiversity. For species, the spatial distribution and changes over time (temporal trends), were estimated within each of three forest regions using a modelling approach. For habitats and structures, change over time was estimated for each region using the same approach as for species, and the spatial variation visualized based on original data from the Swedish National Forest Inventory database (NFI) (SLU 2024).

The species and habitat trends were analysed for three Swedish regions: central, south-northern, and northern (Figure 1). Sweden is a country that stretches from nemoral/boreo-nemoral zone in the south to boreal and sub-alpine/alpine zone in the north. The forests differ along this gradient, with variation in structural characteristics and species composition. Importantly, forest management intensity has varied historically. Both the extent and intensity of management has been higher in the south and successively lower towards the north of the country. At the same time, FSC standard requirements apply similarly to forests in the whole country. Analysing different regions separately provides an opportunity to better understand changes in habitat structures that may be attributed to implementation of FSC standard requirements, in the context of regional forest landscape characteristics and management history. Regional analyses also better consider natural variation in species distributions.

Figure 1. Map over the three Swedish regions of study: northern (orange), south-northern (green) and central Sweden (purple).

1.1. Methods

1.1.1 Data

The **habitat data** were obtained from the NFI database (SLU 2024). NFI is a standardised survey carried out by the Department of Forest Resource Management at Swedish University of Agricultural Sciences (SLU). The survey covers a grid of sample plots systematically distributed across the country, and every year a sample of about 12 000 plots is inventoried. The recorded environmental indicator variables include tree species composition, tree age and growth parameters, dead wood, as well as site characteristics and history.

Estimations for habitat variables based on summarised values from sample plots were obtained from NFI for each one of three Swedish regions: central, south-northern, and northern. We were interested in the habitats/structures of old forest, old deciduous-rich forest, forests with substantial proportion of deciduous trees, total amount of dead wood, amount of hard dead wood and amount of decayed dead wood (Table 2). The summarised data per region were obtained for years 2003-2021. NFI does not share raw data or geographic locations of individual sample plots, but they can provide estimates for specific areas based on all sample plots within that area. The data was in this case summarised for the area with certified forests and split into the three regions. NFI provided estimates for total area (old and deciduous-rich forests) or total volume (dead wood) for each region as floating 5-year averages, meaning that each value is calculated as an average between the specific year, the two previous years and the two following years.

Table 1. List of selected habitats, based on data collected by the Swedish National Forest Inventory (SLU).

Habitat	Units	Description
Old forest	ha	Productive forest land with a stand age >140 years in the boreal region and >120 years in boreo-nemoral and nemoral region.
Older deciduous-rich forest	ha	Productive forest land with >30% deciduous trees and a stand age >80 years in the boreal region and >60 years in boreo-nemoral and nemoral region.
Deciduous-rich forest (≥30%)	ha	Productive forest land with ≥30% deciduous trees.
Deciduous-standard forest (≥10%)	ha	Productive forest land with ≥10% deciduous trees. This is a target for deciduous tree proportion according to FSC FM standard.
All dead wood	m^3	Total volume of dead wood, including all decomposition stages.
Hard dead wood	m^3	Total volume of dead wood for which 0-10% of the volume consists of soft/decomposed parts. Includes completely raw/fresh dead wood.
Decayed dead wood	m^3	Total volume of dead wood for which 10-100% of the volume consists of soft/decomposed parts.

The **species data** were obtained from open access species data (GBIF 2020). We used the species data set produced during the first phase of biodiversity analysis (FSC Biodiversity Conservation – final rapport) and split the data geographically into the three regions. Species observations were extracted between year 2000 – 2023 from areas with certified forests. The spatial data on geographical extent of certified forests covering large parts of northern and central Sweden were obtained from several FSC certificate holders. To extract species records and compute analyses, we have applied a 100m hexagon grid to the selected forest area.

Table 2. List of selected species, their Swedish IUCN red-list (2023) status, indicator status according to the Swedish forest agency (Swedish Forest Agency 2023), their association to Natura 2000 habitats (i.e. classified as a typical species for a specific habitat) and their main habitat associations.

Species	Taxon	Red-list status	Forest indicator	Natura-2000 types	Habitat associations
Climacocystis borealis	Fungi	LC	Yes	Taiga 9010, Herb-rich forests with Picea abies 9050	Old growth forests, dead wood
Fuscoporia viticola	Fungi	LC	Yes	Taiga 9010	Old growth forests, dead wood
Hydnellum ferrugineum	Fungi	LC	Yes	Taiga 9010	Old growth forests
Phellinidium ferrugineofuscum	Fungi	NT	No	Taiga 9010, Herb-rich forests with Picea abies 9050, Natural forests of primary succession stages of landupheaval coast 9030	Old growth forests, dead wood
Phellinus populicola	Fungi	LC	Yes	Taiga 9010, Natural forests of primary succession stages of landupheaval coast 9030	Old aspen trees, old growth forests
Phellopilus nigrolimitatus	Fungi	NT	No	Taiga 9010	Old growth forests, dead wood
Phlebia centrifuga	Fungi	VU	No	Taiga 9010, Herb-rich forests with Picea abies 9050, Natural forests of primary succession stages of landupheaval coast 9030	Old growth forests, dead wood
Pulsatilla vernalis	Plant	EN	No	Coniferous forests on, or connected to, glaciofluvial eskers 9060	Old growth forests
Rhodofomes roseus	Fungi	NT	No	Taiga 9010, Herb-rich forests with Picea abies 9050	Old growth forests, dead wood
Sarcodon squamosus	Fungi	NT	No	Taiga 9010	Old growth forests
Aromia moschata	Insect	LC	Yes		Old growth forests
Cacotemnus thomsoni	Insect	LC	Yes		Dead wood, old forests
Callidium coriaceum	Insect	LC	Yes	Taiga 9010	Dead wood, old forests
Microbregma emarginatum	Insect	LC	Yes	Taiga 9010	Old trees
Necydalis major	Insect	LC	Yes	Taiga 9010	Old growth forests, dead wood
Nothorhina muricata	Insect	NT	No	Taiga 9010, Coniferous forests on, or connected to, glaciofluvial eskers 9060	Old trees, open forests
Peltis ferruginea	Insect	LC	Yes	Coniferous forests on, or connected to, glaciofluvial eskers 9060	Dead wood, old forests

Semanotus undatus	Insect	LC	Yes		Dead wood, old forests
Tomicus minor	Insect	LC	Yes	Coniferous forests on, or connected to, glaciofluvial eskers 9060	Old forests, dead wood

1.1.2 General description of the analyses

To determine the distribution of species associated with high natural values in certified forests, we analysed species occurrence over the last 20 years. During this time FSC certification has been implemented at large scale by the selected CHs. The biodiversity analysis focused on species of fungi, insects and plants that were either red listed or indicating forests with high natural value. Species were associated with habitats and substrates such as dead wood, old growth forests, deciduous trees and for wood, or forest fires. This analysis identified in which areas and how likely the species can be found in certified forests of central, south-northern and northern Sweden.

Distribution maps and probability of occurrence over time were estimated for 19 species using a modelling approach. We obtained open data on species observations between years 2003 – 2023 and restricted the geographic area to FSC certified forests. We also obtained open data for the entire forest species community and habitat data (ground moisture and forest type) for the same forest areas. Observations were organized into hexagonal grid cells of 100m radius. An algorithm (FRESCALO) was applied to account for biased observations in the open species data. Frescalo estimates the probability of finding a species in each grid cell (per year) by considering the habitat and forest species assemblage, both within and adjacent to the grid cell. Time trends and distribution maps for each species were then created from these adjusted values.

1.1.3 Technical methods description

Working with species observations from open data bases comes with several challenges. Presence-only data means that while the presence of a species can be considered as true, a species that has not been reported might be because the species is not there (true absence) or because it was not detected (false absence). The recorder effort will also be unknown for each grid-cell and uneven across grid-cells, which needs to be addressed (Prendergast et al. 1993, Guillera-Arroita 2017).

To tackle these issues, we estimated the probability of finding (or observing) each species with the Frescalo approach (Hill 2012). Frescalo is an algorithm developed to estimate unknown recording effort and species occurrence of data that is aggregated in time periods (i.e per year and grid). It is a well-established method to model the data collection process of biological recording schemes (Isaac et al. 2014, Pescott et al. 2019). As input, the algorithm requires community data and environmental data. It then estimates the expected frequency of each species in a grid-cell for each year (a value between 0 and 1) that can be converted into a species' probability to be observed.

To estimate the expected frequency, the algorithm uses a neighbourhood around each grid cell that will weight each frequencies by 1) the geographic distance between the focal cell and the surrounding cells; 2) environmental similarity between the focal and the surrounding grid-cells; and 3) the observed frequency of the species in the community. In our analysis, we used 100 m grid cells covering the area with certified forests. For each grid cell, we extracted all species observations (i.e. community data) and both humidity (SLU 2020) and forest type (Ahlkrona et al. 2019) (i.e environmental data).

As community data, we used the same taxa as our focus species (beetles, vascular plants, mosses, lichens, and fungi) using conifer, deciduous and mixed forests as their biotope according to the Swedish Species Information Centre. To reduce the size of the data set, we first removed grids with few observations (i.e. grids that only had species richness lower than 10% of the grid with the maximum value) and then species occurring in few grids (covering ≥ 0,5% of the grid cells).

Once we obtained the estimated frequency of each species from the Frescalo algorithm, we investigated the species' annual trends from 2003 to 2023. The first three years had to be excluded subsequently, because the algorithm did not work. Similarly, for the habitat data we investigated the annuals trends of each habitat type across the same year range. However, when data is collected within a temporal framework, the data points are not independent from each other (Turner and Gardner 2015). This means that the risk of finding statistical significance when it does not exist, increases. To avoid this issue, we need to account for temporal autocorrelation within the data. Therefore, for each species and each habitat, we ran a regression model with temporal dependency assuming that regression residuals follow a random walk process 'Rw1' (a model in itself, as described in Zuur et al. (2017)).

We used Integrated Nested Lapplace Approximation (INLA) for Bayesian inference (Rue et al. 2009) and the R-package R-INLA (www.r-inla.org for model execution (Rue et al. 2017, Bakka et al. 2018)) to compute the temporal trends. INLA is a method for approximate Bayesian inference for Latent Gaussian Models (such as models with temporal dependency where a dependency structure – the temporal trend – needs to be captured by the model). INLA has a high computational-cost-efficiency and allows incorporating temporal dependency with higher flexibility than other Bayesian methods, especially when modelling large datasets over large geographical areas (Blangiardo and Cameletti 2015, Zuur et al. 2017).

1.2. Results and Discussion

1.2.1 Species

The results of the analysis for the entire study region show that occurrence of the species has been stable. For most species, we detected no clear increase (or decrease) of the probability of finding the species across time, but rather a random oscillation around the average probability with no defined direction.

In general, the results mean that either the probability of finding a species has remained stable across time (with random increases and decreases) or that the trend cannot be determined with certainty (is not significant). A trend is 'significant' if the 95% CI do not overlap the mean value. The results indicate that the distribution of species has been maintained in managed certified forests, and we are as likely to find these species now as we were 20 years ago.

From the analyses performed for the three regions separately, however, for two species of wood-decaying fungi, *Phellinidium ferrugineofuscum* and *Phlebia centrifuga*, there were positive trends in the region of central Sweden. An increase in probability of occurrence was observed after 2015 for both species (Figure 3). For a few additional species (*Phellinus populicola*, *Rhodofomes roseus*, *Phellinidium ferrugineofuscum*), there were temporary positive increases in probability of occurrence around 2009-2011 in south-northern Sweden, which then returned to the previous levels (Figure 4). No negative significant trends were observed in any of the forest regions.

The species trends could not be calculated for all 19 species in all three regions. This is because the models need sufficient amount of open occurrence data for each species, split per year over a 15-year period in each region. For some species in some regions, the number of species records per year was insufficient to produce a time trend or the trend could only be calculated for a shorter time period. The number of species for which time trends could not be calculated was the highest in the northern region.

The analysis does not account for species coverage or abundance but responds (or is based) on recorded presence of the species and associated species community within a type of habitat. The analysis is only correlative, meaning that we cannot quantify to what extent certification is causing the observed patterns. In addition, the probability of species occurrence does not describe species abundance, coverage, population size or viability.

