# Coarse woody debris: Pre- and post-thinning

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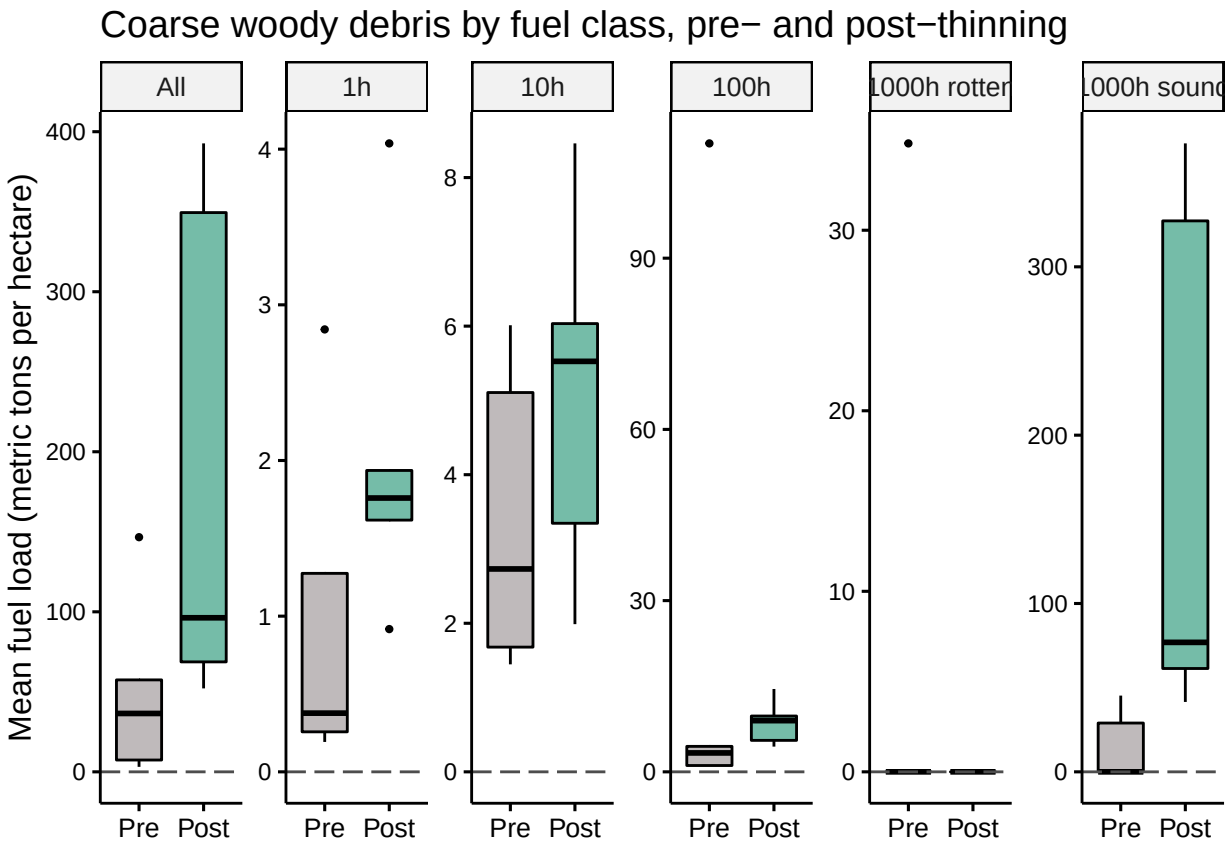
**Read and summarize coarse woody debris data (plot-level total, plot-level mean)**

```
# Read data tables for derived total and mean, with metric units
input_wd <-
  read_csv(here(path_derived, "thin_total-by-plot-type-trmt.csv")) %>%
  bind_rows(read_csv(here(path_derived, "thin_mean-by-plot-type-class-trmt.csv"))) %>%
  arrange(survey, plot_id, data_type, fuel_class) %>%
  mutate_if(is.character, as_factor)  %>%
  mutate(value = fxn_digit(value_si),
         timing = ifelse(survey %in% "cont", "survey1", "survey2")) %>%
  select(-value_si,
         -units) %>%
  rename(units = units_si,
         metric = statistic) %>%
  relocate(c(metric, subset), .after = value)  %>%
  filter(data_type %in% "wd")

# # Create subset for mean by fuel class
# wd_class <-
#   input_wd %>%
#   filter(data_type %in% "wd",
#          metric %in% "mean")
#
# # Create subset for total (all fuel classes combined)
# wd_total <-
#   input_wd %>%
#   filter(data_type %in% "wd",
#          metric %in% "total") %>%
#   remove_empty("cols")
```

```
# Visualize coarse woody debris by fuel type and treatment
# Total fuel load (all CWD classes combined) increased after thinning
# Mean fuel load increased after thinning for all fuel classes except 1000-hr rotten
#   Data for 1000-hr rotten were mostly 0; difficult to interpret (see below)

input_wd %>%
  arrange(fuel_class) %>%
  mutate(lab_thin = str_remove_all(lab_thin, "-thinning"),
         lab_fuel = as_factor(str_replace_all(lab_fuel, "-hr", "h"))) %>%
  ggboxplot(x = "lab_thin",
```

```
            y = "value",
            fill = "lab_thin",
            outlier.size = 0.8,
            palette = colors_thin_faded) +
  geom_hline(yintercept = 0,
             linetype = "longdash",
             color = "gray30") +
  theme(legend.position = "none",
        axis.title.x = element_blank(),
        axis.text.x = element_text(size = 10),
        axis.text.y = element_text(size = 9)) +
  labs(title = paste0(index_wd, " by fuel class, pre- and post-thinning"),
       y = index_units_lab_wd,
       fill = "Timing") +
  facet_wrap(~lab_fuel, nrow = 1, scales = "free")
```




```
# Pre- and post-thinning fuel load by fuel class
input_wd %>%
  group_by(lab_type, lab_fuel, lab_thin, metric, units) %>%
  get_summary_stats(value, type = "mean_sd") %>%
  select(lab_type,
         lab_fuel,
         lab_thin,
         metric,
         units,
```

```
        mean,
        sd,
        n) %>%
  fxn_kable()
```

