Impact of variable retention harvesting on carbon sequestration in a red pine (*Pinus resinosa* Ait.) plantation in southern Ontario

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1. Context

- The impacts of greenhouse gas production and climate change are important for natural and managed ecosystems.
- There is concern about the sustainability, health, and carbon sequestration potential of many forest ecosystems as global temperatures continue to rise.
- Variable retention harvesting (VRH) may be a potential method to increase forest biodiversity, growth, and carbon (C) sequestration.
- A field trial was established in an 88-year-old red pine (Pinus resinosa Ait.) plantation in southern Ontario, Canada (Fig. 1), using a completely randomized design to examine the response of tree productivity and other forest values to four harvesting treatments (Fig. 2) that altered the number of trees within a plot and their spatial distribution after management techniques were applied in February 2014 (Fig. 3)
- Control sites, where no treatments were applied, were also studied.

2. Aim of the study: The aim of our study was to determine the impacts that different variable retention harvesting treatment types (e.g., changing the percentage and spatial distribution of remaining trees) have on tree growth and carbon sequestration at the tree- and stand-level.

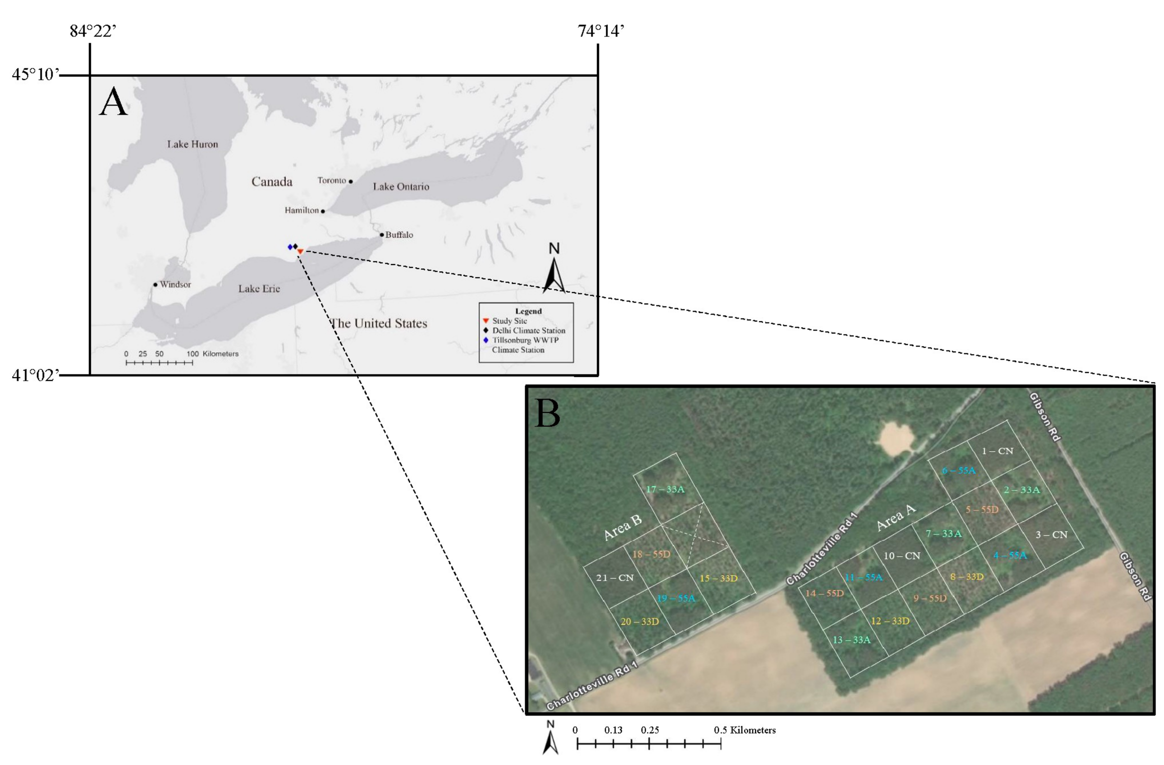


Figure 1 (A) Regional location of the study sites in the lower Great Lakes in southern Ontario, Canada. (B) Randomized locations of the 20 study plots, including four unharvested control plots (CN), and four of each of the following treatment plots: 33% dispersed retention plots (33D), 55% dispersed retention plots (55D), 33% aggregate retention plots (33A), and 55% aggregate retention (55A) (From Zugic et al., 2021).

