

Communication

Old-Growth Coniferous Stands on Fertile Drained Organic Soil: First Results of Tree Biomass and Deadwood Carbon Stocks in Hemiboreal Latvia

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Abstract: Organic soils store a large amount of carbon stock, but they are also a large source of greenhouse gas emissions in a forest. Results of previous studies do not provide whole-country representative data of carbon stock in drained fertile organic soil forests in Europe, as the effects of stand age and dominant tree species are significant. Moreover, the growing role of old-growth stands has triggered interest in empirical data about drained organic soils. These data might serve as a reference of theoretical carbon carrying capacity that could be achieved in hemiboreal Latvia. We aimed to characterize tree biomass and deadwood carbon pools in coniferous old-growth stands on fertile, drained organic soils. Seven old-growth Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) dominated stands (131–174 years) were measured. Both groups of stands had similar carbon stocks, reaching 167 and 154 t C ha^{−1} in tree biomass and 11 and 10 t C ha^{−1} in deadwood, respectively. A large variation in deadwood carbon storage was found across sample plots, ranging from 0.6 to 26.6 t C ha^{−1}. Dead standing trees and downed logs store a great share of the total deadwood carbon, 5 and 4 t C ha^{−1}, respectively. Significantly less carbon was stored in dead standing trees with broken tops (1 t C ha^{−1}). Further assessment of soil carbon stock and fluxes is ongoing to reduce uncertainty in the soil carbon evaluation of old-growth stands in the context of climate change mitigation targets in a hemiboreal region.

Keywords: tree biomass; deadwood; carbon pools; peat soils; Scots pine; Norway spruce



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1. Introduction

Forests are expected to increase carbon removal from the atmosphere and decrease greenhouse gas emissions to achieve global climate change mitigation goals. Organic soils store a large amount of carbon stock [1], but drained areas are an especially large source of greenhouse gas emissions in the forest land of many European countries [2,3]. However, some authors have found that soil carbon stock can remain stable or even increase after drainage, especially in the boreal vegetation zone [4–6]. In hemiboreal Latvia, more than 20% of the total forest area is located on organic soils, and almost one-third of the total forest area (29.7%) has been drained, according to the National Forest Inventory (NFI). Few studies have dealt with carbon storage in drained hemiboreal organic soils, where tree biomass and soil carbon were assessed [1,6]. In an earlier study of forests with organic soils (both naturally wet and drained sites), it was concluded that forest age is an important factor affecting carbon stock in dynamics, demonstrating that carbon stocks subsequently decrease in decaying forests [3,6]. Under unmanaged conditions, stands on drained organic soils may also reach the old-growth stage as, in general, management intensity in European forests is decreasing [7]. Moreover, with increasing interest in promoting carbon sequestration in forests in a climate policy context, local reference data from old-growth stands on drained

organic soils is needed to use this information in decision support tools, particularly because old-growth stands have a great influence on biodiversity conservation [8].

The main carbon pools in forests include tree biomass, deadwood, soil, and litter. Old-growth forests are recognized as a major carbon store in the long term; however, natural disturbances can have a significant impact on depleting carbon stocks. Thus, carbon stocks of old-growth stands are highly variable due to large heterogeneity according to the site type, tree species, species structure, and the effects of past natural disturbances [9]. Tree biomass is a large, changing, and manageable forest carbon pool [7,9]. Compared to younger and managed stands, old-growth stands typically store a higher proportion of deadwood [9,10]. So far, a few studies of old-growth coniferous stands have accessed the carbon stocks of tree biomass and deadwood on dry, wet, and drained mineral soils in the hemiboreal region [11,12], but there are no data from old-growth stands on organic soils in this region. Old-growth stands influence biodiversity and species richness with an emphasis on deadwood availability, hosting many dependent species [13].