| lab_type | lab_fuel | lab_thin | metric | units | mean | sd | n |
|---|---|---|---|---|---|---|---|
| Coarse woody debris | All | Pre-thinning | total | tons_per_hectare | 50.214 | 58.286 | 5 |
| Coarse woody debris | All | Post-thinning | total | tons_per_hectare | 191.854 | 165.076 | 5 |
| Coarse woody debris | 1-hr | Pre-thinning | mean | tons_per_hectare | 0.989 | 1.125 | 5 |
| Coarse woody debris | 1-hr | Post-thinning | mean | tons_per_hectare | 2.053 | 1.174 | 5 |
| Coarse woody debris | 10-hr | Pre-thinning | mean | tons_per_hectare | 3.395 | 2.059 | 5 |
| Coarse woody debris | 10-hr | Post-thinning | mean | tons_per_hectare | 5.071 | 2.505 | 5 |
| Coarse woody debris | 100-hr | Pre-thinning | mean | tons_per_hectare | 24.011 | 48.154 | 5 |
| Coarse woody debris | 100-hr | Post-thinning | mean | tons_per_hectare | 8.640 | 3.985 | 5 |
| Coarse woody debris | 1000-hr rotten | Pre-thinning | mean | tons_per_hectare | 6.962 | 15.568 | 5 |
| Coarse woody debris | 1000-hr rotten | Post-thinning | mean | tons_per_hectare | 0.000 | 0.000 | 5 |
| Coarse woody debris | 1000-hr sound | Pre-thinning | mean | tons_per_hectare | 14.856 | 21.144 | 5 |
| Coarse woody debris | 1000-hr sound | Post-thinning | mean | tons_per_hectare | 176.090 | 160.365 | 5 |

```
# 1000-hr rotten (hr1000r) is not normally distributed
#   29 of the 30 transect measurements were 0
#   9 of 10 plot-level means were 0 (pre-thin: 4/5, post-thin: 5/5)
input_wd %>%
  filter(value == 0) %>%
  group_by(lab_type, lab_fuel, lab_thin) %>%
  count() %>%
  fxn_kable()
```

| lab_type | lab_fuel | lab_thin | n |
|---|---|---|---|
| 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 |

### Check assumptions

Subset data subset by fuel class and timing because these are the groupings that will be evaluated with statistical tests.

```
# Determine if there are extreme outliers
#
# No extreme outliers for total CWD
# Outlier for total pre-thinning in FOR08
#
# Three extreme outliers by fuel class :
#   Pre-thinning hr0100 and hr1000r in FOR08
#   Post-thinning hr0001 in FOR06
#
# Overall it looks like something was different about FOR08 during pre- and post-thinning surveys
#
input_wd %>%
  group_by(lab_type, lab_fuel, lab_thin, metric, units) %>%
  identify_outliers(value) %>%
```