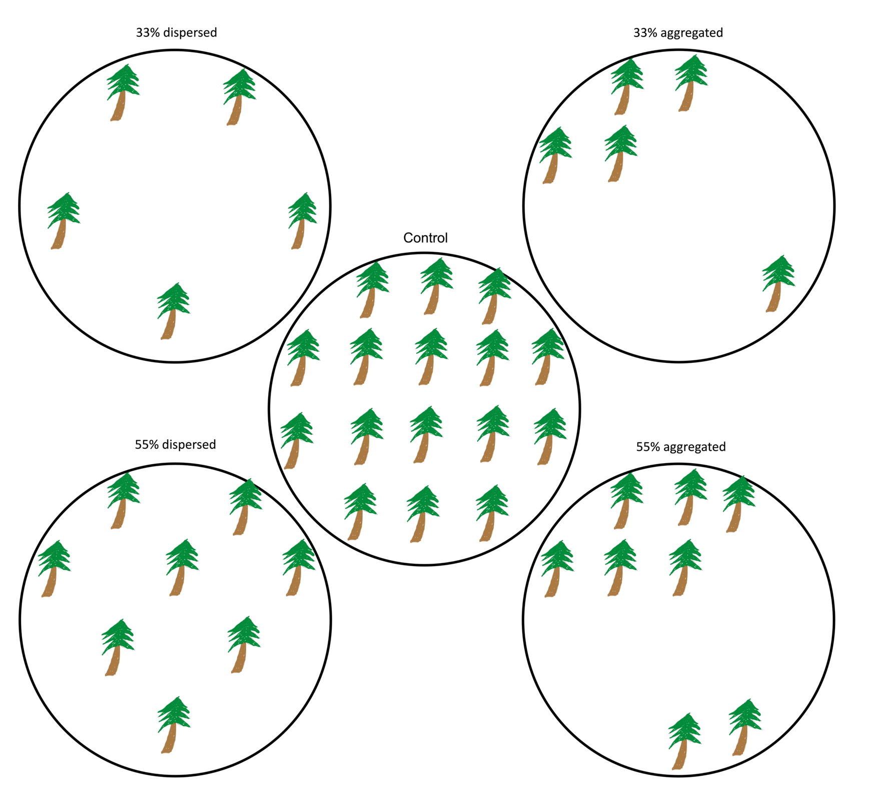


Figure 2. Schematic of control and variable retention harvesting plots that were employed in the study. Retention refers to the percentage of trees that were left within the plot after harvesting. Dispersed and aggregate refer to the spatial distribution of the remaining trees after harvesting.

