Coarse woody debris: Pre- and post-thinning

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Overview

The aim of this research was to understand the impact of fuel load management (i.e., thinning) on fuels. Our objective was to evaluate the short-term impact of thinning on levels of coarse woody debris (total, and by fuel class). To meet this objective, we used a "treatment and control" approach to compare fuel levels before (control, pre-thinning) and after (treatment, post-thinning) thinning was applied at five vegetation monitoring plots.

The control and treatment data sets were collected at two time points in 2021. Control data were collected before thinning, between 6/9/21 and 7/7/21. Treatment data were collected after thinning on 10/18/21 and 10/19/21, with the exception of measurements for plot FOR10 which surveyed on 12/9/21. On average, 133.6 days elapsed between control and treatment surveys (range: 104 to 183, standard deviation = 27.2).

We used these data to answer the following questions:

1. Did the total fuel load (all coarse woody debris fuel classes combined) differ between control and treatment surveys?
2. Did fuel load for between control and treatment surveys differ by fuel class?

Fuel measurements for coarse woody debris mass We answered these questions using plot-level data collected before and after treatment (i.e., pre- and post-thinning) for (1) the total amount of coarse woody debris and (2) the mean amount of each of the five fuel classes. We defined "total (or all) coarse woody debris" as the combined total of the the five fuel classes within a plot: 1-hr, 10-hr, 100-hr, 1000-hr rotten, 1000-hr sound.

Recall that surveys were conducted along three transects within each plot. We calculated the ***plot-level mean for each fuel class*** to account for replicate surveys within each plot. To calculated the the ***plot-level total*** at each time point, we summed the plot means for all CWD fuel classes.

Below is a table that shows the plot-level mean at each time point for coarse woody debris (total and mean by fuel class).

fuel_class	plot_id	Pre-thin	Post-thin	metric	units
All	FOR05	36.479	349.466	total	MT/ha
All	FOR06	3.119	96.256	total	MT/ha
All	FOR07	57.459	392.693	total	MT/ha
All	FOR08	146.628	68.708	total	MT/ha
All	FOR10	7.384	52.145	total	MT/ha
1-hr	FOR05	1.275	1.617	mean	MT/ha
1-hr	FOR06	0.377	4.037	mean	MT/ha
1-hr	FOR07	2.842	1.936	mean	MT/ha
1-hr	FOR08	0.257	0.917	mean	MT/ha
1-hr	FOR10	0.192	1.759	mean	MT/ha
10-hr	FOR05	5.106	6.034	mean	MT/ha
10-hr	FOR06	1.679	5.526	mean	MT/ha
10-hr	FOR07	6.012	8.460	mean	MT/ha
10-hr	FOR08	1.447	1.988	mean	MT/ha
10-hr	FOR10	2.731	3.346	mean	MT/ha
100-hr	FOR05	1.109	14.517	mean	MT/ha
100-hr	FOR06	1.062	9.780	mean	MT/ha
100-hr	FOR07	3.312	8.969	mean	MT/ha
100-hr	FOR08	110.112	4.419	mean	MT/ha
100-hr	FOR10	4.461	5.514	mean	MT/ha
1000-hr rotten	FOR05	0.000	0.000	mean	MT/ha
1000-hr rotten	FOR06	0.000	0.000	mean	MT/ha
1000-hr rotten	FOR07	0.000	0.000	mean	MT/ha
1000-hr rotten	FOR08	34.811	0.000	mean	MT/ha
1000-hr rotten	FOR10	0.000	0.000	mean	MT/ha
1000-hr sound	FOR05	28.989	327.298	mean	MT/ha
1000-hr sound	FOR06	0.000	76.912	mean	MT/ha
1000-hr sound	FOR07	45.293	373.329	mean	MT/ha
1000-hr sound	FOR08	0.000	61.384	mean	MT/ha
1000-hr sound	FOR10	0.000	41.527	mean	MT/ha

The data subset for the 1000-hr rotten fuel class was not normally distributed; most values were equal to zero. Specifically, 29 of the 30 transect measurements equaled 0 and 9 of 10 plot-level means were 0 (pre-thin: 4/5, post-thin: 5/5).

lab_fuel	lab_class	lab_time	count
Coarse woody debris	1000-hr rotten	Pre-thinning	4
Coarse woody debris	1000-hr rotten	Post-thinning	5
Coarse woody debris	1000-hr sound	Pre-thinning	3

Statistical methods Statistically significant differences were identified using repeated measures analysis of variance (ANOVA) and post hoc comparisons. P-values were adjusted using the Bonferroni multiple testing correction method.

