Fuel analysis for Oak Symposium: Ground fuels

Morgan Gray

Overview

The aim of this research was to understand the impact of prescribed fire on fuel loads over time. Our objective was to evaluate the impact of prescribed fire on ground fuel loads over time (duff, litter). To meet this objective, we compared the pre- and post-fire fuel levels at nine long-term vegetation monitoring plots. Surveys were conducted at four time points: 2016 (1y pre-fire), 2017 (0y post-fire), 2019 (2y post-fire), and 2021 (4y post-fire). Each time point had 36 data points for ground fuel measurements: 9 plots x 2 transects x 2 quadrats.

Using the ground fuels data set as input, we asked the following questions:

1. Did total fuel load differ between years?

2. Did fuel load differ between years by fuel class? If so, which years are different?

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.

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.

Data frames To answer these questions, we calculated the total amount of ground fuel within each plot. We defined "total (or all) ground fuels" as the combined total of the duff and litter fuel classes within a plot. Because there were two transects with two quadrats per plot, we used the plot-level mean for each fuel class at each time point (n = 4 quadrats). A subset of the data frame with the plot-level mean for each fuel class by year is shown below.

fuel_type	fuel_class	plot_id	year	value
Ground fuel	Duff	RxF01	2016	1.125
Ground fuel	Litter	RxF01	2016	0.625
Ground fuel	Duff	RxF02	2016	1.562
Ground fuel	Litter	RxF02	2016	2.375
Ground fuel	Duff	RxF03	2016	1.062
Ground fuel	Litter	RxF03	2016	1.938

Next, we summed the plot means for duff and litter fuel classes to determine the plot-level total for ground fuel at each time point. Below is a subset of the data frame for the plot-level values of ground fuels by year.

fuel_type	fuel_class	plot_id	year	value
Ground fuel	All	RxF01	2016	1.750
Ground fuel	All	RxF02	2016	3.938
Ground fuel	All	RxF03	2016	3.000
Ground fuel	All	RxF04	2016	2.625
Ground fuel	All	RxF05	2016	1.625
Ground fuel	All	RxF06	2016	3.013

Q1: Did total fuel load differ between years?

The first question we asked was whether there was a significant main effect of year on total fuel load (plot mean). A one-way repeated measures ANOVA was used to determine whether the mean fuel load was significantly different between the four time points.

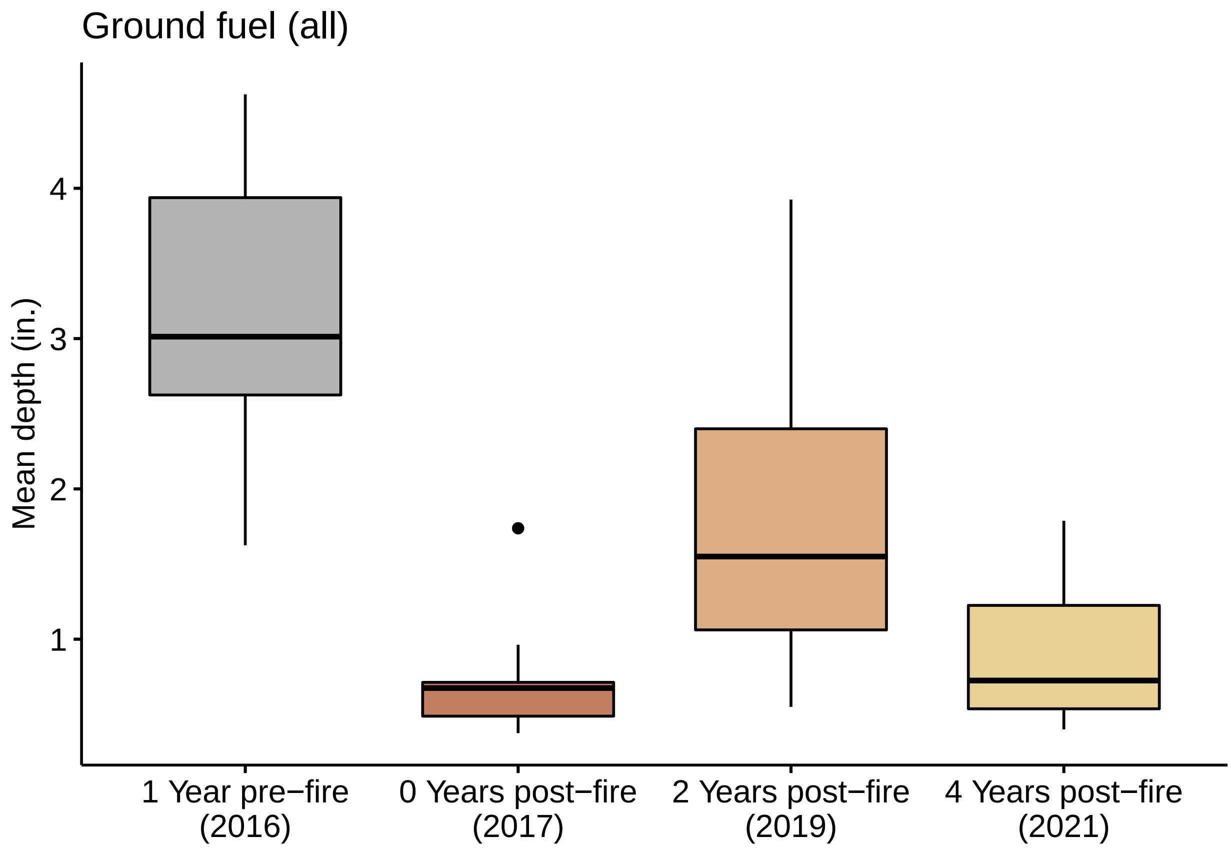
Summary statistics for the plot-level total amount of ground fuels by year