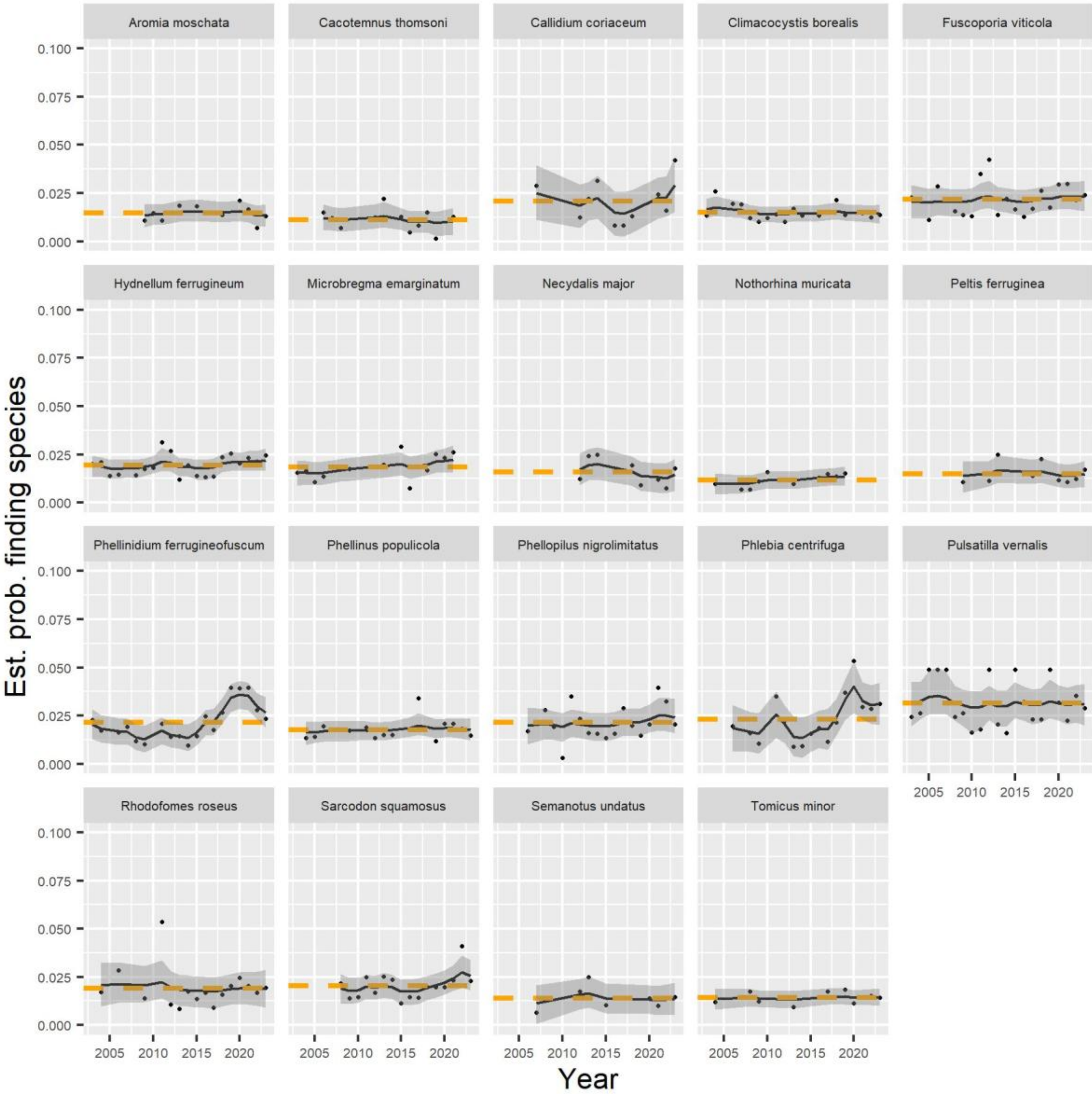


Figure 3. Probability of occurrence for forest species in FSC certified forests of central Sweden, for the last 20 years: changes in species occurrence over time. The black line shows the probability of finding the species over time, during the last 15-20 years. The dashed orange line illustrates the average (mean) level of species occurrence, and the grey area shows the confidence interval. Confidence intervals that overlap the mean value show that there has been no significant trend, i.e. no change in species occurrence.

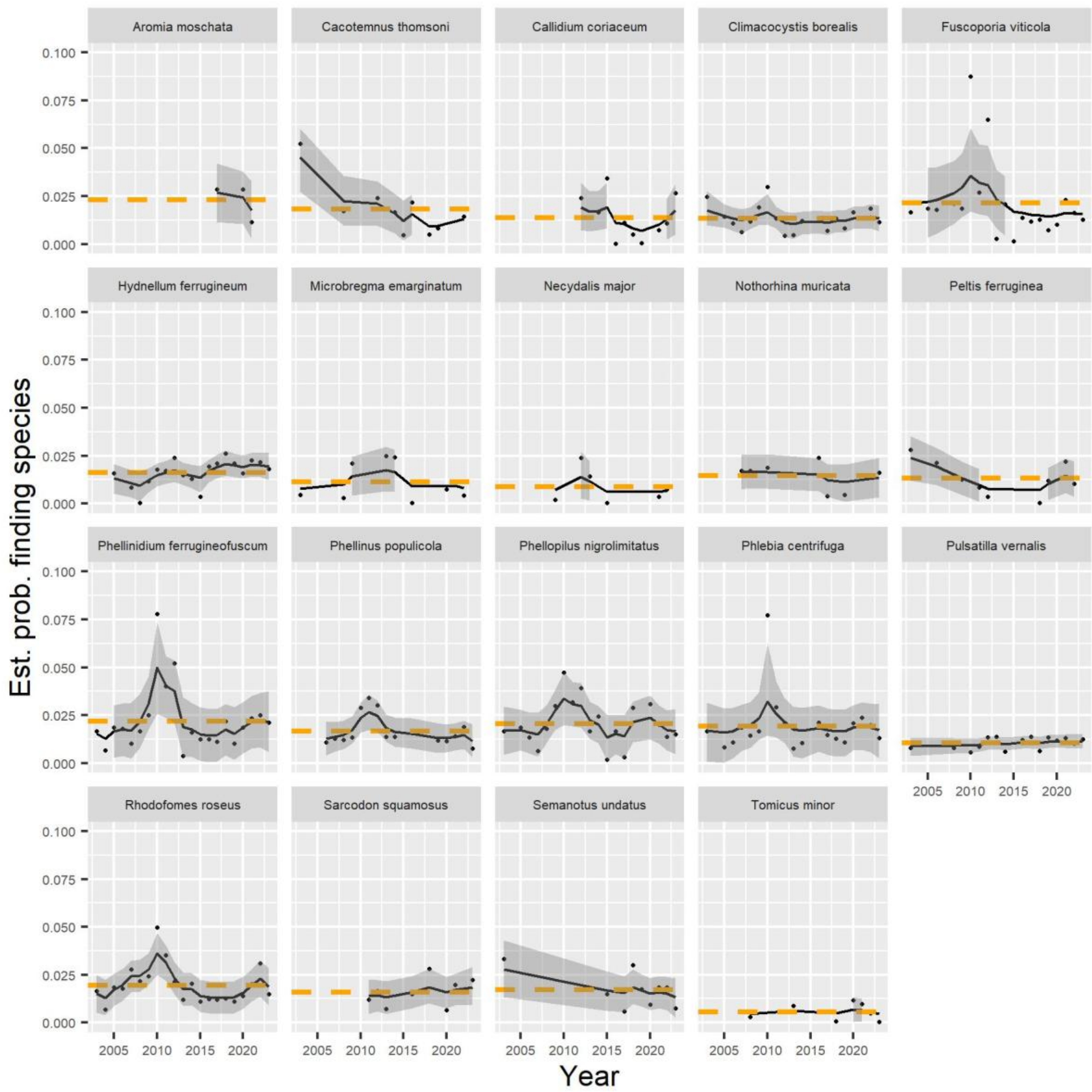


Figure 4. Probability of occurrence for forest species in FSC certified forests of south-northern Sweden, for the last 20 years: changes in species occurrence over time. The black line shows the probability of finding the species over time, during the last 15-20 years. The dashed orange line illustrates the average (mean) level of species occurrence, and the grey area shows the confidence interval. Confidence intervals that overlap the mean value show that there has been no significant trend, i.e. no change in species occurrence.

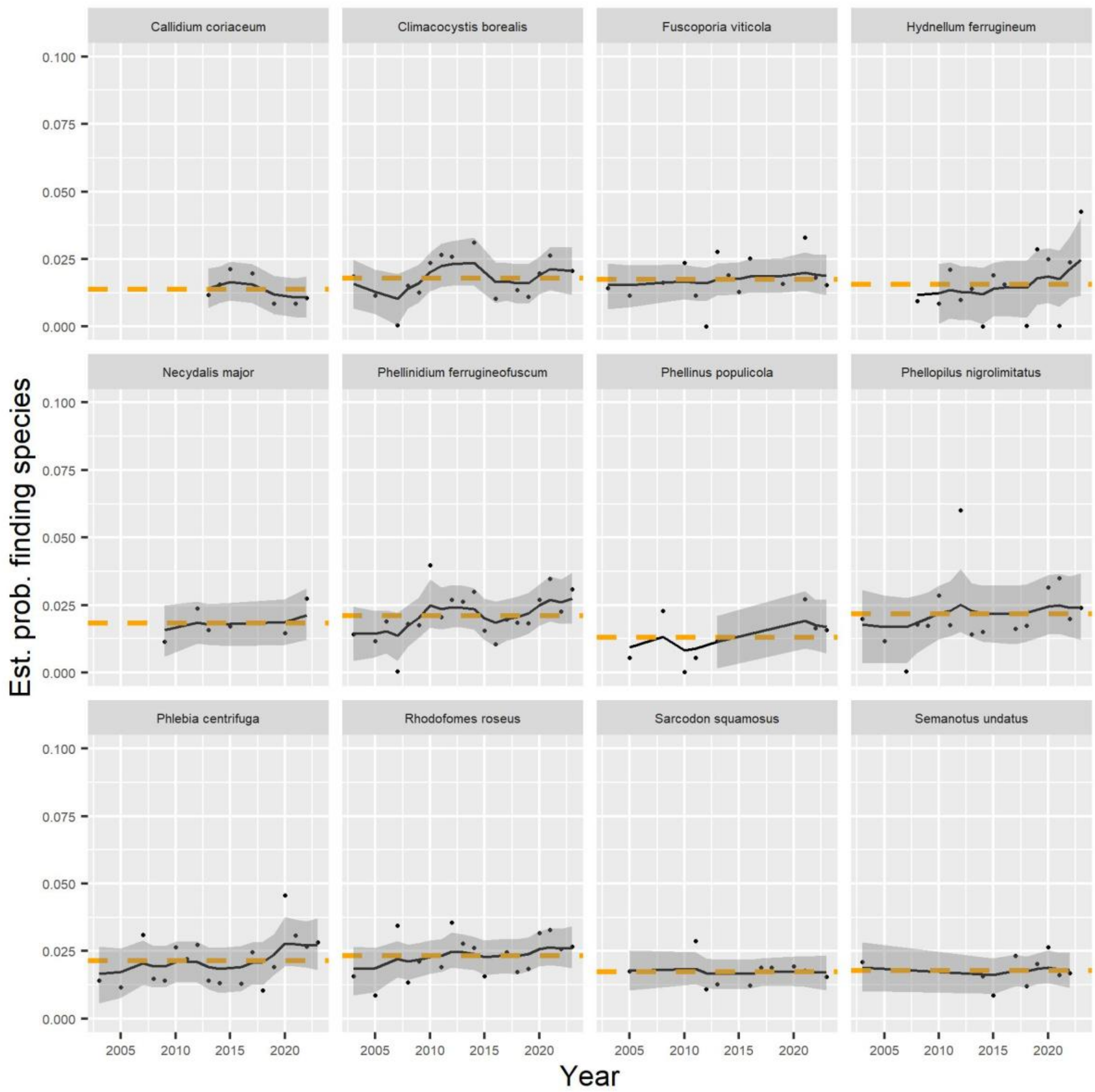


Figure 5. Probability of occurrence for forest species in FSC certified forests of northern Sweden, for the last 20 years: changes in species occurrence over time. The black line shows the probability of finding the species over time, during the last 15-20 years. The dashed orange line illustrates the average (mean) level of species occurrence, and the grey area shows the confidence interval. Confidence intervals that overlap the mean value show that there has been no significant trend, i.e. no change in species occurrence.

1.2.2 Habitats and structures

The results for habitats and structures show varying patterns for the different factors but are generally similar across regions (Table 3).

Table 3. Changes in the amount of habitats and structures that are important for biodiversity over the last 20 years, estimated for FSC certified forests in three regions of Sweden.

Habitat	Central region	South-Northern region	Northern region
Old forest	increase	stable	increase
Older deciduous-rich forest	stable	decrease	stable
Deciduous-rich forest (≥30%)	decrease	decrease	decrease
Deciduous-standard forest (≥10%)	stable	decrease	stable
All dead wood	increase	increase	increase
Hard dead wood	increase	increase	increase
Decayed dead wood	increase	decrease	decrease

The area old forest has been stable or slightly increasing over the last 20 years while the area of older deciduous-rich forest has either been stable or decreasing. No increases in deciduous-rich and deciduous-standard forests were observed, and the forests with the higher proportion deciduous trees (≥30%) have been decreasing consistently across regions. The total amount of dead wood has increased in all regions, and this increase is clearly driven by an increase in the volume of hard dead wood. Decayed dead wood, on the contrary, is only increasing in central Sweden.

