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LONG TERM EFFECTS OF TOTAL BIOMASS HARVESTING ON UNDERSTORY VEGETATION AND TREE STAND IN NORWAY SPRUCE STANDS

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Abstract
Northern Europe will be one of the locations where the renewable energy from forests could displace fossil fuels as a result of climate change: therefore, it will become more crucial to maintain renewable materials that also collect CO_2. By taking tree biomass out of forest stands, we could create more renewable resources to use in practice, but this has certain negative effects on the forest ecology, including nitrogen leaching and vegetation degradation. The goal of the study is to investigate the effects of full biomass removal (FBR) in Norway spruce (*Picea abies* (L.) H. Karst.) forest stands and how this forest management affects vegetation regeneration, tree stock and carbon storage overall. The aforementioned structures were assessed at various forest ages. The central region of Latvia contains Norway spruce stands with all of the sample sites under study situated on drained peaty mineral soils and weakly aerated gleyic soils. As a result of the long-term evaluation, it was determined that the forest vegetation in FBR was similar to that in the same-age control stand (SAC) and that vegetation can successfully regenerate. The average tree height and DBH is lower in areas where stump removal and understory biomass was not carried out. Statistically significant ($p<0.05$) long-term influence of stump removal on the average height and diameter of Norway spruce can be identified in all parameters, except, tree height in *Myrtillosa mel.* forest type. Total biomass removal in long term has almost no significant effect on tree stand and vegetation regeneration.
Key words: picea abies, full biomass removal, long run, vegetation.

Introduction

Since forest ecosystem covers 65 million ha of the region, forestry is economically significant in Northern Europe. The two main tree species are Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) (Thuresson, 2002). Climate change will enhance the need for this region to guarantee a sustainable supply of renewable materials in Europe (Hanewinkel *et al*., 2013). Northern Europe's forestry and forest industry are developed (Thuresson, 2002) and capable of meeting the rising demand brought on by the growth of the human population (Bologna & Aquino, 2020), increasing the share of forest area allotted for different purposes (Weiss *et al*., 2019), and aiming to sequester carbon in the products to slow down climate change (Pukkala, 2017). Climate change mitigation goals are constantly rising (Adams *et al*., 2015) and cannot be achieved alone by reducing emissions; sequestration, which is ensured by forests and wood products, is a crucial component to achieve these goals (Yousefpour *et al*., 2018). Increasing the use of logging residue (branches, tops, and stumps) to replace fossil fuels is one aspect of the approach (Ranius *et al*., 2018). This strategy has recently come under fire, in part because of its unknown long-term effects on the forest ecosystem (Walmsley & Godbold, 2010).

In comparison to the stem, which accounts for 69% of the overall tree biomass, the spruce's stump-root system accounts for about 17% of the biomass of the entire tree (Kaarakka *et al*., 2018). Nowadays, Finland is one of the few nations where whole-tree harvesting is used on a greater scale, along with Sweden and Norway to a lesser extent (Uri *et al*., 2015).

According to recent research, when compared to conventional forest management, the chemical composition and pH of the soil were not significantly altered by removing all tree biomass from the forest (Saarsalmi *et al*., 2010). Yet, even little changes in chemical composition can have an impact on the growth of ground cover since plants are typically sensitive to even small alterations, such as nutrient deficiencies (Haferkamp, 1988). The principal limiting factor of vegetation in boreal forests is nitrogen (N) (Haferkamp, 1988) which largely occurred in the soil and litter, notably in spruce and pine forests (Merilä *et al*., 2013). However, the main sources of nitrogen in the forest stand are theoretically gone when all the biomass has been taken out, which may have a negative impact on ground vegetation regrowth in more rich forest stands (Ring *et al*., 2017).

The majority of recent studies (Aosaar *et al*., 2020; Saarsalmi *et al*., 2010; Uri *et al*., 2015) have concentrated on the effects of increased biomass, mineral element composition, stump generation, and whole-tree harvesting on the spread of root rot (*Heterobasidion* sp.). It is unclear how this form of management would influence ground cover vegetation in the long-term, especially in drained spruce forests, because current research does not account for the long-term effect. One of the main obstacles in developing forestry and doing anything new is being aware of influence of this activity on biodiversity (Messier *et* *al*., 2013). Moreover, the addition of biomass from the use of tree stumps in forest management may help to slow the rate of deforestation.

