SMEAR II forest thinning: Description of the methods and background information for carbon storage estimation

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SMEAR II stand history

SMEAR II measurement station (Station for Measuring Ecosystem-Atmosphere Relations) is hosted by University of Helsinki. It's located in Juupajoki municipality, at Southern Finland, next to the Hyytiälä forestry field station (61°51'N, 24°17'E). Forests in the vicinity of the measurement station are mainly boreal, evergreen coniferous stands, dominated by Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H.Karst). SMEAR II station is located in a stand established by sowing after prescribed burning conducted in 1961. For further details, see Kolari *et al.* (2022).

A tall tower for flux measurements, including CO_2 flux between the forest and atmosphere is located in the middle of the study stand (Suni et al. 2003, Kolari et al. 2009). The study stand, neighboring stands, and majority of all stands within the 200 m radius from the station tall tower have been outside of routine forest management since the establishment of the measurement station more than 25 years ago. The study stand (about 6 hectares) has been thinned in two parts, first the northern half in 1993, and then the central and southern part in 2002. However the effect of the first thinning was mild (Vesala *et al.* 2005), for example the basal area of coniferous trees was reduced from 19.2 m^2 ha^{-1} to 18.0 m^2 ha^{-1} (Kolari *et al.* 2022).

As described by Kolari *et al.* (2022), in 2018 the stands within the 200 m radius from the tower were rather dense, and in addition to a decreasing trend in live crown ration (ratio between the living crown and tree height). In the beginning of year 2020, the live crown ratio was below 40 % for more than half of the pines at the site. Overall, many trees showed signs of decreased vitality, and especially obvious this was for suppressed, sub-dominant and co-dominant trees. Most of the stands located farther than 200 m away from the tall tower have been managed by Metsähallitus (Finnish Forest and Park Service), by following typical routines and schemes applied in Finnish commercially managed forests.

Aim of the forest management

To maintain the SMEAR II stand as a managed forest, a thinning from below was performed in 2020. The aim was to return the forest stand structure to resemble typical Finnish commercially managed forest. For the stands to be thinned, the aim was to reduce the stand basal area by about 40 %, close to the recommended lower limit of stand basal area for a forest at this stage of development (Best Practices for Sustainable Forest Management, Tapio).

To ensure that the majority of footprint area of the CO_2 flux measurement located in the tall tower would be similarly managed, all stands within 400 m radius from the tall tower were considered. Some stands within this radius were already sparse enough and thus not in need of thinning; they were left intact. In practice about 80 % of forest area within 200 m radius from the tall tower was thinned (in total about 12.5 ha, of

which 10 ha was thinned), as well as 10 ha outside of the 200 m radius but inside 400 m radius. In total, the thinned area covered 40 % of the forest area within 400 m radius around the tall tower.

Since the SMEAR II hosts also many long-term ecophysiological measurements requiring sufficient number of control trees for assessing the effect of thinning, a small area (about 0.6 hectare), South-East of the tall tower, was left intact.