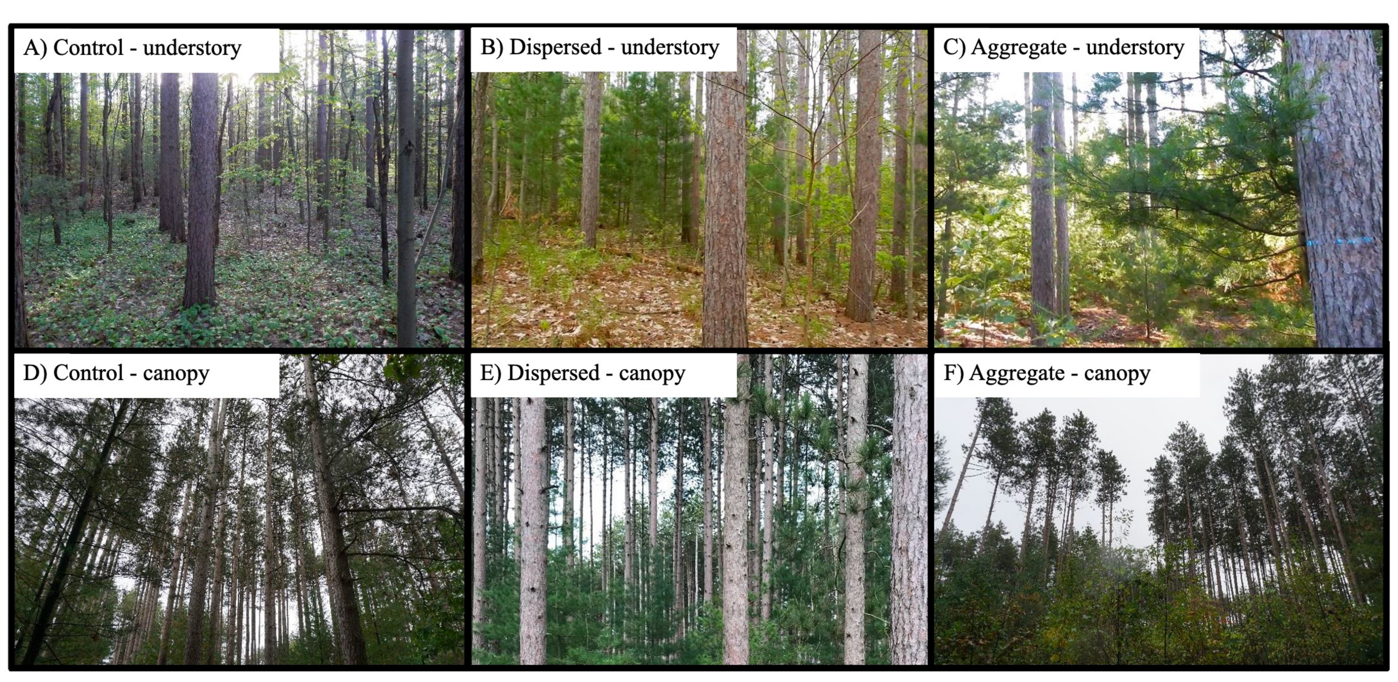


Figure 3. Photographs of understory (A–C) and canopy level (D–F) conditions for control (A,D), dispersed retention (B,E), and aggregate retention (C,F) treatments (From Zugic et al., 2021).

3. Study Site and Methods

- Tree cores were collected from >600 trees across 20 treatment plots at the St. Williams Conservation Area (Figure 2).
- After sanding, cores were scanned at 1600 dpi and ring widths were measured to the nearest 0.001 mm using CooRecorder and CDendro (Larsson, 2018). Visual crossdating was verified using COFECHA (Holmes, 1983, 1994).
- ARSTAN (Cook & Holmes, 1986) was used to detrend the tree-ring data using conservative curve fitting approaches (e.g., negative exponential curves and positive, negative, and horizontal lines). A few samples were detrended with a cubic smoothing spline.
- Summary statistics for each plot chronology are presented in Table 1.
- We quantified tree- and stand-level effects of VRH during a five-year pre-harvest (2009–2013) and post-harvest (2014–2018) period.
- For each plot/treatment, the following were computed:

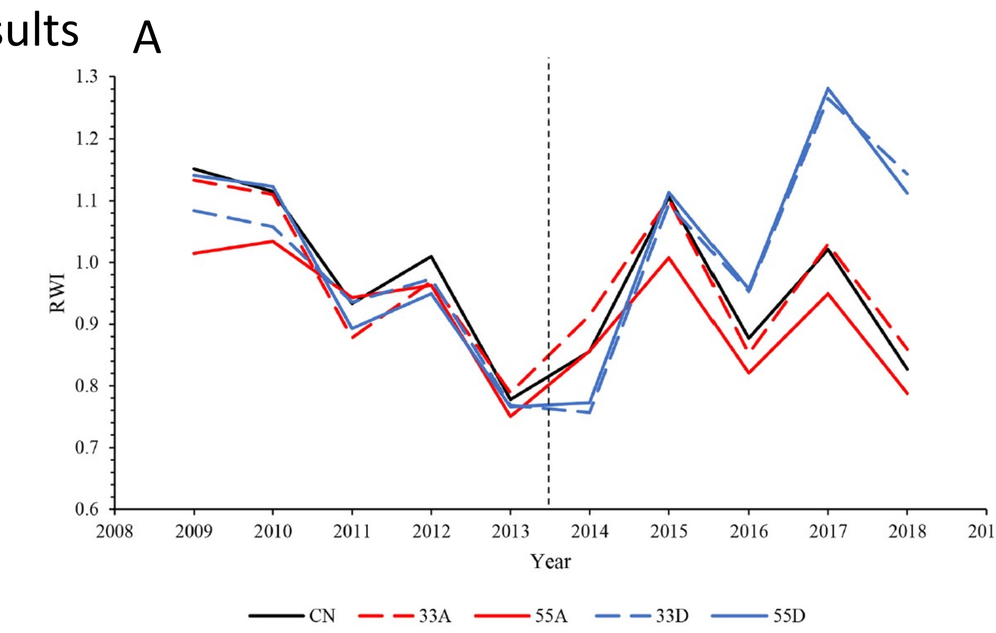
1. Percent growth change (%GC)
2. Annual stem biomass and carbon increment
3. Tree-level stemwood carbon increment
4. Stand-level carbon estimates

