# Forest structure of Dalby Söderskog National Park - patterns of carbon storage in living and dead trees

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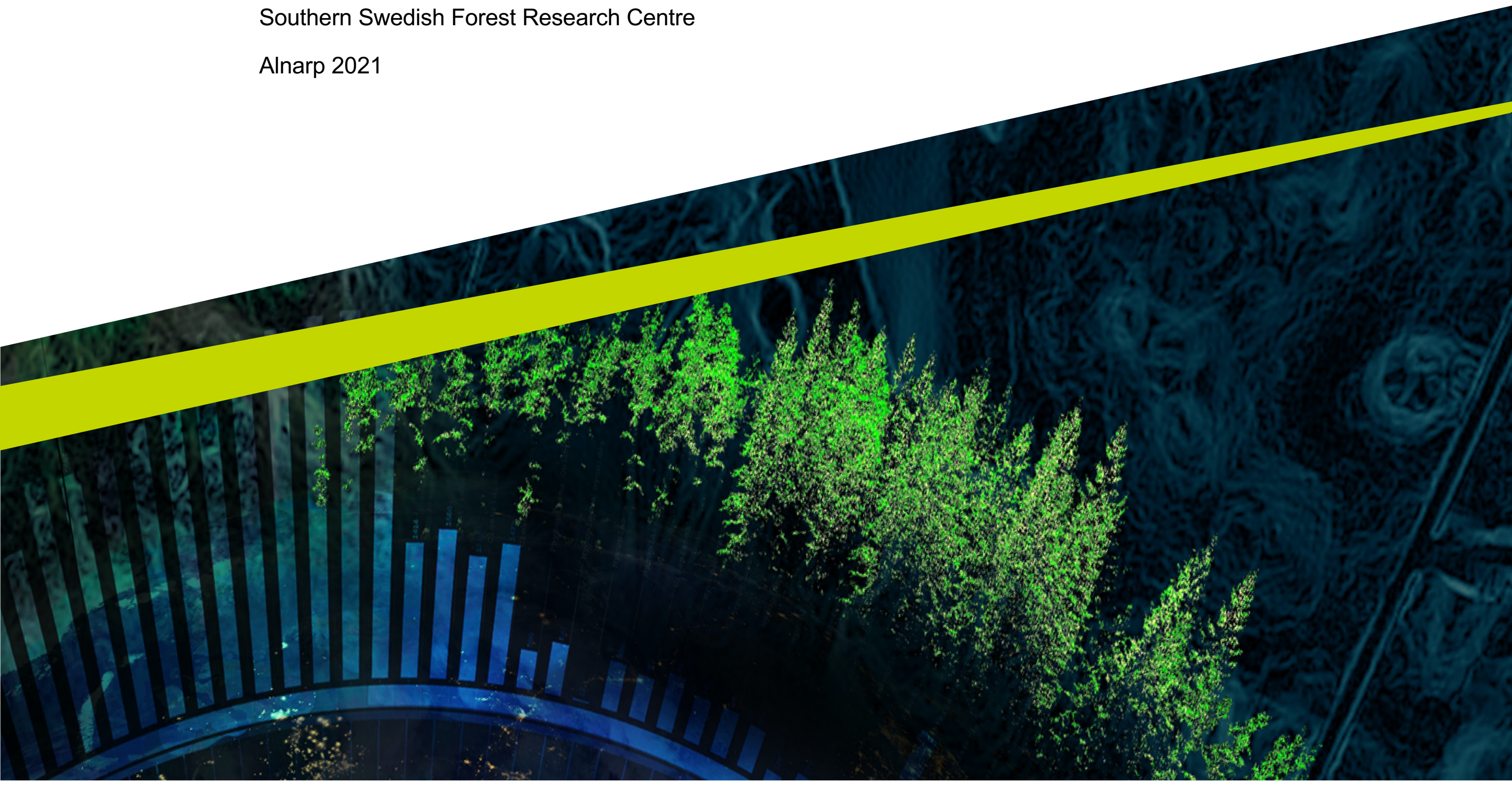

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## Abstract

Carbon sequestration and storage is an ecosystem service supplied by forests, and is of increasing importance in the context of mitigation of global climate change. Forest pest invasions, driven primarily by globalizations, represent a risk to the efficiency of carbon sequestration as they may greatly reduce the amount of the living biomass in forests.

This study provides a combined assessment of living trees and coarse woody debris in the temperate broadleaf forest of Dalby Söderskog National Park in southern Sweden. The specific objectives were: (1) to investigate the storage of biomass and carbon pools, in both live and dead wood; (2) to find out the relationship between the distribution of live and dead woody biomass and carbon in relation to stem diameter; (3) to analyse the relative share of live and dead wood carbon pools along the stem diameter gradient and (4) to study the effect of fungal tree diseases on biomass and carbon dynamics.

Length and diameter of coarse woody debris including dead standing trees, cut stumps, and dead downed trees and branches were measured in 50 circular 100 $m^2$ (5.64 m radius) sample plots. Data for living trees for the same sample plots were taken from a previous inventory.

The results show that the studied broadleaf forest stored a total aboveground carbon stock of 176 t C/ha. Most carbon stock is stored by living trees (107.7 t C/ha), followed by downed deadwood (logs) (52.5 t C/ha) and standing dead wood (15.8 t/ha). The distribution of carbon storage in relation to stem diameter was species specific, and partly influenced by effects of Dutch elm disease and ash dieback.

This study shows that old-growth forests store large carbon stocks in living and dead wood. In the specific case of Dalby Söderskog, effects of tree diseases in mean time have increased the relative share of dead wood compared to live tree volumes, in particular for smaller diameter trees. The mixed tree species composition of the forest has, however, buffered the effects of Dutch elm disease and ash dieback, and living tree biomass and carbon still remains considerably larger than the amounts stored in dead wood.

*Keywords:* Ash dieback; Dead wood; Dutch elm disease; Living tree volume; Coarse woody debris; Carbon stock and storage; Pest invasions; Temperate mixed broadleaved forest.

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# Abbreviations

| | |
|---|---|
| AGB | Above Ground Biomass |
| ADB | Ash Dieback |
| BEF | Biomass Expansion Factor |
| CWD | Coarse Woody Debris |
| DED | Dutch Elm Disease |
| IPCC | Intergovernmental Panel on Climate Change |
| SLU | Swedish University of Agricultural Sciences |

# 1. Introduction

## 1.1. Carbon stock in forest ecosystems

The forest ecosystem is one of the essential parts of terrestrial ecosystems, and it occupies a key role in maintaining the global carbon cycle of terrestrial ecosystems (Liu et al., 1997; Kuuluvainen and Gauthier, 2018). Houghton, Hall, and Goetz (2009) estimated that forests store 70-90 percent of total global terrestrial biomass, even though this biomass is asymmetrically distributed across biogeographical regions: more than half of the total global terrestrial biomass is stored in tropical forests, while a third is stored in boreal forests and only 14% is stored in temperate forests (Pan et al., 2011). Conifers generally contain slightly more carbon (47-55%) than deciduous trees (46-50%), mainly because of a higher average lignin content, approximately 30%, compared with 20% for deciduous trees (Lamlom and Savidge, 2003)

Carbon sequestration and storage is one of the most vital ecosystem services supplied by forests, and it provides a lot of potential for mitigating climate change (Birdsey and Pan, 2015). Forests are major carbon sinks because of their high carbon content (Houghton, 2007). The world's forest ecosystems store more than double the carbon content in the atmosphere (Canadell and Raupach 2008; IPCC 2001). Ekoungoulou et al. (2015) state that the forest acts as a reservoir of carbon as it can store carbon from the atmosphere. This statement is supported by Kumar et al. (2019) who further add that forests keep large amounts of carbon in trees, understory vegetation, forest floor, and soil. Forest ecosystems store more than 80% of all terrestrial aboveground carbon (IPCC, 2001), which render forest ecosystem pivotal to maintaining the global carbon balance and mitigating climate change (IPCC, 2001).

## 1.2. Carbon pool in forest ecosystem

According to the Intergovernmental Panel for Climate Change (2006), the carbon dioxide fixed by plants through photosynthesis is transferred across different carbon pools. The IPCC identified five carbon pools in the terrestrial ecosystem that influence biomass storage: aboveground biomass, below-ground biomass, litter, woody debris, and soil organic matter. The estimates of total carbon stock from each pool are summed to obtain the total forest carbon stock. Each year, as forests develop and their biomass grows, they take up carbon from the surrounding atmosphere and store up as plant tissue; hence, the forest has numerous and major functions regulating the atmospheric concentration of carbon dioxide (Ghosh, 2018).

## 1.3. Forest biomass and carbon stock

The mass of living biological organisms, including plants, animals, and microorganisms, is referred to as biomass in a given region or at a certain period (Hess and Tasa, 2011). Biomass in forest is counted for both above and below-ground biomass. Forest ecosystems contribute to climate change mitigation by storing and sequestering massive amounts of carbon in their biomass. The most accurate method to measure plant biomass is to harvest, dry, and weigh it (Clark and Kellner, 2012). However, this method is costly, time-consuming, and not always feasible, for instance, when monitoring forest's carbon stock. As a result, a number of non-destructive methods for effectively estimating biomass have been developed (Dittmann et al., 2017). Techniques to estimate terrestrial carbon storage and flux for large areas include a combination of simulation modelling, satellite imagery such as remote sensing and ground-measurement inventory data analysis (Goodale et al., 2002)

An allometric equation is a method of determining quantitative correlation between measurable parameters of stem diameter at breast height or height and relating this to characteristics that are harder to quantify, like the Above Ground Biomass (AGB). These relationships are usually species and geographically specific (Muukkonen, 2007). Muukkonen, (2007) further found that the allometric methodology to estimate biomass is relatively accurate but requires time, thus making it best suited for implementing across small areas.

## 1.4. Factors influencing forest biomass

Many drivers contribute to the changes in biomass and carbon storage. Climate (Luyssaert et al., 2008), soil (Angst et al., 2018) and natural disturbance (Bond-Lamberty et al., 2007), as well as forest stand properties including tree species composition (Nord-Larsen et al., 2019), age and silviculture practices (Liski et al., 2006), substantially affect carbon sequestration in forests. Stand age is one of the key factors determining above ground biomass in forests (Bradford et al., 2008; Chatterjee, Vance and Tinker, 2009). Furthermore, Luyssaert et al., (2008) stated that the total ecosystem carbon pool is corresponding to stand age and strongly aligned with site productivity. Besides that, several studies (Vucetich et al., 2000; Seedre et al., 2015), documented that forest biomass storage, particularly AGB storage, has been found to decline with increasing altitude and latitude.

Environmental factors, particularly temperature and precipitation and land use history, have been linked to biomass storage and accumulation in primary forests, with forests with less or no land-use history retaining the most carbon (Keith, Mackey, and Lindenmayer, 2009). These authors further found that the highest biomass densities have been reported in temperate forests with less land use history, where the mean annual temperature is lower than 10°C and the mean annual precipitation is between 1 000 and 2 500 mm. On the other hand, a high amount of live tree biomass can be changed into deadwood following windthrow or fire events, while a high proportion of live biomass is removed from the site following clear-cut (Seedre et al., 2011). Besides that, invasive pests (Fei et al., 2019), due to climate change are also regarded as a factor resulting in biomass losses.

Primary forest carbon storage is receiving more attention (Badalamenti et al., 2019), and research on primary forests in various ecoregions has shown that they can store large amounts of carbon and that many are still accumulating carbon (Luyssaert et al., 2008, Keith, Mackey, and Lindenmayer, 2009; Pan et al., 2011; Pugh et al., 2019). However, there is a lack of research related to natural forest disturbance, although such disturbances are part of natural dynamics in a forest ecosystem.