The observed trends for habitats and structures are broadly in line with the national trends reported by NFI. At a national level, a positive increase in large living trees, volume of dead wood, area of old forests and proportion of deciduous trees has been observed during the last 20-25 years (SLU 2023, Kyaschenko et al. 2022). However, the magnitude of change in habitats and structures varies between geographical regions of Sweden. The positive development is most pronounced in the southern parts of the country. This is probably due to a longer history of intensive forest management in southern regions, which has degraded natural values in most forests.

The patterns observed for certified forests in this analysis confirm that improvement in habitats and structures important for biodiversity is most apparent in the central part of Sweden (southern Sweden was not analysed), while the levels are declining or increasing slower further north (south-northern and northern region). However, the increase in the area of old forest is weaker (between 2% to 20% increase), compared to the national trend for the boreal region where productive forests outside protected areas show close to 30% increase

(SLU 2023, 2024). In addition, the decline of deciduous-rich forests in all study regions is rather pronounced and somewhat surprising, considering that the average proportion of deciduous trees has been increasing on a national level. This pattern can be explained by that based on data summarised in Kyaschenko et al. (2022), the proportion of deciduous trees lies around 12% for production forests, which is below the threshold for deciduous-rich definition implemented by the NFI (≥30% deciduous trees). In addition, while proportion of birch is increasing in all forest regions, proportion of aspen is very low (0.8% national average) and is continuing to decrease in northern and south-northern regions. The decreasing trend of deciduous-rich forests indicates that despite that the average proportion of deciduous trees may be increasing, there is a reduction of forests with highest habitat quality for species associated with deciduous trees in boreal forests.

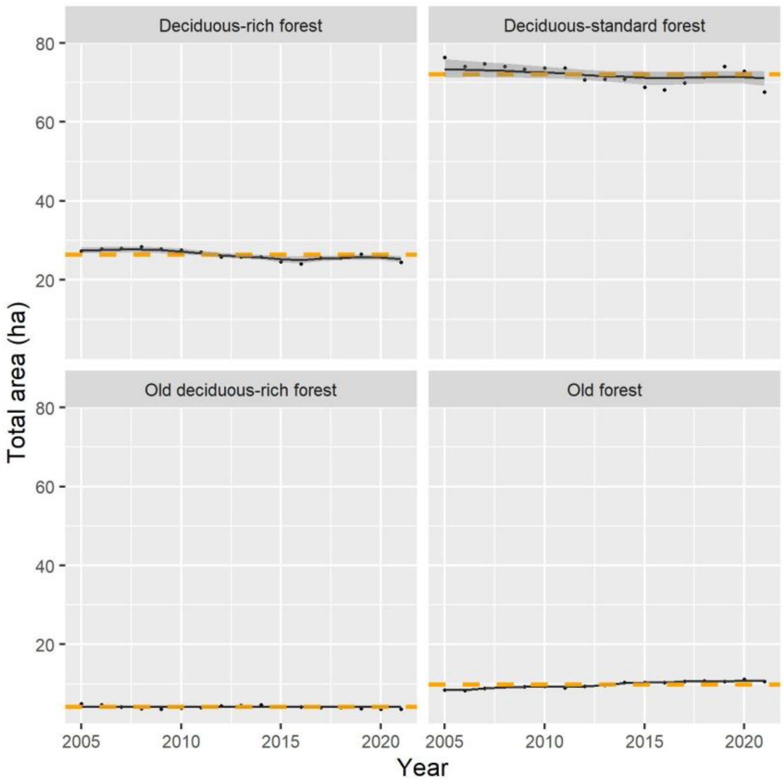


Figure 6. Changes in total habitat amount of old forest (x 1 million ha), deciduous-rich (>30%), deciduous-standard (>10%) forest and older deciduous-rich forest in central Sweden over the last 20 years. The black line shows the total habitat amount over time, during the last 15-20 years. The dashed orange line illustrates the average (mean) habitat amount, and the grey area shows the confidence interval. Confidence intervals that overlap the mean value show that there has been no significant trend, i.e. no change in habitat occurrence.

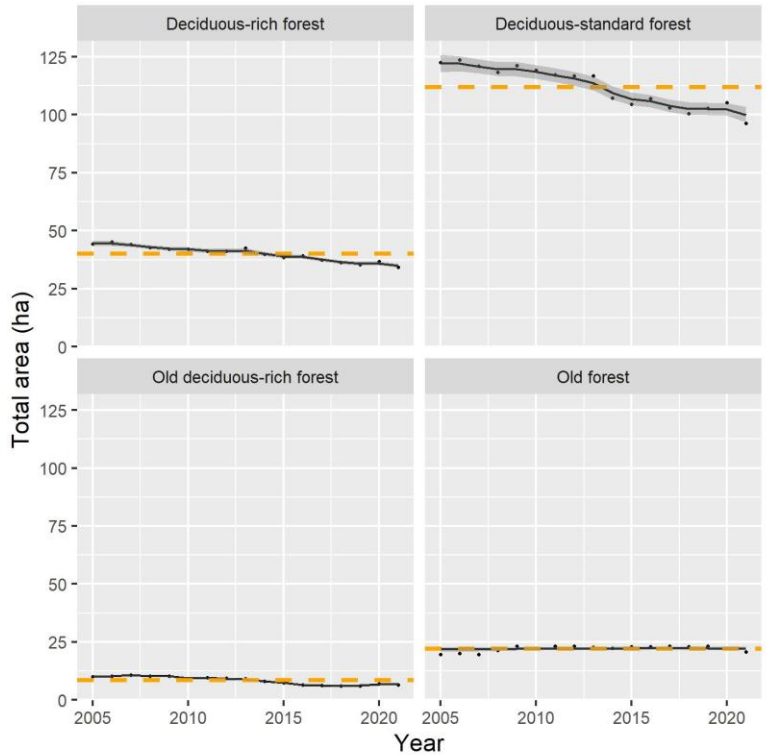


Figure 7. Changes in total habitat amount of old forest (x 1 million ha), deciduous-rich (>30%), deciduous-standard (>10%) forest and older deciduous-rich forest in south-northern Sweden over the last 20 years. The black line shows the total habitat amount over time, during the last 15-20 years. The dashed orange line illustrates the average (mean) habitat amount, and the grey area shows the confidence interval. Confidence intervals that overlap the mean value show that there has been no significant trend, i.e. no change in habitat occurrence.

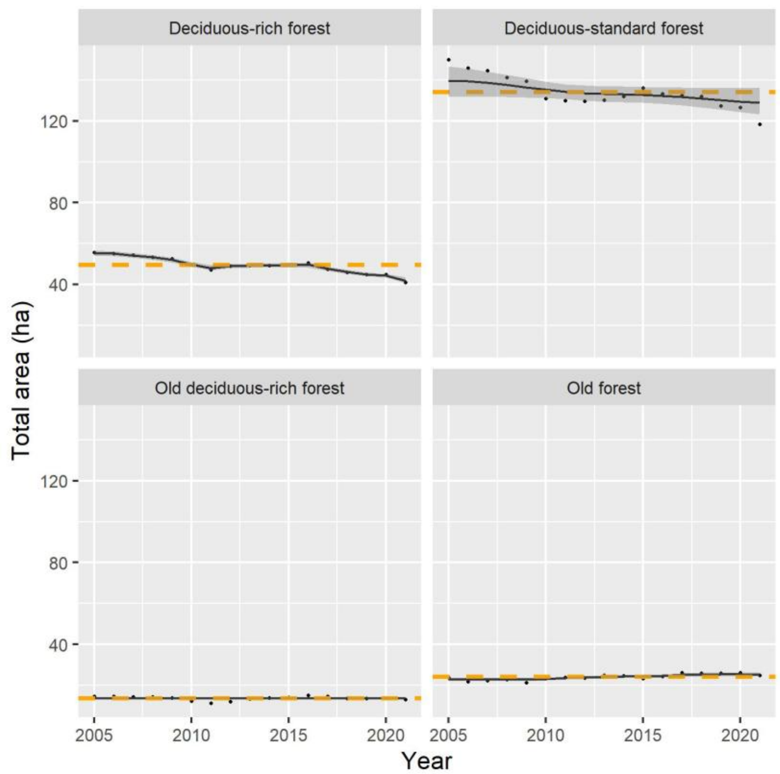


Figure 8. Changes in total habitat amount of old forest (x 1 million ha), deciduous-rich (>30%), deciduous-standard (>10%) forest and older deciduous-rich forest in northern Sweden over the last 20 years. The black line shows the total habitat amount over time, during the last 15-20 years. The dashed orange line illustrates the average (mean) habitat amount, and the grey area shows the confidence interval. Confidence intervals that overlap the mean value show that there has been no significant trend, i.e. no change in habitat occurrence.

The total amount of dead wood shows a clear increase over time. The increase in all regions is primarily due to a rapid increase in hard dead wood, while decayed dead wood is only increasing in central Sweden, relatively stable in the south-northern region and decreasing in the north. National trends align with these results, as only a minor increase and a clear decrease have been reported for the south-northern and northern regions, respectively (Klyaschenko et al. 2022). Decayed dead wood takes longer time to create and accumulate, and it is easily damaged during forestry activities whereupon it loses its quality for many species. Damage from machinery is also a major cause of loss of already existing decayed wood when forests are harvested. Thus, not all fresh wood that is created will remain intact and turn into suitable habitat for dead wood associated species, and increasing the amount of decayed dead wood at large scale takes considerably longer than increasing the amount of hard dead wood. A concerning pattern is the clear observed shift in the trends for dead wood at the last estimated timepoint (2021, calculated by NFI based on data from 2019-2023). It shows that the increase in dead wood appears to have reached a plateau and started to decline again. This might perhaps be attributed to precautionary measures regarding bark beetles, or/and indicate that the limit for how much effort certificate holders are willing to allocate to conservation measures has been reached. In either case, the break of the increasing trends is concerning for dead wood dependent forest biodiversity, as the amounts of dead wood are still below ecologically functional levels (see our main final report).

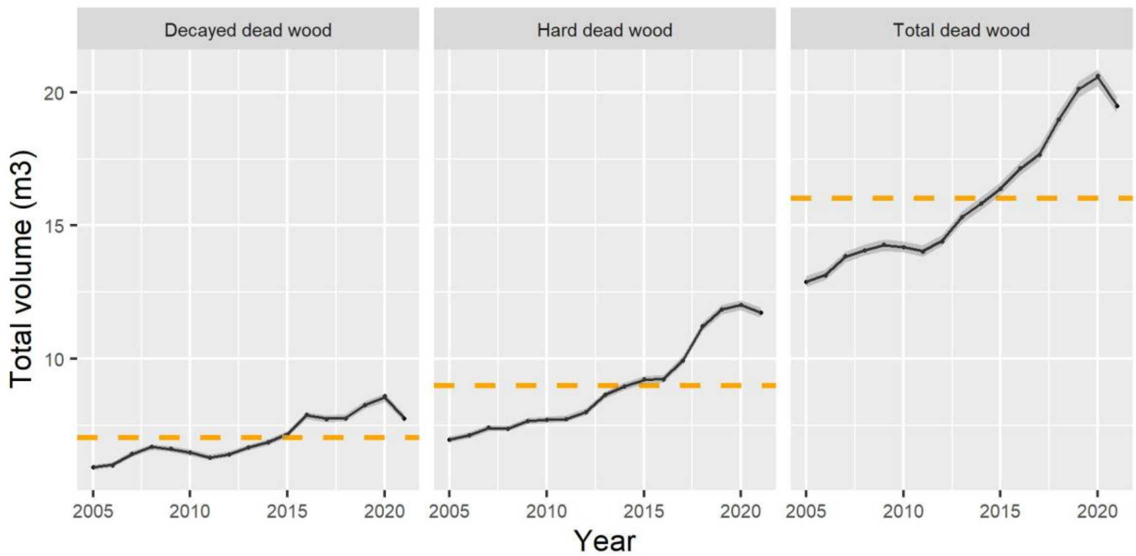


Figure 9. Changes in total volume of dead wood (x100 000ha), hard dead wood and decayed dead wood in central Sweden over the last 20 years. The black line shows the total habitat amount over time, during the last 15-20 years. The dashed orange line illustrates the average (mean) habitat amount, and the grey area shows the confidence interval. Confidence intervals that overlap the mean value show that there has been no significant trend, i.e. no change in habitat occurrence.

