Dead wood basic density, and the concentration of carbon and nitrogen for main tree species in managed hemiboreal forests

Kajar Köster\textsuperscript{a,b,*}, Marek Metslaid\textsuperscript{a}, Jeroen Engelhart\textsuperscript{a}, Egle Köster\textsuperscript{b}

\textsuperscript{a}Institute of Forestry and Rural Engineering, Estonian University of Life Sciences, Estonia
\textsuperscript{b}Department of Forest Sciences, University of Helsinki, Finland

\section*{Abstract}
Forest ecosystems are an important carbon (C) pool, and the decomposition of dead wood plays a key role in its C cycle. Based on the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, IPCC Guidelines for National Greenhouse Gas Inventories were established. Nations that have signed the agreements are encouraged to quantify C pools and fluxes in their forests, including its proportion occurring as dead wood. There are significant differences in density and C concentration of dead wood among tree species. In managed hemiboreal forests of Estonia the dead wood density, and C and N concentration changes in different decay classes for Scots pine (\textit{Pinus sylvestris} L.), Norway spruce (\textit{Picea abies} (L.) Karst.), silver and downy birch (\textit{Betula pendula} Roth. and \textit{Betula pubescens} Ehrh.), black alder (\textit{Alnus glutinosa} (L.) Gaertn.), grey alder (\textit{Alnus incana} (L.) Moench.) and European aspen (\textit{Populus tremula} L.) have been assessed. All together 548 sample discs taken from logs (measurements were restricted to fallen dead trees only) were collected. The results revealed a decrease in mean dead wood density with progressing decay state for all studied tree species. Pine, spruce and grey alder had the smallest wood density reduction with progressing decay state, retaining 37%, 30%, and 36% of initial density, respectively. Other broadleaved tree species (birch, black alder and aspen) had the greatest density reduction during decomposition, retaining 24%, 23%, and 16% of initial density, respectively. For all studied tree species there were no significant differences of wood density between sites with different moisture conditions (dry, medium or wet areas). In case of pine, spruce and birch the C concentrations were significantly affected by the decay class, while in case of both alders and aspen the C concentrations were not significantly affected by changes in decay classes. For all the assessed tree species the N concentration in dead wood was increasing with increasing decay class.

\section*{1. Introduction}
Dead wood is an important component of forests, influencing ecosystem processes and sustaining biodiversity (Samuelsson et al., 1994; Siltotien, 2001; Karjalainen and Kuuluvainen, 2002). Coarse woody debris (CWD), like fallen logs and branches in different stages of decomposition provide a wide range of habitats for saprotrophic and heterotrophic organisms, as well as a seed bed for tree establishment (Harmon et al., 1986; Kuuluvainen and Juntunen, 1998). The amount of dead wood biomass is continuously changing in forest ecosystems. These changes depend on the productivity of forest ecosystems, mortality caused by successional processes and disturbances (Köster et al., 2009a), and the decomposition rate (Köster et al., 2009b).

Decomposition of dead wood affects carbon (C) and nutrient retention and causes the subsequent release of carbon dioxide (CO\textsubscript{2}) (Berg et al., 1994; Janisch and Harmon, 2002; Yatskov et al., 2003). Therefore, the presence and decomposition processes of dead wood in forest ecosystems also plays an important part in worldwide greenhouse-gas-related climate change research activities. By the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, international agreements adopted in 1992 and 1997, respectively, parties are encouraged to reduce the greenhouse gas (GHG) emissions into the atmosphere. Activities brought forth in the Land Use, Land-Use Change and Forestry (LULUCF) sector provide some possible ways to reduce emissions. Reforestation, afforestation and/or managing forests can increase GHG removals from the atmosphere. Controlling of deforestation should reduce emissions. Forest
ecosystems are an important C pool, retaining approximately 80% of all terrestrial aboveground C and 40–47% of soil organic C (Jobbágy and Jackson, 2000; Wei et al., 2014). Based on the IPCC Guidelines for National Greenhouse Gas Inventories, nations and their forest managements are obliged to quantify C pools and fluxes in their forests, including also the proportion of the dead wood (IPCC, 2006).