Disturbances work to move carbon from living trees to dead wood, soil, and the atmosphere in the short term, but they also change long-term patterns of carbon storage as stand structure and species composition shift during recovery (Houghton, Hall and Goetz, 2009). Disturbance can be divided into two factors, biotic (anthropogenic activity, insect damage, disease-causing fungi) and abiotic (storm, wind, fire, and snow).

Fungal pathogens can do significant damage to trees and are a common problem in forests across the world (Potter and Urquhart, 2017). Tree mortality is a critical factor in forest structural dynamics and carbon cycling in terrestrial ecosystems. Disturbance that results in partial stand replacement has been proven to influence biomass accumulation (Keith, Mackey, and Lindenmayer, 2009).

One of the major environmental concerns of the modern era is the increase in carbon dioxide in the atmosphere and its potential effect on climate warming, but also indirect effects of warming on pathogen and disease spreading. Almost all effects of insect outbreaks are strongly dependent on climate (Pinkard et al., 2011). In southern Sweden, the spread of Dutch Elm Disease (DED) started in the 1980s and has since destroyed many elm populations. Since the early 2000s and on a continental scale, the ascomycete *Hymenoscyphus fraxineus* which was first reported in Poland in Europe (McKinney et al., 2014) is causing harm to the widely spread native European ash species, *Fraxinus excelsior*. As a result of a spread across Europe from east to west over the last two decades, populations of ash trees (*Fraxinus excelsior*) were decimated (Pautasso et al., 2013). Ash dieback (ADB) is one of several tree diseases and insect pests that have recently arrived and swept across European forests (Boyd et al., 2013). Besides that, Waller (2013), stated that the global climate change may worsen the long-term effects of Dutch elm disease and ash dieback.

In southern Sweden, a quarter of *Fraxinus excelsior* trees were reported to be dead or critically harmed (Stenlid et al., 2011). Both Ash (*Fraxinus excelsior*) and Elm (all three species; *Ulmus glabra, U. minor,* and *U. laevis*) populations have declined severely in Sweden because of fungal infections and have been categorized as vulnerable on the Swedish red list since 2010 (Pihlgren et al., 2010).

In this thesis, we set out to bridge the gap in knowledge about the effects of disturbance severity on the long-term carbon dynamics in broadleaf tree species. For this purpose, we explore extensive tree volume and coarse woody debris data from an unmanaged deciduous forest located in southern Sweden, Dalby Söderskog. This forest is chosen as it is severely affected by Ash dieback and Dutch elm disease. However, since not all trees are killed, structural growth following perturbations occurs in various ways with different live and dead tree biomass components.

Hence, the aim is to determine how disturbance of DED and ADB affected carbon stocks on live tree boles and coarse woody debris (CWD). Although forest structure in the study area has repeatedly been documented in the past century (Brunet et al., 2014), this is the first study on woody biomass and carbon content to date.

## 1.5. Study aims

The objectives of the study were:

1) To investigate the storage of biomass and carbon pools, in both live and dead wood in Dalby Söderskog.
2) To find out the relationship between the distribution of live and dead woody biomass and carbon in relation to stem diameter.
3) To analyse the relative share of live and dead wood carbon pools along the stem diameter gradient.
4) To study the effect of fungal tree diseases on biomass and carbon dynamics.

# 2. Materials and Method

## 2.1. Study site description

Dalby Söderskog has size of 37 ha and is located in the County of Skåne, which is in southern Sweden, 10 km east of Lund (55°41´N, 13°20´E, 65m a.s.l.). It is a mixed broadleaved deciduous forest that is dominated by Pedunculate oak (*Quercus robur* L.), European ash (*Fraxinus excelsior L.*), European beech (*Fagus sylvatica L.*), and wych Elm (*Ulmus glabra* Huds). The mineral soil, which is derived from Baltic moraine (from the Weichsel glacial period), is a calcareous, nutrient-rich clay with a high calcium content. The soil is a eutric cambisol, and humus is of the mull type. The climate is temperate suboceanic, with an annual mean temperature of 7.5 degrees Celsius and annual mean precipitation of approximately 650 millimeters (Oheimb and Brunet, 2007). The latest significant cuttings were done in 1914 – 1916, whereby 1,600 $m^3$ wood were taken out of a total of 8,000 $m^3$. The forest status changed into a protected forest in the year of 1918. Since then, this forest has no major management except removal of trees that can be dangerous for forest visitors. Since 1988 dead elms were cut down due to safety reasons around hiking paths (Brunet et al. 2014).

## 2.2. Previous inventories

Several inventories were carried out previously in Dalby Söderskog, mainly about stand structure and vegetation (Lindquist 1938; Malmer et al., 1978; Brunet et al., 2014). Lindquist (1938) studied forest structure and vegetation by establishing transect lines and sample plots. This method used a straight path through the forest as a baseline and distributed 74 sample plots along the perpendicular lines. The line-to-line distance is 50 m, while the plot-to-plot distance along lines in most cases is 100 meters (Lindquist 1938). From a first survey in 1909, species wise total stems number with more than 20 cm diameter breast height (DBH) are known, while species wise stem numbers divided in dbh-classes are available for surveys in 1916, 1935, 1970 and 2012 (Brunet et al. 2014).

In the early spring of 2010, 74 sample plots were reconstructed for a survey of herb layer vegetation by using an aerial photograph with Lindquist's map as a digital overlay to extract GPS coordinates (Fig. 1, Brunet et al. 2014). In addition, the plot centre of each plot was marked with a plastic stick, and a short iron rod for future relocation of plots in case of loss of plastic stick. In February 2012, Bukina (2012), carried out a tree inventory in circular sample plots. Trees with dbh of 10 cm or more were identified and measured in plots of 100 $m^2$ (5.7 meter radius); meanwhile trees with dbh of 20 cm or more were inventoried in 314 $m^2$ (10 meter radius plot). Trees below 10 cm in dbh are not included in the inventory. All the plots were taken from the center points of the 74 plots which were established previously.

In addition, vitality of trees was assessed due to the Dutch Elm Disease. All stems were classified as living or dead.

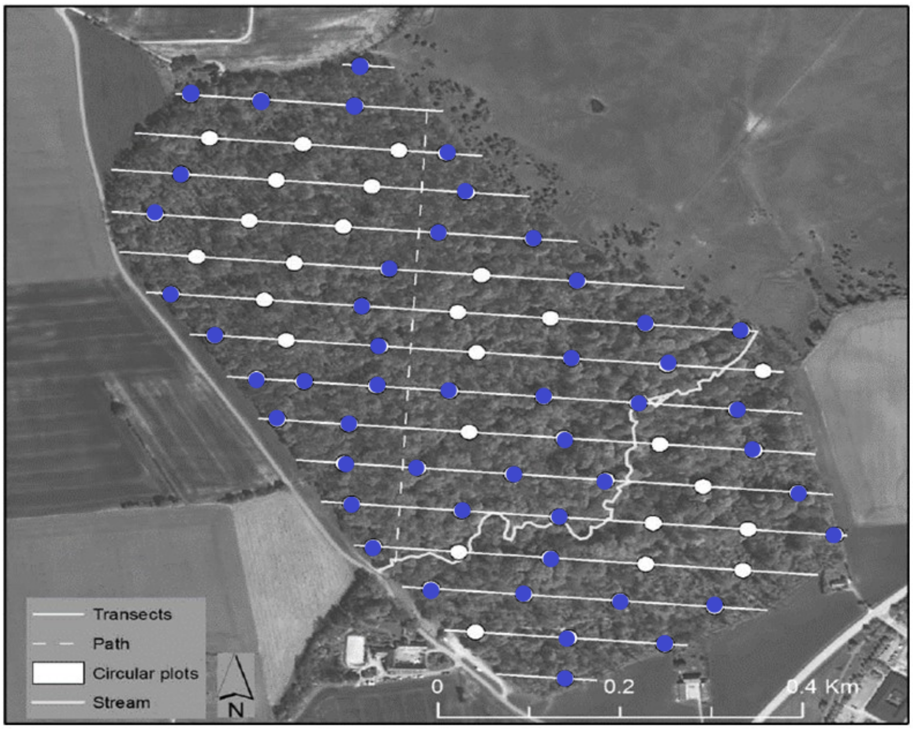


*Figure 1. Transect lines and sample plots in Dalby Söderskog (from Brunet et al., 2014). Blue color indicates the 50 plots included in this study.*

## 2.3. Method for live trees measurement

The most recent inventory was conducted by Ruks (2020), who followed the same method as Bukina (2012) and registered all the trees with dbh class 10 – 19 cm in a plot size of 100 $m^2$ (5.64 m radius), and dbh of 20 cm or more in a plot size of 314 $m^2$ (10 m radius), sharing the same plot centre. All the trees were identified to the species, and stem diameter was measured at 13 m height. Diameter (dbh) was registered for all individuals by using the cross-calliper method. For trees that were larger than 50 cm in dbh, measuring tape was used.

For the calculation of live tree carbon contents in this study, the available data set measured by Ruks (2020) was used. The carbon content of live trees, bole and bark, was assumed to be 50% of bole and bark mass for all species. Tree height and DBH are necessary to estimate volume, used to calculate biomass accumulation and carbon stock. The DBH of trees were directly obtained from Ruks (2020) data set, but live tree height data to calculate volume were lacking. Instead, data from Lindgren´s (1971) volume table chart were used to assume the volume of whole living tree (Table A7). Lindgren's data summarize the results of the forest inventory of Dalby Söderskog in 1970 and provide average volumes in 5 cm diameter classes and specified for the four main tree species and a fifth group containing other species.

## 2.4. Field inventory 2021

Data were collected in January and February 2021. The inventory was conducted on the existing permanent plots used by Ruks (2020). The focus of this inventory was on the measurement of the above ground deadwood accumulation in the forest, partly due to the past DED and the ADB. The sample plots consisted of 50 of the 74 permanent plots (Fig. 1). Due to time constraints, only 50 randomly distributed plots throughout the forest were chosen as sample plots. To locate the plots, handheld GPS and a map were used.

## 2.5. Method for coarse woody debris measurement

Three principal forms of aboveground coarse woody debris were sampled in each plot: logs, stumps and snags. Logs were defined as downed tree boles at least 10 cm in diameter at mid-length. Notably, only sections of logs that fall inside the plots were measured. Stumps were classified as standing cut tree boles with at least 10 cm in stem diameter. Meanwhile, snags were defined as standing, uncut dead trees at least 10 cm in dbh. Finally, each log, stump and snag were assigned having tree bark or not.

Log lengths were measured with measuring tape. Log mid-diameters were measured using a calliper, and a diameter tape was used for diameters more than 50 cm. Stump diameter was measured just below the cut by calliper, meanwhile, stump height by using measuring tape. Snag diameter was measured at 1.3 m height by using a calliper. For snags the height was estimated visually "by eye" calibrating against a 2 m folding rule (Harmon and Sexton, 1996).

The volume of cylinder method calculated log and snag stump volume as below

$V=h \times \pi \times d2/4$ ………………………………………………. Equation 1

Where V is volume ($m^3$), h is height (m), and d is the diameter (cm)

Snag volume is estimated by the formula for an ellipsoid cone method (Brunet and Isacsson, 2009). The formula is as follows:

$V=\pi \times d2 \times h/6$ ……………………………………………. Equation 2

Where V is volume, d is diameter, and h is snag height in meters.

CWD biomass was calculated by multiplying Biomass Expansion Factor (BEF) and total volume of CWD

$W=BEF\times V$……………………………………………………. Equation 3

where W denotes the aboveground tree biomass (dry weight, Mg), BEF denotes the biomass expansion factor (Mg $m^{-3}$), and V denotes the stem volume ($m^3$).

