Count on dead wood

A comparison of nature conservation value assessment methods concerning dead wood

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Count on dead wood. A comparison of nature conservation assessment methods concerning dead wood.

Räkna med död ved. En jämförelse av naturvärdesinventeringsmetoder med avseende av död ved.

Andreas Widell

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Abstract

Dead wood is acknowledged world-wide for its interconnection to biodiversity and sustainable forest management. In Sweden, today's retention forestry requires measures to protect and create dead wood, which raise the need of inventory methods for estimating dead wood quantity and quality. There are however few evidence-based dead wood conservation value assessment methods, why this study aims at investigating the cost-efficiency and performance of two unconventional conservation assessment methods.

The study was conducted in spruce dominated stands in Gävleborg county, which either had been clear-cut or set aside as retention. The *Relascope method* used a relascope to conduct dead wood measurements. The *Triangle-transect method* measured dead wood along three transects, established to form a triangle shape. A total inventory on sample plot level, the *Sample plot method*, was used for evaluation. Both methods were good proxies for dead wood volume on a plot level, though their performance for estimating volume and dead wood diversity varied dependent on forest types on stand level. Both methods were significantly faster than the *Sample plot method*.

The results show a potential cost reduction in forest management, though further studies are needed to improve quantitative and qualitative measures of both methods before applying them in active forest management.

Keywords: conservation value assessment methods, dead wood volume, dead wood diversity, time consumption

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Abbreviations

DBH	Diameter at breast height
ENGO	Environmental non-governmental organization
FSC	Forest Stewardship Council
GIS	Geographical information system
ha	Hectare
NFI	National forest inventory
PEFC	Programme for the Endorsement of Forest Certification
SFA	Swedish Forest Agency
SLU	Swedish University of Agricultural Sciences
WKH	Woodland key habitat

1. Introduction

Dead wood is an essential habitat for biodiversity in forest ecosystems world-wide (Stokland et al. 2012). In Sweden, approximately 24-28 % of the forest dwelling species is associated with dead wood (Skogsstyrelsen, 2004). Many of the species associated with dead wood (saproxylic species) are also listed as threatened or near threatened on the national Red List (Gärdensfors, 2010). Dead wood could also help describe habitat quality and is a widely agreed indicator for biodiversity and sustainable forest management (Rondeux & Sanchez, 2010).

In the natural boreal forest of Fennoscandia, it is estimated that 25 % of the above-ground wood biomass is derived from dead wood (Siitonen, 2001) with a variation between 20-120m^3 ha^{-1} from the northernmost to the southernmost boreal zone (Fridman & Walheim 2000; Siitonen, 2001; Stenbacka et al., 2010). In Sweden, the forest structure has changed due to modern forestry and especially after the introduction of the mechanized rotation forestry in the 1950's. The rotation forestry practise transformed the natural multi-structured forest into single-storied, even-aged stands with trivial conservation values (Östlund et al. 1997). To counter-act the simplification of forest structures, retention forestry was introduced in Sweden in the 1990's (Simonsson et al. 2015). The idea with retention forestry is to manage the landscape so that it contains the same type of habitats, substrates and structures found in the natural forest landscape due to natural disturbances (Angelstam & Pettersson, 1997; Lindenmayer et al., 2006). Retention forestry has induced an increment in dead wood volume of 44 % in a period of 20 years in the productive forest land, from 5.8 m^3 ha^{-1} in 1996 to an average of 8.4 m^3 ha^{-1} in 2017 (Nilsson et al., 2020). However, if the volumes are summed up for all forested land in Sweden there is an average in dead wood volume of 8.9 m^3 ha^{-1} (Nilsson et al., 2020), which still is well below the expected natural values of 20-120 m^3 ha^{-1} (Fridman & Walheim 2000; Siitonen, 2001; Stenbacka et al., 2010).

Also, qualitative measures are important for biodiversity. The composition and diversity of the saproxylic community depend on whether the dead wood substrate is standing or downed (Jonsell & Weslien, 2003; Gibb et al., 2006; Hjältén et al., 2007; Hjältén et al., 2012), what tree species the dead wood are of (Lindhe et al., 2004), the substrate diameter (Schroeder et al. 1999), its exposure (Lindhe et al., 2005), fire history (Wikars 2002; Hjälten et al., 2007; Johansson et al., 2007) and other species interactions (Jonsell et al., 2005). It is therefore important to conserve a diversity of substrates (Jonsell & Weslien, 2003; Hjälten et al., 2007; Johansson et al., 2007). Even though the dead wood diversity therefore would be an important factor to consider, it is the volume of dead wood that most often are used as an indicator for biodiversity (Kunttu, 2015).

Quantitative and qualitative measures of dead wood retention are however not regulated in the Swedish Forestry Act. Recommendations have instead been stipulated by the Swedish Forest Stewardship Council (FSC) and the Swedish Programme for the Endorsement of Forest Certification (PEFC) which are organisations that provide certification schemes for sustainable forest management (Simonsson et al. 2015; Johansson et al. 2013; Beland Lindahl et al., 2017). Both the FSC and PEFC certification specifies that all older dead wood should be retained and three high stumps or girdled trees per hectare should on average be created after thick-stem thinning and clear-felling operations (FSC, 2020; PEFC, 2017). In addition, FSC specifies that all snags, high-stumps and windthrows that have been dead for more than one year should be retained together with at least two coarse new windthrows. FSC also recommends that deciduous trees should be prioritized for the creation of dead wood (FSC, 2020), but there is a general lack of qualitative measures in the Swedish forest policy.

The importance of dead wood and its role in the forest ecosystem has incorporated dead wood assessment in the national forest inventory (NFI) in many European countries and in the USA (Rondeux & Sanchez, 2009). The Swedish NFI has inventoried dead wood for the cause of biodiversity aspects since 1994 (Nilsson et al., 2020). It is important to recall that the information assessed for dead wood not necessarily are the same for the NFI, nature conservation and forestry operations (Rondeux & Sanchez, 2009). In Sweden this is reflected by the usage of different nature conservation value assessment methods between the NFI, the Swedish Forest Agency (SFA), forestry companies, nature conservation consultants and environmental non-governmental organizations (ENGOs) (Drakenberg & Lindhe, 2005; Skogsstyrelsen, 2020; SLU, 2021; Bergman, 2021). With exceptions from the NFI, the foregoing methods are based on indicators and thresholds to reduce time consumption, which gives a more cost-efficient conservation value assessment. Such ecological short-cuts though often exhibit shortage which might lead forest managers to believe that the forest is managed sustainably when it is not (Lindenmayer et al., 2006).

The most widely used dead wood assessment method is the line-intersect method, but a problem with this method is that it lacks the possibility to account for orientation bias of dead wood item (Woldendorp et al., 2004). Other used methods are relascope sampling and fixed area sampling (Teissier du Cros & Lopez, 2009). There is however a lack of systematic analysis of those different methods and approaches, and the superiority of one dead wood assessment method over the other is not yet clear (Woldendorp et al., 2004; Affleck et al., 2005; Teissier du Cros & Lopez, 2009).

This study will therefore compare the outcome of a dead wood assessment with a relascope sampling method and a line-transect based sampling method against an area based total inventory on a sample plot level. The aim is to develop evidence-based and cost-efficient inventory methods for dead wood conservation value assessment. The study will focus on dead wood volume assessment, as well as assessments of dead wood diversity. Dead wood diversity will be evaluated by calculating a Shannon diversity index (Jost, 2006) and compare how well the indices for the *Relascope method* and the *Triangle-transect method* correlates with the dead wood diversity index for the *Sample plot method*. Cost-efficiency will be evaluated by time consumption which is similar to the approach used by Boel & Braendli (2007), and the study will also evaluate the relation between time and the number of dead wood items and volumes registered.

Research questions:

1. Could the relascope method and/or the triangle-transect method be used as proxies of a total inventory of dead wood volume on a plot level? Are the approximations better for a certain type of dead wood? Are the approximations better for a certain forest type?

2. Could the relascope method and/or the triangle-transect method be used as proxies of dead wood diversity on stand level? Are the approximations better for a certain forest type?

3. Are there significant differences in time consumption between the inventory methods, and does it differ between forest types? How does the number of dead wood items that are registered impact time consumption? How does the estimated total volume impact time consumption?

2. Method

2.1 Study area

The study area was located in Gävleborg county, on land owned by the Swedish forest company Holmen Skog. A total of 30 stands were included, located in the transition between the southern and middle boreal vegetation zones (Ahti et al., 1968) centred at 61°57’ N, 16°309 E (figure 1). All stands were larger than 3 ha, situated less than 400 m above sea level with a species composition of at least 50 % *Picea abies* (L.) Karst. by volume (Rudolphi & Gustafsson, 2011). Out of the 30 stands, 17 stands are managed and have been subject for clear-cutting, resulting in an age-distribution between 0-17 years. The remaining 13 stands has been left un-managed, with an age-distribution between 127-190 years.