After decomposition and humification, the organic C contained in CWD becomes an essential component of forest soils (Kahl et al., 2012), and it plays a key role in the forest C cycle (Laio and Prescott, 1999; Janisch and Harmon, 2002). As such, it acts as a temporary storage pool for C, and represents by decomposition and burial a long-term input source of organic matter and nutrients to the soil (Harmon et al., 1986; Goodale et al., 2002; Moroni et al., 2015). Differences in the sequestration of C through growth of living trees (input) and the rate of loss through dead wood decomposition (output), determine if forests are a net C source or sink – also referred as net ecosystem productivity (NEP) (Janisch and Harmon, 2002).

The key factors which influence wood decomposition are: (1) substrate quality and dimensions (Harmon et al., 1986; Didion et al., 2014), and (2) environment; including temperature, moisture and aeration (Laio and Prescott, 1999). The relative importance of these factors varies significantly between geographic regions, and also depends on forest/stand composition, structure and substrate attributes (Harmon et al., 1986; Storaunet and Rolstad, 2002; Shorohova and Kapitsa, 2014). There is large variation in total forest ecosystem C in living and dead wood biomass between regions. Ecosystem productivity and the rate of decomposition is positively correlated with mean annual temperatures (Yatskov et al., 2003; Perry et al., 2008; Shorohova and Kapitsa, 2014). Furthermore, there are significant differences in density and C concentration of CWD among tree species (Harmon et al., 2013). However, differences can also be expected along the moisture gradient from dry to wet forest site-types (Shorohova and Kapitsa, 2014). Different studies have shown that with increasing decomposition stage there is a significant decrease in wood density (kg m⁻³) (Di Cosmo et al., 2013). At the same time, the slight increase in C concentration (Sandström et al., 2007; Di Cosmo et al., 2013), and quite rapid increase in N concentration can be detected with increasing decomposition level of CWD (Palviainen et al., 2008).

Currently estimates of dead wood volumes in forests are becoming more and more often available in National Forest Inventory (NFI) databases. This is also the case with the Estonian NFI database. In order to assess the dead wood contribution to the total forest C pool it is needed to convert dead wood volumes into biomass by using basic density values. While the NFI data-base does not provide usualy information about basic densities, values available in literature are used. In general, the use of these basic density values are considered as a rather good practical solution, however, only to provide initial approximate values, because of the potential risk of errors (Harmon and Sexton, 1996). Therefore, country specific basic density values for the main tree species and decay classes are desired.

There are actually some studies dealing with wood decomposition processes and changes of the wood density during decomposition in boreal forests (Krankina and Harmon, 1995; Mäkinen et al., 2006; Sandström et al., 2007). However, to our knowledge there are no studies dealing with these issues, combined with changes in wood C content through decomposition, in the hemiboreal regions, where tree species found in both boreal and temperate forests occur and grow in mixtures.

The objective of this study was to assess the CWD density, and C and N concentration changes per decay class for Scots pine (Pinus sylvestris L.), Norway spruce (Picea abies (L.) Karst.), silver and downy birch (Betula pendula Roth. and Betula pubescens Ehrh.), black alder (Alnus glutinosa (L.) Gaertn.), grey alder (Alnus incana (L.) Moench.) and European aspen (Populus tremula L.) in managed hemiboreal forests. The dead wood density and C concentration were provided only for logs lying on the ground. Additionally, in an attempt to include the effects of factors that influence the decomposition of CWD, the site moisture condition effect (dry, medium or wet areas) on the density and C content changes in different decay classes has been assessed.

2. Material and methods

2.1. Study areas

For this study dead wood samples have been collected all over the mainland of Estonia (islands were not included) (Fig. 1). Estonia’s hemiboreal forest zone has a moderately cool and moist climate (Ahti et al., 1968), and 51% of its land area is covered with forests. Mean annual temperature is 5 °C. Annual precipitation is 500–700 mm; about 40–80 mm of this total is snow.

