

# FuelAnalysis\_forAFE.R

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2023-11-27

```
##Fuel analysis for AFE
```

```
# Add packages here
```

```
library(knitr)
```

```
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ----- tidyverse 2.0.0 --
```

```
## v dplyr      1.1.2      v readr      2.1.4
```

```
## v forcats    1.0.0      v stringr   1.5.0
```

```
## v ggplot2    3.4.2      v tibble    3.2.1
```

```
## v lubridate  1.9.2      v tidyr     1.3.0
```

```
## v purrr      1.0.1
```

```
## -- Conflicts ----- tidyverse_conflicts() --
```

```
## x dplyr::filter() masks stats::filter()
```

```
## x dplyr::lag()     masks stats::lag()
```

```
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```
library(ggplot2)
```

```
library(car)
```

```
## Loading required package: carData
```

```
##
```

```
## Attaching package: 'car'
```

```
##
```

```
## The following object is masked from 'package:dplyr':
```

```
##
```

```
##      recode
```

```
##
```

```
## The following object is masked from 'package:purrr':
```

```
##
```

```
##      some
```

```
library(dplyr)
```

```
library(car)
```

```
library(broom)
```

```
library(emmeans)
```

```
library(lmerTest)
```

```
## Loading required package: lme4
```

```
## Loading required package: Matrix
```

```
##
## Attaching package: 'Matrix'
##
## The following objects are masked from 'package:tidyr':
##
##     expand, pack, unpack
##
## Attaching package: 'lmerTest'
##
## The following object is masked from 'package:lme4':
##
##     lmer
##
## The following object is masked from 'package:stats':
##
##     step
```

```
library(lme4)
library(pbkrtest)
library(gganimate)
```

```
## No renderer backend detected. gganimate will default to writing frames to separate files
## Consider installing:
## - the 'gifski' package for gif output
## - the 'av' package for video output
## and restarting the R session
```

```
library(ggstream)
```

```
rm(list = ls())
```

```
fuels <- read.csv("C:/Users/edeegan/OneDrive - DOI/Fire_project/Fire_project/PSME_data/PSME_SAGU_Report.csv",
                 sep=",")
```

```
fuels_t<-as_tibble(fuels)
fuels_t=rename(fuels_t, plot=`Macroplot`)
```

```
fuels <- fuels_t %>% select(!starts_with("X"))
fuels <- fuels %>% mutate(year=NA)
fuels$'1000hr'=fuels_t$X.3_Snd+fuels_t$X.3_Rot
```

```
#LUMP 1990-92 together and make a note because they weren't full samples
```

```
fuels <- fuels %>% mutate(year=case_when(MonStatusOrd==0 ~ 1992,
                                         MonStatusOrd==1 ~ 1997,
                                         MonStatusOrd==2 ~ 2001,
                                         MonStatusOrd==3 ~ 2003,
                                         MonStatusOrd==4 ~ 2004,
                                         MonStatusOrd==5 ~ 2008,
                                         MonStatusOrd==6 ~ 2013,
                                         MonStatusOrd==7 ~ 2023))
```

*#weird data here so cutting it for conference, come back to later and check if its the same people reco*  
*#because plots 1 and 7 have some crazy high numbers*  
 fuels <- fuels %>% filter(year!='1992' & year!='1997')

```
fuels_factor1 <- fuels %>%
  mutate(plot=factor(plot))
```

```
fuels_factor2 <- fuels_factor1 %>%
  mutate(year=factor(year))
```

```
fuels_factor2_summ <- fuels_factor2 %>%
  group_by(`Year`=year) %>%
  reframe(n=n(),
    `Min.`=c(min(OneHr),min(TenHr), min(HunHr)),
    `Max.`=c(max(OneHr),max(TenHr),max(HunHr)),
    `Mean`=c(mean(OneHr),mean(TenHr),mean(HunHr)),
    `SD`=c(sd(OneHr),sd(TenHr),sd(HunHr)),
    `SE`=c(sd(OneHr)/sqrt(n),sd(TenHr)/sqrt(n),sd(HunHr)/sqrt(n)),
    `Size_class`=c("One", "Ten", "Hun"))
```

```
kable(fuels_factor2_summ, booktabs=T, digits=3)
```

Year	n	Min.	Max.	Mean	SD	SE	Size_class
2001	10	0.250	0.764	0.519	0.174	0.055	One
2001	10	0.729	3.467	1.669	0.874	0.276	Ten
2001	10	0.953	3.150	2.157	0.673	0.213	Hun
2003	10	0.000	0.383	0.140	0.140	0.044	One
2003	10	0.000	3.114	0.895	1.028	0.325	Ten
2003	10	0.000	2.754	0.993	1.042	0.330	Hun
2004	10	0.004	0.873	0.228	0.267	0.085	One
2004	10	0.000	3.900	1.188	1.259	0.398	Ten
2004	10	0.000	3.381	1.379	1.180	0.373	Hun
2013	9	0.041	0.639	0.281	0.217	0.072	One
2013	9	0.844	2.871	1.588	0.770	0.257	Ten
2013	9	0.718	4.450	2.348	1.198	0.399	Hun
2023	10	0.000	0.420	0.179	0.171	0.054	One
2023	10	0.739	4.146	2.139	1.172	0.371	Ten
2023	10	2.573	6.747	3.763	1.398	0.442	Hun

```
fuels_factor_total_duff_litt <- fuels_factor2 %>%
  group_by(`Year`=year) %>%
  reframe(n=n(),
    `Min.`=c(min(TotalWood),min(Duff), min(Litter)),
    `Max.`=c(max(TotalWood),max(Duff),max(Litter)),
    `Mean`=c(mean(TotalWood),mean(Duff),mean(Litter)),
    `SD`=c(sd(TotalWood),sd(Duff),sd(Litter)),
    `SE`=c(sd(TotalWood)/sqrt(n),sd(Duff)/sqrt(n),sd(Litter)/sqrt(n)),
    `Size_class`=c("Total", "Duff", "Litter"))
```

```
kable(fuels_factor_total_duff_litt, booktabs=T, digits=3)
```