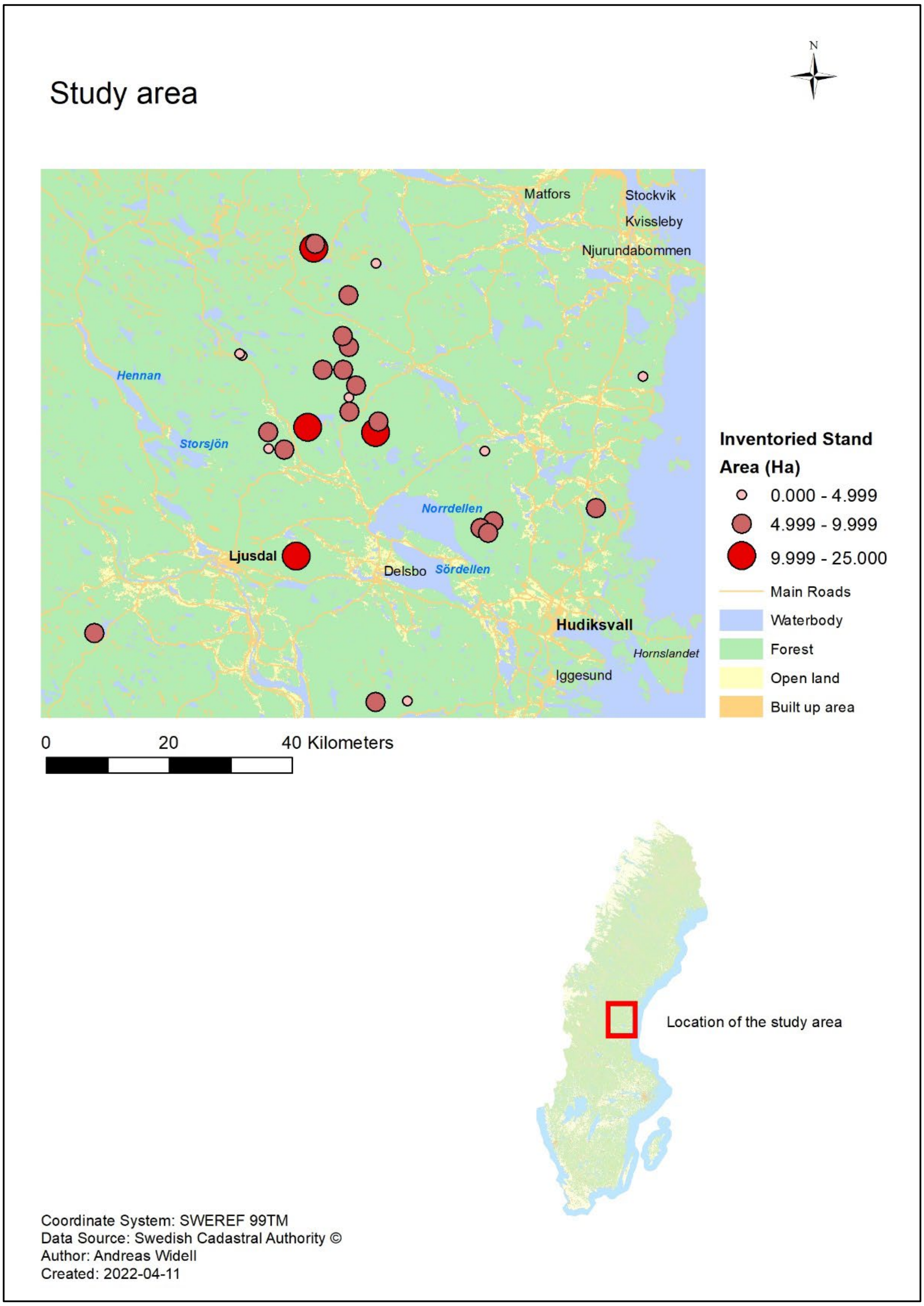

Figure 1. The main map shows the study area and approximate size of the inventoried stands (hectare). The size and colour of the dots representing the stands indicate that the number of inventory plots differs dependent on stand size, where two sample plots were used in stands < 5 ha, three plots were used in stands between 5-10 ha, and four plots were used in stands > 10 ha. The insert map shows were in Sweden the study area is located.

2.2 Field inventory preparation

Stand register data as well as geographic information for the stands were granted by Holmen Skog. The QGIS 3.20 Odense application was used to add a 20 x 20-meter grid to the existing stand information, and each intersect was given a unique id. The web-application RANDOM.ORG were then used to randomly assign intersect identities to use as centre coordinates for the field inventory. The number of inventory plots in each stand were dependant on stand size (table 1.)

Table 1. The table shows the number of inventory plots used in relation to the size of the stand, measured in hectare.

Stand size	**Number of inventory plots**
≤ 5	2
5-10	3
>10	4

2.3 Field inventory

The randomly chosen centre coordinates were located in field and inventoried first by the *Relascope method*, then the *Triangle-transect method* and lastly with the *Sample plot method*, which all are described further in the following sections. If the coordinate were located less than 25 meters from the edge of the stand the plot was moved until a circle of 25-meter radius could be measured. The same procedure was used if a centre coordinate in a managed stand was within a radius < 25 meters to a retention patch. The Field instructions is seen in Appendix 1 and an example of the Field protocol is seen in Appendix 2.

2.3.1 The Relascope method

For this method a relascope was used to measure the basal area of dead wood from the randomly chosen centre coordinate. For downed dead wood measures were taken at an estimated breast height for each object. The degradation of each dead wood item registered with the relascope were assessed ocularly classed into the decay class used in the *Knife method* (Appendix 1). The *Knife method* is similar to the method used by the Finnish National Forest Inventory and has also been used in previous studies (Hottola & Siitonen, 2008; Ekblad 2015). The test was performed by pressing a knife into the dead wood object and classifying the density according to the penetration depth. The four classifications are described in table 2. The expenditure of time was noted as the inventory with the method was finished.

Table 2. The table explains the Knife method, which sort dead wood items into different decay classes dependent on how far into the wood a knife could pierce.

Decay class	**Description**
1	Recently dead tree wood still hard, knife blade penetrates a few millimeters into the wood.
2	Weakly decayed wood of outer layers of stem has started to soften, wood still fairly hard, knife blade penetrates 1-2 cm into the wood.
3	Medium decayed wood of outer layers of stem fairly soft, core still hard, knife blade penetrates 2-5 cm into the wood.
4	Very decayed wood soft throughout the log, no hard core, knife blade penetrates all the way through the wood.

2.3.2 The Triangle-transect method

The *Triangle-transect method* used in this study is a modification of the method used by Ekblad 2015. A triangle-transect was then measured around the coordinate by using a measure tape to measure 10-meter north from the randomly chosen centre coordinate. This new point was the starting point for the triangle-transect. For each transect 1.5 meter at the beginning and end were left without data capture to avoid double counting. The total length of the transect measured 20 meters. A concept drawing of the method is shown in figure 2. The triangle shape of the transects was used to handle orientation bias, which for example could be caused by a storm event. The diameter was measured for all downed dead wood with a diameter larger than a thumb that were passed along the transect. The volume was calculated with the following formula (de Vries, 1986):

$$V = \frac{(\pi^2 \sum_i d_i^2)}{8L} \qquad \text{(Eq. 1)}$$

where V = Volume of downed dead wood (m^3 ha^{-1}),
d = Diameter (dm),
i = Number of dead wood object
L = Length of the transect (m).

A fishing rod with the length of 2.10 meter was used to locate standing dead wood along the transect. Diameter were measured, the height was estimated, and the shape were noted (i.e., if they were whole, broken or cut) for all standing dead wood within the reach of the rod. The volume of whole standing dead wood was calculated with the following functions (Brandel, 1994):

$$V_B = 10^{-0.84627} * DBH^{2.23818} * (DBH + 20.0)^{-1.06930} * H^{6.02015} * (H - 1.3)^{-4.51472} \qquad \text{(Eq. 2)}$$

$$V_P = 10^{-1.20914} * DBH^{1.94740} * (DBH + 20.0)^{-0.05947} * H^{1.40958} * (H - 1.3)^{-0.45810} \qquad \text{(Eq. 3)}$$

$$V_S = 10^{-0.79783} * DBH^{2.07157} * (DBH + 20.0)^{-0.73882} * H^{3.16332} * (H - 1.3)^{-1.82622} \qquad \text{(Eq. 4)}$$

where V_B = Volume of standing dead birches (m^3 ha^{-1}),
V_P = Volume of standing dead pines (m^3 ha^{-1}),
V_S = Volume of standing dead spruces (m^3 ha^{-1}),
DBH = Diameter at breast height (cm)
H = Height (m).

The formula for birch was used to calculate the volume of all standing deciduous trees since there are a shortage in volume formulas for other Swedish deciduous trees.

To calculate the volume of the broken standing dead wood and cut/created dead wood an estimation of the theoretical full height was made. Since the weighted average height were unknown, an assumption of the height of a tree with 25 cm DBH (H25) of 18 meters was used for all high stumps. The height was chosen by recommendations from the Department of Forest Resource management at SLU. H25 replaced average height in the formula by Ollas, 1980:

$H_t = 1.518 - (-1.086) * log_{10}(D) + (-0.518) * H25 * log_{10}(H)$ (Eq. 5)

where H_t = Theoretical height (m),
DBH = Diameter at breast height (cm),
H = the height of the broken stump.

The theoretical height was then used to calculate the full tree volume following the same method as for the standing whole trees (Eq. 2, Eq.3 and Eq.4). The final volume was estimated by calculating the proportion of the high stump out of the theoretical full height (i.e. height of broken high stump divided by theoretical full height) and the volume were reduced as follows; <30% * 0.5, <50% * 0.75, <70% * 0.9 and >70% * 1.0. The proportion of volume reduction was chosen by recommendations from the Department of Forest Resource management at SLU.

The degree of degradation was measured by the *Knife method*. The expenditure of time was noted as the inventory with the method was finished.