The study's aim is to evaluate the long-term effects of full biomass removal and stump harvesting on vegetation growth as well as the quantity of carbon and nitrogen stored in drained spruce forests and forest stocks.

We assume that ground cover vegetation can return to previous state based on earlier findings in Scots pine (Jansons *et al*., 2016), but there have been no investigations of the same nature for Norway spruce in various forest types.

Materials and Methods

The study site was in Norway spruce stands in the central region of Latvia, Kalsnava (56°42'6N, 24°50'22E, 113 m above sea level). According to National forest inventory data, 3.33% of Latvia's forests are *Myrtillosa mel*. forest type with drained mineral soils, and 0.95% are *Myrtilloso-sphagnosa* poorly aerated gleyic soil. Moderately rich soils can be found in *Myrtillosa mel*. and *Myrtilloso-sphagnosa*. (Liepa *et al*., 2014).

The national meteorological agency reported that the mean monthly temperature between January and July, respectively, ranged from -5 to +17.4 °C. The average annual rainfall was about 700 mm. The average number of days with snow cover is 112 days, with a depth of 26–42 cm, the primary wind directions are south and west, and the predominant vegetation period is between 190 and 192 days. Permanent frost occurs on November 15th (Nikodemus *et al*., 2018).

The study site's sampling plots were chosen based on information about specific management that was documented: in 1974, following a clear-cut, all above-ground biomass, stumps, and roots with upper soil layer (approximately 10 cm thick) were removed by a bulldozer, resulting in full biomass removal (FBR). Six FBR stands with the least amount of remaining woody biomass (roots) were created as a consequence. Young stand (five stands), control stand (SAC, nine stands), mature stand (six stands), and old stand (six stands) with ages of (11 years, 50 years, 100 years, and 130 years, respectively) were chosen as the comparative regions in the same forest types (Table 3).

All data were gathered 43 years after FBR in July 2017. A total of 38 transects, each measuring 50 meters, were used to evaluate the vegetation. They were all laid out in a North-South orientation and put within stands that were at least 15 m from the boundaries. We established 17 sampling plots (for a total of 646) with a two-meter spacing and a size of 1 m x 1 m on each transect to visually analyze the ground vegetation. The relative percentage of each plot's ground cover species was calculated, and the vegetation was divided into layers of moss and lichen, vascular plants and dwarf shrubs. Moreover, bare soil and tree seedlings were addressed.

The sample plots were divided into nine sample plots in FBR and SAC stands with a radius of 12.62 m, and their area is 500 m^2. Tree data (height and DBH) were taken on transects where vegetation data had already been collected. The following variables were calculated for each tree whose diameter at 1.3 m exceeded 6 cm: the distance from the plot's center, the species, the diameter at 1.3 m, and the height of the tree.

Moreover, soil samples (100 cm^3) were taken at depths of 0–10 cm, 10–20 cm, 20–40 cm, and 40–80 cm, as well as one litter sample (10*10 cm), roughly in the midpoint of each FBR and SAC transect. These samples were taken in order to better understand the differences in soil composition between FBR and SAC stands. The samples were delivered to the laboratory at LSFRI 'Silava', where they underwent analysis. We utilized the elemental analysis method proposed by (LVS ISO 10694:2006, n.d.) to calculate the total amount of carbon in the soil.

Each stand's mean relative cover of each species was computed. The Shannon-Wiener (H′) index (Shannon, 1948) was used to describe species diversity. (Spellerberg & Fedor, 2003). With the software R 3.4.2, the Shannon-Wiener indices among a set of stands were statistically compared using the analysis of variance at the significance level of $\alpha=0.05$ (R Core Team, 2020). The Analysis of Similarities (ANOSIM) was used to statistically compare the composition of vegetation between all stands in one forest type. The R package 'vegan' (Oksanen *et al*., 2013) was used for both studies. The ANOSIM analysis produced two values: the p-value and the R-value, which ranged from 0 to 1 (Clarke, 1993). Calculations were made for the tree stand's average diameter, average height, basal area. A t-test was used to check whether stand parameters were statistically different. Characterize Elemental analysis is used to calculate the overall amount of carbon in a forest stand, with conifers and deciduous trees having average carbon values of 50.8% and 48.8%, respectively. The formula for Elemental analysis was from Thomas & Martin, 2012 publication.

