Amount and distribution of coarse woody debris in Dalby Söderskog national park

S.Balaji Naik

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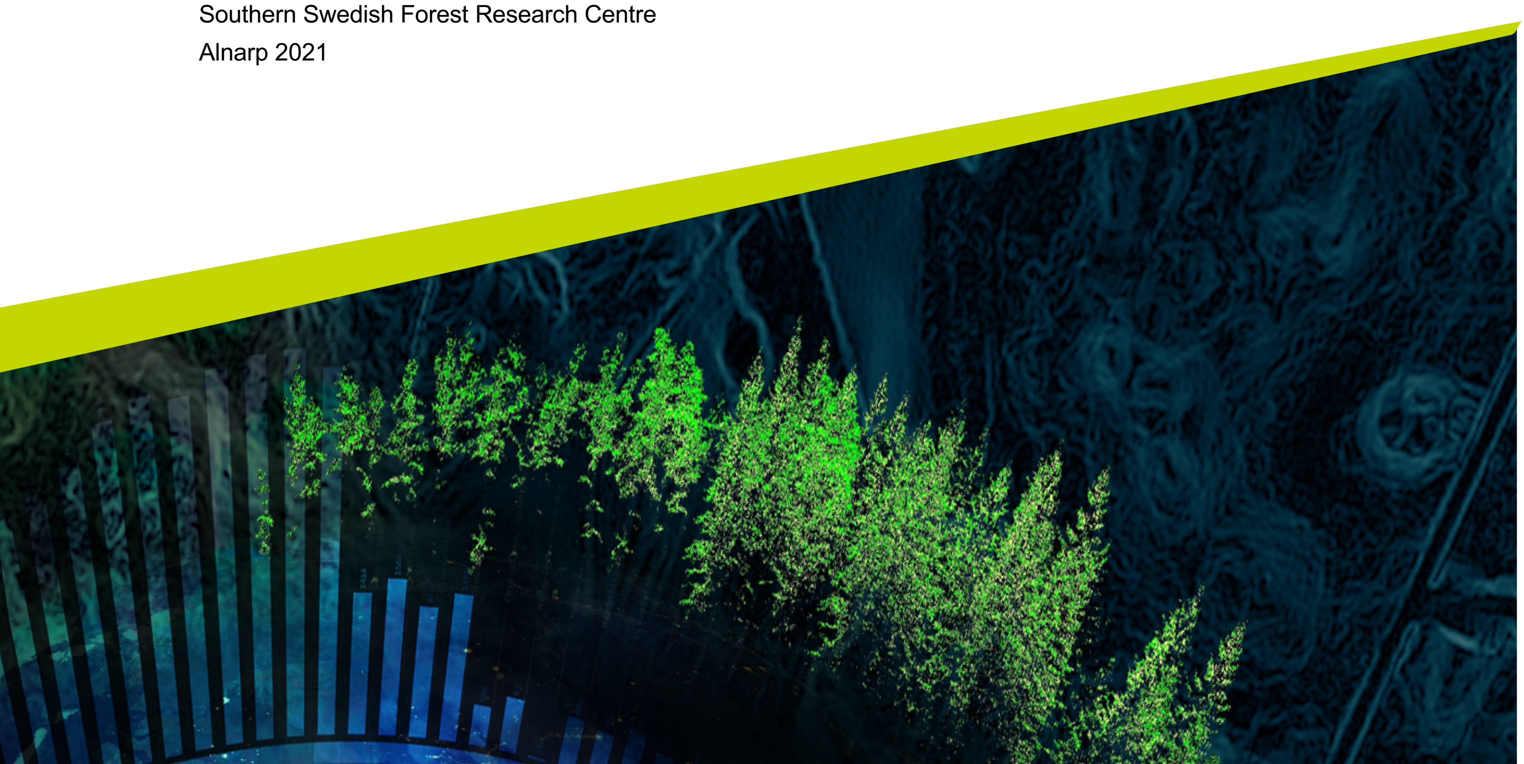

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Abstract

Coarse Woody Debris (CWD) is a critical structural and functional component of all forest ecosystems and comprises non-living woody biomass, standing or lying, larger than 10 cm in diameter. This study provides the first inventory of coarse woody debris in the temperate broadleaf forest of Dalby Söderskog national park in southern Sweden. Specifically, the aims were (1) to quantify the amount of standing and lying CWD, and (2) to study the diameter distribution of CWD in Dalby Söderskog.

Length and diameter of coarse woody debris including dead standing trees, cut stumps, and dead downed trees and branches were registered in 50 circular 100 m^2 (5.64 m radius) sample plots.

According to the results, Dalby Söderskog had an average of 227 m^3/ha coarse woody debris. Out of this volume, 174 m^3/ha were logs, 49 m^3/ha were snags, and 4 m^3/ha were cut stumps. The number of snags and logs was highest in the smallest diameter class (10-19 cm) and decreased with increasing diameter. However, the overall volume increased from the dbh class 10-19 cm to a maximum at the dbh class 30-39 cm, and decreased again at larger dbh classes.

The amount of CWD per hectare measured in Dalby Söderskog is roughly ten times the average amounts found in both Swedish woodland key habitats, formally protected forests, and Natura 2000 forest areas in Sweden, which all contain around 20 m^3/ha. Similar volumes as in Dalby Söderskog can, however, be found in central European temperate old-growth forests.

Although no attempt was made in the present study to determine CWD to tree species, comparisons with previous tree inventories suggest that the exceptional high amount of CWD in Dalby Söderskog is related to greatly increased tree mortality during the past three decades caused by Dutch elm disease and ash dieback.

Keywords: Ash dieback, coarse woody debris, dead wood volume, Dutch elm disease, forest reserve, Sweden, temperate forest, tree log, tree snag.

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Abbreviations

DBH: Diameter at Breast Height

DED: Dutch Elm Disease

CWD: Coarse Woody Debris

SLU: Swedish University of Agricultural Sciences

SOD: Sudden Oak Death

1. Introduction

Coarse Woody Debris (CWD) comprises all non-living woody biomass not contained in the litter, either standing or lying, larger than 10 cm in diameter, and is a critical structural and functional component of all forest ecosystems (McComb & Lindenmayer, 1999). Forests characterized by a high abundance and continuity of CWD are important carbon (C) stores, and the CWD is vital for a range of ecosystem functions. Coarse woody debris is generally considered as dead woody materials in various stages of decomposition, including good and rotting downed wood (logs), large branches, pieces of fragmented wood, stumps, and standing dead trees (snags), and in the form of rot holes, dead limbs, and roots, decay columns, heart rot and hollows in living ancient or veteran trees (Read, 2013).

The amount and distribution of coarse woody debris in forest ecosystems is related to the intensity of forest management with considerable differences between managed and unmanaged forests (Bobiec, 2002; Braunisch et al., 2019; Keren & Diaci, 2018), forest successional status, as influenced by aging and competition (Siitonen et al., 2000; Fraver et al. 2002), site conditions, climate, terrain, as well as site fertility and moisture (Sturtevant et al., 1997; Bujoczek et al., 2018).

1.1. Effects of natural disturbance and site conditions on coarse woody debris

Deadwood in natural forests results from tree mortality and deadwood decay rates. Tree mortality is affected by a multitude of biotic and abiotic factors such as droughts, storms, forest fires, fungal pathogens, insect damage, and damage by large mammals, in combination with competition related to tree stand structure and composition, as well as senescence processes, and tree death at the end of the tree species-specific life cycle (Harmon et al., 1986; Rondeux et al., 2012). The effects of these factors are related to the successional stage of the forest (Harmon et al., 1986; Spies et al., 1988), or the history of natural disturbances (Hansen et al., 1991; Stokland et al., 2012; Sefidi et al., 2016). These disturbance factors vary in scale and intensity leading to a patchy distribution of deadwood at the stand and landscape scales with greater accumulations near canopy gaps and in old-growth stands (Humphrey et al., 2002; Sippola et al., 1998).

The severity and frequency of disturbances are expected to increase in the future due to global change (Dale et al., 2001), and tree mortality rates and, ultimately, stocks of CWD will likely also increase. Moreover, the history of natural disturbances changes the volume of dead trees and their distribution throughout the forest (Garbarino et al., 2015; Bujoczek et al., 2018). In strictly protected areas, trees killed by windthrow or an insect outbreak are usually left in place.

Still, they tend to be removed to varying degrees from other types of forest stands in the process of salvage logging, which substantially reduces overall deadwood volume (Priewasser et al., 2013; Michalov´a et al., 2017). Consequently, a high amount of CWD is an essential characteristic of natural old-growth boreal forests (Ohlson et al., 1997; Linder & Östlund, 1998).

1.2. Effects of management on coarse woody debris

Site conditions are critical in management practices, and indeed site potential determines the species composition and management goals adopted for a given stand. In unmanaged stands, the quantity of deadwood is much higher than in managed forests, depending on the duration of the protection (Christensen et al., 2005). In managed forests, these factors undoubtedly also play a role, but the overriding factors are human ones (Hansen et al., 1991; Siitonen et al., 2000; Fassnacht & Steele, 2016). CWD quantities are typically kept very low in managed forests, as most of the large-sized harvestable timber is extracted and to avoid pest problems, fire hazards and to maximize the commercial value of the harvest (Green & Peterken, 1997). In addition, dead wood in managed stands typically consists only of small twigs and branches and short stumps, with only few large logs or snags (Kruys et al., 1999). In the interest of sustainable forestry and biodiversity conservation, efforts are being made to increase dead wood levels in managed forests (e.g., Hodge & Peterken, 1998; Harmon, 2001). In managed forests, deadwood volume is most significantly affected by the adopted forest management practices based on specific management instructions and guidelines.

