EFFECT OF FOREST STAND THINNING ON TREE BIOMASS CARBON STOCK

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Abstract. Forest store significant amount of carbon and carbon stock in living tree biomass is amongst the largest carbon pools in forest ecosystems. Forest management practises, such as thinning, can improve tree growth, and increase carbon sequestration in forest ecosystems, thus be beneficial for achieving climate change mitigation goals. However, information about additional carbon stock increase as a result of thinning in the first 10 years is lacking in hemiboreal region. Therefore, this study investigates the additional carbon stock of the most common tree species (Scots pine, Norway spruce, and Silver birch) on mineral soils in hemiboreal forest of Latvia, focusing on the effects of thinning 5 and 10 years after. The aim of the study was to evaluate the effect of first commercial thinning on gained additional carbon stock of living tree biomass. Our results show, that thinning has a positive effect on additional carbon stock and timely performed thinning is crucial for the best outcome. Performing thinning in a timely manner results in a significantly higher additional carbon stock, as trees exhibit a more pronounced response, with biomass production peaking at younger age. Positive effect of thinning on additional carbon storage decreases with the age. This study provides valuable insights into the nuanced relationships between the tree species, stand age, and the temporal effects of thinning on carbon accumulation. The observed trends underscore the importance of forest management strategies that consider both species-specific traits and stand age for effective climate change mitigation.

Keywords: commercial thinning, forest management, hemiboreal biome, mineral soil.

Introduction

Forests are an important carbon store for the terrestrial ecosystems [1]. Their importance in mitigating climate change cannot be underestimated, as tree biomass is amongst one of the largest carbon pools in forest ecosystems, as well as harvested wood products provide a substitute for fossil resources, for example, replacing cement or steel structures in construction [2]. Therefore, it is important to understand what management practices contribute to carbon sequestration in tree biomass in hemiboreal forests.

Forests have traditionally been a source of renewable raw materials. Forest thinning is a common silvicultural practice for sustainable forest management in Northern Europe (Scandinavia, the Baltics) [3], where forestry plays an important role in economy due to favourable climatic conditions for timber production and long forest management traditions. In Latvia management of commercially managed hemiboreal forests is similar to those of boreal forest zones, e.g. in Sweden and Finland. Firstly, pre-commercial thinning is performed to improve the stand structure followed by one or two commercial thinnings. The aim of the first commercial thinning (FCT) is to reduce competition between trees, leaving space for the most perspective trees, and excluding the lagging behind in growth damaged and diseased trees. In this way, vitality and resilience of a stand is improved. Better developed trees are more effective in taking up the cleared growing space, strengthening the root system and developing a larger crown and stem. This significantly improves the resistance of trees against abiotic disturbances such as icing [4] and wind [5]. Often thinnings are viewed as preparation for the final harvest, however, studies in Latvia show that within one-rotation cycle about 30-50% of the total growing stock is obtained in thinnings, ensuring a continuous supply of timber to consumers [6] and therefore providing a substitution effect [2].

Thinning intensity and timing of it are dependent upon factors like the site type, dominant tree species and soil characteristics [3]. The time of FCT usually is determined by achieving a certain height of dominant tree layer, e.g. 12-14 meters in Sweden, 12 meters in Latvia. In Finland first thinning is recommended at the age of 25-45 years, the second is carried out 2-3 decades later, but sometimes one is enough [3]. Timing of thinning is essential, because if FCT is delayed, the trees will have grown too tall, and their post-thinning durability may be compromised in high winds or snow. FCT is performed on middle-aged stands, i.e. when the biomass production capacity of trees is the highest. Timely performed FCT gives additional growth to the remaining trees, which occurs directly in the result of the established silvicultural practice [3; 6]. Therefore, the aim of our study is to evaluate the effect of FCT on additional carbon stock of living tree biomass.

Materials and methods

The study objects were Silver birch (*Betula pendula* Roth.), Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L. Karst.) middle-aged forest stands growing on mineral soils. The studied stands are located in different locations in Latvia (Fig. 1). The study analysed 18 birch stands, 21 spruce stands and 30 pine stands 5 years after thinning. And for longer-term impact assessment, the study analysis also includes 10 pine stands and 11 spruce stands 10 years after thinning.

