Differences in forest characteristics between potential green infrastructure areas and other forest areas in the south of Sweden

A study of indicators of forest quality for conservation

IDA BRONNER THELIN 2021
MVEK02 BACHELOR THESIS 15 HP
ENVIRONMENTAL SCIENCE | LUND UNIVERSITY

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2021

Picture: Dalby Söderskog National Park, Skåne, Sweden
Photo: Ida Bronner Thelin

LUND UNIVERSITY

Ida Bronner Thelin

MVEK02 Bachelor thesis 15 hp, Lund University

Supervisor's: Tristan Bakx, PhD Candidate, Department of Physical Geography and Ecosystem Science, Lund University, Cecilia Akselsson, Associate Professor, Department of Physical Geography and Ecosystem Science, Lund University

CEC – Centre for Environmental and Climate Science
Lund university
Lund 2021

Abstract

Biodiversity is today rapidly decreasing, and one of the main threats is land use intensification in forest landscapes. By improving the forest quality in the surrounding landscape of protected areas, the level of biodiversity could increase, and green infrastructure areas have been proposed as a method in Sweden. These areas are called Valuable Forest Areas (VFAs), and contain high densities of so-called value cores consisting of formally and non-formally protected land. I compared aspects of forest quality between the VFAs and other forest areas in southern Sweden. The relevant indicators for forest quality that were chosen were the amounts of deadwood and relative tree species cover. I found that there were significantly higher amounts of total deadwood and higher percentages of Scots pine in the VFAs, compared to the other areas. In conclusion, the Scots pine forest contributes to higher biodiversity in the understory vegetation, which disappears when the tree species cover is replaced with Norway spruce. Therefore, the Scots pine forest in the VFAs should be maintained and not replaced with Norway spruce, which is a common management method in southern Sweden. The amount of deadwood should also be maintained and improved in the VFAs since I found in average very low amounts of deadwood, which has an important function for many red-listed species. It ought to be discussed if the VFAs should have extra protection and if further policies are needed.

Keywords

Valuable forest areas, green infrastructure, south of Sweden, deadwood, tree species cover, biodiversity conservation

Popular Abstract (Swedish)

Grön infrastruktur kan bevara skogens biodiversitet

Du kanske minns från när du var liten och besökte ett naturreservat, hur mjuk mossan var, och du hörde fåglarna sjunga högt där uppe bland trädkronorna. Skogen var levande och kryllade av alla möjliga sorters insekter, mossor, lavar, blommor och träd. Den vittnade om en hög biologisk mångfald som är nödvändig för att våra ekosystem ska fungera och för att generera de produkter och nyttor vi efterfrågar. Naturreservat, nationalparker och andra skyddade områden behövs för att vår biologiska mångfald ska bevaras till kommande generationer. Skyddade områden är dock inte alltid tillräckliga för att bevara biologisk mångfald eftersom de kan vara för små eller för långt ifrån varandra. Därför har den svenska regeringen tillsatt ett handlingsprogram där Sveriges länsstyrelser främjar grön infrastruktur som fungerar som naturens motorvägar. Den gröna infrastrukturen kan koppla ihop skyddade områden så att de kan bli mer livskraftiga.

Biodiversitet utgör grunden för grön infrastruktur. Därför har jag undersökt om skogen i närheten av skyddade områden har extra hög kvalitet, och jag har studerat två olika saker som kan indikera på en stor biologisk mångfald; förekomst av död ved och hur mycket vissa trädarter dominerar ett skogsområde. Död ved fungerar som hem och parningsplats för många arter, därför har områden med hög andel död ved ofta hög biologisk mångfald. Död ved har dock blivit mer sällsynt i dagens skogsbruk. Jag hittade låga mängder död ved i de studerade skogsområdena, men jag såg också att andelen död ved är högre i områden som omges av skyddade områden.

Jag fann också i min studie att det växte mer tall i områden runt skyddade områden, än vad det gjorde i andra skogsbestånd. Även det kan indikera på en rik biologisk mångfald, då tallar ger utrymme för många markväxande arter. I södra Sverige är det dock vanligt att ersätta tall med gran eftersom granen växer mycket fortare. Problemet är dock att granen leder till mycket tätare bestånd, som inte släpper in något ljus till marken under sig. Det leder till att de arter som frodats under tallen inte längre trivs i granskogarna. Jag hittade även generellt väldigt små mängder av lövträd, både i skogsområden i närheten av skyddade områden och i andra skogsområden. Lövträd uppblandat med tall- och granskog är viktiga för den biologiska mångfalden. Lövskogen brukade dominera de södra delarna av Sverige, men då gran och tall premieras av skogsägare är trädarterna ganska sällsynta idag, och därför är många av arterna som är beroende av dessa träd hotade.

För att skogsområdena ska kunna fungera som grön infrastruktur, behövs det en större andel död ved och lövträd i områdena runt de skyddade områdena. Även skogsbestånden av tall behöver stå kvar. Studien kan därför vara relevant för skogsägare eller för beslutsfattare på regional eller nationell nivå som utvärderar vilka åtgärder som behövs i södra Sverige för att skapa grön infrastruktur. Genom att skapa bättre grön infrastruktur kan vi tillsammans bevara den biologiska mångfalden!

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1. Introduction

Biodiversity is today rapidly decreasing, and it is argued that we are living in the 6th mass extinction on Earth (Ceballos et al., 2015). One of the main threats to biodiversity is land use change and intensification in forest landscapes which leads to felling of valuable sites, fragmentation and loss of habitats (Allan et al., 2014; Hanski, 1999; Tilman et al., 2001). This threatens not only biodiversity but also ecosystem services (Allan et al., 2015).

Protected areas can be used as a tool to conserve habitat and species richness (Geldmann et al., 2013). However, to only use protected areas as a conservation method has been demonstrated to sometimes be insufficient, since the level of biodiversity is still decreasing (Halley et al., 2016). One way to supplement nature protection is to improve the quality of the surrounding landscape, or the so-called matrix, by diversifying the forest landscape (Felton et al., 2020; Kremen & Merenlender, 2018). When the matrix consists of a high-quality mosaic of different land uses, supporting both biodiversity and human needs, the level of biodiversity can increase (Kennedy et al., 2011; Mendenhall et al., 2014; Reynolds et al., 2017). In landscapes managed by humans, the matrix type has been found to have a profound impact on biodiversity, since it can be used as a tool to impair species going extinct (Daily et al., 2001; Kennedy et al., 2011). Therefore, the connectivity between protected areas can increase by improving the quality of the matrix. This is called green infrastructure, which can both protect biodiversity and deliver ecosystem services (Bovin et al., 2017; European commission, 2010; Liquete et al., 2015; Ward et al., 1999).

In Sweden 58 % of all land is covered by forests that are used for wood production (Nilsson et al., 2020). Natural or undisturbed forests have become very rare in Sweden, with most trees being planted (Peterken, 1996; Von Oheimb et al., 2005). There is little natural forest left that is not affected by human interventions, and the seminatural forests that still exists are being clear cut (Kouki et al., 2001; Svensson et al., 2019). Clearcutting is the most common harvesting method in forestry practise, creating even-aged, mostly coniferous forests (Lundmark et al., 2013; Östlund et al., 1997). Forestry management with short-rotation systems has proved to have an impact on plant community biodiversity (Ferris et al., 2000). According to Ram et al. (2017), since 1998 after the Swedish Forestry Act 1993, which promoted measures intended to be beneficial for biodiversity, the amount of old growth forests and forest structures beneficial for birds have increased. During the last decade the positive trends have stabilised, potentially in part due to warmer climate (Ram et al., 2017). Further intensification of the forest management could however reduce the benefits of biodiversity from protected areas (Aune et al., 2005; Johansson et al., 2018). Furthermore, there are currently approximately 2000 forest associated species in Sweden on the red-list (Felton et al., 2020; Sandström, 2015). Many of those species are specifically threatened by clearcutting and forest felling (Sandström, 2015). Decreasing biodiversity could further threaten endangered species but also the livelihood for future human generations, and Sweden is currently not on track to meet the Swedish national environmental goals of living forests, "*Levande skogar*" and sustained biodiversity, "*Ett rikt växt- och djurliv*" (Naturvårdsverket, 2012, 2017, 2018).

