Influence of tree species on tree-related micro-habitats in a broadleaf forest in eastern Skåne, Sweden

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Degree project/Independent project • 15 credits
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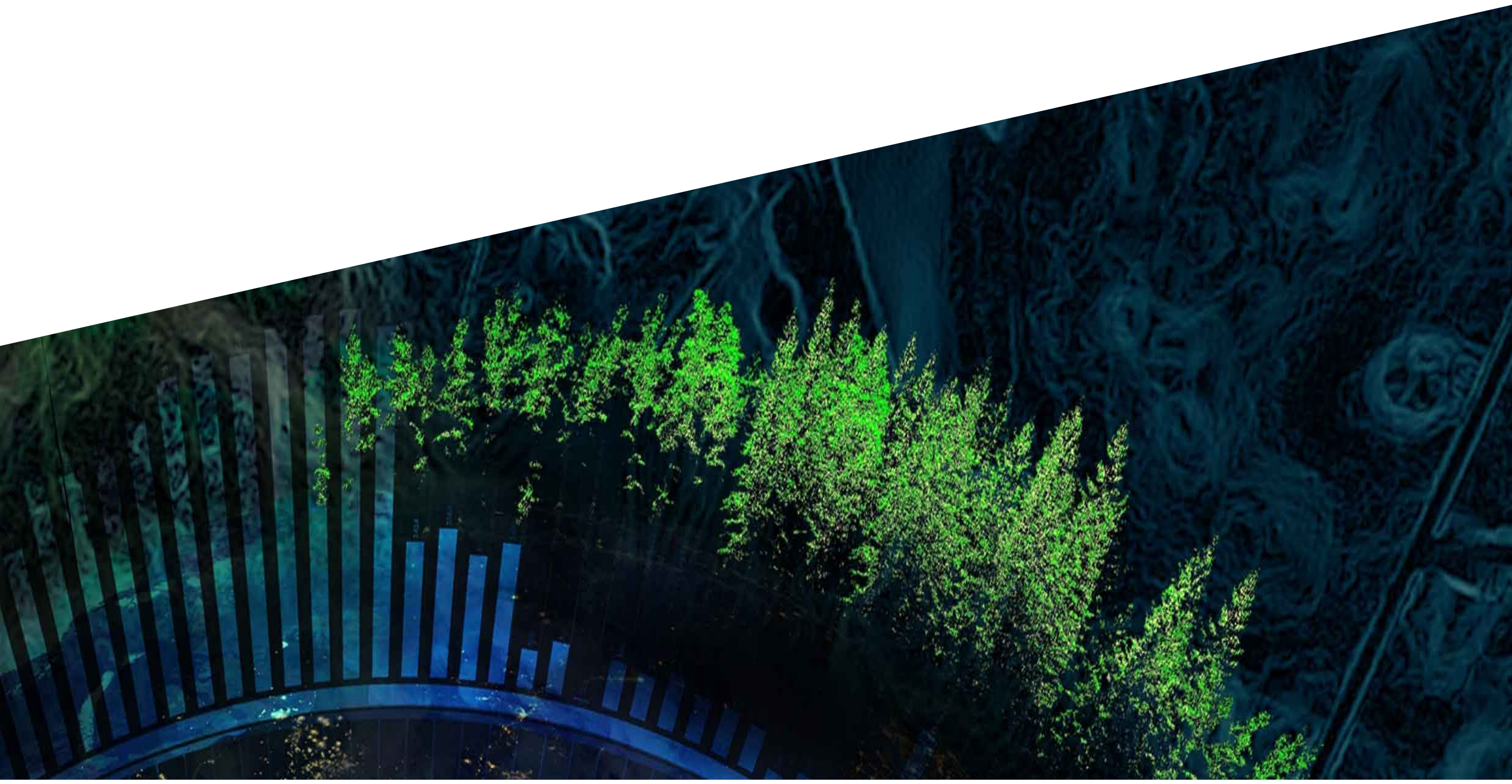
Forest and Landscape
Alnarp 2024



Influence of tree species on tree-related micro-habitats in a broadleaf forest in eastern Skåne, Sweden

Effekter av trädslag och stamdiameter på trädens mikrohabitat i Krubbemöllas lövskog i Skåne

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Credits:	15 credits
Level:	First cycle, G2E
Course title:	Independent project in Forestry science
Course code:	EX1012 VT2024
Programme/education:	Forest and landscape
Course coordinating dept:	Southern Swedish Forest Research Centre
Place of publication:	Alnarp
Year of publication:	2024
Copyright:	All featured images are used with permission from the copyright owner.
Keywords:	Biodiversity, broadleaf forest, ecological indicators, nature, conservation, oak, sallow, tree-related micro-habitats (TreMs)

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Abstract

In this thesis, the effects of different tree species and tree size on tree related micro-habitats (TreMs) in a broadleaf forest at Krubbemölla in Skåne, southern Sweden, have been studied. The hypothesis was that there are different amounts and types of TreMs on different tree species and that there are more TreMs on larger (older) tree individuals. The results show that there is a large difference between tree species and what kind, variation and amount of TreMs that occur on different species. *Salix caprea* had the highest amount of TreM variation, epiphytic structures and fruiting bodies. *Quercus robur* had the largest amount of crown deadwood and the largest amount of TreMs per individual tree together with *S. caprea*. *Fagus sylvatica* and *S. caprea* had the greatest number of cavities and tree injuries. *Prunus avium* had the greatest number of exudates, but excrescences did not seem to differ between species. Fruiting bodies and excrescences did not have many observations in the study area and thus these data may not be reliable. The difference between large and small trees was noticeable for the most part when observing all of the species together, except for fruiting bodies and exudates. For the total amount of TreMs there was a clear difference between the large and small trees for all species. Other aspects that determine which and how many TreMs there will be in a specific area are discussed. *S. caprea* and *Q. robur* should be kept and promoted in the area to increase biodiversity, but other species should also be maintained as they provide other types of TreMs.

Keywords: biodiversity, broadleaf forest, ecological indicators, nature conservation, oak, sallow, tree-related micro-habitats (TreMs)

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Abbreviations

SLU	Swedish University of Agricultural Sciences
TreMs	Tree-related micro-habitats
DBH	Diameter at breast height (1.3 m)

1. Introduction

The integration of biodiversity concerns into land management policies has been a high priority since the conference in Rio 1992 (Siebenhüner, 2007). Yet these policies sometimes seem to be based more on myth than actual science (Vuidot et al., 2011). Therefore, more research is needed to be able to develop good quantitative methods to assess biodiversity indicators for forest management (Vuidot et al., 2011). Currently in the world there is a great loss of old forest, loss of complex forest structures, smaller forests, isolation of forests, loss of natural fire regimes and an increase of infrastructure building in forests which has had an unfavourable effect on biodiversity and the native species in these habitats (Noss, 1999). Therefore, there is a great need to change and mitigate these problems, and methods/techniques to systematically measure biodiversity are needed.

Ecological indicators can be used to measure if there is an increase or decrease in biodiversity. The indicators are species specific and reflect conditions and trends that show improvement to the ecology (Noss, 1999). Effective ways of indicating how biodiversity is doing can show the most important ecological changes with the least amount of resources (National Research Council, 2000). To begin with, one needs to know the forest's health status, if it is in a bad, good, average state and what there is to recover in the forest, in relation to other forests (Noss, 1999). According to Haq et al. (2023) forest health can be decided upon several factors such as the ability for the forest to regenerate, the ecosystems physical and observable structures, tree species (native or invasive), age distribution and tree species composition. It is also of interest to the people working with restoration to know the historical context (Noss, 1999). Furthermore, it is important that managers of the forests know what changes have been made historically that have caused the deterioration of the forests (Noss, 1999). However, without an indicator, it is very difficult to assess what has deteriorated and why, and what changes to implement to improve biodiversity (Noss, 1999). These assessments may be daunting for forest managers as they are complex and difficult, yet there are ways to create a simpler way to understand the biodiversity of a forest (Noss, 1999). This can be achieved by selecting measurable variables in the forest that are indicative of forest health and biodiversity, though it is important to limit these as it is impossible to measure everything (Noss, 1999).