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

data_type	fuel_class	year	mean	sd	n
Ground fuel	All	2016	3.113	1.012	9
Ground fuel	All	2017	0.729	0.420	9
Ground fuel	All	2019	1.861	1.154	9
Ground fuel	All	2021	0.926	0.500	9

Visualization of the plot-level total amount of ground fuels by year

A boxplot of total ground fuel by year showed lower values in post-fire years. Specifically, we observed a decrease in the depth of all ground fuels immediately following the fire (2017; 0-y post-fire). The mean depth of ground fuels did not return to pre-fire levels in subsequent years.



Check assumptions

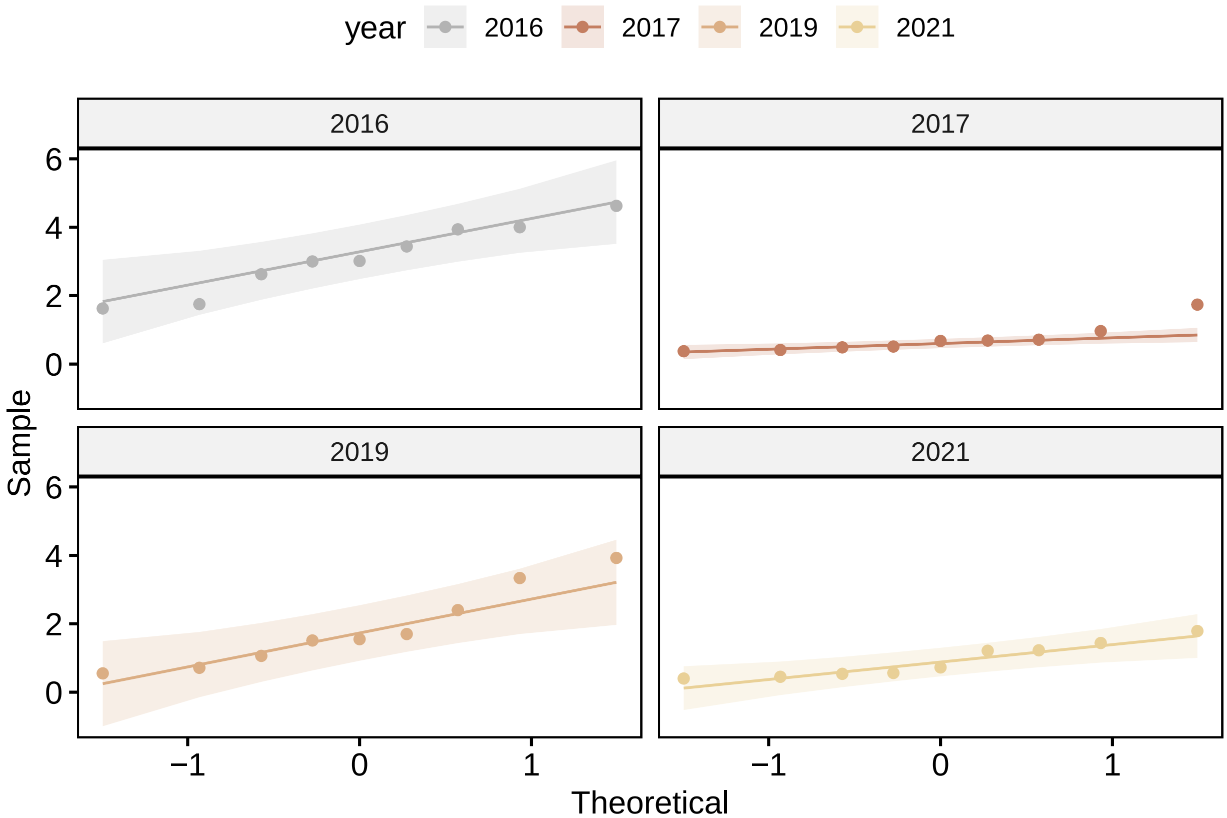
Check for outliers There was one extreme outlier in the data set. Specifically, the value for plot RxF03 in 2017 was 1.738.

data_type	fuel_class	year	plot_id	value	is_outlier	is_extreme
Ground fuel	All	2017	RxF03	1.738	TRUE	TRUE

Check for normality Plot-level ground fuel load was normally distributed at each time point ($p > 0.01$), except for year 2017, as assessed by Shapiro-Wilk's test.

data_type	fuel_class	year	is_normal	p	statistic
Ground fuel	All	2017	FALSE	0.0095626	0.771

The QQ plot showed one point in 2017 that was distant from the reference line.



