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DEVELOPMENT OF YOUNG STANDS AFTER DIFFERENT INTENSITY REGENERATION FELLINGS

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Abstract
The share of the renewable resources used continues to grow due to environmental, economic and political reasons. Consequently, intensification of forest management is ongoing and expected to continue in the future. Logging residues, such as treetops, branches and stumps, are a significant renewable energy source. Since the logging residues are noticeably richer in nutrients than conventionally harvested stems, there is a concern related to the negative impact of intensified harvesting on the ecosystems, productivity of the sites and sustainability of forestry in general. To evaluate the impact, this study has compared different intensity harvesting effect on the next rotation young stand productivity in eight sites in Latvia. In a nutrient-rich site, the productivity of Norway spruce was higher in the whole-tree harvest (WTH) subplot comparing to stem-only harvesting (SOH) subplot three years after the planting. Productivity of Scots pine in oligotrophic conditions was observed to be higher in SOH subplot comparing to WTH subplot two and three years after planting. Furthermore, in a site on a mineral soil relatively richer in nutrients no significant differences were observed. Comparing WTH to whole tree harvest + stump biomass (SB) extraction subplots, the productivity of Norway spruce was higher in WTH four to five years after the planting; in a mixed stand of Norway spruce and black alder no productivity differences of spruce were detected, but productivity of black alder was higher in WTH+SB subplot five years after the planting; in black alder stands a significantly higher productivity was observed in WTH subplot four and five years after the planting.
Key words: whole-tree harvesting; stump harvesting; stand productivity; Scots pine; Norway spruce; black alder.

Introduction

Consumption of renewable energy is growing globally due to both economic reasons and political influence. The European Union in its directive 2009/28/EC has set targets for renewable energy share in total energy consumption that member states have to reach in a specified timeframe. Renewable energy share in Latvia has to reach 40% by 2020 from 37.2% in 2016 (Eurostat, n.d.). Since forestry products are one of the main renewable energy sources in Latvia, intensification of forest management is present and expected in the future. Besides the most valuable forestry product – timber, logging residues such as treetops, branches, bark and roots are a significant renewable energy source (Castro *et al*., 2017).

As stems are not as rich in nutrients as foliage and twigs, stem-only harvesting (SOH) is considered to have little impact on the local ecosystem and site productivity in the future. Intensified forestry activities like whole-tree harvesting (WTH) as well as logging residue extraction from SOH sites rise concerns of sustainable site productivity (Wall, 2012). WTH may exhaust soil nutrient pools, especially on nutrient poor sites (Merino *et al.*, 2005; Tritton *et al.*, 1987), and also lower the nutrient availability in soil nutrient pools (Thiffault *et al*., 2011). On fertile soils, where there are risks of nutrient leaching and acidification of nearby waterbodies, logging residue extraction from felling sites may provide environmental benefits (Swedish National Board of Forestry, 2002). Stump biomass (SB) extraction may cause long lasting disturbance to the soil surface as well as carbon losses (Kaarakka *et al*., 2018), although it may lower the site preparation expenses for planting.

A review article (Wall, 2012) compiled results from 45 field experiments regarding tree productivity after WTH. Majority of them have reported a response of five years after planting, but the results are rather ambiguous. To further investigate the effects of different intensity regeneration fellings in local conditions, eight study sites were established in four different locally typical forest types. The aim of the study was to evaluate the effect of WTH and WTH+SB on young stand productivity.

Materials and Methods

Sites were named with letter combinations corresponding to different forest site types in Latvia.

Three of the study sites (sites DM1, KP, LN) are located in experimental forests of Kalsnava forest district (Figure 1; Table 1) where the development of young stands is measured in WTH and SOH subplots in different forest types: *Hylocomiosa* (mesotrophic conditions); *Oxalidosa tuf. mel.* (eutrophic conditions); *Myrtillosa* (oligotrophic conditions). In these study objects the regeneration felling was performed with a harvester in early spring 2013; logging residues and timber were extracted by a forwarder. Forestry operations were performed while the soil was frozen, and no significant soil damage was observed. In practice, approximately 70% of branches and treetops were removed from the WTH subplots. At SOH subplots slash was evenly scattered. On *Hylocomiosa* and *Myrtillosa* sites soil was prepared by disk trenching in autumn 2014 and Scots pine (*Pinus sylvestris L.*) container seedlings were planted in spring 2015. On *Oxalidosa tuf. mel.* site Norway spruce (*Picea abies L.* (Karst.)) bareroot plants were planted in spring 2015 without soil preparation.