Most of the forests of the area belong to a gradient from oligotrophic to meso-eutrophic and eutrophic forest site-types, with varying average water levels (Löhmus et al., 2004). Therefore an overall mixed coniferous–deciduous tree species composition is prevalent. The main tree species in Estonian managed forests are Scots pine, Norway spruce, silver and downy birch, black alder, grey alder and European aspen. Among others, also small-leaved linden (Tilia cordata Mill.), Norway maple (Acer platanoides L.), pedunculate oak (Quercus robur L.), European ash (Fraxinus excelsior L.), Scots elm (Ulmus glabra Huds.) and European white elm (Ulmus laevis Pall.) can occur.

2.2. Field works

Study sites were located in managed forest land, and were divided into three moisture categories (dry, medium, and wet areas) determined by site type classification (Löhmus, 2004) and soil moisture level. Prior to fieldwork, the potential sample areas were selected from an accessible online database “Forest register” based on main tree species and forest site type. The forest site types used in this study were: Rhododococcus (dry areas); Aegopodium, Oxalis, Oxalis-Myrtillus and Myrtillus (medium areas); Alder (eutrophic) fen, Transitional (mesotrophic) bog and Alder-birch (eutrophic–mesotrophic) swamp (wet areas) (Löhmus, 2004). In the field the actual soil moisture category of each micro-site was checked both visually (the presence of stagnant water or overall dryness of the area, occurring vegetation, etc.), and by measuring the soil moisture content with a soil moisture sensor (Trime-Pico 64, IMKO GmbH, Germany) on both sides of each sample taken. Based on the visual observation and the soil moisture content measurements on the visited locations the sample logs were reclassified into the correct moisture category class.

The following main tree species were included into this study: Scots pine, Norway spruce, birch (silver and/or downy birch), European aspen, black and grey alder. Because silver and downy birch (dead) wood is difficult to distinguish, both birch species were considered as one in further assessment. CWD measurements were restricted to fallen dead trees (logs) lying on the ground with a minimum end diameter of 9 cm and length of the stem more than 1.3 m. Since our assessment focused on tree stems some of the early decay stage logs (e.g. recently windthrown) had root systems still attached to the stems. The selected CWD pieces were divided into decay classes using a five-step wood decay classification (Table 1). The five-class decay classification was based on visual observation (e.g. the presence of leaves/needles, branches, bark...
and persistence) and the ‘knife method’ (modified from Stokland, 2001; Mäkinen et al., 2006), and provided good opportunity to compare our results with findings of other studies.

For each selected log measurements included log dimensions, including length, base and top diameters, and current diameter at 1.3 m from the beginning of the log. From each log three discs (3–5 cm thick) were cut with a chainsaw for further analysis of wood density, C and nitrogen (N) concentration. The first disc was removed at a distance of 1.3 m from the beginning of the log, the third close to the tree top (disc diameter at least 9 cm). The second disc was removed at the centre of the log. If the sample log was shorter than 4 m, which occurred with some material in higher decay classes, only two discs were cut. From each disc the bark was removed from the wood and the outermost diameter in two perpendicular directions and longitudinal thickness (by a sliding calliper) at four to eight points on each disc (with precision of 0.01 cm) were measured. Also the circumference of each disc was measured and all discs were photographed. All wet sample masses were measured in field on a portable electronic scale to the nearest 0.1 g. Discs were transported to the lab on the same day.

Altogether 548 discs from 198 logs were used in analyses (Table 2). The number of discs collected was distributed as equally

---

**Table 1**

Decay classification for dead wood (modified from Stokland (2001) and Mäkinen et al. (2006)).

<table>
<thead>
<tr>
<th>Decay class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Recently dead</td>
<td>Wood hard, fresh or nearly fresh. Bark attached to the stem. Branches present. Rests in part on the ground. The knife penetrates only a few millimeters</td>
</tr>
<tr>
<td>2. Weakly decayed</td>
<td>Wood of outer layer starts to soften. Bark is loose but not fragmented (in case of pine and spruce). Fungus mycelium under bark well developed. Branches present. The knife penetrates for several (1–2) centimetres</td>
</tr>
<tr>
<td>3. Medium decayed</td>
<td>Wood of outer layers of stem soft, core still hard. Pine and spruce without bark. In case of birch, black alder and grey alder bark attached to the stem. The knife easily penetrates to the wood several centimeters (up to 5 cm)</td>
</tr>
<tr>
<td>4. Very decayed</td>
<td>Wood soft through the log. No branches. Most of the wood surface covered with mosses, lichens, and/or other plants. Wood absolutely a part of the land and timber elements lost due to fragmentation. Knife easily penetrates the wood in its entirety</td>
</tr>
<tr>
<td>5. Almost decomposed</td>
<td>Wood soft, fragmented (wood consistency lost). Surface covered with lichens, mosses and dwarf shrubs. Wood brakes up easily even by hand</td>
</tr>
</tbody>
</table>

