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CARBON POOLS IN OLD-GROWTH SCOTS PINE STANDS ON ORGANIC SOILS AND ITS CONCENTRATION IN DEADWOOD: CASES STUDY IN LATVIA

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Carbon sequestration is crucial to mitigate climate changes, therefore it is important to have accurate estimates of carbon pools in the forest. So far, data on carbon pools in old-growth forests are very scarce, therefore aim of the study was to assess the carbon pools in old-growth Scots pine stands on organic soil and carbon concentration in deadwood of different decay classes in Latvia. Carbon content in deadwood was test in samples, collected in 26 randomly selected over mature, unmanaged stands across Latvia (five samples per decay class and tree species). Carbon pools were assessed in 38 sample plots (size 500 m^2) in five Scots pine stands on wet organic soil (*Caricoso- phragmitosa* forest type) at the age of 167 to 203 years. Mean carbon concentration in deadwood across all species and decay classes was 46.6±1.57%. For aspen it did not change with progressing decay was found, but increase was observed for Scots pine, Norway spruce and birch. For these species difference in concentration between first three (more fresh) and last two decay classes (mean 45.9±0.9% and 49.9±1.6%, respectively) was statistically significant. Old-growth Scots pine stands on peat soils had rather large amount of deadwood: 100.6 ± 74.7 m^3ha^{-1}. However, its share in total carbon storage (290.0 ± 57.9 t ha-1) was small and most of carbon (57%) was found in soil. Mean annual carbon storage in tree biomass and deadwood decreased with stand age; its absolute value was similar in over-mature and mature (101-120 years) stands.

Keywords: *biomass, carbon storage, old growth, standing volume, wood decay*

INTRODUCTION

Carbon sequestration had become an important forest service. As numerous other forest service, so far also this has not been a source of income, rather than a potential obligation, for the forest owner. However, ta situation might change in future. Therefore it is important to quantify the carbon storage in old-growth forests and use it in decision support tools. Such information is important also at the state level, when assessing the influence of increased un-managed areas of reduced harvesting rates on the carbon pools. Largest carbon pools in forests are tree biomass and soil. Litter and deadwood plays a role in total carbon flow between the atmosphere and forest.

Biomass equations that are developed or adjusted, based on the local data, are important for accurate estimation of carbon in this pool (Jansons et al., 2017, Kenina et al., 2018, Lībiete et al., 2017). Additionally, information on forest inventory parameters are needed. Such data and/or estimates of carbon pools in old-growth forests are very scarce. Norway spruce had been studied in old-growth (116-145 years) mountain forests of Czech Republic (Seedre et al., 2015), single old growth (140 to 170 years) mixed forest in Finland (Finér et al., 2003), chronosequence (16-142 years) and natural over-mature spruce forest in Central Europe (Jacob et al., 2013, Mund et al., 2003). Old-growth Scots pine has been represented by a single stand (>150 years) in Estonia and Finland (Vucetich et al., 2000), and Mediterranean mountain forests (120 years) in Spain (Moreno et al., 2015) and (up to 177 years) Turkey (Lee et al., 2016). In Latvia the only analysis so far characterizes carbon stock in over-mature (167–213 years) Norway spruce stands (Ķēniņa et al., 2018). All of these studies deal with old-growth forests, where old trees are still the dominant cohort. However, such state is not permanent even in un-managed forests – due to natural disturbance, like storms and forest fires, young stands will be formed (Donis et al., 2017, 2018). Even so the most intensive forest management (whole tree biomass harvesting) does not leave permanent negative effect on forest ecosystem (Jansons et al., 2016) it still changes the dominant age class of trees and leaves a long-lasting impact on forest legacies (Jogiste et al., 2018). Both the growth of trees as well as frequency and severity of disturbances – thus tree mortality – will be (are) affected by climate changes (Katrevics et al., 2018, Matisone et al., 2019, Matisons et al., 2018). Large-scale natural disturbances as well as single-tree mortality is a source of deadwood. This pool retains carbon as long as it has not been completely decayed. For the accuracy of carbon assessment, it is important to know the concentration of it both in living biomass (Bardulis et al., 2017) as well as deadwood of different decay classes. Such analysis has been carried out in Estonia (Köster et al., 2015) but not in Latvia. Therefore we need to verify it and understand its applicability based on independent set of samples.