The BEFs were used to calculate the total aboveground biomass of trees based on the stem volume estimates

In this study, the constant BEF of 0.64 for broadleaved stands was used to calculate the total aboveground biomass of trees based on the stem volume estimates. The constant BEF value (0.64) was obtained from the Swedish National Inventory Report (Feldhusen et al., 2004). This is consistent with the most recent greenhouse gas reporting from Sweden. Still, they consider aboveground biomass as a product of volume and 64 percent for all broadleaved tree species in their calculations (Feldhusen et al., 2004).

Lastly, in accordance with IPCC guidelines, biomass was converted to carbon by assuming a carbon content of 47% (IPCC, 2006):

$C=Wx0.47$……………………………………………………………Equation 4

where W is the aboveground tree biomass (dry weight, Mg), 0.47 carbon content.

Meanwhile for live tree:

$C=Wx0.5$…………………………………………………………...Equation 5

where W is the aboveground tree biomass (dry weight, Mg), 0.50 carbon content.

Assume 50% of biomass is made up of carbon (Houghton 2007; Thomas and Martin, 2012).

Total biomass carbon is the sum of all individual carbon pools. We will refer to the sum of live and dead biomass carbon as total biomass carbon. We used paired sample t-test analysis and analyse of posthoc Tukey HSD test for pairwise comparisons to determine differences between volume of living and deadwood trees after disturbances. All statistical analyses were done in Microsoft Excel 2016 and Minitab 19 (Minitab Inc.) with statistical significance established at $\alpha = 5\%$ level.

# 3. Results

## 3.1. Volume by species for living trees

Dalby Söderskog is mainly dominated by broadleaf species of European Ash (*Fraxinus excelsior*), Beech (*Fagus sylvatica*), Pedunculate oak (*Quercus robur*), and Wych Elm (*Ulmus glabra*). In contrast, other species are less abundant (consist of black alder (*Alnus glutinosa*), Norway maple (*Acer platanoides*) and crab apple (*Malus sylvestris*). The results obtained for the old-growth broadleaf stand show that the mean standing volume for the live trees is 336.7± 29.6 $m^3$/ha (Mean ± S.E., Tables A4, A6). Figure 2 shows that *Fraxinus* and *Fagus* were the most abundant tree species accounting for 35.4% and 32.6% of the total wood volume found in the plots. *Quercus* has the third highest volume (24.2%), followed by *Ulmus,* which has the second lowest volume (4.8%). Other species were least plentiful, constituting only 3.1% of the total volume.

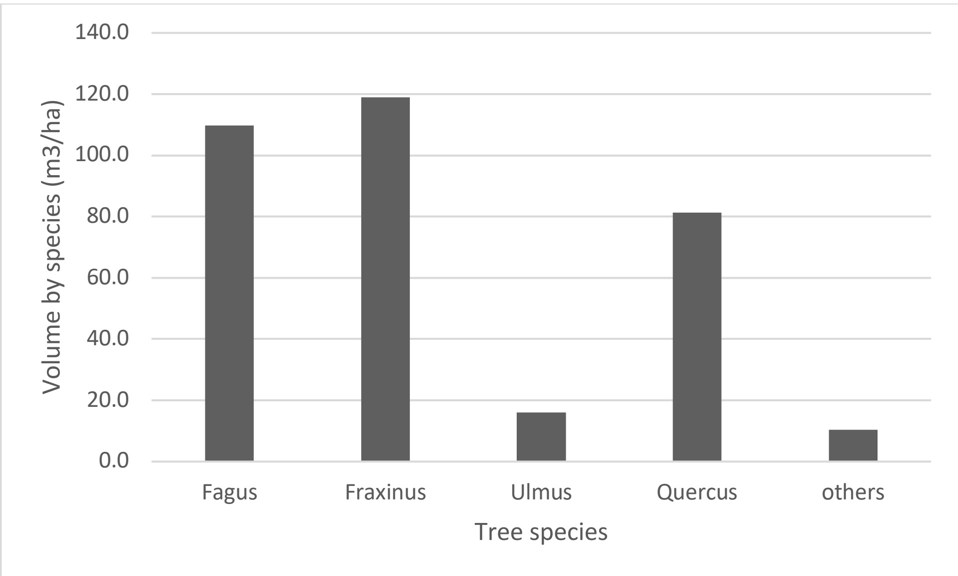


*Figure 2. Volume of living trees by species in Dalby Söderskog.*

## 3.2. The volume of living trees by diameter classes

### *3.2.1. Fagus sylvatica*

For beech, the highest volume was recorded in the diameter class 30 to 39 cm and the lowest in the dbh class of 110 to 119 cm (Fig. 3). Compared to the other tree species, the distribution of volume over diameter classes was more even.

### *3.2.2. Fraxinus excelsior*

For European ash, the diameter class 40 cm to 49 cm held the largest volume (Fig. 3). Besides, the volume of ash occurring in diameter classes greater than 50 cm is relatively high except for diameter classes ranging from 90 to 99 cm (no trees available). Meanwhile, the lowest volume can be seen in the diameter class of 10 to 19 cm, which indicates a low distribution of small trees.

### *3.2.3. Quercus robur*

Penduncarea oak ranks third in terms of living tree volume. The highest value is reported for the diameter class of 80 to 89 cm, meanwhile, only a small volume is recorded for the diameter class of 10 to 19 cm, and no trees with dbh 20 to 39 cm were recorded (Fig. 3).

### *3.2.4. Ulmus glabra*

For wych elm, the volume distribution is very different from other species and dominated by small trees. The volume of trees is highest on the small-sized tree of the diameter class interval 10 to 19 cm, and the smallest volume can be seen in the diameter class of 30 to 39 cm, while no larger trees were found (Fig. 3).

### 3.2.5. Other species

Lastly, for the other tree species, small volumes range from diameter classes from 10 to 19 cm to the diameter class of 70 to 79 cm (Fig. 3).

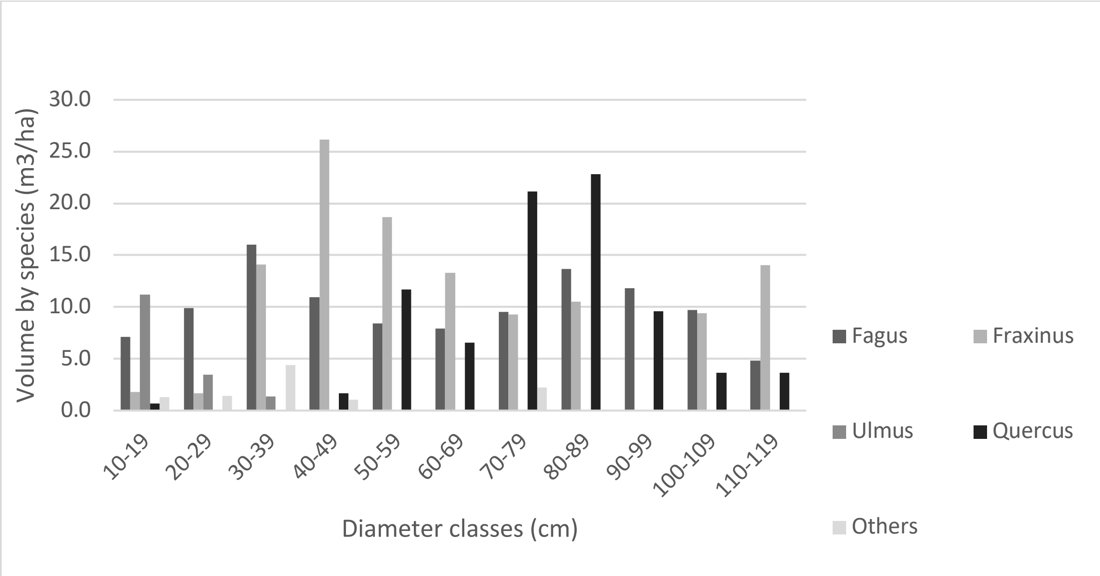


*Figure 3. Volume of living trees divided into diameter classes by species.*

### 3.2.6. Tukey pairwise comparison

According to Table 1, relationships between species and volume revealed that species within groups do not differ significantly in their means, but among groups they do. *Fraxinus, Fagus* and *Quercus* categorized under one group, meanwhile *Ulmus* and Others in another group which is differ from Group A species. The group A has significantly higher means than group B

*Table 1. Grouping information using the Tukey method and 95% confidence.*

| Factor (volume) | N | Mean | Grouping |
|---|---|---|---|
| *Fraxinus* | 50 | 119,0 | A |
| *Fagus* | 50 | 109,9 | A |
| *Quercus* | 50 | 81,4 | A |
| *Ulmus* | 50 | 16,0 | B |
| Other species | 50 | 10,3 | B |

Accordingly, Figure 4 shows the means and confidence intervals for the different species with confidence intervals overlapping for *Fraxinus, Fagus* and *Quercus* on the one hand, and *Ulmus* and Others on the other hand.

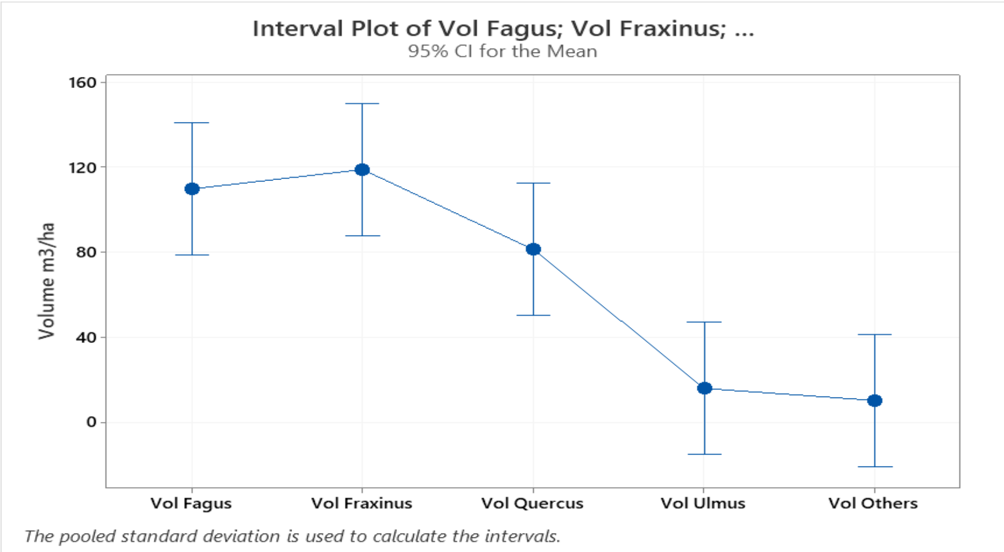


*Figure 4. Distribution of mean living tree volume ($m^3/ha$) among plots by tree species.*

## 3.3. Biomass and carbon

### 3.3.1. Living biomass and its carbon

Dalby Söderskog forest stocked, a total of 215.5 t/ha living aboveground biomass (Table 2). *Fagus sylvatica* and *Fraxinus excelsior* accounted for about 70 % of total biomass stored in the old broadleaf forest (Table 2, Fig. 5). The quantity of carbon stored by the different tree species was hugely different, with *Ulmus glabra* and the group of other species carbon stocking least carbon. The mean carbon stored by the broadleaf forest's living biomass was 107.7 t C/ha.