---

Fig. 1. Location of the sample areas in managed hemiboreal forests in Estonia. Shaded area on the upper graph represents the hemiboreal zone and location of Estonia (dark shading) according to Ahti et al. (1968).
as possible over the site moisture classes. As aspen, black and grey alder were absent in try areas, disc for these species were collected only from medium and wet moisture category sites.

2.3. Laboratory measurements

The volume of each disc was estimated by multiplying the cross section area by the average disc thickness. Cross section areas for discs were calculated from taken photographs using the computer program ImageJ (Abrâmoff et al., 2004). The values provided by ImageJ were controlled with area calculations based on diameter and circumference measurements.

Dry masses of samples were determined in the laboratory after oven drying the samples for 48 h (at 80 °C) to a constant mass (precision 0.01 g). The basic density (d, in g cm⁻³) was estimated as:

\[
d = \frac{m_0}{V}
\]

where \(m_0\) is the dry mass of the sample (g) and \(V\) is the fresh volume (cm³) of the sample.

To analyse the C and N concentrations in CWD we grinded wooden material from half of the collected discs (all together 274 sample discs, keeping in mind that if one disc was chosen also other two discs from the same log were analysed). For discs belonging to the first three decay classes grading was done using a 14 mm drill bit. On each disc two crossing transects were projected and grinded wooden material was taken from nine points on these transects (one from the middle and others evenly distributed over the two transects). Discs that belonged to the fourth and fifth decay class were completely grinded and mixed subsamples for C and N analyses were taken. The C and N concentration analyses in CWD were done with an elemental analyser (varioMAX CN elemental analyser, Elementar Analysensysteme GmbH, Germany). The concentration is expressed as% of C and N weight (microgram) compared to total weight of each sample.

Due to the overall absence of aspen, black and grey alder in dry areas, density values, C and N concentration for these species in different decay stages were only calculated for medium and wet moisture categories.

2.4. Statistical analyses

Statistical tests were performed with SAS version 9.3 software (SAS Institute Inc., Cary, NC, USA). The sample distribution was checked for normality with the Shapiro–Wilk test and wood density values and wood N concentrations were transformed with the binary logarithm (log₂ n) to approximate the residual distribution of the variable to the normal distribution.

To test the hypothesis behind CWD density and wood C and N concentration and how different factors are affecting their variation a mixed models (PROC MIXED) was used. This procedure realizes general linear mixed variance analysis, which in the present case helps to test whether and how, the tree species, decay stage, forest site type, site moisture category and taken disc position along the trunk determine the CWD density and/or wood C and N concentration. In the model the CWD density and wood C and N concentrations were treated as dependent variables, while tree species, decay stage, forest site type, site moisture category and disc position as random factors. A Tukey’s HSD test was used for comparison of means. All calculations and statistical analyses used the plot as the experimental unit and a significance level of \(P < 0.05\).
3. Results

The results reveal a decrease in mean CWD density from decay class 1–5 for all studied tree species (Fig. 2, Table 2). Birch and alder species had higher wood density at the beginning of the decomposition processes, when compared to pine and aspen (Fig. 2, Table 2). For all species, except spruce, the wood densities in decay class 1 and 2 were significantly different when compared to classes 3–5. In case of spruce, the wood densities in decay classes 1–3 were significantly different from classes 4 and 5 (Table 2). Only for pine the decay class was significantly related to the wood density changes over all 5 classes ($P < 0.001$). If we look at the of wood density per species throughout decay, coniferous species (pine and spruce) and grey alder have the lowest loss of density from decay classes 1–5, with 63%, 70%, and 74%, respectively. The broadleaved species (birch, black alder and aspen) have the strongest loss of wood density during decomposition, with 76%, 77%, and 84%, respectively.