Repeated measures ANOVA test

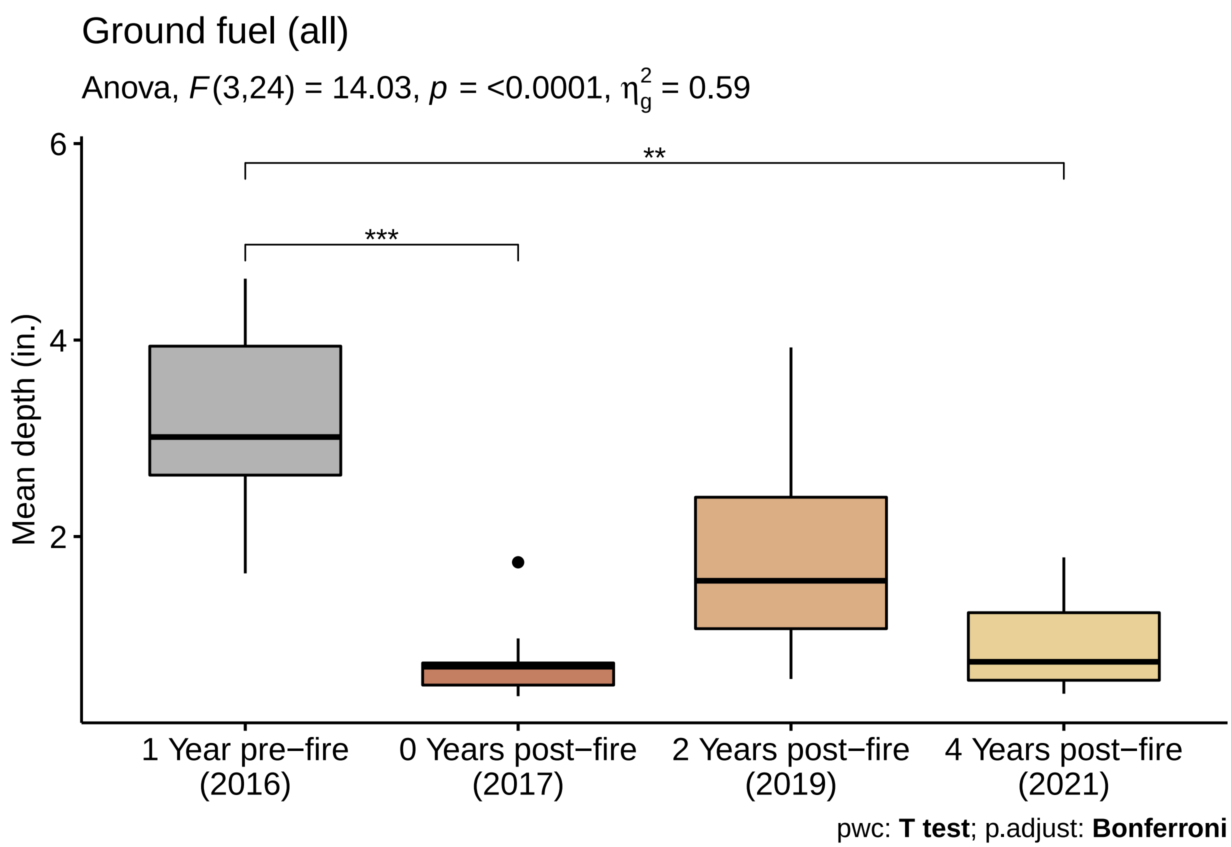
Total ground fuel load differed between years. We found a significant main effect of year on ground fuel load (p-adjusted < 0.001). The mean fuel load for all ground fuels (duff and litter combined) was significantly different between the four years; F(3, 24) = 14.029, p-adjusted (p-adj.) = 1.73e-05, ges = 0.59. The generalized effect size (ges) is the amount of variability due to the within-subjects factor.

data_type	fuel_class	effect	p_adj	statistic	d_fn	d_fd	ges	method
Ground fuel	All	year	1.73e-05	14.029	3	24	0.59	me

Post hoc tests

We conducted post hoc pairwise comparisons between the levels of the within-subjects factor (here, year). The result of paired t-tests between years showed a significant difference between pre- and post-fire mean ground fuel levels in 2017 (p-adj. <0.001) and 2021 (p-adj <0.01).

The results from the pairwise comparisons are shown below as (1) a boxplot of total ground fuel by year updated with p-values, and (2) a table of test results.



data_type	fuel_class	group1	group2	p_adj	p_adj_sig	statistic	df	method
Ground fuel	All	2016	2017	0.000828	***	6.802	8	pwc
Ground fuel	All	2016	2021	0.003000	**	5.548	8	pwc
Ground fuel	All	2017	2019	0.205000	ns	-2.552	8	pwc
Ground fuel	All	2016	2019	0.267000	ns	2.380	8	pwc
Ground fuel	All	2019	2021	0.440000	ns	2.061	8	pwc
Ground fuel	All	2017	2021	1.000000	ns	-0.828	8	pwc

Q2: Did fuel load differ between years by fuel class?

Next, we investigated whether there was a significant change in plot-level fuel load over time when accounting for fuel class (duff, litter). A two-way repeated measures ANOVA was used to determine whether there was a significant interaction between year and fuel class on fuel load.

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

Summary statistics for ground fuels by year and fuel class

The following table summarizes ground fuels by class for each time point.