Tree-related micro-habitats (TreMs) are forest structures that promote biodiversity and support a variety of species (Larrieu et al., 2022). TreMs are specific easily defined structures on living trees that have a correlation to important habitat/ establishing/ foraging/ breeding places for specific organisms during a part of their life (Larrieu et al., 2018). TreMs have more of a complimentary role to stand structure indicators like deadwood and others (Vuidot et al., 2011). TreMs can be used to obtain more specific information about species that use them as foraging or nesting places and may show differences in unmanaged versus manged forests (Vuidot et al., 2011). There is a lot of supporting evidence that shows that the number of TreM rich trees increases the amount of fauna and flora in the forest, and because of this, researchers have seen TreMs as a reliable indicator of biodiversity for forest management (Larrieu et al., 2022). To be able to provide recommendations researchers have studied what factors promote the development of TreMs in trees, these factors include tree species, diameter of trees and health status of trees (healthy, damaged, dying, dead) (Larrieu et al., 2022). By selecting TreM-rich trees or trees that have potential to become TreM-rich as retention trees could make forestry more sustainable by making it easier to balance conservation with economic interests (Larrieu et al., 2022).

The relationship between TreMs density, diversity and variations in biodiversity is complex and varied, especially at smaller scales such as plot or stand scale (Larrieu et al., 2022). There is a relationship between TreM characteristics and species richness but there are also several more factors that contribute such as decaying wood, flora, and water systems in the forest (Larrieu et al., 2022). There can also be errors in the assessments of species and there can be slow reactions in response from species that like these TreMs which makes the assessment more complex (Larrieu et al., 2022). TreMs also differ in how long they live, some are living only for a season while others are long living structures (Larrieu et al., 2022). TreMs can also differ between tree species (Larrieu et al., 2022) which is what this study will investigate. TreMs development can also be induced by forest management such as harvesting, which can cause damages to the trees, for example stem and crown damages by felling or forwarding operations (Larrieu et al., 2022). These complexities with TreMs have triggered more research into environmental factors and investigating what can influence TreMs such as slope, exposure, altitude, cliffs, bark features and more (Larrieu et al., 2022).

This thesis will focus on the study of TreMs and the effect of tree species on TreMs. TreMs are always above ground on the tree, but they are not found on every tree. A recent study defined 47 specific TreM types which can be divided into 15 groups and 7 forms, that are caused by biotic and abiotic factors (Larrieu et al., 2018).

TreMs can be made up of either parts of the tree itself or added materials from the surroundings. Some other factors such as tree specific features, crooked trees, lying deadwood etc have been excluded as to not have too many factors to look for when doing an inventory (Larrieu et al., 2018).

The tree related micro-habitats are classified into different groups of how common, how fast growing, and which fauna and flora that relate to these micro-habitats (Larrieu et al., 2018). The TreMs have a clear link between species and their specialized habitats/ foraging grounds, these micro-habitats have been well studied and proven for each respective species (Larrieu et al., 2018). They are based on either pragmatic or biological thresholds such as woodpecker size (biological), or for example 30 cm in diameter for a cavity to be able to standardize, and reduce the time needed for inventorying and to avoid being subjective (pragmatic) (Larrieu et al., 2018). The listing of all the different TreMs can be seen in either the paper by Larrieu et al. (2018), or in the Field Guide to Tree-related Micro-habitats by Bütler et al. (2020).

This study builds on the current research about TreMs and their importance as an indicator of forest biodiversity. The study will explore the difference between species and their TreM richness, and how and which trees are best suited to achieve more TreMs in nature. The hypothesis is that there will be different amounts and types of TreMs on different species and that there are more TreMs on larger (older) individuals.

2. Methods

2.1 Study area.

The area studied is Krubbemölla, located in the south of Sweden close to the small village Vitaby, figure 1. In Krubbemölla there is a characteristic old mill. The mill has been preserved by an association, Albo härads hembygdsförening, that oversees its renovation and manages the surrounding area (Albo härads hembygdsförening, 2021).

2.1.1 Division of study area

ArcGIS was used to divide the study area in different sub-areas with respect to forest age and to visualize the variation in earth deposits. This was done by downloading maps from Lantmäteriet and fitting them to the right place on the map using geolocator. After this the areas were traced using the polygon tool. The different objects traced was a map from 1926-1931, 1965, 1975 and a current map see figure 3.

2.1.2 Krubbemölla

The property of Krubbemölla has a size of 11.9 hectares, see figure 1. The old mill is located onto the stream Mölleån that runs from west to east in the area and runs out into the sea at the eastern coast of Scania called Hanöbukten.

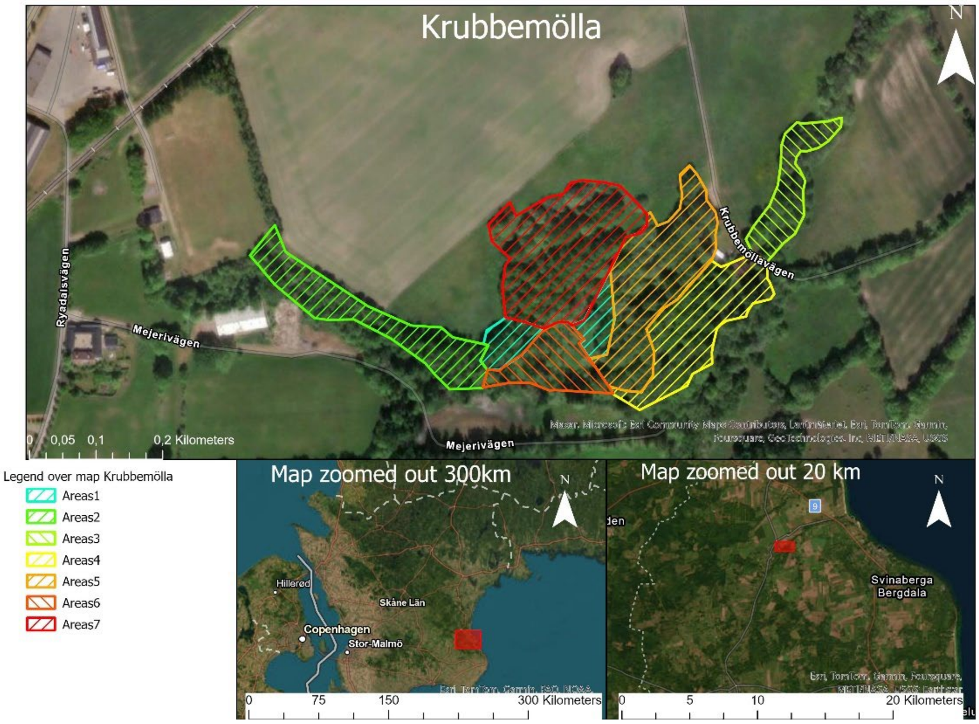

Figure 1. Maps showing where Krubbemölla is located in Scania, southern Sweden and the divisions done to the area. Krubbemölla´s total area is 11.9 hectares but the study area is 4.21 hectares, area 1 is 0.27 hectares, area 2 is 0.62, area 3 is 0.33, area 4 is 0.67 hectares, area 5 is 0.88 hectares, area 6 is 0.34 hectares and area 7 is 1.1 hectares. The legend shows the colour each area division has on the map. Below the division is a zoomed-out version with 20 km and 300 km, the red spot on the 20 km is the Krubbemölla size, and the red square on the 300 km is the map of the 20 km map. The division of Krubbemöllas forested area in numbered inventory units. Map done in ArcGIS and basic map retrieved from Lantmäteriet (Lantmäteriet).

The area contains a variety of earth deposits, as seen in figure 2, with clay moraine in the eastern part, sandy moraine in both the most western part and east middle part, glacial river sediment in the middle part, sandy glacial river sediment in the northwestern part, sand flood deposit in the southwestern part and some bedrock in the southeastern part of the area, the information about the soil was taken from Lantmäteriets map on soils (Lantmäteriet).

Figure 2. Map showing the geology (earth deposits) of Krubbemölla, Map and layout done in ArcGIS and basic map retrieved from Lantmäteriet (Lantmäteriet).

The southern part of the area is forested with forest of different ages as seen in figure 3 with the oldest parts from 1926 and before in the most western and most eastern and some dots in the centre of the area.

Figure 3. Map of Krubbemölla showing where the oldest forest is located (1926 and older) until todays forest cover. Map and layout done in ArcGIS and basic map retrieved from Lantmäteriet (Lantmäteriet).

From these areas the forest has slowly begun colonising the rest of the area until we have the current forested area. These areas form the basis of the division of the area in inventory units as seen in figure 1 with some changes as to where it was accessible to walk.