For all tree species there were no significant differences of wood density between different moisture categories (dry, medium or wet areas); pine ($P = 0.741$), spruce ($P = 0.056$), birch ($P = 0.381$), aspen ($P = 0.798$), black alder ($P = 0.353$) and grey alder ($P = 0.845$), respectively. Only for spruce there was a trend that the wood from dry and wet areas showed lower values when compared to the material from medium moisture level areas (Fig. 2); however the differences were statistically not significant. At the same time the sampling position along the log significantly affects the wood density of pine ($P = 0.018$), spruce ($P = 0.041$), birch ($P = 0.029$) and aspen ($P = 0.023$). Wood density for all these tree species was higher on the lower (thicker) part of the log and started to decrease towards to the direction of the tree top (thinner side of the log). In case of black and grey alder the disc position had no significant effect on the wood density.

In case of pine, spruce and birch the C concentrations were significantly affected by the decay class; pine ($P = 0.048$), spruce ($P = 0.008$), birch ($P = 0.019$). In case of both alders and aspen the

---

**Fig. 2.** Dead wood densities (kg m$^{-3}$) in five decay classes from different moisture classes (dry, medium, wet) for pine (*Pinus sylvestris* L.), spruce (*Picea abies* (L.) H. Karst), birch (*Betula pendula* Roth and *Betula pubescens* Ehrh), aspen (*Populus tremula* L.), black alder (*Alnus glutinosa* (L.) Gaertn.) and grey alder (*Alnus incana* (L.) Moench.). Error bars show standard errors of average wood density (samples from all moisture categories together).
C concentrations were not significantly affected by changes in decay classes. The measured wood C concentrations over the different decay classes where in the range of 47–51% (Table 2). CWD of birch and both coniferous species, pine and spruce, showed a slight increase in C concentration with further decomposition (Table 2). The C concentration in CWD of both alder species showed no changes throughout the whole decomposition process (Table 2). The C concentration of aspen CWD was similar in decay classes 1–3, but started to decrease in decay classes 4 and 5, although the decrease was not statistically significant. For all examined tree species there were no significant differences of wood C concentrations between the different moisture categories.

For all examined tree species the N concentration in CWD was positively correlated with increasing decay class; pine ($P < 0.001$), spruce ($P = 0.003$), birch ($P < 0.001$), aspen ($P < 0.001$), black alder ($P < 0.001$) and grey alder ($P < 0.001$). All the tree species showed a stable increase in N concentration in the first 3 or 4 decay classes, where after there was rapid increase in N concentrations in the last decay classes (Table 2). The lowest N concentrations were detected in coniferous trees and first decay classes of aspen. The highest N concentrations were detected in CWD of black alder (Table 2).

4. Discussion

Estimates of the relative contribution of dead wood to the total forest C pool are based on the conversion of dead wood volumes into biomass by using basic density values. In case of Estonia, dead wood volumes of forests are available in a NFI database, but it does not provide information about dead wood basic densities. Our study sites were located all over the mainland of Estonia and lying dead wood samples were collected from managed forests. One can argue that there may be differences in wood densities of some tree species (e.g. Norway spruce) between managed and non-managed forests as reported by Sandström et al. (2007), but in general they did not find differences in wood density between managed and unmanaged forests.