1.3. Ecological role of coarse woody debris

Coarse woody debris is an essential component in natural forests. It plays a critical role in the forest ecosystem's structural, functional, and productional component (Harmon et al., 1986; McComb & Lindenmayer, 1999). It serves as an essential substrate for many species, including numerous rare and endangered species (Oheimb & Brunet, 2007). Decaying wood is a key factor for biodiversity in boreal forests as it hosts a large number of saproxylic fungi, epixylic bryophytes (Epixylic communities react to differences in substrate pH, water content, and wood decay type, all of which are highly influenced by tree species-specific decomposers, primarily saproxylic fungi (Heilmann-Clausen et al., 2014; Freschet et al., 2012; Fukasawa et al., 2015). and lichens, polypores and other decomposer fungi, invertebrates (Samuelsson et al., 1994; Esseen et al., 1997) and provides important habitat for small vertebrates, and cavity-nesting birds.

Fallen dead wood and stumps provide nurse logs for natural tree regeneration in cool temperate, boreal and sub-montane forest types (Eichrodt, 1969; Hofgaard, 1993; Takahashi et al., 2000; Humphrey et al., 2004; Siitonen et al., 2000; Zielonka, 2006), as well as the provision of habitat for the tree seedlings (Harmon & Franklin, 1989; Gray & Spies, 1997; Sanchez et al., 2009).

Deadwood contributes to ecosystem functioning and fluxes in forests by changing microclimate (i.e., soil moisture by increasing water storage capacity and increasing nutrient availability (Franklin et al., 2006; Harmon et al., 1986; Maser & Trappe, 1984) and significantly contributes to the total amount of organic material on the forest floor, thereby affecting carbon storage, energy flow, and nutrient cycling regulation (Harmon et al., 1986; Harmon & Hua, 1991). Brown-rot deposits can make up a substantial component of the organic layer in coniferous forests as well as increase the soil's water-holding capacity (Larsen et al., 1980). Decomposing logs sustain ectomycorrhizal formation and activity (Harvey et al., 1979). Coarse woody debris affects humification, which secures a continuous supply of organic material to the soil (Schaetzl et al., 1988), and influences hydrologic processes (McComb & Lindenmayer, 1999; Lindenmayer & Noss, 2006). CWD can enhance slope stability and increase soil surface stability to prevent erosion and to control storm surface runoff. CWD also influences fuel loads and fire behaviour (Schoennagel et al., 2004), runoff, and erosion (Gurnell et al., 1995).

Deadwood diversity is essential as well due to the varying habitat requirements of different species (Brin et al., 2009). In Europe, forest reserves with high deadwood diversity have therefore become increasingly important for biodiversity conservation (Bauhus et al., 2009). They also constitute ideal research sites on ecosystem functioning and structure under natural conditions (Korpel, 1995). Analysis of deadwood volume and composition in forest reserves contributes to biodiversity conservation and provides essential data for close-to-nature silviculture (BMNT, 2018). Research in natural forest reserves also helps to deepen the understanding of forest dynamics (Bugmann & Brang, 2009).

1.4. Coarse woody debris carbon stocks

The role of CWD in ecosystem carbon (C) storage has received increasing attention because climate change could alter terrestrial C balance by reducing C storage in this significant detrital pool (Chambers et al., 2000; Jomura et al., 2007; Woodall & Liknes, 2008; Weedon et al., 2009). Forests characterized by a high abundance and continuity of CWD are important carbon (C) stores, and the CWD is important for a range of ecosystem functions. CWD constitutes an essential component of the carbon sequestration and carbon stocks occurring in forests. Its quantification in forest inventories comes to be much more relevant due to forest's interactions with the greenhouse effect and climate change (Smith et al., 2004). Therefore, the analysis of dead woody particles consists of an essential part of efficient woodland administration.

Moreover, evaluating carbon stocks enhances our understanding of climate change and the function of forest carbon dynamics in different future scenarios. More precise quantification of dead woody material just increases the precision of overarching carbon estimates (Woodall & Williams, 2005). The woody debris studies that do exist concentrate on volume and biomass inventories, shunning calculations for actual carbon focus (Russell et al., 2014). Instead, carbon stocks are indirectly approximated with volume estimators and also biomass-carbon conversion constants (Woodall & Monleon, 2008). Since vegetation sequesters atmospheric carbon in biomass, which is frequently revealed as a completely dry weight per unit area, changes in net primary productivity values gradually often show modifications in forest structure (Brown, 1997). Values of biomass are typically converted to carbon values multiplying by the 0.50 constant (i.e., computed as 50% of the biomass value).

Wood density is used to estimate the amount of carbon from deadwood by first converting the sampled deadwood volume into biomass and then into carbon (Sandström et al., 2007).

1.5. Input of coarse woody debris

CWD mostly comes from whole dead trees, and thus volume of CWD is dependent on tree mortality is closely related to inputting of CWD. The following agents are responsible for most of the tree mortality (Jia-bing et al., 2005).

Wind: Strong winds cause stems and branches uprooting, which immediately adds CWD to the forest floor. Wind impacts differ depending on soil depth and moisture content, stand structure, tree age, and tree species.

Fire: Fire either directly causes CWD or makes trees more susceptible to wind, disease, and pest disturbance.

Disease and pests: Both can cause tree death directly or weaken tree resistance, and eventually contribute to tree death.

Competition: Suppressed trees under the stress of water and light are easily be attacked by disease and pests.

Senescence: As a tree ages, it becomes more susceptibility to pests, disease and wind.

These factors influencing on tree mortality vary enormously in different stands.

The growing awareness of the significant role that dead wood plays in ecosystem functioning has resulted in the inclusion of CWD in sustainable forest management around the world. (Bauhus et al., 2009; Hunter, 1994; Grove, 2002; Ranius et al., 2003; Lindenmayer et al., 2006). A common goal of CWD management is to maintain its spatial and temporal arrangement in a way that mimics patterns caused by natural disturbance and stand development and ensures the continuity of habitat conditions (Franklin et al., 2002; Keeton, 2006).

To assign local benchmarks for CWD levels for specific forest types, the natural variation of CWD attributes must be known and monitored. CWD inventories are also essential for reporting C storage in forests (Gough, 2007).

1.6. Aim of the study

This study aims to provide baseline data and estimate the amount and distribution of coarse woody debris in the temperate broadleaf forest of Dalby Söderskog national park in southern Sweden. An inventory was carried out to measure the coarse wood debris in Dalby Söderskog national park. Dalby Söderskog national park is affected by natural disturbances. Insect plagues and diseases such as Dutch elm disease (DED) and ash dieback have damaged the forest since the late 1980s, causing CWD accumulation (Brunet et al., 2014).

The forest has been surveyed on several occasions since the establishment of the Dalby Söderskog national park. Although tree inventories have been done in 1916, 1935, 1970, 2011 and 2020, no inventory of CWD has been carried out (Brunet et al., 2014; Ruks, 2020). The influence of Dutch elm disease (DED) and ash dieback on the amount and distribution of coarse woody debris and the consequent effects on the structure and functioning of Dalby Söderskog national park are not documented. This study was structured to examine the following specific objectives:

(1) To quantify the amount of CWD in the Dalby Söderskog national park.

(2) To study the size distribution of CWD in the Dalby Söderskog national park.

2. Materials and methods

2.1. Site descriptions

Dalby Söderskog national park is a mixed broadleaf deciduous forest covering 37 ha in a matrix of farmland (Fig. 1). The national park is located close to Dalby village, 10 kilometers east of Lund in southern Sweden in the County of Skåne (55°410'N, 13°200'E, 65 meters above sea level, Fig. 2).

The mineral soil is a loamy clay with a mean pH (H_20) of 6.1 (+ 0.08 SE, Persson et al., 1987), which is derived from the glacial till of the Weichsel glacial period. The type of soil is eutric cambisol and the humus type is mull. The slopes next to a small stream in the southeastern part of Dalby Söderskog are relatively well-drained, but the rest of the area is moist or wet.

The climate is temperate, sub-oceanic, with mean annual precipitation of ca. 650 mm and a mean annual temperature of 7.5° C (Brunet et al., 2014; Oheimb & Brunet, 2007). Due to large amounts of old trees and coarse woody debris, the diversity of saproxylic insects and fungi and epiphytic lichens and bryophytes is high, including many taxa of conservation concern (County Administrative Board of Skåne, unpublished data). Apart from an adjacent semi-natural grassland to the north, the forest is mainly surrounded by agricultural land and is considered to be situated in an exceptionally productive area.