Results and Discussion

When comparing the same forest type's FBR and SCA stands, there was no discernible difference in species diversity; nevertheless, species diversity was noticeably and significantly higher on drained soil (Shannon-Wiener indices of 3.2 and 2.2, respectively) than on wet soil (1.1 and 1, respectively). The young stand had the highest index (1.5) in *Myrtillosa-*

sphagnosa, which was significantly different from the FBR and SAC stands. The *Myrtillosa mel*. stand had the highest overall indices (Table 1). Forest stands undergo a rapid change in growth circumstances after clear-cutting. Clear-cutting reduces the number of species. However, as the forest regenerates over time, the former species reappear (Priedītis, 1999). The presence of bare soil in the forest also promotes seed sowing (Smythe, 1970), but as shade and moisture levels rise, many species become unable to thrive, lowering the Shannon-Wiener index (Ellenberg, 1988).

Table 1

Shannon-Wiener diversity indices in the study area of Myrtillosa mel. and Myrtilloso-sphagnosa Equal letters (abcd) in one forest type means that there is no significant difference

FBR[1]	SAC[2]	Young stand	Mature stand	Old stand	
3.4^{ac}	3.19^{cd}	3.16^{ab}	3.12^{b}	2.18^{d}	*Myrtillosa mel.*
1.11^{ac}	1.02^{a}	1.53^{b}	1.03^{a}	1.36^{bc}	*Myrtilloso-sphagnosa*

[1]. FBR – Full biomass removal stand, [2].SAC – Same age control stand.

Table 2

The ANOSIM results between FBR and control stands in both forest types

	SAC[2]	Young stand	Mature Stand	Old stand	Forest Type
FBR[1]	0.03	0.07	0.15	0.38	*Myrtillosa mel.*
FBR[1]	0.11	0.56	0.35	0.47	*Myrtilloso-sphagnosa*

[1]. FBR – Full biomass removal stand, [2].SAC – Same age control stand.

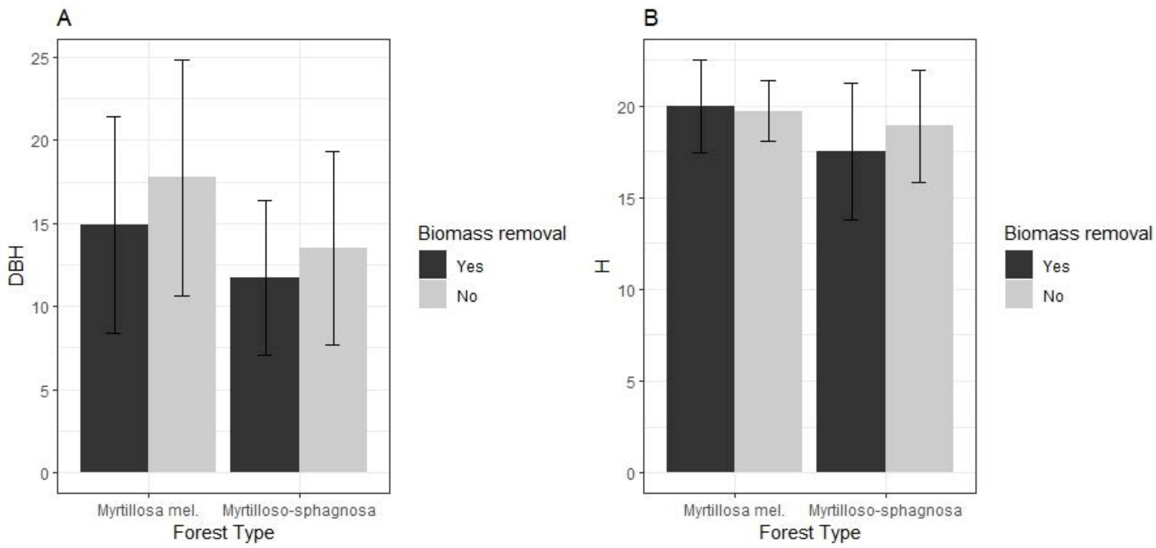

Figure 1. A mean DBH (cm) between biomass removal and conventional harvesting in both forest types. B mean tree height (m) between biomass removal and conventional harvesting in both forest types (in both pictures A and B error bars show standard deviation).