European hemiboreal forests are dominated by a mix of coniferous Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and deciduous species. According to the NFI, Scots pine and Norway spruce are the most widespread and economically important tree species in Latvia, comprising 28% and 19% of the total forest area. Moreover, in drained forests, Scots pine and Norway spruce take up to one-third of the most common forest type on drained organic soils—*Myrtillosa turf.mel*. Therefore, local carbon stock data are needed as the new data may serve as a reference of the carbon carrying capacity that theoretically can be achieved in the particular region. Thus, we aimed to characterize tree biomass and deadwood carbon pools in coniferous old-growth stands on fertile, drained organic soils. Based on the light requirements of the evaluated tree species and thus the potential of formation of a second layer in the stand with substantial contribution to biomass carbon pool, we hypothesized that in pine-dominated stands, carbon storage in tree biomass would be higher than in spruce-dominated old-growth stands.

2. Materials and Methods

Seven Scots pine (four stands) and Norway spruce (three stands) old-growth stands on drained peat soils were measured (Figure 1). Stand age on drained sites was 131 to 174 years. The forest type was *Myrtillosa turf.mel* (mesotrophic site type on drained soils) according to the Latvian forest type classification system [1,14]. The target species in *Myrtillosa turf.mel* forest types are Scots pine and Norway spruce, but also stands of deciduous trees, such as birch (*Betula pendula*, *Betula pubescens*), aspen (*Populus tremula*), and black alder (*Alnus glutinosa*) can be found. These forests typically have a ground cover of *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Pleurozium schreberi*, and *Hylocomium splendens*. Wet forests were drained intensively in the 1960s when open ditch systems were created [1,15]. Since then, no further maintenance or renovation has been completed. The peat layer in such sites does not exceed 20 cm in depth after drainage. The climate at the sampled stands can be characterized as temperate moist continental, yet with explicit coastal features of the Baltic Sea [16].

Stands were pre-selected and checked in the field for actual occurrence of a chosen forest type, age group (>130 years), dominance of target species (>50% from the basal area), and no signs of former logging. The cohort was only measured in stands where old trees are still dominant.

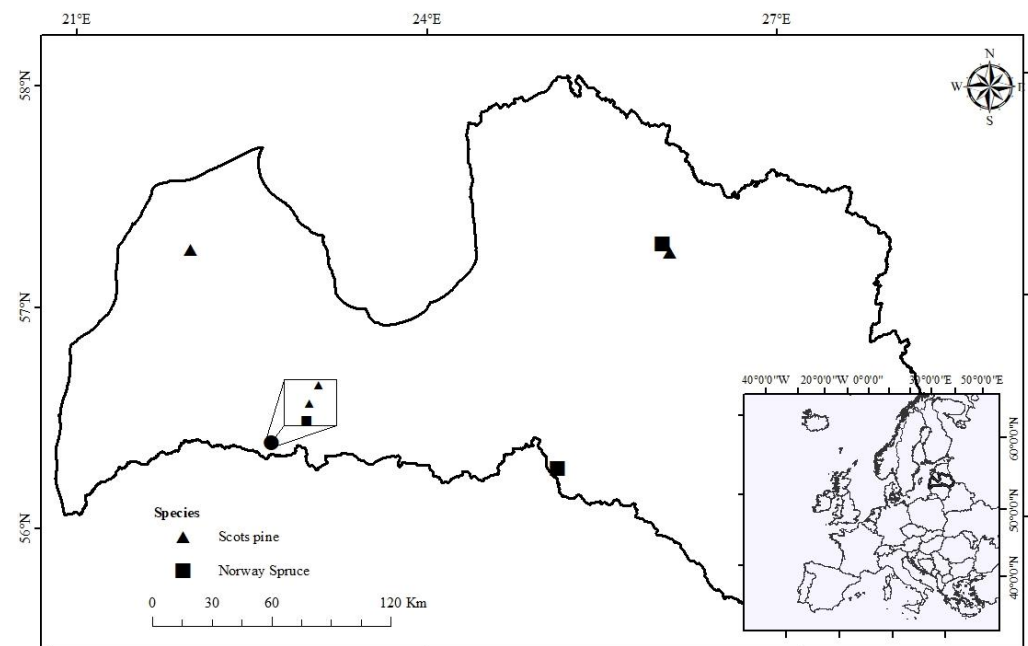


Figure 1. Distribution of sample stands with old-growth Scots pine (▲, *Pinus sylvestris*), and Norway spruce (■, *Picea abies*) in hemiboreal Latvia.