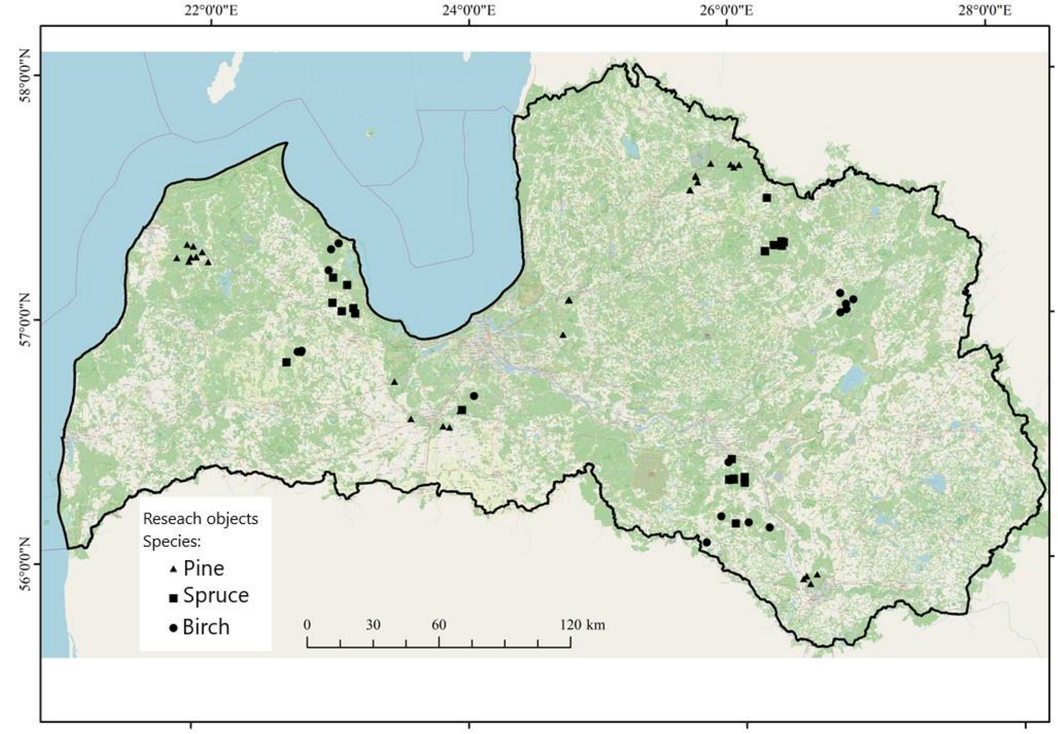

Fig. 1. **Locations of study objects in Latvia**

The age of the analysed birch stands ranged from 34 to 60 years (average 49 ± 4 years), spruce stand age ranged from 36 to 55 years (average 46 ± 2 years), and pine stand age ranged from 41 to 64 years old (average 53 ± 2 years). Thinning intensity and timing in each of the studied stands was performed based on commonly used thinning practice in Latvia following the state regulations of Latvia [7].

In all studied stands, circular sample plots with an area of 500 m^2 (R = 12.62 m) were established. Within each sample plot, the height (H, m), diameter at the breast height (DBH, cm) of the dominant tree species, and the stand basal area ($m^2 \cdot ha^{-1}$) were measured. Also, the standing volume of trees ($m^3 \cdot ha^{-1}$), stand density ($trees \cdot ha^{-1}$) and the site indices were calculated. To determine the age and increment of trees, tree increment cores were collected using a Pressler borer.

The collected increment cores were glued to mounts and sanded. The tree ring widths on increment cores were measured using the LINTAB-IV device and TSAP-Win Scientific computer program. The stem volume additional increment was calculated for each study site.

The stem volume additional increment was calculated according to I. Liepa [8] methodology:

$$Z_M^{kp} = 1.2732.4\psi \;\; GH^{\alpha} D^{\beta lgH-\varphi-2} - G_t H_t^{\alpha} D_t^{\beta lgH-\varphi-2} \;\; , \tag{1}$$

where Z_M^{kp} – cumulative stem volume additional increment, $m^3 \cdot ha^{-1}$;
ψ, α, β, φ – coefficients (Table 1);
t – evaluation period, years;
G, G_t – basal area of stand and predicted values at the end of the period t, m^2 ha^{-1}:

$$G_t = \frac{D_t^2 G}{D^2}, \tag{2}$$

where D, D_t – stand average diameter at the breast height and predicted value at the end of the period t, cm:

$$D_t = D - 0.1 \times Z_D^{kp}, \quad (3)$$

where Z_D^{kp} – cumulative additional increment of the stand average diameter, cm:

$$Z_D^{kp} = 2u\left({}_j^t i_j + {}_j^t i_j^{`} \right), \quad (4)$$

where u – coefficient of the thickness of bark (Table 1);
ij – average width of annual ring data of evaluated stand, mm; it consists of $t + t'$, which is calculated from the data of collected increment cores of the studied stand;
t' – interval of retrospection, years;
$i'j$ – adjusted width of annual ring data of evaluated stand, mm. Correction equation:

$$i_j^{`} = \eta i_{k;j}^{`} {}^\wedge \rho, \quad (5)$$

where η, ρ – coefficients;
i_k – mean values of the annual tree ring width of control trees, mm.
H, H_t – stand average height and predicted value at the end of the period t, m:

$$H_t = H - Z_H^{kp}, \quad (6)$$

where Z_H^{kp} – cumulative additional increment of the stand average height, m:

$$Z_H^{kp} = \frac{H Z_D^{kp}(aD + b)}{u(cD + 100)}, \quad (7)$$

where a, b, c, u – coefficients (Table 1).

The described algorithm calculates the cumulative stem volume additional increment with bark. The value of this index without the bark, $m^3 \cdot ha^{-1}$:

$$Z_{M;bm}^{kp} = \frac{Z_M^{kp}}{s}, \quad (8)$$

where s – coefficient of the bark volume, which is calculated as follows:

$$s = \frac{pD + q}{wD + 100}, \quad (9)$$

where p, q, w – coefficients (Table 1).

Table 1

Values of coefficients for calculations of cumulative stem volume additional increment

u	*a*	*b*	*c*	*ψ*	*α*	*β*	*φ*	*p*	*q*	*w*
1.046	-0.0256	1.693	5.794	$2.3106 \cdot 10^{-4}$	0.78193	0.34175	1.18811	5.25	117.6	5.0

The carbon stock in living trees was calculated using a two-step process. Firstly, we employed biomass models developed for primary tree species of Latvia [9] to estimate tree biomass based on the volume and density. Secondly, we determined the carbon content within tree biomass by utilizing coefficient values of the carbon content from a research conducted in Latvia [10]. These calculations accounted for carbon accumulation in both aboveground and belowground tree components (Table 2).

Table 2

Coefficients of carbon content in tree biomass (aboveground/belowground) for different tree species in Latvia, $g \cdot kg^{-1}$ [10]

Tree section	Norway spruce	Scots opine	Silver birch
Aboveground	524.4	530.4	520.6
Belowground	529.9	531.5	527.9
Whole tree	526.5	533.2	521.4

Taking into account the changes in tree dimensions and stand density as the result of thinning, and the cumulative additional growth achieved, we computed the percentage increase in the standing tree volume. This increase in the standing volume was then utilized to determine the additional carbon increment attributable to thinning.

Tukey's Honestly Significant Difference (Tukey's HSD) post-hoc test was performed to assess significant difference between the analysed group means. To evaluate the relationship between additional carbon storage and the stand age a linear model was used, and analysis of variance (ANOVA) was used to assess the factor significance.

Results and discussion

Effects of thinning on carbon stock 5 *years after thinning*

The analysis of additional carbon storage 5 years after the thinning shows differences in the effect of thinning on tree species (Fig. 2). The additional carbon storage 5 years after thinning in birch stands was 3% from the total carbon stock, in spruce stands 6%, but in pine stands 5%. Statistically significant differences ($p < 0.05$) in additional cumulative carbon accumulation were found between birch stands and other tree species analysed, indicating a species-specific sensitivity to thinning practices.