Green infrastructure for forest landscapes has been proposed in Sweden as a tool to conserve biodiversity in the form of Valuable Forest Areas (VFAs, "skogliga värdetrakter" in Swedish) (Bovin et al., 2017). These VFAs defined as areas with high densities of so called "value cores" (Swedish: "värdekärnor"), which include both formally protected forest areas (e.g. nature reserves and national parks) and not formally protected forest areas (e.g. keystone habitat areas and voluntary set-asides for biodiversity consideration) (Bovin et al., 2017). An example is Söderåsen National Park in northwest of Skåne in Sweden, which is a value core, and the surrounding forest is a VFA (figure 1). Therefore, it is of value to study if the forests within these green infrastructure areas are of better quality for nature conservation than other forest areas. By potentially conserving the quality of the VFAs in the forest landscape, they can function as a buffer for the protected areas, increasing nature conservation efforts, and connecting the protected areas to one another (European commission, 2010). Furthermore, by supporting biodiversity in surrounding land management, ecosystem services and natural resources can be maintained. At the same time it can provide accessory habitats and resources, and facilitate dispersal and climate change adaption for species (Kremen & Merenlender, 2018).

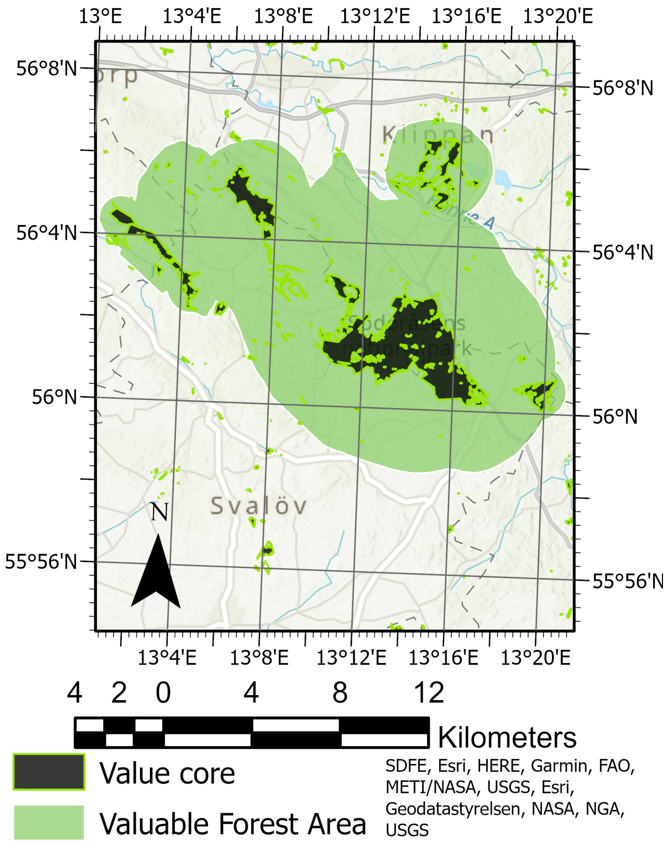

Figure 1. Map of Söderåsen National Park in north-western Skåne, Sweden.

The dark green are examples of value cores, and the lighter green are an example of a VFA.

Here, I evaluated differences in two indicators of forest quality for biodiversity between VFAs and other forest areas in southern Sweden. I have specifically focused on two indicators of forest quality which are important from a southern Swedish perspective, namely relative tree species cover and deadwood, as techniques used in modern forestry have made changes in amount of woody debris and forest heterogeneity in managed forests (Christensen & Emborg, 1996).

Deadwood is the first indicator of biodiversity that I studied here, as forests used for production are usually eliminating or decreasing the amount of deadwood (Blaser et al., 2013). Thus, deadwood is an important indicator of forest biodiversity in boreal and temperate forests, since of the 2000 red-listed species in Sweden, more than 700 are dependent on deadwood (Esseen et al., 1997; Larsson et al., 2011; Paillet et al., 2010). This has made species depending on this type of habitat rare, and except for a decrease in volume, the composition of deadwood has also changed in terms of tree species, diameter distribution and decay classes (Blaser et al., 2013; Jönsson et al., 2007; J N Stokland et al., 2004). Especially large standing dead trees, which have the potential to harbour a high number of species, are uncommon in managed forests (Lonsdale et al., 2008; Siitonen, 2001). However smaller deadwood items are important as well, as the variation of deadwood with different stages of decay are important for the formation of ecological niches, where species specialises on certain types of deadwood (Blaser et al., 2013; Odling-Smee et al., 2013). Decaying wood in situ is also important for the regeneration of the forest and the function of not only the animal wildlife, but also for the trees (Lonsdale et al., 2008).

The second indicator of biodiversity was relative tree species cover, with a mixed forest indicating higher biodiversity. The native species of Norway spruce *(Picea abies)* and Scots pine *(Pinus sylvestris)* are the most common species in Swedish silviculture, covering approximately 80 % of all standing volume (Nilsson et al., 2017, 2019). The species are very common in production forests because they are softwood conifers with higher growth rate than hardwood deciduous trees (Silvy et al., 2018). Temperate deciduous species such as Beech *(Fagus sylvatica)* and Oak *(Quercus)* are much rarer in Swedish production forests (Heilmann-Clausen & Christensen, 2004; Magura et al., 2002). In south of Sweden the more slow-growing, temperate deciduous species used to historically dominate the forest landscape, with elements of conifer trees, but today it is rather the opposite (Björse & Bradshaw, 1998). Thus, a forest type of temperate deciduous forest mix could be an indicator of high biodiversity (Heilmann-Clausen & Christensen, 2004; Magura et al., 2002). Especially in the southern parts of Sweden many threatened species are associated with this covering type and this type of habitat is also generally species rich (Björse & Bradshaw, 1998; Naturvårdsverket, 2000). Recently, there has been raised concerns because of stands of Scots pine are being replaced by Norway spruce in production forests in southern Sweden (Lindbladh et al., 2019). This conversion can cause a loss of biodiversity, since Scots pine and Norway spruce are supporting different plant communities, with Scots pine supporting a higher abundance of species, whereas Norway spruce limits the understory vegetation (Petersson et al., 2019).

1.1 Aim and hypothesis

The aim of the study is to evaluate if there is any difference in forest quality from a perspective of biodiversity conservation between forests in VFAs and outside VFAs in the southern Swedish counties of Skåne, Halland, Blekinge and parts of Västra Götaland (former Bohuslän and Göteborg). This study is part of an ongoing study at Lund University about VFAs and their relationship with biodiversity. I hypothesize that the amount of deadwood will be higher, and that there are more mixed forests in the VFAs than outside the VFAs with higher proportions of deciduous broadleaved trees, indicating a higher forest quality in the former than in the latter.

1.1.1 Problem statement:

- *Is the biodiversity higher in Valuable Forest Areas than in areas outside of Valuable Forest Areas?*

2. Method

I performed all data management and analyses in R (R Core Team, 2020), making an analysis on forest data collected from counties in the southern, nemoral part of Sweden. I compared the means of the two groups of VFAs and non-VFAs regarding indicators (deadwood and relative tree species cover) of forest quality by using a Mann Whitney U-test. The forest data covered a time span of 5 years (2015-2019).

2.1 Forest data

The forest data was derived from the Swedish National Forest Inventory and the Swedish Environmental Protection Agency. In the National Forest Inventory, measurements are made annually, with the purpose to describe the state of the Swedish forests, and provide data for estimating trends about the development of the forests and soil conditions. The inventory is production focused but also environmental variables are used. It is implemented as a sample survey, which is based upon a systematic web of so-called inventory areas. These inventory areas consist of smaller, survey plots, outlaid in a square shape.

2.2 Valuable forest area data and data selection

The Swedish Environmental Protection Agency has, based on summarized data from all formally but also non-formally protected areas, created maps which covers areas in Sweden that are defined as value cores and VFAs. The high density of value cores which defines the VFAs consists of protected areas which are already evaluated to contain high nature values of flora and fauna or prioritised forest types (Naturvårdsverket & Skogsstyrelsen, 2017). The VFAs are evaluated to potentially contain high nature values on a landscape scale, such as biological important structures, functions and processes (Länsstyrelsen Västerbotten, 2016). The VFAs are potentially green infrastructure areas based on the theories of increasing species richness with increasing area and decreasing species richness with increasing isolation. Furthermore, there was a demand that at least 10 % of all forest covers was to be suggested as VFAs (Bovin et al., 2017).