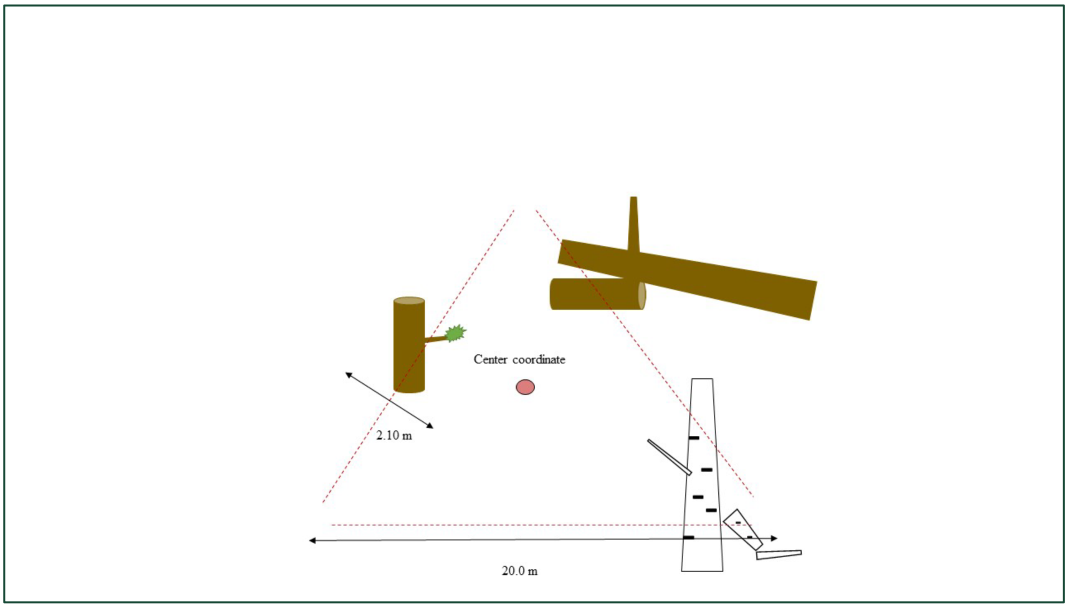

Figure 2. Concept drawing of the triangle-transect method. All downed dead wood with a diameter bigger than a thumb crossed by the transect were measured, as well as all standing dead wood within 2.10 meters from the transect. The total length of each transect was 20 meters, though 1.5 meter at the beginning and end of each transect where left unmeasured to avoid double counting.

2.3.3 The Sample plot method

The randomly chosen coordinate was used as centre for a sample plot with a radius of 25 meter. The length, top diameter and root diameter was measured for all downed dead wood with a germination point within the sample plot. The volume formula of a truncated cone was used to calculate the downed dead wood volume:

$$V = \frac{1}{3} * \pi * l(R^2 + r^2 + R * r) \qquad \text{(Eq. 6)}$$

where V = Volume (m^3),
l = length of the downed tree
R = the base radius of the cone (i.e. the root diameter),
r = the top radius of the truncated cone (i.e. the top diameter).

The DBH were also measured for all standing dead wood on the plot, and their shape were noted. The volume for whole standing dead wood were calculated with eq. 2, eq. 3, eq. 4. Broken and cut/created dead wood was calculated with eq. 5. All volume calculations were performed in the same way as described in section 3.3.2.

The degree of degradation was measured with the *Knife method*. The expenditure of time was noted as the inventory with the method was finished.

2.4 Statistical analysis

The statistical software RStudio (version 4.1.3) (R core team, 2021) with the extension packages *dplyr* (Wickham et al., 2022) and *ggplot2* (Wickham, 2016) were used for all analysis.

2.4.1 Analysis of proxies for dead wood volume

A Pearson correlation test was used to test for linear correlation of basal area registered with the *Relascope method,* and dead wood volume registered with the *Triangle-transect method* in relation to the dead wood volume registered with the *Sample plot method*. Pearson's correlation test was also used to test if there were any differences between the clear-cut groups and the control groups. The correlation coefficient could indicate how good approximations of the true volume that is achieved with the *Relascope method* and the *Triangle-transect* method (Sedgwick, 2012). The correlation test was conducted on both plot level and on stand level. The expectations were that any potential differences in volume assessment on plot level would even out on stand level.

Paired t-tests were executed to test for differences in the total mean volume between the *Triangle-transect method* and the *Sample plot method*, as well as to test for differences in mean volume between forest types. A significant level of $\alpha = 0.05$ were used, with a Bonferroni correction applied to avoid type I errors (Armstrong, 2014). The Bonferroni correction resulted in a significance level of $\alpha = 0.05/3 = 0.016$ which was used for all the test of differences in mean volume.

2.4.2 Analysis of proxies for dead wood diversity

The Shannon-Wiener index, which truly is an entropy, is the most used diversity measure. It gives the possibility to weight elements precisely by their frequency, without favouring either rare or common elements (Jost, 2006). Indices was calculated for each stand with the following equation:

$$D = \exp(-\sum p_i \, ln(p_i)) \qquad \text{(Eq. 7)}$$

where D = Shannon diversity index,
p_i = proportion of total sample represented by species i.

For the *Relascope method* dead wood species were created due to their estimated degradation (1-4) and used to calculate the Shannon diversity index. The dead wood species for the *Triangle-transect method* and the *Sample plot method* were created by giving each item an id-number due to if they were standing or downed (1-2), a number due to if they were whole, broken or cut (1-3) and an additional number dependent on tree species (1-7). Further each item was sorted into a diameter class with a 10-centimeter span resulting in 6 different classes, where each item received one more id-number dependent of which class it was sorted into (1-6). Lastly, an id-number were added due to the registered decay class (1-4), resulting in a five number id which made up the species that were used to calculate the Shannon diversity index.

A Pearson correlation test was used to test for linear correlation between the Shannon index derived from the qualitative measures by the *Relascope method* in relation to the Shannon index derived from the qualitative measures by the *Sample plot method*. A Pearson correlation test were as well performed for the *Triangle-transect method* and the *Sample plot method*.

A paired t-test was then conducted to test for differences in mean of the indices calculated for the *Triangle-transect method* and the *Sample plot method*. A significant level of $\alpha = 0.05$ were used. The test was followed by a regression analysis to further analyse the correlation between the Shannon diversity index derived from the qualitative measures by the *Triangle-transect method* and Shannon diversity index derived from the qualitative measures by the *Sample plot method*. No further analysis was made of the Shannon index calculated from the *Relascope method*, since the number of ingoing parameters were less than for the other two indices, why the index of the *Relascope method* only should be used as a proxy.

2.4.3 Time consumption

Firstly, a mean time consumption was calculated separately for each method. Thereafter a t-test was conducted to test for differences in mean. A Bonferroni correction resulted in a significance level of $\alpha = 0.05/9 = 0.006$ which was used for all the test of differences in time consumption.

Thereafter, regression analysis was conducted to investigate if time consumption could be explained by the number of dead wood object registered for each inventory method. A significance level of $\alpha = 0.05/3 = 0.016$ was used to correct for type 1 errors.

The last step in the time consumption analysis was to perform an additional regression analysis, to investigate how well time consumption could be explained by the registered volume for the *Triangle-transect method* and the *Sample plot method*. A significance level of $\alpha = 0.05/2 = 0.025$ was used to correct for type 1 errors.

3. Results

3.1 Proxies for dead wood volume

The Pearson correlation test for linear correlation between basal area registered with the *Relascope method* and dead wood volume registered with the *Sample plot method*, for registrations on plot level, is seen in table 3. The results show a strong positive correlation between basal area and volume on plot level (0.759). The Pearson correlation test for linear correlation between dead wood volume registered with the *Triangle-transect method* and dead wood volume registered with the *Sample plot method*, for registrations on plot level, is seen in table 3. The results show a moderate positive correlation between the two methods (0.669).

Table 3. The table shows Pearson's correlation coefficients for the basal area, measured in m^2 ha^{-1}, registered with the Relascope method in relation to the dead wood volume measured in m^3 ha^{-1} registered with the sample plot method. Seen are also the Pearson's correlation coefficients for dead wood volume registered measured in m^3 ha^{-1} with the Triangle-transect method in relation to the dead wood volume measured in m^3 ha^{-1} registered with the sample plot method. The correlation tests are made on plot level. Significant values are marked in bold.

	Pearson's correlation coefficient	
Method	Relascope	Triangle-transect
Sample plot	**0.759**	0.699

Further correlation test shows that the resulting basal area of the *Relascope method* has a strong positive correlation to the volume registered by the *Sample plot method* in stands subjected to clear-cutting (0.703) as well as the control stands (0.707) (table 4).

The correlation between the volume registered with the *Triangle-transect method* and the volume registered by the *Sample plot method* showed a moderate positive correlation in both forest types, 0.537 for the stands subjected to clear-cutting and 0.622 for the control (table 4).

Table 4. The table shows Pearson's correlation coefficient between the control groups and the clear-cut groups for basal area (m^2 ha^{-1}) registered with the Relascope method in relation to the dead wood volume (m^3 ha^{-1}) registered with the Sample plot method. Shown are also Pearson's correlation coefficient between the control groups and the clear-cut groups for dead wood volume (m^3 ha^{-1}) registered with the Triangle-transect method in relation to the dead wood volume (m^3 ha^{-1}) registered with the Sample plot method. The correlation tests are made on plot level. Significant values are marked in bold.

		Pearson's correlation coefficient	
Forest type	**Method**	Relascope	Triangle-transect
Clear-cut	Sample plot	**0.703**	0.537
Control	Sample plot	**0.707**	0.622

On a stand level on the other hand, the correlation between basal area registered with the *Relascope method* and dead wood volume registered with the *Sample plot method* were weak (0.300). Also, the correlation between dead wood volume registered with the *Triangle-transect method* and dead wood volume registered with the *Sample plot method* were weak (0.444) (table 5).

Table 5. The table shows Pearson's correlation coefficients for the basal area, measured in m^2 ha^{-1}, registered with the Relascope method in relation to the dead wood volume measured in m^3 ha^{-1} registered with the sample plot method. Seen are also the Pearson's correlation coefficients for dead wood volume registered measured in m^3 ha^{-1} with the Triangle-transect method in relation to the dead wood volume measured in m^3 ha^{-1} registered with the sample plot method. The correlation tests are made on stand level.