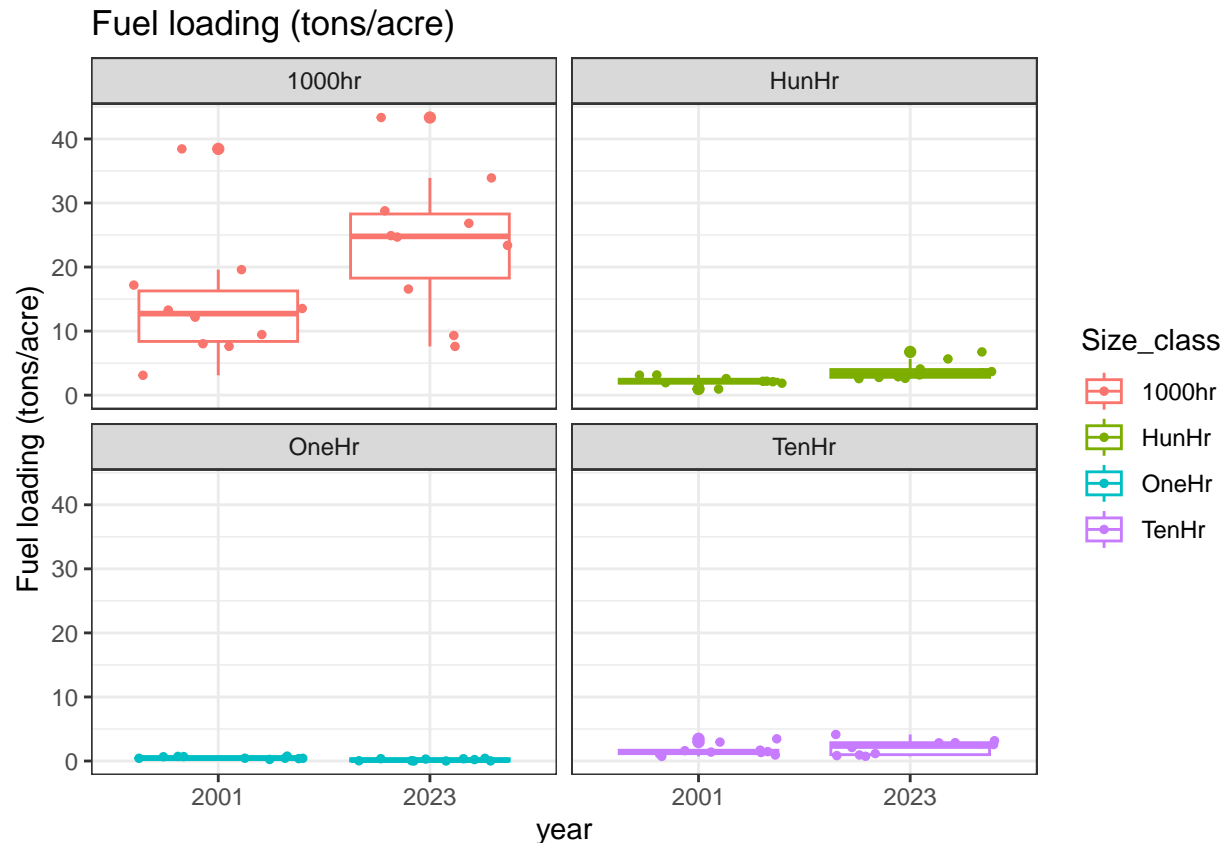
Year	n	Min.	Max.	Mean	SD	SE	Size_class
2001	10	6.798	43.625	18.582	10.227	3.234	Total
2001	10	3.469	17.195	11.134	4.355	1.377	Duff
2001	10	3.344	5.852	4.528	0.925	0.292	Litter
2003	10	1.411	15.091	7.397	4.309	1.363	Total
2003	10	0.000	11.505	3.718	3.757	1.188	Duff
2003	10	0.000	4.654	2.325	1.896	0.600	Litter
2004	10	2.021	14.175	7.860	4.238	1.340	Total
2004	10	0.000	11.130	3.402	3.422	1.082	Duff
2004	10	0.037	7.075	2.566	2.233	0.706	Litter
2013	9	7.087	43.235	19.215	11.250	3.750	Total
2013	9	0.000	13.501	3.135	4.453	1.484	Duff
2013	9	0.998	4.324	2.441	1.213	0.404	Litter
2023	10	15.116	50.943	30.011	10.841	3.428	Total
2023	10	0.175	6.938	3.292	2.293	0.725	Duff
2023	10	1.485	4.555	3.253	1.065	0.337	Litter

```
fuels_prevpost <- fuels_factor2 %>% filter(year!='2003' & year!='2004' & year!='2013')

fuels_prevpost=fuels_prevpost %>%
pivot_longer(cols=c(OneHr, TenHr, HunHr, '1000hr'), names_to="Size_class", values_to="Fuel_Loading")

#2001 - 2023 <.0001 ones
#0.7518 tens
#0.0228 hunts
#0.0510 thou

ggplot() +
  theme_bw() +
  geom_boxplot(aes(y=Fuel_Loading, x=year, color=Size_class),
    data=fuels_prevpost) +
  geom_jitter(aes(y=Fuel_Loading, x=year, color=Size_class),
    height=0,
    data=fuels_prevpost, size=1) +
  ylab("Fuel loading (tons/acre)") +
  ggtitle("Fuel loading (tons/acre)") + facet_wrap(~Size_class)
```



```
ggsave('boxplot_2.png')
```

```
## Saving 6.5 x 4.5 in image
```

```
#look in contrast notes to add letters
```

```
#ask windy how she would calculate total fuel load
```

```
#add a grey band of 30-50% range reducing from the total 2001 number
```

```
#compare now to pre fire levels with percentage
```

```
#run linear model on total as well - think about what makes sense
```

```
#math to calculate if 30-50% reduction in total fuels objective was reached
```

```
totalprefire <- fuels_factor2 %>% filter(year==2001) %>% summarise(mean=mean(TotalWood))
```

```
totalprefire=as.numeric(totalprefire)
```

```
range_min <- totalprefire*0.5
```

```
range_max <- totalprefire*0.7
```

```
totalpostfire <- fuels_factor2 %>% filter(year==2004) %>% summarise(mean=mean(TotalWood))
```

```
totalpostfire=as.numeric(totalpostfire)
```

```
total2023 <- fuels_factor2 %>% filter(year==2023) %>% summarise(mean=mean(TotalWood))
```

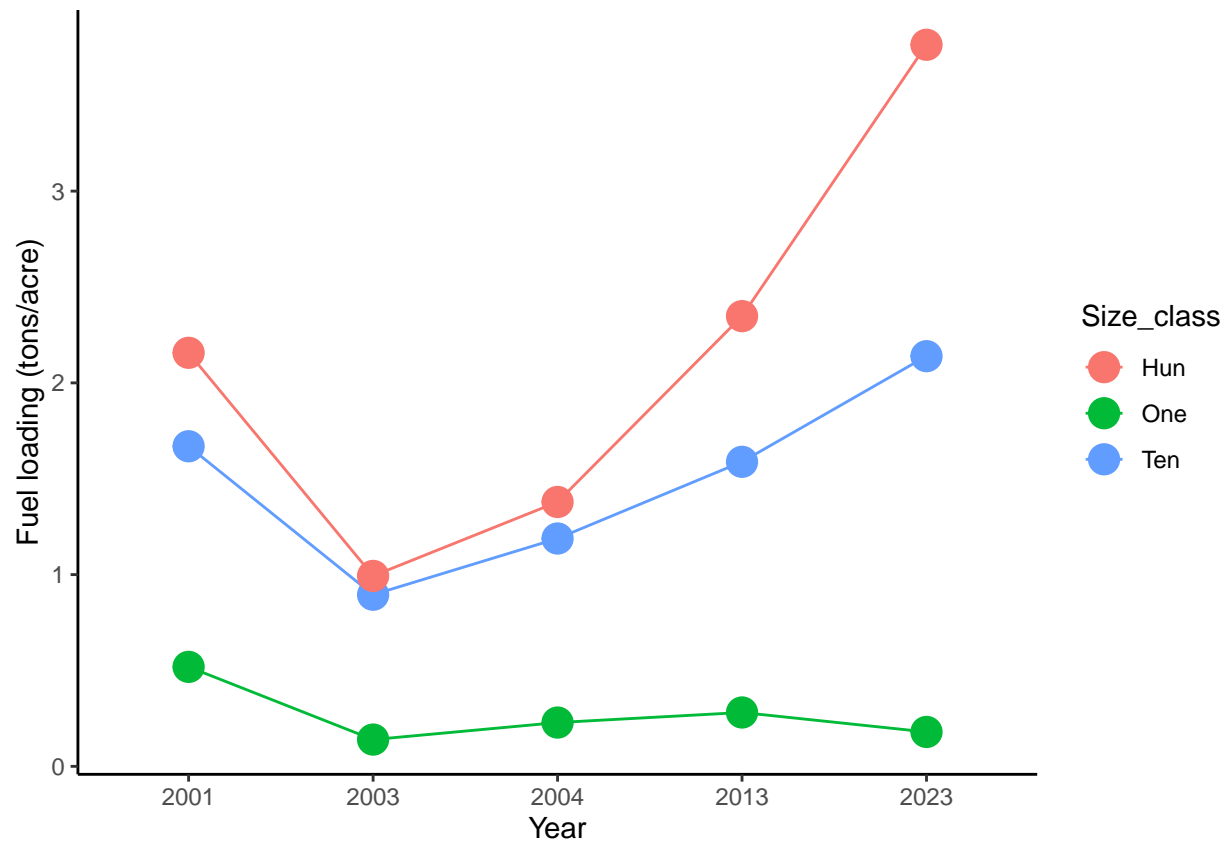
```
total2023=as.numeric(total2023)
```

```
#Eva's timeline graph
```