Fieldwork and the data analysis were performed as described in Ķēniņa et al. [11]. In total, 37 sample plots (500 m²) (19 and 18 sample plots in pine-dominated and spruce-dominated stands, respectively) were systematically established. Six sample plots in each stand were established using previously generated coordinates at least 20 m from the edges. In each sample plot, tree species were recorded, and the diameter at the breast height of all live trees and standing dead trees (≥ 6.1 cm) was measured. The heights of five live trees in the I layer, three live trees in the II layer, and all dead trees (≥ 6.1 cm) were measured. Dead trees were classified as dead standing trees (trees with all primary branches and tops) and dead standing trees with broken tops (snags—standing dead tree with fallen primary branches and without top). The length and diameter of downed logs (≥ 14.1 cm at the thicker end) at both ends, decay stage in five classes (fresh to almost complete decay according to Sandström et al. [17]), and tree species (if possible) were recorded. In a smaller subplot (25 m²) in the center of the sample plot, the diameters of live trees, standing dead trees (2.1 to 6.0 cm at breast height), and downed logs (6.1 to 14.0 cm at the thicker end) were recorded. In each sample plot, three dominant trees were cored using a Pressler increment corer to detect stand age. Only the sample plots where dominant tree species constituted more than 50% of the basal area were included in further analysis (Table 1).

Table 1. Characteristics of sampled old-growth Scots pine and Norway spruce stands.

No.	N	Dominant Species	I Layer	II Layer	Understory
1	5	Pine	7P3S	10S	4S2G1B1H1R
2	4	Pine	6P4S	10S	5A5R
3	5	Pine	7P3S	10S	3S4R1B1H1H
4	5	Pine	8P2S	10S	4S4B2R
5	6	Spruce	9S1P	10S	5S3R1H1A
6	6	Spruce	7S3P	7S3P	4S4R1H1A
7	6	Spruce	8S1P1B	10S	9S1B

N: number of sample plots; species composition is based on the proportion of the species' basal area in the respective stand layer (in understory based on the number of trees): 10 = 90–100%, 9 = 80–89%, 8 = 70–79%, etc. P: Scots pine (*Pinus sylvestris*), S: Norway spruce (*Picea abies*), B: birch (*Betula pendula* and *Betula pubescens*), R: rowan (*Sorbus aucuparia*), H: common hazel (*Corylus avellane*), A: alder buckhorn (*Frangula alnus*), and G: grey alder (*Alnus incana*).

Individual tree biomass (above- and below-ground) was estimated from diameter at breast height and calculated tree height according to local biomass models for the main tree species in Latvia [18]. The local carbon content values for the major tree species were used for tree biomass carbon stock estimation [19]. Deadwood carbon stock was estimated from volume and applying decay class-specific density to classes 1 through 5 to determine carbon content for the main hemiboreal tree species, according to Köster et al. [20].

A linear mixed-effect model (LMER) was used to test dominant tree species and age effect on forest inventory parameters. The LMER was used to test the effect of species, stand density, standing volume, and all two-way interactions with species (independent variables) on the dependent variable: carbon stocks of tree biomass, including separate models for above- and below-ground biomass and deadwood. Stand ID was used as a random factor in all models as sample plot data were used in the calculation. All data analysis was performed using R 4.1.0. software [21].