The ground vegetation of FBR stands in *Myrtillosa mel*. was most comparable to that of SAC and young stands (ANOSIM, R=0.07 and R=0.03, respectively). The same pattern was also seen in the *Myrtilloso-sphagnosa* forest type, where the FBR and SAC stand had the highest resemblance (R=0.11) (Table 2). Although FBR management and clear-cutting are different, the difference is not substantial (Berķis *et al*., 2013; Liepa *et al*., 2014; Olsson & Staaf, 1995). This resemblance between FBR and SAC stands is mostly due to the strong shade provided by spruce forests, which inhibits the growth of species that cannot tolerate shade (Huston, 1994). There were no significant differences on soil carbon (P>0.05) between FBR and SAC stands in *Myrtillosa mel.* (respectively, 90 g kg^{-1} and 111 g kg^{-1}) and *Myrtilloso-sphagnosa* (respectively, 95 g kg^{-1} and 86 g kg^{-1}) forest types when the total quantity of carbon (C) in the soil (80 cm) was examined. As there is also a significant difference amount of C between SAC stands in the two forest types, this type of management is likely to result in CO_2 emissions that do not have a positive effect on climate change in the current situation and should be followed by low-emission management practices (DeLuca & Boisvenue, 2012). Moreover, indications for soil density also indicated a detrimental effect; specifically, higher soil density causes lower C levels in the soil (Lazdiņš, 2012). The average diameter of the SAC stand in the *Myrtillosa mel*. forest type is 2.86 cm or 16%, greater than the FBR stand, which is statistically significant (P<0.05) from each other. The average diameter of the SAC stand in the *Myrtilloso-sphagnosa* forest type is 1.77 cm or 13%, greater than the FBR stand, which is statistically different (P<0.05) from each other (Figure 1). According to a Swedish study, which indicates a considerable difference in DBH between standard clearcutting and removal of all biomass, a stand might be significantly limited in growth by the removal of all biomass (Egnell, 2011).

Table 3

Stand type, composition, age and number of transects in both forest types of newest information

Forest Type	Type	Stand compostition	Age	Stand	Transects
Myrtillosa mel.	FBR[1]	10E	49	111-14	1
	FBR[1]	10E	49	111-15	4
	FBR[1]	10E	35	112-10	2
	SAC[2]	10E	41	108-13	1
	SAC[2]	10E	52	108-19	1
	SAC[2]	9E1B	49	112-12	1
	SAC[2]	10E	40	113-9	1
	SAC[2]	10E	34	121-9	2
	SAC[2]	10E	33	129-20	1
	Young stand	8E2P	24	156-9	1
	Young stand	7E3B	25	192-6	1
	Mature stand	7E2P1B	114	128-6	1
	Mature stand	8E1B1P	118	153-6	1
	Old stand	6E2P1A1B	144	28-35	1
	Old stand	7E3P	138	282-5	1
Myrtilloso-sphagnosa	FBR[1]	10E	50	66-3	1
	FBR[1]	10E	50	66-6	1
	SAC[2]	10E	49	61-15	1
	SAC[2]	10E	50	93-22	1
	Young stand	7E3A	26	72-2	1
	Young stand	9E1B	24	108-14	1
	Mature stand	9E1B	105	289-10	1
	Mature stand	10E	112	260-3	1
	Old stand	7E2A1B	154	247-8	1
	Old stand	10E	156	275-33	1

[1]. FBR – Full biomass removal stand, [2].SAC – Same age control stand.