The rest of the study sites (sites DM2, DM3, DM4, VR1, VR2) are located in state forests in Northern Kurzeme Forestry (sites DM3, VR1), Zemgale Forestry (site VR2), Mid-Daugava Forestry (site DM2) and Western Vidzeme Forestry (site 6) in *Hylocomiosa* and *Oxalidosa* type forests. At each site, two subplots were established: WTH subplot; WTH + stump biomass (WTH+SB) extraction subplot. Regeneration felling in these study sites was performed in winter 2012. Between the subplots a buffer zone consisting of 10 m of WTH zone and 10 m of WTH+SB zone was established. Stump and root biomass harvesting was performed using two types of stump extraction scoops: a stump extraction scoop MCR-500 prototype, constructed in Latvia, mounted on a New Holland E215B excavator; a CBI stump extraction scoop, mounted on a tracked excavator Komatsu PC210LC. Three to six months after the harvesting in 2013, the harvested stump

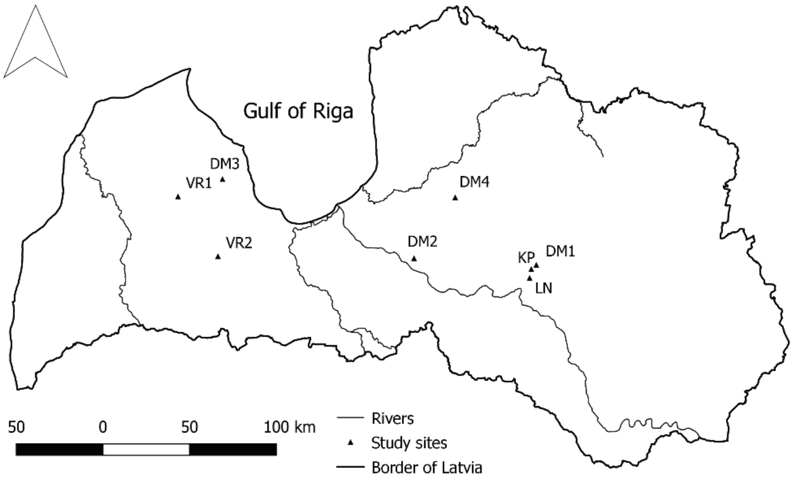

Figure 1. Location of the study sites.

Table 1

Description of the study sites

Site*	Site type*	Dominant tree species	Type of management**	Year of harvest	Year of planting	Coordinates (N;E)	Total felling area, ha	Planted density, n·ha^{-1}
DM1	*Hylocomiosa*	*Pinus sylvestris L.*	SOH; WTH	2013	2015	56° 44' 10.44"; 25° 54' 27.58"	1.8	~3,000
KP	*Oxalidosa turf. mel.*	*Picea abies L.* (Karst.)	SOH; WTH	2013	2015	56° 42' 54.53"; 25° 51' 33.39"	1	~2,000
LN	*Myrtillosa*	*Pinus sylvestris L.*	SOH; WTH	2013	2015	56° 40' 10.71"; 25° 50' 29.76"	0.7	~3,000
DM2	*Hylocomiosa*	*Picea abies L.* (Karst.); *Alnus glutinosa L.* (Gaertn.)	WTH; WTH+SB	2012	2013	56° 46' 57.47"; 24° 45' 16.63"	3.0	~2,100
DM3	*Hylocomiosa*	*Picea abies L.* (Karst.)	WTH; WTH+SB	2012	2013	57° 11' 25.62"; 22° 56' 0.64"	3.4	~2,100
DM4	*Hylocomiosa*	*Picea abies L.* (Karst.)	WTH; WTH+SB	2012	2013	57° 5' 41.57"; 25° 9' 11.30"	1.7	~2,100
VR1	*Oxalidosa*	*Alnus glutinosa L.* (Gaertn.)	WTH; WTH+SB	2012	2013	57° 5' 46.48"; 22° 30' 44.52"	2.0	~2,100
VR2	*Oxalidosa*	*Picea abies L.* (Karst.)	WTH; WTH+SB	2012	2013	56° 47' 25.11"; 22° 54' 7.69"	3.1	~2,100

* Site names correspond to the forest site types
** SOH – stem-only harvest; WTH – whole-tree harvest; WTH+SB – whole-tree harvest and stump biomass extraction

and root biomass was forwarded to the roadside for storage. Soil was prepared using an active disc plough and Norway spruce container seedlings, black alder (*Alnus glutinosa L.* (Gaertn.)) and Norway spruce bare root saplings with an improved root system were planted. In sites DM3, DM4, VR2, the forest regeneration was performed with Norway spruce, in site DM2 with Norway spruce and black alder, and in site VR1 – with black alder.