Method	**Pearson's correlation coefficient**	
	Relascope	Triangle-transect
Sample plot	0.300	0.444

Further tests of Pearson's correlation indicates that the basal area registered with the relascope method has a weak positive correlation between the control groups

(0.466), but a very weak corelation between the clear-cut groups (0.116) for the *Relascope method* and the *Sample plot method* (table 6).

The correlation test between the dead wood volume registered with the *Triangle-transect method* and dead wood volume registered with the *Sample plot method* shows, were in contrast highest for the clear-cut groups, which showed a weak positive correlation (0.431). The control groups showed a very weak correlation (0.228). The results are seen in table 6.

Table 6. The table shows Pearson's correlation coefficient between the control groups and the clear-cut groups for basal area (m^2 ha^{-1}) registered with the Relascope method in relation to the dead wood volume (m^3 ha^{-1}) registered with the Sample plot method. Shown are also Pearson's correlation coefficient between the control groups and the clear-cut groups for dead wood volume (m^3 ha^{-1}) registered with the Triangle-transect method in relation to the dead wood volume (m^3 ha^{-1}) registered with the Sample plot method. The correlation tests are made on stand level.

		Pearson's correlation coefficient	
Forest type	**Method**	Relascope	Triangle-transect
Clear-cut	Sample plot	0.116	0.431
Control	Sample plot	0.466	0.288

The resulting dead wood volume from the inventory by the *Triangle-transect method* and the *Sample plot method* can be seen in figure 3. The inventory result by the *Triangle-transect method* yielded a range of 4.3 - 96.8 m^3 ha^{-1}, and a median of 30.0 m^3 ha^{-1}. The mean dead wood volume was 38.3 m^3 ha^{-1}. The median value of the volume registered by the *Sample plot* method was 43.3 m^3 ha^{-1}, with a range of 8.6 - 163.7 m^3 ha^{-1}. The mean dead wood volume was 47.8 m^3 ha^{-1}.

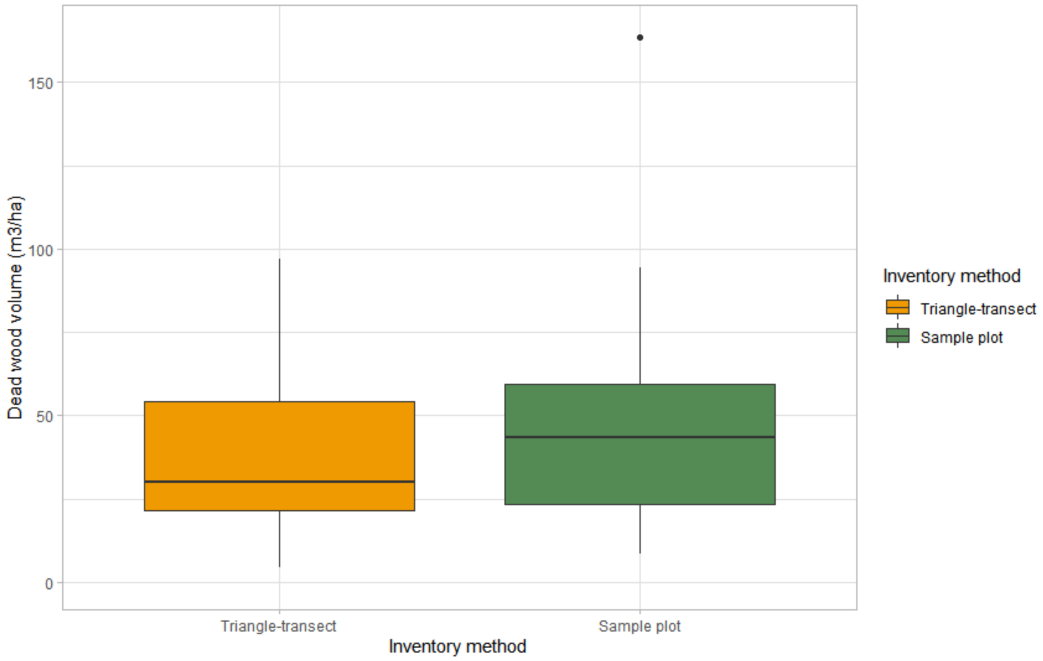

Figure 3. The figure shows the total volume of dead wood in m^3 ha^{-1} registered by the Triangle-transect method and the Sample plot method. The orange box represents the volume estimated by the Triangle-transect method and the green box represent the volume estimated by the Sample plot method.

Figure 4 shows the dead wood volume registered by the *Triangle-transect method* and the *Sample plot method* divided by dead wood type. The median volume of downed dead wood registered by the *Triangle-transect method* was 28.7 m^3 ha^{-1}, with the range 4.3 - 96.8 m^3 ha^{-1}, and a mean of 36.3 m^3 ha^{-1}. The median volume of downed dead wood registered by the *Sample plot method* was 42.0 m^3 ha^{-1}, with a range of 7.6 - 162.4 m^3 ha^{-1}, and a mean of 46.6 m^3 ha^{-1}. The median volume of standing dead wood registered by the *Triangle-transect method* was 1.4 m^3 ha^{-1}, with a range of 0.0 - 7.3 m^3 ha^{-1}, and a mean of 2.5 m^3 ha^{-1}. The median volume of standing dead wood registered by the *Sample plot method* was 1.1 m^3 ha^{-1}, with a range of 0.0 - 4.2 m^3 ha^{-1} and a mean of 1.2 m^3 ha^{-1}.

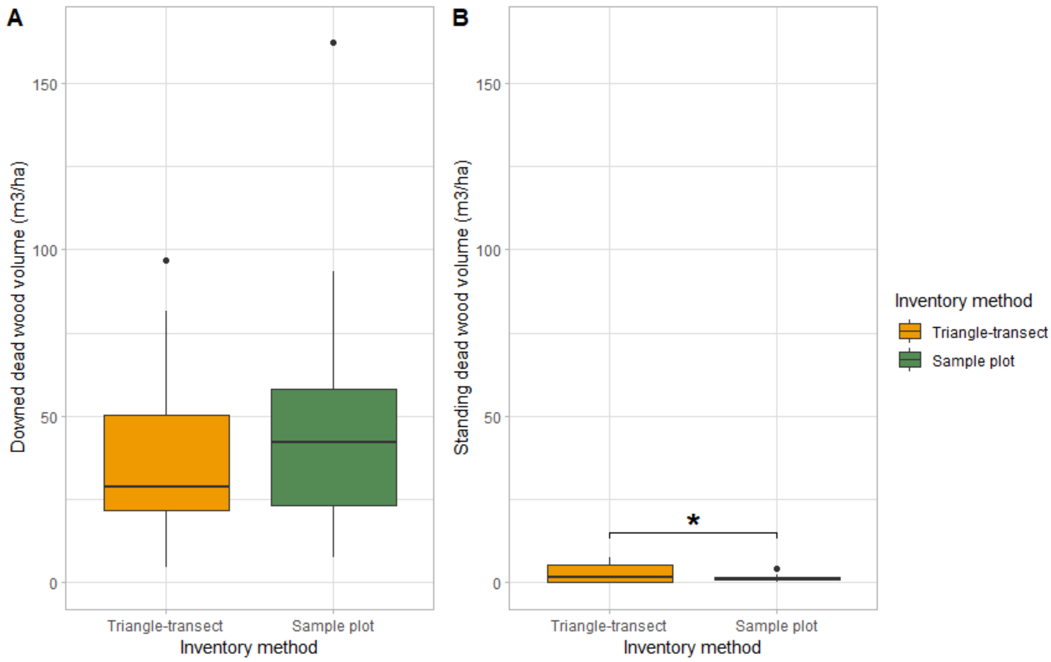

Figure 4. Seen in the figure are the dead wood volume registered by the Triangle-transect method and the Sample plot method, sub-divided on dead wood type. The Triangle-transect method is represented in orange and the Sample plot method is represented in green. A) shows the downed dead volume and B) the standing dead volume, measured in m^3 ha^{-1}. The asterisk in plot B indicates a significant difference between the assessment methods.

The modelled parameters and results of the t-test for differences in mean volume were conducted between the volume registered by *Triangle-transect* method and the volume registered by *Sample plot method* are seen in table 7. As seen, there was no significant difference in mean volume for downed dead wood according to the paired t-test (0.078). The t-test of difference in mean volume for the standing dead did however show a significant difference in mean (0.013), which indicates that the *Triangle-transect method* overestimates the volume of standing dead wood. The differences in standing dead wood volume did not influence the total volume enough for any significance difference (0.119).

Table 7. The table shows the modelled parameters, sample size, mean volume (m^3 ha^{-1}), standard errors (SE) and 95% confidence intervals (CI) of the paired T-test for differences in mean volume between the Triangle-transect method and the Sample plot method. The T-test are conducted for volumes at stand level, measured in m^3 ha^{-1}. Significant values are marked in bold, α = 0.016.

Modelled parameters	N	Mean Triangle-transect	Mean Sample plot	P-value	SE	95 % CI Lower	Upper
Downed dead wood	30	36.3	46.6	0.078	5.617	-1.222	21.756
Standing dead wood	30	2.5	1.2	**0.013**	0.483	-2.275	0.298
All dead wood	30	38.3	47.8	0.119	5.592	-2.455	20.417

3.2 Proxies for dead wood diversity

The Pearson correlation test showed a moderate positive correlation between the Shannon diversity indices calculated for the *Relascope method* and the *Sample plot method* (0.627). The indices correlate better for the control stands (0.588) than the stands subjected to clear-cutting (0.423) (table 8).

The correlation between the calculated Shannon diversity indices of the *Triangle-transect method* and the *Sample plot method* were strongly positive (0.868). In contrast to the *Relascope method* there is higher correlation between the indices in the stands subjected to clear-cutting (0.801) than the control stands (0.621) (table 8).