Our results show a clear decrease in basic wood density during the decomposition process for all studied tree species. Although some species, like birch, black and grey alder, have higher basic wood density at the beginning of decomposition process compared to spruce, pine and aspen – all species become more similar in mean densities as decay class increases. This corresponds with results found in other studies from different regions of the boreal forests (Yatskov et al., 2003; Mákinen et al., 2006; Sandström et al., 2007; Köster et al., 2009b; Seedre et al., 2013). In Yatskov et al. (2003) the mean basic densities for spruce in Russian boreal forests decreased from 358 to 108 kg m$^{-3}$ (decay classes 1–5), while the corresponding basic density values for spruce in this study were higher in all decay classes (Table 2). These differences may be explained by the fact that in Yatskov et al. (2003) ’spruce’ consists out of several species (P. abies (L.) Karst., Picea obovata Ledeb., Picea ajanensis Fisch.). However, when comparing basic density values for spruce in this study, with findings from dead wood in boreal forests in Finland and Sweden (Mákinen et al., 2006; Sandström et al., 2007), also higher values in the hemiboreal forests of Estonia can be observed. This finding is somewhat surprising, as one might expect that in Estonia trees have a faster growth due to climatic conditions, and this in turn should result in lower wood density values in hemiboreal forests when compared to boreal forests (Yatskov et al., 2003; Perry et al., 2008; Shorohova and Kapitsa, 2014). For example, the fresh wood density values from Italy to Finland are found to increase with decreasing ecosystem productivity along the gradient from temperate to boreal forests (Sandak et al., 2015). But in Estonian managed forest one reason for higher density values may be also the management history. Estonian forests are not so heavily managed as Scandinavian forests, especially at the beginning of succession. In earlier times the pre-commercial thinning’s were not practiced and this resulted in more dense and mixed forests. As in such conditions the competition between the trees is high, they are growing more to the height, and diameter growth is smaller. This may result also the higher wood density values in our study compared to other studies.

When comparing the basic density values of all other species used in our study (Table 2) with the findings from other studies, no clear differences could be found. For both birch species, Yatskov et al. (2003), Mákinen et al. (2006) and Sandström et al. (2007) have found variable values, either slightly lower or higher compared to our results. The samples from birch wood in our study could consist both silver and downy birch, as in later decay classes it is almost impossible to separate these two species. We hope that this was not affecting our results much, as Repola (2006) has found earlier that there was no difference between the wood densities of silver and downy birch. In case of Scots pine the wood density values obtained in this study are similar to the findings by Yatskov et al. (2003). However, when comparing our results with findings from Finland and Sweden (Mákinen et al., 2006; Sandström et al., 2007, respectively), similar tendency as with spruce was noticed: the comparable values for Estonia were higher in all decay classes. Due to the lack of references, it was not possible to compare wood density changes within five decay classes for grey and black alder.

In Estonia, NFI database does not provide information about wood density values for different tree species and in calculations values available from neighbouring countries have been used. In case of coniferous species, the density values for different decay classes has previously been slightly underestimated. The wood density of a log is affected by a large number of factors such as tree species, geographical location and other environmental factors like site quality, tree age and size, growth rate and genetic factors, etc. (Harmon et al., 1986; Repola, 2006), but also the position from where on log the sample was taken is affecting the wood density (Repola, 2006). It has been found that the wood density of most coniferous and some of the broadleaved trees decreases from stem base to the top (Repola, 2006; Sandström et al., 2007; Köster et al., 2009b). In our study all the tree species, except both alder species, had the wood density values higher on the lower part of the log, and the wood density was decreasing towards to the direction of the tree top.

The C concentration in CWD increased only for pine, spruce and birch during the decomposition process. Such increase in dead wood C concentration through different decay classes of pine and spruce is also found by Sandström et al. (2007). Furthermore, the average C concentration for pine and spruce found by Sandström et al. (2007) ranged from 50.32% to 52.23% and 49.22% to 51.27%, respectively, which corresponds well with the average dead wood C concentration of pine and spruce found in this study (Table 2). Other broadleaved tree species (black alder, grey alder and aspen) showed more or less stable dead wood C concentrations through the entire decomposition process. Possibly the variation in wood properties between coniferous and broadleaved tree species cause these differences in dead wood C concentration during the decomposition process (Harmon et al., 2013).