To evaluate the differences of young stand development after different intensity regeneration fellings, the tree measurements were performed in May 2016, April 2017 and May 2018 in the sites DM1, KP and LN. In June 2017 and May 2018 measurements of the young stands were performed in the sites DM2, DM3, DM4, VR1 and VR2. In sites DM1, KP and LN, the measurements were carried out in four round sampling plots (R=5.64 m; S=100 m^2) per subplot. In sites DM2, DM3, DM4, VR1 and VR2, the measurements were done in six circular sampling plots (R=5.64 m; S=100 m^2) per subplot. Young trees were counted in 10 cm height classes while evaluating if the tree was healthy, damaged or dead.

Data analysis and visualization was conducted with R (R Developement Core Team & R Core Team, 2018) using analysis of variance (ANOVA) with post-hoc LSD (Least Significant Difference) test. Different letters in results indicate statistically significant differences ($p<0.05$).

Results and Discussion

The mean height of planted Scots pines in 2018 in the sites DM1 and LN had reached the height class of 81 – 90 cm, while the planted Norway spruces in site KP had reached the height class of 101 – 110 (Figure 2). The mean height of the planted trees in all three sites, in both subplots, were statistically different from the previous year. Analysis of variance with post-hoc test did not show significant differences between the subplots during the first two study years, except in site LN in 2017. In site LN in the last two study years the mean height of the planted Scots pine was significantly higher in the SOH subplot. At the same time, in site KP the mean height of the planted Norway spruce was higher in the WTH subplot.

A study in Sweden (Egnell, 2016) on the effect of logging residue biomass removal from the clearcuts revealed an opposite relationship between the WTH and Norway spruce, as well as Scots pine growth. In addition, another study in Sweden (Egnell & Valinger, 2003) and a study in Finland (Wall & Hytönen, 2011) observed a negative impact on Norway spruce young stand height after WTH. No significant differences between WTH and SOH were also observed in the studies in Finland and Sweden (Saarsalmi *et al.*, 2010; Sikström, 2004). In contrast to our results, in the site LN, regarding Scots pine stand height, a positive WTH effect was observed in a study in Sweden (Egnell & Leijon, 1999) five years after planting, but no treatment effects were detected after seven years and onwards. In site DM1 during the study years no significant difference between the subplots in Scots pine stands was observed. Our results indicate the importance of plant nutrients provided by decomposing logging residue biomass to young stands in oligotrophic growth conditions.

Over time the density of planted trees has decreased due to natural competition and mortality, as well as damages caused by ungulates (Figure 2; Table 2). In the third year of the study in sites KP and LN the density of the planted trees had decreased. The density of Norway spruce stands was higher in the WTH

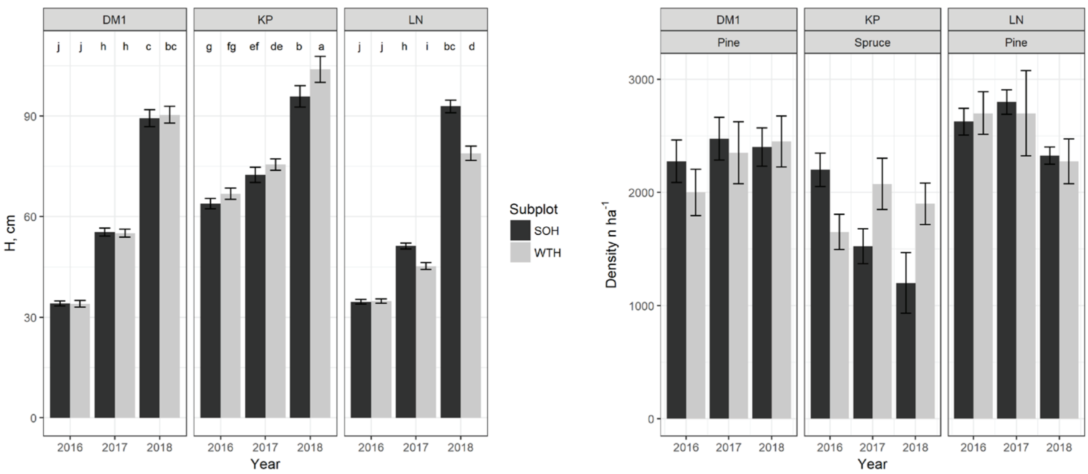

Figure 2. Comparison of mean stand height and density between the subplots of WTH vs SOH sites (DM1, KP and LN – site names as described in Table 1; SOH – stem-only harvest, WTH –whole-tree harvest; error bars present standard errors; different letters note statistically significant differences by ANOVA and LSD post-hoc test ($p<0.05$)).