Data was available at a national scale, but I limited the study to the southern part of Sweden, covering only the nemoral forest-parts (figure 2), corresponding to region 5 of the National Forest Inventory (NFI) survey except Gotland (see region 5, field instructions NFI; (Odell, 2020)). The geographical areas that were included were Halland, Blekinge and the coastal parts of Västra Götaland; former Bohuslän and Göteborg. The data covered a time span of 5 years, from 2015 to 2019. In total data for 2144 survey plots were available for this region.

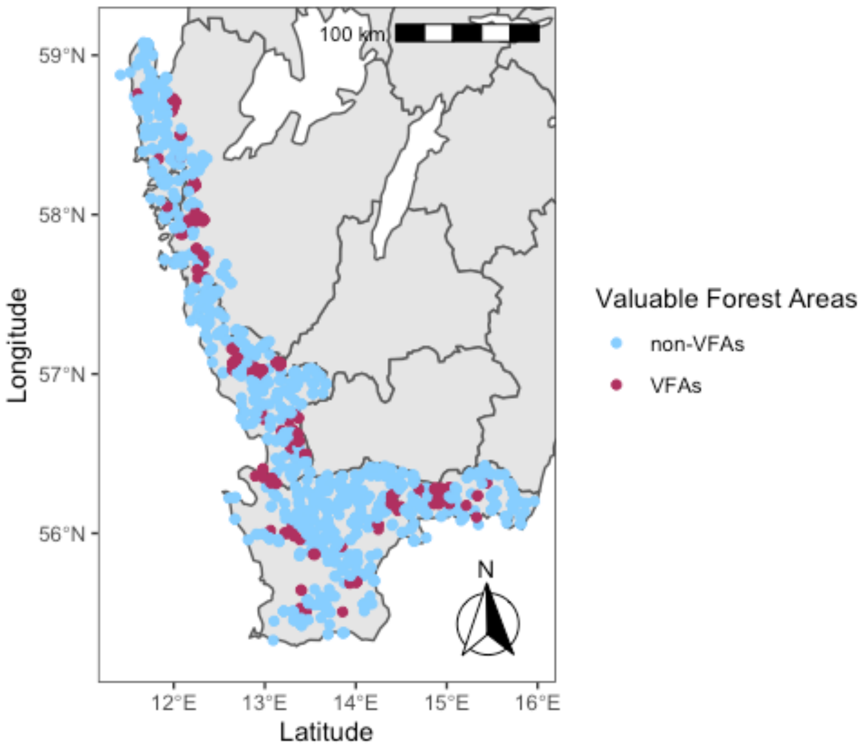

Figure 2. Plots in the selected counties included in the study, showing the VFA plots in blue and the non-VFA plots in in purple.

Only the nemoral zone of Sweden was included in this study, with the counties of Skåne, Blekinge, Halland and parts of Västra Götaland (former Göteborg and Bohuslän). Gotland which is also a part of this zone was excluded.

2.3 Measurement of deadwood and relative tree species cover

Wood was classified as dead when there was a complete lack of needles, leaves or buds. The volume of deadwood (m^3/ha) was measured in four different classes. The degree of degradation and position were classified into hard standing deadwood, hard lying deadwood, soft standing deadwood and soft lying deadwood (Odell, 2020). I calculated the total amount of deadwood as the sum of the four classes (table 1). Registered tree species is seen in table 2. The tree species cover was measured depending on basal area of all trees species classes, with the tree species cover based on the proportion of the total basal area for each tree species class. Development classes "no forest" (class A) and "young forest" (class B) was excluded in the study (see figure 6.1 and 6.2, field instructions NFI; (Odell, 2020)). The selection was done by reason of deadwood and the relative tree species cover variables were incomparable with the plots of the other developmental classes. I also excluded the tree species Lodgepole pine *(Pinus contorta)* since the occurrence was almost non-existent except for one plot in the study area, making statistical comparison impossible. After data filtering 1380 plots remained of which 237 plots were inside VFAs and 1143 plots outside.

Table 1. The subcategories of deadwood.

Definitions of deadwood used to measure total amount of deadwood, and the subcategories of hard, soft, lying and standing deadwood.

Hard standing deadwood	Hard laying deadwood	Soft standing deadwood	Soft lying deadwood
The amount of hard standing deadwood defined as deadwood that has barely decayed.	The amount of hard lying deadwood defined as deadwood that has barely decayed.	The amount of soft standing deadwood defined as deadwood that has already decayed.	The amount of soft lying deadwood defined as deadwood that has already decayed.

Table 2. Tree species and tree species classes included in the study.

All species are included in the statistical analysis. The classes are defined according to the Swedish Forestry Act (Skogsvårdslag SFS 1979:429).

Tree species
Beech *(Fagus sylvatica)*
Birch (Downy Birch - *Betula pubescens,* Silver Birch – *Betula pendula)*
Eurasian aspen *(Populus tremula)*
Norway spruce *(Picea abies)*
Oak (Common - *Quercus robur,* Sessile Oak - *Quercus patraea)*
Scots pine *(Pinus sylvestris)*
Tree species included in temperate broadleaved tree species
Common ash *(Fraxinus excelsior)*
Common hornbeam *(Carpinus betulus)*
European white Elm *(Ulmus laevis)*
Field elm *(Ulmus minor)*
Little leaf linden *(Tilia cordata)*
Norway maple *(Acer platanoides)*
Scots elm *(Ulmus glabra)*
Wild cherry *(Cerasus)*
Tree species included in non-temperate broadleaved tree species
Alder (Black Alder – *Alnus glutinosa,* Grey Alder – *Alnus incana)*
Hazel *(Corylus avellana)*
Sycamore maple *(Acer pseudoplatanus)*
Rowan *(Sorbus aucuparia)*
Sallow *(Salix caprea)*
Swedish whitebeam *(Sorbus intermedia)*

2.4 Simpson's diversity index

Simpson's diversity index (SDI) (equation 0.1) was used to measure evenness and species richness of the tree species, to estimate the dominance of a certain species. The index I used was Simpson's complemented index; D_1, which represents the probability of two random chosen individuals belonging to different species (Morris et al., 2014). The index value; *D* was calculated by n; the total number of organisms of a particular species, and N; the total number of organisms of all species. The range of *D* was between 0 and 1, with 1 representing infinite diversity and 0 no diversity (Simpson, 1949). The method of diversity index was used considering that other types of analysis was limited due to having the raw data only in percentage.

$$D = 1 - \left(\frac{\Sigma n(n-1)}{N(N-1)}\right) \tag{0.1}$$

2.5 Analysis

I have compared the difference in relative tree species cover and deadwood between VFA and non-VFA forest with a nonparametric Mann-Whitney U-test (Field et al., 2012). By ranking plots in the two groups, VFAs and the areas outside the VFAs were compared with each other, investigating if there was a significant difference in mean tree species cover, composition, and volume of deadwood between these two groups. I weighted the data by area because the represented area of each survey plot was different. To control which test that was the most optimal to use for comparing the mean of two independent groups, I estimated the distribution and variance by plotting histograms and performing Levene's test (Appendix, table 1, figure 1-3). The data set did not fulfil the assumptions of having a normal distribution and homogeneity of variance. Therefore, I used the weighted unpaired Mann Whitney U test, which does not have these assumptions and I determined it to be much more robust in this case. The null-hypothesis H_0 for the nonparametric test was that the mean of the two groups is equal, whereas the H_1 hypothesis was that the two populations are not equal. The test ranked the data from the lowest rank to the highest, giving the lowest score 1 and the next lowest a rank of 2 and so on. Furthermore, I plotted the data using violin plots appropriate for non-parametric data and calculated median- and mean, standard deviation and U-value.

3. Results

3.1 Deadwood

The total sum of deadwood was significantly higher in the VFAs than outside the VFAs ($p = 0.032$, figure 2, table 3). The median total deadwood was 2.8 m^3/ha inside VFAs and 1.2 m^3/ha outside VFAs. However, there was no significant difference in any of the subcategories of deadwood (table 3, figure 4).