Table 1. Summary statistics for tree-ring chronologies and sample trees for the 20 VRH treatment plots (From Zugic et al., 2021).

Treatment & plot	Chronology interval	Number of years	Number of series (n)	Series intercorrelation	Mean ring width (mm)	Ring width SD (mm)	Autocorrelation	Mean DBH (cm)	DBH SD (cm)	Range in DBH (cm)
CN–Plot 01	1937–2018	82	62	0.651	1.55	1.240	0.910	30.4	4.0	23.1–42.5
CN–Plot 03	1936–2018	83	60	0.680	1.58	1.216	0.887	30.0	4.5	22.6–40.5
CN–Plot 10	1936–2018	83	62	0.583	1.79	1.565	0.936	34.1	4.6	28.0–44.1
CN–Plot 21	1937–2018	82	60	0.642	1.47	1.123	0.906	28.1	3.9	21.9–35.1
33A–Plot 02	1936–2018	83	60	0.722	1.58	1.308	0.898	30.2	4.5	21.1–37.7
33A–Plot 07	1936–2018	83	60	0.633	1.61	1.372	0.909	30.8	4.1	22.4–38.3
33A–Plot 13	1936–2018	83	61	0.551	1.75	1.525	0.922	33.3	3.4	27.2–40.6
33A–Plot 17	1937–2018	82	60	0.651	1.50	1.123	0.902	28.1	3.1	23.6–37.7
55A–Plot 04	1936–2018	83	60	0.654	1.62	1.314	0.904	31.5	4.9	25.8–44.5
55A–Plot 06	1936–2018	83	62	0.603	1.62	1.294	0.919	31.5	3.6	26.1–40.3
55A–Plot 11	1936–2018	83	60	0.569	1.65	1.396	0.927	31.8	5,1	23.0–44.1
55A–Plot 19	1936–2018	83	60	0.662	1.60	1.332	0.897	29.4	4.0	22.2–39.2
33D–Plot 08	1936–2018	83	60	0.736	1.67	1.173	0.872	31.4	3.5	25.0–38.6
33D–Plot 12	1936–2018	83	60	0.600	1.82	1.571	0.937	34.6	4.1	28.6–45.8
33D–Plot 15	1937–2018	82	60	0.715	1.54	1.088	0.877	29.2	2.6	24.6–36.4
33D–Plot 20	1936–2018	83	60	0.644	1.64	1.163	0.880	30.7	4.5	23.3–42.0
55D–Plot 05	1936–2018	83	63	0.711	1.52	1.152	0.893	29.6	2.8	24.6–38.2
55D–Plot 09	1936–2018	83	61	0.615	1.67	1.308	0.904	32.1	2.8	26.4–37.5
55D–Plot 14	1936–2018	83	60	0.609	1.89	1.352	0.893	35.8	4.1	30.7–45.6
55D–Plot 18	1937–2018	82	60	0.690	1.64	1.148	0.894	30.2	3.6	22.5–36.0

CN, unharvested control; 33A, 33% aggregate retention; 55A, 55% aggregate retention; 33D, 33% dispersed retention; 55D, 55% dispersed retention; SD, standard deviation; DBH, diameter at 1.3 m height.