2.2 Field work

The sub-areas shown in figure 1 were the basic survey units, so that all trees in sub-areas were inventoried before trees in the next areas were surveyed. Only trees with a diameter at breast height (dbh at 1.3 m height) of at least 30 cm were included in the inventory.

The stem diameter was measured with a calliper for dbh up to 50 cm and with a measuring tape for thicker stems. After measuring dbh, the tree species was determined and marked with a paper ribbon to avoid double inventory of the same tree.

TreM types according to the list and definition in Bütler et al. (2020) were inventoried for each tree using the following procedure: The inventory started by looking at the bottom of the tree and then up. Binoculars were used to see if there were any TreMs in the top of the tree. Each single TreM was noted on each tree. Only TreMs clearly visible from the ground were recorded. Appendix 3, Table 12, provides an overview of the inventory data, including number of TreMs of different types recorded on different tree species.

For root concavities generally a stick or the end of a calliper was used to see if rot had begun on the inside where it was not visible. Stems were treated as different trees if they split below breast height as well as shoots coming from below breast height were counted as root shoots.

2.3 Data analysis

2.3.1 TreM variables

Excel was used to create a data base of all trees, with their dbh and their number of individual TreMs. These data were used to calculate various TreM variables of each tree for further data analysis as listed in Table 1.

Table 1. List of TreM variables used for statistical analyses.

Variable	No. TreMs surveyed
Total number of individual TreMs	1210
Total number of TreM types (found)	39
Total number of different TreM types found on each individual.	765
Main TreM forms analysed:	
Cavities	294
Tree injuries and exposed wood	142
Crown deadwood	483
Excrescences	134
Fungal fruiting bodies	20
Epiphytic and epixylic structures	104
Exudates	33

2.3.2 Statistical analysis

The numbers of different TreMs were compared between tree species, and between two dbh classes within the same tree species. Differences between tree species were compared using interval plots with means and 95% confidence intervals for all tree species with at least ten inventoried trees. Differences between trees of the same tree species and stem diameter of 30-49 cm and ≥50 cm, respectively were compared with the Kruskal-Wallis test. Only tree species with at least five trees in each dbh class were included in these analyses.

All statistical analyses were performed in Minitab 21.4.3 (Minitab Inc., 2024).

3. Results

3.1 Amount and species of trees in the inventory.

A total of 443 trees with a dbh of at least 30 cm were included in the data analysis. These trees belong to seven different species. The most common species was *Alnus glutinosa* (57% of all trees), followed by *Quercus robur* (Table 2). 57 trees (14%) had stems of 50 cm or thicker, of which 25 were oaks (Table 2).

Table 2. Number of trees of each species with a dbh of 30-49 cm and 50 cm or higher, respectively. Tree species with less than ten measured stems were excluded from the analysis (Tilia cordata, Prunus padus, Populus spp, Carpinus betulus, Corylus avellana, Pyrus spp and 'other woody species').

Tree species	30-49 cm	50 cm or higher	Sum
Acer platanoides	10	1	11
Alnus glutinosa	249	16	265
Fagus sylvatica	8	7	15
Fraxinus excelsior	26	8	34
Prunus avium	32	1	33
Quercus robur	31	25	57
Salix caprea	23	6	29
Total	379	64	443

3.2 Differences between species

The total number of TreMs recorded on the seven tree species with at least ten measured stems was 1210. Among the seven main forms of TreMs, crown deadwood was most common with 483 individuals TreMs recorded, while fruiting bodies were least common form (table 3, see also table 12).

Table 3. TreM form and number of TreMs found in each of the seven main forms. Tree species with less than ten individuals were excluded from the analysis.

TreM form	No. TreMs
Cavities	294
Tree injuries	142
Crown deadwood	483
Excrescences	134
Fruiting bodies of saproxylic fungi and slime moulds	20
Epiphytic and epixylic structures	104
Exudates	33
Total	1210

The total number of individual TreMs was much higher in *Q. robur* and *Salix caprea* than in the other tree species (Figure 4). There was no difference in the number of total TreMs observed between *Q. robur* and *S. caprea*.

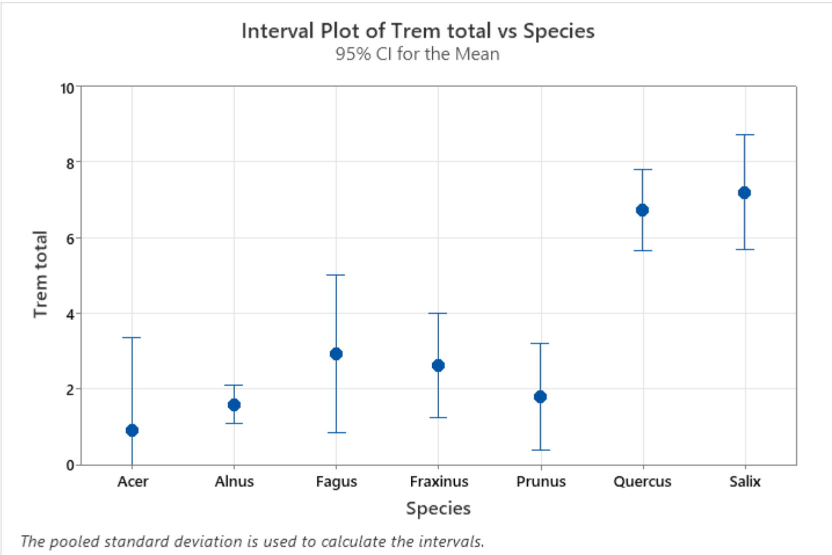

Figure 4. Interval plot of the mean total number of individual TreMs. This and the following figure include tree species that have ten or more observed individuals. Where the interval goes below 0 the amount is 0. Note that the graphs y-axis is between 0-10, when the data label for the lower interval is too close to the bottom, the data is written to the right of the interval.

S. caprea had by far the highest mean number of TreM types per tree (Figure 5). *Q. robur* and *Fagus sylvatica* had clearly less TreM types than *S. caprea*, but more than *A. glutinosa,* and *Q. robur* also had more than *Acer platanoides* (Figure 5).

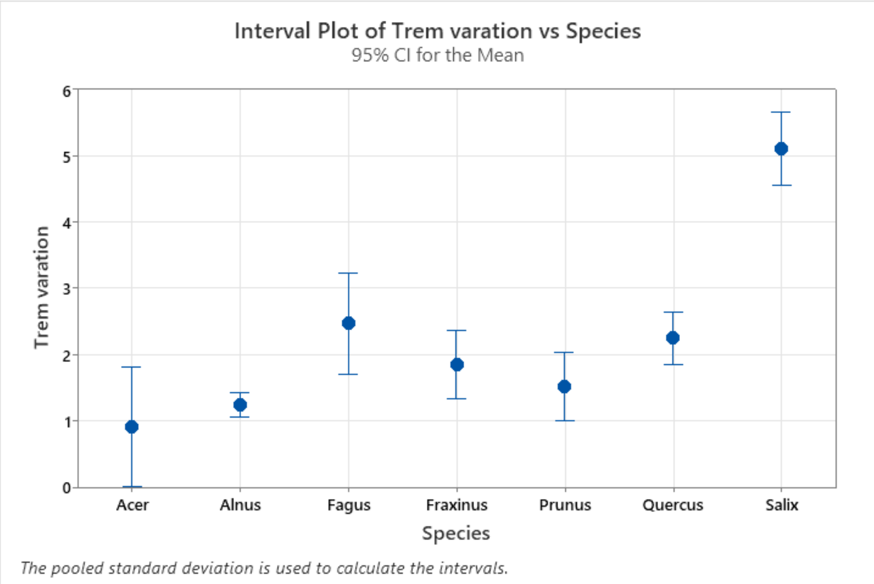

Figure 5. Interval plot of variation in TreM types. Where the interval goes below 0 the amount is 0. Note that the graph is between 0-6 on the y- axis, when the data label for the lower interval is too close to the bottom the data is written to the right of the interval.

S. caprea had the greatest number of cavities compared to the other species except *F. sylvatica*, see figure 6. There was no clear difference between among the other tree species.