[NOTE: A repeated measures ANOVA is appropriate to use for a paired time series (before vs. after, treatment vs. control). For these data in particular, the approach accounts for elements that structure the data set in addition to time. For example, transects within each plot are more likely to be similar than transects between plots.]

The repeated-measures ANOVA is used for analyzing data where same subjects are measured more than once. This test is also referred to as a within-subjects ANOVA or ANOVA with repeated measures. The "within-subjects" term means that the same individuals (here, individuals are plots) are measured on the same outcome variable under different time points. The main goal of a repeated measures ANOVA is to evaluate if there is a statistically significant interaction effect between within-subjects factors in explaining a continuous outcome variable. The repeated measures ANOVA makes the following assumptions about the data:

- No significant outliers in any cell of the design
- Normality: the outcome (or dependent) variable should be approximately normally distributed in each cell of the design
- Assumption of sphericity: the variance of the differences between groups should be equal

We assessed outliers using the the interquartile range (IQR; IQR = Q3 - Q1). Values above Q3 + 1.5xIQR or below Q1 - 1.5xIQR are considered as outliers. Values above Q3 + 3xIQR or below Q1 - 3xIQR are considered as extreme points (or extreme outliers). Q1 and Q3 are the first and third quartile, respectively. Extreme outliers can be due to data entry errors, measurement errors, or unusual values. The outlier may be included if one believes the result will not be substantially affected; this can be evaluated by comparing the result of the ANOVA with and without the outlier.

We assessed normality by visual inspection of a QQ plot for each time point. A QQ plot draws the correlation between a given data and the normal distribution. We also conducted the Shapiro-Wilk test for each time point. Using this method, normally distributed data will have p-value >0.05.

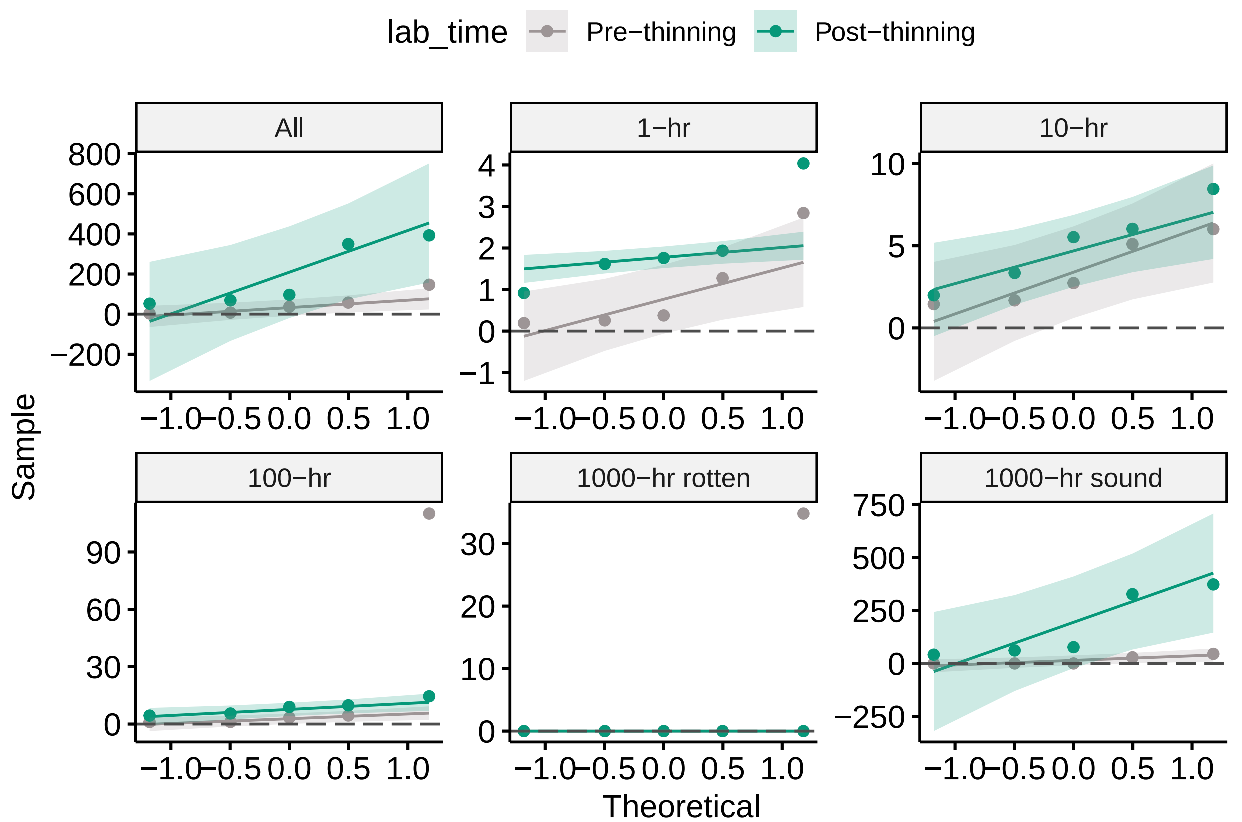
The assumption of sphericity was checked during the computation of the ANOVA test using the R function anova_test() [rstatix package]. The Mauchly's test was internally used to assess the sphericity assumption, and the Greenhouse-Geisser sphericity correction was automatically applied to factors violating the sphericity assumption.