*Table 2. Aboveground biomass (AGB), and carbon stock distribution for the tree species in Dalby Söderskog.*

| Tree species | AGB) (t/ha) | Carbon stock (t C/ha) | Percentage % |
|---|---|---|---|
| *Fagus sylvatica* | 70.3 | 35.2 | 32.6 |
| *Fraxinus excelsior* | 76.2 | 38.1 | 35.4 |
| *Ulmus glabra* | 10.3 | 5.1 | 4.8 |
| *Quercus robur* | 52.1 | 26.0 | 24.2 |
| Others | 6.6 | 3.3 | 3.1 |
| Total | 215.5 | 107.7 | 100.0 |

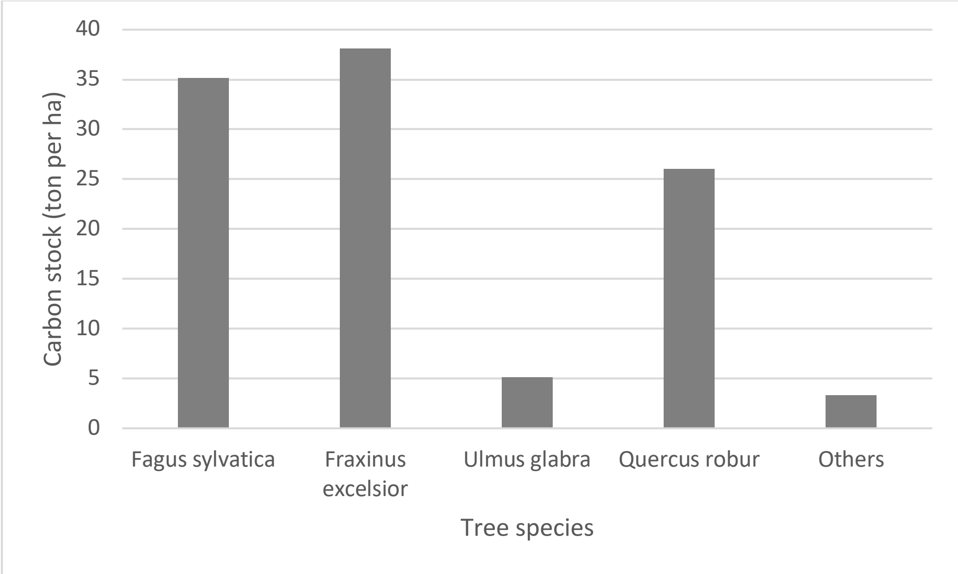


*Figure 5. Carbon stock (t/ha) of different tree species in Dalby Söderskog.*

### 3.3.2. Carbon stock and DBH class relationship in *Fagus sylvatica*

Results obtained show that *Fagus sylvatica* had the second-highest carbon storage (32.6 %) among the tree species. Carbon stock was relatively evenly distributed across DBH-classes (Fig. 6). The diameter class of 30 to 39 cm had the greatest carbon stock, with 5.1 t C/ha, and the largest diameter range from 110 to 119 had the lowest carbon stock, 1.6 t C/ha.

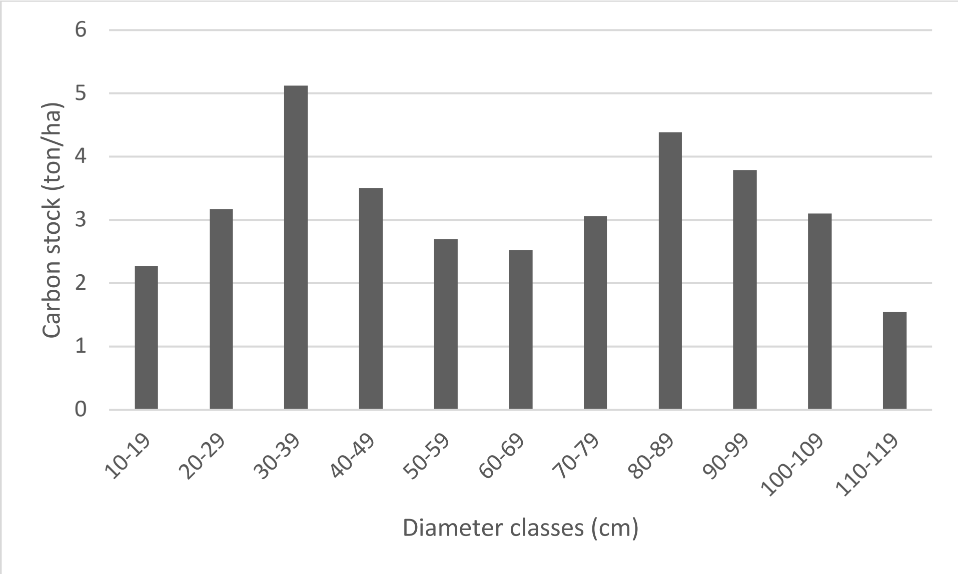


*Figure 6. Amount of carbon stock in different DBH classes in Fagus sylvatica.*

### 3.3.3. Carbon stock and DBH class relationship in *Fraxinus excelsior*

*Fraxinus excelsior* species has recorded the highest carbon stock of 35.4% total carbon content among the tree species for the diameter class of 40 to 49 cm with 8.5 t C/ha. Meanwhile, there were no trees recorded in the 90 to 99 cm class, and the small diameter classes of 10 to 19 cm (0.56 t C/ha) and 20 to 29 cm (0.54 t C/ha) only contained low amounts (Fig. 7).

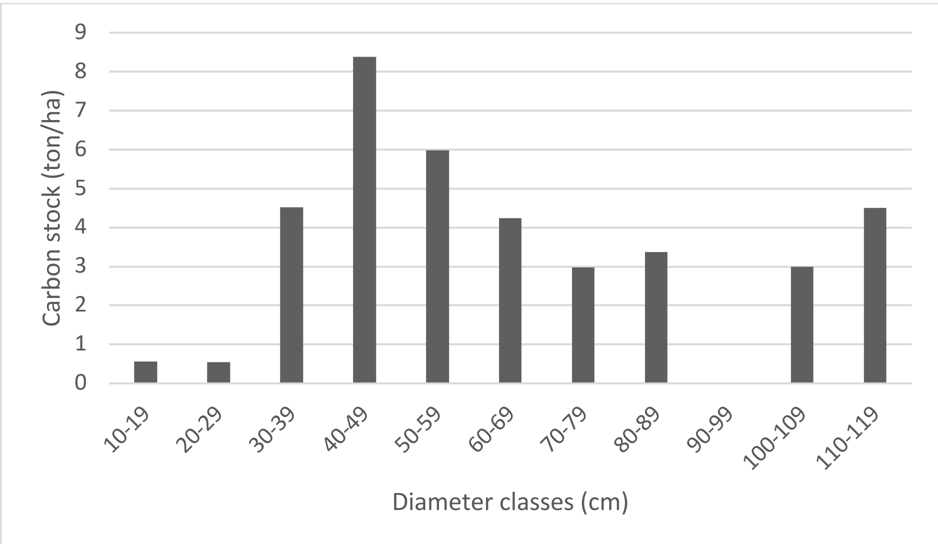


*Figure 7. Amount of carbon stock in different DBH classes in Fraxinus excelsior.*

### 3.3.4. Carbon stock and DBH class relationship in *Ulmus glabra*

*Ulmus glabra* has only three diameter classes of living trees (Fig. 8). There are no trees present for the diameter classes of more than 40 cm, and this species is classified as having young stand distribution across all the area. The amount of stored carbon is gradually decreasing in between diameter classes. The maximum carbon content of 3.6 t C/ha was observed in the 10 to 19 cm diameter class, followed by (1.12 t C/ha) in the 20 to 29 cm, and finally, the lowest value (0.43 t C/ha) in the 30 to 39 cm class.

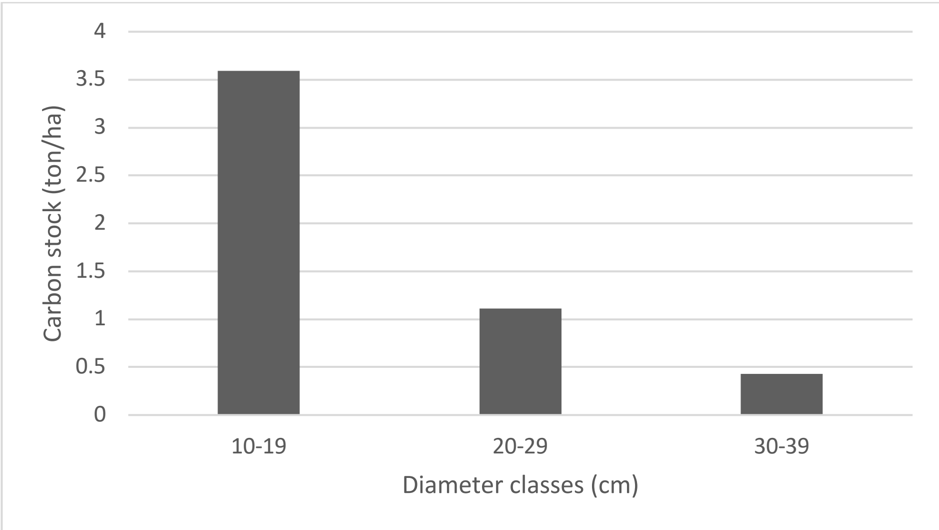


*Figure 8. Amount of carbon stock in different DBH classes in Ulmus glabra.*

### 3.3.5. Carbon stock and DBH class relationship in *Quercus robur*

*Quercus robur* accumulated the third-highest amount of carbon storage among the live tree species. The most significant carbon sequestration (2.84 t C/ha) is seen in the 80 to 89 cm diameter class (Fig. 9). Besides, approximately 52% of the carbon sequestration is represented in the diameter class range between 70 to 79 cm and 80 to 89 cm. Meanwhile, a very low carbon stock is seen in the diameter classes below 50 cm.

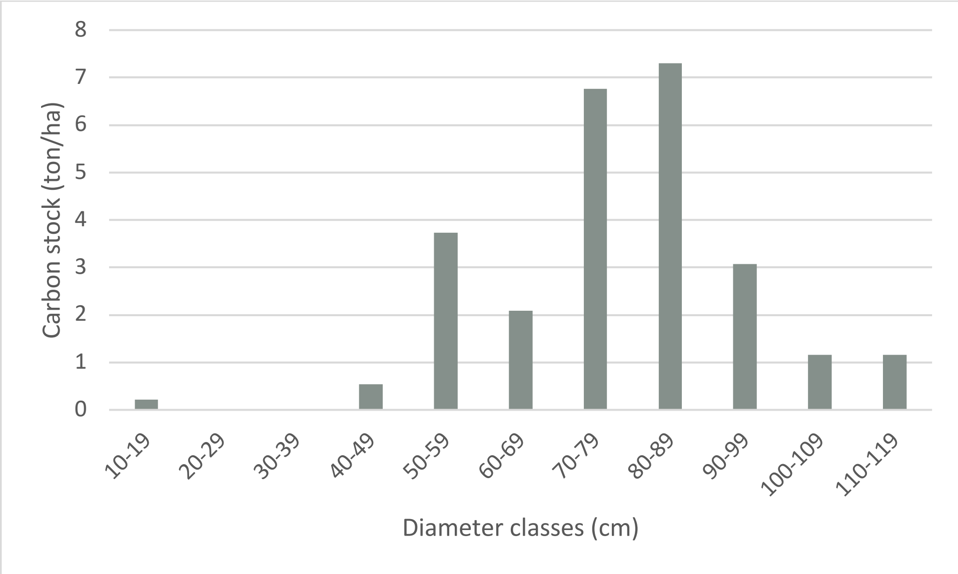


*Figure 9. Amount of carbon stock in different DBH classes in Quercus robur.*

### 3.3.6. Carbon stock and DBH class relationship in other species

The group of other species has been shown to have the lowest carbon storage of all the species studied. The highest carbon content (1.40 t C/ha) was stored between 30 to 39 cm diameter. Meanwhile, no trees and thus no carbon stock was found in the diameter range of 50 to 69 cm (Fig. 10).