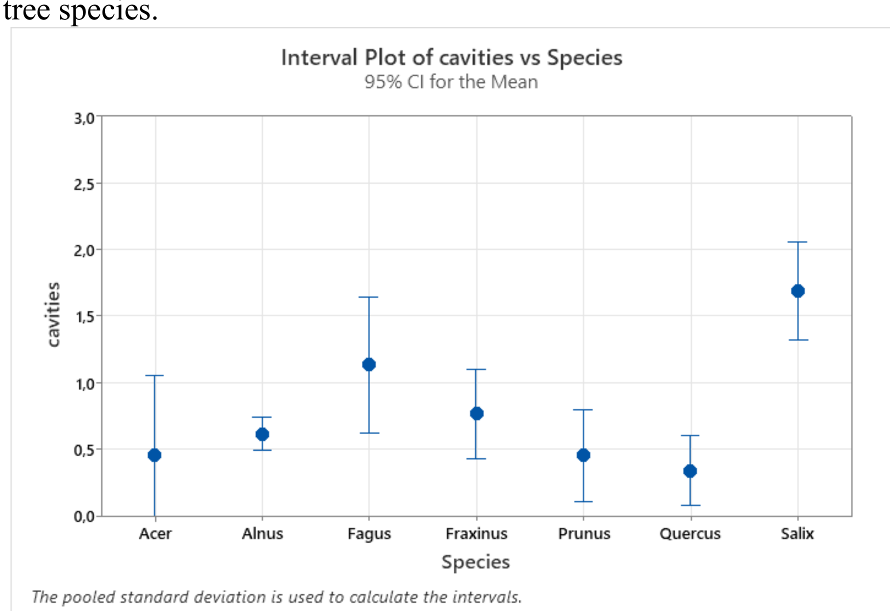

Figure 6. Interval plot of the mean number of cavities observed on each tree species. Where the interval goes below 0 the amount is 0, when the data label for the lower interval is too close to the bottom the data is written to the right of the interval. Note that the y-axis is between 0-3.

S. caprea had the greatest number of injuries and exposed heartwood for all the species except *F. sylvatica*, see figure 7. *F. sylvatica* and *Q. robur* had more tree injuries than *A. glutinosa*.

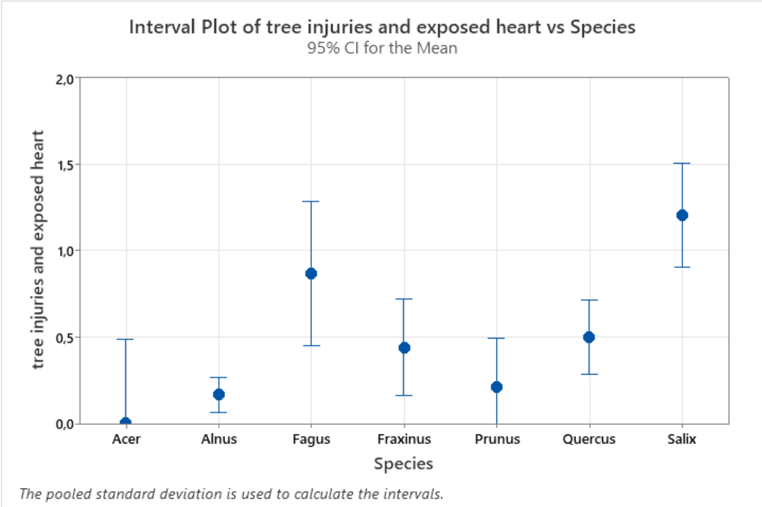

Figure 7. Figure 7. Interval plot of the mean number of injuries and exposed wood observed on each tree species. Where the interval goes below 0 the amount is 0, when the data label for the lower interval is too close to the bottom the data is written to the right of the interval. Note that the y- axis is between 0-2.

For crown deadwood *Q. robur* is clearly the species with the highest number of TreMs compared to the other species, see figure 8. *S. caprea* had more TreMs compared to *A. glutinosa*, while there were no differences between other pairs of tree species.

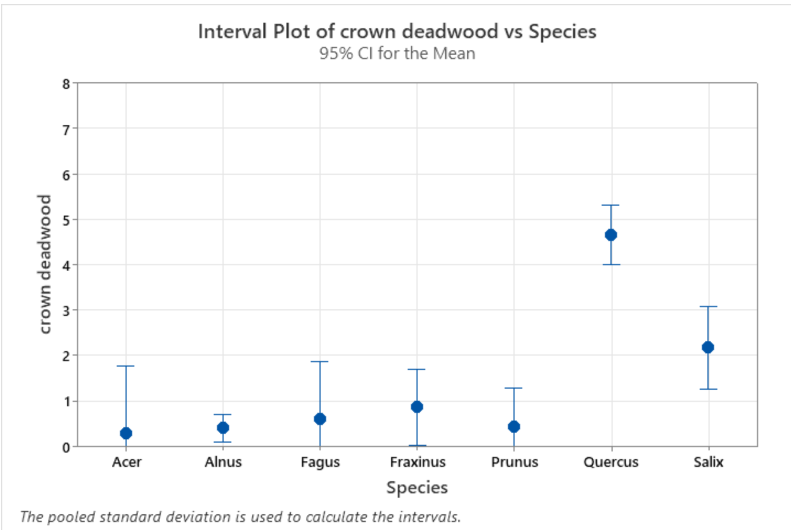

Figure 8. Interval plot of the mean number of crown deadwood units observed on each tree species. Where the interval goes below 0 the amount is 0, when the data label for the lower interval is too close to the bottom the data is written to the right of the interval. Note that the graphs y-axis is between 0-8.

There are only small numbers of excrescences found and no differences between species, see figure 9.

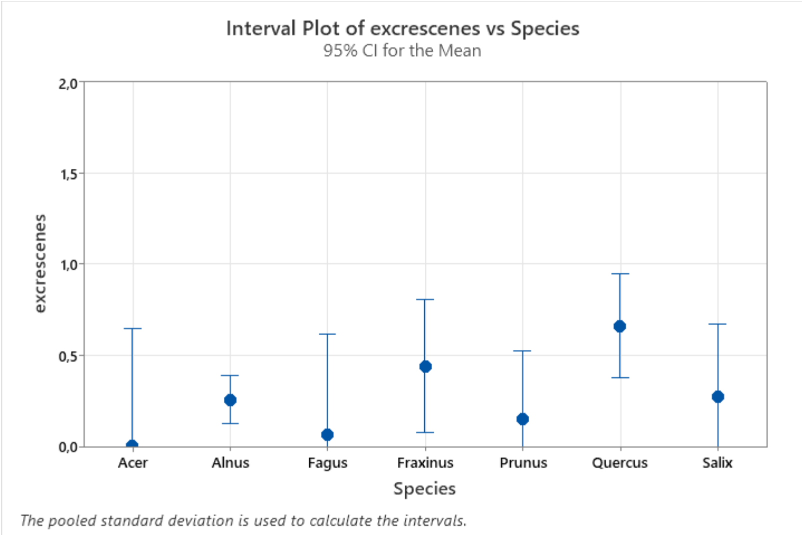

Figure 9. Interval plot of the mean number of excrescences observed on each tree species. Where the interval goes below 0 the amount is 0 when the data label for the lower interval is too close to the bottom the data is written to the right of the interval. Note that the y-axis is between 0-2.

For epiphytic and epixylic structures *S. caprea* had by far the highest number of this kind of TreMs, see figure 10. The other tree species were quite similar.

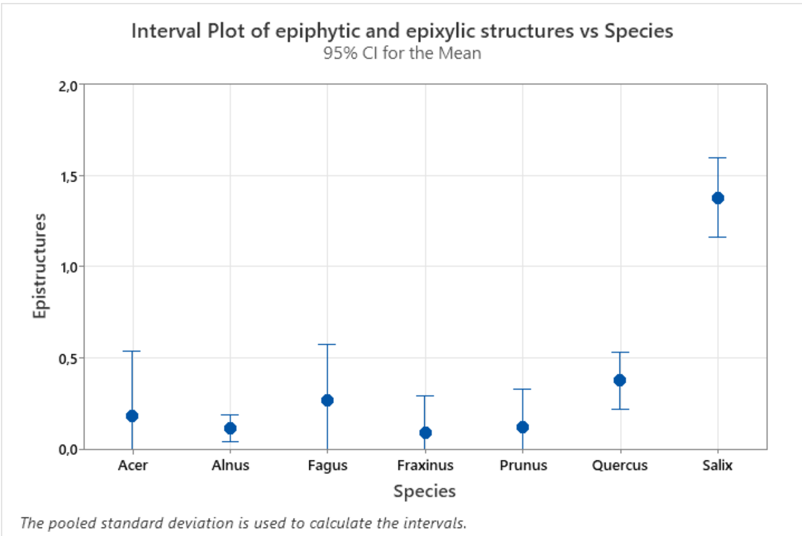

Figure 10. Interval plot of the mean number of epiphytic and epixylic structures observed on each tree species. Where the interval goes below 0 the amount is 0 when the data label for the lower interval is too close to the bottom the data is written to the right of the interval. Note that the graph is between 0-2 on the y-axis.