Carbon storage in soils are often regarded as relative independed from that in tree biomass. However, a study in China had demonstrated an substantial accumulation of this element in top-soil over 24 years in intact forests (Zhou et al., 2016). Soil carbon pool and its fluctuation would be soil and climate specific, therefore it is important to characterize them in each of the set of conditions of interest.

Aim of the study was to assess the carbon pools in old-growth Scots pine stands on organic soil and carbon concentration in deadwood of different decay classes in Latvia.

MATERIALS AND METHODS

Carbon content in deadwood was test in samples, collected in 26 randomly selected over mature, unmanaged stands across Latvia as part of the project “Assessment of greenhouse gas emission and CO2 sequestration in old forest stands” (unpubished project reports in Latvian in www.silava.lv). Five samples have been collected from each tree species (Scots pine, Norway spruce, birch, European aspen) at each of five decay classes (Köster et al., 2015; Sandström et al., 2007). Sampling core (cylinder) with 13 mm inner diameter was used for the harder wood (first two decay classes) and 50 mm for the softer (more degraded) wood (decay classes three to five). Fresh and dry mass (after drying in 105ºC for 3 days) of samples measured. Samples grained and burned at 1360ºC in ELTRA CS-530 analyser to obtain carbon content.

Assess of the carbon pools in old-growth Scots pine stands was done, based on similar method, as described in Ķēniņa et al., 2018. Namely, material was collected in five Scot pine (60-90% of standing volume) stands on wet peat soil, *Caricoso- phragmitosa* forest type. Prior to the fieldwork, the potential sample stands were randomly selected from protected (no documented management) forests across Latvia, based on age limit (>160 years). Selected stands were inspected in the field for conformity of the dominance of species and age group. In the case of any signs of former logging (strip roads, stumps, etc.), they were discarded. Altogether, 38 sample plots (6–8 sample plots in each stand) of 500 m^2 were systematically established in these stands at the age of 167 to 203 years.

The diameter at the breast height (DBH) of all living trees ≥6.1 cm was measured. For all standing dead trees ≥6.1 cm, the DBH and length of the snags were recorded. The tree height for three to five living trees of each species and the layer of stand (upper tree layer, second tree layer) in each sample plot was measured to estimate tree height. The total (above- and belowground) tree biomass was calculated using DBH and height with equations for the main tree species in Latvia developed by Liepiņš et al. (2018). The carbon content of 50% was used for the tree biomass carbon stock estimation. Lying deadwood with a diameter at the thicker end ≥14.1 cm was measured at both ends within the area of the sample plot. The decay stages of lying and standing dead trees were set using a five-class decay classification and ‘knife method’ (modified from Köster et al., 2015). The volume of the lying deadwood and dead trees with broken tops was calculated using a truncated cone formula and converted to mass using the decay class-specific density. The values of the deadwood basic density and carbon content for the main tree species were applied after the testing (part of this study) from Köster et al. (2015).

Soil samples (litter layer and four depths: 0–10 cm, 10–20 cm, 20–40 cm, and 40–80 cm) were taken from each stands at systematically located points outside the sample plots. Obtained samples were returned to the Forest Environment Laboratory at the Latvian State Forest Research Institute Silava, where physical and chemical analyses were carried out following the reference methods outlined in Part X of the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests Manual on Sampling and Analysis of Soil (Fleck et al., 2016). The soil samples were prepared for analyses according to the LVS ISO 11646: 2005 standard. In the soil samples, the following parameters were determined: bulk density (kg m^{-3}) according to LVS ISO 11272:1998, total carbon content using elementary analysis (dry combustion) according to LVS ISO 10694:2006, and carbonate content using the Eijkelkamp calcimeter according to ISO 10693:1995. The organic carbon concentration (g kg^{-1}) in the soil was calculated as the difference between the total carbon content and the inorganic carbon content.