Check assumptions

Check for outliers There were no extreme outliers in the data set for total CWD; a non-extreme outlier was found in pre-thinning total at FOR08. There were three extreme outliers by fuel class: pre-thinning 100-hr and 1000-hr rotten in FOR08; post-thinning 1-hr in FOR06. Overall it looks like something was different about FOR08 during pre- and post-thinning surveys.

fuel_class	time	plot_id	si_value	units	is_outlier	is_extreme
100-hr	Pre-thin	FOR08	110.112	MT/ha	TRUE	TRUE
1000-hr rotten	Pre-thin	FOR08	34.811	MT/ha	TRUE	TRUE
1-hr	Post-thin	FOR06	4.037	MT/ha	TRUE	TRUE

As expected, outliers were seen in the QQ plots created using CWD raw values for 1-hr, 100-hr, and 1000-hr rotten.



Check for normality Shapiro-Wilk's test indicated that plot-level values were normally distributed for total CWD and for mean CWD within the 1-hr and 10-hr fuel classes. Three fuel classes were not normally distributed: 100-hr, 1000-hr rotten (mostly 0 values), 1000-hr sound.

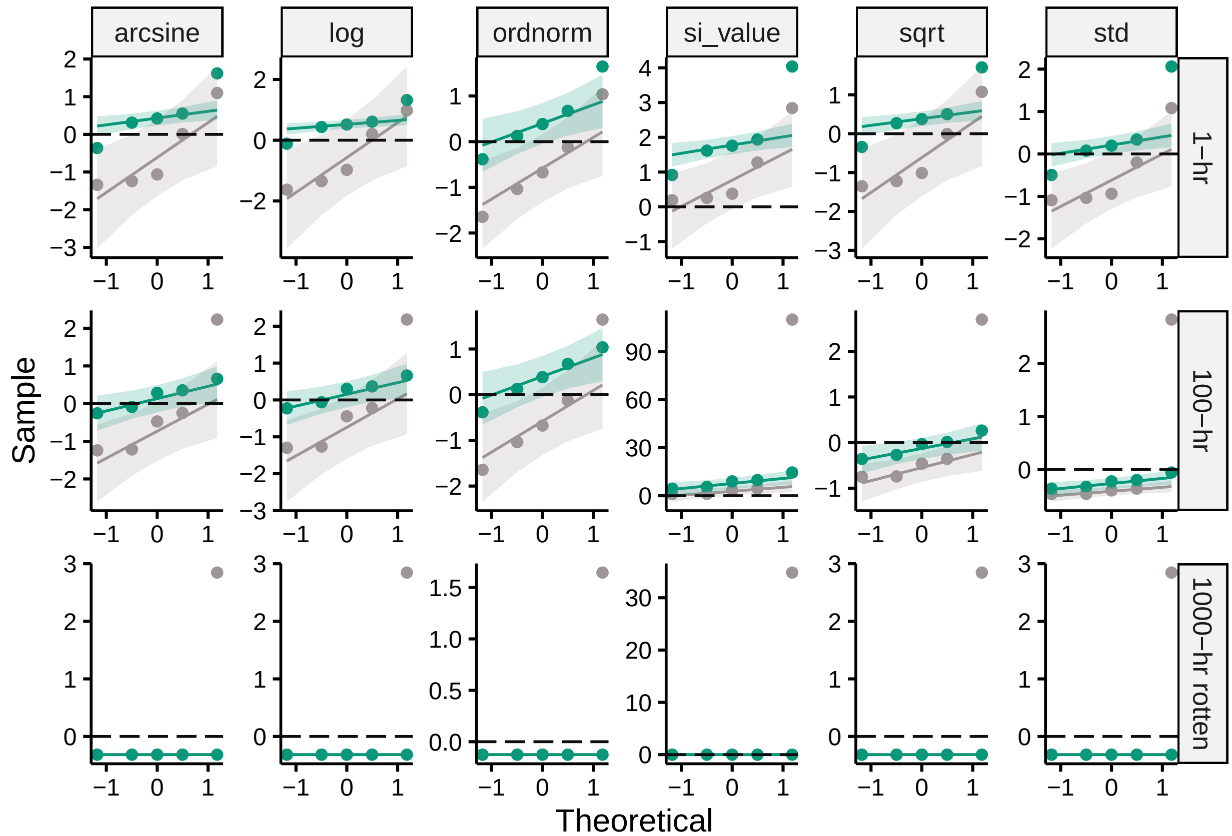
lab_class	time	is_normal	p	statistic