The distribution of the deadwood between VFAs and outside of VFAs were largely similar for soft, lying- and standing deadwood but appeared more different for hard standing- and lying deadwood. The most abundant subcategories in both groups were hard standing and hard lying deadwood. The mean values for hard standing deadwood were 5.3 m^3/ha (sd = 13.3) in VFAs and 5.6 m^3/ha (sd = 17.3) in areas outside of VFAs, and there was no significant difference between the groups ($p = 0.218$). For hard lying deadwood the mean value in the VFAs were the highest of all subcategories of deadwood with 6.0 m^3/ha (sd = 6.0) with a lower mean of 3.9 m^3/ha (sd = 3.9) for the areas outside of VFAs. There were less amounts of soft lying deadwood (VFA: mean = 2.2, sd = 6.6) (non-VFA: mean = 1.9, sd = 8.1). Soft standing deadwood was most rare with a mean of 0.5 m^3/ha (sd = 2.3) for VFAs and 0.4 m^3/ha (sd = 2.7) for areas outside of VFAs. There was little difference between the two groups, which was indicated by the similar mean and the p-value of 0.941.

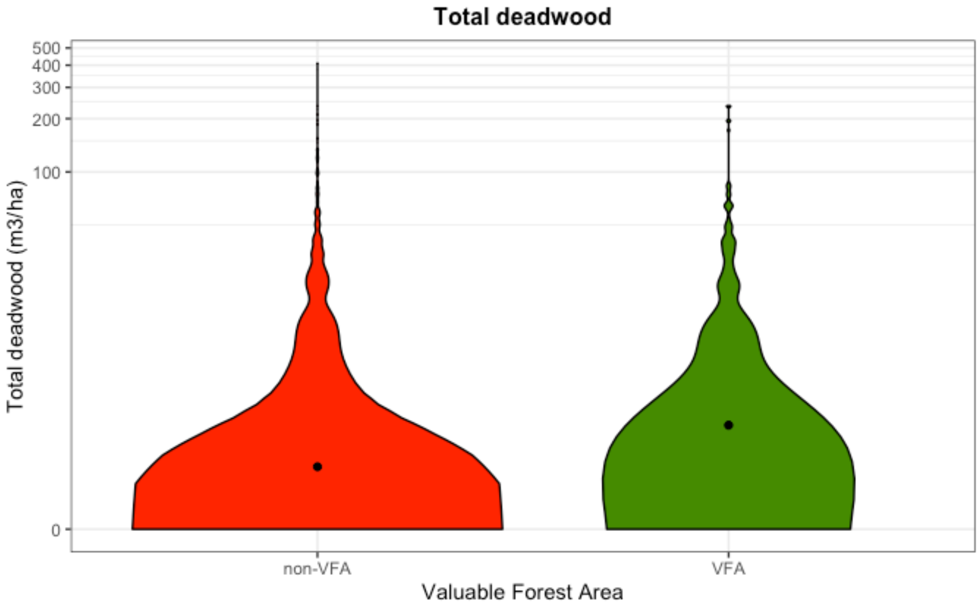

Figure 3. Logged violin plot of total deadwood (m^3/ha).

Weighted violin plot with log-transformed y-axis showing the density distribution of total deadwood in plots in VFAs and outside VFAs. The dots in the plot are median values.

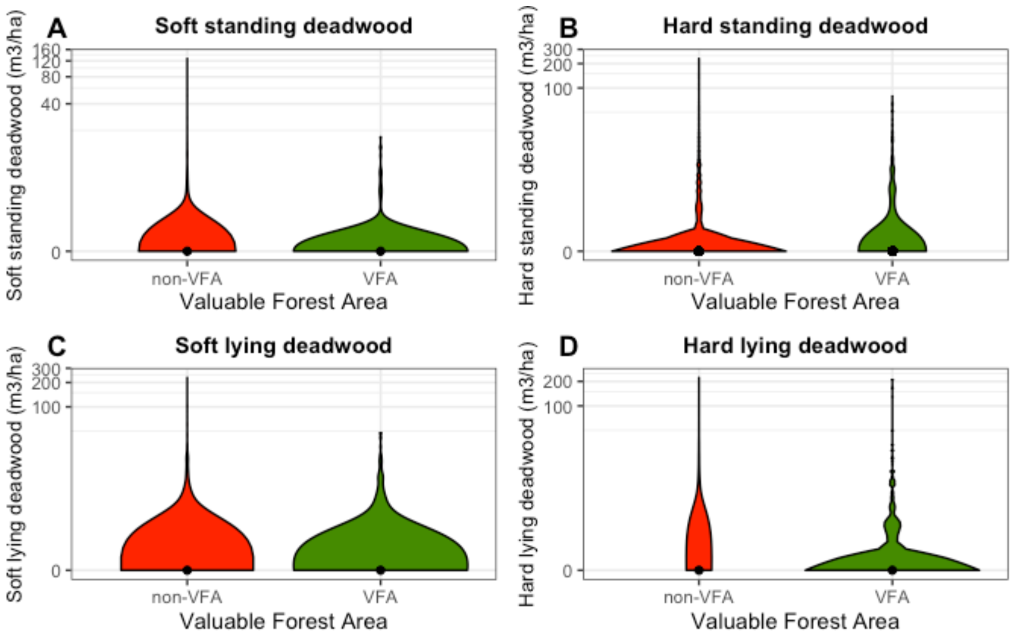

Figure 4. Logged violin plots of deadwood (m^3/ha).

Weighted violin plots with log-transformed y-axis showing the density distribution of total dead wood, soft standing (A), hard standing (B), soft lying (C) and hard lying (D) deadwood in plots in VFAs and outside VFAs. The dots in the plots are median values.

Table 3. Summary of results for deadwood and tree species evenness

The table shows a summary of results from the weighted Mann Whitney U test and from the weighted median, mean and standard deviation tests. All variables tested for estimating mean tree species cover, composition and amount of deadwood are included.

Variable	p-value	Median	Mean	Standard deviation	Sample size	U-value
Total deadwood (m^3/ha)	0.032	**VFA:** 2.8 **Non-VFA:** 1.2	**VFA:** 14.3 **Non-VFA:** 11.6	**VFA:** 33.2 **Non-VFA:** 28.9	**VFA:** 237 **Non-VFA:** 1143	2.1
Hard standing deadwood (m^3/ha)	0.218	**VFA:** 0 **Non-VFA:** 0	**VFA:** 5.3 **Non-VFA:** 5.6	**VFA:** 13.3 **Non-VFA:** 17.3	**VFA:** 237 **Non-VFA:** 1143	1.2
Hard lying deadwood (m^3/ha)	0.356	**VFA:** 0 **Non-VFA:** 0	**VFA:** 6.0 **Non-VFA:** 3.9	**VFA:** 6.0 **Non-VFA:** 3.9	**VFA:** 237 **Non-VFA:** 1143	0.9
Soft standing deadwood (m^3/ha)	0.941	**VFA:** 0 **Non-VFA:** 0	**VFA:** 0.5 **Non-VFA:** 0.4	**VFA:** 2.3 **Non-VFA:** 2.7	**VFA:** 237 **Non-VFA:** 1143	-0.1
Soft lying deadwood (m^3/ha)	0.355	**VFA:** 0 **Non-VFA:** 0	**VFA:** 2.2 **Non-VFA:** 1.9	**VFA:** 6.6 **Non-VFA:** 8.1	**VFA:** 237 **Non-VFA:** 1143	0.9
Pine (% of basal area)	0.022	**VFA:** 0 **Non-VFA:** 0	**VFA:** 24.7 **Non-VFA:** 20.4	**VFA:** 33.8 **Non-VFA:** 32.8	**VFA:** 237 **Non-VFA:** 1143	2.3
Spruce (% of basal area)	0.527	**VFA:** 20 **Non-VFA:** 20	**VFA:** 39.5 **Non-VFA:** 42.2	**VFA:** 40.8 **Non-VFA:** 42.5	**VFA:** 237 **Non-VFA:** 1143	-0.6
Oak (% of basal area)	0.682	**VFA:** 0 **Non-VFA:** 0	**VFA:** 6.1 **Non-VFA:** 6.5	**VFA:** 18.3 **Non-VFA:** 18.9	**VFA:** 237 **Non-VFA:** 1143	-0.4
Beech (% of basal area)	0.649	**VFA:** 0 **Non-VFA:** 0	**VFA:** 7.5 **Non-VFA:** 6.8	**VFA:** 23.3 **Non-VFA:** 22.1	**VFA:** 237 **Non-VFA:** 1143	0.5
Birch (% of basal area)	0.845	**VFA:** 0 **Non-VFA:** 0	**VFA:** 15.7 **Non-VFA:** 14.8	**VFA:** 25.0 **Non-VFA:** 26.9	**VFA:** 237 **Non-VFA:** 1143	-0.2
Aspen (% of basal area)	0.913	**VFA:** 0 **Non-VFA:** 0	**VFA:** 1.3 **Non-VFA:** 1.4	**VFA:** 6.9 **Non-VFA:** 7.9	**VFA:** 237 **Non-VFA:** 1143	-0.109
Non-Temperate Broadleaved(% of basal area)	0.204	**VFA:** 0 **Non-VFA:** 0	**VFA:** 4.5 **Non-VFA:** 6.2	**VFA:** 17.1 **Non-VFA:** 20.2	**VFA:** 237 **Non-VFA:** 1143	-1.3
Temperate Broadleaved (% of basal area)	0.509	**VFA:** 0 **Non-VFA:** 0	**VFA:** 0.8 **Non-VFA:** 1.7	**VFA:** 4.6 **Non-VFA:** 8.9	**VFA:** 237 **Non-VFA:** 1143	-0.7
Simpson's diversity index of all tree species (0-1)	0.389	**VFA:** 0.2 **Non-VFA:** 0.2	**VFA:** 0.3 **Non-VFA:** 0.2	**VFA:** 0.2 **Non-VFA:** 0.2	**VFA:** 237 **Non-VFA:** 1143	0.9