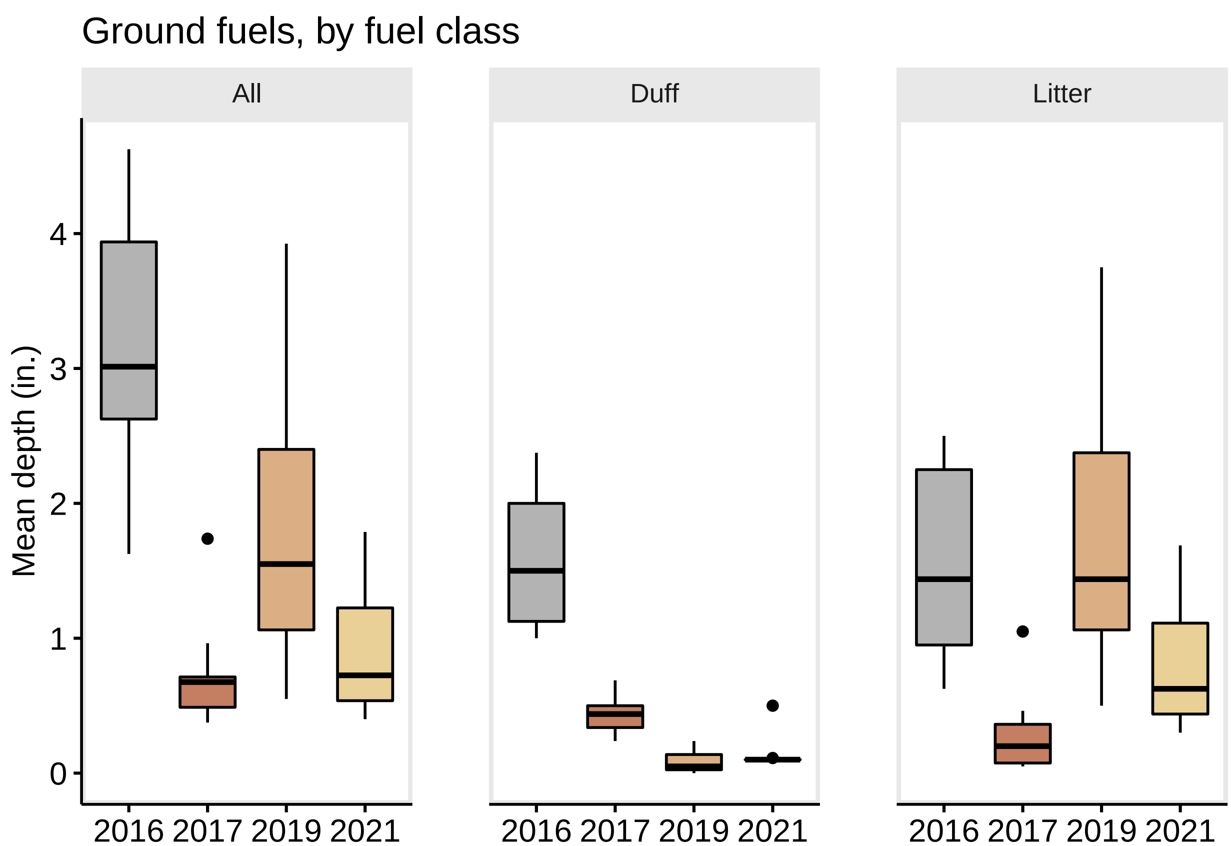
data_type	fuel_class	statistic	2016	2017	2019	2021
Ground fuel	duff	mean	1.569	0.438	0.085	0.146
Ground fuel	duff	sd	0.485	0.132	0.085	0.133
Ground fuel	litter	mean	1.543	0.292	1.776	0.781
Ground fuel	litter	sd	0.745	0.316	1.134	0.467

Visualization of ground fuels by year and fuel class

A boxplot of ground fuel by year and fuel class showed the post-fire trends differed for duff and litter ground fuels. Although both fuel classes showed a decrease in depth immediately following the fire (2017; 0-y post-fire), the annual trends for duff and litter differed. The temporal trend for all ground fuels was more similar to that for the litter fuel class, and showed less similarity to that for the duff fuel class. These results suggest that litter was an influential driver of the post-fire patterns observed for ground fuels.

Duff
– Duff depth remained low in all post-fire years.
– Values in 2019 and 2021 were lower than those for 2017.

Litter
– Litter depth returned to pre-fire levels 2-y after the fire (2019), then showed a second decrease in 2021 (4-y post-fire).
– This post-fire increase and decrease in litter depth was similar to the temporal trend observed for ground fuels overall.