100-hr	Pre-thin	FALSE	0.0003236	0.579
1000-hr sound	Pre-thin	FALSE	0.0448490	0.770

Identify the most appropriate transformation We applied a series of transformations to each subset, then evaluated the resulting data for outliers and normality. To create the transformed subsets, we used scale() from base R and four normalization functions from the bestNormalize package: arcsinh_x, log_x, orderNorm, and sqrt_x.

The application of the orderNorm function resolved outliers within the 1-hr and 100-hr subsets. Outliers within the 1000-hr rotten subset were not improved with any transformation.

lab_class	fuel_class	time	lab_time_abbr	method	plot_id	number	is_outlier	is_extreme
100-hr	hr0100	t1	Pre-thin	value_arcsinh	FOR08	2.231336	TRUE	FALSE
100-hr	hr0100	t1	Pre-thin	value_log	FOR08	2.180986	TRUE	FALSE
100-hr	hr0100	t1	Pre-thin	value_norm	FOR08	1.644854	TRUE	FALSE
100-hr	hr0100	t1	Pre-thin	value_ordnorm	FOR08	1.644854	TRUE	FALSE
1-hr	hr0001	t2	Post-thin	value_norm	FOR06	1.644854	TRUE	FALSE
1-hr	hr0001	t2	Post-thin	value_ordnorm	FOR06	1.644854	TRUE	FALSE