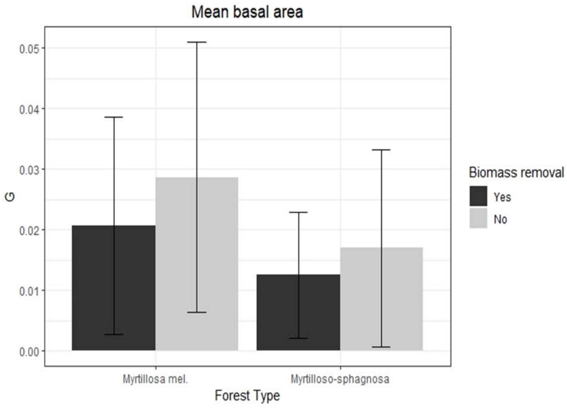

Figure 2. Mean basal area (G) between biomass removal and conventional harvesting in both forest types.

The SAC stand is 0.27 m or 2% lower than the FBR stand in the *Myrtillosa mel*. forest type, which is not statistically different (P>0.05) from each other. The SAC stand is 1.37 m or 6% higher than the FBR stand in the *Myrtilloso-sphagnosa* forest type, which is statistically different (P<0.05) from each other. According to a Finnish study, the removal of all biomass, which is what we observed in the *Myrtillosa mel*. stand in our study, may not have an impact on the growth of trees height (Kaarakka *et al*., 2014), while the removal of all biomass causes a greater deficit of nutrients in the *Myrtilloso-sphagnosa* stand (Egnell, 2011).

The basal area of the SAC stand is 0.0079 m^2 or 28% larger than the FBR stand in the *Myrtillosa mel.* forest type, which is statistically significant (P<0.05) from each other. The basal area of the SAC stand is 1.37 m, or 6%, larger than the FBR stand in the *Myrtilloso-sphagnosa* forest type, which is statistically different from each other (P<0.05) (Figure 2). Because there are no organic materials left in the forest stand from the previous stand after the removal of the whole biomass, the basal area of the trees might be reduced, which is impacted by the lack of minerals (Egnell, 2011; Sterba, 1988).

Conclusions

1. FBR stands were the most comparable to SAC stands among all the studied forest types in terms of the understory flora.
2. Between FBR and SAC stands, there was no statistically significant difference in soil carbon.
3. After all biomass is eliminated, tree stand DBH, height, and basal area have a considerable negative impact.
4. As a result of the long-term evaluation, it was determined that the forest vegetation in FBR was similar to that in the same-age control stand (SAC) and that vegetation can successfully regenerate.

References

Adams, A., Beatton, C., & Harrison, J. (2015). Greenhouse Gas Emission Reduction Strategy 2011–2020.

Aosaar, J., Drenkhan, T., Adamson, K., Aun, K., Becker, H., Buht, M., Drenkhan, R., Fjodorov, M., Jürimaa, K., Morozov, G., Pihlak, L., Piiskop, K., Riit, T., Varik, M., Väär, R., Uri, M., & Uri, V. (2020). The effect of stump harvesting on tree growth and the infection of root rot in young Norway spruce stands in hemiboreal Estonia. Forest Ecology and Management, 475(May), 118425. DOI: 10.1016/j.foreco.2020.118425.

Berķis, A., Meijere, A., Sedlenieks, A., Vanags, A., Ansons, G., Rove, I., Brauns, J., Grīslis, J., & Gaigals, M. (2013). Rokasgrāmata meža tipu noteikšanai (Guide to determination of forest types). LVM – Latvijas Valsts meži, 67 lpp. (in Latvian).

Bologna, M., & Aquino, G. (2020). Deforestation and world population sustainability: a quantitative analysis. Scientific Reports, 10(1), 1–9. DOI: 10.1038/s41598-020-63657-6.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community. *Australian Journal of Ecology*, *18*, 117–143. DOI: 10.1093/bioinformatics/bty844.

DeLuca, T.H., & Boisvenue, C. (2012). Boreal forest soil carbon: Distribution, function and modelling. Forestry, 85(2), 161–184. DOI: 10.1093/forestry/cps003.