For exudates *Prunis avium* had the highest number of these TreMs, see figure 11. All other species had very few exudates.

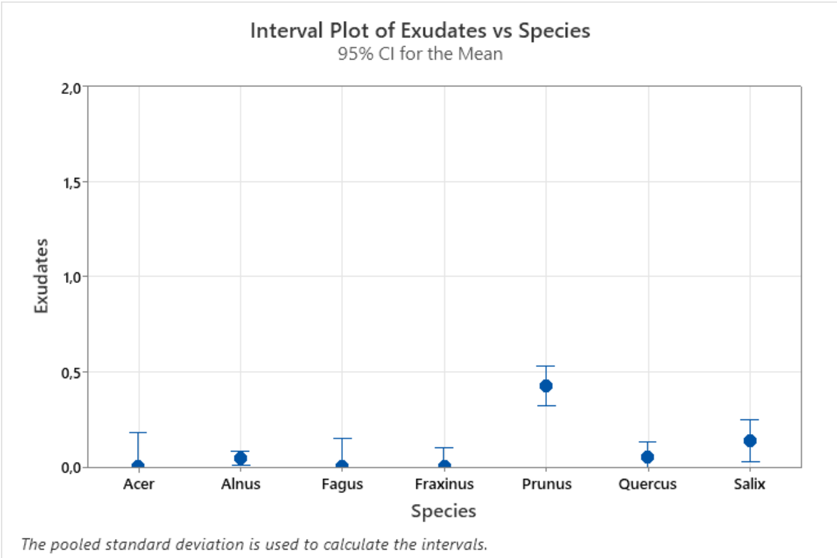

Figure 11. Interval plot of the mean number of exudates observed on each tree species. Where the interval goes below 0 the amount is 0 when the data label for the lower interval is too close to the bottom the data is written to the right of the interval. Note that the y-axis is between 0-2 on the graph.

S. caprea had by far the highest amount of fungal fruiting bodies while very few fruiting bodies were recorded in the other species, see figure 12. *Q. robur*, however, had more fruiting bodies compared to *A. glutinosa*.

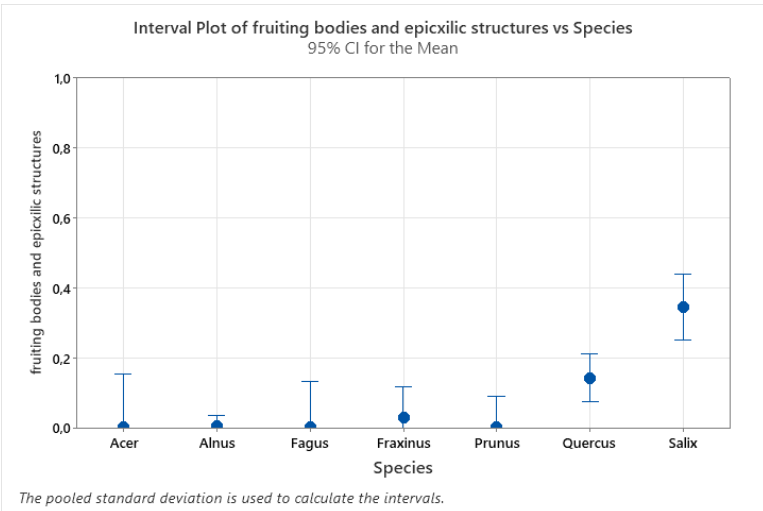

Figure 12. Interval plot of the mean number of fungal fruiting bodies observed on each tree species. Where the interval goes below 0 the amount is 0. Note that the y-axis is between 0-1 on the graph.

3.3 Effects of stem diameter class

Tables 4 to 10 show the results of Kruskal-Wallis tests for all trees and five different tree species with at least five trees in both dbh classes. In all cases below where medians are equal including comparisons of rare TreM-types when both medians are zero, but the test shows significant differences between dbh classes, the mean ranks are higher for the dbh class >50 cm.

Table 4 shows that the medians of all tested TreM forms, except exudates and fruiting bodies, were significantly higher in larger trees.

Table 4. Results of Kruskal-Wallis tests comparing TreM variables for all species and two dbh classes. P-values <0.05 in bold letters.

TreM variable	P-value	Median dbh 30-49 cm	Median dbh ≥50 cm
Cavities	**0.040**	0	1
Crown deadwood	**0.000**	0	1.5
Epiphytic and epixylic structures	**0.001**	0	0
Excrescences	**0.000**	0	0
Exudates	0.979	0	0
Fruiting bodies	0.378	0	0
Tree injuries	**0,003**	0	0
TreM total	**0.000**	1	5.5
TreM variation	**0.000**	1	3

For *A. glutinosa*, the total number of TreMs, the TreM type variation and the number of excrescences was higher in larger trees (Table 5).

Table 5. Results of Kruskal-Wallis tests comparing TreM variables for A. glutinosa and two dbh classes. P-values <0.05 in bold letters.

TreM variable	P-value	Median dbh 30-49 cm	Median dbh ≥50 cm
Cavities	0.376	0	0.5
Crown deadwood	0.223	0	0
Epiphytic and epixylic structures	0.474	0	0
Excrescences	**0.018**	0	0
Exudates	0.849	0	0
Fruiting bodies	0.979	0	0
Tree injuries	0.409	0	0
TreM total	**0.001**	1	4
TreM variation	**0.001**	1	3

For *F. sylvatica*, TreM total, crown deadwood, fruiting bodies and exudates showed to have a significant difference between smaller and bigger trees, see Table 6.

Table 6. Results of Kruskal-Wallis tests comparing TreM variables for F. sylvatica and two dbh classes. P-values <0.05 in bold letters.

TreM variable	P-value	Median dbh 30-49 cm	Median dbh ≥50 cm
Cavities	0.148	0.5	2
Crown deadwood	**0.043**	0	1
Epiphytic and epixylic structures	0.908	0	0
Excrescences	0.643	0	0
Exudates	**0.001**	0	0
Fruiting bodies	**0.001**	0	0
Tree injuries	0.165	0	0
TreM total	**0.037**	1	3
TreM variation	0.083	1	2

For *Fraxinus excelsior*, only TreM total and exudates showed to have a significant difference comparing small and large trees, see table 7.

Table 7. Results of Kruskal-Wallis tests comparing TreM variables for F. *excelsior and two dbh classes. P-values <0.05 in bold letters.*

TreM variable	P-value	Median dbh 30-49 cm	Median dbh ≥50 cm
Cavities	0.871	0.5	0.5
Crown deadwood	0.062	0	2
Epiphytic and epixylic structures	0.372	0	0
Excrescences	0.174	0	0
Exudates	**0.000**	0	0
Fruiting bodies	0.871	0	0
Tree injuries	0.320	0	0.5
TreM total	**0.004**	1	4
TreM variation	0.056	1	2.5

For *Q. robur*, crown deadwood, epiphytic and epixylic structures, TreM total and TreM type variation showed to have a significant statistical difference between small and large trees, see table 8.

Table 8. Results of Kruskal-Wallis tests comparing TreM variables for Q. robur and two dbh classes. P-values <0.05 in bold letters.

TreM variable	P-value	Median dbh 30-49 cm	Median dbh ≥50 cm
Cavities	0.053	0	0
Crown deadwood	**0.017**	1	4
Epiphytic and epixylic structures	**0.011**	0	0
Excrescences	0.051	0	0
Exudates	0.760	0	0
Fruiting bodies	0.400	0	0
Tree injuries	0.396	0	0
TreM total	**0.000**	2	8
TreM variation	**0.000**	1	3

S. caprea showed to only have a significant difference between TreM total and TreM type variation when comparing small and large trees, see table 9.