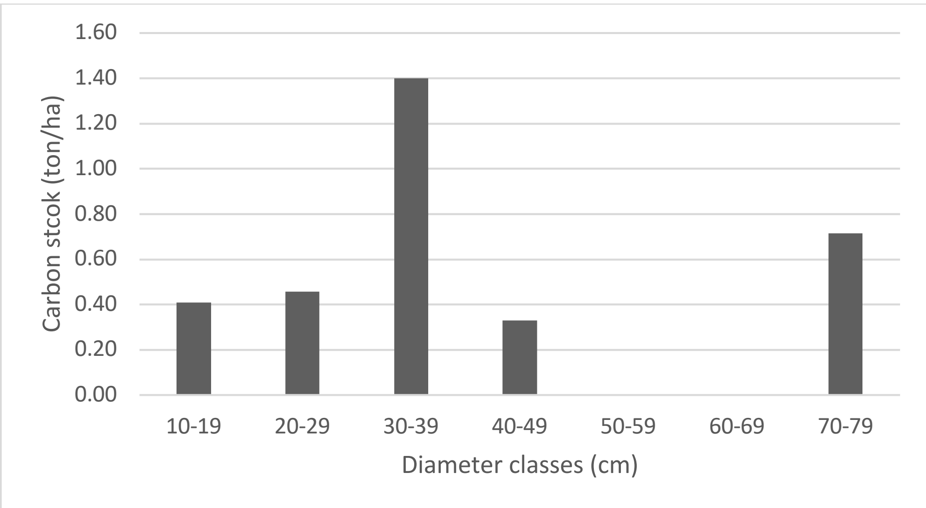


*Figure 10. Amount of carbon stock and DBH class in Other species*

### 3.3.7. Volume of deadwood

According to the findings, the mean deadwood volume in Dalby Söderskog is 227.8 ± SD 196.1 $m^3$/ha (Tables A5, A6). The volume of deadwood is divided into two types: logs had the highest amount (174.4± SD 156.4 $m^3$/ha), and the snags had (53.5± SD 117.9 $m^3$/ha, Fig. 11).

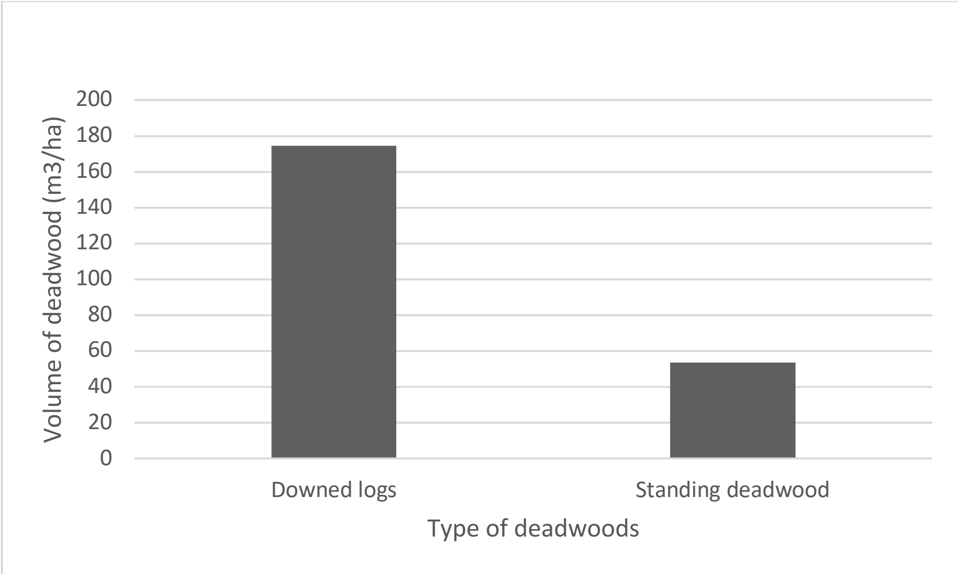


*Figure 11. Volume of different types of deadwood*

### 3.3.8. Deadwood biomass and its carbon

The mean deadwood aboveground biomass in Dalby Söderskog was estimated to be 145.3± SD 125.5 t/ha (Table 3). The details show large variation around the means, which is expected given the relatively small size of our sample plots.

A higher biomass is stored in downed logs (111.6 t/ha), than in standing dead wood (33.7 t/ha). Downed deadwood comprised the greatest proportion of total carbon stock, followed by standing deadwood 77%, and 23%, respectively (Table 3). The total carbon stored in deadwood was 68.3± SD 59.0 t C/ha on average.

*Table 3. Deadwood aboveground biomass (AGB) and carbon stock distribution for the different types of deadwood category.*

| Type of deadwood | AGB)<br>(t/ha) | Carbon stock<br>(t C/ha) | Percentage<br>% |
|---|---|---|---|
| Downed logs | 111.6 | 52.5 | 77 |
| Standing deadwood | 33.7 | 15.8 | 23 |
| **Total** | 145.3±SE17.7 | 68.3±SE8.3 | 100 |

### 3.3.9. Carbon stock and DBH class relationship in downed deadwood (logs)

The overall amounts of carbon stored in logs were higher in smaller than larger diameter classes (Fig. 12), due to a much higher number of logs and snags in these classes (Appendix, Fig. A17, A18).

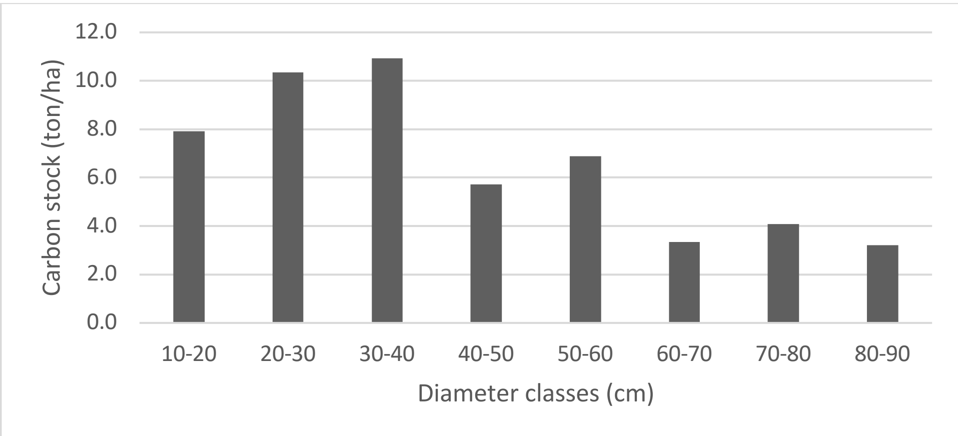


*Figure 12. Carbon stock and DBH class relationship in logs.*

### 3.3.10. Carbon stock and DBH class relationship in standing dead wood

Results show that the carbon content among standing deadwood was largely stored in smaller diameter classes (< 60 cm) (Fig. 13).

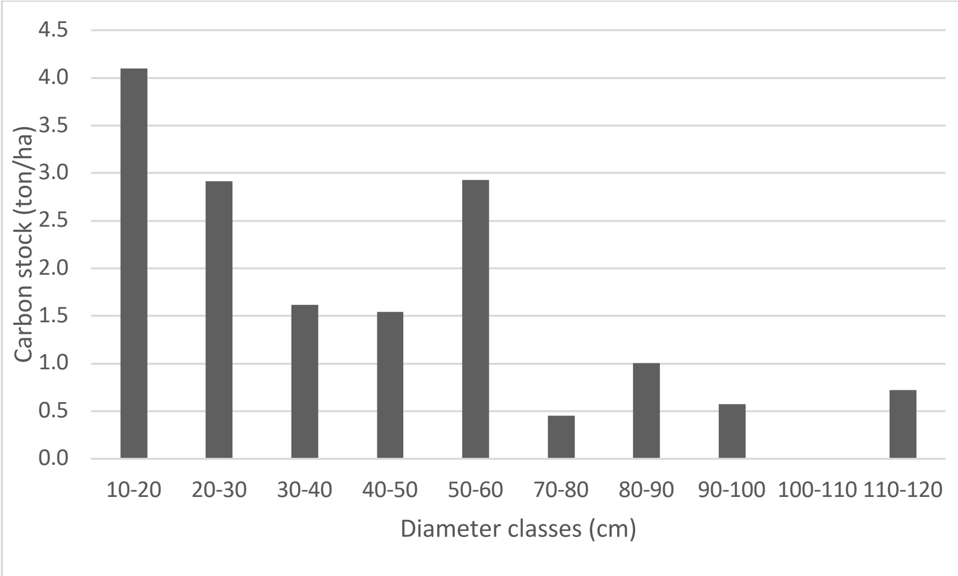


*Figure 13. Carbon stock and DBH class relationship in standing deadwood.*

### 3.3.11. Overall carbon stock

The results obtained indicate that in Dalby Söderskog, the total aboveground carbon stock is 176 t C/ha. The overall result for carbon storage among various aboveground biomass shows that carbon storage decreases from live trees over logs to standing dead wood (Fig. 14). The highest biomass is stored in living trees 107.7 t C/ha, followed by downed deadwood (logs) 52.5 t C/ha, and then standing dead wood with 15.8 t C/ha.

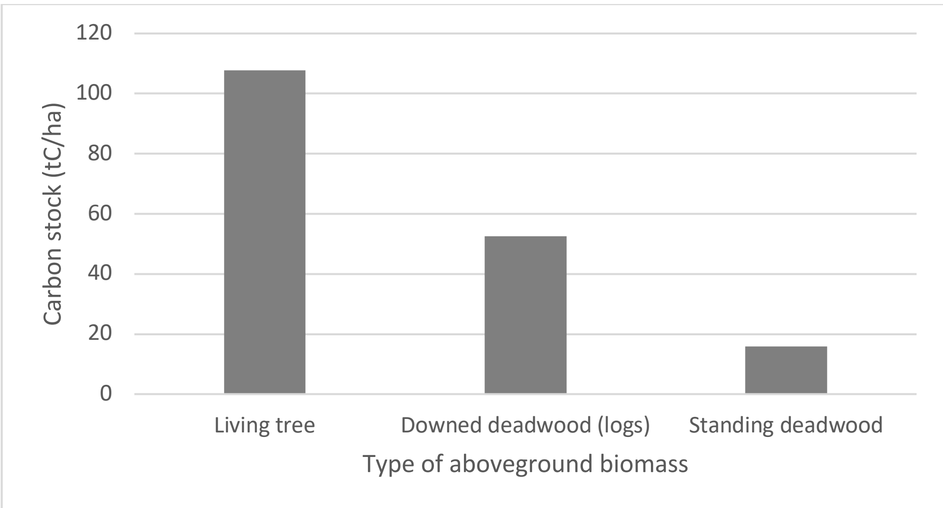


*Figure 14. Carbon stock among three fractions of aboveground tree biomass.*

### 3.3.12. Relative share of carbon stock in living and dead woody biomass

According to Figure 15, the relative share of carbon stored in live trees increases with stem diameter. Up to a stem diameter of 39 cm, it is lower than 50%, which means that more carbon is stored in dead than living trees. For the large diameter classes, living trees generally store more carbon than dead wood, ranging from a share of 59 to 100% of total carbon stored in wood.