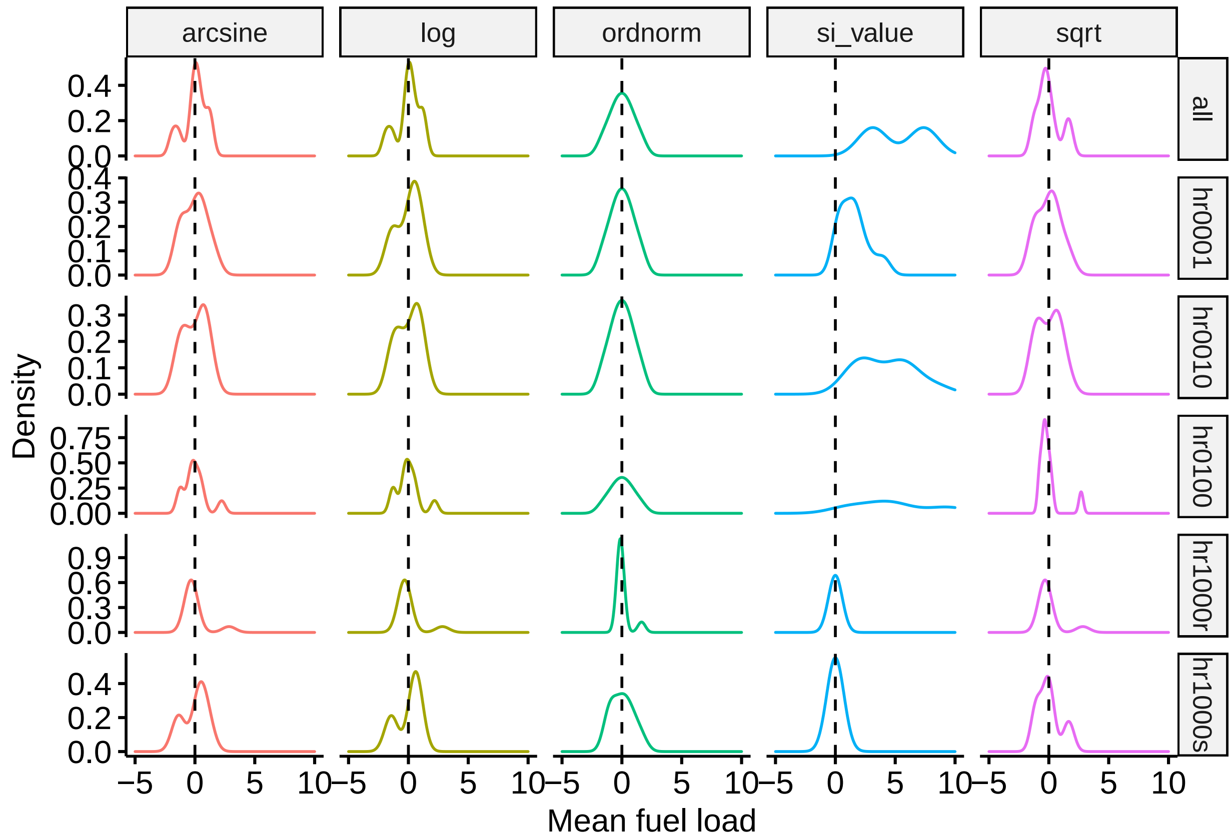
A QQ plot of the values for fuel classes with outliers (rows) by transformation (columns) is below.



The application of the orderNorm function resulted in values for the 100-hr fuel class that were normally distributed, as assessed by Shapiro-Wilk's test. No transformation normalized the distribution of the 1000-hr sound subset.

fuel_class	time	is_normal	method	p	statistic
hr0100	t1	TRUE	value_arcsine	0.0762655	0.7967817
hr0100	t1	TRUE	value_log	0.1061219	0.8146592
hr0100	t1	TRUE	value_norm	0.5416692	0.9218079
hr0100	t1	TRUE	value_ordnorm	0.5416692	0.9218079

The following plot shows the values by fuel class (rows) and transformation method (columns). The orderNorm function (green) appeared to be an effective normalization method for most data subsets overall, and was used to tranform CWD values (total and by fuel class).