During winter and spring, surface water may be visible in depressions throughout the area (Malmer et al., 1978; Lindquist, 1938). Several of the important European temperate broad-leaved tree species are represented in Dalby Söderskog. The tree layer of the forest is dominated by Pedunculate oak (*Quercus robur*), European ash (*Fraxinus excelsior*), European beech (*Fagus sylvatica*), and, until the arrival of Dutch elm disease, wych elm (*Ulmus glabra*). However, several other species occur (Lindquist, 1938). During the last decade, maple (*Acer platanoides*) invaded the tree layer and is now scattered throughout the forest. Hazel (*Corylus avellana*), hawthorn (*Crataegus monogyna*) and small individuals of elm and ash presently form the shrub layer. Beech-dominated forest occupies parts of the forest in the southeast. There is abundant beech regeneration in these parts, while in other parts of the forest, beech does not regenerate. The oldest oak trees date from the early 18th century and must have grown during one of the periods with less extensive grazing (Malmer et al., 1978**)**. The forest is also home to numerous threatened species of bryophytes, fungi, and saproxylic beetles (Brunet et al., 2014). Large mammals in the area include wild boar (*Sus scrofa*), roe deer (*Capreolus capreolus*), and fallow deer (*Dama dama* L.). The shrub flora is rich and varied but typically consists of hazel and species of hawthorn (*Crataegus spp.*) together with the regeneration of multiple tree species. The rich ground vegetation is one of the most distinctive characteristics of the forest, especially the vernal flora with holewort (*Corydalis cava*) and species of *Anemone spp*. Later in the season, species such as dog's mercury (*Mercurialis perennis*), wood avens (*Geum urbanum*), and yellow archangel (*Lamium galeobdolon* L.) are common (Oheimb & Brunet, 2007). However, several herbaceous species are now being reduced in abundance due to increasing wild boar populations and the invasive Spanish slug (*Arion vulgaris*; Brunet et al., 2016).

Most of the forest in Dalby Söderskog has experienced secondary succession due to a lack of management since the area was protected in 1918. Dalby Söderskog was used for grazing, especially horses, but grazing ceased gradually during the 19th century (Malmer et al., 1978). The last significant cuttings were recorded in 1914 – 1916 when 1600 m^3 wood were taken out of a total of 8000 m^3 wood. Since 1988 dead elms were cut down due to safety reasons around hiking paths (Brunet et al., 2014).

2.2. Previous studies in Dalby Söderskog

The forest has been surveyed on several occasions since the establishment of the Dalby Söderskog national park. Tree inventories from Dalby Söderskog are available from the years 1916, 1935, 1970, 2011 and 2020. Only trees with a diameter greater than 20 cm at breast height were measured during inventories in 1916 and 1935. All trees with a diameter of more than 10 cm at breast height were included in the later inventories (Malmer et al., 1978; Brunet et al. 2014; Ruks, 2020).

Ecologist Bertil Lindquist (1938) established a system of transect lines and sample plots to study the forest structure and vegetation. He used a straight path through the forest as a baseline and mapped trees along 16 transect lines perpendicular to the baseline, and 74 plots were located on these lines (Fig. 1). 50 m was the distance between the lines. In most cases, the distance between plots along the lines was 100 m with few exceptions (50 or 75 m) due to the margins of the forest (Lindquist, 1938). A standard forestry approach was used to investigate the development of the tree layer, which included recording tree species and measuring their diameters at breast height (dbh).

In 2010 the grid of sample plots was reconstructed using an aerial photograph of the forest with Lindquist' map as a digital overlay and the corresponding GPS coordinates (Brunet et al., 2014). In late 2011 and early 2012, a tree inventory was carried out in all 74 plots. Stem diameter of all trees >10 cm or 19 cm at 1.3 m height (dbh) was measured and identified to species in 100 m^2 (5.64 m radius) plots using the center of the plot as a starting point (Fig. 2). In 314 m^2 (10 m radius, same center point), all trees above 20 cm in dbh were measured and identified. All stems were classified as living or dead. Alive wych elms and European ashes were classified as alive or sick regarding whether they showed symptoms of Dutch elm disease or ash dieback (Brunet et al., 2014; Bukina, 2012).

The latest inventory of tree species in Dalby Söderskog was done in 2020 (Ruks, 2020). The inventory was carried out in all 74 plots, and with the same method as the 2012 inventory. Elms were judged as damaged when epicormic sprouting, dying bark, and dieback at the top of the tree were recorded, while ash was classified as damaged when a significant part of the tree crown was either dead or top shoots were severely stunted (Ruks, 2020).

Figure 1. Transect lines and sample plots in Dalby Söderskog (from Brunet et al., 2014).

Figure 2. Location of Dalby Söderskog national park within Northern Europe. Source: Google Earth.

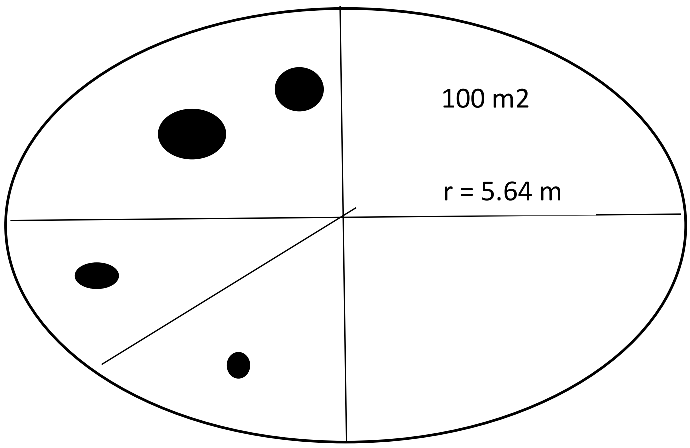

Figure 3. Representation of a sample plot, black circle represents dead trees.

2.3. Inventory 2021

In January 2021, an inventory was carried out to measure the coarse woody debris in Dalby Söderskog national park. Due to time constraints, a total of 50 of the previously created 74 plots were used as sample plots, evenly spread across the forest. To locate the plots, handheld GPS and a map were used. The plot center was marked with plastic sticks in earlier inventories, but some sticks had been removed due to uprooting by wild boar. Centers were relocated with the help of marked trees and pictures of plots from previous inventories. The plot relocation was estimated to be less than 1 m from the original plot center in these cases.

All coarse woody debris was registered in circular 100 m^2 (5.64 m radius, Fig. 3). The diameter and length, of each element within the circle plot was recorded, excluding those parts of downed wood elements outside the circle border (Fig. 4). The following typologies of deadwood are defined in the plot: (i) dead standing trees or snags (dbh $\geq$ 10 cm, height > 1.3 m), (ii) dead downed trees or logs (dbh $\geq$ 10 cm), (iii) downed branches (logs, mid diameter of the element $\geq$ 10 cm) and (iv) stumps (diameter at mid-height $\geq$ 10 cm, total height < 1.3 m). Diameter at breast height (dbh) was registered for all standing dead trees using the cross-calliper method, and at the mid-height of snag stumps. For standing dead trees and lying coarse wood debris that was larger than 50 cm in dbh, measuring tape was used.

2.4. Data analysis

To estimate standing and downed tree volumes, stem and branch equations were used considering the diameter and length of the CWD elements.

The volume of a cylinder was used to calculate log and snag stump volumes as below

V=h ×π ×d2/4 ………………………………………………. Equation 1

Where V is volume (m^3), h is height in meters, and d is the mid-length diameter (m).

Snag volume is estimated by the formula for an ellipsoid cone (Brunet & 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.

Based on the volumes (m^3) calculated for the sample plots, volumes m^3 per hectare were calculated for each 100 m^2 sample plot by multiplying by factor 100. The mean volumes per hectare of the sample plots were multiplied by 37 to estimate the total amount of coarse dead wood in Dalby Söderskog (area size 37 ha). These calculations were done by using Microsoft Excel (2016). Summary statistics and paired t-test were calculated in Minitab 19.

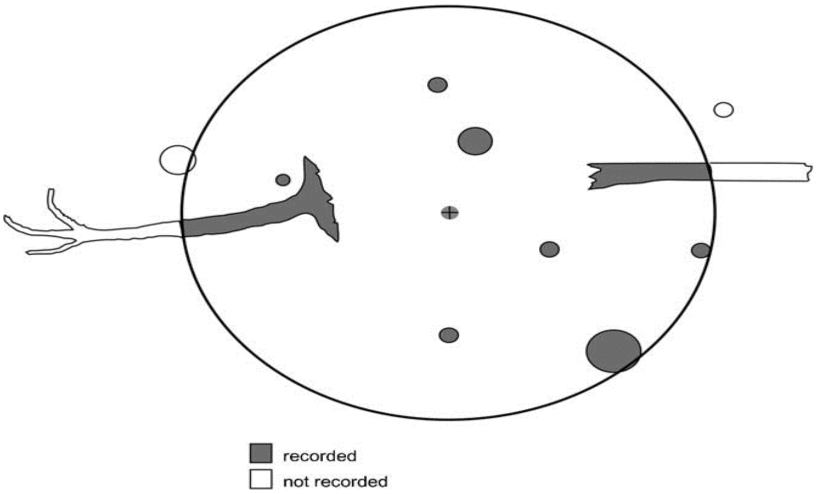

Figure 4. Representation of a sample plot with stems and parts of logs included or excluded in the survey depending on their location.

3. Results

3.1. Volume of deadwood

The study results show that the overall deadwood volume of Dalby Söderskog national park is 8434 m^3. The total volume of deadwood is divided into three components: 6453 m^3 in logs, 1828 m^3 in snags, and 152 m^3 in stumps.

The mean deadwood volume is 227 m^3/ha, however, with large variation among plots (standard deviation: 196; minimum 8; maximum 805, see Appendix Table A1 for total CWD and its components). The mean volume of deadwood is divided into three components: 174 m^3/ha in logs, 49 m^3/ha in snags, and 4 m^3/ha is in stumps (Fig. 5). A paired t-test showed that the volume of logs in sample plots was significantly higher than the volume of standing CWD (sum of snags and stumps, P<0.001, Appendix Table A2).

