

## Proceedings of the 10<sup>th</sup> International Scientific Conference Rural Development 2021

Edited by assoc. prof. dr. Judita Černiauskiėnė

ISSN 1822-3230 (Print)  
ISSN 2345-0916 (Online)

Article DOI: <http://doi.org/10.15544/RD.2021.042>

# DEVELOPMENT OF YOUNG STANDS AFTER WHOLE TREE HARVESTING AND WHOLE TREE HARVESTING COMBINED WITH STUMP BIOMASS EXTRACTION

**Ivars KLAVIŅŠ**, Latvian State Forest Research Institute ‘Silava’, Rigas str. 111, Salaspils, LV2169, Latvia / University of Latvia, Raina Blvd. 19, Riga, LV1586, Latvia, [ivars.klavins@silava.lv](mailto:ivars.klavins@silava.lv) (*corresponding author*)

**Zane KLAVIŅA**, Latvian State Forest Research Institute ‘Silava’, Rigas str. 111, Salaspils, LV2169, Latvia / University of Latvia, Raina Blvd. 19, Riga, LV1586, Latvia

Forest management pressures on ecosystems are expected to rise due to increased use of renewable resources and environmental, economic and political reasons. Extraction of nutrient rich logging residues from felling sites has become a common practice, therefore risks of negative impact on the nutrient cycling as well as site future productivity must be assessed. To evaluate effect of whole-tree harvesting (WTH) and whole-tree harvesting combined with stump biomass extraction (WTH+SB) on productivity of next rotation young stands measurements were carried out in eight sites for four to six years in typical forest site types in Latvia (*Oxalidosa turf. mel.* – eutrophic peat soil site; *Hylocomiosa*, *Oxalidosa* – mesotrophic mineral soil sites, *Myrtillosa* – oligotrophic mineral soil site). Harvesting in the sites was carried out in 2012-2013 and regeneration was carried out after one to two years with Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* L. (Karst.)) and black alder (*Alnus glutinosa* L. (Gaertn.)). Comparing conventional harvesting or so-called stem only harvesting (SOH) to WTH no statistically significant differences were observed regarding tree height, but in eutrophic Norway spruce site WTH plot smaller stem diameters were observed. Comparing WTH to WTH+SB statistically significantly higher Norway spruce and black alder heights in mono-stands were observed in WTH plots, while no significant differences were detected in Norway spruce and black alder mixed stand. No explicit differences were found regarding height/diameter ratio between WTH and WTH+SB treatments.

*Keywords: whole tree harvesting; stump harvesting; stand productivity; Scots pine; Norway spruce; black alder*

## INTRODUCTION

In time period from 2005 to 2018 energy produced from renewable energy sources in gross final energy consumption in Latvia have increased from 32.6 % to 40.3 % (Central Statistical Bureau of Latvia, 2020) reaching targets set by the European Union for year 2020 (The European Parliament..., 2009). With the recent and ongoing growth of biomass energy market in Latvia as well as in Baltic Sea region countries logging residues available after forest harvesting are of high interest.

Whole tree harvesting (WTH) and whole tree harvesting combined with stump biomass extraction (WTH+SB) is becoming a common practice where besides stem harvesting for commercial wood products, slash and stumps are extracted as renewable energy source (Clarke et al., 2021; Muñoz Delgado et al., 2019). Extraction of treetops, branches and foliage rich in nutrients may cause prolonged nutrient imbalance in site and negative effects on site productivity when compared to conventional stem-only harvesting (SOH) (Helmisaari et al., 2011; Tveite & Hanssen, 2013). Results from many studies reveal non-consistent effects on stand productivity indicators following WTH when compared to SOH (Wall, 2012). More recent studies also report rather site- and tree species-specific effects of WTH when compared to SOH, i. e., no effects on Norway spruce stand productivity (Kaarakka et al., 2014); negative effects on Norway spruce stand productivity (Egnell, 2016); positive effects on Scots pine stand productivity (Egnell, 2016). WTH+SB is reported to have positive effect on spruce height growth (Aosaar et al., 2020; Egnell, 2016; Piri et al., 2020).