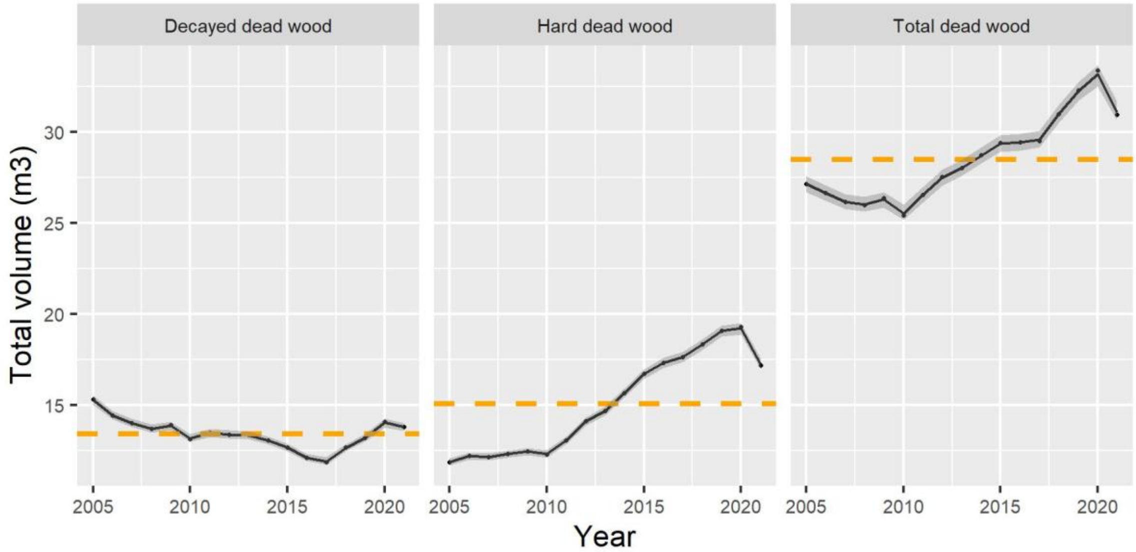


Figure 10. Changes in total volume of dead wood (x100 000ha), hard dead wood and decayed dead wood in south-northern Sweden over the last 20 years. The black line shows the total habitat amount over time, during the last 15-20 years. The dashed orange line illustrates the average (mean) habitat amount, and the grey area shows the confidence interval. Confidence intervals that overlap the mean value show that there has been no significant trend, i.e. no change in habitat occurrence.

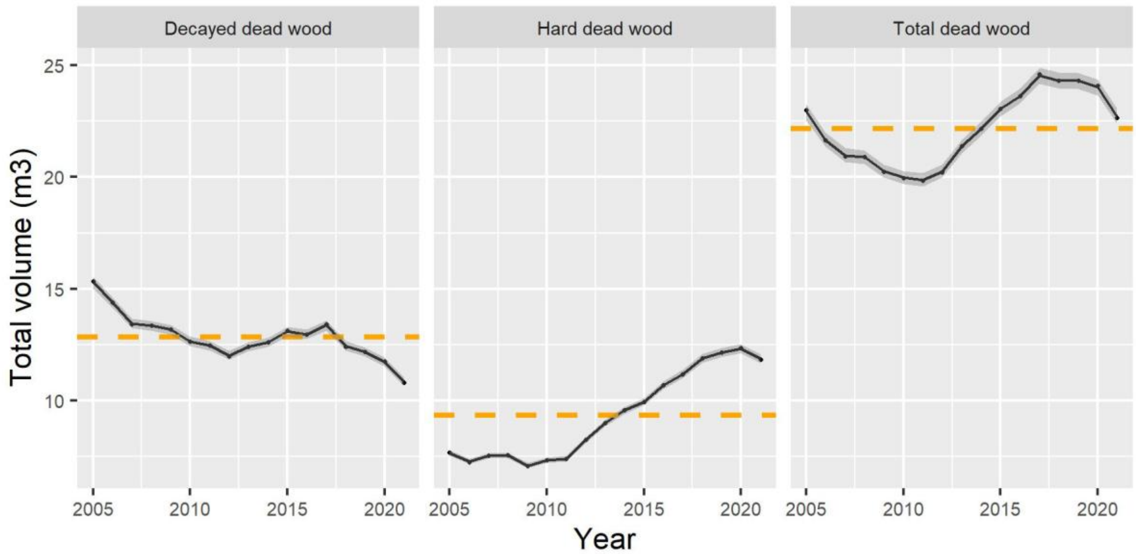


Figure 10. Changes in total volume of dead wood (x100 000ha), hard dead wood and decayed dead wood in northern Sweden over the last 20 years. The black line shows the total habitat amount over time, during the last 15-20 years. The dashed orange line illustrates the average (mean) habitat amount, and the grey area shows the confidence interval. Confidence intervals that overlap the mean value show that there has been no significant trend, i.e. no change in habitat occurrence.

Conclusions

Part 1

- Occurrence of forest species has been largely stable across central and northern Sweden over the last 20 years.
- Some species of wood-decaying fungi show positive increase in probability of occurrence.
- Area of old forest has been stable over time or slightly increasing.
- Area of deciduous-rich forests shows a clear decrease in all regions of central to northern Sweden.
- Volume of dead wood is increasing, but the increase is mainly associated with hard dead wood.
- Decayed dead wood is increasing in central Sweden but shows a decrease in the two northern regions.
- The changes over time in habitats and structures are broadly similar to the national trends, but some differences exist. The area of old forest shows a weaker increase and the decline in deciduous-rich forests is more pronounced

2. Part 2 - correlations between species and habitats

The goal of this analysis was to investigate correlations between the changes in occurrence of species and habitats. The same data as for Part 1 was used for forest species and habitats. Correlations between changes in the amount of habitat and occurrence of species can show that there is an association between the species and the habitat. It can either be a direct association, that the species is dependent of the specific habitat, or an indirect association, meaning that both the species and the habitat are dependent on other factors.

Investigating correlations does not provide a clear answer regarding causality, i.e. whether the habitat changes are causing the change in species occurrence, but they show that there is a significant association between the habitat and the species.

2.1. General methods description

Correlations between habitats and species were analysed using a modelling approach. The same model structure was used as for the species trend analysis described before with some modifications. The outcome of the correlation analysis is an estimated value called β, which describes the effect of habitat type on the species frequency. The value of β shows both the type of relationship (positive or negative association) and the shape of correlation, i.e. how rapidly the species frequency changes when the habitat amount changes. The relationship is positively linear when $\beta=1$; approaching an exponential shape when $\beta>1$; saturated when $0<\beta<1$; and exponentially negative when $\beta<0$ (Figure 11). The correlation is significant if the confidence interval for β does not overlap zero.

2.2. Technical methods and description

To analyse the relationships between habitat type and the estimated frequency of each species (from the Frescalo algorithm), we fitted the same model structure as for the species-trend analysis but introducing two changes: 1) we considered the logarithm of the estimated species frequency instead of the probability itself; and 2) we included the logarithm of habitat type as a variable into the model. This is a log-log model (with temporal dependency as described in Part 1). A log-log model is a powerful statistical model used to analyse trends and patterns within predictive analytics, risk management, trend analysis, and forecasting of future events. It uses the logarithmic transformation for the variables we are interested in investigating their relationship (i.e. habitat type and estimated species frequency) as well as for the model error terms. It improves model accuracy due to its ability to account for non-linear relationships. It improves model stability because the parameters estimate β (i.e. the effect of habitat type over species frequency) is relative rather than absolutes. The interpretation of the log-log model is as follows: 1% increase in habitat type is associated with an average change of β % in species frequency. In short, the relationship is positively linear when $\beta=1$; approaching an exponential shape when $\beta>1$; saturated when $0<\beta<1$; and exponentially negative when $\beta<0$ (Figure 11).

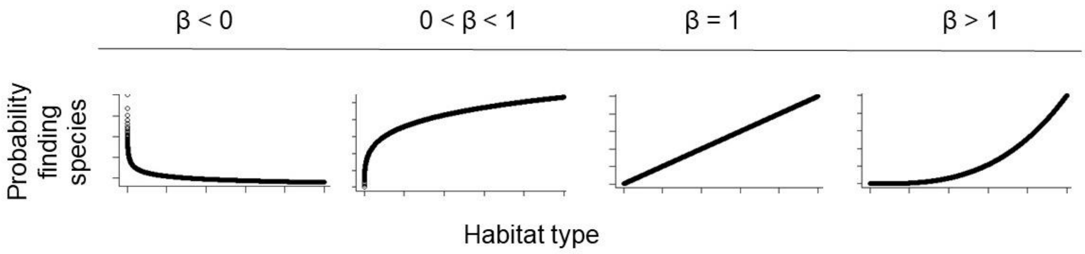


Figure 11. Graphic diagram visualising the association between 1% increase habitat type and the average change of species probability across time, in four different scenarios.

Similarly, as for the trend analysis in Part 1, we used Integrated Nested Lapplace Approximation (INLA) for Bayesian inference (Rue et al. 2009) and the R-package R-INLA (www.r-inla.org) for model execution (Rue et al. 2017, Bakka et al. 2018).

2.2.1 Model interpretation

Let's imagine the case where our model estimates a mean effect β of hard dead wood over the probability of finding *Aromia moschata* in Central Sweden at β=0.76. This means that for a volume increase of 1% on hard dead wood we expect an average increase of 0.76% on the probability of finding our targeted species. If β=-0.76, then the expected change on the probability for a 1% increase on hard dead wood would be a decrease of -0.76%. When β>1 the relationship is positive and the impact of habitat type over species probability becomes larger as its value increases. When 0<β<1 the impact of habitat type becomes smaller as its value increases. And when β=1 there is a 1% to 1% positive (linear) relationship. When β<0 the curve has always the negative concave shape in the diagram, but the drop is smoother when β approaches 0.

The temporal relationships investigated in this study account for long-term relationships, i.e. we analysed the associations between habitat type and species frequency across the whole time period 2003-2021 (the correlation does not reflect year-to-year effects). This means that what the models are trying to capture is how increasing trends on species A would be associated to increasing trends on e.g. old forest. However, most of the species in our study show no significant trends. Hence, if significant relationships are found in these cases, those could probably be pinpointed to specific species annual events having an effect over all time period and the interpretations must be done with care.

2.3. Results and Discussion

2.3.1 General patterns

Significant positive and negative correlations between habitats and species occurrence were observed in all three forest regions. In the central region, the associations were mainly positive, but relatively more negative associations were identified towards the north. All significant correlations for each of the three regions are listed in table 4 and displayed in graphs in Appendix 2.

Table 4. Summary of results for the species-habitat associations; relationship between the 1% increase in habitat type and the average change of species probability across time. The estimated effects (β) are listed in three columns, depending on the type of relationship (value of β <0, 0< β <1, or β >1). The lower and upper 95% confidence intervals are listed in grey. As an example, in south-northern Sweden *Rhodofomes roseus* (NT) was negatively associated with total dead wood (β = - 3,83) and positively associated with old deciduous-rich forest (β = 1,31). Only significant results are included in the table. No significant relationships are identified by habitat type in grey.

Region	Species	Estimated effect (β) and 95% credible interval: β < 0	95% CI		0 < β < 1	95% CI		β > 1	95% CI		Habitat type
Northern Sweden	Semanotus undatus							7,31	3,08	11,54	Old forest
	Callidium coriaceum							7,66	3,45	11,87	Old deciduous-rich forest
	Necydalis major	-3,54	-5,92	-1,16							
	Callidium coriaceum							4,08	1,15	7,02	Deciduous-rich forest
	Phellinidium ferrugineofuscum	-5,37	-10,3	-0,395							
	Phellopilus nigrolimitatus	-6,82	-13,06	-0,59							
	Callidium coriaceum							6,88	3,25	10,51	Deciduous-standard forest
	Climacocystis borealis	-8,89	-16,29	-1,49							
	Phellinidium ferrugineofuscum	-8,46	-15,04	-1,88							
	Phellopilus nigrolimitatus	-10,38	-18,39	-2,37							
	Rhodofomes roseus	-3,92	-6,72	-1,12							
											Total dead wood
											Hard dead wood
	Callidium coriaceum							4,43	2,13	6,72	Decayed dead wood
	Phlebia centrifuga	-2,75	-5,24	-0,26							
	Rhodofomes roseus	-3,49	-5,35	-1,62							
South northern Sweden											Old forest
	Rhodofomes roseus							1,31	0,57	2,05	Old deciduous-rich forest
	Rhodofomes roseus							2,44	0,27	4,61	Deciduous-rich forest
	Cacotemnus thomsoni							7,01	1,66	12,36	
	Nothorhina muricata							7,16	2,58	11,75	
	Rhodofomes roseus							3,01	0,87	5,16	Deciduous-standard forest
	Cacotemnus thomsoni							8,11	2,74	13,48	
	Nothorhina muricata							7,48	1,87	13,10	
	Rhodofomes roseus	-3,83	-5,63	-2,04							Total dead wood
	Cacotemnus thomsoni	-5,79	-11,30	-0,27							
	Nothorhina muricata	-5,72	-10,52	-0,92							
	Rhodofomes roseus	-1,73	-2,55	-0,92							Hard dead wood
	Nothorhina muricata	-2,44	-4,66	-0,22							
											Decayed dead wood
Central Sweden	Phellinidium ferrugineofuscum							2,78	0,39	5,17	Old forest
	Nothorhina muricata							3,27	1,26	5,28	
	Aromia moschata							2,22	0,66	3,78	
	Phellinidium ferrugineofuscum	-2,73	-5,09	-0,38							Old deciduous-rich forest
	Phlebia centrifuga	-2,87	-5,67	-0,07							
	Cacotemnus thomsoni							4,77	0,21	9,34	
	Necydalis major							2,96	0,63	5,29	
	Aromia moschata	-3,05	-5,87	-0,22							Deciduous-rich forest
											Deciduous-standard forest
	Phellinidium ferrugineofuscum							2,38	1,32	3,44	Total dead wood
	Nothorhina muricata							1,47	0,33	2,60	
	Aromia moschata				0,96	0,09	1,83				
	Phellinidium ferrugineofuscum							1,93	1,07	2,79	Hard dead wood
	Phlebia centrifuga							1,39	0,01	2,78	
	Nothorhina muricata							1,17	0,28	2,05	
	Aromia moschata				0,76	0,05	1,47				
	Phellinidium ferrugineofuscum							3,02	1,47	4,58	Decayed dead wood
	Cacotemnus thomsoni	-4,07	-7,40	-0,74							
	Nothorhina muricata							1,94	0,26	3,63	
	Aromia moschata							1,41	0,19	2,64	

In central Sweden, several species showed positive correlations with old forest and dead wood. The polypore fungus *Phellinidium ferruginofuscum* (NT) and beetle *Aromia moschata* were the species with highest number of significant associations that were positively associated with all dead wood habitats and old forest, while negatively associated with old deciduous-rich forests.