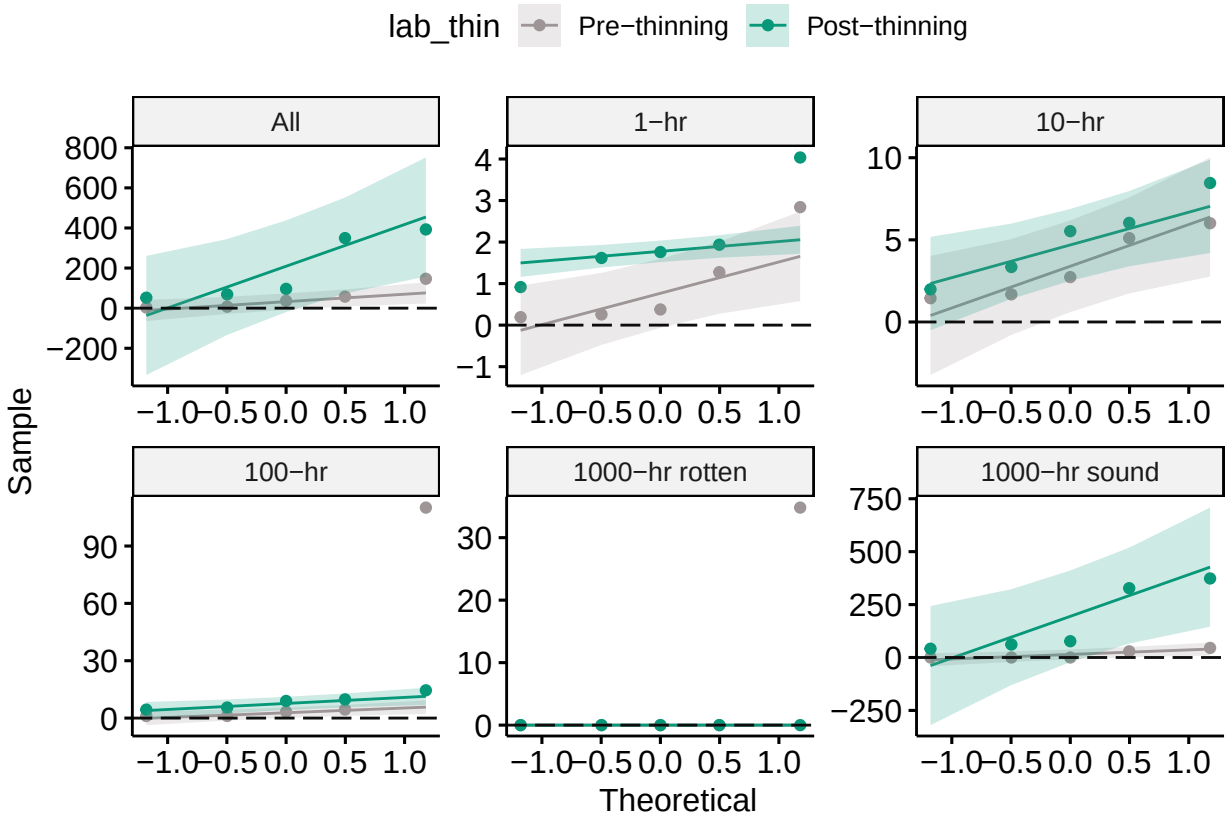
```
  clean_names() %>%
  select(lab_type,
         lab_fuel,
         lab_thin,
         plot_id,
         value,
         metric,
         units,
         starts_with("is")) %>%
  arrange(desc(is_extreme), metric, lab_fuel) %>%
  # filter(is_extreme == TRUE) %>%
  fxn_kable()
```

| lab_type | lab_fuel | lab_thin | plot_id | value | metric | units | is_outlier | is |
|---|---|---|---|---|---|---|---|---|
| Coarse woody debris | 1-hr | Post-thinning | FOR06 | 4.037 | mean | tons_per_hectare | TRUE | T |
| Coarse woody debris | 100-hr | Pre-thinning | FOR08 | 110.112 | mean | tons_per_hectare | TRUE | T |
| Coarse woody debris | 1000-hr rotten | Pre-thinning | FOR08 | 34.811 | mean | tons_per_hectare | TRUE | T |
| Coarse woody debris | All | Pre-thinning | FOR08 | 146.628 | total | tons_per_hectare | TRUE | FA |
| Coarse woody debris | 1-hr | Pre-thinning | FOR07 | 2.842 | mean | tons_per_hectare | TRUE | FA |
| Coarse woody debris | 1-hr | Post-thinning | FOR08 | 0.917 | mean | tons_per_hectare | TRUE | FA |

```
# Evaluate normality
#
# Shapiro test results indicated total CWD was normally distributed at each time point
#
# Shapiro test results by fuel class indicated 100-hr, 1000-hr sound (pre-thin) were not normally distr
#
input_wd %>%
  # Exclude hr1000r because we already know it's not normal
  filter(fuel_class %nin% "hr1000r") %>%
  # Rename columns for shapiro test
  select(id = plot_id,
         time = lab_thin,
         score = value,
         lab_type,
         lab_fuel,
         metric) %>%
  group_by(lab_type, lab_fuel, time, metric) %>%
  shapiro_test(score) %>%
  clean_names() %>%
  mutate(statistic = fxn_digit(statistic),
         # p = fxn_digit(p),
         is_normal = p>0.05) %>%
  select(lab_type,
         lab_fuel,
         lab_thin = time,
         metric,
         is_normal,
         p,
         statistic) %>%
  arrange(is_normal, metric, lab_fuel) %>%
  filter(is_normal == FALSE) %>%
  fxn_kable()
```