Total fuel load

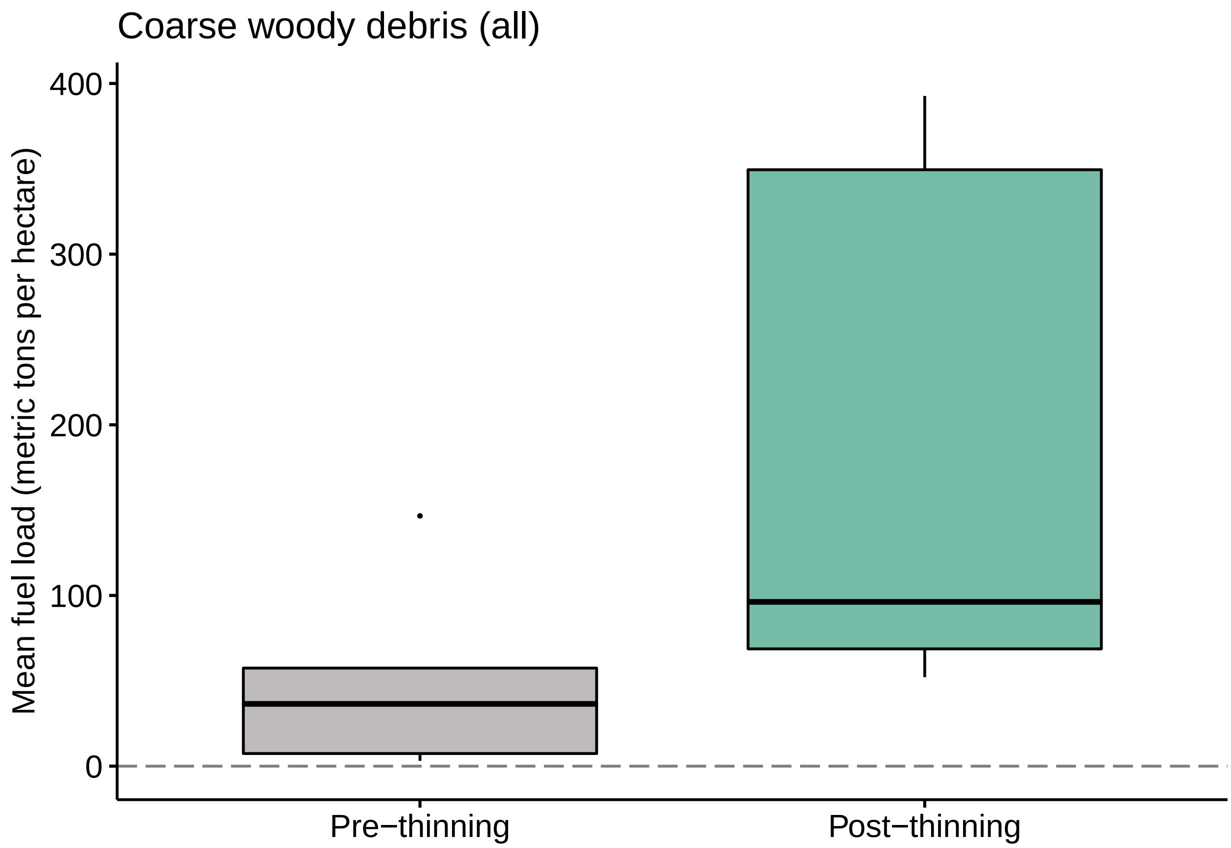
Summary statistics for total fuel load by treatment

The following table summarizes the plot-level total amount of CWD for each time point.

fuel_type	fuel_class	lab_time	si_units	mean	sd	n
Coarse woody debris	All	Pre-thinning	Metric tons per hectare	50.214	58.286	5
Coarse woody debris	All	Post-thinning	Metric tons per hectare	191.854	165.076	5

Visualization of total fuel load by treatment

Visual inspection of a boxplot for total CWD by treatment suggests a post-thinning increase in mass.



Main effect of treatment on total fuel load

We found no significant effect of treatment on total fuel load (all CWD fuel classes combined), F(1, 4) = 4.205, p-adj. = 0.11, ges = 0.313. P-values were adjusted using the Bonferroni multiple testing correction method.

fuel_type	fuel_class	method	effect	p_adj	p_adj_sig	statistic	d_fn	d_fd	ges	index_value
Coarse woody debris	All	main effect	time	0.11	n.s.	4.205	1	4	0.313	value_norm

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Mean fuel load, by fuel class

Next, we investigated whether there was a significant change in plot-level fuel load by treatment when accounting for fuel class. A two-way repeated measures ANOVA was used to determine whether there was a significant interaction between treatment and fuel class on fuel load.

Here, the effect of treatment on fuel load was our focal variable of primary concern. However, the effect of treatment may differ between fuel classes, so fuel_class was considered a moderator variable.