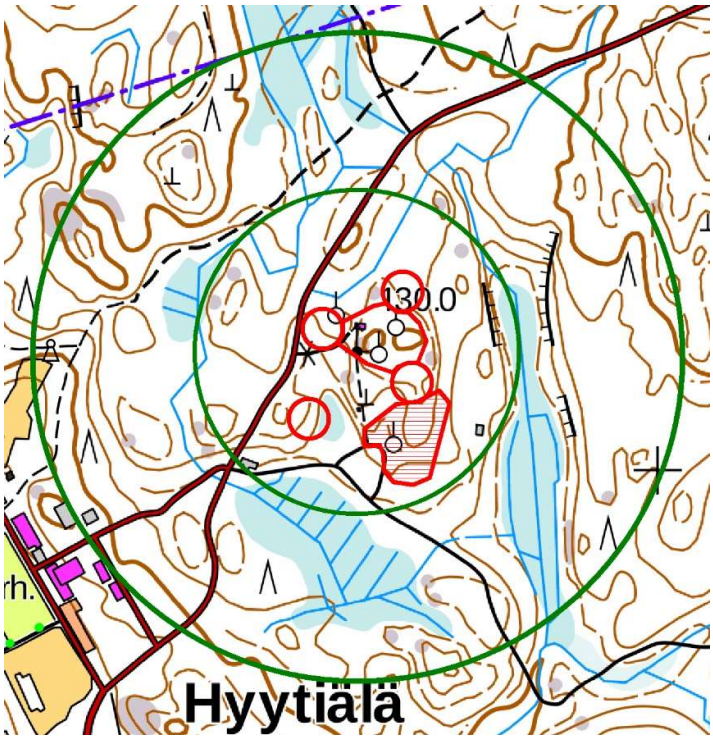

Figure 1. Target area for the management. The center of the target area is SMEAR II station tall tower. Two circles around the tall tower indicate 200 m and 400 m radii, of which the latter defines the thinning target area. Four open small circles & one open polygon near the tall tower indicate areas, where manual felling was applied as main method. The striped polygon indicates the unthinned control area.

Timing of the forest management

The management took place in two phases. First, the clearing of understorey trees (small, non-commercial trees), from those stands to be thinned took place in spring 2019. This is the practice according to the management recommendations (Best Practices for Sustainable Forest Management, Tapio), Second, the actual thinning took place in February-March 2020. Small area (about 1 hectare) in the middle of the study stand was thinned already in December 2019 and January 2020. Wintertime was chosen in order to minimize root damages caused by forest machines.

Management method

The first management, i.e. the clearing of understorey trees was conducted manually with a brush saw. The general guideline for clearing was to remove all understorey trees, except juniper (*Juniperus communis* L.). All felled understorey trees were left at the ground. It's worth noticing that the stands that were not in need of thinning were mostly left intact in understorey clearing.

The actual thinning was mostly conducted with normal machine used for logging, i.e. harvester, and short-distance transport of timber was done with forwarders, except where the measurement infrastructure or other sensitive objects required the usage of special methods. For those areas the thinning was conducted manually with a chainsaw.

For the majority of thinning area the thinning was classified as thinning from below, where most of the removed trees weare suppressed or sub-dominant, and only few co-dominant or dominant trees were cut. This type of thinning is the most typical method in case of even-aged forests in Finland. Cutting residue was left at the site in the thinning.

Some parts of the forest within 400 m radius had already achieved the condition enabling final cutting (regeneration felling). However, no final cuttings were conducted, and instead thinning from above or quality harvesting was applied.

Scots pines were favored in selection of remaining trees. Thus, the thinning decreased stand heterogeneity, when the proportion of other species than Scots pine was reduced. However, dominant tree species did not change at any of the thinned stands. Because Scots pine was already dominant species around the measurement station, majority of the cutting yield consisted of pines.