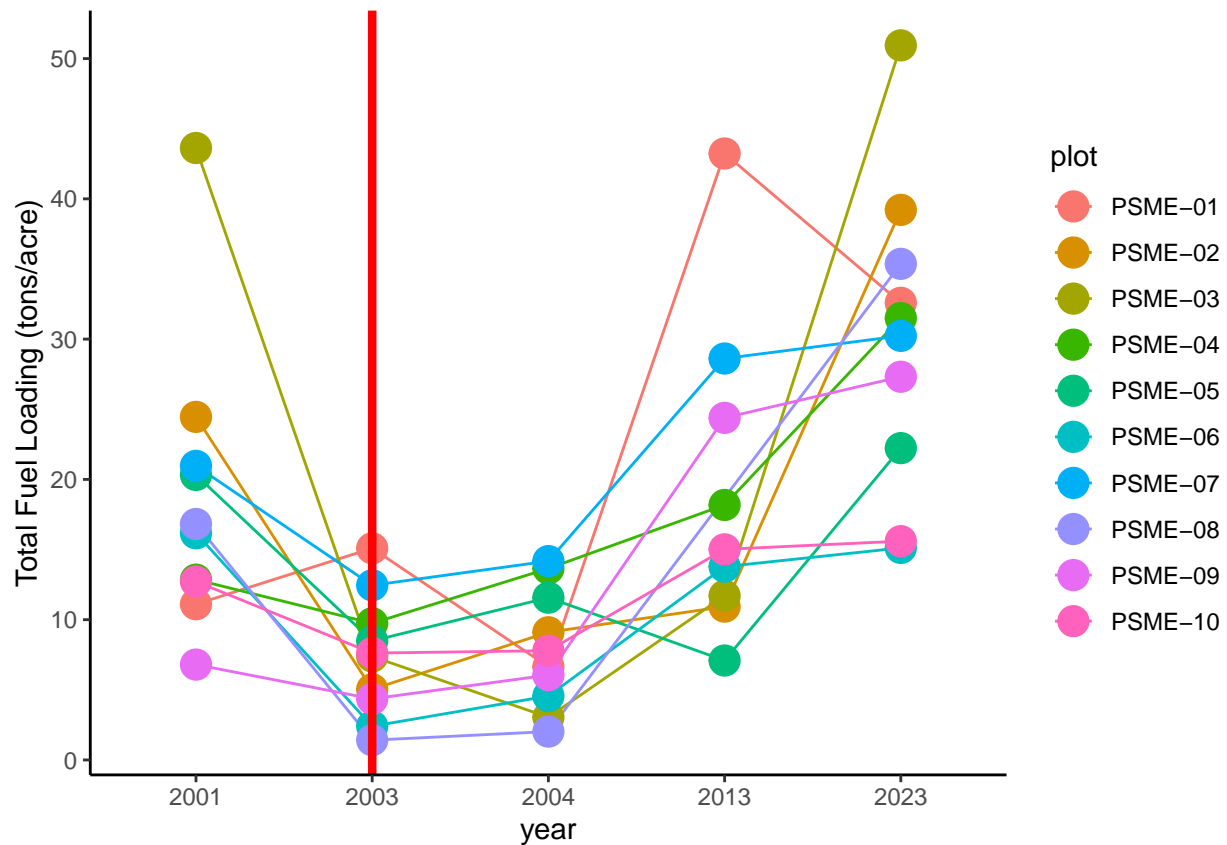
```
fuels_factor2_summ %>%
```

```
ggplot(aes(x=Year, y=Mean, group=Size_class, color=Size_class))+
```

```
geom_line()+geom_point(size=5)+theme_classic()+ylab("Fuel loading (tons/acre)")
```



```
#timeline graph 2
fuels_factor2 %>%
  ggplot(aes(x=year, y=TotalWood, group=plot, color=plot))+
  geom_line()+geom_point(size=5)+theme_classic()+ylab("Total Fuel Loading (tons/acre)")
```