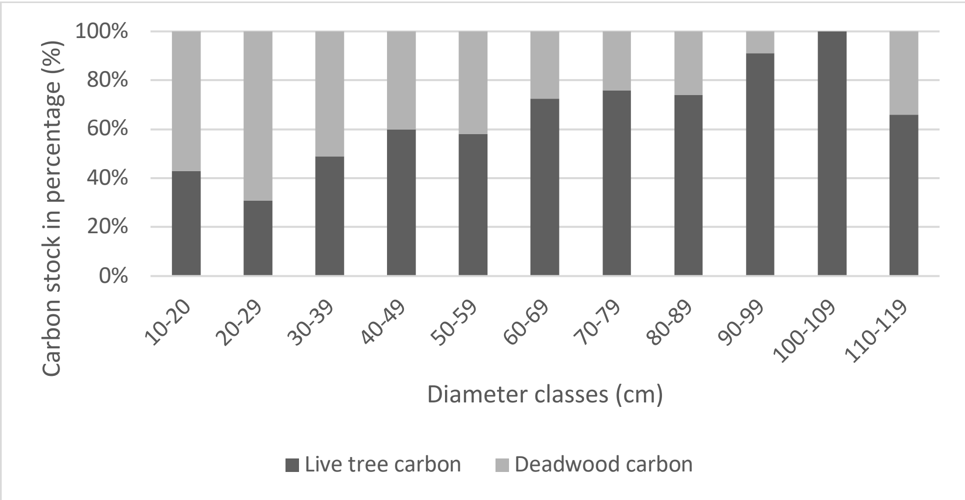


*Figure 15. Percentage of the carbon stock in live and deadwood in different diameter classes.*

### 3.3.13. Paired analysis of live tree and CWD volumes

A paired t-test analysis indicated that the mean living tree volume (336.8 ± SE 29.6) was significantly higher than the CWD volume (227.9 ± SE 27.7) with ($t$=-2.32, $P$=0.025). The variation between plots is high, but the p-value is still statistically significant.

### 3.3.14. Regression live tree and deadwood

A linear regression analysis showed that there is a weak but significant negative relationship between live tree volume and CWD ($p$=0.015). The model is implying that the amount of CWD increases with decreasing live tree volume (Fig. 16).

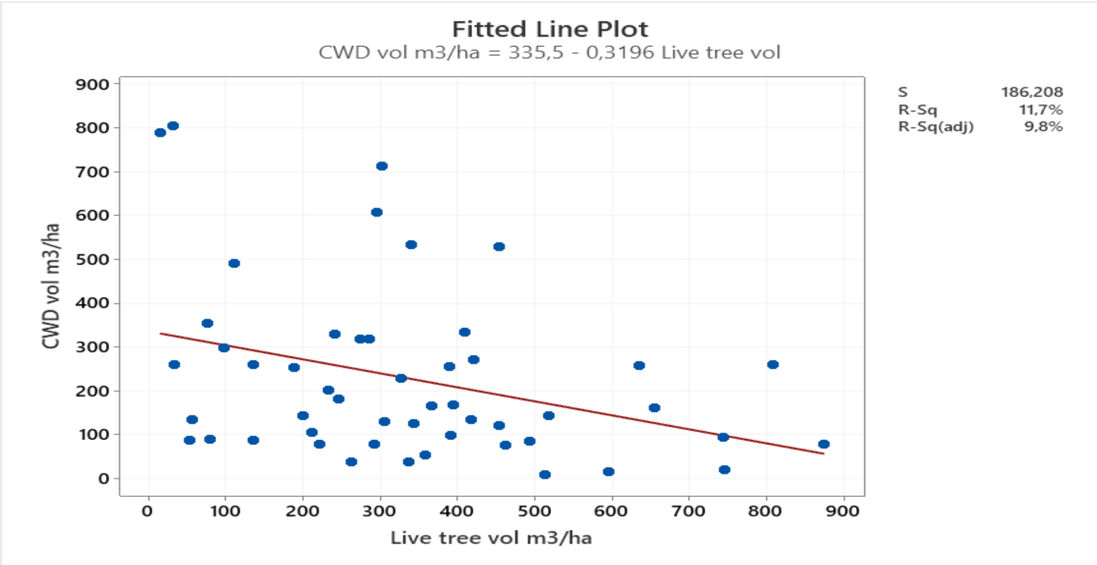


*Figure 16. Relationship between CWD volume and live tree volume (V=335, P<0.015<, $R^2$ 11.7%. The regression equation is: CWD vol $m^3$/ha = 335.5 – 0.3196 (y), y = live tree volume.*

# 4. Discussion

## 4.1. Disturbance by tree diseases

Insect and disease invasions in southern Sweden have resulted in considerable increases in regional tree death rates and the conversion of live carbon to dead matter. The findings of this study show that CWD has a substantial carbon storage capacity; however, it is lower than live tree biomass. The Dutch elm disease, which wiped out millions of elms in the 20$^{th}$ century (Martin et al., 2010), has been affecting Dalby Söderskog since 1990. It appears to be a significant influence in modifying forest succession processes. A comparable investigation carried out by Brunet et al., (2014), reported pests and diseases can shape ecosystems and influence succession. Meanwhile, Ash dieback was also affecting the trees in Dalby Söderskog. In Sweden, the first evidence of ash dieback was documented in 2002 (Stener, 2013).

The regression model between living and deadwood volume was found to be inversely related. The model predicts that CWD increases with decreasing live tree volume. When living trees in a stand with low live tree stocking have been killed by disturbance, the highest deadwood stocking will be obtained. This study's findings are comparable to those of other studies which indicated that forest disturbance influences pattern of deadwood accumulation (Woodall and Westfall, 2009) as the amount of deadwood in the forest is determined by both accretion variables (disturbance, self-thinning, and senescence) and depletion variables (harvesting and decay). Forest debris is formed because of forest biomass mortality (Sollins, 1982; Spies et al., 1988; Sturtevant et al., 1997; Bond-Lamberty and Gower, 2008), hence correlation between live and dead forest biomass should be apparent at some level. Such mortality might be expected to impact carbon dynamics by reducing forests' carbon sequestration capacity and by converting live materials to dead carbon source (Fei et al., 2019).

## 4.2. Deadwood volume dynamics

The total mean volume of deadwood found in the study area is 227.8 $m^3$/ha. Deadwood was present in all the surveyed plots as lying logs and snags (standing and stump). However, lying logs accounted for a greater proportion of the total dead volume than snags. Logs are the most important deadwood components with 77 % of total volume.

This finding is supported by prior research by Krankina et al., (2002). Meanwhile, several studies have found similar results, reporting 2–3 times more lying (approximately 60%–70%) than standing deadwood regardless of the dominant species (Siitonen, 2001; Nilsson et al., 2002; Karjalainen and Kuuluvainen, 2002). The most recent study conducted in Romanian deciduous forests (Öder et al., 2021) reported that lying deadwood objects accounting more than 70% of the total deadwood compares to standing deadwood (30%).

The fact that there were fewer snags in most plots surveyed could be due to the transitory nature of this component. This finding means that after increasing tree mortality, the number of snags can increase briefly, but they eventually fall over and become felled logs (Herrero et al., 2014). Therefore, the distribution of downed deadwood on the forest floor is higher. Additionally, Passovoy and Fule, (2006) found that standing dead trees with a smaller diameter collapse over more quickly, resulting in top breaking, so this could be why the volume of downed deadwood is higher.

The present study highlights that in the broadleaf forest of Dalby Söderskog, deadwood pieces are mainly concentrated in the smaller diameter classes (diameter class between 10 cm and 30 cm). Data from Dalby Söderskog significantly correlate to the finding of Keßler et al. (2012) that the *Hymenoscyphus fraxineus* pathogen attacks all size classes, yet, symptoms and eventual mortality progress more rapidly in smaller individuals classes. When a tree is dead and standing, it requires a certain amount of structural support to keep its vertical structure; failing in doing it will cause more destruction (Woodall and Westfall, 2009). Alternatively, CWD is highest in young stands, decreases in developing stands, and rises slightly in mature stands as tree mortality increases after disturbance (Harmon et al., 1986; Spies et al., 1988).

The CWD volume found in Dalby Söderskog is comparable with the findings of Bujoczek et al. (2018) who found a mean volume of deadwood in montane beech-fir forests of 223.9 $m^3$/ha. Meanwhile, according to Christensen et al. (2005), the mean deadwood amount in unmanaged beech forests was 130 $m^3$/ha, but the variation among reserves was high, ranging from almost nil to 550 $m^3$/ha. Also, in the Pacific Northwest, Spies et al. (1988) identified tremendous values for Douglas fir of 423 $m^3$/ha mean CWD volume for young stands (age 65 years) and 250 $m^3$/ha for mature forests (age 121 years). Also, according to Burrascano et al. (2013), significant levels of deadwood (over 200 $m^3$/ha) are typical in old growth stands in central European forest. These findings can be correlated with our study whereby the old stand has almost similar values.

## 4.3. Deadwood carbon stock

The large disturbance initiated by Dutch elm disease three decades ago greatly influenced the amount and composition of carbon stock. Notably, CWD stored 68 t C/ha, 39% of the total carbon stock of woody material in the entire surveyed area. Modelled deadwood carbon stocks for broadleaf species are higher than most results from other literature. This could be due to the decay rates reduction factors were not used in this investigation.

According to Christensen et al., (2005), the carbon stock of deadwood in beech forests in central and eastern Europe ranges from 1.4 to 82.4 t C/ha. Similar species composition in the semi-natural forest reserve Suserup Skov in Denmark accounted for the carbon stocks in deadwood about 35 t C/ha from the overall ecosystem carbon stock (Nord-Larsen et al., 2019). Dalby Söderskog stored two times higher carbon stock compared to Suserup Skov. This could be because of disease related supply of large diameter logs from ash and elm, not only beech and oak on the forest floor, versus Suserup Skov, which is only dominated by beech and oak deadwood.

Apart from it, a study by Wirth and Lichtstein (2009), show at the age of 200 years, deadwood stocks in temperate broadleaved forest (among others *Nothofagus* and *Fagus*) lies between 10 and 90 t C/ha. This finding falls within the range of our results. Hadden and Grelle (2017), demonstrated when relatively slight disruptions resulted in more deadwood in the primary boreal forest. Therefore, net emissions from deadwood rose, changing overall ecosystem respiration and shifting the forest from a carbon sink to a source of carbon dioxide (Hadden and Grelle, 2017).

## 4.4. Live tree volume dynamics

The mean volume of live trees is 338 $m^3$/ha, 100 $m^3$ more than the deadwood volume. The live tree volume remains high after forest disturbance, except there are changes in species composition per volume. Remarkably, the present composition and structure of Dalby Söderskog vary drastically from their historical range of variability. According to Malmer et al. (1978), the order of species abundance in Dalby Söderskog in the 1970's was as follow *Ulmus* > *Fraxinus*> *Fagus* > *Quercus*. However, the recent finding indicates *Fraxinus* > *Fagus* > *Quercus* > *Ulmus*, and this corresponds to Waring and Running (2007) that disturbances alter forest species composition.

Elm was once the most dominant tree in the forest (≥ dbh 20 cm), but Dutch elm disease had devastated the elm population by 2011 (Brunet et al., 2014). Then it appears to play a significant role in modifying forest succession trends. DED occurrence in Dalby Söderskog was followed by increasing regeneration of ash. According to Oheimb and Brunet (2007), canopy gaps create ideal conditions for ash recruitment. Ash was known to be relatively robust; yet, it has recently become a primary issue in most of Europe due to a pathogenic fungus that causes ash dieback (McKinney et al., 2011).

## 4.5. Live tree carbon stock

The Dalby Söderskog mixed broadleaf species contribute to carbon storage by storing 107.7 t C/ha. The capacity of forest ecosystems to store carbon in biomass is affected by species composition, age, and population density (Mendoza-Ponce and Galicia 2010).