Table 2

Stand densities in SOH and WTH subplots

Year	Site*	Healthy, n·ha^{-1}		Damaged, n·ha^{-1}		Alive, n·ha^{-1}		Dead, n·ha^{-1}		Natural*** pine, n·ha^{-1}		Natural spruce, n·ha^{-1}	
		SOH**	WTH**	SOH	WTH	SOH	WTH	SOH	WTH	SOH	WTH	SOH	WTH
2016	DM1	2,125	1,425	300	50	2,425	1,475	50	525	9,425	4,175	0	0
	KP	725	925	1,375	575	2,100	1,500	100	200	0	0	225	25
	LN	2,250	2,500	300	150	2,550	2,650	75	50	10,400	5,175	0	0
2017	DM1	2,150	2,225	325	100	2,475	2,325	0	0	7,575	7,025	10,025	9,775
	KP	850	250	575	1,775	1,425	2,025	100	50	0	0	250	125
	LN	2,725	2,550	75	150	2,800	2,700	0	0	11,850	3,725	225	300
2018	DM1	600	625	1,800	1,825	2,400	2,450	0	0	625	1,175	6,850	8,100
	KP	775	950	425	950	1,200	1,900	0	0	25	0	200	0
	LN	1,725	1,675	600	600	2,325	2,275	0	0	225	225	25	625

* Site names as described in Table 1
** SOH – stem- only harvest, WTH –whole tree harvest
*** Naturally regenerated

subplot of site KP. No significant differences in young Scots pine stands were observed regarding density.

A significant damage by ungulates to planted Norway spruces was observed in site KP in 2016 with consequences still noticeable in 2017 (Table 2). In year 2018 significantly less damaged trees were observed. In sites DM1 and LN, a significant damage to Scots pines by ungulates during winter was observed in 2018. Most damages were caused to upper branches because of the deep snow cover. The treetops were left intact because of successful treatment with *Cervacol*.

Naturally ingrown trees were more represented in SOH subplots during the initial year of the measurements. In year 2018 such relationships were no longer noticeable. In addition, the density of naturally regenerated trees in all three sites has decreased during the three study years.

According to literature data, the productivity of Norway spruce in WTH+SB sites may be affected negatively (Egnell, 2016; Persson, 2016). In our study, the mean height of planted Norway spruce was significantly higher in WTH subplots in sites DM3, DM4, and VR2 (Figure 3). In site DM2, where Norway spruce was planted in mixture with black alder, no significant differences were observed in the mean height of Norway spruce, but significantly higher mean height of black alder was observed in the WTH+SB subplot. In site VR1 significantly higher mean height of black alder was observed in WTH subplot.

During the timeframe of the study density of the planted trees in site DM2, DM3, DM4, VR1 and VR2 did not change significantly.