| lab_type | lab_fuel | lab_thin | metric | is_normal | p | statistic |
|---|---|---|---|---|---|---|
| Coarse woody debris | 100-hr | Pre-thinning | mean | FALSE | 0.0003236 | 0.579 |
| Coarse woody debris | 1000-hr sound | Pre-thinning | mean | FALSE | 0.0448490 | 0.770 |

```
# Create QQ plots for raw data subset by fuel_class and treatment
ggqqplot(input_wd,
         "value",
         palette = colors_thin_bright,
         color = "lab_thin") +
  facet_wrap(~lab_fuel,
             scales = "free") +
  theme(legend.position = "top") +
  geom_hline(yintercept = 0,
             linetype = "longdash",
             color = "gray5")
```




**Identify appropriate transformation**

Apply a series of transformations to each subset, then evaluate impact on outliers and normality.

```
# Use four normalization functions from the bestNormalize package to create transformed subsets:
#   arcsinh_x
#   log_x
#   orderNorm
#   sqrt_x
```

```
#
# Most important for subsets that had extreme outliers or were not normally distributed:
# Outlier for total:
#   Pre-thin in FOR08
#
# Extreme outliers by fuel class:
#   Pre-thin hr0100 in FOR08
#   Pre-thin hr1000r in FOR08
#   Post-thin hr0001 in FOR06
#
# Not normally distributed:
#   Pre-thin hr0100
#   Pre-thin hr1000s
#
wd_transform_eval <-
  fxn_tranform_eval(index_data = input_wd,
                    index_list = list_classes_wd)  %>%
  gather(transform, value, value_raw:value_sqrt)
```

```
# Check outliers for each transformation
check_transform_outlier <-
  wd_transform_eval %>%
  group_by(timing,
           fuel_class,
           transform) %>%
  identify_outliers(value) %>%
  clean_names() %>%
  select(transform,
         fuel_class,
         timing,
         plot_id,
         value,
         starts_with("is")) %>%
  arrange(desc(is_extreme), transform, fuel_class)

# Pre-thin total in FOR08: No extreme outliers for orderNorm, log_x, arcsinh_x, sqrt_x
check_transform_outlier %>%
  filter(fuel_class %in% "all" & timing %in% "survey1" & plot_id %in% "FOR08") %>%
  fxn_kable()
```

| transform | fuel_class | timing | plot_id | value | is_outlier | is_extreme |
|---|---|---|---|---|---|---|
| value_raw | all | survey1 | FOR08 | 146.6280000 | TRUE | FALSE |
| value_std | all | survey1 | FOR08 | 0.1847408 | TRUE | FALSE |

```
# Pre-thin hr0100 in FOR08: No extreme outliers for orderNorm, log_x, arcsinh_x
check_transform_outlier %>%
  filter(fuel_class %in% "hr0100" & timing %in% "survey1" & plot_id %in% "FOR08") %>%
  fxn_kable()
```

| transform | fuel_class | timing | plot_id | value | is_outlier | is_extreme |
|---|---|---|---|---|---|---|
| value_raw | hr0100 | survey1 | FOR08 | 110.112000 | TRUE | TRUE |
| value_sqrt | hr0100 | survey1 | FOR08 | 2.697155 | TRUE | TRUE |
| value_std | hr0100 | survey1 | FOR08 | 2.823576 | TRUE | TRUE |
| value_arcsine | hr0100 | survey1 | FOR08 | 2.231336 | TRUE | FALSE |
| value_log | hr0100 | survey1 | FOR08 | 2.180986 | TRUE | FALSE |
| value_ordnorm | hr0100 | survey1 | FOR08 | 1.644854 | TRUE | FALSE |

```
# Post-thin hr0001 in FOR06: No extreme outliers for orderNorm
check_transform_outlier %>%
  filter(fuel_class %in% "hr0001" & timing %in% "survey2" & plot_id %in% "FOR06") %>%
  fxn_kable()
```