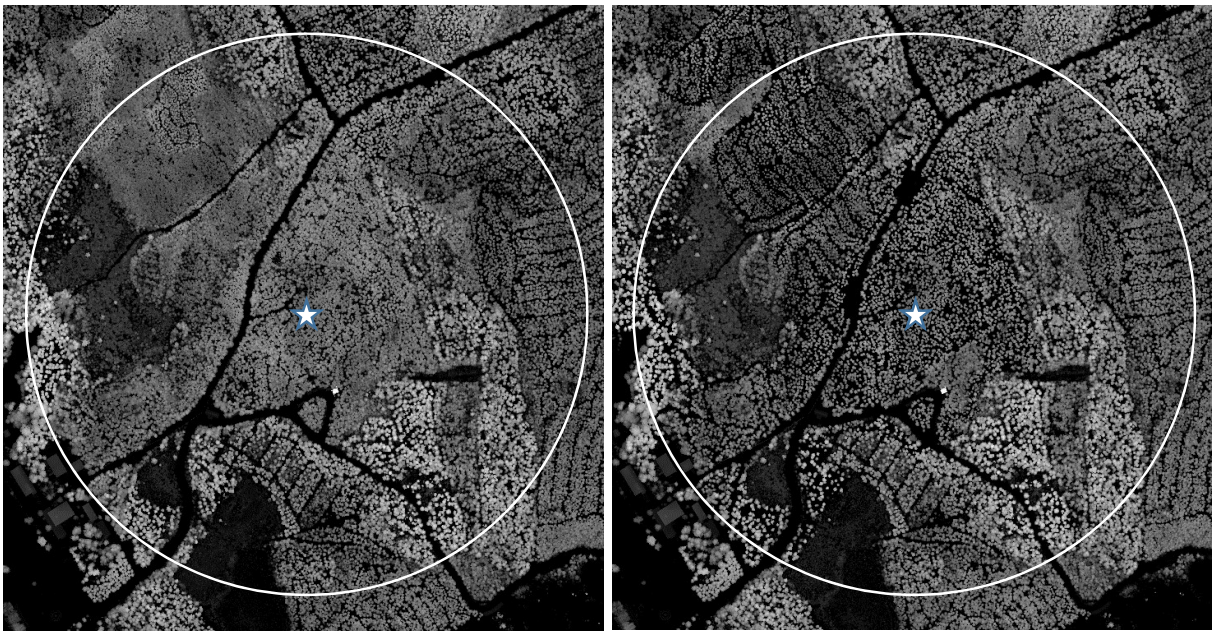

Figure 2. The target area before (May 2018, left) and after (June 2020, right) the thinning. Greyscale denotes the highest LiDAR (light detection and ranging) return height in 40-cm raster cells in the repeated LiDAR datasets. Airborne laser scanning and simultaneous RGB photography were carried out in May 24, 2018 (06:30 GMT) and June 3, 2020 (05:50 GMT) using a Riegl 1560 sensor operating at the wavelength of 1064 nm. LiDAR data has a pulse density of 30−50 pulses per m^2 and image resolution is 10 cm. The same flight trajectories and sensor settings were used to minimize their influence. The white circle is 400 radius around the tall tower (white star).

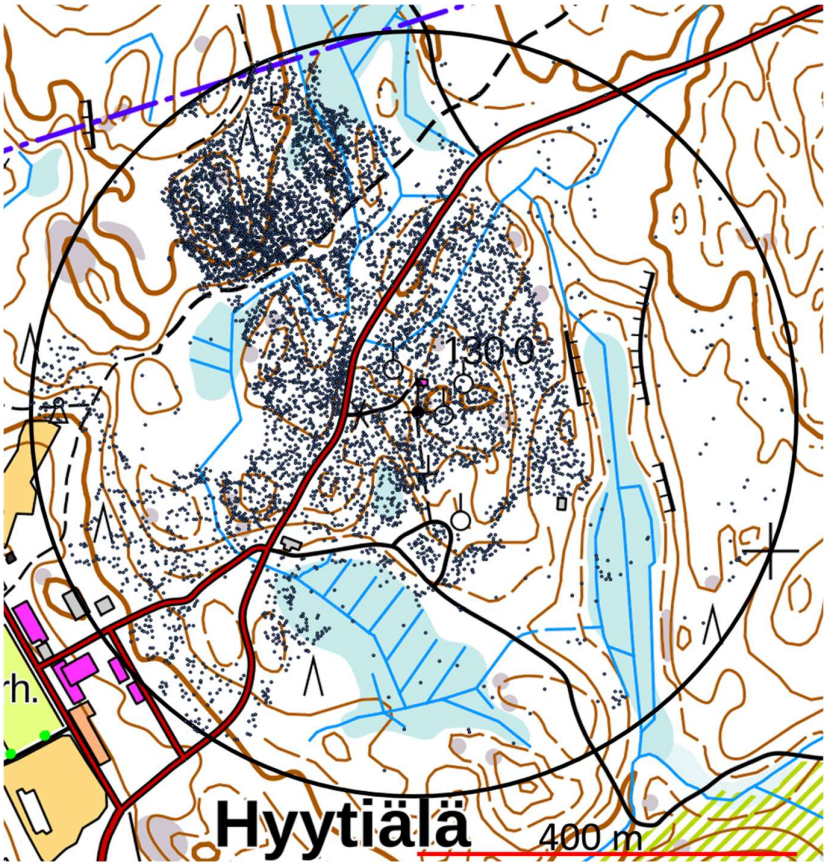

Figure 3. Map of trees that were removed in the thinning, or had felled in wind or were broken by snow between LiDAR campaigns of May 24, 2018 and June 3, 2020. The count of the dots is about 7200. Circle has a radius of 400 m and is centered at the SMEAR II tall tower. Standing trees in dominant canopy layer (N>40000) inside the circle were manually mapped (treetop 3D position, height, tree species) using aerial images and LiDAR of 2018 and an algorithm was used to detect tree removal using the 2020 LiDAR point cloud data.