There are several mechanisms that influence the possible effects. Slash left on felling site provide nutrients for the regenerated stand for several years while decomposing (Hosseini Bai et al., 2014; Pearson et al., 2017; Vávřová et al., 2009); in addition, slash may act as a nutrient sink reducing leaching of nutrients from the site (Barber & Van Lear, 1984). Furthermore, slash suppresses the expansion of plants by lowering the competition by ground vegetation to tree saplings (Fahey et al., 1991). Stump extraction from site causes structural mixing of soil that facilitates soil mineralization processes providing

nutrients to regenerated stand (Kataja-Aho et al., 2012), but also negatively affect carbon pool in the organic layer (Kaarakka et al., 2018; Persson et al., 2017).

Due to generally non-consistent effects as well as variations between regions and sites in other studies, knowledge on effects of WTH and WTH+SB cannot be directly transferred for use in Latvian conditions. Therefore, scientifically sound information is crucial at local scale to promote the most suitable operations for given conditions. To address this issue in this study eight sites were established in typical forest site types in Latvia to observe possible positive and negative effects of WTH and WTH+SB relative to conventional or so called stem-only harvesting (SOH).

## MATERIALS AND METHODS

This paper presents results from an ongoing study. Preliminary results have been published in 2019 by (Klavins et al., 2019); in this paper results have been supplemented with three recent observation years from 2019 to 2021 as well as with new data.

To evaluate development of young stands after different intensity regeneration fellings eight study sites were established in typical forest site types in Latvia. To assess possible effects of WTH in comparison to SOH three study sites (*Oxalidosa turf. mel.*, *Hylocomiosa*, *Myrtillosa*) were established in experimental forests of Kalsnava forest district; to assess possible effects of WTH+SB in comparison to WTH five study sites were established in state forests in Northern Kurzeme Forestry (*Oxalidosa* 2, *Hylocomiosa* 2), Zemgale Forestry (*Oxalidosa* 1), Mid-Daugava Forestry (*Hylocomiosa* 1) and Western Vidzeme Forestry (*Hylocomiosa* 3) (Figure 1; Table 1).

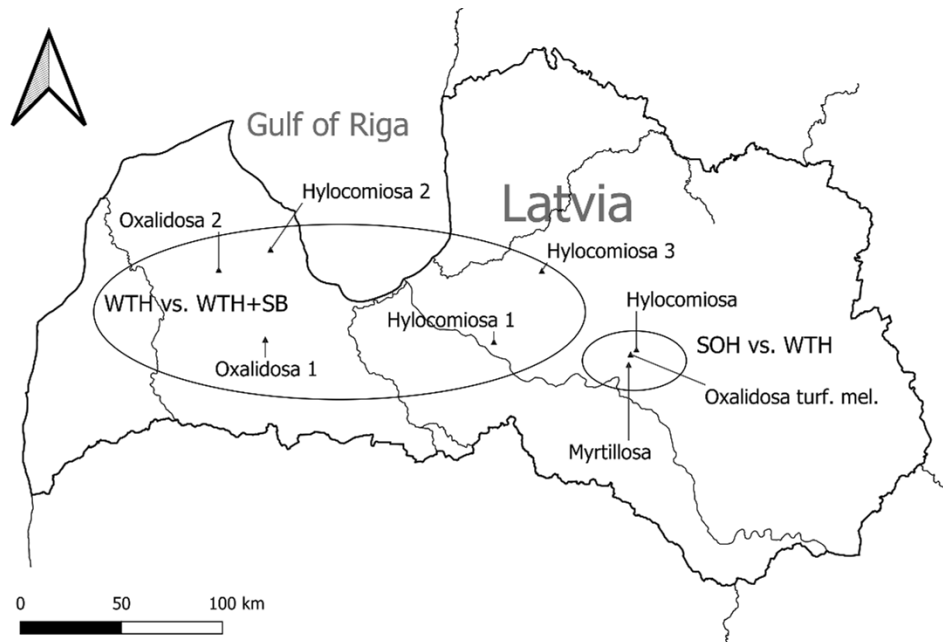


Figure 1. Location of SOH vs. WTH and WTH vs. WTH+SB study sites in Latvia; SOH – stem-only harvesting, WTH – whole tree harvesting; WTH+SB – whole-tree harvesting combined with stump biomass extraction.