4. Results



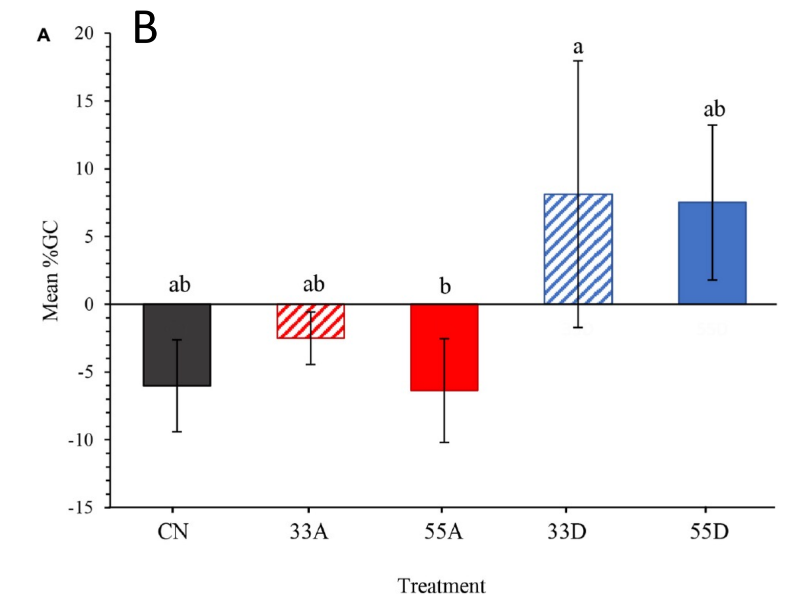
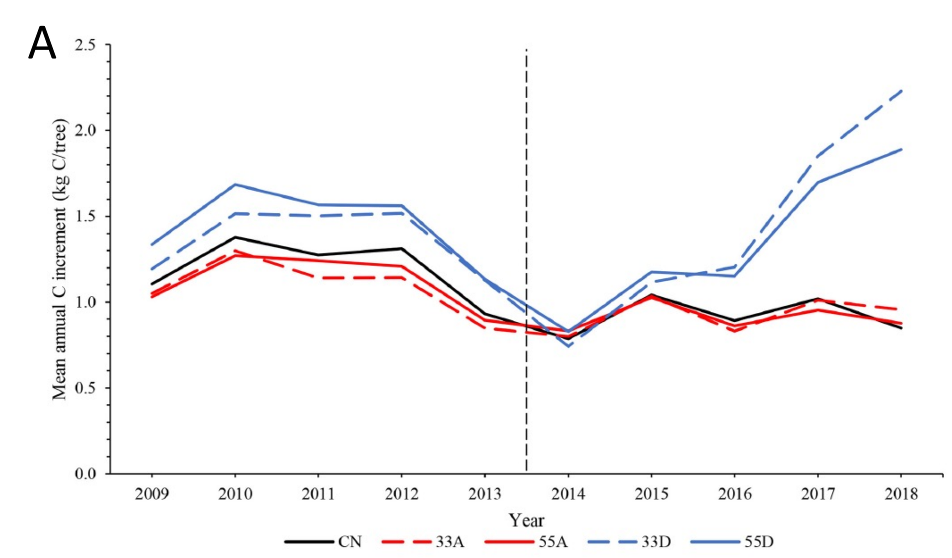
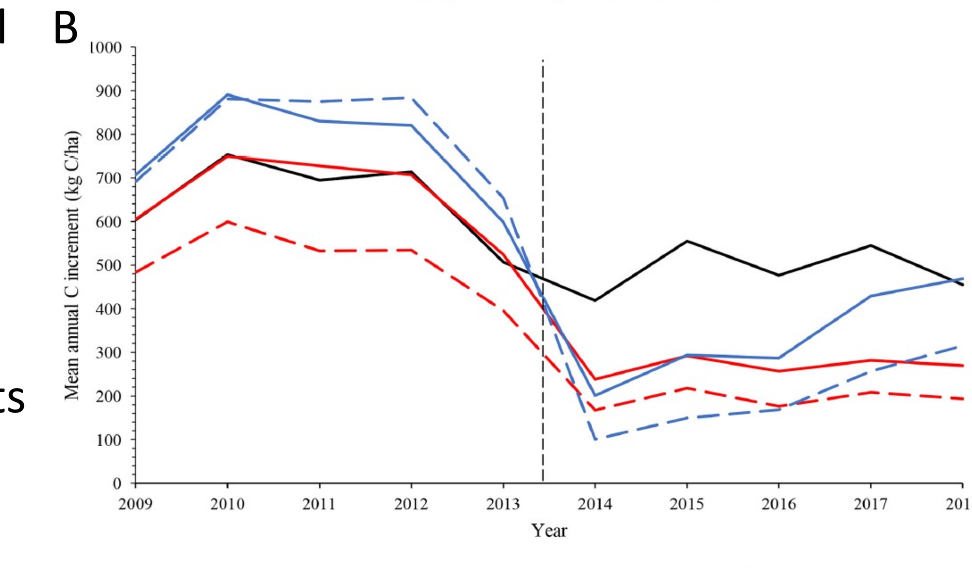