Summary statistics for mean fuel load by fuel class and treatment

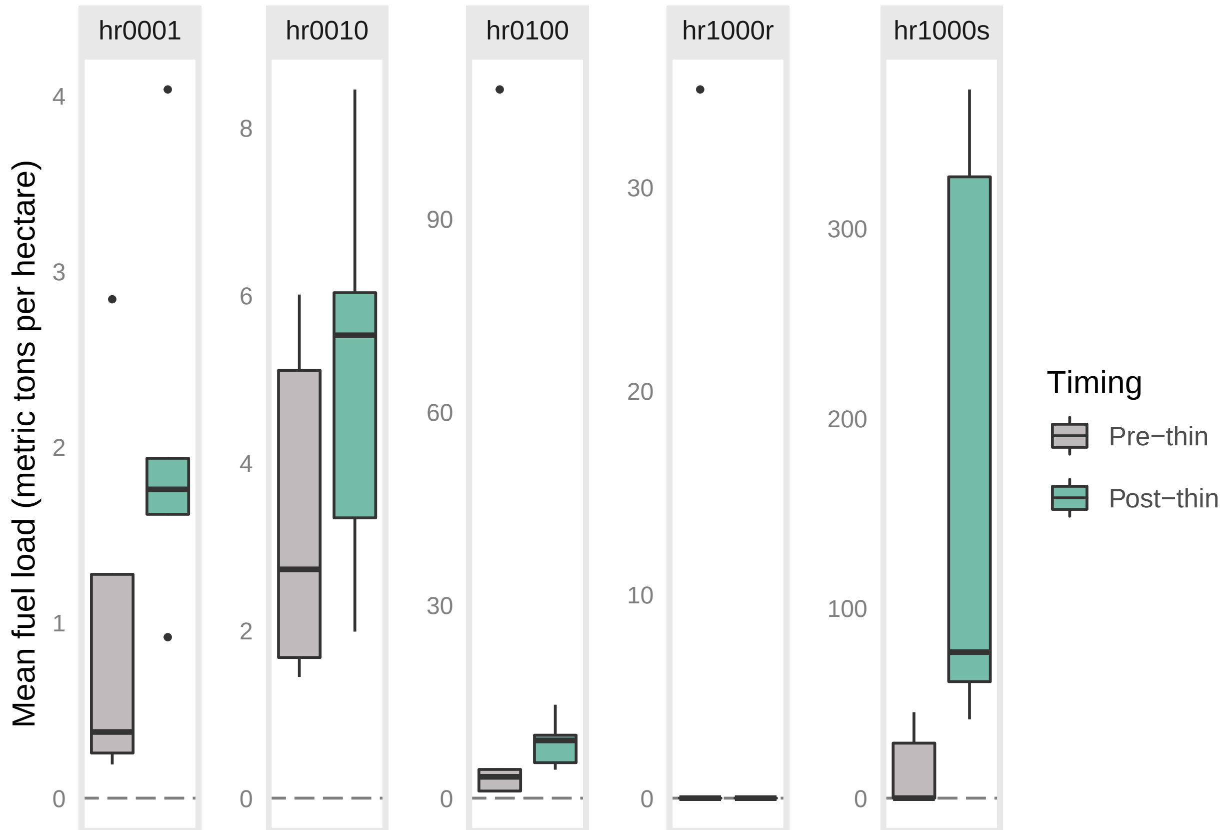
The following table shows the plot-level mean values for the five CWD fuel classes at each time point. We observed an increase in mean fuel load after thinning for the following fuel classes: 1-hr, 10-hr, 1000-hr rotten, and 1000-hr sound. Mean fuel load for the 100-hr fuel class decreased after thinning (pre-thin = 24.01, post-thin = 8.64).