Ash is the most important species with total carbon stock contribution (36.7 %), then beech (33.2 %), followed by oak (22.7%), Elm (4.5%), and the lowest contribution of other species (2.9%). Beech is the most abundant shade-tolerant tree species in European temperate forests and may be additionally favoured by adverse effects of ash dieback in eutrophic forests, where Ash usually shows a faster initial growth during regeneration (Emborg, Christensen and Heilmann-Clausen, 2000). European Ash (*Fraxinus excelsior)* is a fast-growing tree species (Fraxigen, 2005), common in different forest types and can regenerate naturally through seed fall.

Meanwhile, pedunculate oak was ranked third. In Dalby Söderskog, it is mainly represented by old individuals (Brunet et al., 2014). Oak distribution in small diameter classes is very poor due to canopies closed due to other dominating species, making no gaps for the light-demanding oak to grow in. Consequently, regeneration of oak drastically declined because of mortality and low regeneration due to canopy closure.

Elm species noticed low carbon storage due to the forest is severely impacted by Dutch elm disease, which has devastated the whole forest standings since the late 1980s. Furthermore, according to Brunet et al. (2014), Elm was limited to the shrub layer, surviving as shrubs or small trees. Other species such as maple and cherry all exhibited low abundance and carbon stocks. It may be due to the low frequency of the tree species in the adjacent forests and a quick establishment by other more persistent and competitive tree species.

If 50% of biomass is carbon (Houghton, 2007; Thomas and Martin, 2012), mean biomass carbon density in the Swedish primary forests ranged between 9 t C/ha and 91 t C/ha. Our findings show that the Dalby Söderskog stored more carbon than the average Swedish forest. However, compared to 28 t C/ha and 229 t C/ha in other research on carbon storage in Nordic and Baltic primary forests (Vucetich et al., 2000; Kenina et al., 2019; Nord-Larsen et al., 2019), 107.7 t C/ha is within that range.

Our research demonstrates the substantial carbon stores associated with large-diameter trees in the region. Still, there is the potential for significant losses in aboveground carbon with giant trees prone to biotic and abiotic causes if any additional disturbance occurs soon.

## 4.6. Live tree versus dead tree carbon

Even though biotic and abiotic factors affect the forest, the results show that living tree carbon is higher than deadwood carbon in this circumstance. The Dalby Söderskog obtained above ground carbon (without soils) of 175.7 t C/ha with 107.7 t C/ha stored in the living biomass pool and 68.3 t C/ha in the deadwood carbon pool. This forest has a relatively high total carbon stock.

According to findings, highest carbon stock of live trees stored in diameter class is more than 50 cm, 71.2 t C/ha, and for coarse wood debris in diameter class of less than 60 cm, 50.7 t C/ha. The higher share of deadwood in lower dbh classes is likely related to the high elm mortality that previously dominated these smaller dbh classes, as shown in the carbon stocked along diameter gradient (Fig. 15). This simplifies, most small diameter classes less than 60 cm are abundant in the form of CWD, indicating that the stand still maintains an abundance of large trees that are consistently productive and have numerous second generations upraised.

The succession pattern changes, the dispersal is allowed to run its course, and mortality will occur at different rates among different size classes, influencing regeneration differently among species. As a result, it will impact the accumulation of living biomass and cause things to alter in unexpected ways.

The absence of management promoted the existence of developed forest successional growth phases, resulting in a higher level of living biomass, tree density and deadwood volumes. In this scenario, the current disruption for Ash is still early, and the pattern of carbon stored in CWD rather than live trees has considerably less influence. For the time being, Ash continues to outnumber other tree species in terms of distribution, with the distribution of species predicted to shift again in the following decades.

## 4.7. Study limitations

The main limitation in our study is the lack of decay classes for each deadwood type. The results on biomass and carbon obtained in this study, especially for deadwood, vary as published in other scientific papers; this is because most studies have applied deadwood decomposing reduction classes (1 to 5) when calculating deadwood biomass. The decay class represents the stage of decomposition of dead wood and is usually determined by visual criteria. The classification of CWD by decay class is crucial since decay affects wood density and subsequent carbon content. Grove et al. (2009), show that log volumes measured in field inventories can be transformed into CWD mass and carbon content based on the decay class and estimate corresponding wood densities. Failing to apply decay classes in calculation could produce errors for measured carbon pools.

In this study, with the absence of a survey about decay classes for each piece of deadwood, we cannot apply the decomposition reduction factor when computing carbon, it's possible that the carbon content of deadwood has been overestimated. Based on field observation on 692 pieces of deadwood, 72% was with absence of barks, and only 18% had intact bark. Based on surveyed deadwood, it can be said deadwood mainly in early decay stages, were still fresh, and the structure is hard. Hence, considering carbon contents in different decay stages would improve the accurate assessment of carbon stocks in deadwood.

Besides that, the resulting biomass and carbon estimate highly depend on the samples and the conceptual approach utilized (i.e., whether biomass functions or biomass expansion factors are used), Neumann et al. (2016). In this study, a constant biomass expansion factor of 0.64 was used, which might probably influence the results obtained. Pietsch and Hasenauer (2002), underlined that constant biomass expansion factors are widely known for overestimating young trees and underestimating biomass for older trees.

Another limitation is that the secondary data from previous research have no data on essential parameters, the height of the live tree. Estimating volume value from the volume production table was used to resolve these issues, which raises some doubts about the volume and biomass of the live tree.

## 4.8. Conclusion

As a concluding remark, this study found that old-growth forest stores large carbon stocks, implying the maintaining protection of old broadleaved forests is crucial not only for increasing biodiversity dead wood but also for carbon storage. In the specific case of Dalby Söderskog, effects of tree diseases have temporarily increased the relative share of dead wood compared to live tree volumes, in particular for smaller diameter trees. The mixed tree species composition of the forest has, however, buffered the effects of Dutch elm disease and ash dieback, and living tree volume still remains considerably larger than the volumes of dead wood.

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# Appendix

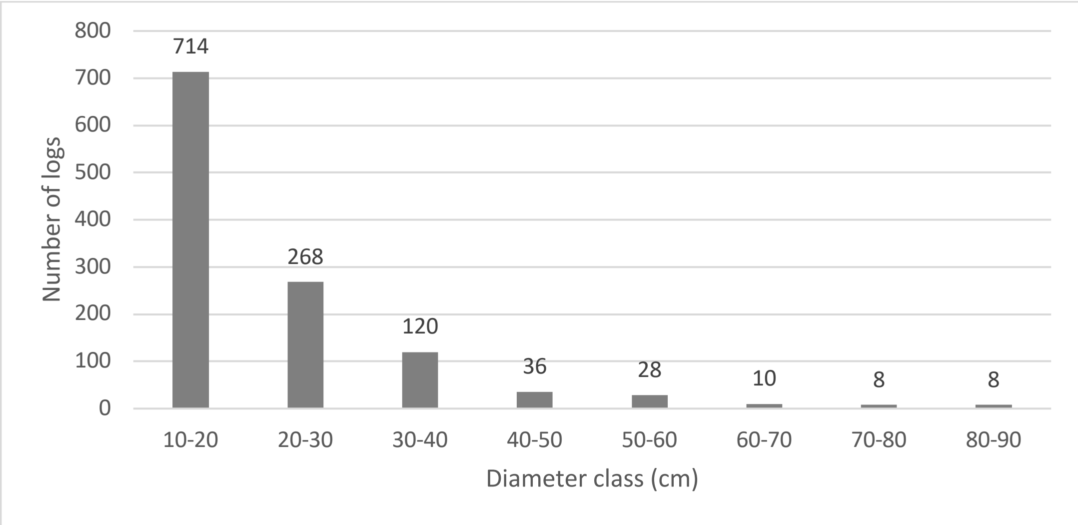


*Figure A17. Distribution of downed dead wood (logs) in different diameter classes.*

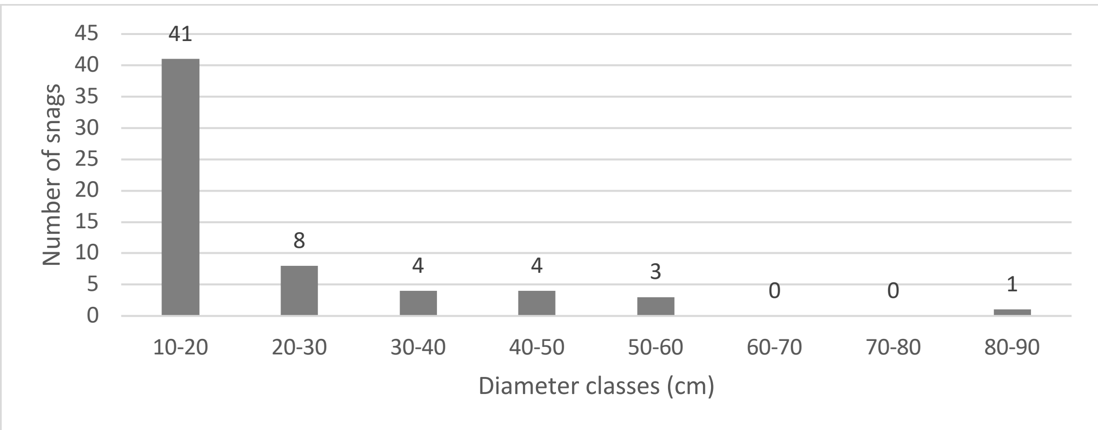


*Figure A18. Distribution of snags in different diameter classes.*

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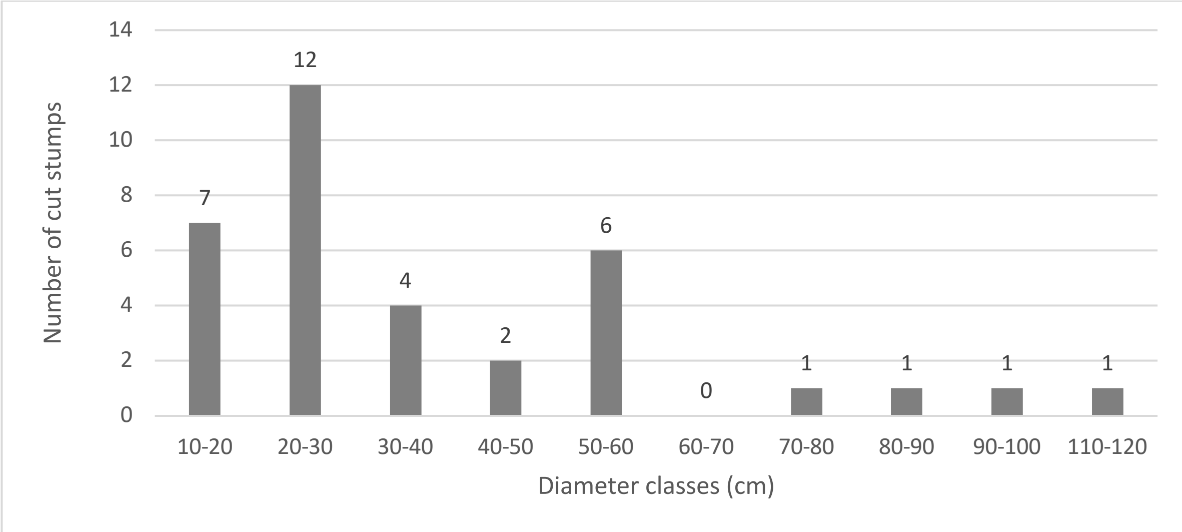