**SOH vs. WTH.** In corresponding study sites regeneration fellings were performed in early spring/late winter 2013 with harvester; stems and logging residues were extracted by forwarder. No significant disturbance or damage of soil was caused by forestry operations as soil was frozen. About 70 % of logging residues (branches and treetops) were extracted from WTH plots; logging residues were evenly scattered at SOH plots. In autumn 2014 disc trenching was carried out to prepare soil in *Hylocomiosa* and *Myrtillosa* sites; in spring 2015 regeneration was performed with Scots pine (*Pinus sylvestris* L.) container seedlings. In *Oxalidosa turf. mel.* site no soil preparation was done and in spring 2015 regeneration was performed with Norway spruce (*Picea abies* L. (Karst.)) bareroot saplings. Measurements of young stands were performed yearly in spring 2016-2021 in four circular sampling plots ( $S=100\text{ m}^2$ ;  $R=5.64\text{ m}$ ) per treatment (WTH and SOH) plot. All trees were measured and arranged in 10 cm height classes; root collar diameter and exact height was determined for planted trees.

**WTH vs. WTH+SB.** Regeneration fellings in corresponding sites were performed in winter 2012. Harvesting of stumps and roots was carried out in 2013 with a New Holland excavator (E215B) with stump extraction scoop prototype MCR-500 and Komatsu tracked excavator (PC210LC) with CBI stump extraction scoop. Harvested stumps and roots were forwarded from sites in three to six months after the extraction. In 2013 soil in all sites was prepared with active disc plough and stands were regenerated. In sites *Oxalidosa* 1, *Hylocomiosa* 2 and *Hylocomiosa* 3 Norway spruce container seedlings; in site *Hylocomiosa* 1 Norway spruce and black alder (*Alnus glutinosa* L. (Gaertn.)) bare root saplings with improved root system; in site *Oxalidosa* 2 black alder bare root saplings with improved root system were planted.

Table 1. Description of SOH vs. WTH and WTH vs. WTH+SB study sites in Latvia; SOH – stem-only harvesting, WTH – whole tree harvesting; WTH+SB – whole-tree harvesting combined with stump biomass extraction.

	Site: Forest site type (+ number)	Trophic conditions	Planted tree species	Type of management	Year of harvest	Year of planting	Coordinates (N;E)	Total felling area, ha	Planted density, n·ha <sup>-1</sup>
SOH vs. WTH	<i>Oxalidosa turf. mel.</i>	Eutrophic	<i>Picea abies</i> L. (Karst.)	SOH; WTH	2013	2015	56°42'54.53"; 25°51'33.39"	1	~2,000
	<i>Hylocomiosa</i>	Mesotrophic	<i>Pinus sylvestris</i> L.	SOH; WTH	2013	2015	56°44'10.44"; 25°54'27.58"	1.8	~3,000
	<i>Myrtillosa</i>	Oligotrophic	<i>Pinus sylvestris</i> L.	SOH; WTH	2013	2015	56°40'10.71"; 25°50'29.76"	0.7	~3,000
WTH vs. WTH+SB	<i>Oxalidosa</i> 1	Mesotrophic	<i>Picea abies</i> L. (Karst.)	WTH; WTH+SB	2012	2013	56°47'25.11"; 22°54'7.69"	3.1	~2,100
	<i>Oxalidosa</i> 2	Mesotrophic	<i>Alnus glutinosa</i> L. (Gaertn.)	WTH; WTH+SB	2012	2013	57°5'46.48"; 22°30'44.52"	2.0	~2,100
	<i>Hylocomiosa</i> 1	Mesotrophic	<i>Picea abies</i> L. (Karst.); <i>Alnus glutinosa</i> L. (Gaertn.)	WTH; WTH+SB	2012	2013	56°46'57.47"; 24°45'16.63"	3.0	~2,100
	<i>Hylocomiosa</i> 2	Mesotrophic	<i>Picea abies</i> L. (Karst.)	WTH; WTH+SB	2012	2013	57°11'25.62"; 22°56'0.64"	3.4	~2,100
	<i>Hylocomiosa</i> 3	Mesotrophic	<i>Picea abies</i> L. (Karst.)	WTH; WTH+SB	2012	2013	57°5'41.57"; 25°9'11.30"	1.7	~2,100

Measurements of young stands were performed yearly in spring 2017-2020 in six circular sampling plots (S=100 m<sup>2</sup>; R=5.64 m) per treatment (WTH and WTH+SB) plot. All trees were measured and arranged in 10 cm height classes; root collar diameter and exact height was determined for planted trees.

**Statistical analysis.** Data analysis was carried out in R (R Development Core Team, 2020). Analysis of variance (ANOVA) as well as LSD (Least Significant Difference) *post-hoc* test (Mendiburu, 2020) was applied to compare means of grouped data (different treatments and years within sites). To visualize results “ggplot2” package (Wickham, 2016) was used. In figures different letters point out statistically significant differences (*p-value* <0.05).