Table 9. Results of Kruskal-Wallis tests comparing TreM variables for S. *caprea and two dbh classes. P-values <0.05 in bold letters.*

TreM variable	P-value	Median dbh 30-49 cm	Median dbh ≥50 cm
Cavities	0.554	1	2
Crown deadwood	0.118	1	4
Epiphytic and epixylic structures	0.247	1	1.5
Excrescences	0.095	0	0.5
Exudates	0.628	0	0
Fruiting bodies	0.957	0	0
Tree injuries	0.206	0	1.5
TreM total	**0.021**	6	12
TreM variation	**0.043**	5	7

3.3.1 Overview of results

When reviewing the p-values for all species, TreMs are more common in larger trees, see table 10. TreMs vary more with size, except for *F. sylvatica* and *F. excelsior*. Cavities and Epiphytic and epixylic structures are only affected by the size of the tree for *Q. robur*, and tree injuries do not seem to be affected by tree size in any individual species, while still significantly different for the total data set. Crown deadwood showed to be more common in larger trees for *F. sylvatica* and *Q. robur*. Excrescences were more frequent in the larger trees for *A. glutinosa* and *Q. robur*. Fruiting bodies only showed a significant difference for *F. sylvatica*.

Table 10. Overview of p-values from Kruskal-Wallis tests comparing TreM variables between dbh-classes for five tree species. P-values <0.05 in bold letters.

TreM variable	All	*A. glutinosa*	*F. sylvatica*	*F. excelsior*	*Q. robur*	*S. caprea*
Cavities	**0.040**	0.376	0.148	0.871	0.053	0.554
Crown deadwood	**0.000**	0.223	**0.043**	0.062	**0.017**	0.118
Epiphytic and epixylic structures	**0.001**	0.474	0.908	0.372	**0.011**	0.247
Excrescences	**0.000**	**0.018**	0.643	0.174	0.051	0.095
Exudates	0.979	0.849	**0.001**	**0.000**	0.760	0.628
Fruiting bodies	0.378	0.979	**0.001**	0.871	0.410	0.957
Tree injuries	**0.003**	0.409	0.165	0.320	0.396	0.206
TreM total	**0.000**	**0.001**	**0.037**	**0.004**	**0.000**	**0.021**
TreM variation	**0.000**	**0.001**	0.083	0.056	**0.000**	**0.043**

3. Discussion

Is there a difference between tree species and the form of TreMs they host? The data suggests that this is the case, as *S. caprea* is on top for most of the TreM forms and with the highest amount of fruiting bodies and epiphytic and epixylic structures. *S. caprea* also has more TreMs than all other trees except *F. sylvatica*. *Q. robur* had the highest amount of deadwood and *P. avium* had the greatest number of exudates. Yet many of the other species, *A. platanoides, F. excelsior* and *A. glutinosa* did not have any significant differences between them. This may be because their sample sizes were too small and that there were not enough of each tree species in each of the categories. This would probably be the case for *A. platanoides* as there were no more than 11 individuals found, yet it would definitively not be true for *A. glutinosa* as for this species 265 individuals were inventoried. *F. sylvatica* also had few individuals, only 15, yet in some cases it was equal to *S. caprea* and had more TreMs than *A. glutinosa*. Though it could be because the amounts of TreMs found were not enough to show a difference between the species, as only 20 were found for fruiting bodies and 33 were found for exudates. It may be that more differences could have be seen with a larger sample size.

For all species, exudates and fruiting bodies were shown to have no significant difference between large and small trees. However, when individual species were tested *F. sylvatica* had significant differences between large and small trees. This is probably due to the small sample size for these two TreM forms, with fruiting bodies only having 20 findings, see table 3.

3.3.2 Stem diameter and TreM occurrence

The Kruskal Wallis tests showed that there were little to no differences of some TreM forms on larger versus smaller trees. For fruiting bodies and exudates this is probably due to the small sample size of each TreM form, as one can see that on the tree species where these were found (*F. sylvatica* and *F. excelsior)*, the tests showed that there was a great difference between small and large trees. For tree injuries there was no great difference between larger and smaller trees when looked upon separately for any of the species. This could be because tree injuries are more related to where the tree grows than age. Though with age there is more time for the tree to get injured (Vuidot et al., 2011). Yet there are studies that suggest that there are some micro-habitats that are not affected by either tree species or dbh, such as bark pockets (Vuidot et al., 2011).

The data suggests that there are different thresholds for different species when it comes to their dbh and when the TreMs start to occur. The study by Cabanettes et al. (2012) shows that the first TreMs for beech start appearing at around 40 cm in diameter and significantly increase after that. This is also supported by the study by Przepiora and Ciach (2023) showing that the effect of dbh to TreM amount and variation may also be dependent on the specific tree species. In their study there was a difference between tree species and at what size they had the most TreMs. *A. platanoides* and *Q. robur* had more TreMs at the later stages whilst *Carpinus betulus* had a steep curve upwards of getting TreMs from earlier stages (Przepiora and Ciach, 2023).

3.3.3 Ontogenetic stage

The age of the tree may not matter as much as the ontogenetic stage of the tree, the four stages of a trees development. The stages include adolescent, adult, mature and senescent (Larrieu et al., 2022). During the adolescent stage each tree species has different branching strategies, they are usually thin, and it is the beginning of the formation of the crown (Larrieu et al., 2022). During the adult stage the trees build on their original branching strategy, the structure of the crown is also established in this stage (Larrieu et al., 2022). When the crown has developed and obtained its definitive volume, the crowns development is irreversible, as new shoots can't be produced in the same amount. This stage and the last stage account for half of the trees life span and are the stages where the most amount of crown deadwood and TreMs are caused by wounds (Larrieu et al., 2022). Also, in the adult stage the forks are created in the crown, therefore in the later stages it creates possible places of where micro soils and dendrothelms can emerge (Larrieu et al., 2022). The trees dbh is correlated with age, but other factors play a role as well such as site fertility, competition, and the climate/growing conditions (Larrieu et al., 2022). This is a possible reason for the small difference in some of the Kruskal-Wallis tests, i.e. that they may not be as old/in the ontogenetic where they create the most TreMs. The site has many different soils, providing varying growing conditions, and therefore, trees of the same size may be in different ontogenetic stages. A deeper study would be needed to be able to determine how much the ontogenetic stages and soil conditions influence the formation of TreMs in this area and if it has caused a larger difference for the TreM formation than tree species.

Another possible reason for the small difference between large and small trees, especially for tree injuries, is the large amount of quite recently deceased *Ulmus glabra*, in area 6, that may have fallen on the trees next to them and causing more injuries on smaller trees than would otherwise be observed.

3.3.4 Site conditions

Site conditions may affect development of TreMs (Larrieu et al., 2022). Site conditions such as soil moisture and soil acidity can also influence tree species composition and thus TreM assemblages, yet it is usually less important than age and species when influencing TreM assemblages (Larrieu et al., 2022). Other factors such as the occurrence of herbivores damaging the tree bark of certain tree species can also affect the occurrence of TreMs (Larrieu et al., 2022). Other more direct TreM related site factors are the occurrence of woodpeckers and their size (Larrieu et al., 2022). Site topography may also have an effect on TreMs, rocks can fall and other tree injuries that can be caused by abiotic factors can happen (Larrieu et al., 2022), it can also affect tree species composition such as beech that grows well on slopes in Sweden (Skogskunskap 3, 2024). To summarize, several other factors than tree species and size influence TreM formation.

The area of Krubbemölla contains a large variety of soil substrates, bedrock, glacial river sediment, sand flood deposit, sandy moraine, sand glacial river sediment and clay moraine. This means that the study area may show large differences between growing conditions for each species. It also has some steep slopes, with the highest 83 m in elevation and lowest around 56 m (Lantmäteriet). The study area showed to have varying amounts and variation of TreMs and different amounts of trees in the area, see appendix 4, yet it is difficult to say if this was due to the impact of the geology of the area or other factors.

3.3.5 Salix caprea

S. caprea showed to be a very important tree species, that was in the top for TreM variation, epiphytic and epixylic structures and fruiting bodies, and it also shared the top spot with total amount of TreMs, cavities and tree injuries. This could be because of *S. caprea* has soft wood (Skogskunskap 1, 2024), is a fast-growing pioneer species, with irregular cracked bark, is shade intolerant and flood sensitive (Enescu et al., 2016). The soft wood could be easier for woodpeckers to forage and build nests, and for insects to live in (Vuidot et al., 2011). There were woodpeckers found during the fieldwork, at least two different species, see appendix 2, and they have been seen in the area before as well. One can also see in appendix 3 that only *S. caprea* and *A. glutinosa* had woodpecker breeding cavities and that *S. caprea* had many woodpecker foraging excavations. The irregular cracked bark could possibly create more cracks/bark loss and open heartwood. As it is fast growing the tree reaches its maturity earlier than some other species and therefore comes in the age where TreMs are more common. As seen in the Kruskal-Wallis test, the diameter of the tree is important, and the higher the diameter the more TreMs are there. It is also shade intolerant and as the Krubbemölla area used to be more open in the past but the forest has expanded outwards, more shade has come upon the *S. caprea* trees in the area, which possibly has caused more deadwood at the top of the trees. It is also flood sensitive and as explained in the appendix 1 many of the areas were very wet, and could be prone to flooding, causing the *S. caprea* being more prone to stress and therefore damages causing more TreMs on the tree.