Differences in wood properties may also be related to the variation in wood density between species due to decomposition processes. Ideally the loss of density of decayed wood should be compared to fresh wood densities of living trees in the same sampling areas. Since fresh wood samples were not analyzed in this study, only a comparison between decay classes 1 to 5 was made. The reduction of density from fresh wood to decay class 1 is expected to be relatively small when compared to further decomposition stages. Harmon et al. (2013) found such reduction of 19
tree species occurring in boreal Northern America and Russia, ranging from 1% to 7%. Estonian fresh wood density values found in literature match only partly with results of decay class 1. For example, the fresh wood density for pine has been found to be 471.1 (±39.3) kg m\(^{-3}\) (Kask and Pikk, 2009). Much higher fresh wood values compared to our decay class one were also available for spruce (515 (±16) kg m\(^{-3}\)) (Sandak et al., 2015) birch (650 kg m\(^{-3}\)) (Utri et al., 2012), and grey alder (415 (±16) kg m\(^{-3}\)) (Aosaar et al., 2011). The encountered variety in values between studies could be explained by the moisture regimes and study design. In our study samples from three different moisture categories (dry, medium and wet) were taken and discs from three different positions from the log were analysed and averaged. The values, however, indicate a trend towards reduction of wood density from fresh wood to decay class 1, which matches the further overall loss of density throughout decomposition.

The smallest wood density loss through entire decomposition process was found for both coniferous species: pine (63%) and spruce (70%), whereas for birch and other broadleaved species the respective values were 76% and more. Only grey alder, with the loss of 64% of its wood density during decay, seems to stand out as an exception when compared to the other broadleaved trees. However, this might be explained by the fact that during the decomposition processes grey alder wood quickly loses its cohesion while its mass persists constant, and therefore proceeds more rapidly to higher decay classes while holding its wood density for a longer period of time.

The increase in N concentration with increasing decay class coincide with the results by Krankina et al. (1999), who found increase in N concentration with increasing decay class for pine, spruce and birch. However, in case of pine their mean N concentration was lower in decay class 1 compared to decay class 2 and in decay class 5 compared to decay class 4. The mean N concentration of pine in Russia ranging from 0.17% to 0.55% is similar to values found in this study (Table 2). Furthermore, in the case of spruce and birch in Russia there were only decay classes 1–4 available, and the mean N concentration values for spruce and birch ranged from 0.17% to 0.54% and from 0.18% to 0.49%, respectively. The corresponding N concentration values in Table 2 for spruce and birch are similar.

This study expected that site conditions may influence the decomposition processes through the moisture regimes. Shorohova and Kapitsa (2014) reported more rapid CWD decomposition on open fertile sites with moderate moisture compared to poor dry or wet sites under closed tree canopies. It was also suggested that the relationship is assumed to be non-linear, which means that in both excessively dry and wet sites the decomposition process is slower compared to moderate moisture sites (Shorohova and Kapitsa, 2014). In this study, only in the case of Norway spruce slightly lower but wood density values in dry and wet sites, when compared to medium moisture sites, were observed. However, like all other examined tree species the differences in wood density between the three moisture categories (dry, medium and wet) were statistically not significant. Possibly this is partly due to less extreme environments in the hemi-boreal zone, but more research of dead wood decomposition in the hemi-boreal zone would be needed.

5. Conclusions

Studies dealing with changes in basic densities of CWD and its C and N concentrations over different decomposition classes, mainly relate to temperate or boreal forests, but this study contributes to the specific conditions in hemiboreal areas, where forest ecosystem productivity is higher than in boreal systems, and common boreal and temperate tree species are mixed (growing in mixtures). The densities of dead wood were expected to be different in the hemiboreal forests compared to the boreal forests, but in overall no clear differences have been found. Thus, we can conclude that more specific research would be needed to find out the possible causes for that.

Our second important outcome that the mean dead wood density decreased with progressing decay state for all the assessed tree species, but none of the studied tree species showed no significant differences of wood density between site moisture conditions gives us reason to conclude that site differences were not affecting wood density in different decay classes. Wood density in first of fifth decay class in different areas with different moisture conditions was not significantly different. Expectedly, concentrations of C and N were affected by the decay classes for most of studied species. The C concentration for both alder species and aspens showed more or less stable values through entire decomposition. One reason here can be the variation in wood properties between coniferous and broadleaved tree species, but further analysis would be needed to support our conclusions.

Acknowledgements

This study was supported by the Environmental Investment Centre, by the Institutional Research Funding IUT21-4 of the Estonian Ministry of Education and Research, and by the Estonian Research Council Grant PUT (PUT715).

References