3. Results

All forest inventory parameters were similar in old-growth Norway spruce and Scots pine-dominated stands on drained peat soils ($p > 0.05$) (Table 2). There were no dominant tree species or age effects at the stand-level and I-layer forest inventory parameters ($p > 0.05$) in the old-growth stage. The mean old-growth stand age was 152 years. The mean I layer standing volume was similar in pine- and spruce-dominated stands, ranging from 204 to 855 $\text{m}^3 \text{ha}^{-1}$. The mean basal area in the I layer was $35.0 \pm 4.37 \text{ m}^2 \text{ha}^{-1}$, of which $20 \text{ m}^2 \text{ha}^{-1}$ was Scots pine in pine-dominated stands, and 13 m^2 comprised of Norway spruce. A similar mean I layer basal area was found in spruce-dominated stands ($32.6 \pm 4.49 \text{ m}^2 \text{ha}^{-1}$), of which $28 \text{ m}^2 \text{ha}^{-1}$ was Norway spruce. The mean stand density of the upper tree layer was $374 \pm 24 \text{ trees ha}^{-1}$. In the II layer, the mean standing volume was significantly different between pine- and spruce-dominated old-growth stands, $59.5 \pm 12.24 \text{ m}^3 \text{ha}^{-1}$ and $24.5 \pm 10.54 \text{ m}^3 \text{ha}^{-1}$, respectively.

Table 2. Characteristics (mean $\pm$ 95% confidence interval) of old-growth Scots pine-dominated and Norway spruce-dominated stands in *Myrtillosa turf.mel.* forest type.

Characteristics	Pine Stands	Spruce Stands
Stand age, years	145 $\pm$ 8	162 $\pm$ 3
Diameter at breast height, cm	35.0 $\pm$ 1.27	34.1 $\pm$ 2.75
Tree height, m	28.2 $\pm$ 1.35	28.9 $\pm$ 2.00
I layer basal area, $\text{m}^2 \text{ha}^{-1}$	35.0 $\pm$ 4.37	32.6 $\pm$ 4.49
II layer basal area, $\text{m}^2 \text{ha}^{-1}$	7.1 $\pm$ 1.55	3.2 $\pm$ 1.28
I layer standing volume, $\text{m}^3 \text{ha}^{-1}$	459.3 $\pm$ 74.01	443.0 $\pm$ 82.24
II layer standing volume, $\text{m}^3 \text{ha}^{-1}$	59.5 $\pm$ 12.24	24.5 $\pm$ 10.54
I layer number of trees, ha^{-1}	380 $\pm$ 35	367 $\pm$ 37
II layer number of trees, ha^{-1}	545 $\pm$ 168	315 $\pm$ 151
Understory number of trees, ha^{-1}	1485 $\pm$ 434	2972 $\pm$ 660

Standing volume ($p < 0.01$) had a significant effect on tree biomass carbon stock in both pine- and spruce-dominated old-growth stands. Neither stand age, dominant tree species, nor other forest inventory parameters affected tree biomass carbon stock. The mean tree biomass carbon stock was $167 \pm 24.6 \text{ t C ha}^{-1}$ in pine-dominated old-growth stands. Similar tree biomass carbon stock ($162 \pm 25.0 \text{ t C ha}^{-1}$) was found in spruce-dominated stands. A large variation of tree biomass carbon stock was observed among sampling plots, varying from 84 to 270 t C ha^{-1} in pine-dominated stands and from 103 to 237 t C ha^{-1} in spruce-dominated stands. The mean carbon in above-ground biomass accounted for 79% of total tree biomass in both pine- and spruce-dominated old-growth stands (Figure 2).