## RESULTS

### SOH vs. WTH

During the two recent observation years no statistically significant differences were observed between the treatments regarding tree height (Figure 2). Furthermore, no statistically significant differences were observed in eutrophic site *Oxalidosa turf. mel.* and mesotrophic site *Hylocomiosa*. However, results from oligotrophic site *Myrtillosa* indicated a noticeable tendency from fourth to eighth year after harvesting; the tree height was greater in SOH plot than in WTH plot, and in fifth to sixth year after harvesting the difference was statistically significant (*p-values* <0.001).

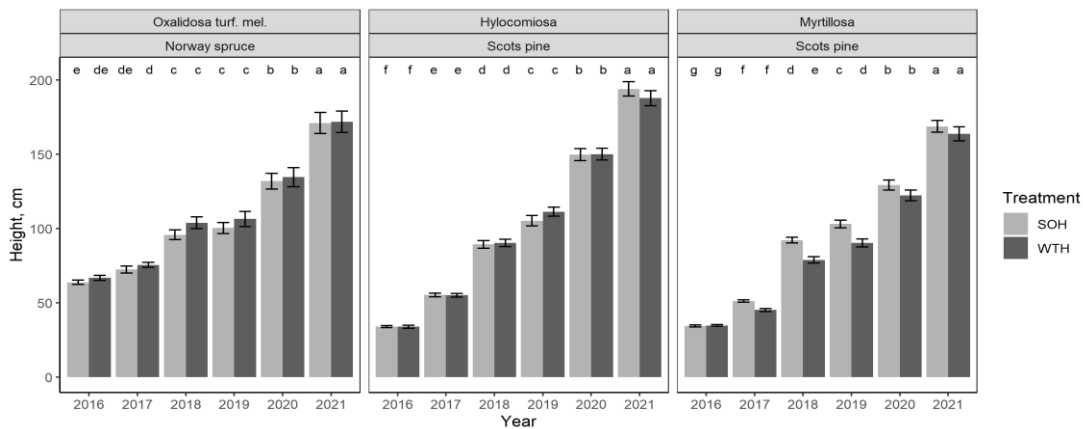


Figure 2. Mean stand heights in treatment plots of SOH vs. WTH sites; SOH – stem-only harvesting, WTH – whole tree harvesting, error bars present standard errors; different letters indicate statistically significant differences by ANOVA and LSD *post-hoc* test (*p*<0.05).

In the mesotrophic site *Hylocomiosa* and oligotrophic site *Myrtillosa* tree growth regarding height and root collar diameter ratio was similar in both treatment plots (Figure 3). In the eutrophic peat soil site *Oxalidosa turf. mel.*, however, trees have smaller root collar diameter at similar tree height in the WTH plot compared to the SOH plot.

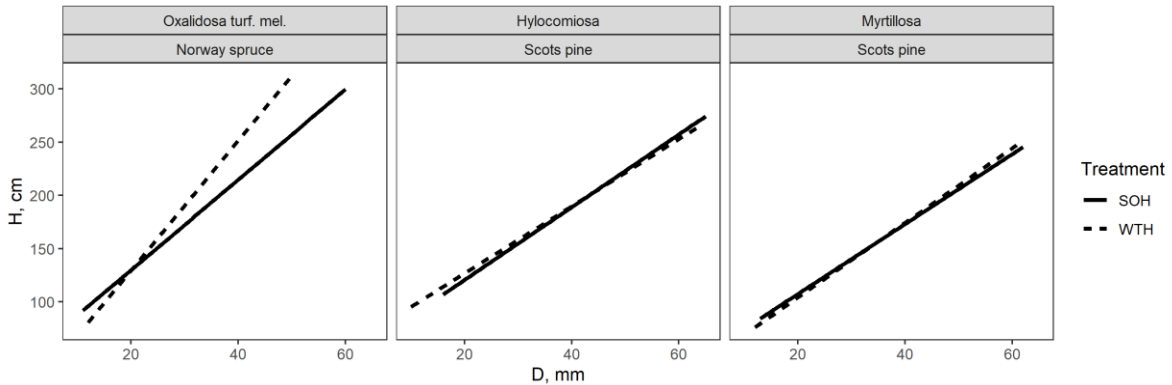


Figure 3. Correlation of tree height and root collar diameter in treatment plots of SOH vs. WTH sites; SOH – stem-only harvesting, WTH – whole tree harvesting.