3.2 Relative tree species cover

There was a significant difference between the VFAs and the areas outside of VFAs (table 3, p = 0.022) when analysing the proportion of Scots pine cover, having a higher mean covering the VFAs of 24,7 % of basal area (sd = 33.8) compared to the non-VFAs with a mean of 20.4 % of basal area (sd = 32.8). However, there was no significant difference between the two groups for any other tree species analyzed, separately or together (Simpson's diversity index). Norway spruce was the species that had the highest average cover of all analyzed tree species (figure 4B), with the highest median and mean value with 20 % of basal area as median in both the VFAs and the non-VFAs (table 3, mean = 39.5, sd = 40.8, non-VFA: mean = 42.2, sd =42.5). Furthermore, Norway spruce was found to have quite a large distribution of the studied forest areas dominated by spruce (>75%) in both the VFAs and outside the VFAs (figure 5B). All other tree species were less common, with a median much lower for all other tree species, being 0 for all of them (table 3). Pine seemed to be the second most common tree species in the studied forest areas.

Considering the broadleaved tree species (figure 5), both groups of VFAs and those outside the VFAs were seemingly very similar to each other in dispersion in all species categories. The type of species that had the lowest average cover was temperate broadleaved, with a mean close to 0 (table 3, figure 5E, VFA: mean = 0.8, sd = 4.6, non-VFA: mean = 1.7, sd = 8.9). The tree species cover was slightly larger in the areas outside of VFAs. Aspen was also a species that had very low cover, and with the two groups of VFAs and the areas outside being very similar (table 3, figure 4H, VFA: mean = 1.3, sd = 6.9, non-VFA: mean = 1.5, sd = 7.9, p = 0.913). Birch was the deciduous broadleaved species that had the highest average cover (table 3, VFA: mean = 15.7, sd = 25.0, non-VFA: mean = 14.8, sd = 26.9) with a slightly higher mean in the VFAs, but not significantly. Non-temperate broadleaved had as well a low mean value, especially in the VFAs (table 3, VFA: mean = 0.8, sd = 4.8, non-VFA: mean = 1.7, sd = 8.9).

Simpson diversity index test (figure 6) showed no significant difference between the VFAs and the areas outside the VFAs, regarding relative tree species cover and dominance on all tree species in total (table = 3, p = 0.389). The two groups appeared to be very similar since they got the same median value and almost the same mean and standard deviation (VFA, non-VFA: median = 0.18, VFA: mean = 0.3, sd = 0.3, non-VFA: mean = 0.2, sd = 0.2).

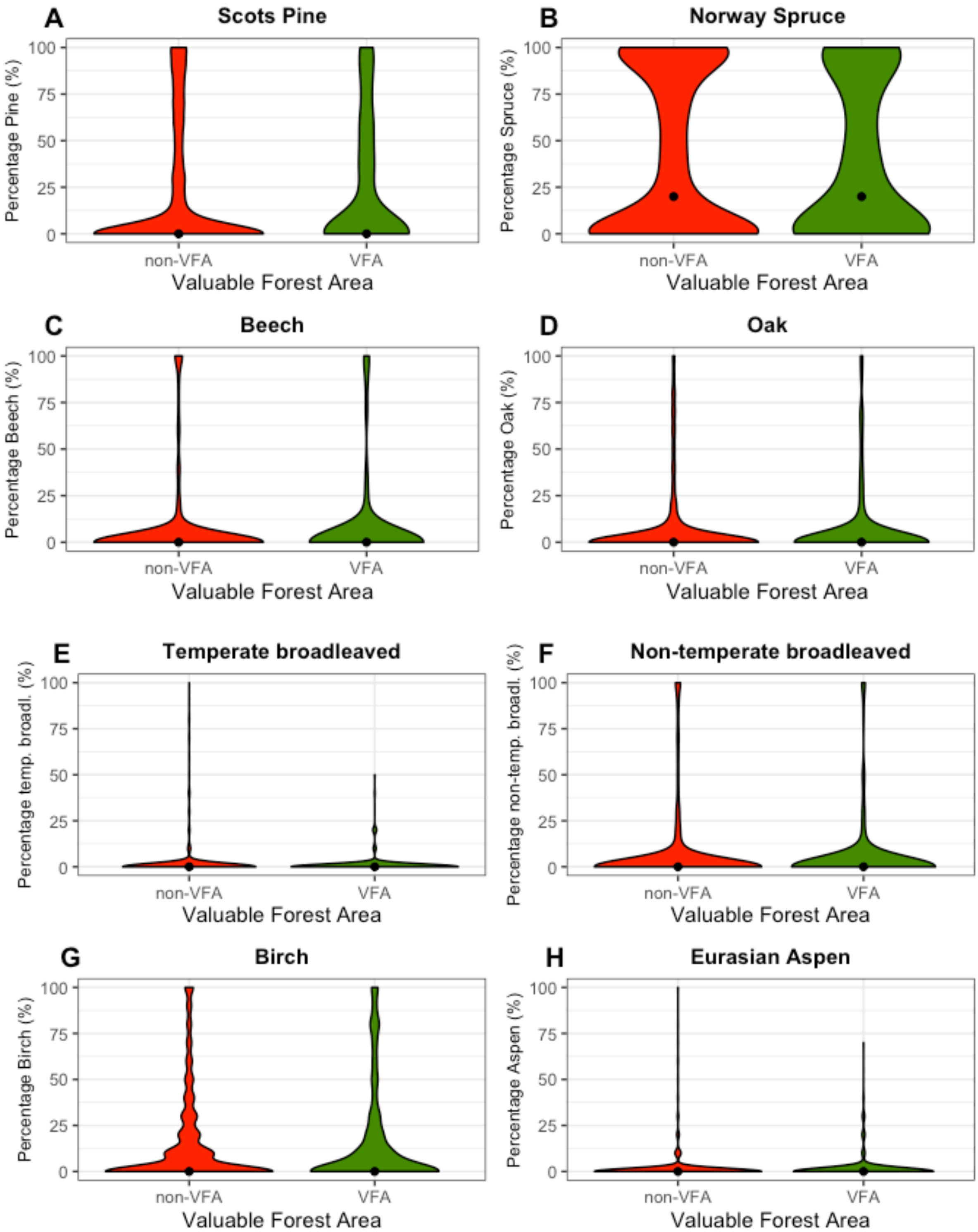

Figure 5. Violin plots of Scots pine and Norway spruce (% of basal area).