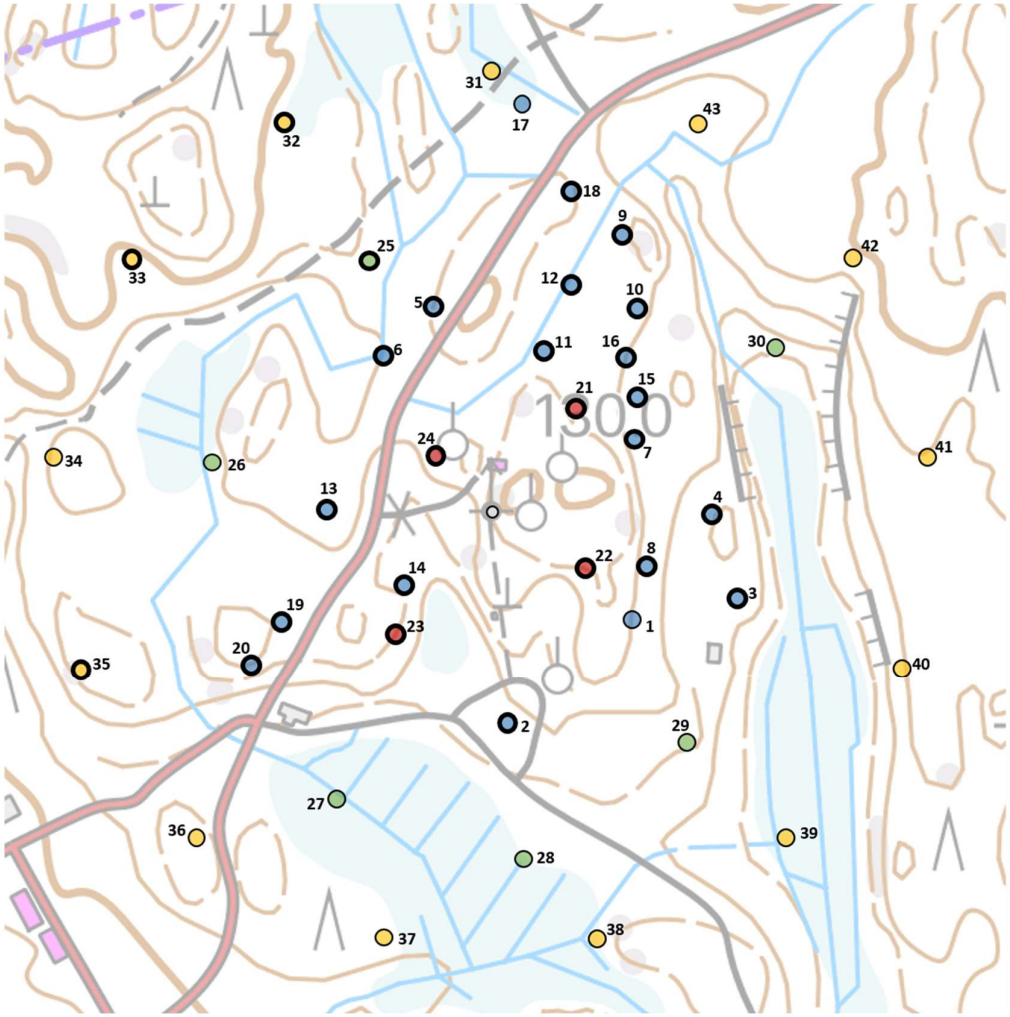

Figure 4. Measurement plots for biomass measurements. 43 plots in total, including 20 ICOS spatial sampling plots (numbers 1-20, blue dots in the map), 4 ICOS continuous measurements plots (21-24, red dots), 19 complementary plots (25-43, green and yellow dots). The plots marked with thick circle were thinned, whereas the plots marked with thin circle were not (plots 1 and 17 were thinned partially, i.e. some part of the plot thinned, some left intact).