Table 8. The table shows Pearson's correlation coefficient for the Shannon diversity indices of the control groups and the clear-cut groups. The tested indices are calculated from measurements by the Relascope method, measurements by the Triangle-transect method and measurements by the Sample plot method. The correlation tests are made on stand level. Significant values are marked in bold.

		Pearson's correlation coefficient	
Forest type	**Method**	Relascope	Triangle-transect
Clear-cut	Sample plot	0.423	**0.801**
Control	Sample plot	0.588	0.621
All	Sample plot	0.627	**0.868**

The conducted paired t-test for differences in mean between the Shannon index calculated from the *Triangle-transect method* and the Shannon index calculated from the *Sample plot* method showed a significant difference (< 0.001). As seen in table 9, this means that the Shannon diversity index of the *Sample plot method* was significantly higher.

Table 9. The table shows the modelled parameters, sample size, mean Shannon diversity index, difference of the paired sample value (D), standard errors (SE) and 95% confidence intervals (CI) of the paired T-test for differences in mean volume between the indices of the Triangle-transect method and the Sample plot method. The T-test are conducted for diversity at stand level. Significant values are marked in bold, α = 0.05.

Modelled parameters	N	Mean Triangle-transect	Mean Sample plot	D	P-value	SE	95 % Lower	CI Upper
Shannon diversity index	30	7.404	12.266	-4.862	**< 0.001**	0.482	-5.848	-3.877

The regression analysis of how well the variation of the Shannon diversity index calculated from the registrations by the *Sample plot method* is explained by the Shannon diversity index calculated from the registrations by the by the *Triangle-transect method* was statistically significant ($R^2 = 0.753$, $F(1,28) = 85.53$, $p < 0.001$, $\alpha = 0.05$), meaning that ~ 75 % of the variation in the index from the *Sample plot method* is explained could be explained by the index of the *Triangle-transect method*. The relationship is seen in figure 5.

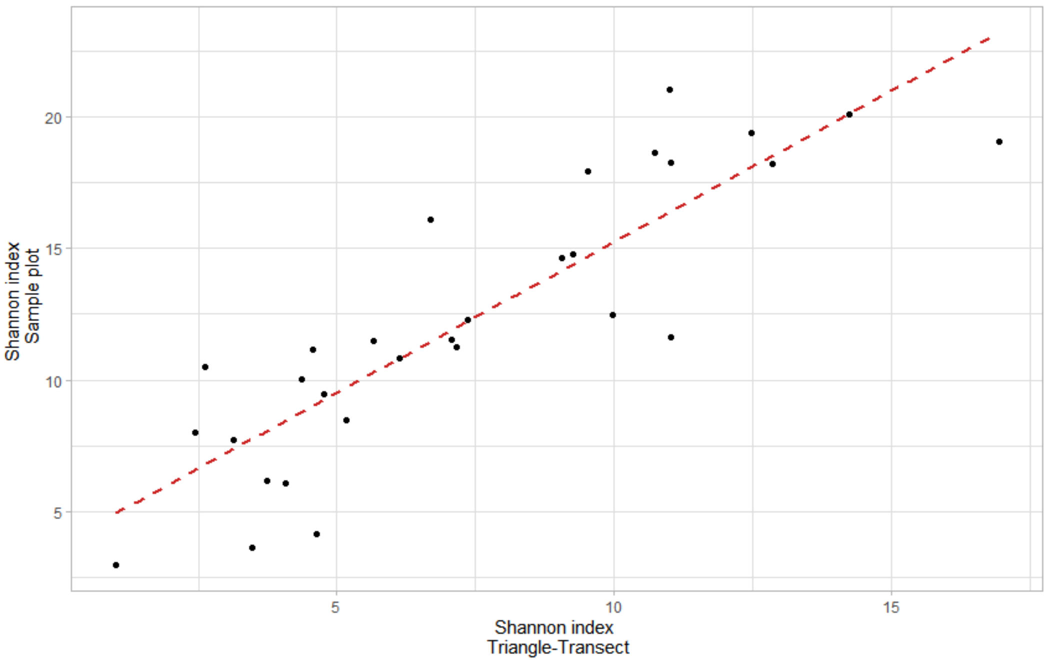

Figure 5. The figure shows the relationship between the Shannon diversity indices calculated from the registrations by the Triangle-transect method and from the registrations by the Sample plot method.

3.3 Time consumption

Shown in table 10 are the mean time consumption for a stand level inventory by each dead wood inventory method measured in minutes. The table also shows the difference in mean between forest types.

Table 10. The table shows the mean time consumption for a stand level inventory by each dead wood inventory method, divided by forest type and in total. The time consumption is reported in minutes.

	Mean time consumption		
Method	**Clear-cut**	**Control**	**Total**
Relascope	1.8	3.5	2.6
Triangle-transect	33.2	44.8	37.9
Sample plot	57.2	140.1	93.1

The paired t-test for differences in mean time consumption shows that the *Relascope method* was significantly faster than the the *Sample plot method* ($p < 0.001$). The *Relascope method* was also significantly faster than the *Triangle-transect method* ($p < 0.001$), though the *Triangle-transect method* was as well significantly faster than the *Sample plot method* ($p < 0.001$). As seen in table 11, there was also significant differences in mean time consumption between forest types, where both the *Relascope method* and the *Triangle-transect* method was significantly faster than the *Sample plot* method in both the clear-cuts and the control.

Table 11. The table shows the modelled parameters, sample size, standard errors (SE) and 95% confidence intervals (CI) of the paired T-tests for differences in mean time consumption (minutes). The tests were conducted for difference in mean time consumption of the Relascope method and the Sample plot method, the Triangle-transect method and the Sample plot method, and also the Relascope method and Triangle-transect method. Significant values are marked in bold, α = 0.006.

Modelled parameters	N	P-value	SE	95 % CI Lower	Upper
Relascope – Sample plot					
Clear-cut	30	**< 0.001**	6.8	41.0	69.7
Control	30	**< 0.001**	15.9	101.8	171.2
Total	30	**< 0.001**	10.8	68.6	112.5
Triangle-transect – Sample plot					
Clear-cut	30	**< 0.001**	4.4	14.7	33.2
Control	30	**< 0.001**	13.4	66.9	125.1
Total	30	**< 0.001**	9.1	36.6	73.7
Relascope – Triangle-transect					
Clear-cut	30	**< 0.001**	3.1	25.0	37.9
Control	30	**< 0.001**	4.1	31.5	49.5
Total	30	**< 0.001**	2.6	30.1	40.7

On a plot level, the regression analysis of how well time consumption is explained by the basal area, which for the *Relascope method* is the same as the number of dead wood objects registered, was statistically significant ($R^2 = 0.666$, $F(1,81) = 161.9$, $p = < 0.001$, $α = 0.016$). This means that ~ 66 % of the variation in time consumption could be explained by the basal area registered and the number of dead wood objects registered. The relationship is seen in figure 6.

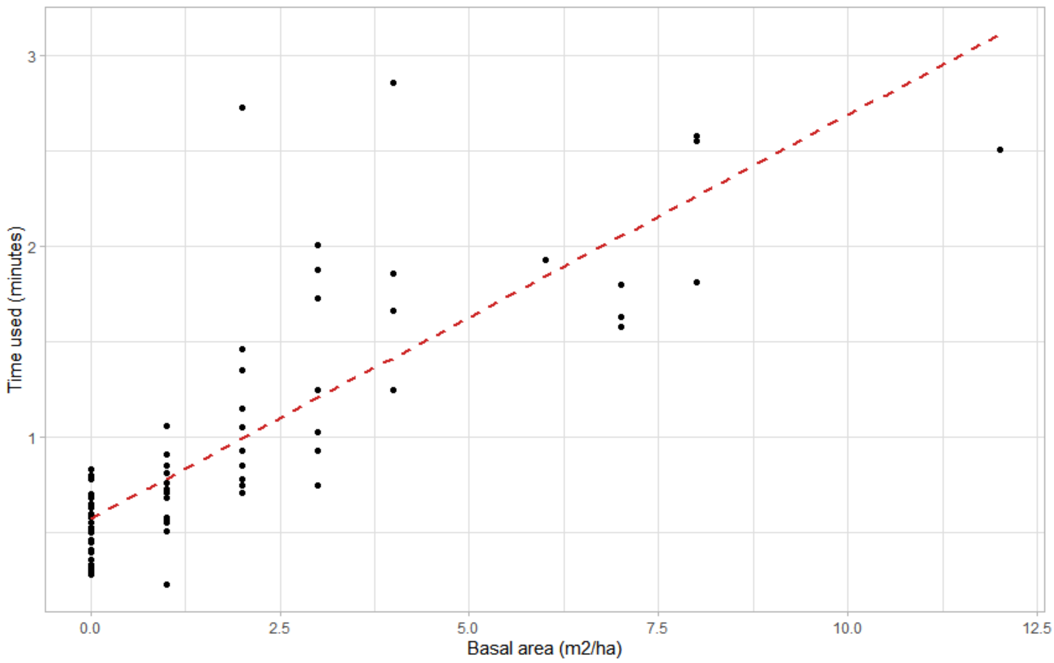

Figure 6. The figure shows the relationship between the expenditure of time and basal area (m^2 ha^{-1}), which for the Relascope method is the same as the number of dead wood items registered.

Also, the regression analysis of how well time consumption is explained by the number of dead wood objects registered by the *Triangle-transect method* was statistically significant ($R^2 = 0.263$, $F(1,28) = 10.01$, $p = 0.004$, $\alpha = 0.016$), which means that ~ 26 % of the variation in time consumption could be explained by the number of objects registered. The model was as well statistically significant for *the Sample plot method* ($R^2 = 0.910$, $F(1,28) = 285$, $p < 0.001$). This means that ~ 91 % of the variation in time consumption could be explained by the number of objects registered. The relationships are seen in figure 7.