Weighted violin plots showing the density distribution of the percentage of Scots pine (*Pinus sylvestris*, A), Norway spruce (*Picea abies*, B), Beech (*Fagus sylvatica*, C), Oak (*Quercus robur, Quercus patraea*, D), temperate broadleaved (E), non-temperate broadleaved (F), Birch (*Betula pubescens*, *Betula pendula*, G) and Eurasian aspen (*Populus tremula*, L) by basal area in plots in VFAs and outside VFAs. The dots in the plots are median values.

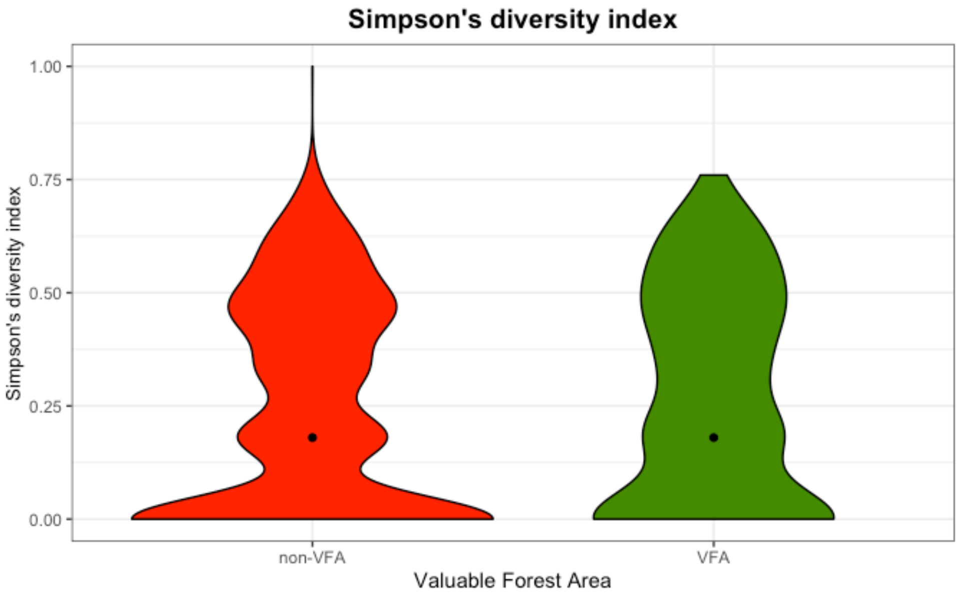

Figure 6. Violin plot of Simpson’s diversity index on all tree species.

Weighted violin plot showing the distribution of dominance of species in each plot in percentage, with 0 indicating low diversity and high species dominance, and 1 indicating high diversity and low species dominance. The dots indicate median value.

4. Discussion

4.1 Amount of deadwood

The total amount of deadwood showed a significant difference between the areas of VFAs and those outside, with higher amounts in the VFAs which could indicate a higher forest quality, at least for threatened species depending on deadwood. Having more total deadwood in the VFAs could indicate that the value cores have an influence on the VFAs. It could also indicate that the forest area in the VFAs overall has a higher forest quality and is worth protecting. The question is if the higher amount of deadwood in the VFAs can favour threatened species dependent on deadwood. A Swedish study investigated if the proposed VFAs compared to non-VFAs, showed a difference in occurrence of species richness of red-listed beetles in clear-cuts depending on deadwood. The conclusion was that there was little difference to be seen between the two areas (Hallinger et al., 2018).

Furthermore, the amount of deadwood in the studied forest areas were generally low or often completely absent, which could lower the forest quality in these forest areas. The national average of deadwood volume is in general very low as well, confirming that the result of the study is reflecting the situation in rest of Sweden (Lindbladh et al., 2019). Therefore, to induce higher forest quality the amount of deadwood needs to increase further (Lindbladh et al., 2019). To generate viable habitats for deadwood dependent species, it has been suggested that the total amount should approximately be 20 times higher than the median volume of total deadwood found in the VFAs in this study (Bütler & Schlaepfer, 2004). The amount of soft standing deadwood was especially low. This could depend on that soft, lying deadwood is a structure appearing in later decay stages, being not as common in a forestry management with short rotation cycles (Jonsson & Siitonen, 2012). In Sweden, there is a positive trend of increasing deadwood since the midst of 1990, but this has had probably only minor effects since the heterogeneity of deadwood is still low (Jonsson et al., 2016). This could be due to that the amount of deadwood is increasing, but from very low amounts (Jonsson et al., 2016). It can be especially important to increase the amounts of soft lying deadwood since it is essential with different types of deadwood structures (Heilmann-Clausen & Christensen, 2004).

Especially logs with larger diameter in late stages of decay are rare in managed forests (Jonsson & Siitonen, 2012). Thus, to be able to further increase the forest quality of these VFAs, the abundance of older deadwood in general needs to increase additionally.

4.2 Relative tree species cover

Scots pine was the only tree species that showed a difference in tree species cover between the two groups of VFAs and the non-VFAs. This could indicate a difference in forest quality, since the ongoing replacement of Scots pine to Norway spruce in forestry management can cause biodiversity loss on a landscape level (Lindbladh et al., 2019). Replacement of Scots pine with Norway spruce can also give effects on the biodiversity of saproxylic (deadwood-dependent) species (Jonsson & Siitonen, 2012). Other characteristics of the studied forest areas could be that Beech were found in very few stands. However, in the stands where it was found it dominated the area. A small fraction of Beech dominated up to 100 % of a few forest areas, but most plots did not contain Beech at all. This could be due to that the species itself is strongly competitive and other light demanding species have difficulties to penetrate the canopy cover (Niklasson & Nilsson, 2005).

4.3 Simpson's diversity index

I found that the Simpson's diversity index was generally low and that there were no significant differences between the VFAs and the non-VFAs. This indicates that most forests in the study area were dominated by a single tree species and some plots being dominated by two species, which is typical for rotation forestry systems (Jonsson & Siitonen, 2012). Since Norway spruce had the highest average cover in the studied forest areas, the most common characteristics of the studied forest area was stands dominated by Norway spruce, and secondly, Scots pine. The dispersal in the graph of Simpson's diversity index also indicates that two species were second most common to dominate in the studied forest areas. A common coverage in forest management in Sweden is stands with one dominating species, mixed with smaller outspread stands of broadleaved tree species (Drössler, 2010). This could be an example of the forest cover found in the studied forest areas.

4.4 Implications for policy

From what I found in the study, most areas had very little levels of deadwood and low heterogeneity in relative tree species cover. However, the large distribution indicates that there also occurred forest areas in the study with very high levels of deadwood and mixed forest, although very few. These areas can be worth extra protection since they were so rare. In a study of Angelstam et al. (2020), "High Conservation Value Forests" (HCVF) were identified to find potential additions to protected forest areas networks and strengthen the green infrastructure functionality. The HCVFs indicated that the forest areas with high connectivity and high functional green infrastructure were unevenly distributed along Sweden. Most of the forests contributing to a functioning green infrastructure were not found in southern Sweden. In the nemoral zone, around 1 % of the forest were protected, and of the 14 % of the area that was stated to potentially contribute to green infrastructure, only 3 % were fulfilling demands that was necessary to create a functional connectivity (Angelstam et al., 2020). Therefore, VFAs with higher forest quality could be extra valuable in the southern parts of Sweden which could be essential for the survival of numerous red-listed species (Felton et al., 2010).

Examples of measures to increase forest quality could be to have more retention trees and longer rotation cycles, which increases the amount of deadwood in later stages of decay and create more varied structures (Fedrowitz et al., 2014; Jonsson et al., 2016). A higher retention level would however increase the economic cost (Santaniello et al., 2016). Additionally, more large-scale targeted creations of deadwood could also be important (Jonsson et al., 2016). The dominance of tree species monoculture can further influence the amount of deadwood. Having monocultures in forests, which is common in forest management, generate less diversity in deadwood quality between sites (Jonsson & Siitonen, 2012). Having a more uniform input from only one or a few tree species could thus result in a loss of the variation of saproxylic species (Jogeir N Stokland & Siitonen, 2012). Therefore, it could be beneficial to biodiversity to replace these monocultures creating a more mixed forest of Norway spruce and Birch stands (Felton et al., 2010). The nemoral zone would naturally contain an abundance of deciduous tree species, and with many red-listed species associated to these tree species, another useful conservation method to increase forest quality could be to increase the number of deciduous trees in the VFAs (Lindbladh et al., 2019). However, methods for creating and sustaining deadwood as well as protecting stands of deciduous broadleaved tree species are already a part of the Swedish Forestry Act (*Skogsvårdslag* SFS 1979:429).