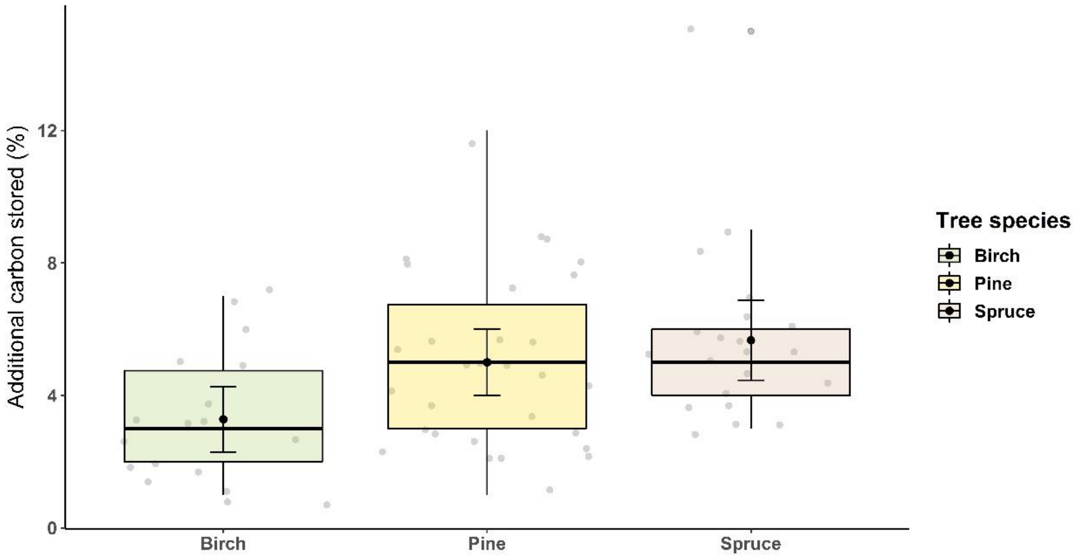

Fig. 2. **Additional carbon storage (%) after thinning:** black line denotes median; black dot represents mean value; grey dots represent age of each study site; whiskers denote ± 95% confidence interval

The total carbon stock of living tree biomass in birch stands was 80.7 ± 11.77 $tC·ha^{-1}$, in spruce stands 95.1 ± 14.1 $tC·ha^{-1}$, and in pine stands 86.4 ± 7.68 $tC·ha^{-1}$. There were no statistically significant differences between the total carbon stock of the analysed tree species. The average additional carbon storage 5 years after thinning in birch stands was 2.4 ± 0.68 $tC·ha^{-1}$, in spruce stands 5.0 ± 0.76 $tC·ha^{-1}$, in pine stands 4.1 ± 0.74 $tC·ha^{-1}$. Statistically significant differences ($p < 0.001$) 5 years after thinning have been observed in additional carbon storage between birch stands and other tree species stands (Fig. 2). The obtained results are in accordance with other studies of hemiboreal and boreal regions that highlight the positive effect of thinning on tree biomass increment [3; 11].

A negative trend was observed when analysing additional carbon storage as a result of thinning depending on the age of the stand. With the increase of the average stand age, a decrease in additional carbon accumulation was observed for all tree species (Fig. 3); this indicates the importance of timely applied thinning [6]. The differences between spruce and pine stands are not pronounced – their response is very similar, as also observed in other studies [3]. However, birch stands exhibit lower additional carbon accumulation in the first 5 years after thinning. The disparity in the response of birch 5 years after thinning, significantly lower compared to conifers, is attributed to the biological characteristics of this species. The general knowledge in the field indicates that birch tends to exhibit optimal biomass accumulation up to the age of 40-50 years, after which the rate of accumulation tends to diminish [6]. Therefore, our findings align with this broader understanding, emphasizing that the observed average age of 49 years in our study reflects a stage in birch growth where the biomass accumulation is expected to slow down.

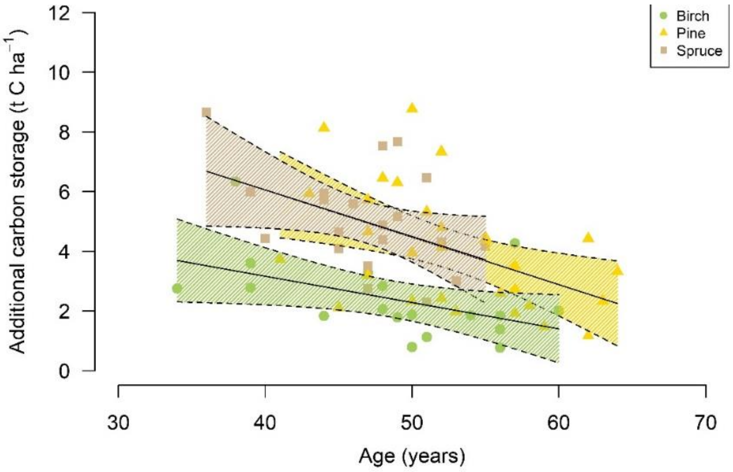

Fig. 3. **Additional carbon storage (tC·ha-1) depending on the dominant tree species and age:** soloured polygon denotes ± 95% confidence interval