| transform | fuel_class | timing | plot_id | value | is_outlier | is_extreme |
|---|---|---|---|---|---|---|
| value_arcsine | hr0001 | survey2 | FOR06 | 1.617466 | TRUE | TRUE |
| value_log | hr0001 | survey2 | FOR06 | 1.320270 | TRUE | TRUE |
| value_raw | hr0001 | survey2 | FOR06 | 4.037000 | TRUE | TRUE |
| value_sqrt | hr0001 | survey2 | FOR06 | 1.706900 | TRUE | TRUE |
| value_std | hr0001 | survey2 | FOR06 | 2.061163 | TRUE | TRUE |
| value_ordnorm | hr0001 | survey2 | FOR06 | 1.644854 | TRUE | FALSE |

```
# Pre-thin hr1000r in FOR08: No improvement with any transformation
check_transform_outlier %>%
  filter(fuel_class %in% "hr1000r" & timing %in% "survey1" & plot_id %in% "FOR08") %>%
  fxn_kable()
```

| transform | fuel_class | timing | plot_id | value | is_outlier | is_extreme |
|---|---|---|---|---|---|---|
| value_arcsine | hr1000r | survey1 | FOR08 | 2.846050 | TRUE | TRUE |
| value_log | hr1000r | survey1 | FOR08 | 2.846050 | TRUE | TRUE |
| value_ordnorm | hr1000r | survey1 | FOR08 | 1.644854 | TRUE | TRUE |
| value_raw | hr1000r | survey1 | FOR08 | 34.811000 | TRUE | TRUE |
| value_sqrt | hr1000r | survey1 | FOR08 | 2.846050 | TRUE | TRUE |
| value_std | hr1000r | survey1 | FOR08 | 2.846050 | TRUE | TRUE |

```
# Check normality for each transformation
check_transform_normal <-
  wd_transform_eval %>%
  # Exclude hr1000r because we already know it's not normal
  filter(fuel_class %nin% "hr1000r") %>%
  # Rename columns for shapiro test
  select(id = plot_id,
         time = timing,
         score = value,
         fuel_class,
         transform) %>%
  group_by(fuel_class,
           time,
           transform) %>%
  shapiro_test(score) %>%
  clean_names() %>%
  mutate(statistic = fxn_digit(statistic),
         is_normal = p>0.05) %>%
  select(fuel_class,
```

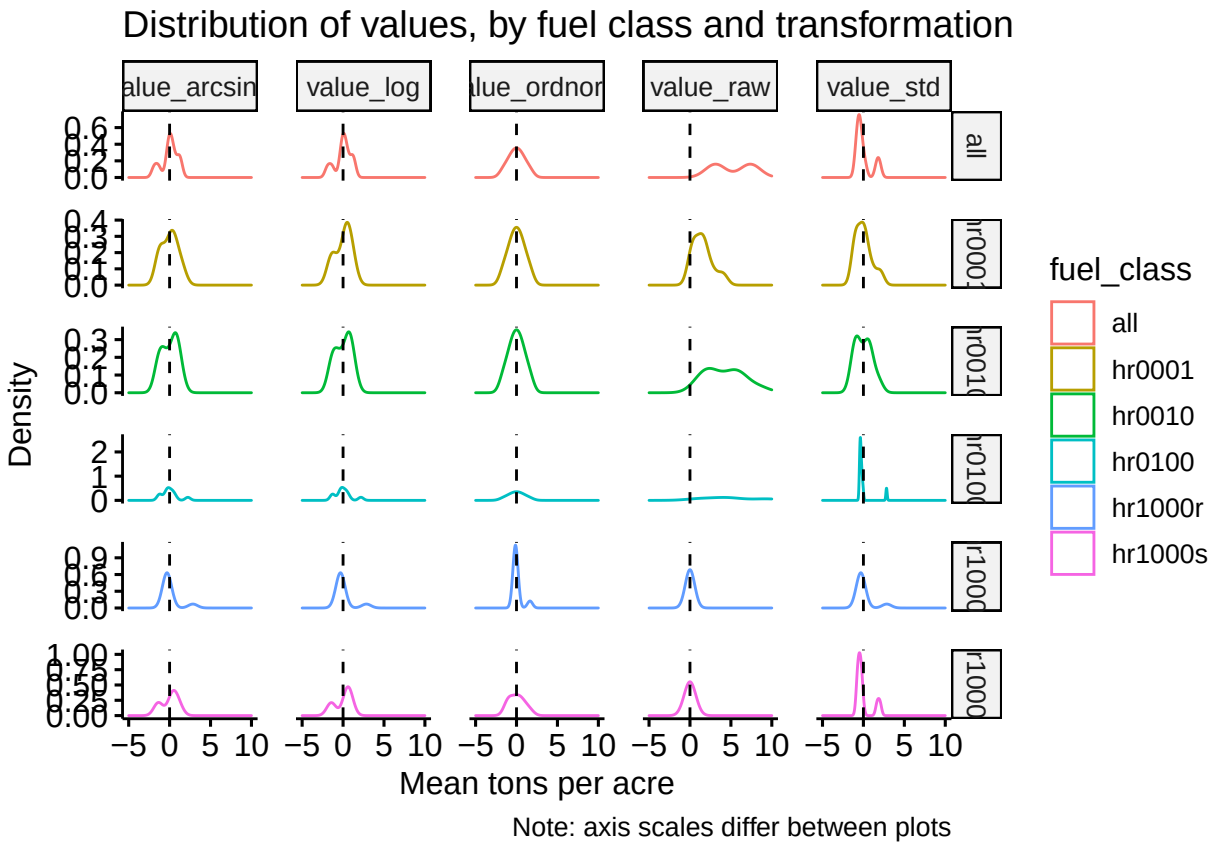
```
         timing = time,
         transform,
         is_normal,
         p,
         statistic)

# Pre-thin hr0100: Normal distribution with orderNorm, log_x, arcsinh_x
check_transform_normal %>%
  filter(fuel_class %in% "hr0100" & timing %in% "survey1",
         is_normal == TRUE) %>%
  fxn_kable()
```