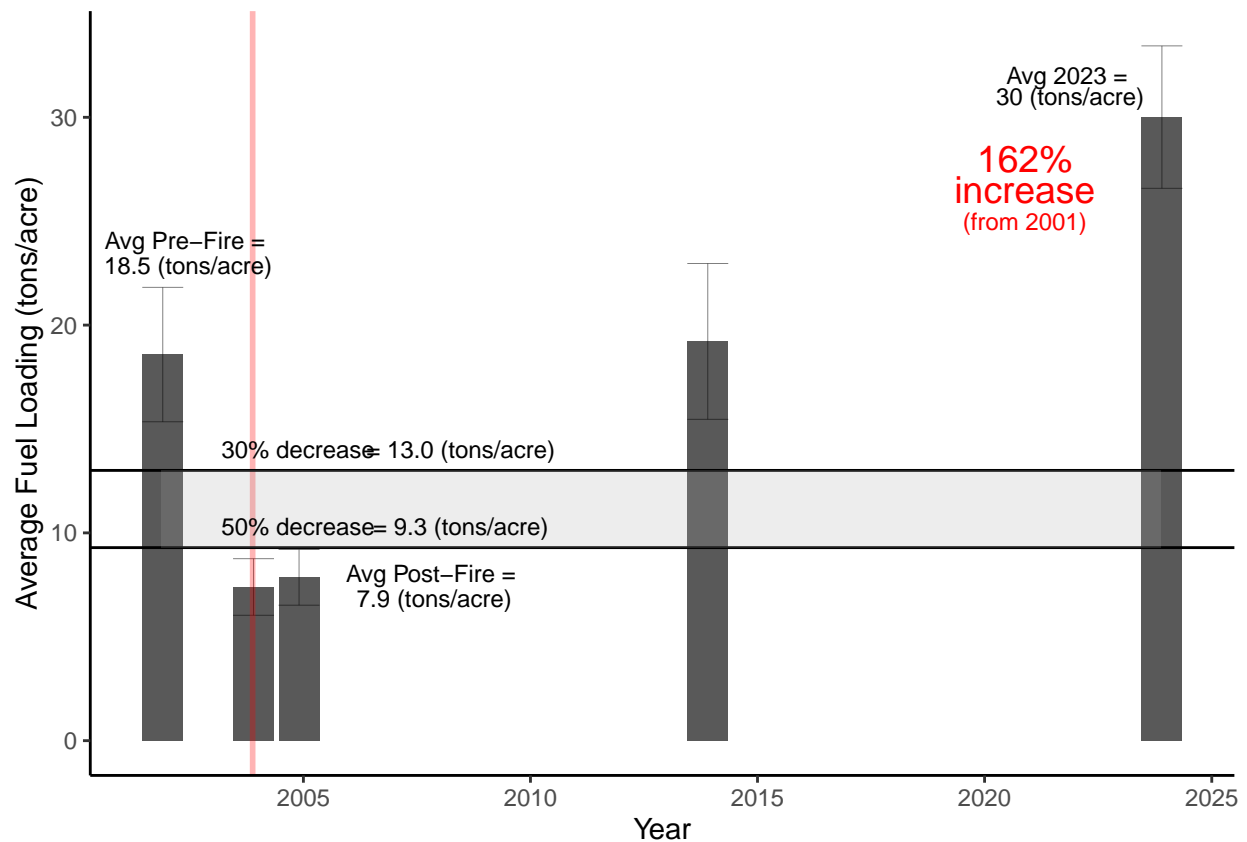


```
fuels_factor2$year=as.Date(fuels_factor2$year, "%Y")

fuels_factor2 %>% ggplot(aes(x=year, y=TotalWood, group_by(plot)))+geom_bar(stat="summary", fun="mean")+
  stat_summary(fun.data = mean_se, geom = "errorbar", size=0.1, alpha=0.5)+
  geom_vline(xintercept=as.Date("2003-11-20", format="%Y-%m-%d"), color='red', linewidth=1, alpha=0.3)+
  geom_hline(yintercept=range_min)+geom_hline(yintercept=range_max)+
  annotate('rect', xmin=as.Date("2001-11-20", format="%Y-%m-%d"), xmax=as.Date("2023-11-20", format="%Y-%m-%d"),
  ytotalprefire+5.5, label="Avg Pre-Fire = 18.5 (tons/acre)", size=5, color="green", weight="bold",
  ytotalprefire+4.3, label="18.5 (tons/acre)", size=5, color="green", weight="bold",
  yrange_min+1, label="50% decrease", size=5, color="green", weight="bold",
  yrange_min+1, label="= 9.3 (tons/acre)", size=5, color="green", weight="bold",
  yrange_max+1, label="30% decrease", size=5, color="green", weight="bold",
  yrange_max+1, label="= 13.0 (tons/acre)", size=5, color="green", weight="bold",
  ytotalpostfire+0.2, label="Avg Post-Fire = 7.9 (tons/acre)", size=5, color="green", weight="bold",
  ytotalpostfire-1, label="7.9 (tons/acre)", size=5, color="green", weight="bold",
  ytotal2023+2, label="Avg 2023 = 30 (tons/acre)", size=5, color="green", weight="bold",
  ytotal2023+1, label="30 (tons/acre)", size=5, color="green", weight="bold",
  ytotal2023-2, label="162%", size=5, color="green", weight="bold",
  ytotal2023-3.5, label="increase", size=5, color="green", weight="bold",
  ytotal2023-5, label="(from 2001)", size=5, color="green", weight="bold",
  ylab("Average Fuel Loading (tons/acre)"+xlab("Year"))
```

```
## Warning: Using 'size' aesthetic for lines was deprecated in ggplot2 3.4.0.
## i Please use 'linewidth' instead.
## This warning is displayed once every 8 hours.
```

```
## Call 'lifecycle::last_lifecycle_warnings()' to see where this warning was
## generated.
```



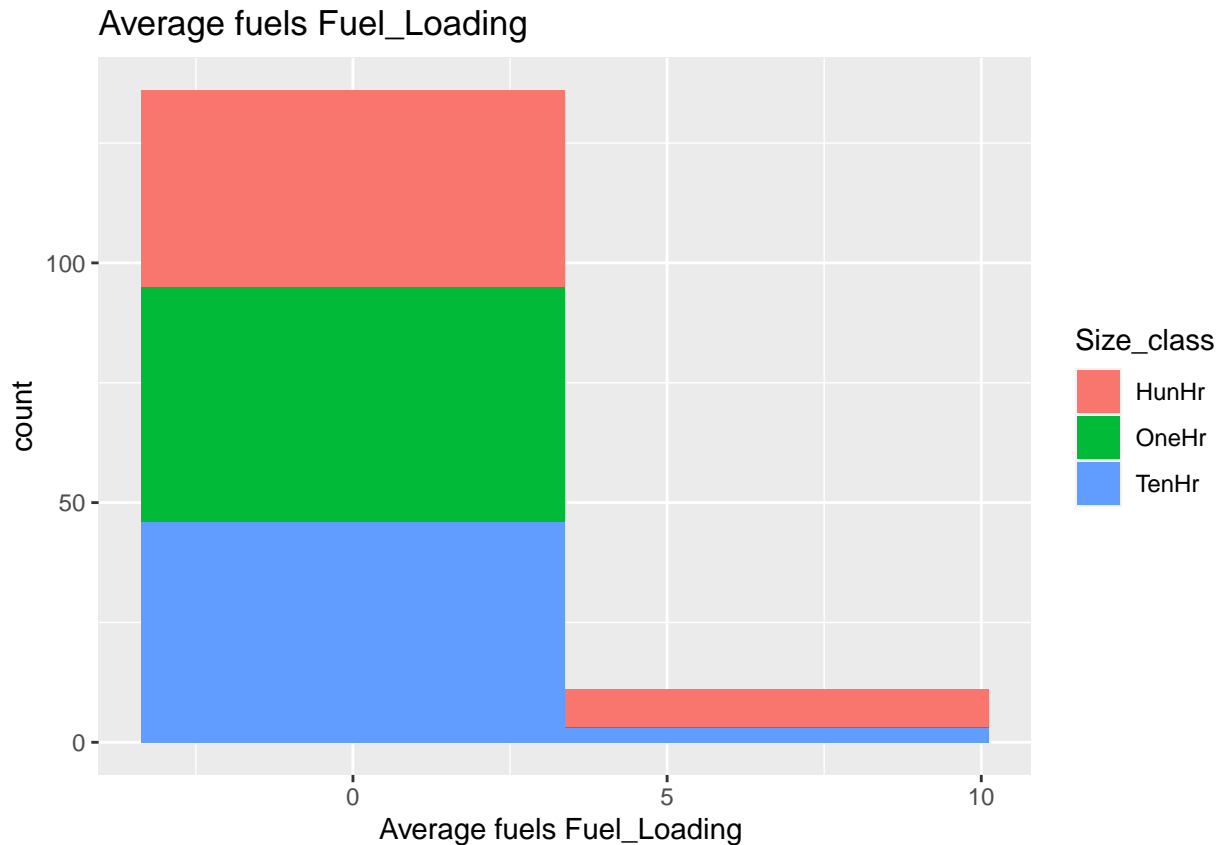
```
ggsave('barplot.png')
```

```
## Saving 6.5 x 4.5 in image
```

```
fuels_factor2_long=fuels_factor2 %>%
  pivot_longer(cols=c(OneHr, TenHr, HunHr), names_to="Size_class", values_to="Fuel_Loading")

#Lauras graph - don't know if its useful
ggplot() +
  geom_histogram(aes(x=Fuel_Loading, fill=Size_class),
                 bins=2,
                 data=fuels_factor2_long) +
  xlab("Average fuels Fuel_Loading ") +
  ggtitle("Average fuels Fuel_Loading ")
```





```
#linear models
#poisson uses count data, doesn't like non integers. log normal data usually rates
#gaussian is the same as a normal distribution so lmer model works
#repeated measures anova, nothing crazy
#because we have permanent plots but multiple levels of fuel loading
#later we can look at covariates but started here
fuels_factor2$year=as.factor(fuels_factor2$year)

fuels_lmer_One <- lmer(OneHr~year+ (1|plot),
                      data=fuels_factor2)
summary(fuels_lmer_One)
```