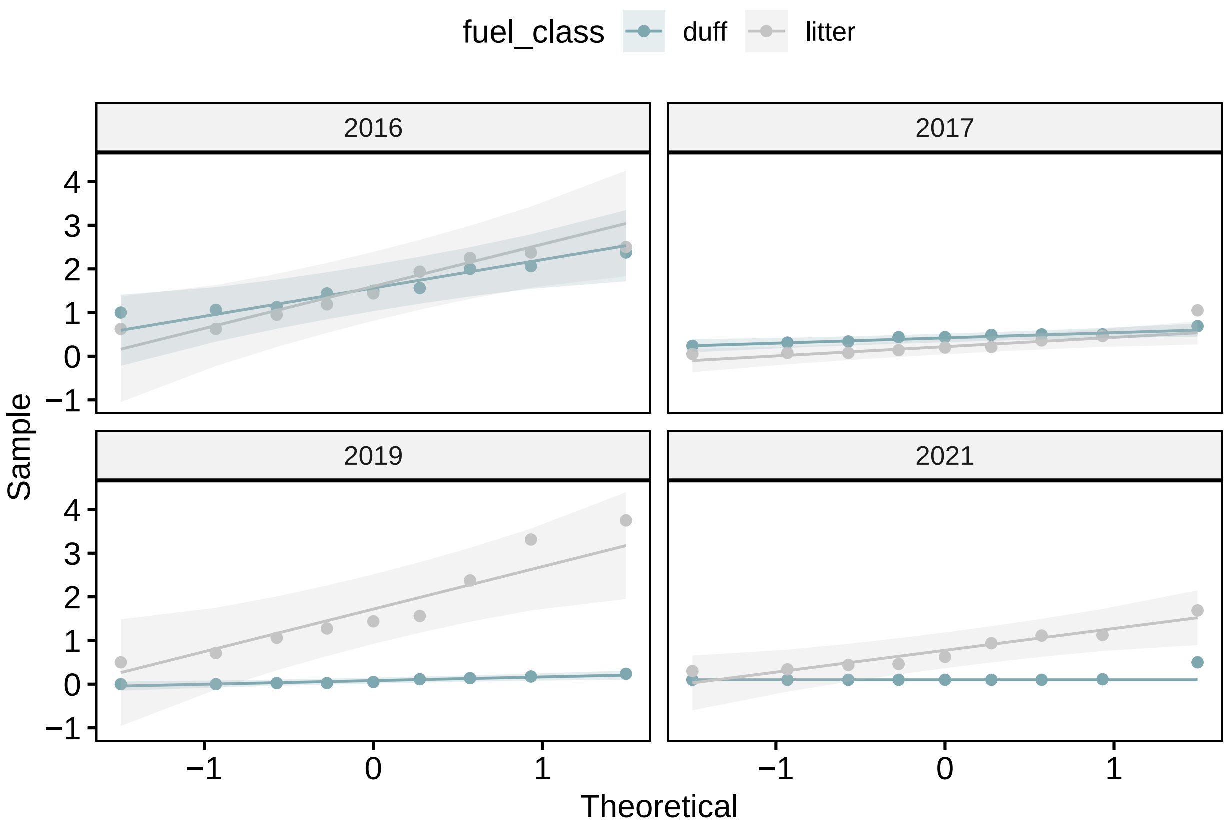
Check assumptions

Check for outliers There were two extreme outliers in the data set. Specifically, the values for duff at plots RxF03 and RxF04 in 2021 were 0.112 and 0.500, respectively.

data_type	fuel_class	year	plot_id	value	is_outlier	is_extreme
Ground fuel	duff	2021	RxF03	0.112	TRUE	TRUE
Ground fuel	duff	2021	RxF04	0.500	TRUE	TRUE

Check for normality Plot-level litter and duff values were normally distributed at each time point (p > 0.01), except for year duff in 2021 and litter in 2017, as assessed by Shapiro-Wilk's test.

data_type	fuel_class	year	is_normal	p	statistic
Ground fuel	duff	2021	FALSE	0.0000005	0.406
Ground fuel	litter	2017	FALSE	0.0065427	0.757