Tree inventories

In this work understorey tree are trees that are at least 1 m in height but with diameter at stump height (at 0.15 m height) less than 9 cm.

Trees in dominant canopy layer are those with diameter at stump height 9 cm or higher.

We measured the standing and felled tree biomass in 43 plots (fig. 4), including 20 ICOS (Integrated Carbon Observation System) sparse sampling plots, 4 ICOS continuous measurements plots, 6 complementary plots at about 200 meter distance from the main mast, and 13 complementary plots at 300 meter distance from the main mast. ICOS refers to Integrated Carbon Observation System, in which the SMEAR II station is both Class 1 Ecosystem and Class 1 Atmosphere station. 26 of these plots were thinned, whereas 15 where left intact. 2 plots were thinned partially.

The understorey measurement grid consisted of the 43 above-mentioned measurement plots. Four 50 m^2 circular sub-plots (radius 3.99 m) were measured from each plot, one from each cardinal direction, center points at 10 m distance from measurement plot center stake. The total number of sub-plots was 43x4=172. Measured variable was stump height diameter ($D_{0.15}$), which was measured for both living and freshly felled trees. Understorey measurements were conducted during summer 2019.

Tree heights for felled understorey trees were estimated by determining an empirical relation between stump height diameter and tree height. As a material for determining the empirical relation, measured tree heights from every fourth sub-plot (that located to north from plot center) were utilized.

Trees forming the dominant canopy layer were measured from 43 plots. Size of the circular plot was 707 m^2 (radius 15 m), except at 5 plots, where it was reduced to 314 m^2 (radius 10 m) because of high tree count. Measurements were conducted during summer 2020, i.e. in the summer following the thinning. Diameter at stump height of living trees and fresh stumps inside the plots were measured. In addition, also standing deadwood was measured in the same way. Also the dimensions of pieces of fallen, fresh stemwood left at the site during the thinning and the deadwood felled by the harvester were measured.

Tree height, crown base height, crown ratio and diameter at breast height for individual trees in dominant canopy layer were estimated by determining empirical relations between stump height diameter and the target variables. As a material for determining those empirical relations, the detailed measurements carried out at plots 1-24 were utilized; those measurements were part of regular ICOS Ecosystem measurements.

Understorey tree biomasses were estimated separately for belowground and aboveground compartment. Biomasses for trees in dominant canopy layer were estimated separately for stem, bark, dead and living branches, stump, coarse roots and leaves. Detailed description on the utilization of biomass equations can be found from the datafile 'read me' tab. In short, key methods were the Repola biomass equations (Repola 2008, 2009), the stem volume equations according to Laasasenaho's method (Laasasenaho 1982) and the stem and bark biomass functions (Lehtonen et al. 2004). All biomasses were converted to carbon by assuming that half of the dry mass is carbon; other carbon content factors can be used after reverse calculation of mass C to biomass with factor of 2.

Table 1. Mean and median tree count, diameter at breast height, tree height and dominant height of trees in dominant layer before and after the thinning, calculated based on plot-specific means. For the thinned plots n=26, for all plots n=43.

	Tree count before 1 ha^{-1}	Tree count after 1 ha^{-1}	$D_{1,3}$ before cm	$D_{1,3}$ after cm	Height before m	Height after m	Dominant height before m	Dominant height after m
All plots								
mean	954	614	16.6	20.5	17.6	18.9	22.7	22.7
median	891	523	16.8	22.1	17.9	20.5	23.0	22.9
200 m radius								
mean	961	488	17.4	22.2	18.6	20.5	22.9	22.8
median	934	439	18.2	22.6	19.0	20.9	23.0	22.9
Thinned plots								
mean	1021	465	17.1	22.2	18.4	20.5	23.0	22.9
median	934	453	17.8	22.6	18.8	20.8	23.0	22.9

Table 2. Basal areas and summertime leaf mass of trees in dominant layer before and after the thinning, calculated based on plot-specific means. For the thinned plots n=26, for all plots n=43.

