Deadwood in managed and protected forest in southern Sweden: in the wake of storm

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# Title
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## Abstract
Deadwood has increased over the last 25 years, but it remains unclear to what extent this is driven by forestry practices or storms. Therefore, I wanted to study the change in volume, decay stage and tree species during a 22-year period, to see if there was a correlation between increase of deadwood and storm. This study included data from southern Sweden, collected by the Swedish National Forest Inventory between 1994-2016. Deadwood in production forest have doubled over the last 25 years and almost quadrupled in protected forest. The increase does not depend on storm since much of the fallen wood was probably removed following year. In protected forest there was an increase in deadwood of broadleaved trees and a drastic decrease in Pinus sylvestris. While in production forest, conifer trees dominate and there was no lasting effect due to the storm Gudrun (2005) on Picea abies. Hard deadwood decreased in production forest, possibly due to increased removal of branches and treetops, used as forest fuel in forest management. Possible reasons for the increase in deadwood could be the awareness in forestry, especially certification system and voluntarily set asides. Though, there is still necessary to increase the volume of deadwood in production forest, since it covers the largest parts of Swedish forests and does not seem to reach the national environment objective in 2030.

## Keywords
Deadwood, production forest, protected forest, storm, volume
1 Abstract

Deadwood has increased over the last 25 years, but it remains unclear to what extent this is driven by forestry practices or storms. Therefore, I wanted to study the change in volume, decay stage and tree species during a 22-year period, to see if there was a correlation between increase of deadwood and storm. This study included data from southern Sweden, collected by the Swedish National Forest Inventory between 1994-2016. Deadwood in production forest had doubled over the last 25 years and almost quadrupled in protected forest. The increase did not depend on storm since much of the fallen wood was probably removed following year. In protected forest there was an increase in deadwood of broadleaved trees and a decrease in *Pinus sylvestris*. While in production forest, conifer trees dominate and there was no lasting effect due to the storm Gudrun (2005) on *Picea abies*. Hard deadwood decreased in production forest, possibly due to increased removal of branches and treetops for fuel. Possible reasons for the increase in deadwood could be the awareness in forestry, especially certification system and voluntarily set asides. A further increase of the volume of deadwood in production forest is needed to achieve the national environment objective in 2030.

2 Introduction

Forest in Sweden, which covers a large part of the country, is an important part of the natural environment. This because many species are adapted to forest structures, such as deadwood. Out of 28 million hectare of forest, 23.5 million ha is used as production forests (Swedish University of Agricultural Sciences 2017). Two percent of all protected areas are located in south of Sweden (Simonsson et al. 2016). Sweden has an intense forestry that include action such as thinning, pre commercial thinning and clearcut, where thinning is the most common action (Swedish University of Agricultural Sciences 2017). Because of intense forestry, old- growth forest with variation and different structures are rare (Stokland et al. 2012). In protected forests the average volume of deadwood is between 10 and 20 m³, depending on forest type (Swedish University of Agricultural Sciences. 2017). However, In production forest
there is an average of 5.3 m$^3$ deadwood per ha in Svealand and 4.3 m$^3$ per ha of deadwood in Götaland (Swedish University of Agricultural Sciences 2017).

Over the last decades, there is an increase in the amount of deadwood (Swedish University of Agricultural Sciences 2017). The most likely factor for the increase could be the actions within forestry to improve biodiversity. In Sweden, there are two certifying system, Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC). These associations strive towards a more substantiable forest management and the certification systems are supposed to be positive for increased levels of deadwood (Simonsson et al. 2015). In forestry, tree retention for conservation have an impact on the increased amount of deadwood in young forests (Kruys et al. 2013). Another reason could be that landowners can voluntarily set asides forestland to promote biodiversity (Skogsstyrelsen 2017). Such voluntarily set asides provides structural factors, that is necessary and important for biodiversity (Simonsson et al. 2016). The third factor with likely impact on increase in deadwood is storm damages. One storm in particular, Gudrun, effected southern Sweden in January 2005, felling about 75 million m$^3$ of trees (Skogsstyrelsen 2006).

The presence of deadwood is an important factor in forest ecosystems. Deadwood includes standing dead trees (snags) and downed deadwood (logs). Since deadwood is a large part of biomass in natural forests, many of species are dependent on deadwood (Nilsson et al. 2002), so called saproxylic species (Stokland et al. 2012). Due to increased forest management over the last 150 years (Linder & Östlund 1998), the abundance of valuable qualities of deadwood has decreased (Stokland et al. 2012).

Earlier studies have pointed to a lack of deadwood in large dimensions in Swedish forests (Fridman andWalheim 2000). Another observation by Jonsson and colleagues (2016) was that the increase of deadwood since first inventory (1994 until 2012), depends mostly of the storm in 2005 (Jonsson et al. 2016). All these studies including my own, are based on the same data, collected by Swedish National Forest Inventory (SNFI) from Swedish University of Agricultural Sciences.