In the south-northern region, three species species showed significant positive relationships with all old- and deciduous forest habitats and negative relationships with dead wood. The species were the fungus *Rhodofomes roseus* (NT), and beetles *Cacotemnus thompsoni* and *Nothorhina muricata* (NT), and all of them showed similar response to the habitat factors.

In the northern region, positive associations between old forest or different types of deciduous-rich forests were found for wood-boring beetles *Callidium correaceum* and *Semanotus undatus*. *Callidium coreaceum* lives in dead spruce and can use rather small standing trees in swampy forests. The association indicates that deciduous-rich forests have some qualities that also provide good spruce habitats for the species. Wet forest areas tend to be more deciduous-rich and have abundance of small-size dead wood; this may better reflect the habitat availability for the species than estimated dead wood amount. Negative associations with dead wood habitats were observed for several species of wood-dependent fungi and beetles: 7 negative correlations in total.

2.3.2 Focus species

Significant associations were observed for some of the focus species selected in the previous report. Since the analysis is only correlative, definite conclusions cannot be drawn regarding the cause and effect of the significant associations. Below, we offer some potential explanations based on the biology of species and characteristics of the different habitats.

Occurrence of the flowering plant, *Pulsatilla vernalis (EN)* has a stable occurrence trend. The species depends on open, usually pine forests on sandy soils. The species did not show any significant associations with habitats or structures, probably because the analyzed factors do not capture the specific habitat conditions needed by the species. Open pine forests with limited ground vegetation are a rare and declining habitat type, and targeted conservation actions like prescribed burning are being used to promote *Pulsatilla vernalis* in certified forests.

The longhorn beetle, *Nothorhina muricata* (NT) has a stable occurrence trend in all forest regions and showed significant positive associations with old forests and dead wood in the central region. In south-northern region it was negatively associated with dead wood, but positively with deciduous-rich and deciduous-standard forests. As *N. muricata* depends on old, living, and sun-exposed pine trees, the correlation with dead wood does not indicate a direct association. In managed forests, most of the dead wood is created during harvesting when also tree retention is implemented, meaning the dead wood creation and tree retention are likely positively correlated. Suitable habitat for the species is created when large pine trees are retained and perhaps this is reflected in the association with dead wood. Pine trees in forests with deciduous trees are more sun exposed, which also benefits *N. muricata.* In the south-northern region where negative association with dead wood was observed, the occurrence of species is quite limited and declines slightly, which could cause a negative correlation.

The dead wood dependent beetle, *Necydalis major* that has a stable occurrence was positively associated with old deciduous-rich forests in the central region. The species depends on dead wood of deciduous trees in open forests and has its main occurrence in central Sweden. This relationship appears rather straight forward and shows that retaining old deciduous trees and dead wood is positive for maintaining the species occurrence in managed forests. The habitat type old deciduous-rich forests have become rare and is still decreasing in the region. Also, the species' occurrence shows a weak tendency for decline, even if not significant, which means that protecting the remaining habitats is highly important for maintaining the species.

The beetle, *Microbregma emarginatum,* has a stable occurrence with a weak tendency to increase in the central region. The species depends on old, coarse living spruce trees and benefits from old spruce forest set asides. The species did not show any significant associations with habitats or structures, even though old forest was included in the analysis. This might indicate that the size or age of spruce trees in old production forest set asides does not yet fully meet species requirements and it relies more on large spruce trees in protected areas.

The polypore fungus, *Phellinus populicola,* grows on large living aspen trees and requires forest with high abundance of aspen. The species shows stable occurrence trends in all regions. The species did not show any significant associations with habitats or structures, probably because aspen only makes up a small proportion of deciduous trees in boreal forests, and the deciduous-rich forests contain mostly birch. Therefore, monitoring data on occurrence of large aspen would be needed to estimate habitat availability for this species.

The polypore fungus, *Rhodofomes roseus (NT)* shows a stable occurrence with a temporal positive peak around 2010 in south-northern region. The species was positively associated with all types of deciduous-rich forest habitats in the south-northern region, but negatively with deciduous-standard forests in the north. The occurrence of the species was also negatively correlated with dead wood in the south-northern region. *R. roseus* grows on freshly dead spruce in natural-like forests and at least the older deciduous-rich forests may also contain suitable dead spruce trees for the species. The dominant conifer species, spruce or pine, in deciduous-rich forests in different regions might also affect whether the association with deciduous-rich forests is positive or negative. The negative correlation with dead wood seems to only reflect a short temporal positive peak in species occurrence around years 2009-2011, which coincides with a temporary dip in dead wood occurrence.

2.3.3 Interpretation of correlation patterns

Correlation with dead wood might be expected to be positive for dead wood dependent species, but several negative correlations were observed in this analysis. In addition to the associations described for the focus species, significant negative correlations were observed for many dead wood dependent species in the south-northern Sweden. It is, however, not unusual to find negative correlations between species and their preferred habitats. One known explanation for such patterns is the dilution effect, when the habitat amount is increasing rapidly, but the species populations cannot match that increase due to e.g., dispersal limitations or poor landscape connectivity. This also means that the occurrences of the species can become harder to detect when a large proportion of available habitat is unoccupied. An additional factor to consider is that the habitat that is created might not have sufficient quality for the species; therefore, while the total habitat amount is apparently increasing, it does not reflect the habitat quality or diversity; thus, the amount of *suitable* habitat might actually be decreasing.

Significant correlations can sometimes emerge for species or habitats without an overall time trend from temporal changes in occurrence, e.g. specific peaks in abundance. Several species displayed a temporary increase in occurrence during 2009-2011, which was particularly pronounced in the south-northern region. During the same approximate time, a decrease was apparent in the trend for total dead wood. These co-occurring opposite shifts are most likely responsible for several significant negative correlations observed.

It would be particularly interesting if there was an ecological explanation for this pattern. One possibility could be that following two major storms in southern and central Sweden in 2005 and 2007 with large amounts of damaged forests, the risk of bark beetle outbreaks increased substantially. Extra efforts were made to remove dead and damaged trees from the forests to minimize risks for outbreaks. Even though these storms affected mainly the southern part of the country, the effects in terms of precautionary management and removal of dead wood might have spread further north. Bark beetles pose increasing risks to spruce trees nationally and the forestry sector has become more restrictive in retaining large amounts of dead wood. This could perhaps explain the dip in the dead wood amount. The fact that this is matched by an increase in probability to find species, specifically several wood-dependent fungi, is surprising. It has been suggested that the spread of spores of wood-dependent fungi is facilitated by bark beetles. Increased dispersal in combination with reduced amount of habitat could lead to a concentration effect (as opposed to dilution effect) and subsequently lead to a higher probability that the species are observed. This explanation is plausible but also speculative and should be evaluated scientifically.

Conclusions

Part 2

- Significant associations exist between many of the studied forest species and habitats
- In the central region, mostly positive associations are present, which means that species are responding to positive changes in occurrence of old forest and dead wood habitats
- In the south-northern region, positive associations were present for old and deciduous-rich forests, but negative associations for dead wood. A matching temporary peak in species abundance and decline in dead wood is likely creating the negative association.
- In the northern region, many associations were significantly negative indicating that species patterns and habitat patterns over time show opposite trends. Most of the habitat types are declining in the region, like deciduous-rich forests, while species occurrence so far remains stable, which could explain the negative associations.

3. Part 3 – Spatial distribution of habitats and structures

To better understand how spatial variation in habitat amount relates to spatial occurrence patterns of species, we mapped the habitats based on NFI data for each one of the Swedish municipalities in northern, south northern, and central Sweden.

3.1. Data and Methods

The data were obtained from NFI sample plots within the studied FSC certified forest area for the time period of 2003-2021 and mapped at municipality level since the spatial positions of the sample plots cannot be obtained. For each municipality, we calculated the proportion of each forest type (old, old deciduous-rich, deciduous-rich, and deciduous-standard forests) in relation to the total area of productive forest (% ha). Similarly, we calculated the volume of total-, hard- and decayed- dead wood in relation to the total number of hectares of productive forest within each municipality (m^3/ha). The entire municipality was assigned the average habitat value in the maps, but the data only came from the parts of municipality that were within the study area. The number of sample plots varied per municipality (Appendix 1).

3.2. Results and Discussion

The results show that the area of old forest and older deciduous-rich forest are highest in the north-western part of Sweden, mainly within the south-northern study region. Deciduous-rich forests were also abundant in the north-west, but they are also present in other parts, like along the northern coastline and central Sweden. Quite similar patterns were observed for dead wood.

The area with highest concentration of valuable habitats, both dead wood and old forests, includes sub-alpine forests above nature conservation boundary applied by the FSC forest management standard for delineation of intact forest landscapes (HCV2). These areas are known to contain the last remaining large natural forest landscapes in Sweden. Forest management and harvesting does occur in these areas, and the pressure for increased harvesting has increased during the last years. This is perhaps indicated by lower levels of habitat values in the northern region, and declining habitat trends in this region (see part 1).

FSC forest management standard has targets for proportion of old forest (5%) and the proportion of deciduous trees in boreal forests (10%). While up to 30% old forests are present in the sub-alpine area, this area includes forests with limited forestry activities; meanwhile for most of the remaining studied forest area the proportion of old forest lies between 0-5%. Our results show that for the studied forest area, in most municipalities about 30-75% of the forests have at least 10% deciduous trees (Figure 13).