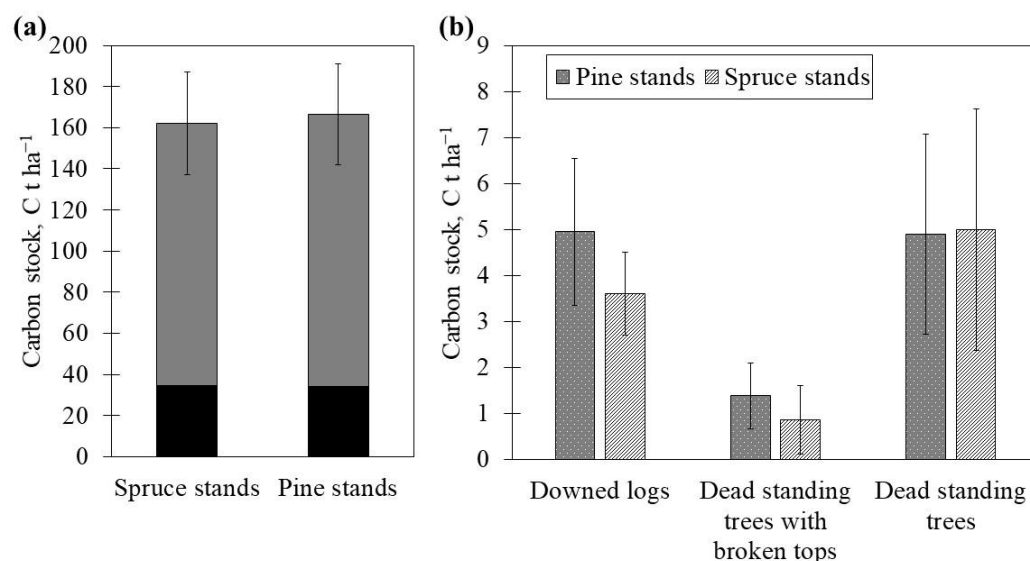


Figure 2. The mean ($\pm 95\%$ confidence interval) carbon stock of live tree biomass: (a) above-ground biomass carbon stock (grey stacked bars) and below-ground biomass carbon stock (black stacked bars) in old-growth pine- and spruce-dominated stands; and (b) deadwood carbon stock by deadwood types in old-growth pine-dominated (dark grey dotted) and spruce-dominated (light grey diagonal stripes) old-growth stands.

Dominant tree species and other factors had no significant impact on deadwood carbon stock. The mean total deadwood carbon stock was 11 ± 3.0 and 10 ± 2.8 t C ha⁻¹ in pine- and spruce-dominated stands. Deadwood carbon storage also was highly variable across sample plots, ranging from 0.6 to 20.4 t C ha⁻¹ in pine stands and 1.2 to 22.0 t C ha⁻¹ in spruce stands. Significant differences were observed between deadwood types ($p < 0.001$)—downed logs, dead standing trees, and dead standing trees with broken tops. Dead standing trees constituted the greatest share (pine-dominated stands, 5 ± 2.1 t C ha⁻¹, 44%; spruce-dominated stands, 5 ± 2.6 t C ha⁻¹, 53%) of the total deadwood carbon storage. A similar part of carbon was stored in downed logs (5 ± 1.6 t C ha⁻¹, 44% in pine-dominated stands; 4 ± 0.9 t C ha⁻¹, 38% in spruce-dominated stands). Significantly less ($p < 0.001$) carbon was stored in dead standing trees with broken tops in both pine- and spruce-dominated old-growth stands, only 1 ± 0.7 t C ha⁻¹. Only 10% of the total deadwood carbon was stored in recently dead deadwood (1 ± 0.77 t C ha⁻¹), but the largest share was weakly decayed deadwood (38%; 4 ± 2.12 t C ha⁻¹), followed by moderately decayed (29%; 3 ± 1.31 t C ha⁻¹) and very decayed wood (2 ± 1.30 t C ha⁻¹), and almost completely decomposed wood (0.3 ± 0.18 t C ha⁻¹) comprised the smallest share (2%) in pine-dominated stands. Most of the deadwood carbon came from Scots pine (58%) and Norway spruce (37%) trees in pine-dominated stands. In spruce-dominated stands, a similar distribution between decomposition stages was observed: 28% of the total deadwood carbon was stored in recently dead deadwood (3 ± 1.40 t C ha⁻¹), 32% in weakly decayed deadwood (3 ± 1.47 t C ha⁻¹), followed by moderately decayed (22%; 2 ± 0.86 t C ha⁻¹), very decayed (16%; 2 ± 0.64 t C ha⁻¹), and almost completely decomposed wood (2%; 0.2 ± 0.15 t C ha⁻¹). In spruce-dominated stands, Norway spruce trees comprised 57% of the deadwood carbon, followed by Scots pine (36%).