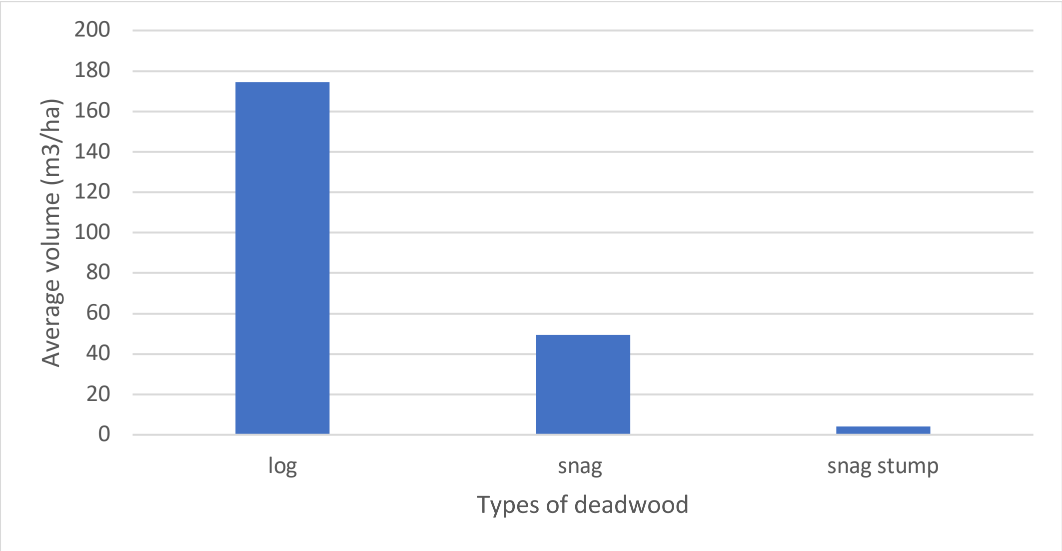

Figure 5. Mean volume of deadwood per hectare in Dalby Söderskog.

3.2. Distribution of logs in different diameter classes

Observing the data of logs by diameter classes (cm) in Figure 6 reveals that the total number of logs recorded per ha in different diameter classes varied greatly. It was found to be highest in the 10- 20 cm diameter class (714), and decreased with increasing diameter class.

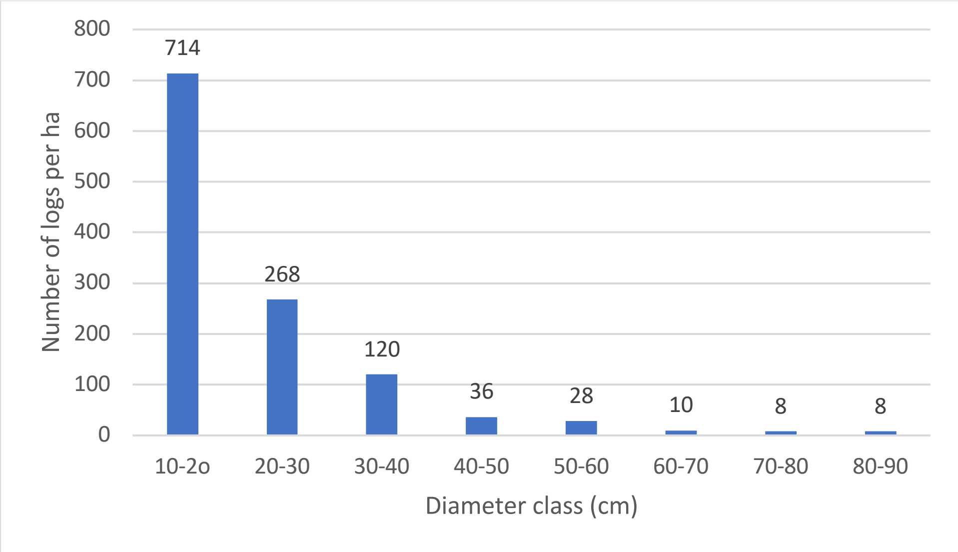

Figure 6. Distribution of logs per hectare in different diameter classes (cm) in Dalby Söderskog.

The total number of snags recorded per ha in different diameter classes was highest in the 10-20 cm diameter class (82) and much lower in the larger diameter classes (Fig. 7).

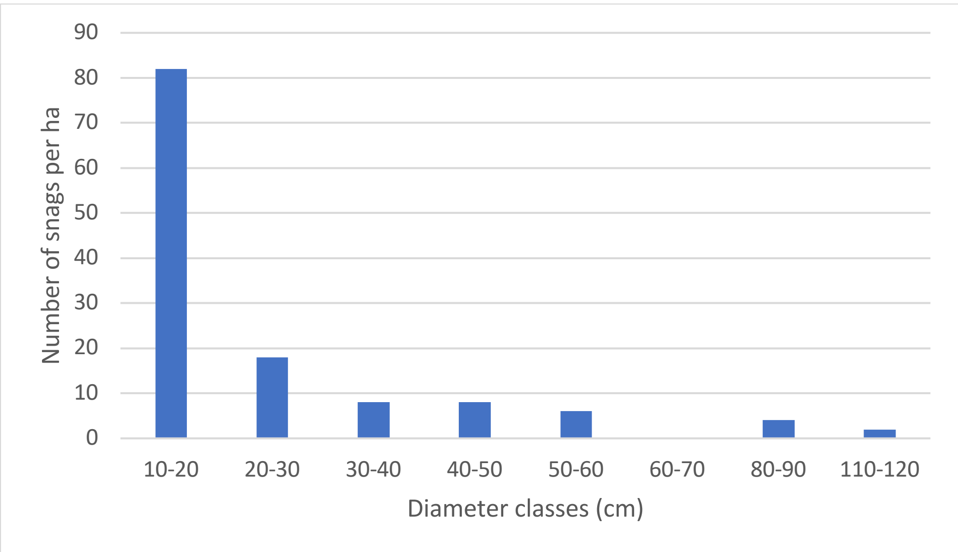

Figure 7. Distribution of snags per hectare in different diameter classes (cm) in Dalby Söderskog.

The total recorded number of snag stumps was highest in the 20- 30 cm diameter class (22), followed by the 10- 20 cm diameter class (14), the 50- 60 cm diameter class (12), the 30- 40 cm diameter class (8), 40- 50 cm diameter class (4), and the remaining larger diameter classes. (Fig. 8).

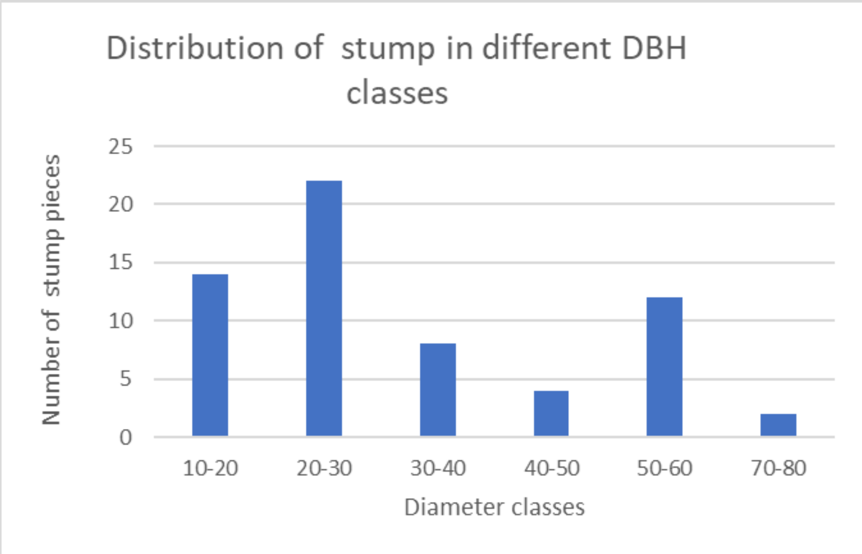

Figure 8. Distribution of stumps in different diameter classes (cm) in Dalby Söderskog

3.3. The volume of deadwood by diameter classes

Volume of deadwood also varied significantly between different diameter classes (cm) in Dalby Söderskog (Fig. 9). The highest volume was found in the 30- 40 cm diameter class (41 m^3/ha), and the lowest volume was found in 90 - 100 cm diameter class (2 m^3/ha respectively (Fig. 9).

Figure 9. Volume of deadwood in different diameter classes (cm) in Dalby Söderskog.

4. Discussion

The results showed that Dalby Söderskog on average contained as much as 227 m^3/ha coarse woody debris. This is multiple times more than the deadwood amounts compared to the Swedish national average volumes of CWD (standing and downed combined, dbh $\geq$10 cm) in woodland key habitats (WKH, 19.5 m^3/ha, range 0–168 m^3/ha), and the average volumes of 9.3 m^3/ha in mature managed forests and 12.2 m^3/ha in overmature managed forests (Jönsson & Jonsson, 2007). Similar differences were found in comparison to forest stands classified as Natura 2000 habitats according to the EU species and habitat directives (20.3 m^3/ha) and protected forests in Sweden where deadwood volumes are estimated to be 23.7 m^3/ha (Anon., 2006). It is noteworthy that these observed deadwood volumes are similar to the average deadwood volume of 20 m^3/ha for European forests (Forest Europe, 2020).