*Figure A19. Distribution of stumps in different diameter classes.*

*Table A4. Descriptive Statistics. Volume of live trees by species.*

| Variable | N | Mean | SE Mean | StDev | Minimum | Q1 | Median | Q3 | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Fagus | 50 | 109.9 | 21.8 | 153.9 | 0.0 | 0.0 | 23.0 | 207.0 | 589.0 |
| Fraxinus | 50 | 119.0 | 22.8 | 161.2 | 0.0 | 0.0 | 20.5 | 205.6 | 659.9 |
| Ulmus | 50 | 16.0 | 2.8 | 19.6 | 0.0 | 0.0 | 9.9 | 21.0 | 103.0 |
| Quercus | 50 | 81.4 | 15.3 | 108.4 | 0.0 | 0.0 | 0.0 | 138.9 | 351.0 |
| Others | 50 | 10.3 | 3.1 | 21.8 | 0.0 | 0.0 | 0.0 | 14.0 | 111.5 |
| **Total volume** | **50** | **336.7** | **29.6** | **209.6** | **15.0** | **197.2** | **316.2** | **453.5** | **874.8** |

*Table A5. Summary of statistics for CWD.*

| Variable | N | Mean | SE Mean | StDev | Minimum | Q1 | Median | Q3 | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Log vol m3/ha | 50 | 174.4 | 22.1 | 156.4 | 7.9 | 67.6 | 124.3 | 241.6 | 779.6 |
| Snag vol m3/ha | 50 | 49.3 | 16.6 | 117.3 | 0.0 | 0.0 | 9.3 | 33.7 | 621.7 |
| Stump vol m3/ha | 50 | 4.1 | 1.5 | 10.6 | 0.0 | 0.0 | 0.0 | 2.8 | 62.2 |
| CWD vol m3/ha | 50 | 227.9 | 27.7 | 196.1 | 7.9 | 87.7 | 162.9 | 303.2 | 805.4 |
| CWD biomass t/ha | 50 | 145.8 | 17.7 | 125.5 | 5.1 | 56.1 | 104.3 | 194.1 | 515.5 |
| CWD carbon tC/ha | 50 | 68.5 | 8.3 | 59.0 | 2.4 | 26.4 | 49.0 | 91.2 | 242.3 |

*Table A6. Wood volumes in 50 sample plots in Dalby Söderskog.*

| Sample plot no. | Log vol m3/ha | Snag vol m3/ha | Stump vol m3/ha | CWD vol m3/ha | Living trees m3/ha | All wood m3/ha |
|---|---|---|---|---|---|---|
| 1 | 117.13 | 7.63 | 0.00 | 124.76 | 342.71 | 467.47 |
| 2 | 60.51 | 30.42 | 3.67 | 94.60 | 744.72 | 839.32 |
| 3 | 61.24 | 21.24 | 1.45 | 83.93 | 494.09 | 578.02 |
| 4 | 551.63 | 161.10 | 0.00 | 712.73 | 302.82 | 1015.54 |
| 5 | 156.83 | 4.52 | 0.00 | 161.35 | 655.93 | 817.28 |
| 6 | 70.59 | 6.12 | 0.00 | 76.72 | 461.57 | 538.28 |
| 7 | 104.16 | 0.00 | 0.00 | 104.16 | 210.82 | 314.98 |
| 8 | 465.81 | 140.60 | 0.00 | 606.41 | 295.57 | 901.99 |
| 9 | 120.00 | 1.59 | 0.00 | 121.59 | 453.18 | 574.77 |
| 11 | 60.17 | 15.62 | 1.53 | 77.31 | 874.84 | 952.15 |
| 12 | 48.65 | 49.26 | 0.00 | 97.91 | 390.71 | 488.63 |
| 14 | 75.89 | 0.00 | 11.87 | 87.77 | 135.35 | 223.12 |
| 17 | 253.13 | 2.86 | 2.56 | 258.56 | 33.00 | 291.56 |
| 18 | 216.15 | 44.11 | 0.00 | 260.26 | 809.24 | 1069.49 |
| 23 | 110.98 | 13.90 | 10.00 | 134.89 | 416.91 | 551.80 |
| 27 | 256.38 | 40.65 | 1.45 | 298.49 | 97.40 | 395.89 |
| 28 | 125.15 | 10.51 | 6.98 | 142.64 | 199.97 | 342.62 |
| 29 | 46.63 | 0.00 | 6.78 | 53.41 | 357.62 | 411.04 |
| 30 | 241.34 | 15.44 | 0.00 | 256.78 | 634.98 | 891.76 |
| 31 | 178.63 | 23.12 | 0.00 | 201.75 | 233.12 | 434.88 |
| 32 | 195.37 | 58.74 | 1.45 | 255.55 | 389.44 | 644.99 |
| 33 | 153.98 | 0.00 | 12.74 | 166.71 | 395.22 | 561.94 |
| 34 | 96.61 | 174.14 | 0.00 | 270.75 | 421.34 | 692.09 |
| 36 | 350.32 | 0.00 | 2.56 | 352.88 | 75.87 | 428.75 |
| 39 | 9.23 | 132.85 | 0.00 | 142.09 | 517.54 | 659.62 |
| 41 | 14.57 | 0.00 | 0.00 | 14.57 | 595.02 | 609.59 |
| 42 | 38.47 | 0.00 | 0.00 | 38.47 | 337.28 | 375.75 |
| 44 | 319.08 | 0.00 | 0.00 | 319.08 | 274.52 | 593.60 |
| 45 | 158.83 | 175.94 | 0.00 | 334.78 | 408.99 | 743.77 |
| 46 | 171.29 | 88.17 | 0.00 | 259.46 | 134.91 | 394.37 |
| 47 | 471.47 | 0.00 | 62.19 | 533.66 | 340.13 | 873.79 |
| 49 | 118.10 | 12.34 | 0.00 | 130.44 | 304.80 | 435.24 |
| 51 | 24.02 | 14.50 | 0.00 | 38.52 | 263.23 | 301.75 |
| 52 | 77.79 | 0.00 | 0.00 | 77.79 | 292.68 | 370.47 |
| 54 | 158.45 | 6.05 | 0.00 | 164.50 | 366.86 | 531.36 |
| 55 | 304.41 | 9.03 | 4.07 | 317.51 | 285.36 | 602.86 |
| 57 | 294.77 | 31.35 | 2.46 | 328.58 | 240.90 | 569.48 |
| 58 | 19.48 | 0.00 | 0.00 | 19.48 | 746.18 | 765.65 |
| 59 | 76.30 | 2.22 | 0.00 | 78.52 | 220.68 | 299.20 |
| 62 | 449.98 | 0.00 | 39.70 | 489.68 | 110.44 | 600.12 |
| 64 | 16.80 | 512.18 | 0.00 | 528.98 | 454.57 | 983.55 |
| 65 | 242.38 | 9.48 | 0.00 | 251.86 | 188.78 | 440.64 |
| 66 | 123.35 | 3.19 | 6.95 | 133.50 | 57.00 | 190.50 |
| 67 | 179.47 | 0.00 | 2.51 | 181.98 | 246.82 | 428.80 |
| 68 | 69.76 | 15.10 | 2.51 | 87.37 | 53.54 | 140.91 |
| 69 | 779.61 | 10.49 | 0.00 | 790.10 | 15.00 | 805.10 |
| 70 | 86.78 | 0.00 | 1.45 | 88.23 | 79.54 | 167.77 |
| 72 | 167.09 | 621.72 | 16.62 | 805.43 | 32.00 | 837.43 |
| 73 | 224.55 | 0.00 | 4.11 | 228.67 | 327.62 | 556.29 |
| 74 | 7.91 | 0.00 | 0.00 | 7.91 | 514.01 | 521.93 |
| **Total Mean** | **174.42** | **49.32** | **4.11** | **227.86** | **336.70** | **564.56** |

*Table A7. Summary of the complete tree inventory in Dalby Söderskog in 1970 (Lindgren 1971). Calculated volumes include stems and branches down to 3 cm at the top.*

| **Middle dbh, cm** | 12.5 | 17.5 | 22.5 | 27.5 | 32.5 | 37.5 | 42.5 | 47.5 | 52.5 | 57.5 | 62.5 | 67.5 | 72.5 | 77.5 | 82.5 | 87.5 | 92.5 | >97.5 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quercus, no stems | 8 | 3 | 6 | 9 | 10 | 24 | 50 | 52 | 89 | 121 | 94 | 97 | 97 | 90 | 89 | 57 | 57 | 68 | 1021 |
| Quercus, m3 sum | | | 2 | 5 | 7 | 28 | 81 | 109 | 236 | 366 | 310 | 355 | 355 | 378 | 378 | 268 | 268 | 387 | 3533 |
| **Quercus, m3 per stem** | | | **0.33** | **0.56** | **0.70** | **1.17** | **1.62** | **2.10** | **2.65** | **3.02** | **3.30** | **3.66** | **3.66** | **4.20** | **4.25** | **4.70** | **4.70** | **5.69** | |
| Fagus, no stems | 362 | 204 | 99 | 50 | 51 | 52 | 62 | 64 | 72 | 56 | 56 | 42 | 41 | 36 | 36 | 22 | 21 | 23 | 1349 |
| Fagus, m3 sum | 22 | 35 | 34 | 31 | 51 | 71 | 107 | 146 | 207 | 193 | 212 | 181 | 176 | 180 | 180 | 121 | 115 | 175 | 2237 |
| **Fagus, m3 per stem** | **0.06** | **0.17** | **0.34** | **0.62** | **1.00** | **1.37** | **1.73** | **2.28** | **2.88** | **3.45** | **3.79** | **4.31** | **4.29** | **5.00** | **5.00** | **5.50** | **5.48** | **7.61** | |
| Fraxinus, no stems | 674 | 572 | 440 | 268 | 173 | 132 | 104 | 100 | 94 | 87 | 63 | 42 | 36 | 31 | 20 | 15 | 5 | 14 | 2870 |
| Fraxinus, m3 sum | 50 | 102 | 150 | 151 | 150 | 161 | 178 | 225 | 270 | 296 | 237 | 175 | 164 | 151 | 103 | 81 | 30 | 103 | 2777 |
| **Fraxinus, m3 per stem** | **0.07** | **0.18** | **0.34** | **0.56** | **0.87** | **1.22** | **1.71** | **2.25** | **2.87** | **3.40** | **3.76** | **4.17** | **4.56** | **4.87** | **5.15** | **5.40** | **6.00** | **7.36** | |
| Ulmus, no stems | 3010 | 1520 | 841 | 437 | 352 | 247 | 220 | 216 | 149 | 159 | 97 | 56 | 55 | 43 | 43 | 20 | 20 | 20 | 7505 |
| Ulmus, m3 sum | 187 | 232 | 260 | 236 | 304 | 310 | 366 | 479 | 411 | 520 | 354 | 227 | 223 | 202 | 202 | 104 | 104 | 131 | 4852 |
| **Ulmus, m3 per stem** | **0.06** | **0.15** | **0.31** | **0.54** | **0.86** | **1.26** | **1.66** | **2.22** | **2.76** | **3.27** | **3.65** | **4.05** | **4.05** | **4.70** | **4.70** | **5.20** | **5.20** | **6.55** | |
| Other, no stems | 316 | 120 | 137 | 103 | 51 | 33 | 13 | 5 | 8 | 5 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 798 |
| Other, m3 sum | 15 | 17 | 43 | 56 | 41 | 40 | 21 | 12 | 20 | 16 | 14 | | | | | | | 7 | 302 |
| **Other, m3 per stem** | **0.05** | **0.14** | **0.31** | **0.54** | **0.80** | **1.21** | **1.62** | **2.40** | **2.50** | **3.20** | **3.50** | | | | | | | **3.50** | |