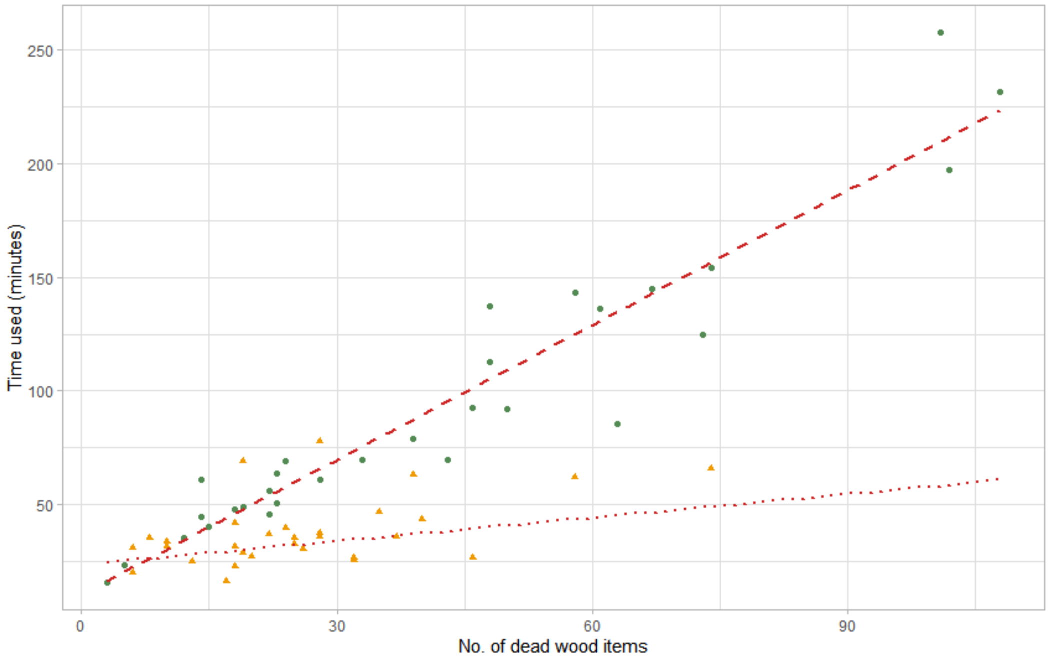

Figure 7. The figure shows the relationship between the expenditure of time and the number of dead wood items registered with the use of the Triangle-transect method and the Sample plot method. The time consumption of the Triangle-transect method is visualized with triangles and a dotted trendline. The time consumption of the Sample plot method is visualized with dots and a dashed trendline.

The regression analysis of time consumption and dead wood volume registered by the *Triangle-transect method* was statistically significant (R^2 = 0.085, F(1,28) = 2.604, p = 0.118, α = 0.025). The regression analysis of time consumption and dead wood volume registered by the *Sample plot method* was however not statistically significant (R^2 = 0.024, F(1,28) = 0.680, p = 0.417, α = 0.025). The relationships are seen in figure 8.

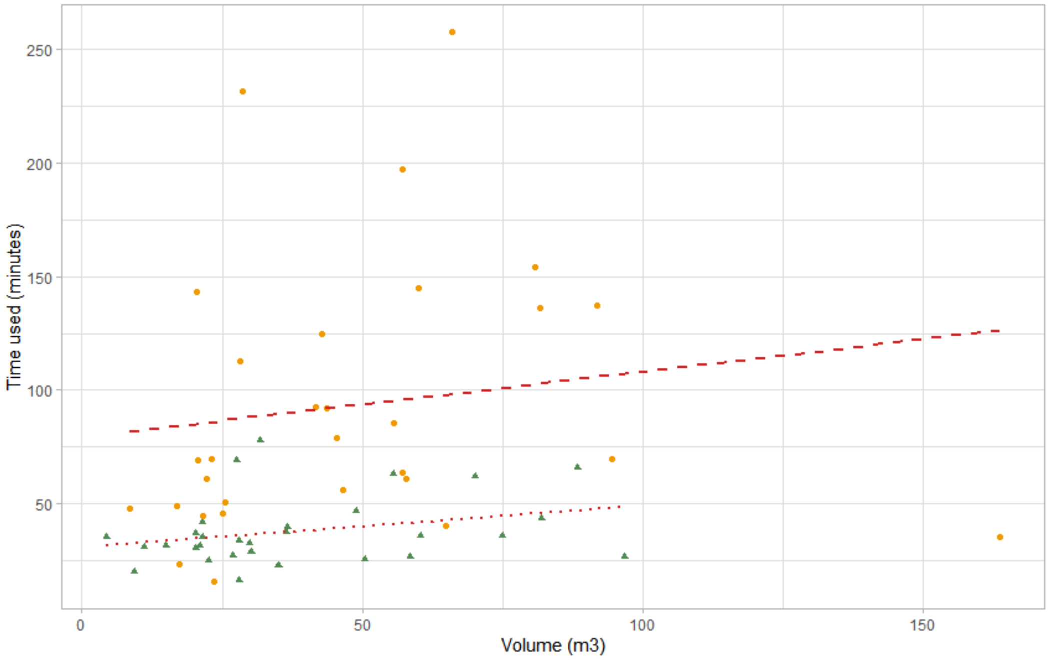

Figure 8. The figure shows the relationship between the expenditure of time and the dead wood volume registered with the use of the Triangle-transect method and the Sample plot method. The time consumption of the Triangle-transect method is visualized with triangles and a dotted trendline. The time consumption of the Sample plot method is visualized with dots and a dashed trendline.

4. Discussion

4.1 Proxies for dead wood volume

The results of the correlation tests indicate that basal area registered by the *Relascope method* is a good proxy for dead wood volume at plot level. Also, the volume estimated by the *Triangle-transect method* is a fairly good proxy of the actual dead wood volume. Both methods are best at predicting dead wood in the control stands. However, both methods perform better on plot level then on stand level, which contradict the expectation that differences on plot level would be evened out when scaling up the results. A possible explanation for the low precision on stand level might be due to the relatively low area sampled in comparison to the area of the sample plot.

The Pearson correlation indicates that both the *Relascope method* and the *Triangle-transect method* is weak proxies for dead wood volume on a stand level. On stand level, the *Relascope method* act as a better predictor in the control stands. This indicates that the *Relascope method* underestimates dead wood volume in forest types with a lower dead wood concentration. The reason might be difference in visuals between the forest types, were rejuvenating saplings and undergrowth on the former clear-cuts made it harder to spot both standing and downed dead wood. The reason why the *Triangle-transect method* on the other hand correlates less in the control stands might be due to that it captures too few of the dead wood items when the amount is high. A previous study by Woldendorp et al. (2004) shown that the precision in estimated volume increases as the total transect length increases, and that longer transects lines are needed in denser forest. Another study did however indicate that the precision increased more with the increment in number of transects than an increment in length (Teissier du Cros & Lopez, 2009).

Though the correlation test indicated that the *Triangle-transect* were a weak proxy for dead wood volume at a stand level, no significant differences in mean volume were found between the *Triangle-transect method* and the *Sample plot method*. The result differs from previous studies which indicates that if gaps are present, the volume is likely overestimated if the transect falls through a cluster, and contrariwise underestimates the volume if the transect falls between clusters (Woldendorp et al. 2004).

Further, the result of this study shows no significant differences in downed dead wood volume, as the total volume are divided on dead wood type. There was however significant difference in standing dead wood volume, were the *Triangle-transect method* overestimates the volume. One possible explanation for the overestimation might be the fact that the height of standing dead wood items only were estimated. This could be avoided by having field practises where estimations are followed by measurements before the start of an inventory season, and by sampling heights continuously to make sure that the estimations are within a reasonable range of deviation. Future studies should investigate if the estimation of standing dead wood volume could be improved by taking measures of height, and how that would influence the time consumption for the method.

Summed up, the *Relascope method* are a good proxy for dead wood volume, and the *Triangle-transect method* shows potential for estimating total dead wood volume on stand level, though improvements are needed in the measuring techniques for standing dead wood.

4.2 Proxies for dead wood diversity

The study results indicates that the *Relascope method* gave the least correlation as a proxy for estimating biodiversity. This could either be due to the simplified sampling of diversity factors or the fact that this method samples the fewest objects of the survey. A previous study by Kunttu et al. (2015) shown that the selected indicators affect the output of a diversity assessment considerably. As for dead wood volume, the method was a better proxy in the control stands, which as well for biodiversity likely were due to a higher number of dead wood items and better visuals than in the rejuvenating clearcuts.

The *Triangle-transect method* had a high correlation as a proxy for estimating biodiversity. The reason that the method correlates less for the control might be due to that it captures too few dead wood items when the amount is high, just as for dead wood volume. This might as well be the reason why the *Triangle-transect method* systematically underestimates the dead wood diversity.

4.3 Time consumption and cost efficiency

The results indicates that the *Relascope method* is an extremely time efficient method, with minor differences between forest types. There were as well minor differences in time consumption between forest types for the *Triangle-transect method,* which though it was the second most time efficient method was significantly faster than the *Sample plot method*. There were big differences in time consumption between forest types for the *Sample plot method*. The differences reflect that 86 % of the variation in time were explained by the number of registered dead wood objects, which is natural since the amount of dead wood could be expected to be greater in the control stands than in the clear-cuts. The results are in line with previous results which found that a fixed area sample had a high time consumption, in relation to relascope and transect sampling (Teissier du Cros & Lopez, 2009). Volume was however not a significant predictor of time consumption. The variation in time was to a big degree (66 %) explained by the number of registered dead wood objects and basal area for the *Relascope method,* which reinforces the perception of the effectiveness of the method.