Mean values of deadwood volume differ across countries due to differences in management practices and specific factors associated with the landscape, the proportions of various types of sites, the protected area, disturbances, and so on. In Polish forests, the average deadwood volume (including stumps) ranged from 5 m^3/ha in managed forests to 60 m^3/ha in strictly protected forests. CWD also increased in general with slope gradient, site fertility and stand age (Bujoczek et al., 2021).

Temperate forest reserves, such as Denny Inclosure (273 m^3/ha) and Ridge Hanger (265 m^3/ha) in the United Kingdom, have comparable amounts of deadwood, where several mature/old-growth stands in the United Kingdom had broken-up under the influence of severe drought and/or windstorms, resulting in extraordinarily high volumes shortly or just a few decades after they were established as strict reserves (Christensen et al., 2005). Similar volumes as in Dalby Söderskog can also be found in central European temperate old-growth forests (Christensen et al., 2005; Burrascano et al., 2013).

While national parks and nature reserves serve as natural deadwood reservoirs (Christensen et al., 2005; Eckelt et al., 2018), the type of protection is critical. All dead trees are retained in the ecosystem in strictly protected areas, with some exceptions possible (Müller et al., 2019). Active protection, on the other hand, involves management treatments that are designed to achieve specific protection goals, and deadwood is frequently removed (Staniaszek-Kik et al., 2019).

The amount of deadwood in strictly protected areas is determined by a variety of random factors, as well as protection duration, which is positively correlated with deadwood accumulation (Seidl et al., 2017; Müller et al., 2019; Christensen et al., 2005). In the long run, however, the situation becomes more complicated, with the actual deadwood volume resulting primarily from the relationship between the input of dead trees and the rate of wood decomposition (Rock et al., 2008; Prvetiv et al., 2018; Bujoczek et al., 2018).

Dutch elm disease, ash dieback, storm damage and tree felling for safety reasons, were all factors that contributed to the exceptionally high CWD accumulation in Dalby Söderskog (Bukina, 2012; Brunet, et al. 2014; Ruks, 2020). In the following sections, the four main tree species in Dalby Söderskog are discussed individually.

4.1. Ash

Ash dieback disease has often been a predisposing factor that weakened the trees before a storm felling event or a cut by a forest manager in Dalby Söderskog (Brunet et al., 2014). The percentage of diseased ash has risen from 55 per cent in 2012 to 73 per cent in 2020, but ash mortality has increased the most. Only 2% of all registered ashes were dead in 2012, but by 2020, the number had risen to 26% (Ruks, 2020). A master thesis study in 2016 found that in Dalby Söderskog, also smaller ash trees above 1.3 m and < nine cm in dbh are severely affected by ash dieback (Dietrich, 2016). This recent ash mortality certainly contributed to the current high volumes of CWD in Dalby Söderskog.

The previous inventories showed that most affected trees were in lower diameter classes (Bukina, 2012; Ruks, 2020). This is explained by that larger ash trees could have been more vigorous and withstand the disease for a longer period than trees with smaller crowns. In 2020 almost all trees were affected by ash dieback, and many of them have died. If this tendency continues in Dalby Söderskog, this would lead to a strong reduction of the ash population in the long run, raising serious doubts about the species' future dominance in the forest (Ruks, 2020).

4.2. Elm

More than two-thirds of the elm population in Dalby Söderskog vanished due to Dutch elm disease (DED) (Oheimb & Brunet, 2007). DED was first detected in Skane in 1979; it appeared in Dalby Söderskog after 1986 and spread rapidly (Oheimb & Brunet, 2007). By 2012, dead elm trees could be seen throughout the forest, and numerous canopy gaps were created due to infected elm's death. As a result, a sizable proportion of elm trees were reported as dead or diseased (Brunet et al., 2014). Elm has lost its dominant position in Dalby Söderskog's tree species composition and is now ranked third behind ash and beech by stem numbers (Ruks, 2020). In Dalby Söderskog, however, a high level of large tree mortality has been partly compensated for by the abundant recruitment of smaller elms (Brunet et al., 2014).

By 2020, DED had affected 36 percent of all registered living elms, according to data collected for estimating elm vitality. 64 percent of elms appeared to be disease-free, but it's worth noting that nearly all healthy elms fall into the smallest diameter category (Ruks, 2020). The long-standing mortality of both smaller and larger individuals has broken the previous elm dominance in Dalby Söderskog (Ruks, 2020). This continuous mortality is also an important factor for the large supply of dead wood in the study area. In addition, the high amount of dead small elm trees contributes to the dominance of the small diameter classes in terms of overall dead stem numbers.

It has been suggested that increased nitrogen accumulation in the topsoil of Dalby Söderskog (Persson et al., 1987) extends the susceptibility period and greatly increases the intensity of elm external symptoms (Martin et al., 2010). Furthermore, as climatic extremes become more common worldwide, elms' ability to resist DED is likely to be hampered even more (Resco et al., 2007). As a result, the DED situation in Sweden, particularly in Dalby Söderskog, is likely to remain unchanged in the near future, with DED impact being a key factor in forest succession.

4.3. Oak

Since 1935, the mortality rate among older oak trees has remained constant. This means that the formation of CWD from oak has been more even in the past than that of ash and elm. If mortality continues at the current rate, the vast majority of oaks that are currently >30 cm dbh will most likely be dead by the year 2080 (Larsson, 2021). As a result, there will be a scarcity of old, living habitat trees in the future, but also a decreasing addition of oak CWD.

Given the population's stable mortality, it is unclear whether any young trees will have time to develop old tree structures before today's old trees die, as there is a large gap in the age structure of the oak population (Brunet et al., 2014). Another possibility is that the mid-sized oaks' low vitality leads to earlier development of hollows and dead wood, but their time alive will still be limited in comparison to the larger old oaks of today's forest.

Extreme weather conditions, such as droughts during the vegetation season, play a significant role in oak mortality in southern Sweden (Sonesson & Drobyshev, 2010). Studies show a correlation between droughts and oak mortality (Drobyshev et al., 2007).

In 1999, 59 per cent of oaks in southern Sweden were classified as damaged, meaning they had at least 25% crown defoliation. However, from 2000 to 2008, a trend of improving crown conditions was observed. Additionally, *Phytophthora* species may be involved. However, the majority of soils in southern Sweden are acidic, which may inhibit the ability of some of these pathogens to exploit and affect oaks (Sonesson & Drobyshev, 2010). As a result, forecasting the future is difficult, as a large proportion of dead oaks have demonstrated that growth was affected multiple years before the tree's demise (Drobyshev et al., 2007).

Sudden oak death (SOD) has been identified as a common disease affecting oaks in southern Sweden, which raises questions about the future role of the oak tree (Drobyshev et al., 2007). Even though the rich soil in Dalby Söderskog creates favorable sites for SOD (Sonesson & Drobyshev, 2010), no SOD was found among the oak population during the latest oak inventories in 2012 and 2021 (Brunet et al., 2014; Larsson, 2021). Crown damage caused by insects and fungi did not appear to be a significant factor in the decline of oak trees in southern Sweden (Sonesson & Drobyshev, 2010).

Increased nitrogen input from the atmosphere and acidification processes in the soil, both currently observed across Europe, including Dalby Söderskog, may act as a predisposing factor for the oak decline (Persson et al. 1987; Bobbink et al. 2010). Stress tolerance and the flow of nutrients in oak ecosystems are both decreased due to these processes (Jonsson, 2004). As a result of a reported relationship between nitrogen deposition and insect activity, oak will be more susceptible to damage from pathogens or insects in the future (Flückiger & Braun, 1998).

It is possible that oak powdery mildew could pose a threat to oaks due to the fact that it is common in Europe and could be present in stands that do not show signs of excessive mortality (Camy et al., 2003). This means that future oak wellbeing, particularly for young oaks, may be jeopardized as a result of the deterioration of regional soil conditions (Sonesson & Drobyshev, 2010).

4.4. Beech

Cleary et al. (2016) reported that European beech is threatened in southern Sweden by *Phytophthora gonapodyides* and other *Phytophthora species*. Also *P. cambivora, P. plurivora,* and *P. cactorum* are believed to be the primary causes of beech's declining health. Additionally, *Phytophthora* spp. can infect a broader range of hosts (Schoebel et al., 2014). Crown deterioration and bleeding canker are two of the disease's symptoms observed in Dalby Söderskog. This is concerning. Even though *Phytophthora* spp. rarely kill the host as quickly as ash dieback and DED do, the future may see an increase in the mortality of mature beech trees. Beech decline due to *Phytophthora* diseases in European forests has recently been reported, revealing a susceptibility to pathogens and potentially reducing its value as a competitive species (Jung & Burgess, 2009). Since *Phytophthora* symptoms have been reported in southern Sweden, we can expect them to appear in Dalby Söderskog, resulting in increased instability and vulnerability in the beech population, resulting in a further supply of CWD.

4.5. Conclusion

This study provides an overview of the amount and size distribution of coarse woody debris in Dalby Söderskog national park. Our study revealed exceptionally high deadwood amounts in Dalby Söderskog, probably mainly due to increased tree mortality due to the Dutch elm disease and Ash dieback.

In addition to contributing to a better understanding of the factors that influence deadwood distribution variability, the findings presented here have the potential to be helpful in the development of forest management practices that promote biodiversity.

