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

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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 (*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.) 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.

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1. Introduction

Dead wood is an important component of forests, influencing ecosystem processes and sustaining biodiversity (Samuelsson et al., 1994; Siitonen, 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 succession 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_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

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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 (Laiho 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 (Laiho 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 databases do not provide usually 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 (Lõhmus 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 (Lõhmus, 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: *Rhodococcum* (dry areas); *Aegopodium*, *Oxalis*, *Oxalis-Myrtillus and Myrtillus* (medium areas); Alder (eutrophic) fen, Transitional (mesotrophic) bog and Alder–birch (eutrophic–mesotrophic) swamp (wet areas) (Lõhmus, 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

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