fuel_type	fuel_class	lab_time	si_units	mean	sd	n
Coarse woody debris	hr0001	Pre-thinning	Metric tons per hectare	0.989	1.125	5
Coarse woody debris	hr0001	Post-thinning	Metric tons per hectare	2.053	1.174	5
Coarse woody debris	hr0010	Pre-thinning	Metric tons per hectare	3.395	2.059	5
Coarse woody debris	hr0010	Post-thinning	Metric tons per hectare	5.071	2.505	5
Coarse woody debris	hr0100	Pre-thinning	Metric tons per hectare	24.011	48.154	5
Coarse woody debris	hr0100	Post-thinning	Metric tons per hectare	8.640	3.985	5
Coarse woody debris	hr1000r	Pre-thinning	Metric tons per hectare	6.962	15.568	5
Coarse woody debris	hr1000r	Post-thinning	Metric tons per hectare	0.000	0.000	5
Coarse woody debris	hr1000s	Pre-thinning	Metric tons per hectare	14.856	21.144	5
Coarse woody debris	hr1000s	Post-thinning	Metric tons per hectare	176.090	160.365	5

Visualization of mean fuel load by fuel class and treatment A visual inspection of boxplots of the plot-level mean values for the five CWD fuel classes at each time point were mostly consistent with the summary table above. We observed an increase in fuel load after thinning for the following fuel classes: 1-hr, 10-hr, 1000-hr rotten, and 1000-hr sound.

BUT!

What I don't understand is why the values for the 100-hr fuel class appear to increase after thinning, which is in contrast to the summary statistics that show a decrease in mean values after thinning (pre-thin = 24.01, post-thin = 8.64).



Interaction between treatment and fuel class We wanted to know if the thinning treatment induced a significant change in fuel load among the five fuel classes. In other words, was there a significant interaction between thinning and fuel class on fuel load for coarse woody debris? We conducted a two-way repeated measures ANOVA to evaluate the effect of thinning over different fuel classes on CWD fuel load.

There was no statistically significant interaction between thinning treatment and fuel class on CWD fuel load, $F(4, 16) = 2.512$, p-adj. = 0.249, ges = 0.141. P-values were adjusted using the Bonferroni multiple testing correction method.

fuel_type	fuel_class	method	effect	p_adj	p_adj_sig	statistic	d_fn	d_fd	ges	index_value
Coarse woody debris	By class	interaction	time:fuel_class	0.249	n.s.	2.512	4	16	0.141	value_norm

Effect of treatment on each fuel class

To analyze the effect of thinning treatment on each fuel class, we used a repeated measures ANOVA. We found a significant main effect of treatment on fuel load for the 1000-hr sound () and 10-hr (p-adj. <0.01) fuel classes.

fuel_type	fuel_class	method	p_adj	p_adj_sig	statistic	d_fn	d_fd	ges	index_value
Coarse woody debris	1000-hr sound	main effect	0.00229	**	111.145	1	4	0.627	value_norm
Coarse woody debris	10-hr	main effect	0.04000	*	23.752	1	4	0.234	value_norm
Coarse woody debris	1-hr	main effect	0.65500	n.s.	3.585	1	4	0.272	value_norm
Coarse woody debris	100-hr	main effect	1.00000	n.s.	0.879	1	4	0.153	value_norm
Coarse woody debris	1000-hr rotten	main effect	1.00000	n.s.	1.000	1	4	0.200	value_norm

We conducted post hoc pairwise comparison tests to identify significant differences in fuel load values between measurements collected before and after thinning treatments. Mean fuel load values were significantly different between pre- and post-thinning surveys for 1000-hr sound (p-adj. < 0.001) and 10-hr (p-adj. < 0.01) fuel classes. No other comparisons were significant.

Pairwise comparisons of mean fuel load between treatments, by fuel class

fuel_type	fuel_class	method	group1	group2	p_adj	p_adj_sig	statistic	df	index_value
Coarse woody debris	1000-hr sound	pairwise comparison	t1	t2	0.000458	***	-10.543	4	value_norm
Coarse woody debris	10-hr	pairwise comparison	t1	t2	0.008000	**	-4.874	4	value_norm
Coarse woody debris	1-hr	pairwise comparison	t1	t2	0.131000	n.s.	-1.893	4	value_norm
Coarse woody debris	1000-hr rotten	pairwise comparison	t1	t2	0.374000	n.s.	1.000	4	value_norm
Coarse woody debris	100-hr	pairwise comparison	t1	t2	0.402000	n.s.	-0.937	4	value_norm