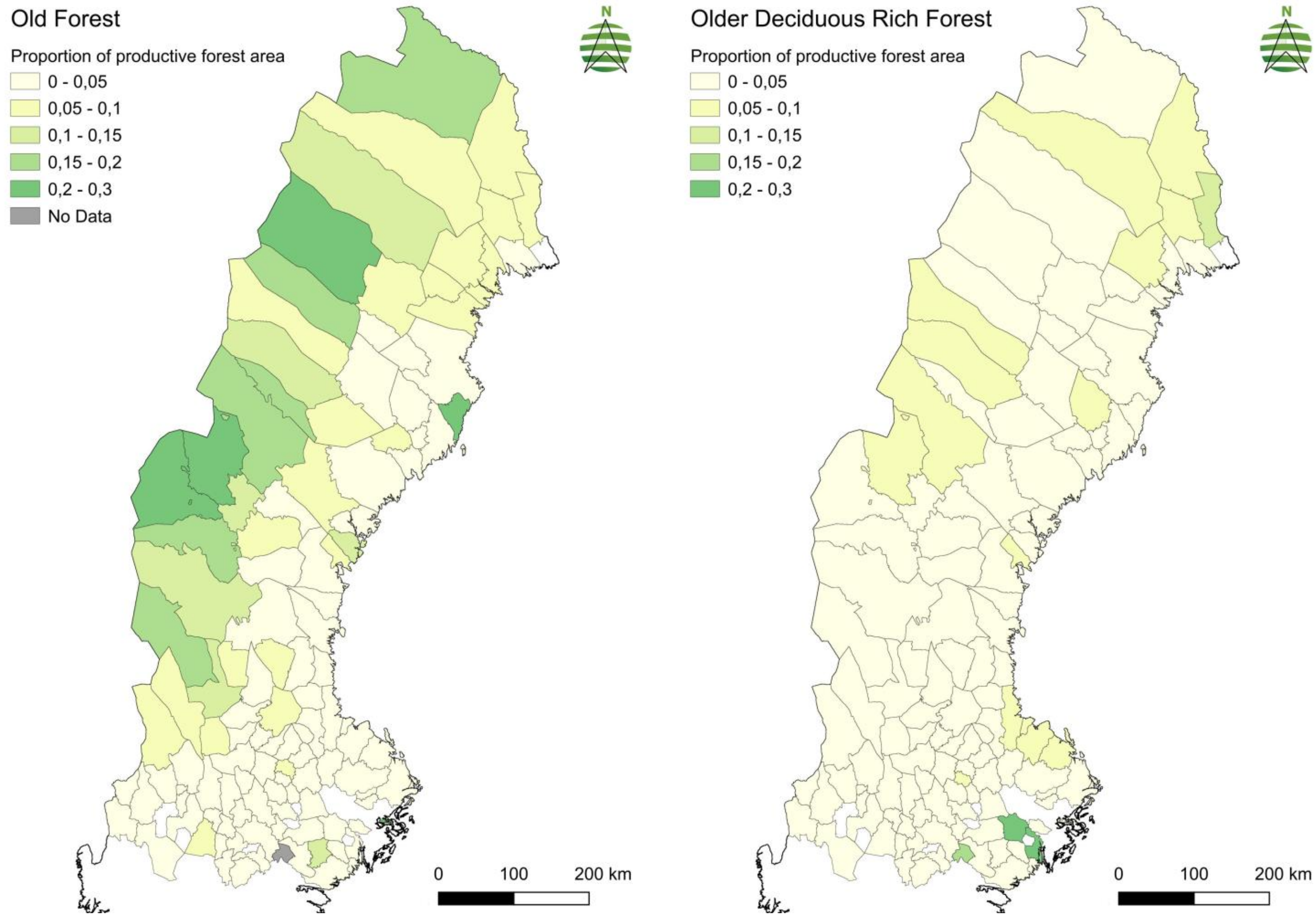
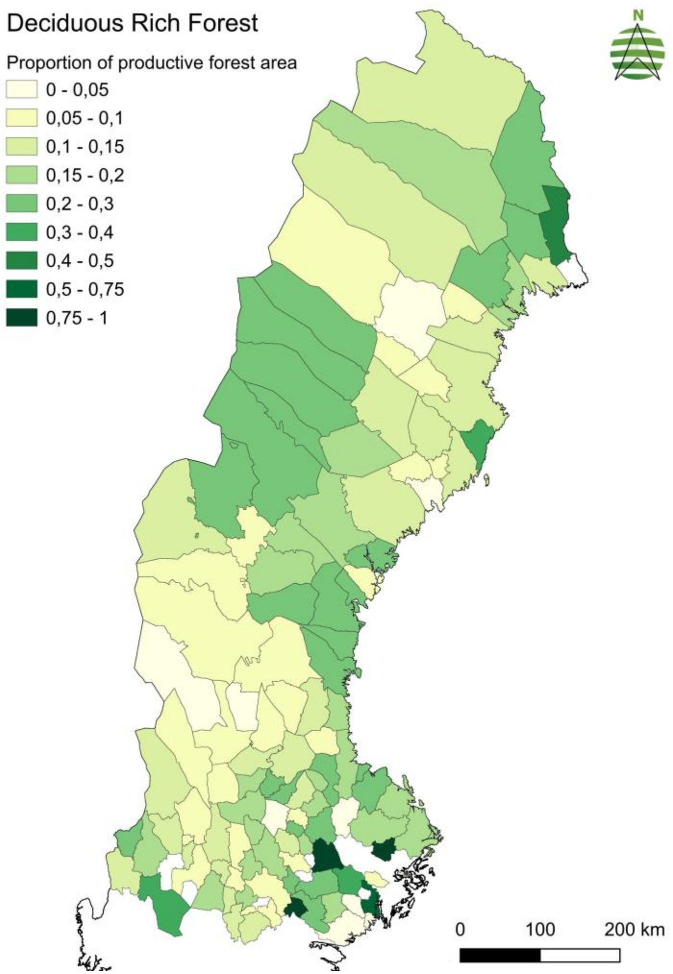


Figure 12. Spatial distribution of proportion old forest and older deciduous-rich forest, displayed per municipality. The data were obtained from NFI and summarised based on the number of sample plots within the study area with certified forests; therefore, the values do not represent the entire area of each municipality (Appendix 1, Table 4).



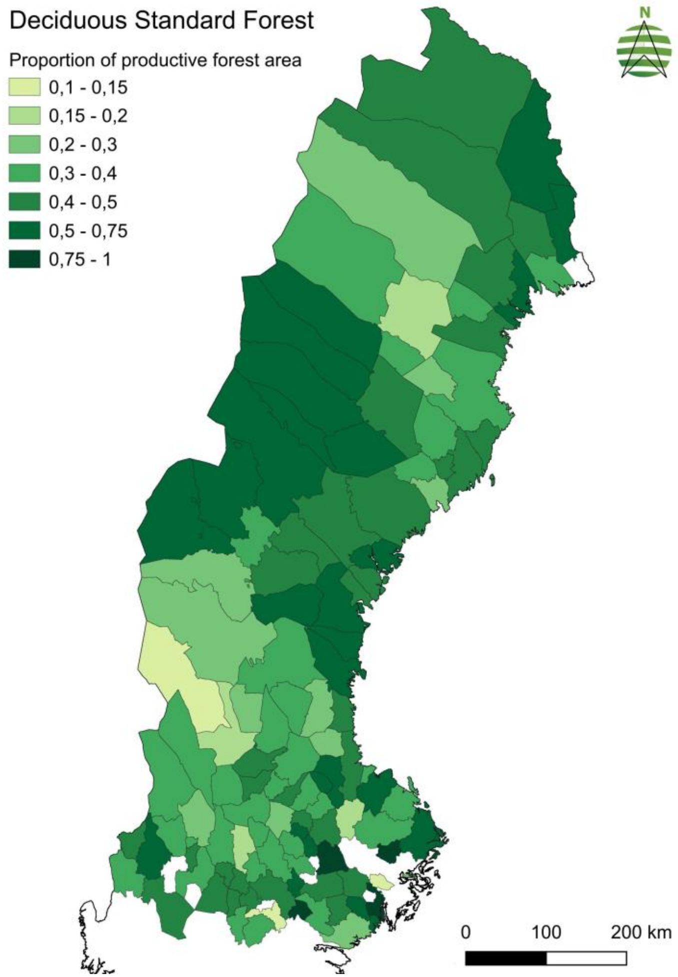


Figure 13. Spatial distribution of proportion deciduous-rich forest (>30%) and deciduous-standard (>10%) forest, displayed per municipality. The data were obtained from NFI and summarised based on the number of sample plots within the study area with certified forests; therefore, the values do not represent the entire area of each municipality (Appendix 1, Table 4).

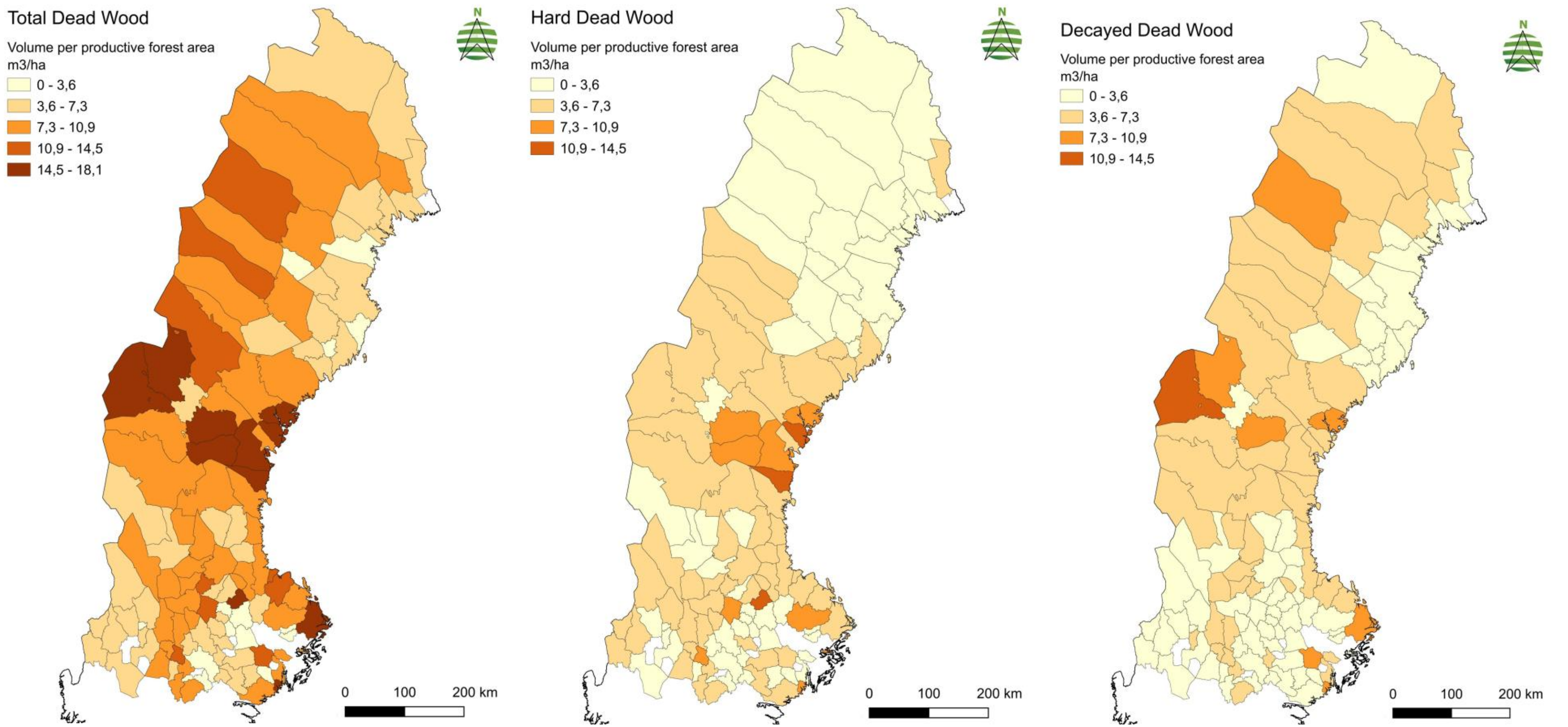


Figure 14. Spatial distribution of proportion deciduous-rich forest (>30%) and deciduous-standard (>10%) forest, displayed per municipality. The data were obtained from NFI and summarised based on the number of sample plots within the study area with certified forests; therefore, the values do not represent the entire area of each municipality (Appendix 1, Table 4).

Conclusions

Part 3

- Abundance of the assessed habitat types varies across the forest regions
- Higher proportions of old forests are observed in the sub-alpine areas of Sweden, especially in the south-central study region.
- The amount of dead wood was also high in sub-alpine areas, but also in certain areas near the coast and in central Sweden.
- Deciduous-rich and deciduous-standard forests have high-abundance areas in all forest regions.

Final conclusions

The occurrence of species is maintained in FSC certified managed forests.

Analyses of forest indicator and red-listed species occurrence in FSC certified forests show that the probability to find the species has been stable over the last 15-20 years. Some species of wood-decaying fungi show positive regional increase in probability of occurrence and a few additional species show short temporary increases. That the distributions of species have been maintained indicates that structures and habitats that are retained or created in certified forests, like dead wood, retention trees, set asides and prescribed burning, have contributed to providing habitats and supporting occurrences of these species over time.

The occurrence of habitats varies between regions

Analyses of habitat occurrence over time shows positive developments for some important habitats but negative for others. The area of old forests has been stable over time or slightly increasing, while old deciduous-rich forests have mainly remained stable. In contrast, deciduous-rich and deciduous standard forests have high-abundance areas in all forest regions, but the total area is nevertheless decreasing. Even though most areas currently have rather large proportion of forest that meets the target of the FSC standard (≥10% deciduous trees), a continued decrease in this habitat may have negative consequences for biodiversity. The volume of dead wood has a positive trend for hard wood while decayed wood is declining in all but the central region.

In summary, most positive developments in habitat occurrence were observed for the region of central Sweden, while several trends were negative in the north. These changes over time in habitats and structures are broadly similar to the national trends, which also show a higher relative improvements in the central and southern parts of Sweden. There appears to be a potentially concerning break in the positive trends for dead wood during the last survey years, which might suggest that a plateau has been reached for how much investment in biodiversity conservation certificate holders are willing to allocate, or that dead wood is removed to a higher extent to control bark beetle outbreaks.