In the present study, I wanted to investigate the increased amount of deadwood, during a study period of 22 years, where I focused on sample plots that have been revisited. In my study, given that during the study period the storm Gudrun was
present in 2005, my aim was to study how much the storm contributed to the increased levels of deadwood, maximum diameter, decay stage and tree species, in both managed production and protected forest. The same data was used by Widen (2017), who analysed decay of individual objects of deadwood.

3 Material and methods

3.1 Study area

The study included southern Sweden with a delimitation along Limes Norrlandicus and thereby included 15 out of 21 counties in Sweden. The forest in southern Sweden is heterogenous, with a mixture of conifers and deciduous (hemi-boreal and nemoral forest) trees. Götaland, which is included in this study contributes with the largest proportion of harvest in volume (Swedish University of Agricultural Sciences 2017).

3.2 Data collection

All data had been collected by Swedish National Forest Inventory (SNFI), a sample inventory of forest in Sweden, that has been ongoing since 1923. The inventory covers all types of forest, and are done in so called tracts, with both permanent and temporary tracts. The permanent tracs are visited every five years and the temporary tracs are only visited once. A tract is made up of a cluster with sample plots. The current study include region 4 (Counties of Stockholm, Södermanland, Uppsala, Västmanland, Örebro, Östergötland, Jönköping, Kronoberg, Kalmar, Västra Götaland (excluding the former Göteborgs and Bohuslän)) and region 5 (Counties of Gotland, Blekinge, Skåne, Halland and Göteborgs and Bohuslän). Tracts in region 4 are 800 m (side) and tracts in region 5 are 300 m (side). For further information regarding tracts and sample plots see Fridman et al. (2014). Deadwood has been recorded since 1994 and among the variables recorded, I have used volume, tree species identity and decay stage. When deadwood is being inventoried, decay stage is recorded in one of five different groups: 0 = raw wood, 1 = hard deadwood, where 90 % of bark cover still occur, 2 = slightly decomposed deadwood, 3 = decomposed deadwood and 4 = very decomposed deadwood.
3.3 Data management

In this study I focused on sample plots from the permanent tracts and arranged the data in two different ways. First, I grouped data according to time periods covered, and named them after the first year of inventory (Table 1). For this merge, I included tree species and decay stage (number of dead trees/ha)

Table 1. Groups of years with records on deadwood collected by SNFI.

|-------------|---------|---------|---------|---------|

I used these time periods, except for change in volume per ha. For this, I instead focused on three different cohorts (where, a cohort is a set of plots that have been revisited), to get a better precision in data (Table 2).

Table 2. Cohorts of plots that were visited four times by SNFI.

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1997</td>
</tr>
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</table>

Earlier studies included all collected data from the deadwood inventory, while I was focusing on revisited sample plots. Furthermore, I also separated production forest and protected forest, i.e. forest that was under official protection in 2016 (but not always so when the first sampling occurred).

Data were handled in Excel. First, I divided the volume (m³) of deadwood, with the sample plot area (ha). A sample plot is 0.314 ha, or smaller if it was a divided plot (a sample plots can be divided into multiple subsplots if vegetation or management differs in a plot).

As most tree species were rare in data, I merged some species to allow meaningful analyses. *Ulmus glabra, Fraxinus excelsior, Fagus sylvatica, Carpinus betulus, Prunus avium, Tilia cordata* and *Acer platanoides* were merged to “broadleaved
trees”. *Populus tremula, Sorbus aucuparia, Alnus spp.* and *Sorbus intermedia* were merges into “other tree species”. *Betula pubescens* and *Betula pendula* were merged into *Betula* spp.

### 3.5 Statistical analyses

Estimates of volume of deadwood per ha were accompanied by 95% confidence intervals. For the model predicted I merged all mean for each cohort and therefore used a linear model to calculate future increase. These predictions are based on production forest and protected forest.

### 4 Results

Deadwood had increased over time, both in production and protected forest and for all three cohorts (Figure 1). Deviating from the overall trend of steady increase was seen only in the second cohort where there was a clear peak in deadwood for both forest types in 2005 (Figure 1), i.e the year when Gudrun hit Sweden in January.

![Figure 1. Volume of deadwood per ha (95% confidence interval) in three cohorts of sample plots visited on four occasions.](image-url)
An estimated prediction from my data analysis (Figure 1) with a linear model, shows that in the year of 2030 there would be 22.55 m$^3$/ha in protected forest and 8.73 m$^3$/ha in production forest.

Production forest: $y = 0.1767x - 349.97$

Protected forest: $y = 0.5682x - 1130.9$

As for tree species there was a decrease in number of deadwood of *Betula* spp. in production forest (Figure 2a), from first time period (1994) to the latest (2013). Number of *P. abies* increased over the last time period (Figure 2a). Another observation was that there was an increase in numbers of *P. abies* the year of 2005 (Gudrun), and a decrease the year after (Figure 4). *Q. robur* and broadleaved trees increased from second time period (2003) to last time period (2013).