For the *Triangle-transect method* only 26 % of the variation in time were explained by the number of dead wood objects registered, and 8.5 % of the variation were explained by volume. Unlike the other methods, a certain and amount of time was used to put out the transects, whether there would be any dead wood objects along them or not. This gives a hint that the variation in times lies more within the method itself and the perceptions is strengthened by a previous study by Boehl & Braendli (2007). They showed that most of the time needed to establish the transect line, and that time consumption only could be reduced by using shorter transect lines. The shortening of transect line did however come with a cost of a higher standard error (Boehl & Braendli, 2007). The *Triangle-transect method* is slightly more complex than a line inventory, but still shows a potential to lower inventory costs in relation to an area-based inventory method as the *Sample plot method*. It would likely be easier to make cost prediction for an inventory by the *Triangle-transect method* as well, and the method is less sensible to variation in forest types.

4.4 Limitations and sources of error

There are several limitations and error sources to acknowledge. Firstly, the *Sample plot method* which in this study are used to evaluate the other method against is no true total inventory. The result might therefore differ from the true volume and true diversity for the population. Secondly, there is always the risk of human error in the sampling process and there are as well uncertainties for each measuring tool used. Thirdly, the accuracy in the calculation of broken and created dead wood volume (eq. 5) are limited by the assumption that the height of a tree with 25 cm DBH would be 18 m. The accuracy might have been improved by calculating an average height based on field measurements. Lastly, the time consumption and cost efficiency analysis are coarse simplification. A multiple regression analysis might be better suited to find the most influential factor for time consumption. More factors than just labour cost due to time consumption should be accounted for to make a proper cost analysis.

4.5 Implication for practise

This study is in line with previous result, indicating that relascope sampling and transect sampling is efficient assessment methods for estimating dead wood volume and dead wood diversity. Previous studies have indicated that there is advantage in arranging transects where orientation bias of dead wood is present (Woldendorp et al. 2004), which are accounted for with the *Triangle-transect method*. Further studies are however needed to investigate if the accuracy of *Triangle-transect method* best could be improved with increasing transect length or through denser sample points, and which of the two solutions that are the least time consuming.

Previous studies have concluded that dead wood volume is strong predictor for biodiversity of saproxylic beetles (Lassauce et al., 2011; Gao et al., 2015) and wood living fungi (Gao et al., 2015). This study does however indicate that the quality of predictors varies between assessment methods and forest types, why the significance of those studies should be taken by caution. For coming studies, it is therefore important to be transparent with what sampling technique that is used for the study.

Conclusion

This study indicates that the *Relascope method* and the *Triangle-transect method* are good proxies for dead wood volume on a plot level were both perform best in the control stands. Both methods where less successful on a stand level, however no significant differences in means were detected between the volumes of dead wood registered by the *Triangle-transect method* and the *Sample plot method*.

The study results indicate that the *Triangle-transect method* are a good proxy for biodiversity. Also, the *Relascope method* is a fairly good predictor of biodiversity. The *Triangle-transect method* seems to be more accurate in the control stands, whereas the *Relascope method* seems most accurate for the stands subjected to clear-cutting. The results though indicates that the *Triangle-transect method* systematically underestimates dead wood diversity.

Both the *Relascope method* and the *Triangle-transect method* were significantly faster than the *Sample plot* method in all forest types. Yet, the *Relascope method* was significant faster than the *Triangle-transect method* in all forest type, making it the most cost-efficient dead wood assessment method of the study. Most of the time consumption of the *Triangle-transect method* are likely in establishing the transect. Both the *Relascope method* and *Triangle-transect method* shows a potential to give a high degree of precision in estimating dead wood volume and dead wood diversity for a less effort and cost than the *Sample plot method*.

Further studies are needed to improve the quantitative and qualitative measures of the two methods. For the *Relascope method*, improvements could be made by addressing more indicators for dead wood diversity, while for the *Triangle-transect method* further studies should investigate if an increment in length or an increment of the number of transects improves the accuracy in volume prediction. It is also of interest to investigate if measurements of height could improve the accuracy for estimating standing dead wood volume. It should also be investigated how the added complexity of measures impacts time consumption.

This study indicates that the accuracy of predictors of volume and dead wood diversity varies between assessment methods and forest types. Therefore, coming studies on the subject must be transparent on which assessment method that is used.

References

Affleck D.L.R., Gregoire T.G., and Valentine H.T., 2005. Edge effects in line intersect sampling with segmented transects. J. Agr. Biol. Env. Stat. 10: 460–477.

Ahti, T., Hämet-Ahti, L., & Jalas, J. (1968). Vegetation zones and their sections in northwestern Europe. *Annales botanici fennici*, 5 (3), 169–211

Angelstam, P & Pettersson, B. (1997). Principles of Present Swedish Forest Biodiversity Management. *Ecological bulletins*, (46), 191–203

Armstrong, R.A. (2014). When to use the Bonferroni correction. *Ophthalmic & physiological optics*, 34 (5), 502–508. https://doi.org/10.1111/opo.12131

Bergman, P. (2021). *Naturvärdesbedömning Mellersta Sverige*. Stockholm: Sveaskog AB

Boehl, J. & Braendli, U.-B. (2007). Deadwood volume assessment in the third Swiss National Forest Inventory: Methods and first results. *European journal of forest research*, 126 (3), 449–457. https://doi.org/10.1007/s10342-007-0169-3

Brandel, G. 1990. Volymfunktioner för enskilda träd. Tall, gran och björk. SLU, Inst f skogsproduktion, Rapport 26, 72 s., Garpenberg.

de Vries, P.G. 1986. *Sampling theory for forest inventory.* A teach-yourself course. Berlin Heidelberg: Springer-Verlag.

Drakenberg, B & Lindhe, A. Naturvärdesbedömning av skogsmark. Saltsjö-boo: Skogsbiologerna AB (2015).

Ekblad, E. (2015). *Förutsättningar för naturhänsyn i bestånd med contortatall (Pinus contorta)*. Umeå: Sveriges lantbruksuniversitet.

FSC. (2020). *The FSC National Forest Stewardship Standard of Sweden*. Bonn: FSC International Center.

Fridman, J. & Walheim, M. (2000). Amount, structure, and dynamics of dead wood on managed forestland in Sweden. *Forest ecology and management*, 131 (1), 23–36. https://doi.org/10.1016/S0378-1127(99)00208-X

Gao, T., Nielsen, A.B. & Hedblom, M. (2015). Reviewing the strength of evidence of biodiversity indicators for forest ecosystems in Europe. *Ecological indicators*, 57, 420–434. https://doi.org/10.1016/j.ecolind.2015.05.028

Gibb, H., Hjältén, J., P. Ball, J., Atlegrim, O., Pettersson, R.B., Hilszczański, J., Johansson, T. & Danell, K. (2006). Effects of landscape composition and substrate availability on saproxylic beetles in boreal forests: a study using experimental logs for monitoring assemblages. *Ecography (Copenhagen)*, 29 (2), 191–204. https://doi.org/10.1111/j.2006.0906-7590.04372.x

Gärdenfors, U. (2010). *Rödlistade arter i Sverige 2010 = The 2010 red list of Swedish species*. Uppsala: Artdatabanken i samarbete med Naturvårdsverket.

Hjältén, J., Johansson, T., Alinvi, O., Danell, K., Ball, J.., Pettersson, R., Gibb, H. & Hilszczański, J. (2007). The importance of substrate type, shading and scorching for the attractiveness of dead wood to saproxylic beetles. *Basic and applied ecology*, 8 (4), 364–376. https://doi.org/10.1016/j.baae.2006.08.003

Hjältén, J., Stenbacka, F., Pettersson, R.B., Gibb, H., Johansson, T., Danell, K., Ball, J.P. & Hilszczański, J. (2012). Micro and macro-habitat associations in saproxylic beetles: Implications for biodiversity management. *PloS one*, 7 (7), e41100–e41100. https://doi.org/10.1371/journal.pone.0041100

Hottola, J. & Siitonen, J. (2008). Significance of woodland key habitats for polypore diversity and red-listed species in boreal forests. *Biodiversity and conservation*, 17 (11), 2559–2577. https://doi.org/10.1007/s10531-008-9317-4

Johansson, T., Hjältén, J., Gibb, H., Hilszczanski, J., Stenlid, J., Ball, J.P., Alinvi, O. & Danell, K. (2007). Variable response of different functional groups of saproxylic beetles to substrate manipulation and forest management: Implications for conservation strategies. *Forest ecology and management*, 242 (2), 496–510. https://doi.org/10.1016/j.foreco.2007.01.062

Johansson, J. (2013). Constructing and contesting the legitimacy of private forest governance : The case of forest certification in Sweden (PhD dissertation, Statsvetenskapliga institutionen, Umeå universitetet). http://urn.kb.se/resolve?urn=urn:nbn:se:umu:diva-63948

Jonsell, M. & Weslien, J. (2003). Felled or standing retained wood—it makes a difference for saproxylic beetles. *Forest ecology and management*, 175 (1), 425–435. https://doi.org/10.1016/S0378-1127(02)00143-3

Jonsell, M., Schroeder, M. & Weslien, J. (2005). Saproxylic beetles in high stumps of spruce: Fungal flora important for determining the species composition. *Scandinavian journal of forest research*, 20 (1), 54–62. https://doi.org/10.1080/02827580510008211

Jost, L. (2006). Entropy and diversity. *Oikos*, 113 (2), 363–375. https://doi.org/10.1111/j.2006.0030-1299.14714.x

Kunttu, P., Junninen, K. & Kouki, J. (2015). Dead wood as an indicator of forest naturalness: A comparison of methods. *Forest ecology and management*, 353, 30–40. https://doi.org/10.1016/j.foreco.2015.05.017

Lassauce, A., Paillet, Y., Jactel, H. & Bouget, C. (2011). Deadwood as a surrogate for forest biodiversity: Meta-analysis of correlations between deadwood volume and species richness of saproxylic organisms. *Ecological indicators*, 11 (5), 1027–1039. https://doi.org/10.1016/j.ecolind.2011.02.004