Effects of thinning on carbon stock 10 *years after thinning*

In this study, the evaluated effect of thinning is a relatively short period of time (5 years), however, when evaluating the impact of a longer-period (10 years), the effect of thinning can have an even greater effect on additional carbon accumulation. As a result of thinning, 10 years after thinning the additional carbon storage in spruce stands was 10.7 ± 2.08 tC·ha^{-1}, but in pine stands 7.2 ± 2.12 tC·ha^{-1} (Fig. 4). It was observed that in the longer-term after thinning, additional carbon accumulation significantly ($p < 0.05$) increased in both spruce and pine stands compared to the results obtained 5 years after thinning. Furthermore, the findings emphasize the extended temporal influence of thinning on coniferous stands, with additional carbon accumulation continuing up to 10 years after maintenance. Other studies report that spruce maintain a growth boost for a longer time than pine [3], which is in line with our obtained results (Fig. 4). This underscores the need for a long-term perspective when evaluating the impacts of thinning, particularly for coniferous species, and informs sustainable management practices that account for increased carbon sequestration over time.

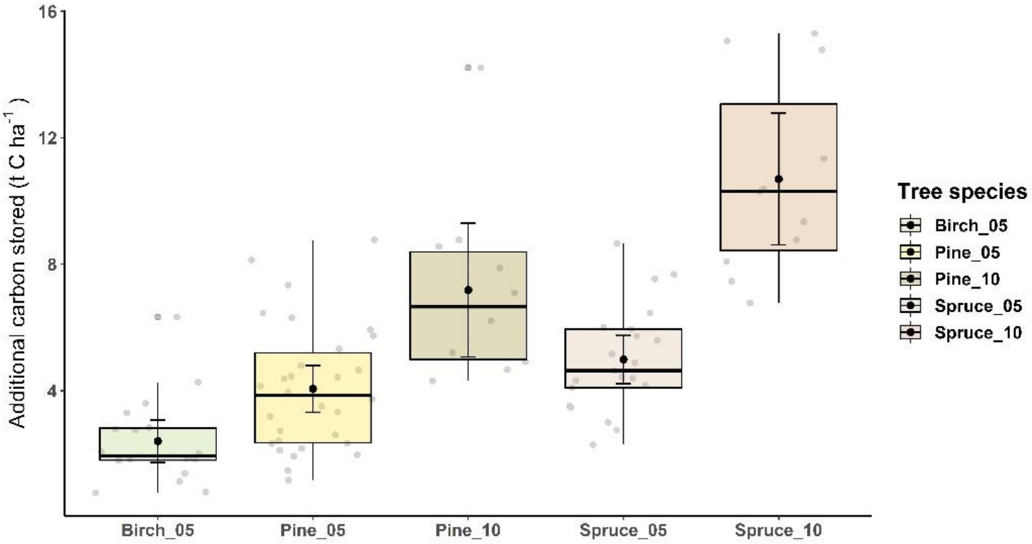

Fig. 4. **Additional carbon storage (tC·ha^{-1}) 5 and 10 years after thinning for different tree species:** black line denotes median; black dot represents mean value; grey dots represent age of each study site, whiskers denote ± 95% confidence interval

Conclusions

The study provides valuable insights into the nuanced relationships between the tree species, stand age, and the temporal effects of thinning on carbon accumulation. The observed trends and disparities underscore the importance of forest management strategies, considering both species-specific traits and stand age dynamics. Thinning resulted in additional carbon stored for all tree species. The effect of thinning varies from 3-6% depending on the tree species. The greatest gain in carbon accumulation can be observed in conifers (additional 7.2 and 10.7 $tC \cdot ha^{-1}$ after 10 years for pine and spruce, respectively). Average age of a forest stand has a significant effect on the additional carbon stored, it decreases with the age, indicating importance of timely performed thinning to ensure a greater additional carbon storage. Thinning of forest stands provides a positive effect on the growing stock and additional accumulation of carbon even after 10 years. These findings pave the way for further research and refinement of forestry practices to optimize carbon sequestration in diverse forest ecosystems to benefit climate change mitigation.

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Author contributions

Conceptualization, Ā.J.; methodology, Ā.J. and V.S.; software, V.S.; validation, Ā.J.; formal analysis, V.S and K.B..; investigation, K.B., V.S.; data curation, V.S., K.B.; writing – original draft preparation, K.B.; writing – review and editing, Ā.J. and V.S.; visualization, V.S., K.B.; project administration, Ā.J.; funding acquisition, Ā.J. All authors have read and agreed to the published version of the manuscript.

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