3.3.6 Quercus robur

Q. robur had a lot of TreMs and shared the highest amount of TreMs found with *S. caprea*. It also had the highest amount of crown deadwood, probably due to the high number of dead branches found in almost all of the individuals. *Q. robur* has good woodworking qualities such as hardness, durability, and rot resistance (Skogskunskap 2, 2024). The faster the oak grows the harder the wood becomes, the oak also dries out very slowly, and risk of it cracking in the process is large (Skogskunskap 2, 2024). If the oak grows on sandy soils or bedrock, it can become crooked and branchy, if left alone the oak can become very large in diameter (Skogskunskap 2, 2024). *Q. robur* is a light demanding tree that can grow up to a 1000 years old (Eaton, 2016) As the old oaks in the study area have been previously growing in an open field or meadow, they have had time to grow fast and wide. However, currently they have been encroached by neighboring woody vegetation, which may explain why they have so much crown deadwood as oak is a light demanding species. This may also explain why there is such a large difference in TreMs between young and old oaks, as the older oaks have had time to grow large and have been more affected by the somewhat recent forest growing around them, whilst the oaks with smaller diameter have not had such a great change in their environment and therefore have not been as stressed, making them less susceptible to develop TreMs. According to Vuidot et al. (2011), oaks had significantly larger number of micro-habitats per individual than other trees. This is similar to the findings by Vuidot et al. (2011). That study mentions that oaks had more TreMs than beech which was also found in this study. Vuidot et al. (2011) also mention that more deadwood occurs on oaks and more cracks on beech. Yet this may be because the study method of TreMs differ, where Vuidot et al. (2011) only recorded the presence of TreM types, while this study counted each individual TreM. Therefore, it may be better to compare between TreM type variation instead. There one can see that *Q. robur* only had a higher TreM variation than *A. glutinosa* and *A. platanoides*.

3.3.7 Alnus glutinosa

A. glutinosa was for the most part lower in TreMs or had no observable difference to the other tree species. This may be because *A. glutinosa* either does not get that many TreMs in general or that the trees were too young. According to the study by Acloque et al. (2023), *A. glutinosa* is a very important species that supports specific TreMs. It seems likely that the grouping into forms (see appendix 3 root buttress concavity) and that only around 6% of all the *A. glutinosa* trees in the area were over 50 cm in diameter is the reason for the low occurrence of TreMs on *A. glutinosa* in this area. This uneven amount between small and large trees may also be the reason why, except for excrescences, TreM total and TreM variation, stem size showed to have little impact.

3.3.8 *Prunus avium*

P. avium had a significant higher amount of exudates compared to the other tree species. *P. avium* also seemed to have more dendrothelms than the other species and some were noted down (appendix 3), though many that could have been dendrothelms were left out due to the angle of the binoculars making it impossible to determine if they could hold water or not/if there was a hole at all. Another thing that may have affected the result for *P. avium* is that woodpeckers dislike resinous trees to nest in (Cabanettes et al., 2012), and as seen in the results *P. avium* had the greatest number of exudates. The trees were also generally in the smaller dbh group and as TreMs increase with tree size (Przepiora and Ciach, 2023) that could also be an explanation for the generally low number of TreMs.

3.3.9 *Fagus sylvatica*

F. sylvatica has a very hard and tough wood but is not resistant to rot and insects. Beech trees can become around 400 years old and have a smooth bark. They usually have layered straight branches (Skogskunskap 3, 2024). As *F. sylvatica* had many intervals that overlapped it is hard to say if its wood qualities had an effect on TreMs, yet it may be more dependent on that *F. sylvatica* is a more slope-oriented tree and it may not have grown best in the varied environment around Krubbemölla and therefore had more tree injuries than *A. glutinosa*. It could also be that the *F. sylvatica* trees were found in more specific spots close to area 6, where there had been a lot of natural deaths of trees that had then fallen over and damaged the beeches, whilst *A. glutinosa* was found all around in the area.

3.3.10 *Acer platanoides and Fraxinus excelsior*

Something that was not expected in the results is the lack of crown deadwood for *F. excelsior*. It would be expected that they would be very affected by the ash dieback but as the results show it may not be as affected or the trees that were affected have already died and are lying down.

According Przepiora and Ciach (2023), Norway maple had more TreMs compared to oaks. This study shows the opposite, which probably is due to the size difference between *Q. robur* and *A. platanoides*. There was only one maple above 50 cm in size whilst there were 25 oaks larger than 50 cm, and in the study by Przepiora and Ciach (2023), the diameter had a large impact on the occurrence of TreMs.

3.4 Limitations

The measuring of TreMs in trees was sometimes limited by the terrain and weather conditions. This was due to there being a stream in the middle of the stand and herbaceous vegetation making it difficult to pass through and stand stable and thus making it difficult to inventory. The weather was also not always in favour and when it hailed it made it difficult to identify and/or spot TreMs higher up in the trees. The terrain also sometimes made it impossible to measure the thinnest part of the stem as other trees were in the way. Also, as the trees had not all buds down in the lower part/clearly visible part it sometimes made it difficult to assess which tree species it was. Another limitation was that the inventory was only conducted in a single study area. The study was also limited to TreMs visible during spring and therefore most fungi and epiphytic vascular plants were not visible. One can also argue that the data is partly biased, as for example every individual dead branch was counted whilst bryophytes were not, as it is hard to decide the quantity of bryophytes without additional tools. Finally, it could be due to difficulties seeing at the top of the trees when inventorying for *F. excelsior*, as compared to *Q. robur* the dead branches were not as obvious. This may be the reason as to why there was less dead branches and crown deadwood registered in *F. excelsior*.

4. Conclusions

To conclude, the data collected in this study support the hypothesis that the total number of TreMs and the variation of TreM types vary with species and size of tree. There is a large difference between tree species when it comes to the type and amount of TreMs that were found. *S. caprea* had the highest amount of TreM variation, epiphytic and epixylic structures and fruiting bodies. *Q. robur* had the largest amount of crown deadwood and the largest amount of TreMs per individual together with *S. caprea*. *F. sylvatica* and *S. caprea* had the greatest number of cavities and tree injuries. *P. avium* had the greatest number of exudates, and excrescences did not seem to differ between species. The difference between large and small trees was observable for the most part when observing all of the species together, except for fruiting bodies and exudates. For the total amount of TreMs there was a clear difference between the large and small trees for all species. Tree injuries may be influenced more by environmental factors than dbh. TreM occurrence is likely more related to the trees developmental stage rather than dbh. Tree species develop differently and can host TreMs at different ages. Yet other factors may play a role as well like soil conditions, competition and species like woodpeckers being present. *S. caprea* and *Q. robur* should be maintained and promoted in the area to increase biodiversity, but other species should also be maintained as they provide other types of TreMs. This study highlights the complexity of TreM formation but shows that species form different amount and types of TreMs, and as stem diameter increases the amount of TreMs also increases.

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Acknowledgements

I want to thank Thomas Palo and Albo härads hembygdsförening that offered the project and let us do the inventory in their area. A special thanks to my supervisor Jörg Brunet for guiding me in this project and providing invaluable insights. Also, thanks to Kristina Johansson for lending me her car, and to Christian Johansson for helping identifying birds and mushrooms in the area. Finally, thanks to Daniel Wiking Holm for helping with the data collection.

Appendix 1

Description of the studied subsections

Section 1

Section 1 is divided into two smaller areas of old forest, these were located in the middle of the forested area of Krubbemölla. They were dominated by larger trees. In area 1 there were 44 trees inventoried. Section one is in the middle of the area with one part located more south than the other. The southern part is quite damp and is also quite open, it has two very big old oaks that dominate the area. The northern part of the area is on top of a slope and is much drier, it also had some orchids.