Lindahl, K.B., Sténs, A., Sandström, C., Johansson, J., Lidskog, R., Ranius, T. & Roberge, J.-M. (2017). The Swedish forestry model: More of everything? *Forest policy and economics*, 77, 44–55. https://doi.org/10.1016/j.forpol.2015.10.012

Lindenmayer, D.., Franklin, J.. & Fischer, J. (2006). General management principles and a checklist of strategies to guide forest biodiversity conservation. *Biological conservation*, 131 (3), 433–445. https://doi.org/10.1016/j.biocon.2006.02.019

Lindhe, A., Åsenblad, N. & Toresson, H.-G. (2004). Cut logs and high stumps of spruce, birch, aspen and oak – nine years of saproxylic fungi succession. *Biological conservation*, 119 (4), 443–454. https://doi.org/10.1016/j.biocon.2004.01.005

Lindhe, A., Lindelöw, Å. & Åsenblad, N. (2005). Saproxylic beetles in standing dead wood density in relation to substrate sun-exposure and diameter. *Biodiversity and conservation*, 14 (12), 3033–3053. https://doi.org/10.1007/s10531-004-0314-y

Nilsson, P., Roberge, C. & Fridman, J. (2020). *Skogsdata : aktuella uppgifter om de svenska skogarna från SLU Riksskogstaxeringen 2020 Tema: Den döda veden*. Umeå: Institutionen för skoglig resurshushållning, Sveriges lantbruksuniversitet.

Ollas, R. 1980. Nya utbytesfunktioner för träd och bestånd. Forskningsstiftelsen Skogsarbeten, Ekonomi nr 5

PEFC. (2017). *PEFC Sweden Forest Standard*. https://cdn.pefc.org/pefc.se/media/2021-02/49cc8975-4e4e-4f6e-9c95-37f4829f869f/2c1bd611-0b7f-5c7a-b76d-137e70cfdf42.pdf [2022-04-06]

R Core Team (2021). R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org

Rondeux, J. & Sanchez, C. (2009). Review of indicators and field methods for monitoring biodiversity within national forest inventories. Core variable: Deadwood. *Environmental monitoring and assessment*, 164 (1-4), 617–630. https://doi.org/10.1007/s10661-009-0917-6

Rudolphi, J. & Gustafsson, L. (2011). Forests regenerating after clear-cutting function as habitat for bryophyte and lichen species of conservation concern. *PloS one*, 6 (4), e18639–e18639. https://doi.org/10.1371/journal.pone.0018639

Schroeder, L.., Weslien, J., Lindelöw, Å. & Lindhe, A. (1999). Attacks by bark- and wood-boring Coleoptera on mechanically created high stumps of Norway spruce in the two years following cutting. *Forest ecology and management*, 123 (1), 21–30. https://doi.org/10.1016/S0378-1127(99)00013-4

Sedgwick, P. (2012). Pearson's correlation coefficient. *BMJ (Online)*, 345 (jul04 1), a1837–e4483. https://doi.org/10.1136/bmj.e4483

SOU (2020). Stärkt äganderätt, flexibla skyddsformer och naturvård i skogen. (Betänkande av Skogsutredningen 2019, del 2.). Stockholm: Statens Offentliga Utredningar.

Siitonen, J. (2001). Forest Management, Coarse Woody Debris and Saproxylic Organisms: Fennoscandian Boreal Forests as an Example. *Ecological bulletins*, (49), 11–41

Simonsson, P., Gustafsson, L. & Östlund, L. (2015). Retention forestry in Sweden: driving forces, debate and implementation 1968-2003. *Scandinavian journal of forest research*, 30 (2), 154–173. https://doi.org/10.1080/02827581.2014.968201

Skogsstyrelsen (2020). Handbok – Nyckelbiotopsinventering. Jönköping: Skogsstyrelsen

Skogsstyrelsen (2004). *Vedlevande arters krav på substrat - sammanställning och analys av 3 600 arter*. (Rapport 7:2004). Jönköping: Skogsstyrelsen. http://shop.skogsstyrelsen.se/shop/9098/art85/4646085-51e2f5-1733.pdf

SLU (2021). Riksinventeringen av skog: Fälthandbok 2021. Umeå: SLU. https://www.slu.se/globalassets/ew/org/centrb/rt/dokument/faltinst/21_ris_fin.pdf [2022-04-08]

Stenbacka, F., Hjältén, J., Hilszcza ski, J. & Dynesius, M. (2010). Saproxylic and non-saproxylic beetle assemblages in boreal spruce forests of different age and forestry intensity. *Ecological applications*, 20 (8), 2310–2321. https://doi.org/10.1890/09-0815.1

Stokland, J.N., Siitonen, J. & Jonsson, B.G. (2012). *Biodiversity in dead wood*. Cambridge: Cambridge University Press.

Teissier du Cros, R. & Lopez, S. (2009). Preliminary study on the assessment of deadwood volume by the French national forest inventory. *Annals of forest science (Print)*, 66 (3), 302–302. https://doi.org/10.1051/forest/2009007

Wester, J. & Engström, A. (2016). Nulägesbeskrivning av nyckelbiotoper. (7). Jönköping: Skogsstyrelsen

Wickham H, François R, Henry L, Müller K (2022). *dplyr: A Grammar of Data Manipulation*. https://dplyr.tidyverse.org, https://github.com/tidyverse/dplyr [2022-04-11]

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. https://ggplot2.tidyverse.org/ [2022-04-11]

Wikars, L.-O. (2002). Dependence on fire in wood-living insects: An experiment with burned and unburned spruce and birch logs. *Journal of insect conservation*, 6 (1), 1–12. https://doi.org/10.1023/A:1015734630309

Woldendorp, G., Keenan, R.., Barry, S. & Spencer, R.. (2004). Analysis of sampling methods for coarse woody debris. *Forest ecology and management*, 198 (1), 133–148. https://doi.org/10.1016/j.foreco.2004.03.042

Östlund, L., Zackrisson, O. & Axelsson, A.-L. (1997). The history and transformation of a Scandinavian boreal forest landscape since the 19th century. *Canadian journal of forest research*, 27 (8), 1198–1206. https://doi.org/10.1139/x97-070

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Appendix 1

Field instructions

Post a screenshot with coordinates from the SOS-alarm mobile app to the emergency contact upon arrival to the location.

Relascope method
Locate the centre coordinate of the randomly chosen grid intersect.
Start the timer.
Relascope all downed and standing dead wood and notice the result in the following protocol.
Estimate the degree of degradation for each tree counted with the relascope on the scale of the knife method (see separate description of the *Knife method*).
Stop the timer when the whole plot has been surveyed.
Note the expenditure of time.

Triangle-transect method
Centre a triangle in the sample plot. Leave 1.5 meter unmeasured at the beginning and end of each transect. The total length of the transect should be 20m.
Measure the diameter of every downed log along the transect. Use the fishing rod to locate standing dead wood along the transect. Measure diameter and height, estimate the shape.
Measure the degree of degradation (see separate description of the *Knife method*).
Notice the result in the following protocol.
Stop the timer when the whole triangle-transect has been surveyed.
Note the expenditure of time.

Sample plot method
Relocate the centre coordinate of the sample plot.
Start the timer.
Measure the length and diameter of the top and root side of the dead wood that has been growing on the plot. If the germination point is placed outside the sample plot, the log is not counted. The radius of the plot should be 25m.

Measure height and diameter at breast height and estimate the shape of all standing dead wood.
Measure the degree of degradation (see separate description of the *Knife method*)
Notice the result in the following protocol.
Stop the timer when the whole plot has been surveyed.
Note the expenditure of time.

The *Knife method*
The test is performed by pressing a knife into the log and classifying the density according to the penetration depth.

Decay class:
1 – Recently dead tree wood still hard, knife blade penetrates a few millimeters into the wood.
2 – Weakly decayed wood of outer layers of stem has started to soften, wood still fairly hard, knife blade penetrates 1-2 cm into the wood.
3 – Medium decayed wood of outer layers of stem fairly soft, core still hard, knife blade penetrates 2-5 cm into the wood.
4 – Very decayed wood soft throughout the log, no hard core, knife blade penetrates all the way through the wood.

Appendix 2

Stand number:	10	Retention										
Centre cordinate:	N.6833026	E.0581712		(fid 3803 moved)								
Date:	2021-10-16											
Relascope method												
GY	1	1										
Degradation class	1	3										
Time used (minutes)	0.85	(51seconds)										
Sample plot method												
Downed dead wood	Spruce	Spruce	Birch	Spruce	Spruce	Spruce	Spruce	Spruce	Spruce	Birch	Spruce	Spruce
Dbh (cm)				27.4								
Length (m)	7.3	9.3	8.78	24.9	2.7	19.9	15.7	21.45	17.55	5.1	4.6	6.8
Top diameter (cm)	7.73	0.9	11.8	0.9	5.1	2.6	7.8	1.7	7.8	9.7	14.1	20
Root diameter (cm)	14.3	11.6	18.7	29.5	11.1	27.3	23.8	26.7	33.8	16.9	16.8	30.7
Degradation class	3	1	1	2	3	2	3	2	3	4	4	3
Standing dead wood	Pine	Pine	Spruce									
Height (m)	17.3	28.9	5.6									
Dbh (cm)	20.4	24.8	42.1									
Shape	Whole	Whole	Broken									
Degradation class	1	1	1									
Time used (minutes)	36.38	(36minutes,23seconds)										
Triangle-transect method												
Downed dead wood	Spruce	Spruce	Birch									
Diameter (cm)	8.5	6.8	3.9									
Degradation class	2	3	1									
Standing dead wood												
Diameter (cm)												
Estimated height (m)												
Shape												
Degradation class												
Time used (minutes)	8.2	(8minutes,12seconds)										

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