The consequences of DED, ash dieback, but also reduced vitality of old oak and beech trees may result in the local extinction of species that rely on the habitats provided by old living trees of these species. As a result, the overall biodiversity of epiphytic lichens and bryophytes in Dalby Söderskog is likely to suffer. However, at least temporarily, the availability of CWD for species depending on dead wood, in particular many saproxylic insects and saprophytic fungi is very high.

This study also provides baseline data for future inventories of coarse woody debris in Dalby Söderskog national park. An interesting question to answer is whether amounts of CWD are currently peaking as a result of disease-induced mortality or if even larger volumes will accumulate.

5. References

Anonymous (2006). Forest Statistics 2006. Official Statistics of Sweden, Swedish University of Agricultural Sciences.

Bauhus, J., Puettmann, K., & Messier, C. (2009). Silviculture for old-growth attributes. *Forest Ecology and Management,* 258(4), 525–537. https://doi.org/10.1016/j.foreco.2009.01.053

Braunisch, V., Roder, S., Coppes, J., Froidevaux, J. S. P., Arlettaz, R., & Bollmann, K. (2019). Structural complexity in managed and strictly protected mountain forests: Effects on the habitat suitability for indicator bird species. *Forest Ecology and Management,* 448, 139–149. https://doi.org/10.1016/j.foreco.2019.06.007

Brin, A., Brustel, H., Jactel, H. (2009). Species variables or environmental variables as indicators of forest biodiversity: a case study using saproxylic beetles in Maritime pine plantations. *Annals of Forest Science,* 66, 306. https://doi.org/10.1051/forest/2009009.

Brunet, J., Bukina, Y., Hedwall, P. O., Holmström, E., & Von Oheimb, G. (2014). Pathogen induced disturbance and succession in temperate forests: Evidence from a 100-year data set in southern Sweden. *Basic and Applied Ecology,* 15(2), 114–121. https://doi.org/10.1016/j.baae.2014.02.002

Brunet, J., Hedwall, P. O., Holmström, E., & Wahlgren, E. (2016**).** Disturbance of the herbaceous layer after invasion of an eutrophic temperate forest by wild boar. *Nordic Journal of Botany,* 34(1), 120–128. https://doi.org/10.1111/njb.01010

Brunet, J., & Isacsson, G. (2009). Restoration of beech forest for saproxylic beetles-effects of habitat fragmentation and substrate density on species diversity and distribution. *Biodiversity and Conservation,* 18(9), 2387–2404. https://doi.org/10.1007/s10531-009-9595-5

Brown, S. (1997). Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134:1–55.

Burrascano, S., Keeton, W. S., Sabatini, F. M., & Blasi, C. (2013). Commonality and variability in the structural attributes of moist temperate old-growth forests: A global review. *Forest Ecology and Management.* https://doi.org/10.1016/j.foreco.2012.11.020

Bukina, Y. (2012). Long-term succession and loss of foundation species in a temperate broadleaved forest in southern Sweden. Master Thesis. Southern Swedish Forest Research Centre. Swedish University of Agricultural Sciences. Alnarp.

Bujoczek, L., Bujoczek, M., & Zięba, S. (2021). How much, why and where? Deadwood in forest ecosystems: The case of Poland. *Ecological Indicators*, 121. https://doi.org/10.1016/j.ecolind.2020.107027

Bujoczek, L., Szewczyk, J., & Bujoczek, M. (2018). Deadwood volume in strictly protected, natural, and primeval forests in Poland. *European Journal of Forest Research.* Springer Verlag. https://doi.org/10.1007/s10342-018-1124-1

Bobbink, R., Hicks, K., Galloway, J., Spranger, T., Alkemade, R., Ashmore, M., … De Vries, W. (2010). Global assessment of nitrogen deposition effects on terrestrial plant diversity: A synthesis. *Ecological Applications,* 20(1), 30–59. https://doi.org/10.1890/08-1140.1

Bobiec, A. (2002). Living stands and dead wood in the Białowieża forest: Suggestions for restoration management. *Forest Ecology and Management,* 165(1–3), 125–140. https://doi.org/10.1016/S0378-1127(01)00655-7.

Bugmann, H., & Brang, P. (2009). Ausgewählte Ergebnisse aus fünfzig Jahren Forschung in Schweizer Naturwaldreservaten. Forum für Wissen 93–102.

BMNT (2018). Naturwaldreservate [WWW Document]. URL https://www.bmnt.gv.at/forst/oesterreich-wald/oekosystem/naturwaldreservate.html (accessed 7.29.19).

Camy, C., Delatour, C., & Marçais, B. (2003). Relationships between soil factors, *Quercus robur* health, *Collybia fusipes* root infection and *Phytophthora* presence. *Annals of Forest Science,* 60(5), 419–426. https://doi.org/10.1051/forest:2003034

Chambers, J. Q., Higuchi, N., Schimel, J. P., Ferreira, L. V., & Melack, J. M. (2000). Decomposition and carbon cycling of dead trees in tropical forests of the central Amazon. *Oecologia,* 122(3), 380–388. https://doi.org/10.1007/s004420050044

Christensen, M., Hahn, K., Mountford, E. P., Ódor, P., Standovár, T., Rozenbergar, D., … Vrska, T. (2005). Dead wood in European beech (*Fagus sylvatica*) forest reserves. *Forest Ecology and Management,* 210(1–3), 267–282. https://doi.org/10.1016/j.foreco.2005.02.032

Cleary, M., Ghasemkhani, M., Blomquist, M., & Witzell, J. (2016). First report of *Phytophthora gonapodyides* causing stem canker on European beech (*Fagus sylvatica*) in Southern Sweden. *Plant Disease,* 100(10), 2174. https://doi.org/10.1094/PDIS-04-16-0468-PDN

Dale, V. H., Joyce, L. A., McNulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., … Wotton, B. M. (2001). Climate change and forest disturbances. *BioScience.* https://doi.org/10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2

Dietrich, M. (2016). The impact of ash dieback on ash regeneration in the forest reserve Dalby Söderskog. Master thesis. Southern Swedish Forest Research Centre. Swedish University of Agricultural Sciences. Alnarp.

Drobyshev, I., Linderson, H., & Sonesson, K. (2007). Temporal mortality pattern of pedunculate oaks in southern Sweden. *Dendrochronologia,* 24(2–3), 97–108. https://doi.org/10.1016/j.dendro.2006.10.004

Eckelt, A., Müller, J., Bense, U., Brustel, H., Bußler, H., Chittaro, Y., … Seibold, S. (2018). “Primeval forest relict beetles” of Central Europe: a set of 168 umbrella species for the protection of primeval forest remnants. *Journal of Insect Conservation,* 22(1), 15–28. https://doi.org/10.1007/s10841-017-0028-6

Eichrodt, R., 1969. Über die Bedeutung von Moderholz für die natürliche Verjüngung im subalpinen Fichtenwald. ETH Zürich Diss. Nr. 4261, *Beiheft Schweiz. Zeitschrift für Forstwesen*, 1970, p. 122

Esseen P. A., Ehnström B., Sjöberg K., & Ericson, L. (1997). Boreal forests. In: “Boreal ecosystems and landscapes: structures, processes and conservation of biodiversity” (Hanson, L. ed.). *Ecological Bulletins,* 46, pp. 16-47. [online] URL: http://www.jstor.org/stable/20113207

Fassnacht, K. S., & Steele, T. W. (2016). Snag dynamics in northern hardwood forests under different management scenarios. *Forest Ecology and Management,* 363, 267–276. https://doi.org/10.1016/j.foreco.2015.12.003

Flückiger, W., & Braun, S. (1998). Nitrogen deposition in Swiss forests and its possible relevance for leaf nutrient status, parasite attacks and soil acidification. In *Environmental Pollution,* 102, pp. 69–76. Elsevier Ltd. https://doi.org/10.1016/S0269-7491(98)80017-1

Forest Europe, (2020). State of Europe’s Forests 2020. https://foresteurope.org/

Franklin, J. F., Shugart, H. H., & Harmon, M. E. (2006). Tree death as an ecological process. *Bioscience,* 37, 550–556. https://doi.org/10.2307/1310665.