Egnell, G. (2011). Is the productivity decline in Norway spruce following whole-tree harvesting in the final felling in boreal Sweden permanent or temporary? Forest Ecology and Management, 261(1), 148–153. DOI: 10.1016/j.foreco.2010.09.045.

Ellenberg, H. (1988). Vegetation Ecology of Central Europe (4th edn). UK Cambridge University Press.

Haferkamp, M.R. (1988). Environmental factors affecting plant productivity. In R. S. White & R. E. Short (Eds.), Achieving Efficient Use of Rangeland Resources (pp. 27–36). Montana Agr. Exp. Sta.

Hanewinkel, M., Cullmann, D.A., Schelhaas, M.J., Nabuurs, G.J., & Zimmermann, N.E. (2013). Climate change may cause severe loss in the economic value of European forest land. Nature Climate Change, 3(3), 203–207. DOI: 10.1038/nclimate1687.

Huston, M. (1994). Biological diversity. The coexistence of species on changing landscapes. Cambridge University Press.

Jansons, Ā., Robalte, L., Čakšs, R., & Matisons, R. (2016). Long-term effect of whole tree biomass harvesting on ground cover vegetation in a dry Scots pine stand. *Silva Fennica*, *50*(5). DOI: 10.14214/sf.1661.

Kaarakka, L., Tamminen, P., Saarsalmi, A., Kukkola, M., Helmisaari, H.-S., & Burton, A.J. (2014). Effects of repeated whole-tree harvesting on soil properties and tree growth in a Norway spruce (*Picea abies* (L.) Karst.) stand. Forest Ecology and Management, 313, 180–187. DOI: 10.1016/j.foreco.2013.11.009.

Kaarakka, L., Vaittinen, J., Marjanen, M., Hellsten, S., Kukkola, M., Saarsalmi, A., Palviainen, M., & Helmisaari, H.S. (2018). Stump harvesting in Picea abies stands: Soil surface disturbance and biomass distribution of the harvested stumps and roots. Forest Ecology and Management, 425(May), 27–34. DOI: 10.1016/j.foreco.2018.05.032.

Lazdiņš, A. (2012). Mežsaimniecisko darbību ietekmes uz siltumnīcefekta gāzu emisijām un CO_2 (Effects of forestry activities on greenhouse gas emissions and CO_2). Pētījuma pārskats. 144 lpp (in Latvian).

Liepa, I., Miezīte, O., Luguza, S., Šulcs, V., Straupe, I., Indriksons, A., Dreimanis, A., Saveļjevs, A., Drēska, A., Sarmulis, Z., & Dubrovskis, D. (2014). Latvijas meža tipoloģija. (Latvian forest typology). Studentu biedrība 'Šalkone'. 119 lpp. (in Latvian).

LVS ISO 10694:2006. (n.d.). Augsnes kvalitāte. Organiskā un kopējā oglekļa noteikšana pēc sausās sadedzināšanas (elementanalīze) (Soil quality. Determination of organic and total carbon after dry combustion (elemental analysis)). VSIA Latvijas Standarts: Rīga, Latvija, 12 lpp (in Latvian).

Merilä, P., Mustajärvi, K., Helmisaari, H. S., Hilli, S., Lindroos, A.-J., Nieminen, T.M., Nöjd, P., Rautio, P., Salemaa, M., & Ukonmaanaho, L. (2013). Above- and below-ground N stocks in coniferous boreal forests in Finland: Implications for sustainability of more intensive biomass utilization. Forest Ecology and Management, 311, 17–28. DOI: 10.1016/j.foreco.2013.06.029.

Messier, C., Puettmann, K.J., & Coates, K.D. (2013). Managing Forests as Complex Adaptive Systems: Building Resilience to the Challenge of Global Change. *International Journal of Environmental Studies*. Routledge.

Nikodemus, O., Kļaviņš, M., Krišjāne, Z., & Zelčs, V. (2018). Latvija – Zeme, Daba, Tauta, Valsts (Latvia – Land, Nature, Nation, State). Latvijas Universitātes Akadēmiskais apgāds, 752 lpp. (in Latvian).