	Scots pine basal area before	Scots pine basal area after	Total basal area before	Total basal area after	Stem volume before	Stem volume after	Summertime leaf mass before	Summertime leaf mass after
	$m^2\ ha^{-1}$	$m^2\ ha^{-1}$	$m^2\ ha^{-1}$	$m^2\ ha^{-1}$	$m^3\ ha^{-1}$	$m^3\ ha^{-1}$	$kg\ ha^{-1}$	$kg\ ha^{-1}$
All plots								
mean	18	12	27	19	262	189	4251	3133
median	19	15	29	18	280	189	4017	2590
200 m radius								
mean	24	15	31	18	298	185	4308	2638
median	28	16	31	18	306	189	4017	2382
Thinned plots								
mean	25	15	31	18	302	182	4323	2500
median	28	16	31	18	304	187	4065	2449

Table 3. Some key carbon storage statistics before and after the thinning, as arithmetic means over plot-specific estimates, for thinned (n=26) and all (n=43) plots. For the mean of deadwood other than cutting residue, the count for thinned plots was 22, and for all plots 24; certain deadwood measurements were not conducted for plots 25… …43. Unit for all readings is Mg C ha^{-1}.

	Understorey trees		All trees				
	Living trees before	Living trees after	Living trees before	Living trees after	Commercial removal (logs and pulpwood)	Cutting residue (including understorey)	Other deadwood (present already before the thinning)
Thinned plots	6.1	0.8	92.6	53.2	24.4	15.0	3.8
200 m radius	6.4	1.0	92.0	54.4	23.1	14.5	3.7
All plots	5.5	1.9	82.2	57.8	14.9	9.5	4.0

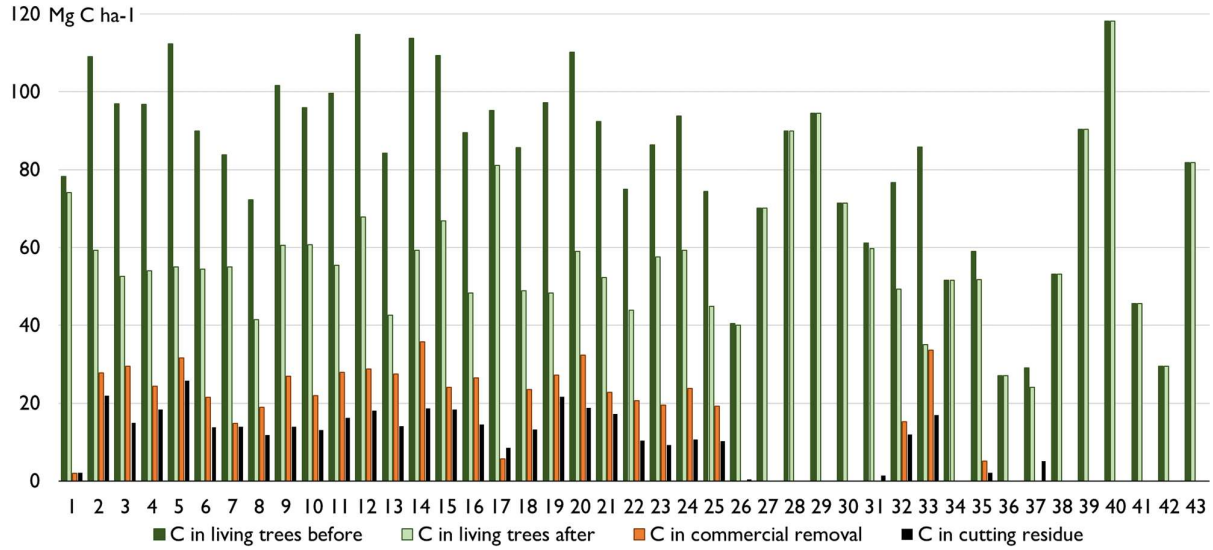

Figure 5. Carbon storage in living trees, including understorey trees, before and after the thinning at the 43 biomass measurement plots around the SMEAR II stand. Cutting residue was left at the site in the thinning. Commercial removal means timber that was transported away during the thinning.