**WTH vs. WTH+SB**

Starting from the first observation year (or fourth year after planting) in *Hylocomiosa* sites ( $p$ -values <0.006); starting from second to third observation year (or sixth to seventh year after planting) in *Oxalidosa* sites ( $p$ -values <0.032) statistically significantly higher mean tree height was observed in WTH treatment plots compared to WTH+SB where single tree species were planted (Figure 4). These tendencies were observed regardless of the planted tree species – Norway spruce or black alder – and they tend to become more distinguished (decrease in  $p$ -values). On the contrary, such differences were not present in site *Hylocomiosa* 1 where Norway spruce and black alder had been planted in mixed stands.

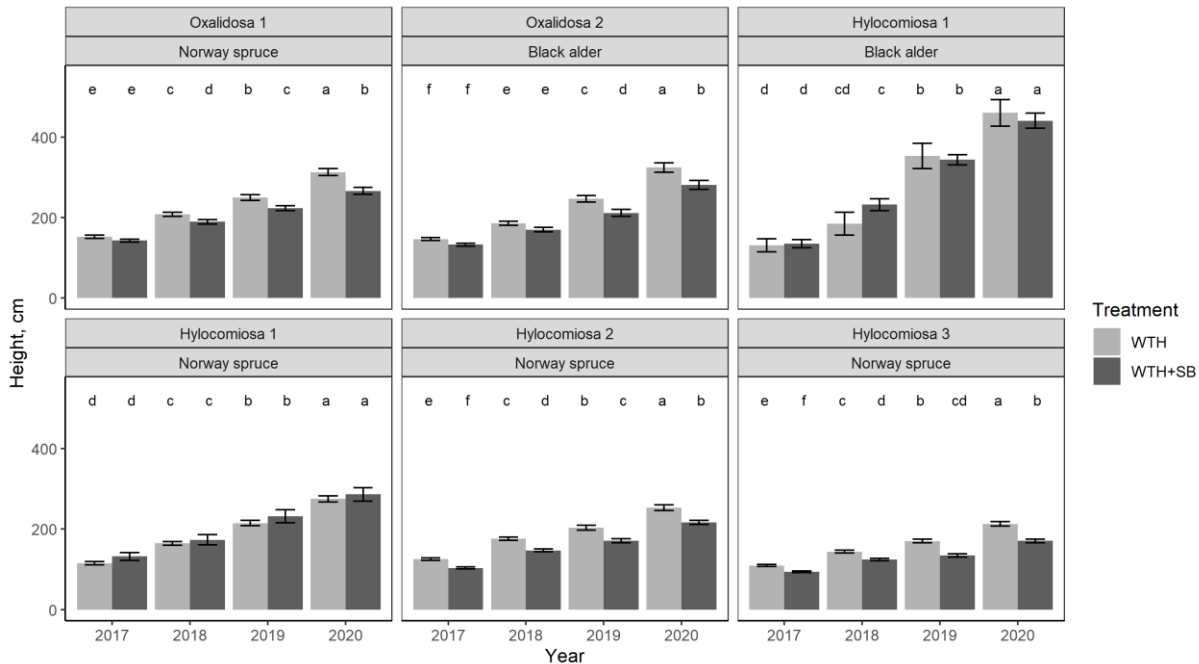


Figure 4. Mean stand heights in treatment plots of WTH vs. WTH+SB sites; WTH – whole tree harvesting; WTH+SB – whole-tree harvesting combined with stump biomass extraction, error bars present standard errors, different letters indicate statistically significant differences by ANOVA and LSD post-hoc test ( $p$ <0.05).

Root collar diameter and tree height ratio in site *Oxalidosa* 1 indicated that Norway spruce reaches larger diameter in the WTH+SB plot compared to the WTH plot at a given height (Figure 5). Even though this relationship was unambiguous in the mentioned site, such distinct differences between treatment plots were not observed in all other sites.