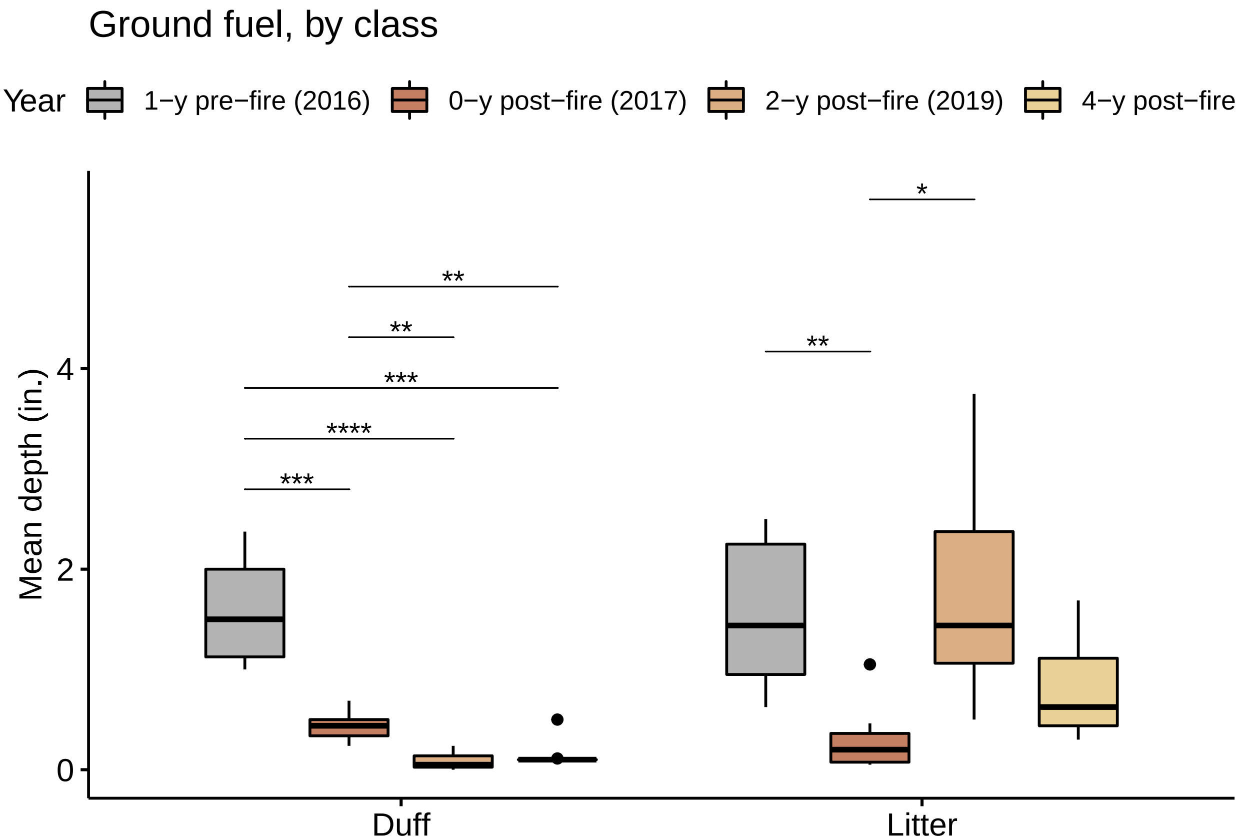
Repeated measures ANOVA test

There was a statistically significant two-way interaction between ground fuel class and year, F(2, 14) = 10.382, p-adj. = 0.006, ges = 0.329. A significant two-way interaction indicates that the impact of fuel class on fuel load depends on year (and vice versa).

data_type	effect	p_adj	p_adj_sig	statistic	d_fn	d_fd	ges	method
Ground fuel	year	5.19e-05	***	14.029	3.00	24.00	0.451	aov2
Ground fuel	fuel_class	5.82e-04	***	41.884	1.00	8.00	0.211	aov2
Ground fuel	fuel_class:year	6.00e-03	**	10.382	1.75	13.99	0.329	aov2

Post hoc tests

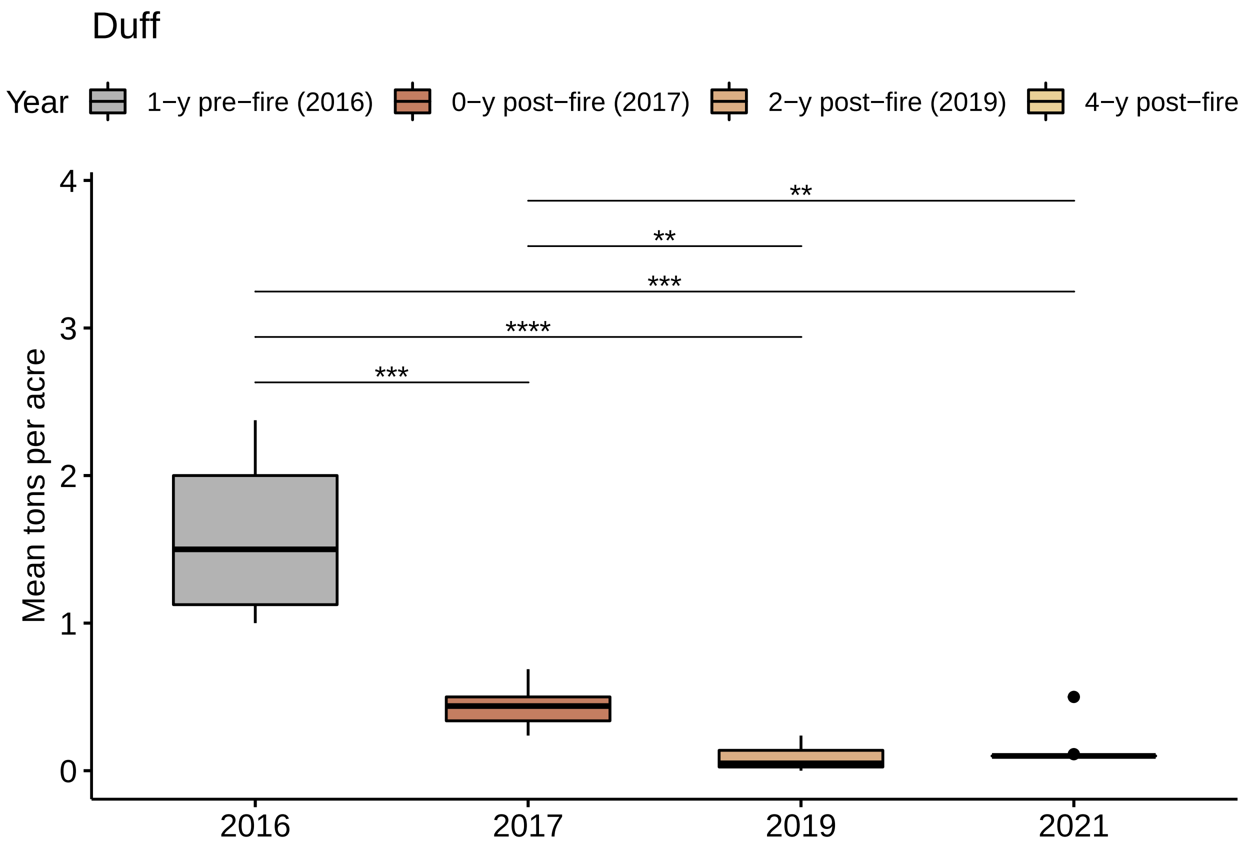
We found a significant main effect of year on fuel load for both ground fuel classes. One thing the pairwise comparison by fuel class had in common: For both fuel class, the fuel load in 2016 was significantly different from that in 2017 (duff: $p < 0.001$; litter: $p < 0.01$).