Species and habitats are connected but the associations are complex

There are both positive and negative significant associations between the analysed forest species and habitats. Positive associations dominate in the central region, while increasingly more associations are negative towards the north. Many correlations can be interpreted directly, such as species dependent on deciduous wood is positively associated with deciduous-rich forests, or species dependent on living trees negatively associated with dead wood. Other correlations cannot be explained directly but are likely due to unknown indirect associations. Some of the negative associations appear to be linked to a temporary decrease in dead wood and a simultaneous increase in species occurrence, which could potentially be attributed to increased risks of bark beetle damage and control measures implemented by certificate holders, but this explanation is has not been scientifically evaluated. Understanding the causation of significant relationships can be complex and cannot be determined by correlative analyses. In the northern region, several species-habitat associations were negative as many habitat types are declining in the region, while species occurrence so far remains stable. This can be due to time lags in species response and shows that it is important to turn around the negative habitat trends in order to avoid loss of species occurrences in the region in the future.

Implications for FSC

The goal of this project has been to increase the understanding of FSC contribution to biodiversity conservation, via evaluation of the monitoring principle, and analyses of biodiversity data from certified forests. The present species and habitats analyses are a quantitative complement to the qualitative evaluation presented in the main report. The analyses provide insights on the changes that have occurred in the Swedish forests during time when FSC FM certification has been implemented at a large scale.

FSC requirements target specific structural forest qualities that are known to be important for biodiversity. A commitment by certificate holders (CH) to either maintain certain levels or work towards a positive development of these qualities over time is central to successful implementation of the standard requirements and to achieving ecological sustainability. However, species and habitats are influenced by multiple factors, which means that evaluating what benefits for biodiversity have been achieved can be complex.

The species and habitat analyses focus on the changes in occurrence over time. Evaluating a long time period can provide some answers on the success of the long-term commitments by CH towards improved conditions for biodiversity. For instance, the estimated time trends show that the overall development for dead wood has been positive but may have levelled off during the recent years. This suggests that, despite positive developments, active engagement from CHs is still needed to ensure that the positive changes are persistent and continue towards ecologically sustainable levels.

The old forest area has been either stable or increasing, but the positive development in the analysed certified forests appears to be slower than the national trend for the boreal region. Old and old-growth forests are often set aside by CH, and the FSC FM standard requires 5% of the forest area to be set aside for conservation. The distribution of old forests shows that the old forest proportion lies below 5% in certified forests in many municipalities, which again suggests that even though positive changes are occurring, more effort is needed to fully achieve the target. Alternatively, it could suggest that the set asides are unevenly distributed in the landscape and concentrated towards the north-western sub-alpine forest areas where forestry activities are more limited.

The habitat type for which no positive development was observed was deciduous-rich forests. Specific requirements regarding proportion of deciduous trees in boreal forests exist in the FSC FM standard, with a target of 10%. The habitat distribution map suggests that many forests already meet this target, even though areas where most forests are below the threshold also exist. However, the time trend for this habitat type is either stable or decreasing, which means that long-term improvements are currently not being achieved. For the higher quality thresholds (older deciduous-rich forests and forests with >30% deciduous trees), the habitat availability and change over time show mainly negative patterns. This illustrates that creating and maintaining high-quality habitats for species associated with deciduous trees in certified forests is challenging and more active efforts may be needed.

Both habitat and species trends were relatively more positive in the central region, which has historically been more affected by forestry. These patterns show that implementing environmental consideration during forest management, e.g. via FSC FM standard requirements, in landscapes dominated by managed forests, has positive effects on the availability of important habitats for biodiversity, which in turn are positively correlated to occurrence of forest indicator species. In contrast, in landscapes that undergo transformation from natural to planted and managed forests, the currently implemented levels of consideration may still lead to a net loss of high-quality habitats for forest biodiversity, and the relationships between species and their habitats become more disconnected, e.g. species that can still be found despite their habitats decreasing. The negative habitat changes were most pronounced in the south-northern region of Sweden, while negative correlations between species and habitats were most pronounced in the northern region. To conclude, implementation of FSC standard requirements have some positive effects on occurrence of habitats and structures important for biodiversity. The effect is, however, dependent on the regional context: improvements are easier to achieve in landscapes that have previously been degraded by forestry, whereas in landscapes with relatively more natural forests habitat maintenance or improvement is clearly more difficult to achieve with current implementation of standard requirements.

It is important to consider that the analyses and results presented in this report are based on a sample and not a full extent of FSC certified forest areas. The habitat data and trends are also based on a sample of NFI survey plots which were located within the selected certified forest areas, and do not represent the total values for the entire region. The certified forests of southern Sweden could not be analysed due to many small forest owners for which geographical data were not accessible. Thus, even though we consider the present analyses to be broadly representative for the forest regions of central to northern Sweden, access to fully mapped FSC certified forests across the country would improve the geographical range and enable more comprehensive analyses in the future.

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Appendix 1. Sample sizes for habitat estimates

Table 4. Sample size (number of NFI plots) for estimations of average habitat values for municipality-based spatial distribution maps, for each of the three study regions: northern = Norra Norrland, south-northern = Södra Norrland, and central = Svealand.

Sample size for estimations of average habitat values for municipality-based spatial distribution maps																		
Number of NFI sample plots		**Year**																
Region	**Municipality**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Norra Norrland		**3 186**	**3 211**	**3 260**	**3 258**	**3 225**	**3 145**	**3 163**	**3 169**	**3 279**	**3 408**	**3 526**	**3 495**	**3 520**	**3 379**	**3 253**	**3 192**	**2 937**
	Nordmaling	24	24	25	21	21	21	33	34	43	43	43	35	33	24	32	36	32
	Bjurholm	74	61	51	55	55	47	60	76	85	88	95	82	77	64	55	49	49
	Vindeln	148	146	150	137	147	132	145	144	156	141	172	165	157	153	169	161	155
	Robertsfors	27	27	19	7	7	7	7	6	18	21	21	30	40	28	25	27	18
	Norsjö	85	105	99	95	106	109	97	112	121	102	106	99	97	90	100	100	100
	Malå	46	61	56	56	53	47	39	44	46	48	46	39	42	39	40	42	42
	Storuman	96	105	103	145	129	122	114	104	76	103	121	125	145	147	139	122	106
	Sorsele	100	107	117	95	81	100	105	99	100	112	108	96	102	107	98	80	79
	Dorotea	62	70	67	56	47	51	66	79	77	85	81	69	57	61	53	53	43
	Vännäs	10	10	10	2	2	2	2	2	2	2	11	12	12	12	12	3	2
	Vilhelmina	114	91	82	87	99	112	112	122	120	114	94	108	105	101	100	98	90
	Åsele	141	158	167	185	193	176	158	160	142	167	185	192	190	193	169	157	147
	Umeå	50	51	56	73	74	72	74	72	61	65	57	55	52	60	56	60	59
	Lycksele	197	212	224	224	220	188	175	185	185	208	232	232	220	219	212	217	203
	Skellefteå	197	172	170	179	158	152	159	150	181	206	211	209	221	187	154	172	169
	Arvidsjaur	249	240	212	209	192	176	169	196	191	203	225	247	232	238	236	232	207
	Arjeplog	95	84	84	81	69	72	78	91	112	107	98	115	123	113	111	122	100
	Jokkmokk	173	165	176	186	189	187	194	198	214	227	224	220	229	208	197	184	166
	Överkalix	141	140	143	142	183	185	178	183	184	166	170	152	130	142	137	132	122
	Kalix	68	68	63	50	35	42	62	68	68	62	66	47	41	41	41	47	47
	Övertorneå	80	72	72	71	76	58	70	69	61	69	67	58	61	59	49	51	47
	Pajala	228	249	259	245	221	207	194	180	205	226	246	229	240	235	236	240	229
	Gällivare	240	246	275	248	247	240	238	211	198	192	205	209	206	221	211	213	197
	Älvsbyn	120	111	133	134	124	122	142	131	137	138	151	140	146	129	148	150	140
	Luleå	27	26	28	33	39	41	47	47	42	37	35	34	21	21	20	22	17
	Piteå	128	126	130	130	149	153	150	147	184	184	181	178	191	168	150	140	133
	Boden	221	237	240	262	270	279	250	223	223	232	219	250	268	247	227	207	176
	Kiruna	45	47	49	50	39	45	45	36	47	60	56	68	82	72	76	75	62
Södra Norrland		**3 392**	**3 452**	**3 424**	**3 349**	**3 403**	**3 419**	**3 441**	**3 392**	**3 514**	**3 457**	**3 456**	**3 397**	**3 372**	**3 347**	**3 334**	**3 298**	**3 004**
	Ockelbo	20	15	15	15	8	21	21	21	42	41	28	28	28	6	6	15	15
	Hofors	19	19	29	29	29	25	30	20	20	20	20	16	16	16	16	23	23
	Ovanåker	122	133	148	138	148	137	145	115	109	91	109	99	97	119	117	115	106
	Nordanstig	64	74	62	79	89	109	99	109	93	74	57	57	55	44	38	44	44
	Ljusdal	277	288	334	310	310	280	278	250	230	245	274	266	274	289	274	254	247
	Gävle	75	71	80	72	93	100	121	111	111	95	85	70	79	88	83	81	71
	Sandviken	43	43	74	65	56	45	47	16	16	16	16	15	15	15	15	15	14
	Söderhamn	33	28	38	37	48	51	69	60	63	54	53	50	49	46	46	53	38
	Bollnäs	48	48	48	50	32	35	35	36	34	34	35	44	61	61	61	59	50
	Hudiksvall	137	125	89	84	88	96	104	119	134	139	133	145	137	129	141	138	113
	Ånge	189	162	194	187	172	182	208	180	204	196	188	172	172	149	151	166	152
	Timrå	47	58	56	46	46	37	41	33	33	33	33	18	20	20	21	21	21
	Härnösand	27	27	27	27	27	27	27	32	50	50	50	50	55	45	45	45	45
	Sundsvall	90	119	108	111	121	143	108	114	117	96	98	115	107	118	121	122	107
	Kramfors	15	18	20	20	40	42	39	42	43	25	24	34	29	33	31	31	21
	Sollefteå	318	333	276	287	308	328	338	356	363	337	322	288	291	306	303	293	276
	Örnsköldsvik	331	297	302	311	333	341	332	349	337	333	320	336	305	302	291	300	280
	Ragunda	161	162	145	130	105	104	105	107	128	129	120	122	126	135	156	163	156
	Bräcke	185	205	208	185	178	157	128	134	158	180	206	211	196	189	202	195	180
	Krokom	63	58	58	54	61	52	48	50	48	47	47	52	50	53	57	57	54
	Strömsund	474	518	483	492	500	464	447	447	437	454	480	454	455	459	431	417	380
	Åre	29	26	33	34	33	24	41	39	39	48	61	46	41	44	37	40	38
	Berg	176	166	142	152	153	154	169	195	202	201	191	192	180	172	184	186	170
	Härjedalen	424	447	443	422	414	450	446	443	480	487	477	480	489	470	472	436	382
	Östersund	25	12	12	12	11	15	15	14	23	32	29	37	45	39	35	29	21