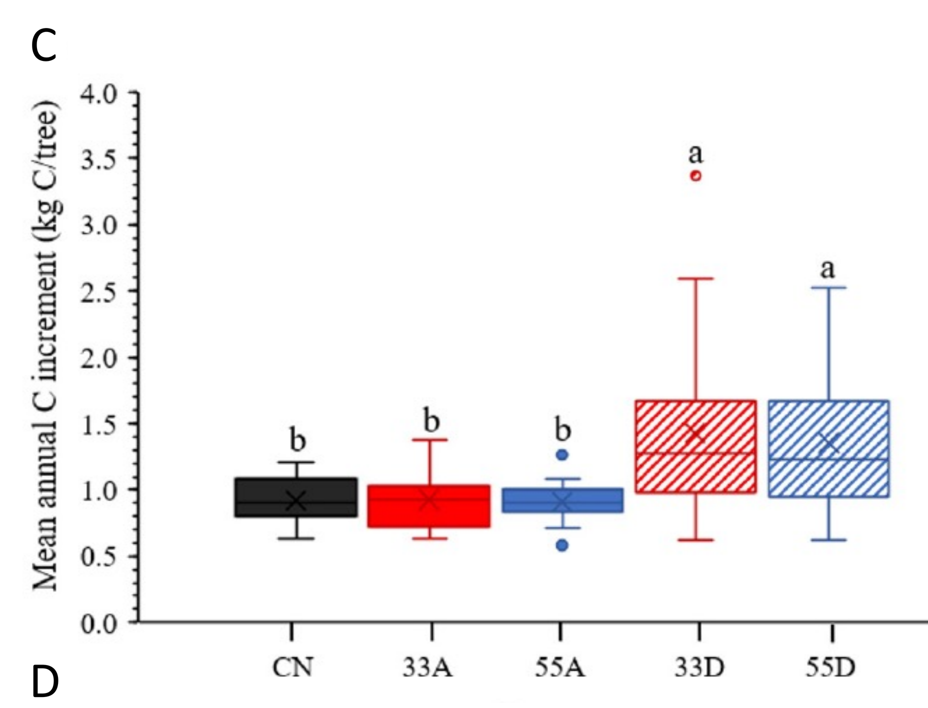
Figure 4. (A) Ring width indices (RWI) for residual chronologies for each of the different treatments and the control plots. The vertical line represents when the VRH treatments occurred and divides the pre-harvest (2009–2013) and post-harvest (2014–2018) periods. (B) Percent growth change (%GC) for the VRH treatments between the pre- and post-harvest (2014–2018) periods (From Zugic et al., 2021).