data_type	fuel_class	effect	p_adj	p_adj_sig	statistic	d_fn	d_fd	ges	method
Ground fuel	duff	year	1.07e-05	***	62.909	1.29	10.3	0.853	me
Ground fuel	litter	year	4.00e-03	**	6.830	3.00	24.0	0.423	me

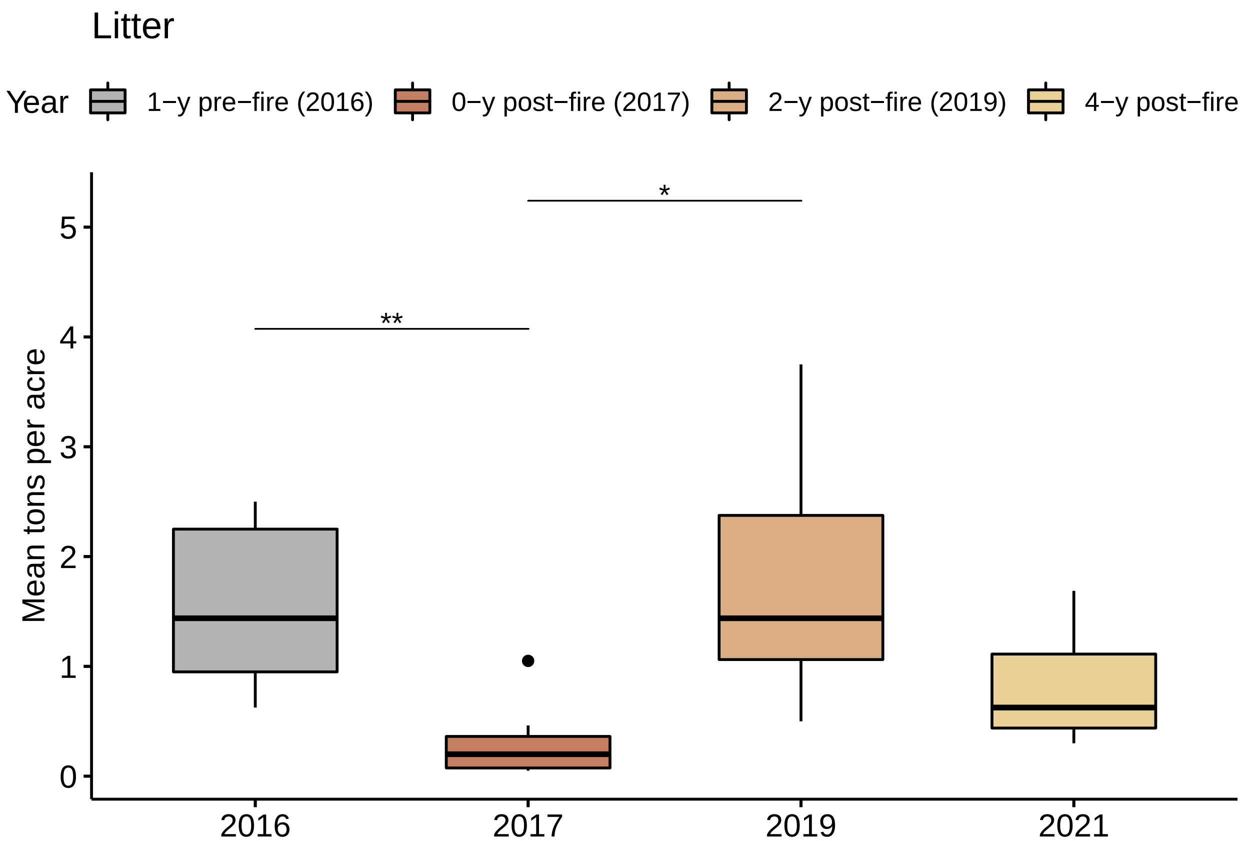
The following sections present the results from post hoc tests by fuel class for (1) the main effect of fuel class on fuel load at each time point, and (2) significant pairwise differences between years.

Duff vs. Year There was a statistically significant main effect of year on duff; $F(3, 24) = 62.909$, p-adj. = 1.07e-05, ges = 0.853. Pairwise comparisons showed that the mean duff depth was significantly different between all years except 2019/2021. This result indicated that duff depth differed between 2016 (pre-fire) and all post-fire years, as well as between 2017 (0y post-fire) and subsequent years.