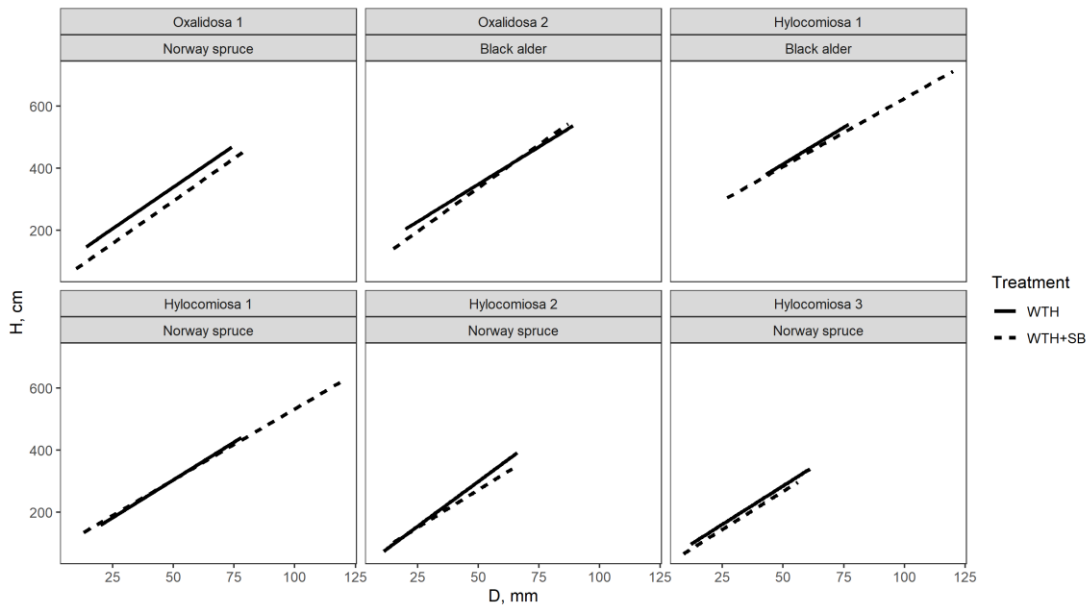


Figure 5. Correlation of tree height and root collar diameter in treatment plots of WTH vs. WTH+SB sites; WTH – whole tree harvesting; WTH+SB – whole-tree harvesting combined with stump biomass extraction.

## CONCLUSIONS AND DISCUSSION

### SOH vs WTH

Other authors have observed negative effects of WTH to stand heights of Norway spruce (Egnell, 2016; Wall & Hytönen, 2011) and no effects (Wall & Hytönen, 2011) or even positive effects to stand heights of Scots pine (Egnell, 2016). Our experiment showed no significant differences in mean tree heights between SOH and WTH treatment plots of eutrophic Norway spruce and mesotrophic Scots pine site during all years of observations. Meanwhile in oligotrophic Scots pine site statistically significantly lower mean height was observed in WTH treatment plot during fifth and sixth year after harvesting. This tendency appeared on the fourth year after harvesting, and is still there, but the differences are becoming less pronounced. The length of the period when differences were observed corresponds to the time of logging residue decomposition (Pearson et al., 2017; Vávřová et al., 2009) indicating the importance of nutrient supply from this source in SOH treatment plot in oligotrophic conditions.

Reduced Norway spruce and Scots pine stem diameters at 1.3 m height have been reported after WTH by a study in Finland (Wall & Hytönen, 2011). Similarly, reduced root collar diameters after WTH treatment in eutrophic Norway spruce site were observed in our study. The negative effect on Norway spruce may be caused by competition of ground vegetation. Fahey et al. (1991) reported that increase in ground vegetation biomass after WTH was twice as rapid when compared to SOH due to slash suppressing the expansion of plants. In contrary, no differences between the treatments were observed in Scots pine stands in mesotrophic and oligotrophic sites where the competition by ground vegetation is less pronounced.

### WTH vs WTH+SB

Significantly greater mean Norway spruce and black alder tree height was observed in WTH treatment plots compared to WTH+SB where single tree species were planted. The negative effect on Norway spruce height by WTH+SB has been also observed in Sweden (Egnell, 2016). In the site where Norway spruce and black alder was planted in mixed stands, no differences between the treatments were observed.

In one of the sites increased Norway spruce diameters were observed in WTH+SB treatment plot, but such differences were not observed in other Norway spruce sites.

**ACKNOWLEDGEMENTS.** The study was carried out within the frames of Latvian State Forest Research Institute ‘Silava’ and JSC ‘Latvia’s State Forests’ collaboration research programme ‘The impact of forest management on ecosystem services provided by forests and related ecosystems’.

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