- Harvest treatments took place in February 2014, prior to the onset of the growing season
- By 2016 (2 years post-harvest), trees in the dispersed treatment plots experienced significantly higher growth than the control and aggregate treatment plots, with ring-width indices being ~30% higher in dispersed treatment plots by 2017 (Fig. 4 A and B)





- Comparing individual tree- and stand-level annual C increment for the pre-harvest (2009–2013) and post-harvest (2014–2018) periods, yields very different results (Fig. 5A-D).
- At the tree-level, forest thinning led to significant increases in mean annual tree C increment (kg C/tree) for the 33D and 55D treatment plots (Fig. 5A).
- Mean annual tree C increment (kg C/tree) for the 33D and 55D treatment plots were comparable and not statistically different from one another post-harvest in 2014 (Fig. 5C). However, both treatment plots showed significantly higher mean annual tree C increment (kg C/tree), compared to the Control and Aggregate plots (Fig. 5C)
- At the stand-level, annual C increment (kg C/ha) was lower across all treatment types in the post-harvest (2014–2018) period compared to the pre-harvest period (Fig. 5B).
- At the stand level, the 55D treatment plots had lower annual C increment (kg C/ha) compared to the Control plots, but the difference was not statistically significant (Fig. 5D). For all other treatments, annual C increment at the stand-level (kg C/ha) were significantly lower than the Control plots (Fig. 5D).



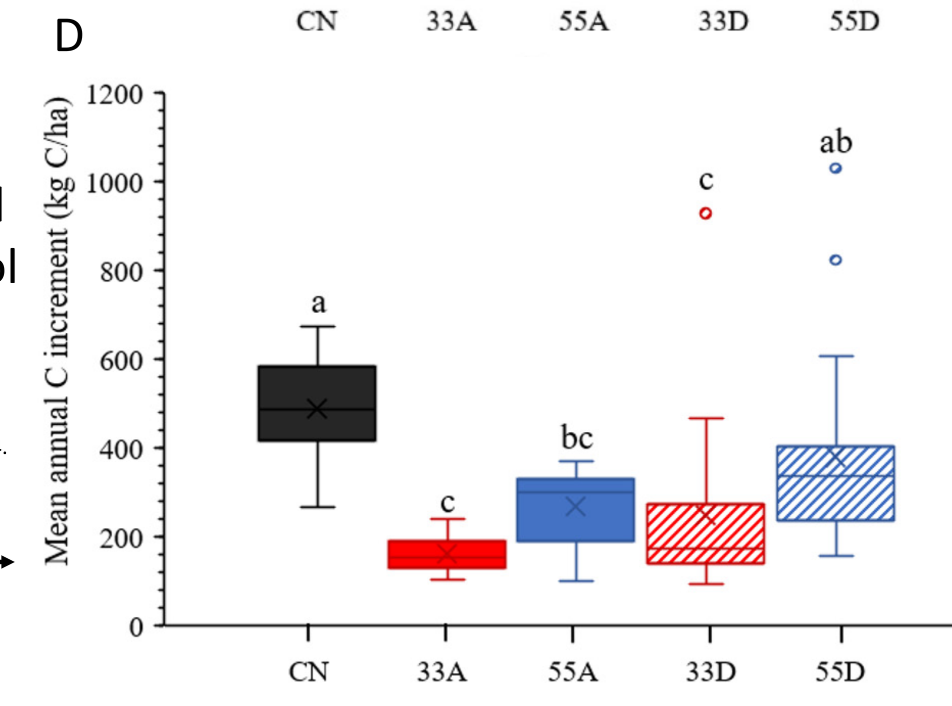


Figure 5. (5A) Tree and (5B) stand-level carbon (C) increments during the pre- and post harvest periods for each VRH treatment type. The vertical dashed line represents timing of the VRH treatments in February 2014. Box and whisker plots comparing differences in tree- (5C) and stand-level (5D) mean annual C increment across the different VRH treatment types for the post-harvest period (2014–2018). Means sharing the same letters are not significantly different. The X in the middle of each box represents the treatment mean (From Zugic et al., 2021).

5. Conclusions

- Our study shows that VRH has a significant effect on tree- and stand-level stem growth.
- Greater C increment was related to the level and spatial pattern of tree retention.
- Dispersed treatments (33D and 55D) were more effective in promoting post-harvest tree-level growth
- Stand-level growth and C increment were highest for greater levels of tree retention, regardless of pattern.

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6. References

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