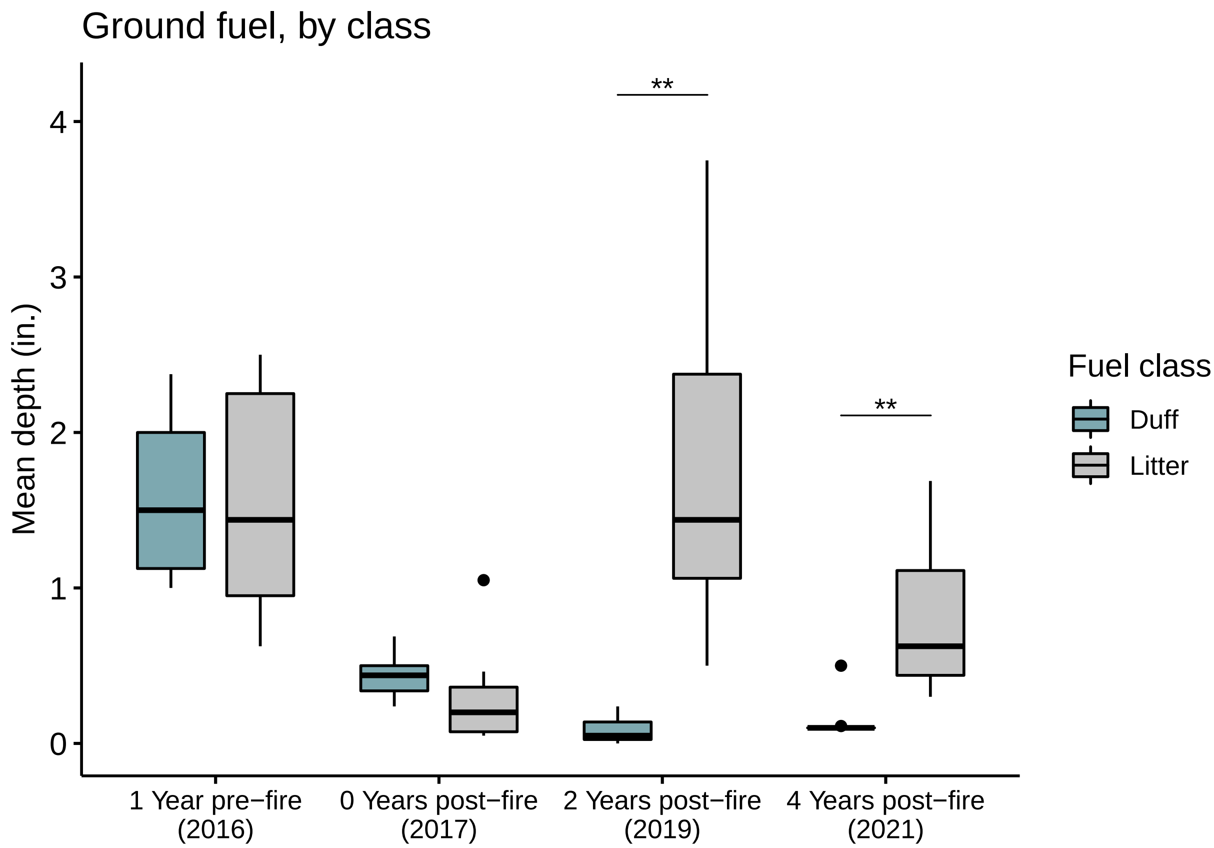
data_type	fuel_class	group1	group2	p_adj	p_adj_sig	statistic	df	method
Ground fuel	Duff	2016	2019	9.24e-05	****	9.231576	8	pwc
Ground fuel	Duff	2016	2021	2.08e-04	***	8.263229	8	pwc
Ground fuel	Duff	2016	2017	7.38e-04	***	6.909283	8	pwc
Ground fuel	Duff	2017	2019	1.00e-03	**	6.540808	8	pwc
Ground fuel	Duff	2017	2021	5.00e-03	**	5.125700	8	pwc
Ground fuel	Duff	2019	2021	1.00e+00	ns	-1.225933	8	pwc

Litter vs. Year There was a statistically significant main effect of year on litter; $F(1, 10) = 6.83$, p-adj. = 0.004, ges = 0.423. Pairwise comparisons showed that the mean litter depth was significantly different between 2016 and 2017 (p-adj. <0.01), as well as 2017 and 2019 (p-adj. <0.05).



data_type	fuel_class	group1	group2	p_adj	p_adj_sig	statistic	df	method
Ground fuel	Litter	2016	2017	0.006	**	5.057550	8	pwc
Ground fuel	Litter	2017	2019	0.046	*	-3.535831	8	pwc
Ground fuel	Litter	2017	2021	0.248	ns	-2.428722	8	pwc
Ground fuel	Litter	2016	2021	0.273	ns	2.366693	8	pwc
Ground fuel	Litter	2019	2021	0.335	ns	2.236022	8	pwc
Ground fuel	Litter	2016	2019	1.000	ns	-0.470791	8	pwc

Duff vs. Litter We found a significant difference in mean ground fuel depth betwen duff and litter in 2019 and in 2021.



data_type	year	group1	group2	p_adj	p_adj_signif	statistic	df
Ground fuel	2016	duff	litter	0.919	ns	0.105	8
Ground fuel	2017	duff	litter	0.108	ns	1.810	8
Ground fuel	2019	duff	litter	0.002	**	-4.526	8
Ground fuel	2021	duff	litter	0.004	**	-4.046	8

Date of last revision
2022-08-03