RESULTS AND DISCUSSION

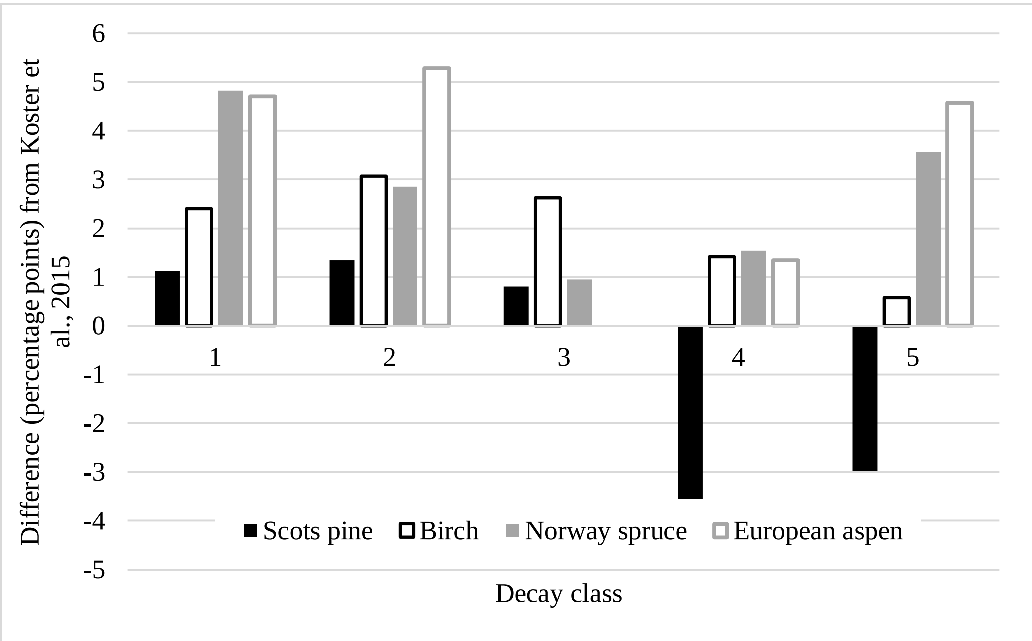
Carbon concentration in deadwood increases with increasing its decay class (Figure 1): from fresh deadwood (decay class 1) to almost complete decay (class 5) it changes by 40 g kg^{-1} in pine deadwood, and by 58.9 and 52.2 g kg^{-1} for spruce and birch, respectively.

Our results follow the general patter, found also by Köster et al. (2015) and Sandström et al. (2007). Exception is decay of European aspen, where the trend in our data is not specifically clear, presumably due to small sample size and larger variation of carbon concentration in deadwood of this tree species. Scots pine and birch have rather similar tendency in changes of carbon concentration – slow in the first decay classes, followed by rather sharp rise in decay classes 4 and 5 (differences between these two groups of decay classes were statistically significant). For birch and spruce similar tendency is observed in Estonia (Köster et al., 2015); however, concentration in carbon with the decay class rises more gradually in this study. In Estonia, similarly than in our study, slight decline of carbon concentration in aspen wood in is observed, when comparing decay classes 1 and 2 with decay class 5. Tendency that for aspen carbon concentration is not significantly affected by changes in decay class, is in notable contract to that observed for other tree species and needs to be considered t ensure accurate carbon estimates.

Decay increases from class 1 (fresh deadwood) to 5 (almost complete decay); Köster et al., 2015, Sandström et al., 2007. Linear trendiness added to ensure visibility of tendencies.

Figure 1. Carbon concentration (%) in deadwood of different tree species depending on the decay class

Mean carbon concentration in deadwood across all species and decay classes in our study was on average by 1.9 percentage points lower than that, reported in Estonia (Köster et al., 2015): 46.6±1.57% vs.48.5±0.66, respectively. However, the differences were not statistically significant, mostly due to relative large variation within each of the species and decay class. When analysis each tree species and decay class separately, the only significant differences were found between estimates in decay class 2 for spruce and aspen and decay class 5 for spruce. Largest difference were found for carbon concentration in aspen deadwood (on average 4%), smallest – in pine deadwood (Figure 2). Considering the large heterogeneity of the carbon concentration in cross-section of even a single log classified as specific decay class due to e.g. contact to water from one side of the log, fungal, insect impact, resin concentration etc., the estimates based on largest set of samples shall be considered more accurate. Thus we conclude, that the estimates of carbon concentration in deadwood as set by Köster et al. (2015) can be used for deadwood carbon estimation in Latvia.



Decay increases from class 1 (fresh deadwood) to 5 (almost complete decay); Köster et al., 2015, Sandström et al., 2007.