The study has shown that there are existing values in the VFAs that indicate higher forest quality, compared to the non-VFAs. The chosen indicators are vital from a conservation perspective since both deadwood and Scots pine are important for biodiversity in the southern Swedish context. The VFAs are to be used as a tool to improve connectivity between protected areas, which is a political decision and a part of reaching the Swedish national environmental goals (Naturvårdsverket & Skogsstyrelsen, 2017). Thus, the question is if extra measures should be taken to preserve the quality difference, or if the forest quality in the VFAs should increase further. Therefore, it is worth discussing if the forest management should be different in the VFAs and if further policy is needed to accomplish this.

4.5 Limitations and future studies

Looking at only two indicators of biodiversity, there could be aspects that are not covered in this study regarding the forest quality of the studied forest areas. Examples of indicators of biodiversity that could be included in future studies to strengthen the basis of measured forest quality is stand age, number of canopy layers, total volume of wood, number of stems, number of ground level and understory vegetation. These indicators among others are available in the data base from the Swedish Environmental Forest Agency and the Swedish National Forest Inventory.

Since the study was limited to the southern part of Sweden, covering the nemoral zone, the result can only tell something about this specific area. In future studies investigating differences between VFAs and areas outside of those, it would be good to expand to a national scale. Since data from all of Sweden is available from the Swedish National Forest Inventory and the Swedish Environmental Protection Agency, this could be used to expand the study area to evaluate if the same trends can be seen all over Sweden. Worth noting as well is that Birch in areas outside of VFAs, can be seen in the figure to have a shape standing out from the other tree species figures. This is probably due to the data being calculated in percentage groups of 0 %, 10 %, 20 %, 30 % etc and not in-between, creating a specific pattern when the data is differing between the values, and not due to any natural patterns.

Additionally, an interesting analysis would be to compare different regions in Sweden ("Regionindelning", page 2:3, Swedish University of Agricultural Sciences (SLU), (2018)), since Sweden consists of several different types of forest biomes, including Hemi-Boreal, Boreal and Sub-alpine zones (Angelstam et al., 2020). Different forest types could give contrasting results regarding the structure of deadwood, e.g. distribution and fraction, which could give different results than found in this study (Jonsson et al., 2016). Hence, these are suggestions to make a more broad and nuanced analysis, offering a more robust and comprehensive analysis of how VFAs can be used as green infrastructure between protected areas in Sweden today.

5. Conclusion

There was a small but significant difference between the VFAs and the areas outside of those, with a higher total amount of deadwood and Scots pine cover inside the VFAs, which make the VFAs worth protecting.

- Even if the forest quality in the VFAs is higher, it is still low in terms of deadwood, especially soft, lying deadwood. It would be beneficial to biodiversity if the amount and diversity of deadwood in different structures and decay stages increases.
- I found that many plots were monocultures and had a high spruce cover, and that broadleaved forests were less common. It could be beneficial for biodiversity to conserve and promote a higher amount of Scots pine in the VFAs. It would also be beneficial for biodiversity if the proportion of deciduous broadleaved tree species increased in the VFAs.
- To conserve and increase the forest quality in the VFAs, additional policies may be required for the specific forest areas.
- An analysis on a national scale or on other types of forest biomes in Sweden would be useful to conclude if the same results apply to rest of Sweden. It would also be useful to include several other indicators of biodiversity to evaluate if the forest quality differs between different aspects of biodiversity.

Acknowledgement

I want to give a huge thank you to my supervisor Tristan Bakx, who has given me so much support and help, especially with R and R-studio. I would also like to thank Cecilia Akelsson for support and appreciated feedback. Finally, I would like to thank my friends, especially Marieke for programming support, Serena and Maria for our long hours in school, Tom and Tove for all your feedback and our zoom meetings! I would also like to thank Amanda for technical support!

Thank you!

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Appendix

In table 1, Levene's tests were summarized to test whether the assumption of homogeneity variance had been violated. If the p-value is > 0.050 the homogeneity of variance was tenant. An F -value < 0.050 indicates that the assumption of variance is equal across groups has been violated. The degrees of freedom are the number of observations in the data set which can vary when the statistical parameters are estimated.

The histograms (figure 1A, 2A-D) showed an un-normalized distribution, with a displacement to low values of deadwood. Most of the values of deadwood was 0, indicating no amounts or very little amounts of deadwood in general. Regarding tree species, there were also an un-normalized distribution for all tree species, with very low values dominating the graphs (figure 3), including Simpson's diversity index (figure 1B). The graph of the diversity index showed a larger distribution, but most (0-0.2) had still high species dominance (only one or two species per plot). The distribution of Scots pine was similar but with slightly higher values distributed over higher percentages. For Norway spruce, the distribution was the highest, with quite many values of 90-100 %, except for high values of around 0 % as well and other distribution over the x-axis.

Table 1. Levene-test's (one-way Anova).

Tests that were made to decide if the collection of data fulfilled homogeneity or heterogeneity variance.

Variable	*Degrees of freedom*	*F-value*	*p - value*
Total deadwood (m^3/ha)	1378	0.123	0.725
Hard standing deadwood (m^3/ha)	1378	0.519	0.472
Hard lying deadwood (m^3/ha)	1378	6.321	0.012
Soft standing deadwood (m^3/ha)	1378	0.271	0.603
Soft lying deadwood (m^3/ha)	1378	0.912	0.340
Pine (% of basal area)	1378	0.739	0.390
Spruce (% of basal area)	1378	3.952	0.047
Birch (% of basal area)	1378	3.681	0.055
Aspen (% of basal area)	1378	0.072	0.788
Beech (% of basal area)	1378	0.888	0.346
Oak (% of basal area)	1378	0.443	0.506
Non-temp broadleaved (% of basal area)	1378	1.901	0.168
Temperate broadleaved (% of basal area)	1378	5.482	0.019
Simpson's diversity index of all tree species (0-1)	1378	0.027	0.869

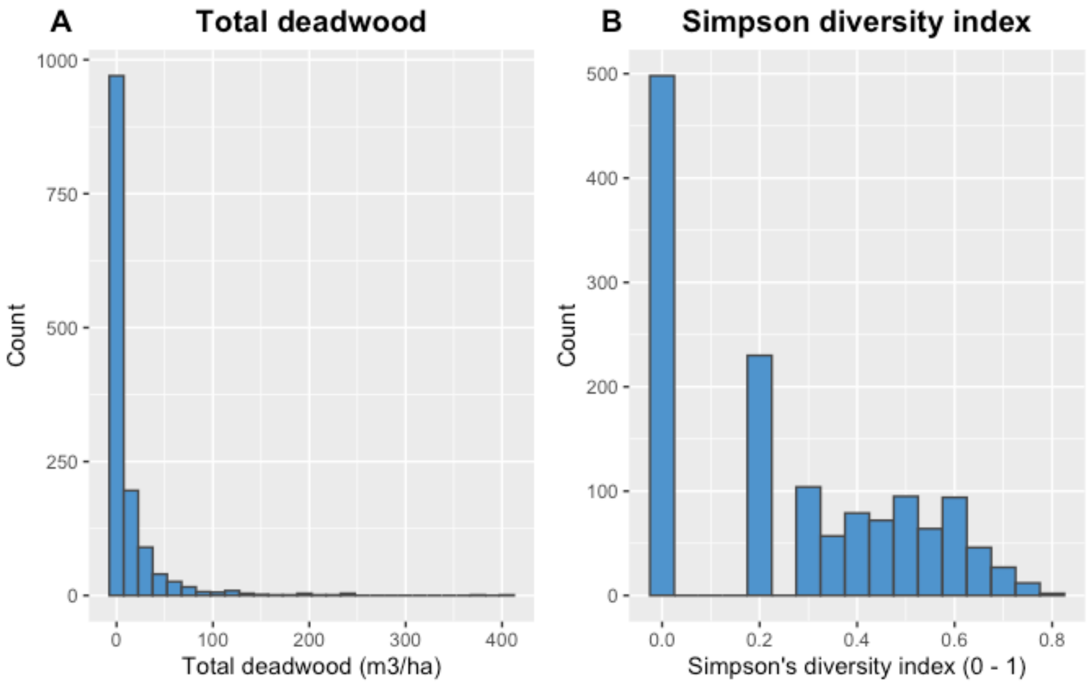

Figure 1. A histogram of total deadwood (m^3/ha) and relative tree species cover in Simpson's diversity index.