| fuel_class | timing | transform | is_normal | p | statistic |
|---|---|---|---|---|---|
| hr0100 | survey1 | value_arcsine | TRUE | 0.0762655 | 0.797 |
| hr0100 | survey1 | value_log | TRUE | 0.1061219 | 0.815 |
| hr0100 | survey1 | value_ordnorm | TRUE | 0.5416692 | 0.922 |

```
# Pre-thin hr1000s: No transformation normalized hr1000s
check_transform_normal %>%
  filter(fuel_class %in% "hr1000s" & timing %in% "survey1",
         is_normal == TRUE) %>%
  fxn_kable()
```

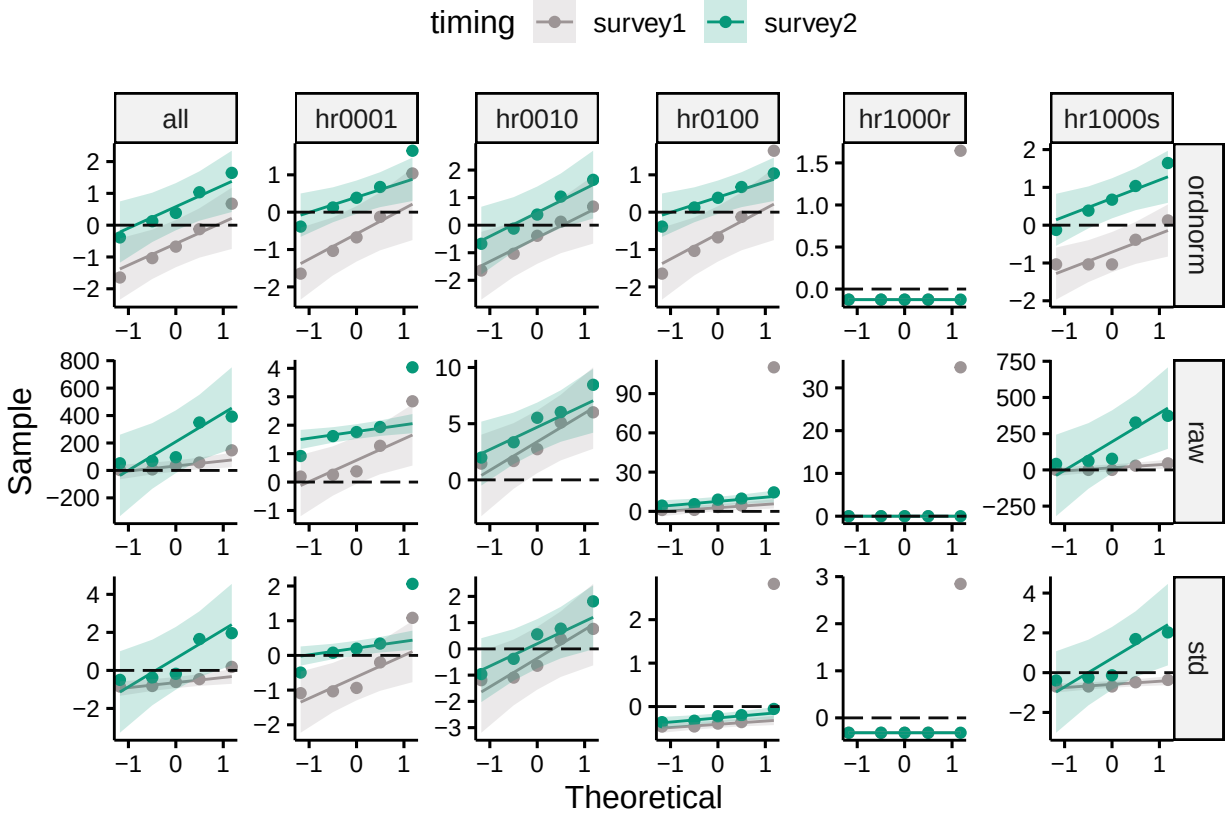
| fuel_class | timing | transform | is_normal | p | statistic |
|---|---|---|---|---|---|

```
# The orderNorm transformation looks pretty good for the total and mean subsets
#
wd_transform_eval %>%
  filter(transform %nin% "value_sqrt") %>%
  ggdensity(x = "value",
            color = "fuel_class") +
  geom_vline(xintercept = 0,
             linetype = "dashed") +
  facet_grid(fuel_class~transform,
             scales = "free") +
  theme(panel.spacing = unit(1, "lines"),
        legend.position = "right") +
  labs(title = "Distribution of values, by fuel class and transformation",
       caption = "Note: axis scales differ between plots",
       x = "Mean tons per acre",
       y = "Density") +
  xlim(-5, 10)
```