In protected forest, *P. sylvestris* decreased from first to last time period (Figure 2b). For *P. abies*, *Betula* spp., *Q. robur*, broadleaved trees and other tree species, there was an increase in number in second time period (2003). *P. abies* increased from first to third time period (1994-2008), and a minor decrease in last time period (2013). Number of deadwood of broadleaved trees had increased from first cohort (1994) to last (2013).
Figure 2. Numbers of dead trees/ha at different time periods. Figure 2a shows number of dead trees in production forest. Figure 2b shows number of dead trees in protected forest. Broad-leaved deciduous forest was merged as broadleaved trees and all other inventoried tree species were merged as other hardwood.

In both production and protected forests, decay stage “1” dominated (Figure 3a, 3b). In both forests, decay stage “0” was not recorded at the first time period (1994). Variation in decomposition class were similar in production and protected forest.
Figure 3. Number of dead trees/ha at different time periods. Different decay class are estimated over time measured in numbers/ha. Figure 3a shows numbers of dead trees in different decay stage in manage production forest. Figure 3b show numbers of dead trees in different decay stage in protected forest.

5 Discussion

Deadwood in production forest had doubled over the last 25 years and almost quadrupled in protected forest. Both forests had a clear peak in 2005, the year of the storm. On the other hand, there was no corresponding peak, in either forest type, in the cohort involving sampling in 2006. It was therefore likely that storm-felled wood was removed in production forest as well as in protected. Note that some areas were not yet protected during the storm damage, and that deadwood were removed from some protected areas for forest sanitation purposes. It might have expected that there should be some form of equilibrium in protected forest, but this was not the case. This could mean that protected areas will bear more dead wood in the future than today. Possible reasons for the increase could be the adjustments in forestry, especially certification system and voluntarily set asides.

Storms in Sweden may contribute with a temporary increase of deadwood (volume and number). But it did not seems that it contributed to the increase for the last 22 years. The storm that felled the most trees and gave a visible peak in deadwood was Gudrun, January 2005. Other significant storms (Figure 1, Table 4) had no visible impact in data. This was probably because they generated much less timber than Gudrun (2005), and partly because no cohort data existed from the season following the storm.
There is an ongoing trend that forest owners in southern Sweden avoid to plant pine, because of grazing damage, and therefore plant spruce instead (Skogsstyrelsen 2017). Since many of the sample plots in protected forest, probably belonged to previous production forest, this could be one reason for the reduction of numbers in *P. sylvestris* in protected forest (Swedish University of Agricultural Sciences 2017). Another important observation was the large increase of broadleaved trees. One possible reason could be the diseases of *U. glabra* and *F. excelsior*. In production *P. abies* and *P. sylvestris* dominated (Figure 3a), which was expected, since conifers trees dominate in production forest (Larsson et al. 2011). One possible reason for decrease in numbers of *P. abies*, the year after Gudrun (2005), might be the fear of attack from *Ips typographus*, and therefore a great effort to remove spruce wood that was felled during that storm.

Figure 4. Numbers of dead trees/ha (*Picea abies*), in different years.
One possible reason for the decrease in decay stage “1” in production forest, could be
the removal of branches and treetops used as forest fuel (Skogsstyrelsen 2008). When
removing these substrates, 20 % must be left behind, since these are valuable to
organism (Skogsstyrelsen 2008).

The national environmental objective say that deadwood in production forest should
increase to 10 m$^3$ per ha, before 2030 (Naturvårdsverket 2018), and there should also
be an average of 20 m$^3$ in protected areas (Almstedt and De Jong 2005). According to
my calculations, protected forest in southern Sweden had an average of 15.9 m$^3$ per
ha in 2016, and production forest 5.9 m$^3$ per ha. Assuming a continued increase in
volume protected forest would probably reach the national environment objective by
2030 (20 m$^3$ per ha). The same fulfilment does not apply to production forest (10 m$^3$
per ha). For further studies it would be interesting to know more about what kind of
deadwood there is, especially location of coarse deadwood and estimate how much
that is needed for some species survival, especially threatened ones.

5.1 Conclusions

Overall, there has been an increase of deadwood over the last 20 years. Although the
large storm event added deadwood, it was not the primary reason for the increase
which instead is likely due to adjusted forestry practices. If the increase continues at
its current rate, the national objective for the volume of deadwood in production
forest will not be reached by 2030.

5.2 Social and ethical aspects

The data that The Swedish National Forest Inventory from Swedish University of
Agricultural Sciences collect every year is a great source for further analysis. It is
therefore important that we use these data for monitoring changes in boreal forest in
Sweden as a result of forestry, since the forest and especially dead wood give rise to
many valuable habitats. This study is built exclusively on already existing data and
has no apparent impact on any ethical aspects.
6 Acknowledgement

I would like to give a huge thanks to my supervisor Per Milberg for helping me with my data and all of his guidance and help during this project. I would also like to thank Jonas Fridman who have provided me with all data collected by SNFI. Lastly, I would like to thank Andrey Höglund for helping me in R.
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