Section 2

In section 2 there were 46 trees, it is a gorge running through the middle of the area going westward with the stream. It has a mixture of very large trees in the borders west and east and in the middle section were many trees that were under 30 cm. The surrounding area is mostly fields and through the middle of the area, an old path (kärlekstigen) goes but is now mostly unwalkable as it has many elms and ash trees fallen over it.

Section 3

Section 3 of the forested area in Krubbemölla consisted mostly of *A. glutinosa glutinosa* in the most northern part and was swampy/wet with a stream running through it. When going more south the area opened up and on "ön" it was very open and oaks and other trees grew there. The leaflitter was also removed in this part and grass was growing, but in other parts the litter were not removed. The area has several layers with some hazels at the bottom and bushes and taller trees above. It is a very thin area with a lot of light going through it. Around it there are pastures/open fields. It is also the lowest point according to Lantmäteriets measurements (Lantmäteriet). 62 trees were inventoried in this area.

Section 4

Section 4 has a stream running to the south of it and is dominated by oak trees. It crosses over the stream as it moves further south. It is open with large oaks and one can see the mill in the west. The path of Krubbemölla goes through it. It is managed and has no leaves on the ground and the association is currently working on removing dead trees from the stream as seen when doing the fieldwork. At the edges there were some alders both towards the stream in the south and towards section 5 to the north. It is very soggy but probably would be less soggy other times of the year as it has rained a lot this spring. There were 103 trees inventoried in this area.

Section 5

In section 5 there were 226 trees. Area 5 went north to south in the middle of the forested area. It was made up of mostly *A. glutinosa* and was quite damp especially in the southern part of the section. In the most northern part of the area which was higher up in the landscape, north of the path, there was a lot of oaks. In the middle part of the area there was a swamp like area with lots of *P. padus* of smaller sizes.

Section 6

Section 6 was dominated by *U. glabra* and *F. excelsior* but due to ash dieback they have for the most part died and the section is quite empty of living trees except along the borders. There is a swamp to the west of the section where large bushes and small trees have grown. The area has a slope in the north and a stream in the south and has a large quantity of deadwood making it hard to pass through.

Section 7

In section 7 there were 84 trees. It is located higher up compared to areas 1, 3-6 of Krubbemölla and therefore dry compared to the other areas. It has a mixture of *P. avium* and oaks and on its northern border there are some *S.* caprea and then a field. There were some *Corylus avellana* and small *U. glabra* and *F. excelsior* in the area as well. There were also some orchids in this area.

Appendix 2

Table 11. Species noted during the inventory that were not trees. Shown are English name, Swedish name and Latin name.

Common name	Swedish name	Latin name
Hollow root	Hålnunneört	*Corydalis cava*
Suffolk lungwort	Mörk Lungört	*Pulmonaria obscura*
Wood anemone	Vitsippa	*Anemone nemorosa*
Yellow wood anemone	Gulsippa	*Anemone ranunculoides*
Yellow Star-of-Bethlehem	Vårlök	*Gagea lutea*
Red-belted conk	Klibbticka	*Fomitopsis pinicola*
Red Kite	Rödglada	*Milvus milvus*
Great tit	Talgoxe	*Parus major*
Eurasian blue tit	Blåmes	*Cyanistes caeruleus*
Common chaffinch	Bofink	*Fringilla coelebs*
Eurasian blackbird	Koltrast	*Turdus merula*
Grass/ Moor/ Agile frog	Vanlig/åker/långbensgroda	*Rana temporaria/ arvalis/ dalmatina*
Common raven	Korp	*Corvus corax*
Blackcap	Svarthätta	*Sylvia atricapilla*
Butterbur	Pestskråp	*Petasites hybridus*
Green elfcup	Grönskål	*Chlorociboria aeruginascens*
Eurasian wren	Gärdsmyg	*Troglodytes troglodytes*
Black Woodpecker	Spillkråka	*Dryocopus martius*
Resinous polypore	Sydlig sotticka	*Ischnoderma resinosum*
Common toothwort	Vätteros	*Lathraea squamaria*
Jelly ear	Judasöra	*Auricularia auricula-judae*
False Puffball	Sotägg	*Reticularia lycoperdon*
Violet oil beetle	Violett majbagge	*Meloe violaceus*
Early purple orchid	Sankt Pers nycklar	*Orchis mascula*
Eurasian jay	Nötskrika	*Garrulus glandarius*
Treecreeper	Trädkrypare	*Certhia familiaris*
Great/lesser spotted Woodpecker	Större/mindre hackspett	*Dendrocopos major/ Dryobates minor*

Appendix 3

Table 12. Individual types of TreMs found in Krubbemölla. Trem types are grouped in seven main forms and total number of individual TreMs per type and tree species are given.

TreM type	*Species*							Total
	S. caprea	Q. robur	P. avium	F. excelsior	F. sylvatica	A. glutinosa	A. platanoides	
Cavities								
Small woodpecker breeding cavity	1	0	0	0	0	4	0	5
Medium-sized woodpecker breeding cavity	1	0	0	0	0	3	0	4
Large woodpecker breeding cavity	0	0	0	0	0	3	0	3
Woodpecker “Flute”	0	0	0	0	0	1	0	1
Trunk-base rot-hole	4	4	0	7	2	40	1	58
Trunk rot-hole	2	2	3	3	2	9	0	21
Semi-open trunk rot-hole	1	0	1	1	1	0	0	4
Chimney trunk-base rot-hole	0	0	0	0	0	0	0	0
Chimney trunk rot-hole with no ground contact	0	0	0	0	0	0	0	0
Hollow branch	1	0	0	2	0	1	0	4
Insect galleries and bore holes	15	8	0	11	0	41	0	75
Dendrotelm	0	0	3	2	3	4	0	12
Woodpecker foraging excavation	19	2	0	0	0	3	0	24
Bark-lined trunk concavity	2	0	0	0	0	3	0	5
Buttress-root concavity	3	3	8	0	9	51	4	78
Tree injuries and exposed wood								
Bark loss	5	11	2	8	5	14	0	45
Fire scar	0	0	0	0	0	0	0	0
Bark shelter	3	9	0	1	0	0	0	13
Bark pocket	12	3	3	2	1	10	0	31
Stem breakage	3	1	0	0	2	6	0	12
Limb breakage	7	1	2	4	3	10	0	27
Crack	5	3	0	0	2	4	0	14

Lightning scar	0	0	0	0	0	0	0	0
Fork split at the intersection	0	0	0	0	0	0	0	0
Crown deadwood								
Dead branches	49	256	14	24	5	100	1	449
Dead top	1	0	0	2	0	0	0	3
Remnants of a broken limb	13	5	0	3	4	4	2	31
Excrescences								
Witches' broom	0	0	0	0	0	0	0	0
Epicormic shoots	0	7	0	1	1	16	0	25
Burr	8	19	5	14	0	44	0	90
Canker	0	11	0	0	0	8	0	19
Fruiting bodies of saproxylic fungi and slime moulds								
Perennial polypore	8	0	0	0	0	0	0	8
Annual polypore	0	0	0	1	0	1	0	2
Pulpy agaric	0	2	0	0	0	0	0	2
Large pyrenomycete	0	2	0	0	0	0	0	2
Myxomycetes	2	4	0	0	0	0	0	6
Epiphytic and epixylic structures								
Bryophytes	22	9	0	1	1	12	0	45
Foliose and fruticose lichens	0	0	0	0	0	0	0	0
Ivy and lianas	0	0	0	0	0	0	0	0
Ferns	0	4	0	0	0	0	0	4
Mistletoe	0	0	0	0	0	0	0	0
Vertebrate nest	6	1	0	1	1	14	1	24
Invertebrate nest	1	0	0	0	0	0	0	1
Bark microsoil	3	5	0	0	0	0	0	8
Crown microsoil	8	2	4	1	2	4	1	22
Exudates								
Sap run	4	3	10	0	0	12	0	29
Heavy resinosis	0	0	4	0	0	0	0	4

Appendix 4

Table 13. Data on the sub-areas of the study.

Area	Size, ha	TreM total no.	TreM variation, no.	Tree no.
Area 1	0.27	172	97	39
Area 2	0.62	108	66	29
Area 3	0.33	72	54	56
Area 4	0.67	176	80	34
Area 5	0.88	429	338	213
Area 6	0.34	No data	No data	No data
Area 7	1.10	253	130	72
Total	4.21	1210	765	443

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