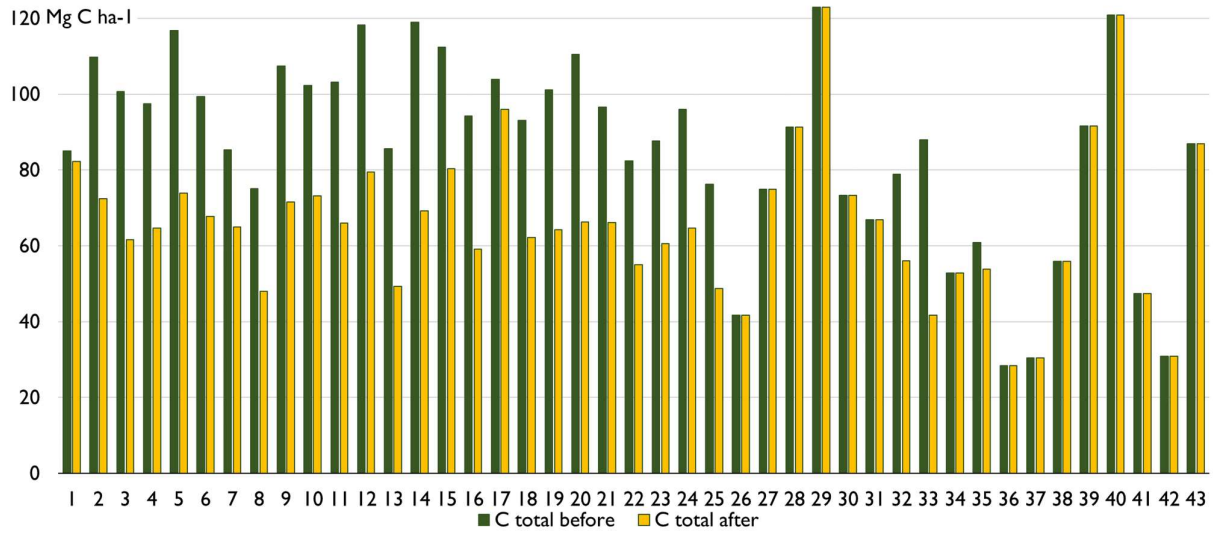

Figure 6. Carbon storage at the SMEAR II stand before and after the thinning. Bars indicate C in living trees, including understorey trees, deadwood and cutting residue at the 43 biomass measurement plots around the SMEAR II stand. The difference between the storages measured before and after the thinning equals to the carbon storage in commercial removal.