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: OneHr ~ year + (1 | plot)
## Data: fuels_factor2
##
## REML criterion at convergence: -27.4
##
## Scaled residuals:
## Min 1Q Median 3Q Max
## -1.9900 -0.4897 -0.1187 0.3619 2.8931
##
## Random effects:
## Groups Name Variance Std.Dev.
## plot (Intercept) 0.02359 0.1536
```

```
## Residual          0.01570  0.1253
## Number of obs: 49, groups:  plot, 10
##
## Fixed effects:
##              Estimate Std. Error      df t value Pr(>|t|)
## (Intercept)    0.51876    0.06268  18.31977   8.276 1.32e-07 ***
## year2003-11-27 -0.37913    0.05604  35.00893  -6.765 7.69e-08 ***
## year2004-11-27 -0.29038    0.05604  35.00893  -5.181 9.27e-06 ***
## year2013-11-27 -0.25162    0.05790  35.13539  -4.345 0.000113 ***
## year2023-11-27 -0.33930    0.05604  35.00893  -6.054 6.55e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr) y2003- y2004- y2013-
## y2003-11-27 -0.447
## y2004-11-27 -0.447  0.500
## y2013-11-27 -0.433  0.484  0.484
## y2023-11-27 -0.447  0.500  0.500  0.484
```

*#fixed effects compares everything to 1990*

```
fuels_lmer_Ten <- lmer(TenHr~year + (1|plot),
                      data=fuels_factor2)
summary(fuels_lmer_Ten)
```

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: TenHr ~ year + (1 | plot)
## Data: fuels_factor2
##
## REML criterion at convergence: 134.7
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.6747 -0.5833 -0.1997  0.5575  2.3741
##
## Random effects:
## Groups   Name                Variance Std.Dev.
## plot     (Intercept)  0.3204    0.5661
## Residual                  0.7679    0.8763
## Number of obs: 49, groups:  plot, 10
##
## Fixed effects:
##              Estimate Std. Error      df t value Pr(>|t|)
## (Intercept)    1.6693    0.3299  32.7665   5.060 1.57e-05 ***
## year2003-11-27 -0.7742    0.3919  34.9057  -1.975  0.0562 .
## year2004-11-27 -0.4811    0.3919  34.9057  -1.227  0.2279
## year2013-11-27 -0.1426    0.4043  35.2268  -0.353  0.7264
## year2023-11-27  0.4699    0.3919  34.9057   1.199  0.2386
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
```

```
##           (Intr) y2003- y2004- y2013-
## y2003-11-27 -0.594
## y2004-11-27 -0.594  0.500
## y2013-11-27 -0.576  0.485  0.485
## y2023-11-27 -0.594  0.500  0.500  0.485
```

```
fuels_lmer_Hun <- lmer(HunHr~year + (1|plot),
                      data=fuels_factor2)
```

```
## boundary (singular) fit: see help('isSingular')
```

```
summary(fuels_lmer_Hun)
```

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: HunHr ~ year + (1 | plot)
## Data: fuels_factor2
##
## REML criterion at convergence: 146.4
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.4518 -0.7989 -0.1926  0.4821  2.6576
##
## Random effects:
## Groups Name Variance Std.Dev.
## plot (Intercept) 4.474e-20 2.115e-10
## Residual 1.260e+00 1.123e+00
## Number of obs: 49, groups: plot, 10
##
## Fixed effects:
##              Estimate Std. Error    df t value Pr(>|t|)
## (Intercept)    2.1568    0.3550 44.0000   6.076 2.61e-07 ***
## year2003-11-27 -1.1636    0.5020 44.0000  -2.318  0.02516 *
## year2004-11-27 -0.7780    0.5020 44.0000  -1.550  0.12838
## year2013-11-27  0.1913    0.5158 44.0000   0.371  0.71251
## year2023-11-27  1.6066    0.5020 44.0000   3.200  0.00255 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##           (Intr) y2003- y2004- y2013-
## y2003-11-27 -0.707
## y2004-11-27 -0.707  0.500
## y2013-11-27 -0.688  0.487  0.487
## y2023-11-27 -0.707  0.500  0.500  0.487
## optimizer (nloptwrap) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
fuels_factor2=rename(fuels_factor2, thouhr='1000hr')
```

```
fuels_lmer_1000 <- lmer(thouhr~year + (1|plot),
```

```

data=fuels_factor2)
summary(fuels_lmer_1000)

```

```

## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: thouhr ~ year + (1 | plot)
## Data: fuels_factor2
##
## REML criterion at convergence: 320.3
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.75871 -0.42162  0.00119  0.23107  2.70577
##
## Random effects:
## Groups Name Variance Std.Dev.
## plot (Intercept) 11.16 3.34
## Residual 57.16 7.56
## Number of obs: 49, groups: plot, 10
##
## Fixed effects:
## Estimate Std. Error df t value Pr(>|t|)
## (Intercept) 14.2371 2.6138 39.9494 5.447 2.83e-06 ***
## year2003-11-27 -8.8676 3.3811 35.2038 -2.623 0.01281 *
## year2004-11-27 -9.1722 3.3811 35.2038 -2.713 0.01026 *
## year2013-11-27 0.7167 3.4837 35.6567 0.206 0.83818
## year2023-11-27 9.6916 3.3811 35.2038 2.866 0.00696 **
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
## (Intr) y2003- y2004- y2013-
## y2003-11-27 -0.647
## y2004-11-27 -0.647 0.500
## y2013-11-27 -0.628 0.485 0.485
## y2023-11-27 -0.647 0.500 0.500 0.485

```

```

#anovas
anova(fuels_lmer_One) #year is having an effect

```

```

## Type III Analysis of Variance Table with Satterthwaite's method
## Sum Sq Mean Sq NumDF DenDF F value Pr(>F)
## year 0.88761 0.2219 4 35.058 14.129 5.796e-07 ***
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

```

anova(fuels_lmer_Ten)

```

```

## Type III Analysis of Variance Table with Satterthwaite's method
## Sum Sq Mean Sq NumDF DenDF F value Pr(>F)
## year 8.9956 2.2489 4 35.029 2.9285 0.03445 *
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

```
anova(fuels_lmer_Hun)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##      Sum Sq Mean Sq NumDF DenDF F value    Pr(>F)
## year 45.679   11.42     4    44  9.0626 1.982e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(fuels_lmer_1000)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##      Sum Sq Mean Sq NumDF DenDF F value    Pr(>F)
## year 2449.9   612.48     4   35.377 10.715 8.546e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#2001 - 2023 <.0001 ones
#0.7518 tens
#0.0228 huns
#0.0510 thou
```

```
fuels_lmer_One_emm <- emmeans(fuels_lmer_One, ~year)
#estimated marginal mean - main effect taking into account marginal effects
contrast(fuels_lmer_One_emm, method="pairwise")
```

```
## contrast                estimate      SE    df t.ratio p.value
## (2001-11-27) - (2003-11-27)  0.3791 0.0560 35.0   6.765 <.0001
## (2001-11-27) - (2004-11-27)  0.2904 0.0560 35.0   5.181 0.0001
## (2001-11-27) - (2013-11-27)  0.2516 0.0579 35.1   4.343 0.0010
## (2001-11-27) - (2023-11-27)  0.3393 0.0560 35.0   6.054 <.0001
## (2003-11-27) - (2004-11-27) -0.0887 0.0560 35.0  -1.584 0.5174
## (2003-11-27) - (2013-11-27) -0.1275 0.0579 35.1  -2.201 0.2031
## (2003-11-27) - (2023-11-27) -0.0398 0.0560 35.0  -0.711 0.9527
## (2004-11-27) - (2013-11-27) -0.0388 0.0579 35.1  -0.669 0.9618
## (2004-11-27) - (2023-11-27)  0.0489 0.0560 35.0   0.873 0.9049
## (2013-11-27) - (2023-11-27)  0.0877 0.0579 35.1   1.514 0.5609
##
## Degrees-of-freedom method: kenward-roger
## P value adjustment: tukey method for comparing a family of 5 estimates
```