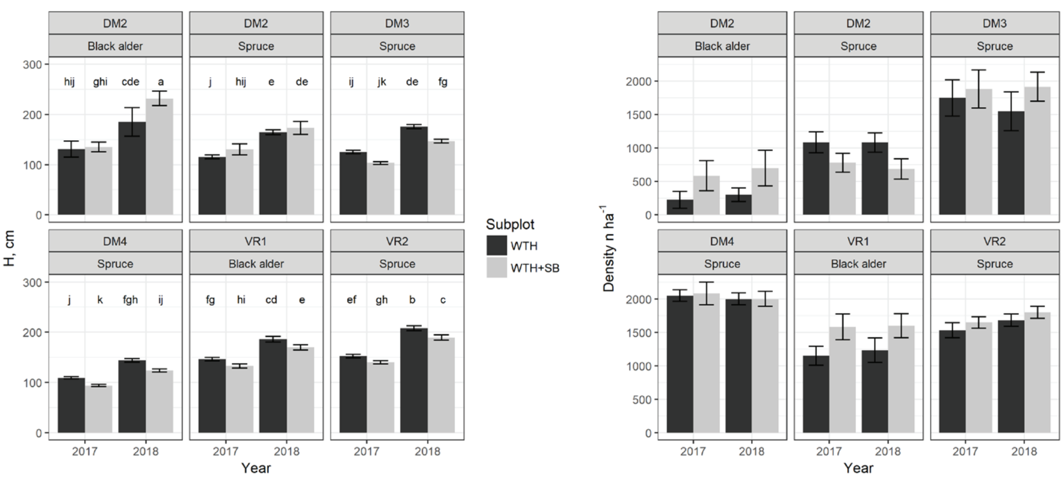

Figure 3. Comparison of mean stand height and density between the subplots of WTH vs WTH+SB sites (DM2, DM3, VR1 and VR2 – site names as described in Table 1; WTH – whole tree harvest, WTH+SB – whole three harvest and stump biomass extraction; error bars present standard errors; different letters note statistically significant differences by ANOVA and LSD post-hoc test ($p<0.05$)).

Table 3

Stand densities in WTH and WTH+SB subplots

Year	Site*	Tree species	Healthy, n·ha^{-1}		Damaged, n·ha^{-1}		Alive, n·ha^{-1}		Natural*** pine, n·ha^{-1}		Natural spruce, n·ha^{-1}	
			WTH**	WTH+SB**	WTH	WTH+SB	WTH	WTH+SB	WTH	WTH+SB	WTH	WTH+SB
2017	DM2	Spruce	1,083	650	0	0	1,233	1,233	200	183	0	100
	DM2	Black alder	150	583	0	0						
	DM3	Spruce	1,733	1,850	17	33	1,750	1,883	1,417	433	50	167
	DM4	Spruce	2,033	2,017	17	67	2,050	2,083	167	50	83	0
	VR1	Black alder	1,150	1,567	0	17	1,150	1,584	167	133	350	50
	VR2	Spruce	1,533	1,650	0	0	1,533	1,650	0	0	0	50
2018	DM2	Spruce	1,083	683	0	0	1,183	1,266	367	550	17	50
	DM2	Black alder	100	583	0	0						
	DM3	Spruce	1,550	1,917	0	0	1,550	1,917	2,167	1,117	183	133
	DM4	Spruce	1,950	2,000	50	0	2,000	2,000	317	167	117	0
	VR1	Black alder	1,233	1,600	0	0	1,233	1,600	433	1,150	783	283
	VR2	Spruce	1,683	1,800	0	0	1,683	1,800	17	33	17	350

*Site names as described in Table 1
**WTH –whole tree harvest, WTH+SB – whole three harvest and stump biomass extraction
***Naturally regenerated

In site DM2, DM3, DM4, VR1 and VR2 significantly less damaged trees were observed comparing to sites DM1, KP and LN (Table 2; Table 3). In addition, no mortality was detected. A research about natural regeneration after SB harvesting was conducted in southern Finland (Saksa, 2013), where more natural Scots pine seedlings and less natural Norway spruce seedlings were observed in SB harvesting sites. In sites DM2, DM4, VR2 no significant differences in the density of naturally ingrown Scots pine and Norway spruce trees was observed between subplots. Furthermore, density of naturally ingrown trees in these study sites was low. In site DM3 where Norway spruce was planted in combination with black alder natural Norway spruce density was low and no significant differences between subplots were observed, but naturally regenerated Scots pine density was significantly higher, especially in the WTH subplot contrary to the results of the mentioned Finnish study. In site VR1 in young stand of black alder naturally ingrown tree density was low, but in 2018 significant differences were observed: natural Norway spruce density was higher in the WTH subplot; natural Scots pine density was higher in the WTH+SB subplot similarly as observed in the Finnish study.

Conclusions

SOH vs. WTH

1. The effect of WTH tree height was not detected during three initial years after planting in site DM1; during first two years after planting in site KP; during first year after planting in site LN.
2. In site KP (site rich in nutrients) three years after planting statistically significant differences were detected – the height of Norway spruce was higher in the WTH subplot.
3. In site LN (oligotrophic growth conditions) two and three years after planting statistically significant differences were observed – the height of Scots pine was higher in the SOH subplot.

WTH vs. WTH+SB

4. In Norway spruce stands (site DM3, DM4 and VR2) tree height was significantly higher in WTH subplots – in the fourth and fifth year after planting in site DM4 and VR2, in the fifth year after planting in site DM3.
5. In mixed stands of Norway spruce and black alder (site DM2) no significant differences were observed regarding the height of Norway spruce; while the height of the black alder was significantly higher during the fifth year after planting in the WTH+SB subplot.

6. In black alder stands (site VR1) the height of trees in the WTH subplot both during the fourth and fifth year after planting was significantly greater than in the WTH+SB subplot.

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