Note: axis scales differ between plots

```
# The orderNorm transformed subsets look ok compared to the raw or standardized data
wd_transform_eval %>%
  filter(transform %in% c("value_raw", "value_std",  "value_ordnorm")) %>%
  mutate(transform = str_remove_all(transform, "value_")) %>%
  ggqqplot("value",
           palette = colors_thin_bright,
           color = "timing") +
  # To let scales on y-axis vary between faceted columns
  ggh4x::facet_grid2(transform ~ fuel_class,
                     scales="free",
                     independent = "all") +
  theme(legend.position = "top",
        axis.text = element_text(size = 9)) +
  geom_hline(yintercept = 0,
             linetype = "longdash",
             color = "gray5")  +
  scale_x_continuous(breaks = c(-1, 0, 1))
```




**Create transformed data as input for statistical tests**

```
wd_transform <-
  read_csv(here(path_derived, "thin_wd_transformed_metric-units.csv")) %>%
  arrange(timing, plot_id, data_type, fuel_class) %>%
  # Non-numeric variables must be factors for rstatix
  mutate_if(is.character, as_factor)

wd_transform_total <-
  wd_transform %>%
  filter(data_type %in% "wd",
         metric %in% "total")

wd_transform_class <-
  wd_transform %>%
  filter(data_type %in% "wd",
         metric %in% "mean")
```

**Conduct statistical tests**

```
# Test for an effect of treatment on total CWD load (all CWD fuel classes combined)
# We found no significant difference in total fuel load between measurements collected pre- and post-th
```

```
wd_transform_total %>%
  # Use transformed values as input for statistical tests
  fxn_aov_me(index_value = "value_tran",
             index_id = "plot_id",
             index_time = "lab_thin")  %>%
  fxn_signif_adj() %>%
  mutate(data_type = index_wd,
         fuel_class = "All") %>%
  select(data_type,
         fuel_class,
         starts_with("p_adj"),
         statistic,
         starts_with("d_"),
         ges) %>%
  fxn_kable()
```

**Did thinning treatment have a significant effect on total coarse woody debris fuel load?**

| data_type | fuel_class | p_adj | p_adj_sig | statistic | d_fn | d_fd | ges |
|---|---|---|---|---|---|---|---|
| Coarse woody debris | All | 0.079 | n.s. | 5.474 | 1 | 4 | 0.358 |

```
# Two-way interaction between thinning treatment and fuel class
# We wanted to know if the thinning treatment induced a significant change in fuel load among the five
#   In other words, was there a significant interaction between thinning and fuel class on fuel load fo
# We conducted a two-way repeated measures ANOVA to evaluate the effect of thinning over different fuel
#
# There was no statistically significant interaction between thinning treatment and fuel class on CWD f
wd_transform_class  %>%
  fxn_aov2_me(index_value = "value_tran",
              index_id = "plot_id",
              index_time = "timing",
              index_variable = "fuel_class") %>%
  fxn_signif_adj() %>%
  mutate(data_type = index_wd) %>%
  select(data_type,
           effect,
             starts_with("p_adj"),
             statistic,
             starts_with("d_"),
             ges) %>%
  fxn_kable()
```