```
#contrast compares everything to everything
```

```
fuels_lmer_Ten_emm <- emmeans(fuels_lmer_Ten, ~year)
contrast(fuels_lmer_Ten_emm, method="pairwise")
```

```
## contrast                estimate      SE    df t.ratio p.value
## (2001-11-27) - (2003-11-27)  0.774 0.392 35.0   1.976 0.2987
## (2001-11-27) - (2004-11-27)  0.481 0.392 35.0   1.227 0.7356
```

```
## (2001-11-27) - (2013-11-27)    0.143 0.405 35.3    0.352 0.9965
## (2001-11-27) - (2023-11-27)   -0.470 0.392 35.0   -1.199 0.7518
## (2003-11-27) - (2004-11-27)   -0.293 0.392 35.0   -0.748 0.9434
## (2003-11-27) - (2013-11-27)   -0.632 0.405 35.3   -1.560 0.5316
## (2003-11-27) - (2023-11-27)   -1.244 0.392 35.0   -3.175 0.0243
## (2004-11-27) - (2013-11-27)   -0.338 0.405 35.3   -0.836 0.9175
## (2004-11-27) - (2023-11-27)   -0.951 0.392 35.0   -2.427 0.1320
## (2013-11-27) - (2023-11-27)   -0.613 0.405 35.3   -1.513 0.5610
##
## Degrees-of-freedom method: kenward-roger
## P value adjustment: tukey method for comparing a family of 5 estimates
```

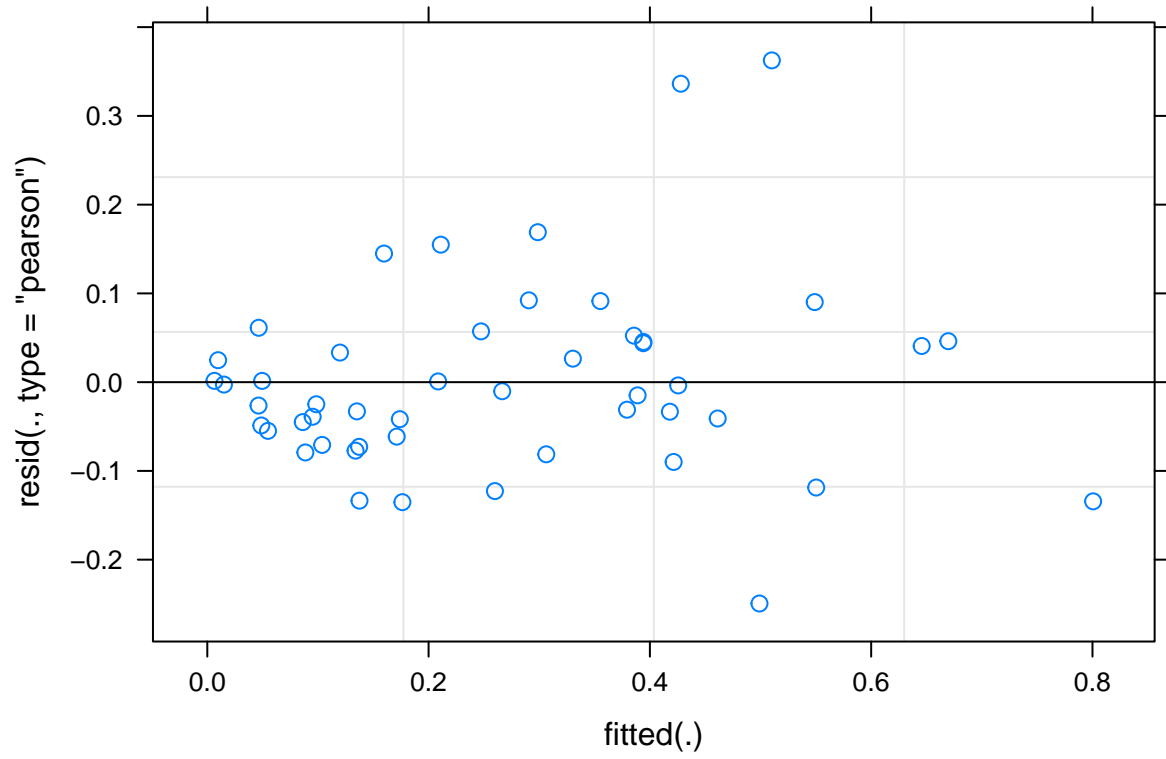
```
fuels_lmer_Hun_emm <- emmeans(fuels_lmer_Hun, ~year)
contrast(fuels_lmer_Hun_emm, method="pairwise")
```

```
## contrast                estimate    SE    df t.ratio p.value
## (2001-11-27) - (2003-11-27)    1.164 0.502 35.0    2.318 0.1633
## (2001-11-27) - (2004-11-27)    0.778 0.502 35.0    1.550 0.5384
## (2001-11-27) - (2013-11-27)   -0.191 0.517 35.8   -0.370 0.9958
## (2001-11-27) - (2023-11-27)   -1.607 0.502 35.0   -3.200 0.0228
## (2003-11-27) - (2004-11-27)   -0.386 0.502 35.0   -0.768 0.9380
## (2003-11-27) - (2013-11-27)   -1.355 0.517 35.8   -2.621 0.0878
## (2003-11-27) - (2023-11-27)   -2.770 0.502 35.0   -5.518 <.0001
## (2004-11-27) - (2013-11-27)   -0.969 0.517 35.8   -1.875 0.3490
## (2004-11-27) - (2023-11-27)   -2.385 0.502 35.0   -4.750 0.0003
## (2013-11-27) - (2023-11-27)   -1.415 0.517 35.8   -2.737 0.0679
##
## Degrees-of-freedom method: kenward-roger
## P value adjustment: tukey method for comparing a family of 5 estimates
```

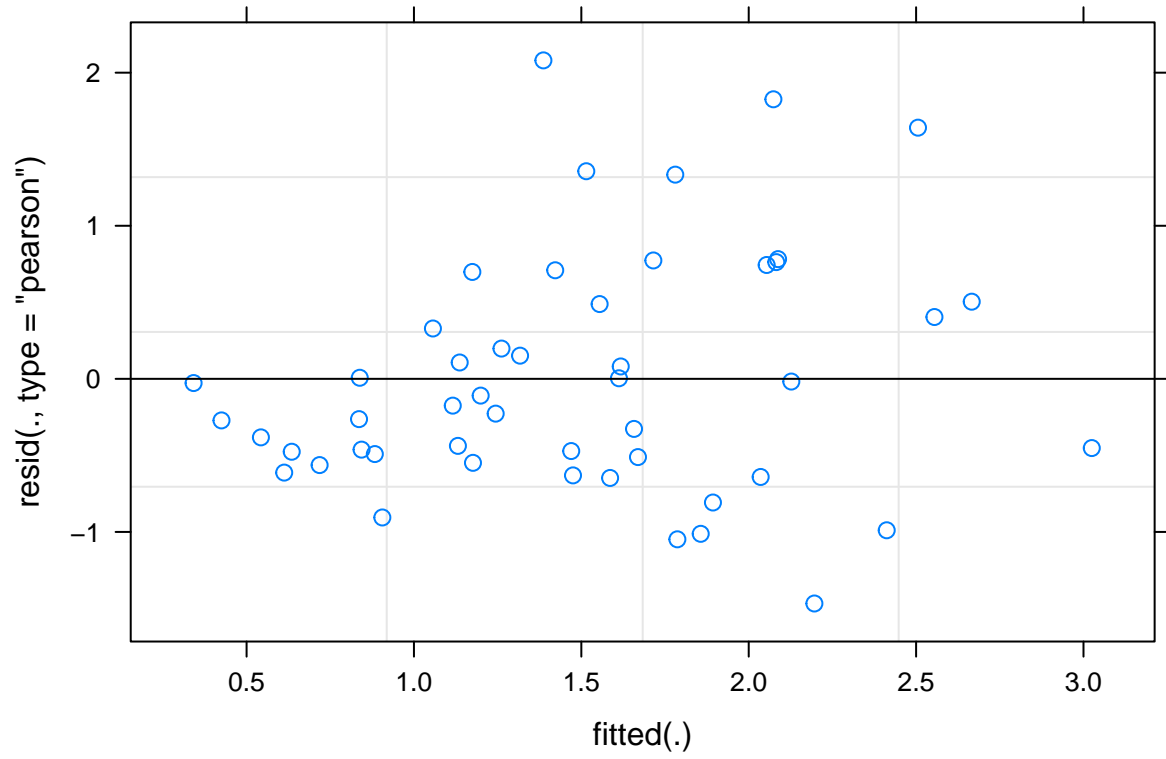
```
fuels_lmer_1000_emm <- emmeans(fuels_lmer_1000, ~year)
contrast(fuels_lmer_1000_emm, method="pairwise")
```