Number of NFI sample plots		Year																
Region	**Municipality**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Svealand		**3 580**	**3 487**	**3 426**	**3 387**	**3 379**	**3 355**	**3 439**	**3 461**	**3 575**	**3 612**	**3 665**	**3 639**	**3 645**	**3 541**	**3 509**	**3 409**	**3 112**
	Ekerö	9	12	9	10	7	7	4	4	3	3	3	3	3	3	3	2	2
	Södertälje	7	7	7	7	7	7	7	14	14	14	14	18	11	10	10	10	6
	Vaxholm	2	2										2	2	2	2	2	
	Norrtälje	32	32	26	26	28	28	27	27	27	30	30	30	30	30	25	25	23
	Sigtuna	1	1	1	1	1												
	Älvkarleby	15	16	16	16	16	15	15	15	16	16	28	28	28	28	28	18	18
	Knivsta	7	1	1	1													
	Heby	14	14	14	14	15	12	12	12	12	12	12	15	15	15	17	17	14
	Tierp	60	58	62	61	60	60	67	59	59	65	62	59	64	73	67	71	62
	Uppsala	51	55	67	65	61	65	62	50	48	48	46	49	49	50	60	57	53
	Östhammar	55	49	42	36	33	38	44	51	55	52	50	44	48	52	58	69	63
	Vingåker	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Gnesta	5	5	1	1													
	Nyköping	23	24	24	30	33	36	37	37	32	37	30	28	28	37	32	32	32
	Flen	19	13	7	11	10	10	11	11	7	7	7	6	10	10	10	10	10
	Katrineholm	8	8	8	8	8	8	8	8	8	8	8	8	13	13	13	13	13
	Eskilstuna			5	11	11	11	11	11	5	5	5	6	2	8	8	8	7
	Strängnäs	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	Trosa	1	1	1	6	6	6	13	13	8	8	8	6	6	6	6	6	1
	Eda	45	51	38	45	45	55	42	51	44	45	35	41	41	50	50	50	46
	Torsby	361	339	314	279	274	256	284	283	343	346	339	329	339	306	318	304	287
	Storfors	32	24	24	19	11	11	12	19	19	19	19	19	12	19	28	28	24
	Munkfors	8	9	19	19	28	31	33	23	23	24	21	28	28	28	18	23	13
	Forshaga	14	24	24	43	43	43	33	33	23	23	23	23	29	23	23	23	23
	Årjäng	71	64	56	56	50	50	50	52	52	46	56	64	50	50	50	40	32
	Sunne	65	50	55	55	76	75	70	79	81	69	81	77	70	79	68	78	78
	Karlstad	35	29	29	29	33	28	28	27	45	41	41	47	48	30	30	30	24
	Kristinehamn	30	30	27	16	11	11	11	19	26	30	30	30	37	30	27	31	31
	Filipstad	196	189	191	191	178	180	195	185	207	211	184	154	174	188	192	190	190
	Hagfors	248	258	273	265	261	256	232	237	223	238	257	283	260	257	244	239	204
	Arvika	189	182	207	206	208	209	226	204	217	196	201	189	199	185	202	179	170
	Säffle	29	22	22	22	12	12	12	11	23	23	23	24	25	13	13	13	12
	Lekeberg	17	17	18	18	18	18	18	18	18	18	23	28	30	30	30	25	20
	Laxå	33	43	48	55	55	56	61	59	60	60	59	51	50	43	55	54	44
	Hallsberg	18	24	24	19	20	20	14	14	14	19	19	19	24	24	18	18	18
	Degerfors	55	49	47	44	44	45	47	46	44	49	50	52	60	65	61	56	52
	Hällefors	29	39	38	43	43	43	37	36	31	35	49	45	40	47	44	30	30
	Ljusnarsberg	41	41	43	41	41	47	48	52	63	56	50	55	58	47	47	55	50
	Örebro	15	10	7	7	7	7	8	9	9	9	9	8	8	8	8	8	8
	Askersund	48	43	43	36	30	32	31	32	31	31	24	24	30	30	30	36	39
	Karlskoga	12	12	15	8	14	14	14	11	16	10	9	9	16	17	17	17	17
	Nora	44	38	39	45	47	45	46	55	56	52	58	61	48	48	45	39	34
	Lindesberg	41	34	44	44	50	50	56	46	53	53	63	58	58	56	62	49	49
	Skinnskatteberg	74	77	72	67	63	62	65	58	65	72	71	82	86	85	75	76	57
	Surahammar	8	8	8	7	13	13	13	13	20	14	20	20	26	18	18	15	15
	Norberg	4	4	4	4	4		6	6	6	6	6						
	Västerås	2	1	1	1	1	1	7	7	7	7	7	1	1	1	1	1	1
	Sala	7	13	10	10	10	7	1	1	1	1	1	1	7	7	7	7	7
	Fagersta	13	13	13	13	13	7	7	7	7	7	7	7	7	7	7	7	7
	Köping	18	18	18	21	18	17	19	19	19	19	18	16	16	18	23	24	24
	Arboga				3	3	5	5	5	2	2							
	Vansbro	187	176	166	154	162	149	161	170	172	178	182	169	162	172	161	161	152
	Malung-Sälen	134	140	123	87	99	106	113	117	122	125	131	138	129	122	110	103	83
	Gagnef	74	74	84	73	56	47	47	38	47	46	46	57	63	64	64	64	54
	Leksand	109	110	81	85	85	89	84	108	121	121	125	149	164	146	146	131	103
	Rättvik	167	144	146	137	150	141	157	166	171	168	166	142	138	144	147	128	127
	Orsa	49	47	38	56	65	65	57	59	39	31	31	32	27	38	38	37	38
	Älvdalen	185	204	209	202	197	199	214	213	223	227	225	185	175	142	136	142	143
	Smedjebacken	56	54	56	57	57	57	65	51	41	54	61	63	63	75	72	74	61
	Mora	99	90	96	109	122	133	145	150	123	141	141	138	126	118	100	110	101
	Falun	164	143	134	148	123	104	112	121	130	130	146	149	152	131	160	157	147
	Borlänge	14	22	22	22	22	29	21	21	21	21	15	15	16	16	16	24	24
	Säter	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Hedemora	36	41	31	37	37	46	41	53	55	56	47	47	35	33	33	33	33
	Avesta		15	15	15	20	20	5	6	6	1	1	1					
	Ludvika	181	160	149	156	150	147	154	145	148	163	178	193	195	180	162	146	122

Appendix 2. Species-habitat associations – additional visualisation

Results for the species-habitat associations from table 4, visualised and displayed as graphs, exemplified for the habitat type *Old Forest*. The estimated effects (β) (black points) and the lower and upper 95% confidence intervals (error bars) are shown for each species. Significant effects are those for which the confidence interval does not overlap zero. As an example, in northern Sweden *Pulsatilla vernalis* (EN) was significantly negatively associated, while *Hydnellum ferrugineum* was significantly positively associated with old forest.

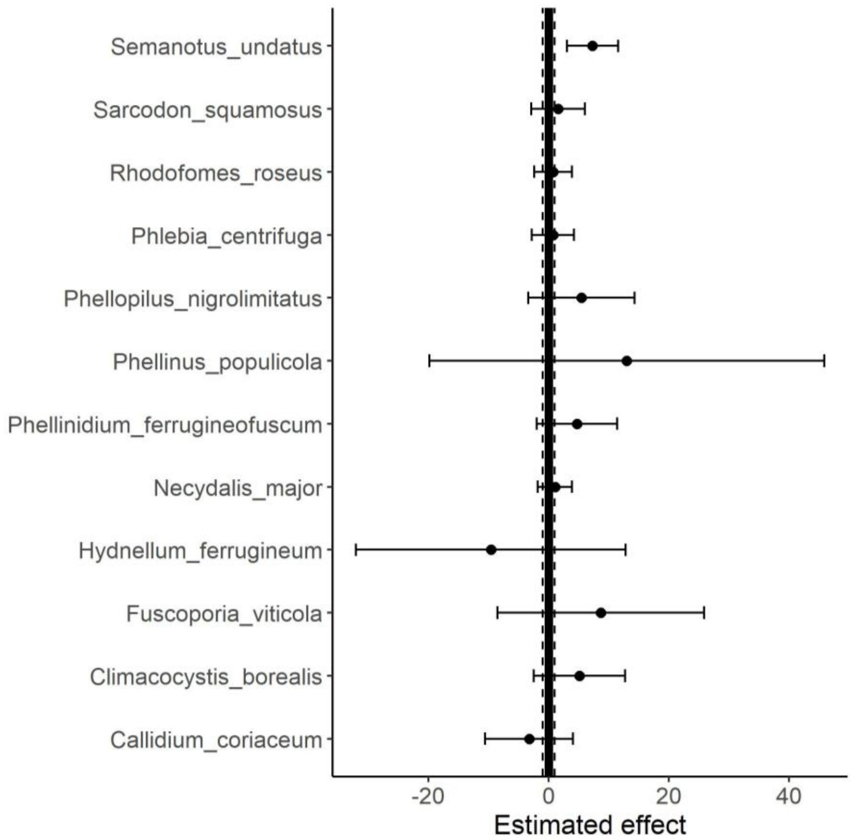

Figure 15. Associations between species and old forest habitats in northern Sweden.

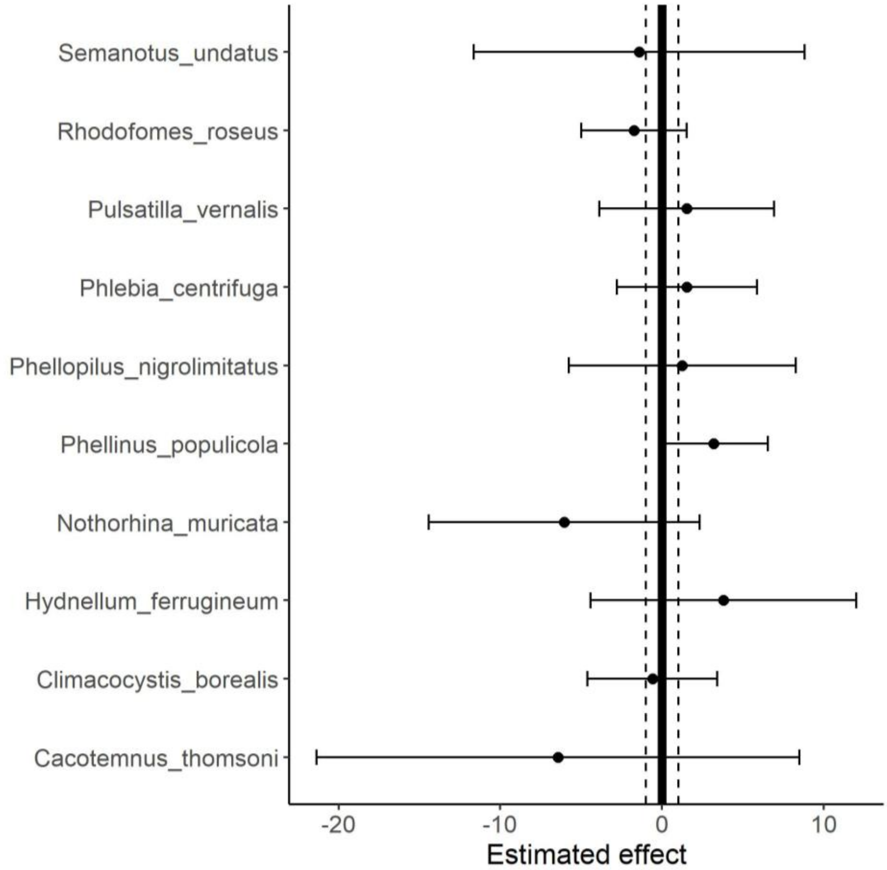

Figure 16. Associations between species and old forest habitats in south-northern Sweden.

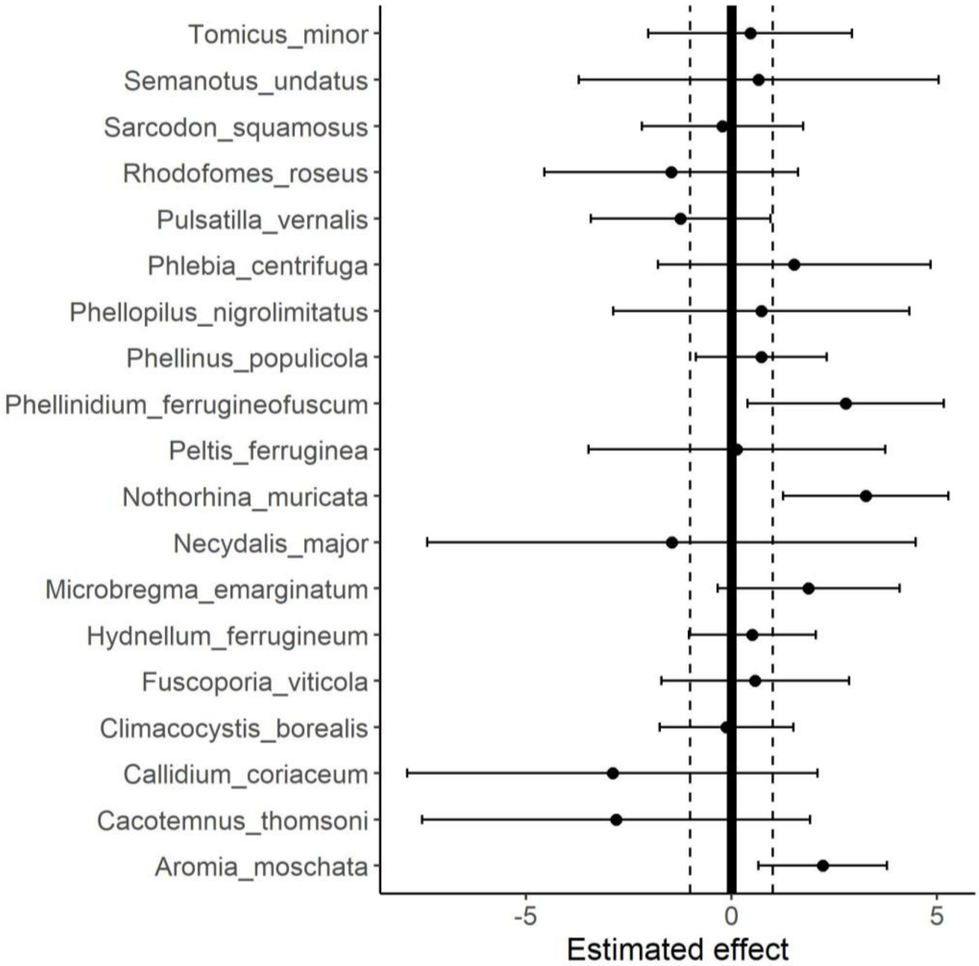

Figure 17. Associations between species and old forest habitats in central Sweden.