Franklin, J. F., Spies, T. A., Pelt, R. V., Carey, A. B., Thornburgh, D. A., Berg, D. R., … Chen, J. (2002). Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management,* 155(1–3), 399–423. https://doi.org/10.1016/S0378-1127(01)00575-8

Fraver, S., Wagner, R. G., & Day, M. (2002). Dynamics of coarse woody debris following gap harvesting in the Acadian forest of central Maine, U.S.A. *Canadian Journal of Forest Research,* 32(12), 2094–2105. https://doi.org/10.1139/x02-131

Freschet, G. T., Weedon, J. T., Aerts, R., van Hal, J. R., & Cornelissen, J. H. C. (2012). Interspecific differences in wood decay rates: Insights from a new short-term method to study long-term wood decomposition. *Journal of Ecology,* 100(1), 161–170. https://doi.org/10.1111/j.1365-2745.2011.01896.x

Fukasawa, Y., Takahashi, K., Arikawa, T., Hattori, T., & Maekawa, N. (2015). Fungal wood decomposer activities influence community structures of myxomycetes and bryophytes on coarse woody debris. *Fungal Ecology*, 14, 44–52. https://doi.org/10.1016/j.funeco.2014.11.003

Garbarino, M., Marzano, R., Shaw, J. D., & Long, J. N. (2015). Environmental drivers of deadwood dynamics in woodlands and forests. *Ecosphere,* 6(3). https://doi.org/10.1890/ES14-00342.1

Gray, A. N., & Spies, T. A. (1997). Microsite controls on tree seedling establishment in conifer forest canopy gaps. *Ecology,* 78(8), 2458–2473. https://doi.org/10.1890/0012-9658(1997)078[2458:MCOTSE]2.0.CO;2

Green, P., & Peterken, G. F. (1997). Variation in the amount of dead wood in the woodlands of the Lower Wye Valley, UK in relation to the intensity of management. *Forest Ecology and Management,* 98(3), 229–238. https://doi.org/10.1016/S0378-1127(97)00106-0

Grove, S. J. (2002). Saproxylic insect ecology and the sustainable management of forests. *Annual Review of Ecology and Systematics.* https://doi.org/10.1146/annurev.ecolsys.33.010802.150507

Gough, C. M., Vogel, C. S., Kazanski, C., Nagel, L., Flower, C. E., & Curtis, P. S. (2007). Coarse woody debris and the carbon balance of a north temperate forest. *Forest Ecology and Management,* 244(1–3), 60–67. https://doi.org/10.1016/j.foreco.2007.03.039

Gurnell, A. M., Gregory, K. J., & Petts, G. E. (1995). The role of coarse woody debris in forest aquatic habitats: Implications for management. Aquatic Conservation: *Marine and Freshwater Ecosystems.* https://doi.org/10.1002/aqc.3270050206

Harmon, M. E., & Hua, C. (1991). Coarse Woody Debris Dynamics in Two Old-Growth Ecosystems. *BioScience,* 41(9), 604–610. https://doi.org/10.2307/1311697

Harmon, M. E., & J. F. Franklin. (1989). Tree seedlings on logs in *Picea-Tsuga* forests of Oregon and Washington. *Ecology,* 70, 48–59.

Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., … Cummins, K. W. (1986). Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research,* 15(C), 133–302. https://doi.org/10.1016/S0065-2504(08)60121-X

Harmon, M. E. (2001). Moving towards a new paradigm for woody detritus management. *Ecological Bulletins,* 49, 269–278. Retrieved from http://www.jstor.org/stable/20113283

Harvey, A. E., Larsen, M. J., Jurgensen, M. F., (1979). Comparative distribution of ectomycorrhizae in soils of three western Montana forest habitat types. *Forest Science.* 25, 350-358.

Hansen, A. J., Spies, T. A, Swanson, F. J., & Ohmann, J. L. (1991). Conserving biodiversity in managed forests. Lessons from natural forests. *BioScience,* 41(6), 382–392.

Heilmann-Clausen, J., Aude, E., van Dort, K., Christensen, M., Piltaver, A., Veerkamp, M., … Òdor, P. (2014). Communities of wood-inhabiting bryophytes and fungi on dead beech logs in Europe - reflecting substrate quality or shaped by climate and forest conditions? *Journal of Biogeography*, 41(12), 2269–2282. https://doi.org/10.1111/jbi.12388

Humphrey, J. W., Sippola, L., Lemperiere, G., Dodelin, B., Alexander, K. N., & Butler, J. E. (2004). Deadwood as an indicator of biodiversity in European forests: From theory to operational guidance. *Monitoring and Indicators of Forest Biodiversity in Europe - from Ideas to Operationality* (pp. 193–206).

Humphrey, J. W., Davey, S., Peace, A. J., Ferris, R., & Harding, K. (2002). Lichens and bryophyte communities of planted and semi-natural forests in Britain: The influence of site type, stand structure and deadwood. *Biological Conservation,* 107(2), 165–180. https://doi.org/10.1016/S0006-3207(02)00057-5

Hunter, M. L. (1994): Dying, dead, and down trees. In Hunter M.L. Jr (ed.) *Managing Forests for Biological Diversity.* New Jersey, USA: Prentice Hall: pp. 157–180.

Hodge, S. J., & Peterken, G. F. (1998). Dead wood in British forests: priorities and a strategy. *Forestry,* 71 (2), 99–112.

Jia-bing, W., De-xin, G., Shi-jie, H., Mi, Z., & Chang-jie, J. (2005). Ecological functions of coarse woody debris in forest ecosystem. *Journal of Forestry Research,* 16(3), 247–252. https://doi.org/10.1007/bf02856826

Jomura, M., Kominami, Y., Tamai, K., Miyama, T., Goto, Y., Dannoura, M., & Kanazawa, Y. (2007). The carbon budget of coarse woody debris in a temperate broad-leaved secondary forest in Japan. In Tellus, Series B: *Chemical and Physical Meteorology* (Vol. 59, pp. 211–222). https://doi.org/10.1111/j.1600-0889.2006.00234.x

Jönsson, M. T., & Jonsson, B. G. (2007). Assessing coarse woody debris in Swedish woodland key habitats: Implications for conservation and management. *Forest Ecology and Management,* 242(2–3), 363–373. https://doi.org/10.1016/j.foreco.2007.01.054

Jonsson, U. (2004). *Phytophtora* and oak decline – impact on seedlings and mature trees in forest soil. – Ph.D. thesis, Lund University, Sweden

Jung, T., & Burgess, T. I. (2009). Re-evaluation of *Phytophthora citricola* isolates from multiple woody hosts in Europe and North America reveals a new species, *Phytophthora plurivora* sp. nov. Persoonia: *Molecular Phylogeny and Evolution of Fungi*, 22, 95–110. https://doi.org/10.3767/003158509X442612

Keren, S., & Diaci, J. (2018). Comparing the quantity and structure of deadwood in selection managed and old-growth forests in South-East Europe. *Forests,* 9(2). https://doi.org/10.3390/f9020076

Kruys, N., Fries, C., Jonsson, B. G., Lämås, T., & Ståhl, G. (1999). Wood-inhabiting cryptogams on dead Norway spruce (*Picea abies*) trees in managed Swedish boreal forests. *Canadian Journal of Forest Research,* 29(2), 178–186. https://doi.org/10.1139/x98-191

Korpel, S. (1995). Die Urwälder der Westkarpaten, Gustav Fischer.

Keeton, W. S. (2006). Managing for late-successional/old-growth characteristics in northern hardwood-conifer forests. *Forest Ecology and Management,* 235, 129–142. https://doi. org/10.1016/j.foreco.2006.08.005.

Larsen, M. J., Harvey, A. E., & Jurgensen, M. F. (1980). Residue decay processes and associated environmental functions in northern Rocky Mountain Forests. In:

Environmental consequence of timber harvesting in Rocky Mountain Coniferous Forests. USDA For Serv Gen Tech Rep. Vol. 90, pp. 157–194.

Larsson, J. (2021). Changes in the oak (*Quercus robur*) population in Dalby Söderskog national park 2011–2020: stem size distribution, spatial distributions, vitality and mortality. Master thesis. Southern Swedish Forest Research Centre. Swedish University of Agricultural Sciences. Alnarp.

Lindenmayer, D. B., & Noss, R. E. (2006). Salvage logging, ecosystem processes, and biodiversity conservation. *Conservation Biology.* 20, 949–958.

Lindquist, B. (1938). Dalby Söderskog, en skånsk lövskog i forntid och nutid. *Acta Phytogeographica Suecica,* vol. 10, 1 – 273.

Linder, P., & Östlund, L. (1998). Structural changes in three mid-boreal Swedish forest landscapes, 1885-1996. *Biological Conservation,* 85(1–2), 9–19. https://doi.org/10.1016/S0006-3207(97)00168-7

Malmer, N., Lindgren, L., & Persson, S. (1978). Vegetational succession in a South Swedish deciduous wood. *Vegetatio,* 36(1), 17–29. https://doi.org/10.1007/BF01324768

Martin, J. A., Fuentes-Utrilla, R., Gil, L., & Witzell, J. (2010). Ecological factors in Dutch elm disease complex in Europe-a review. *Ecological Bulletins,* 53, 209–224. Retrieved from https://www.jstor.org/stable/41442032

Maser, C., & Trappe, J. M. (1984). The seen and unseen world of the fallen tree. Gen. Tech. Rep. PNW-164. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. pp. 56.

McComb, W., & Lindenmayer, D. (1999). Dying, dead, and down trees. In M. Hunter (Ed.), Maintaining Biodiversity in Forest Ecosystems (pp. 335-372). Cambridge: Cambridge University Press. doi:10.1017/CBO9780511613029.012

Michalová, Z., Morrissey, R. C., Wohlgemuth, T., Bače, R., Fleischer, P., & Svoboda, M. (2017). Salvage-logging after windstorm leads to structural and functional homogenization of understory layer and delayed spruce tree recovery in Tatra Mts., Slovakia. *Forests,* 8(3). https://doi.org/10.3390/f8030088

Müller, J., Noss, R. F., Thorn, S., Bässler, C., Leverkus, A. B., & Lindenmayer, D. (2019). Increasing disturbance demands new policies to conserve intact forest. *Conservation Letters,* 12(1). https://doi.org/10.1111/conl.12449

Oheimb, G. von, & Brunet, J. (2007). Dalby Söderskog revisited: long-term vegetation changes in a south Swedish deciduous forest. *Acta Oecologica,* 31(2), 229–242. https://doi.org/10.1016/j.actao.2006.12.001

Ohlson, M., Söderström, L., Hörnberg, G., Zackrisson, O., & Hermansson, J. (1997). Habitat qualities versus long-term continuity as determinants of biodiversity in boreal old-growth swamp forests. *Biological Conservation,* 81(3), 221–231. https://doi.org/10.1016/S0006-3207(97)00001-3

Persson, S., Malmer, N., & Wallén, B. (1987). Leaf litter fall and soil acidity during half a century of secondary succession in a temperate deciduous forest. *Vegetatio,* 73(1), 31–45. https://doi.org/10.1007/BF00031849

Priewasser, K., Brang, P., Bachofen, H., Bugmann, H., & Wohlgemuth, T. (2013). Impacts of salvage-logging on the status of deadwood after windthrow in Swiss forests. *European Journal of Forest Research,* 132(2), 231–240. https://doi.org/10.1007/s10342-012-0670-1

Prvetiv, T., Adam, D., & Vrška, T. (2018). Decay dynamics of Abies alba and Picea abies deadwood in relation to environmental conditions. *Forest Ecology and Management*, 427, 250–259. https://doi.org/10.1016/j.foreco.2018.06.008

Ranius, T., Kindvall, O., Kruys, N., & Jonsson, B. G. (2003). Modelling dead wood in Norway spruce stands subject to different management regimes. *Forest Ecology and Management,* 182(1–3), 13–29. https://doi.org/10.1016/S0378-1127(03)00027-6

Read, H. (2013). Veteran Trees : A guide to good management. Peterborough (United Kingdom): English Nature.