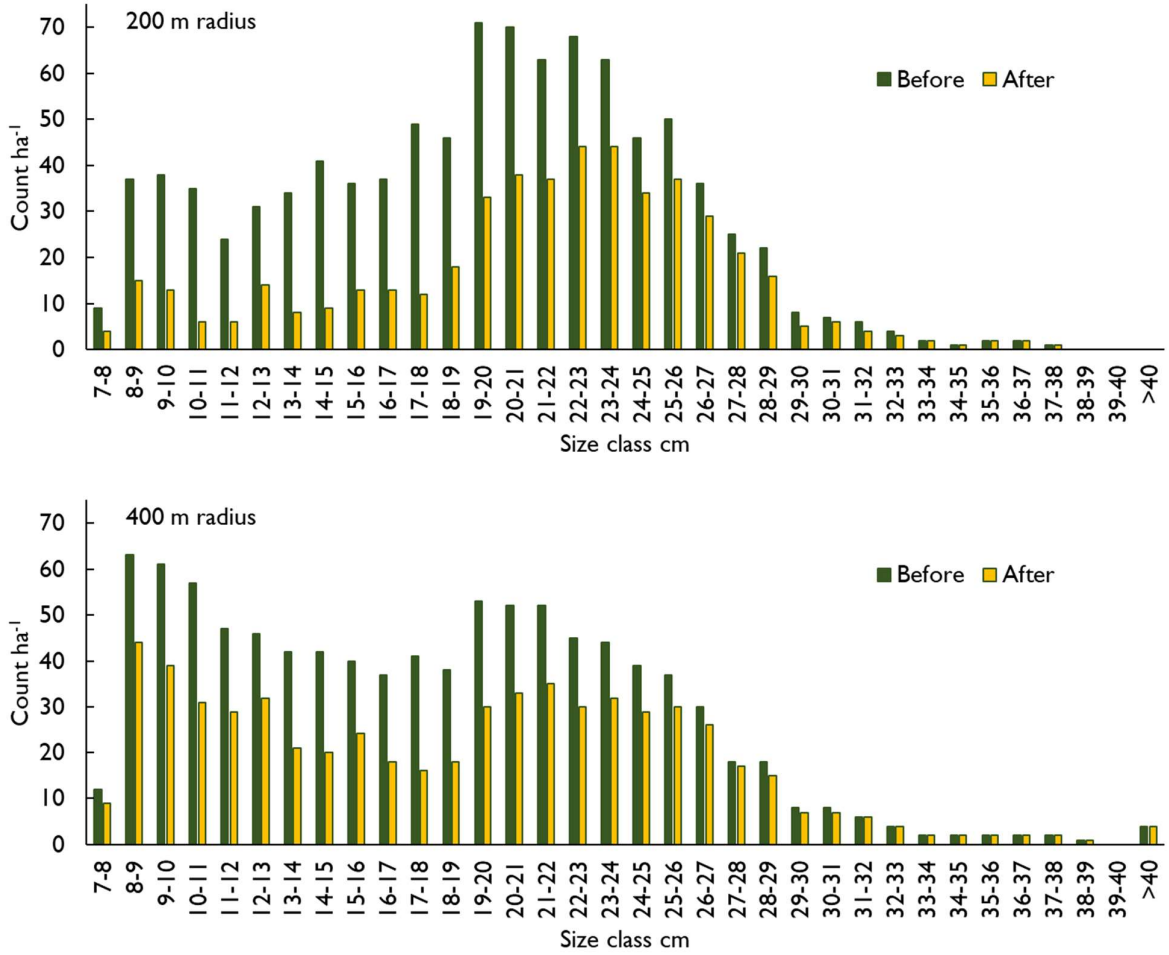

Figure 7. Tree size distribution (by diameter at 1.3 m) at 200 m radius (upper panel) and 400 m radius (lower panel) around the tall tower, before and after the thinning. Trees with $D_{0.15}$>90 mm area included in the count, i.e understorey trees have been left out.

References

Laasasenaho J 1982. Taper curve and volume functions for pine, spruce and birch. *Communicationes Instituti Forestalis Fenniae* 108.

Lehtonen A, Mäkipää R, Heikkinen J, Sievänen R, Liski J 2004. Biomass expansion factors (BEFs) for Scots pine, Norway spruce and birch according to stand age for boreal forests. *Forest Ecology and Management* 188, 211-224. doi:10.1016/j.foreco.2003.07.008

Kolari P, Kulmala L, Pumpanen J, Launiainen S, Ilvesniemi H, Hari P, Nikinmaa E 2009 CO_2 exchange and component CO_2 fluxes of a boreal Scots pine forest. *Boreal Environment Research* 14, 761-783

Kolari P, Aalto J, Levula J, Kulmala L, Ilvesniemi H, Pumpanen J 2022 Hyytiälä SMEAR II site characteristics [Data set]. Zenodo. https://doi.org/10.5281/zenodo.5909681

Repola J 2008 Biomass equations for Birch in Finland. *Silva Fennica* 42(4), 605-624

Repola J 2009 Biomass equations for Scots pine and Norway spruce in Finland. *Silva Fennica* 43(4), 625-647

Suni T, Rinne J, Reissell A, Altimir N, Keronen P, Rannik Ü, Dal Maso M, Kulmala M, Vesala T 2003. Long-term measurements of surface fluxes above a Scots pine forest in Hyytiälä, southern Finland, 1996-2001. *Boreal Environment Research* 8(4), 287-301

Vesala T, Suni T, Rannik Ü, Keronen P, Markkanen T, Sevanto S, Grönholm T, Smolander S, Kulmala M, Ilvesniemi H, Ojansuu R, Uotila A, Levula J, Mäkelä A, Pumpanen J, Kolari P, Kulmala L, Altimir N, Berninger F, Nikinmaa E, Hari P 2005. Effect of thinning on surface fluxes in a boreal forest. *Global Biogeochemical cycles* 19. doi:10.1029/2004GB002316

Best Practices for Sustainable Forest Management, Tapio, https://metsanhoidonsuositukset.fi/en (cited on the 13th of Feb 2023)