```
## contrast                estimate    SE    df t.ratio p.value
## (2001-11-27) - (2003-11-27)    8.868 3.38 35.0    2.623 0.0879
## (2001-11-27) - (2004-11-27)    9.172 3.38 35.0    2.713 0.0722
## (2001-11-27) - (2013-11-27)   -0.717 3.49 35.5   -0.205 0.9996
## (2001-11-27) - (2023-11-27)   -9.692 3.38 35.0   -2.866 0.0510
## (2003-11-27) - (2004-11-27)    0.305 3.38 35.0    0.090 1.0000
## (2003-11-27) - (2013-11-27)   -9.584 3.49 35.5   -2.747 0.0667
## (2003-11-27) - (2023-11-27)  -18.559 3.38 35.0   -5.489 <.0001
## (2004-11-27) - (2013-11-27)   -9.889 3.49 35.5   -2.834 0.0547
## (2004-11-27) - (2023-11-27)  -18.864 3.38 35.0   -5.579 <.0001
## (2013-11-27) - (2023-11-27)   -8.975 3.49 35.5   -2.572 0.0976
##
## Degrees-of-freedom method: kenward-roger
## P value adjustment: tukey method for comparing a family of 5 estimates
```

```
plot(fuels_lmer_One) #hoping to see even distribution above and below 0 line, looking for patterns, con
```

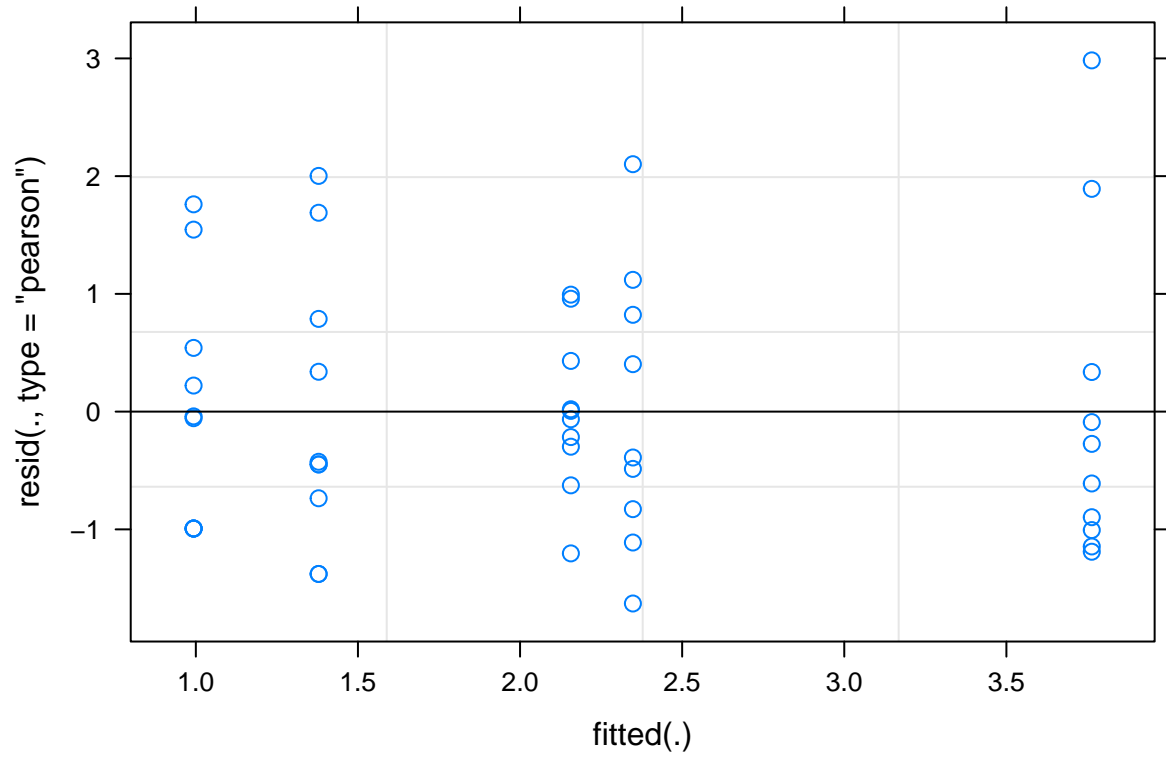