Resco De Dios, V., Fischer, C., & Colinas, C. (2007). Climate change effects on Mediterranean forests and preventive measures. *New Forests.* Springer Netherlands. https://doi.org/10.1007/s11056-006-9011-x

Rock, J., Badeck, F. W., & Harmon, M. E. (2008). Estimating decomposition rate constants for European tree species from literature sources. *European Journal of Forest Research,* 127(4), 301–313. https://doi.org/10.1007/s10342-008-0206-x

Rondeux, J., Bertini, R., Bastrup-Birk, A., Corona, P., Latte, N., McRoberts, R. E., … Chirici, G. (2012). Assessing deadwood using harmonized national forest inventory data. *Forest Science,* 58(3), 269–283. https://doi.org/10.5849/forsci.10-057

Ruks, J. (2020). Effects of ash dieback and Dutch elm disease on forest structure in Dalby Söderskog 2012-2020. Master Thesis. Southern Swedish Forest Research Centre. Swedish University of Agricultural Sciences. Alnarp.

Russell, M. B., Woodall, C. W., Fraver, S., D'Amato, A. W., Domke, G. M., & Skog, K. E. (2014). Residence times and decay rates of downed woody debris biomass/carbon in Eastern US Forests. *Ecosystems,* 17(5), 765–777. https://doi.org/10.1007/s10021-014-9757-5

Samuelsson, J., Gustafsson, L., & Ingelög, T., (1994). *Dying and dead trees - a review of their importence for biodiversity.* Swedish threatened species unit, Uppsala, Sweden, 109 pp.

Sandström, F., Petersson, H., Kruys, N., & Ståhl, G. (2007). Biomass conversion factors (density and carbon concentration) by decay classes for dead wood of *Pinus sylvestris*, *Picea abies* and *Betula spp*. in boreal forests of Sweden. *Forest Ecology and Management,* 243(1), 19–27. https://doi.org/10.1016/j.foreco.2007.01.081

Sanchez, E., Gallery, R., & Dalling, J.W. (2009). Importance of nurse logs as a substrate for the regeneration of pioneer tree species on Barro Colorado Island, Panama. *Journal of Tropical Ecology* 25, 429–437.

Schaetzl, R. J., Burns, S. F., Johnson, D. L., & Small, T. W. (1988). Tree uprooting: review of impacts on forest ecology. *Vegetatio,* 79(3), 165–176. https://doi.org/10.1007/BF00044908

Schoennagel, T., Veblen, T. T., & Romme, W. H. (2004). The interaction of fire, fuels, and climate across Rocky Mountain forests. *BioScience.* American Institute of Biological Sciences. https://doi.org/10.1641/0006-3568(2004)054[0661:TIOFFA]2.0.CO;2

Schoebel, C. N., Stewart, J., Gruenwald, N. J., Rigling, D., & Prospero, S. (2014). Population history and pathways of spread of the plant pathogen *Phytophthora plurivora*. *PLoS ONE,* 9(1). https://doi.org/10.1371/journal.pone.0085368

Sefidi, K., Esfandiary Darabad, F., & Azaryan, M. (2016). Effect of topography on tree species composition and volume of coarse woody debris in an oriental beech (*Fagus orientalis* lipsky) old growth forests, Northern Iran. *Forest,* 9(4), 658–665. https://doi.org/10.3832/ifor1080-008

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., … Reyer, C. P. O. (2017). Forest disturbances under climate change. *Nature Climate Change.* Nature Publishing Group. https://doi.org/10.1038/nclimate3303

Smith, J. E., Heath, L. S., & Woodbury, P. B. (2004). How to estimate forest carbon for large areas from inventory data. *Journal of Forestry*, 102(5), 25–31. https://doi.org/10.1093/jof/102.5.25

Spies, T. A., Franklin, J. F., & Thomas, T. B. (1988). Coarse woody debris in Douglas-fir forests of western Oregon and Washington. *Ecology,* 69(6), 1689–1702. https://doi.org/10.2307/1941147

Sippola, A. L., Siitonen, J., & Kallio, R. (1998). Amount and quality of coarse woody debris in natural and managed coniferous forests near the timberline in Finnish Lapland. *Scandinavian Journal of Forest Research,* 13(1–4), 204–214. https://doi.org/10.1080/02827589809382978

Siitonen, J., Martikainen, P., Punttila, P., & Rauh, J. (2000). Coarse woody debris and stand characteristics in mature managed and old-growth boreal mesic forests in southern Finland. *Forest Ecology and Management,* 128(3), 211–225. https://doi.org/10.1016/S0378-1127(99)00148-6

Staniaszek-Kik, M., Ýarnowiec, J., & Chmura, D. (2019). The effect of forest management practices on the deadwood resources and structure in protected and managed montane forests during tree-stand reconstruction after a dieback of Norway spruce. *Baltic Forestry*, 25(2), 249–256. https://doi.org/10.46490/vol25iss2pp249

Sturtevant, B. R., Bissonette, J. A., Long, J. N., & Roberts, D. W. (1997). Coarse woody debris as a function of age, stand structure, and disturbance in boreal Newfoundland. *Ecological Applications,* 7(2), 702–712. https://doi.org/10.1890/1051-0761(1997)007[0702:CWDAAF]2.0.CO;2

Stokland, J. N., Siitonen, J., & Jonsson, B. G. (2012). Biodiversity in dead wood. Biodiversity in Dead Wood (pp. i–vii). Cambridge University Press. https://doi.org/10.1017/CBO9781139025843

Sonesson, K., & Drobyshev, I. (2010). Recent advances on oak decline in southern Sweden. *Ecological Bulletins,* 53, 197–207.

Takahashi, M., Sakai, Y., Ootomo, R., & Shiozaki, M. (2000). Establishment of tree seedlings and water-soluble nutrients in coarse woody debris in an old-growth Picea-Abies forest in Hokkaido, northern Japan. *Canadian Journal of Forest Research,* 30(7), 1148–1155. https://doi.org/10.1139/cjfr-30-7-1148

Weedon, J. T., Cornwell, W. K., Cornelissen, J. H. C., Zanne, A. E., Wirth, C., & Coomes, D. A. (2009). Global meta-analysis of wood decomposition rates: A role for trait variation among tree species? *Ecology Letters,* 12(1), 45–56. https://doi.org/10.1111/j.1461-0248.2008.01259.x

Woodall, C. W., & Liknes, G. C. (2008). Relationships between forest fine and coarse woody debris carbon stocks across latitudinal gradients in the United States as an indicator of climate change effects. *Ecological Indicators,* 8(5), 686–690. https://doi.org/10.1016/j.ecolind.2007.11.002

Woodall, C.W., & Monleon, V.J., (2008). Sampling Protocols, Estimation Procedures, and Analytical Guidelines for Down Woody Materials Indicator of the Forest Inventory and Analysis Program. US Department of Agriculture, Forest Service Gen. Tech. Rep. NRS-22. 68 pp.

Woodall, C.W. & Williams, M.S. (2005) Sampling, estimation, and analysis procedures for the down woody materials indicator of the FIA program. Gen. Tech. Rep. NC-256, U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN.

Zielonka, T. (2006). When does dead wood turn into a substrate for spruce replacement? *Journal of Vegetation Science,* 17(6), 739. https://doi.org/10.1658/1100-9233(2006)17[739:wddwti]2.0.co;2

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6. Appendix

Table A1. Summary statistics for different components of CWD in Dalby Söderskog.

Statistics

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	4,11	1,50	10,60	0,00	0,00	0,00	2,84	62,19
CWD vol m3/ha	50	227,9	27,7	196,1	7,9	87,7	162,9	303,2	805,4

Table A2. Results of a paired t-test comparing volume of logs and standing CWD in 50 sample plots in Dalby Söderskog.

Paired T-Test and CI: Log vol m3/ha; Standing CWD m3/ha

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Log vol m3/ha	50	174,4	156,4	22,1
Standing CWD m3/ha	50	53,4	117,9	16,7

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
121,0	195,6	27,7	(65,4; 176,6)

μ_difference: population mean of (Log vol m3/ha - Standing CWD m3/ha)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0

T-Value	P-Value
4,37	0,000