Figure 2. Deadwood carbon concentration difference (percentage points) from the results in Köster et al., 2015

Old-growth Scots pine stands on peat soils had rather notable differences in all forest inventory parameters (Table 1). Men standing volume (both first and second layer trees together) of the stands was 311±131.0 m^3 ha^{-1}. It was significantly larger than that, found in mature stands (101-120 years) in the same forest type based on 12 National forest inventory sample plots: in first layer 276.9±122.3 and 170.2±36.1 m^3 ha^{-1}, respectively, in second layer 34.3±20.2 and 8.3±4.5 m^3 ha^{-1}, respectively; even so, the stand densities in any of the layer were not significantly different.

Table 1. Measured forest inventory parameters and carbon in selected old-growth Scots pine stands on wet peat soil

Age, years	I layer					No of sample plots	Carbon, t ha^{-1}, in:	
	DBH, cm	H, m	G, m^2ha^{-1}	M, m^3ha^{-1}	N, ha^{-1}		biomass	deadwood
177	31.4	20.0	14.7	136.2	240	6	57.8	3.8
167	28.7	21.7	41.1	401.9	800	8	116.9	18.7
177	31.1	25.4	29.4	328.6	480	8	125.4	17.5
203	31.3	19.3	28.8	253.4	430	8	92.0	5.0
187	25.9	21.9	26.7	264.6	575	8	110.6	18.7

DBH – diameter at breast height, H – height, G – basal area, M – standing volume, N – density

Above-ground biomass pool is on average 79.2 ± 26.3 t ha^{-1} (from 45.5 to 99.2 t ha^{-1}), in below ground (roots and stump) 21.3 ± 7.0 t ha^{-1} (from 12.3 to 26.2 t ha^{-1}). Old-growth Scots pine stands on peat soils had rather large amount of deadwood: 100.6 ± 74.7 m^3ha^{-1}; however, due to decay the amount of carbon in this pool was rather limited. Tree (biomass and deadwood) carbon was similar (p=0.7) in old-growth and mature stands 113.2 ± 41.9 and 104.8 ± 37.3 t ha^{-1}, respectively. Mean annual rate of changes in the tree biomass and deadwood carbon pool is decreasing over time (Figure 3).

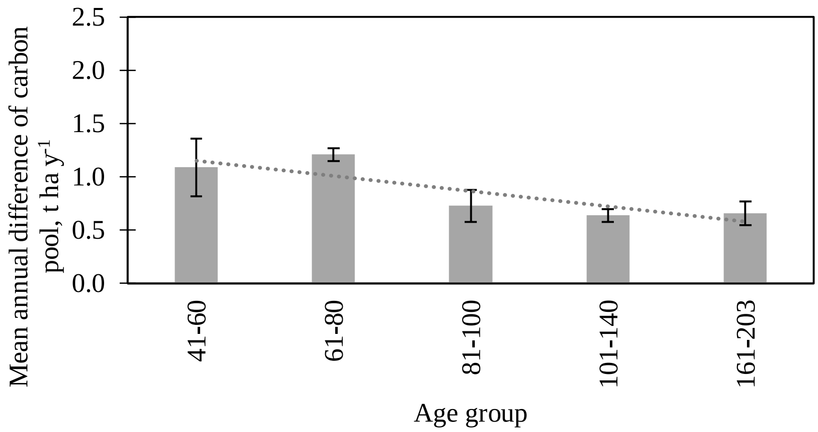


Figure 3. Mean annual increase of biomass and deadwood carbon pools (data of this study and National forest inventory)

Soil, especially organic soil, is a large carbon pool. In the old-growth pine stands in depth up to 80 cm there was 166.3 ± 78.6 t ha^{-1} – that is one third more in the wood (dead and alive). Additionally, in the litter layer there were 10.5 ± 6.2 t ha^{-1} carbon. Thus the total carbon storage in old-growth pine stands was 290.0 ± 57.9 t ha^{-1}.

CONCLUSIONS

Carbon concentration increased with increasing decay of deadwood for Scots pine, Norway spruce and birch and the differences between first three and last two decay classes were statistically significant. In contrast, for aspen no significant changes in deadwood carbon concentration with progressing decay was found. Mean carbon concentration in deadwood across all species and decay classes was not significantly different from that reported in Estonia and were rather variable within species and decay class; thus the estimates based on largest set of samples needs to be used for carbon assessment in deadwood. Total carbon storage in old-growth pine stands on peat soil was 290.0 ± 57.9 t ha^{-1} and its main component was carbon in soil (57%), followed by carbon in tree biomass (35%).

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