**Did thinning treatment have a significant effect on the individual fuel classes?**

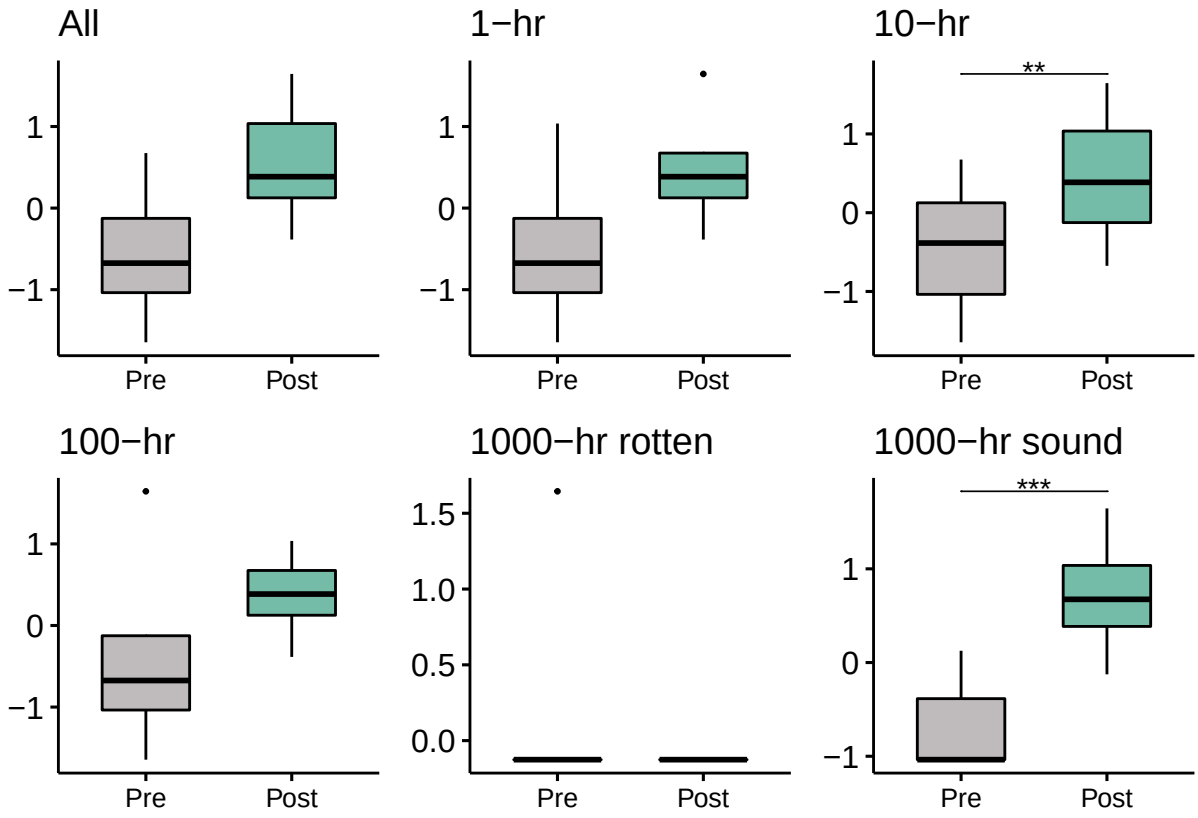
| data_type | effect |
|---|---|
| Coarse woody debris | time |
| Coarse woody debris | time:varia |
| Coarse woody debris | variable |

```
# time:variable 0.249   n.s.    2.512   4.00    16.00   0.141000
```

```r
# Main effect of thinning treatment on fuel load, for each fuel class
# We analyzed the effect of thinning treatment for each fuel class. The Bonferroni adjustment was appli
wd_transform_class  %>%
  group_by(fuel_class) %>%
  fxn_aov_me(index_value = "value_tran",
             index_id = "plot_id",
             index_time = "timing") %>%
  fxn_signif_adj() %>%
  mutate(data_type = index_wd) %>%
  select(data_type,
         fuel_class,
         starts_with("p_adj"),
         statistic,
         starts_with("d")) %>%
  arrange(p_adj) %>%
  fxn_kable()
```

| data_type | fuel_class | p_adj | p_adj_sig | statistic | d_fn | d_fd |
|---|---|---|---|---|---|---|
| Coarse woody debris | hr1000s | 0.00229 | ** | 111.145 | 1 | 4 |
| Coarse woody debris | hr0010 | 0.04000 | * | 23.752 | 1 | 4 |
| Coarse woody debris | hr0001 | 0.65500 | n.s. | 3.585 | 1 | 4 |
| Coarse woody debris | hr0100 | 1.00000 | n.s. | 0.879 | 1 | 4 |
| Coarse woody debris | hr1000r | 1.00000 | n.s. | 1.000 | 1 | 4 |

```r
# Create individual plots
all <- fxn_boxplot_class("all")
hr0001 <- fxn_boxplot_class("hr0001")
hr0010 <- fxn_boxplot_class("hr0010")
hr0100 <- fxn_boxplot_class("hr0100")
hr1000r <- fxn_boxplot_class("hr1000r")
hr1000s <- fxn_boxplot_class("hr1000s")

# Join plots using patchwork
all + hr0001 + hr0010 + hr0100 + hr1000r + hr1000s
```


All
1−hr
10−hr
100−hr
1000−hr rotten
1000−hr sound
**
***
Pre
Post
1
0
−1
1.5
1.0
0.5
0.0