4. Discussion

Old-growth pine- and spruce-dominated stands had similar inventory parameters indicating equal growth between Scots pine and Norway spruce in similar growing conditions in the old-growth stage. However, growth rates for Scots pine and Norway spruce are more divergent in younger stands, especially in annual increments [22]. All examined stands were mixed according to species structure in old-growth pine- and spruce-dominated stands. Simi-

lar standing volume in pine-dominated and spruce-dominated stands indicated that a mixture of Scots pine and Norway spruce did not provide significantly higher standing volume [22]. Therefore, carbon storage was also similar for pine- and spruce-dominated stands. We found similar mean carbon stocks of tree biomass in pine-dominated and spruce-dominated old-growth stands in *Myrtillosa turf.mel*, $167 \pm 22.3 \text{ t C ha}^{-1}$ and $154 \pm 23.7 \text{ t C ha}^{-1}$, respectively. The obtained results are similar to the results from old-growth Scots pine stands ($171 \pm 6.1 \text{ t C ha}^{-1}$) and Norway spruce stands ($149.2 \pm 18.9 \text{ t C ha}^{-1}$) on mineral soils in hemiboreal Latvia [11,12]. Carbon stock in tree biomass generally varies with stand age [23], but as selection age criteria of dominant tree species were the same in forests on mineral soils and drained organic soils, similar results can be obtained. Carbon storage in tree biomass increased significantly with increasing standing volume ($p < 0.001$). Although Norway spruce can produce the same or even more tree biomass in moderate and rich sites, the competition effect in mixed Scots pine and Norway spruce stands drives tree growth [22]. Therefore, we assume that the obtained tree biomass carbon pools were similar because Norway spruce had a higher proportion. Therefore, the effect on tree biomass in pine-dominated old-growth stands is an important part of the first and the second layer, as was also observed in hemiboreal old-growth stands on mineral soils [24].

Mean deadwood carbon stocks were similar between pine- and spruce-dominated stands on drained organic soils. The deadwood volume in the studied stands was high (mean 10 t C ha^{-1}), as it typically is at the old-growth stage. However, the large variation of deadwood carbon storage across sample plots (ranging from 0.6 to 26.6 t C ha^{-1}) might be the result of influence of various natural disturbances during the life span of these stands as well as tree age and species composition [13,25]. As stand age showed no relationship to deadwood carbon storage, we can assume that the large carbon storage in deadwood was because stand maturity was very high in these stands [13]. We did not have data about previous natural disturbance events; however, those events are likely due to the frequency of natural disturbances [26]. There was significant variation in carbon stocks between deadwood types, of which dead standing trees formed the greatest share. Previous studies reported downed logs as the main deadwood type in old-growth stands on mineral soils, revealing that different stand structures are impacted both by tree species and by site type [11,12,27]. Moreover, differences between deadwood types are in line with the species composition effect on the proportion of standing/downed deadwood; this is because dead Norway spruce falls down quickly, but Scots pine remains as standing deadwood [13]. Furthermore, the position of the deadwood of different tree species affects decomposition rates due to differences in wood properties [13]. Overall, deadwood carbon stock distribution according to decomposition stages indicates an increased dieback over recent years.

Recent estimations of carbon storage capacity in hemiboreal and boreal Europe have been biased toward above-ground forest-related components [28]. Moreover, in Latvia, country-specific weighted mean carbon values of above- and below-ground tree parts for the main tree species have been developed to improve the accuracy of National Greenhouse Gas Inventory estimates [19], but below-ground components—roots and soil carbon storage—remained neglected [28].

The results of our study provide an indication, that biomass and deadwood carbon storage might be similar for the same tree species in different site types [11,12], as well as conclude, that these carbon pools are similar in old-growth pine- and spruce-dominated stands on drained organic soils. These preliminary findings need to be further tested on larger variety of site and climatic conditions.

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