Figures of histograms, describing the distribution of collected data, to investigate if there was a normal distribution or not. No normal distribution was found.

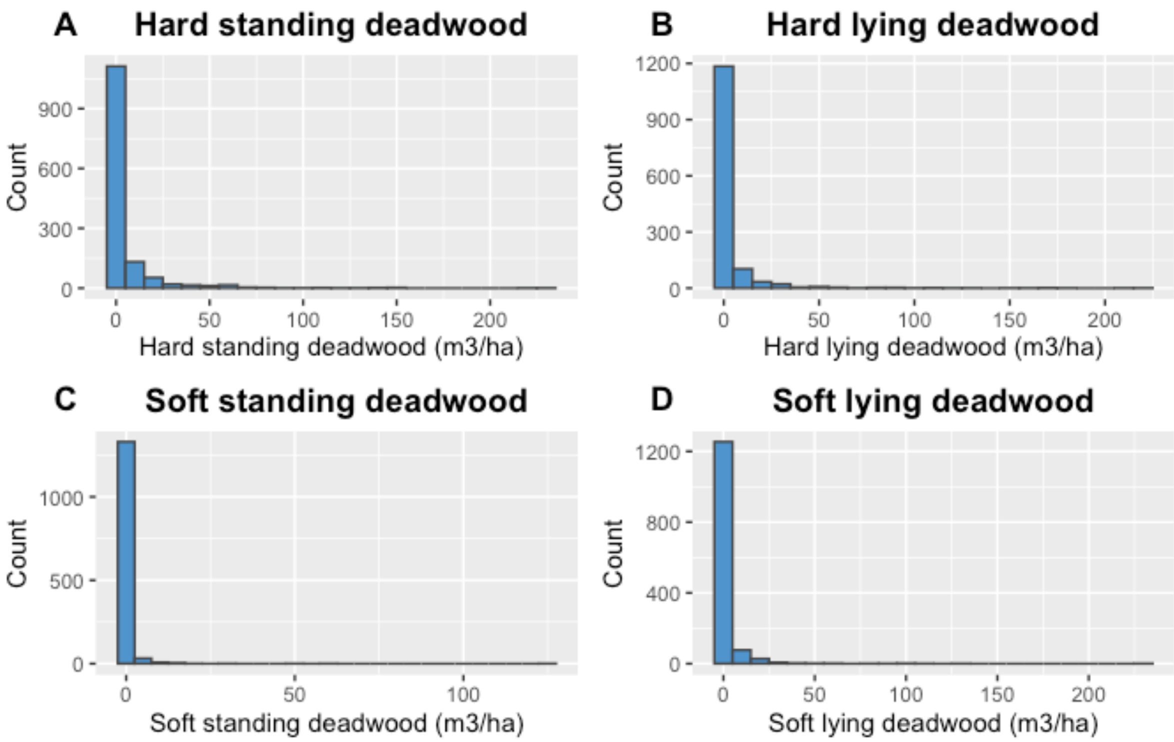

Figure 2. Histogram of hard standing, hard lying, soft standing and soft lying deadwood (m^3/ha).

Figures of histograms, describing the distribution of collected data, to investigate if there was a normal distribution or not. No normal distribution was found.

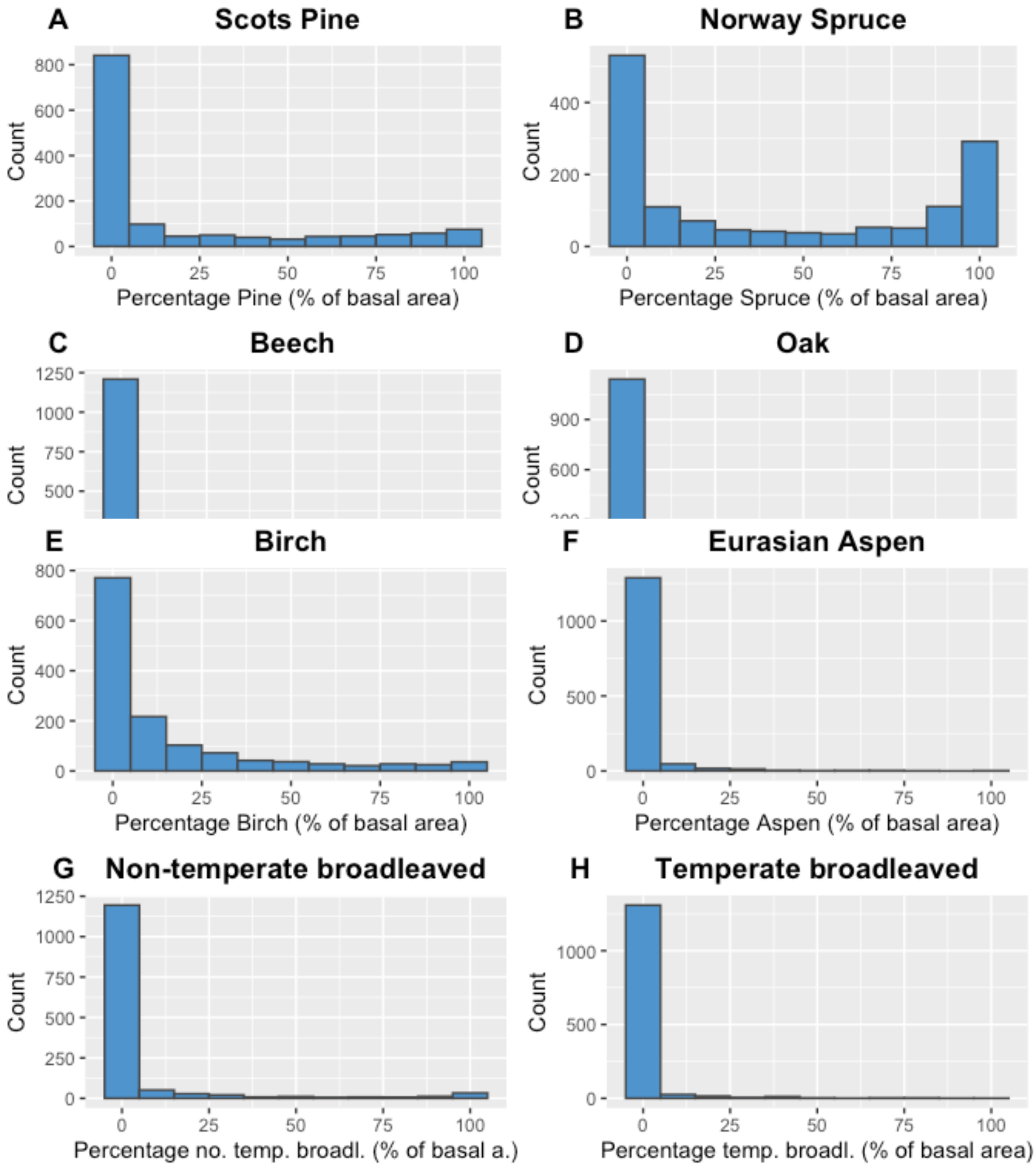

Figure 3. Histogram of the cover of Scots pine *(Pinus sylvestris),* Norway spruce *(Picea abies)*, Beech *(Fagus sylvatica)*, Oak *(Quercus- robur & patraea)*, Birch *(Betula- pubescens & pendula)*, Eurasian aspen *(Populus tremula)*, non-temperate and temperate broadleaved (% of basal area).

Figures of histograms, describing the distribution of collected data, to investigate if there was a normal distribution or not. No normal distribution was found.

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Lund University

Environmental Education
Centre for Environmental and
Climate Science
Ecology building
223 62 Lund