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Henry, M.H., & Wagner, H. (2013). Vegan: Community Ecology Package. R Package Version 2.0-10.

Olsson, B.A., & Staaf, H. (1995). Influence of Harvesting Intensity of Logging Residues on Ground Vegetation in Coniferous Forests. *Journal of Applied Ecology*, 32(3), 640–654.

Priedītis, N. (1999). *Latvijas mežs: daba un daudzveidība* (Latvian forest: nature and diversity). WWF – Pasaules Dabas fonds, 209lpp. (in Latvian).

Pukkala, T. (2017). Does management improve the carbon balance of forestry? Forestry, 90(1), 125–135. DOI: 10.1093/forestry/cpw043.

R Core Team. (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing.

Ranius, T., Hämäläinen, A., Egnell, G., Olsson, B., Eklöf, K., Stendahl, J., Rudolphi, J., Sténs, A., & Felton, A. (2018). The effects of logging residue extraction for energy on ecosystem services and biodiversity: A synthesis. Journal of Environmental Management, 209, 409–425. DOI: 10.1016/j.jenvman.2017.12.048.

Ring, E., Jacobson, S., Jansson, G., & Högbom, L. (2017). Effects of whole-tree harvest on soil-water chemistry at five conifer sites in Sweden. *Canadian Journal of Forest Research*, 47(3), 349–356. DOI: 10.1139/cjfr-2016-0338.

Saarsalmi, A., Tamminen, P., Kukkola, M., & Hatajarvi, R. (2010). Whole-tree harvesting at clear-felling: Impact on soil chemistry, needle nutrient concentrations and growth of Scots pine. Scandinavian Journal of Forest Research, 25, 148–156. DOI: 10.1080/02827581003667314.

Shannon, C.E. (1948). A Mathematical Theory of Communication. *Bell System Technical Journal*, *27*(3), 379–423. DOI: 10.1002/j.1538-7305.1948.tb01338.x.

Smythe, N. (1970). Relationships between Fruiting Seasons and Seed Dispersal Methods in a Neotropical Forest. The American Naturalist, 104(935), 25–35. DOI: 10.1086/282638.

Spellerberg, I.F., & Fedor, P.J. (2003). Tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon–Wiener' Index. Global Ecology and Biogeography, 12, 177–179.

Sterba, H. (1988). Increment losses by full-tree harvesting in Norway spruce (*Picea abies*). Forest Ecology and Management, 24(4), 283–292. DOI: 10.1016/0378-1127(88)90105-3.

Thomas, S.C., & Martin, A.R. (2012). Carbon Content of Tree Tissues: A Synthesis. Forests, 3(2), 332–352. DOI: 10.3390/f3020332.

Thuresson, T. (2002). Northern Europe. In: Global Forest Resources Assessment 2000. Food and Agriculture

Organization of the United Nations.

Uri, V., Aosaar, J., Varik, M., Becker, H., Kukumägi, M., Ligi, K., Pärn, L., & Kanal, A. (2015). Biomass resource and environmental effects of Norway spruce (*Picea abies*) stump harvesting: An Estonian case study. Forest Ecology and Management, 335, 207–215. DOI: 10.1016/j.foreco.2014.10.003.

Walmsley, J.D., & Godbold, D.L. (2010). Stump harvesting for bioenergy – A review of the environmental impacts. Forestry, 83(1), 17–38. DOI: 10.1093/forestry/cpp028.

Weiss, G., Lawrence, A., Hujala, T., Lidestav, G., Nichiforel, L., Nybakk, E., Quiroga, S., Sarvašová, Z., Suarez, C., & Živojinović, I. (2019). Forest ownership changes in Europe: State of knowledge and conceptual foundations. Forest Policy and Economics, 99, 9–20. DOI: 10.1016/j.forpol.2018.03.003.

Yousefpour, R., Augustynczik, A.L.D., Reyer, C.P.O., Lasch-Born, P., Suckow, F., & Hanewinkel, M. (2018). Realizing Mitigation Efficiency of European Commercial Forests by Climate Smart Forestry. Scientific Reports, 8(1), 1–11. DOI: 10.1038/s41598-017-18778-w.