```
plot(fuels_lmer_Ten)
```



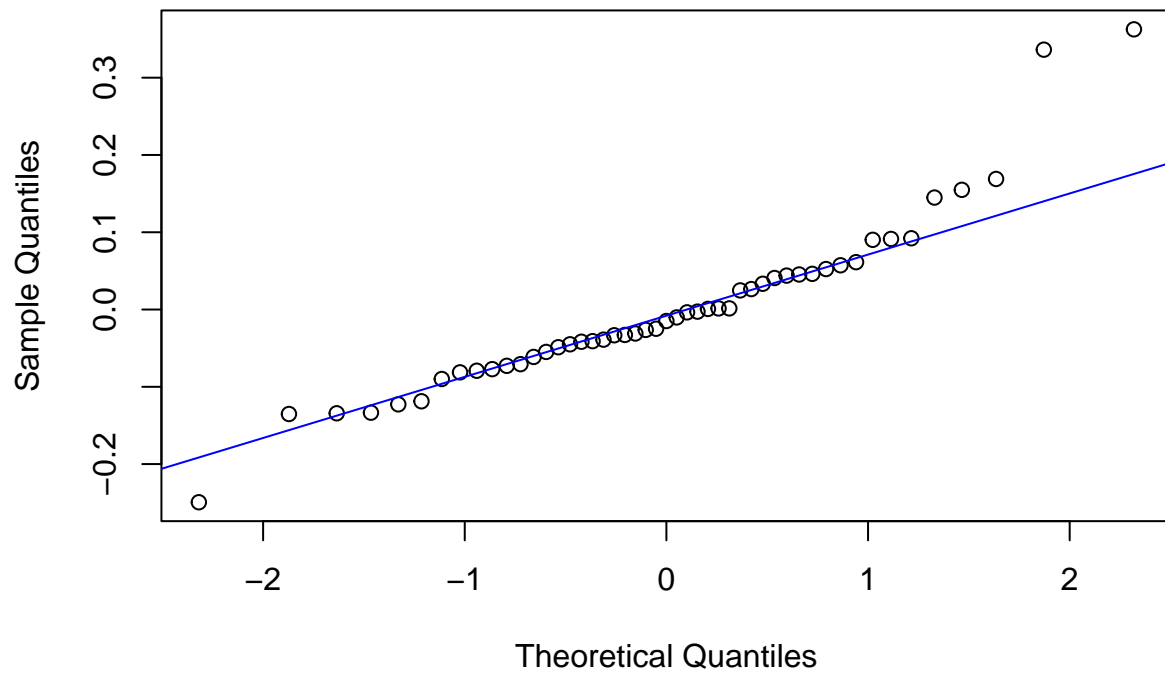
```
plot(fuels_lmer_Hun)
```





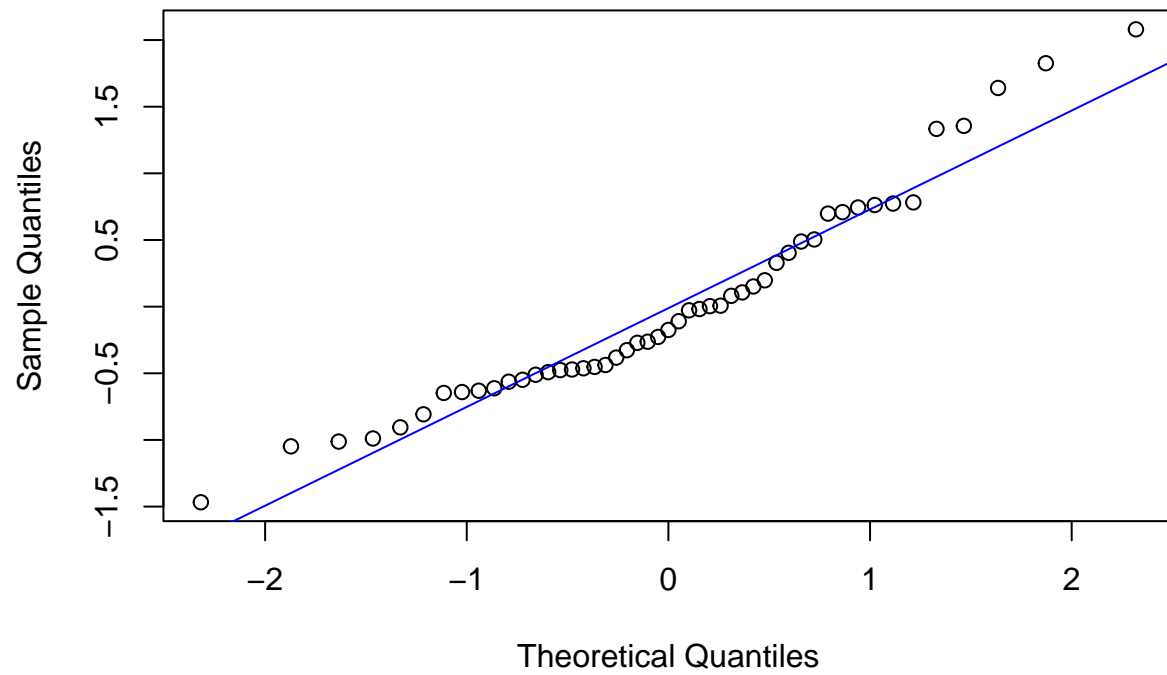
```
qqnorm(residuals(fuels_lmer_One))  
qqline(residuals(fuels_lmer_One), col = "blue")
```

Normal Q-Q Plot



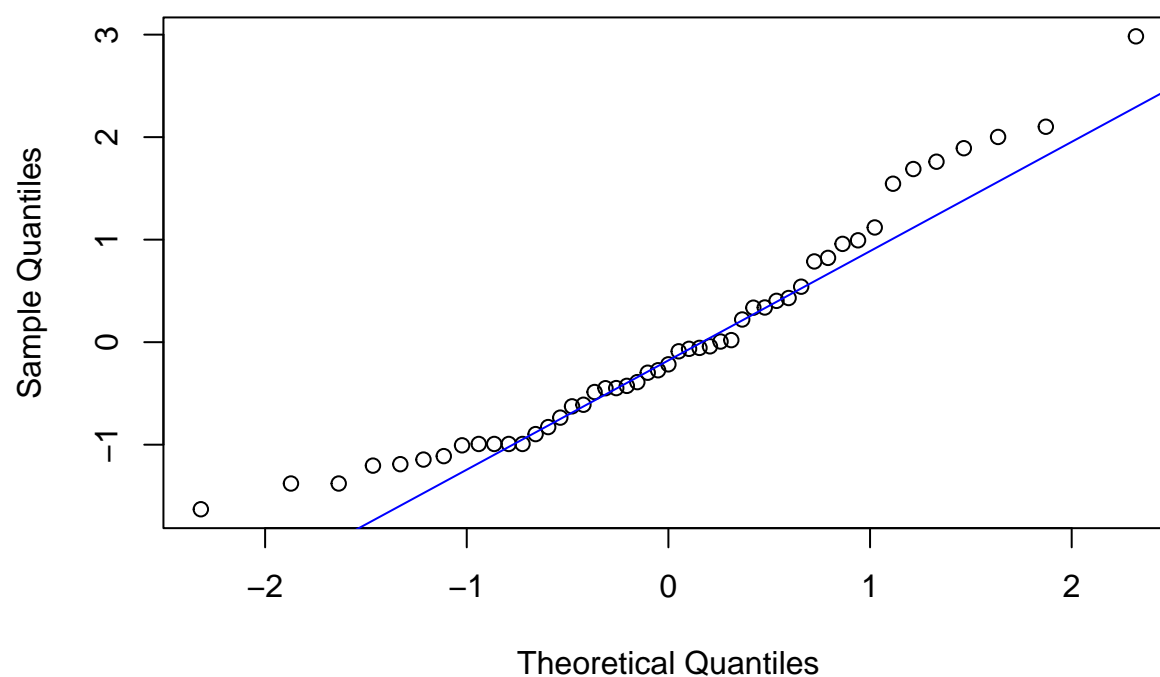
```
qqnorm(residuals(fuels_lmer_Ten))  
qqline(residuals(fuels_lmer_Ten), col = "blue")
```

Normal Q-Q Plot



```
qqnorm(residuals(fuels_lmer_Hun))  
qqline(residuals(fuels_lmer_Hun), col = "blue")
```

## Normal Q-Q Plot



```
fuels_lmer_One_emm <- emmeans(fuels_lmer_One, ~year)
contrast(fuels_lmer_One_emm, "pairwise", infer=TRUE, conf.int=TRUE)
```

##	contrast	estimate	SE	df	lower.CL	upper.CL	t.ratio
##	(2001-11-27) - (2003-11-27)	0.3791	0.0560	35.0	0.2180	0.5403	6.765
##	(2001-11-27) - (2004-11-27)	0.2904	0.0560	35.0	0.1292	0.4515	5.181
##	(2001-11-27) - (2013-11-27)	0.2516	0.0579	35.1	0.0851	0.4181	4.343
##	(2001-11-27) - (2023-11-27)	0.3393	0.0560	35.0	0.1782	0.5004	6.054
##	(2003-11-27) - (2004-11-27)	-0.0887	0.0560	35.0	-0.2499	0.0724	-1.584
##	(2003-11-27) - (2013-11-27)	-0.1275	0.0579	35.1	-0.2940	0.0390	-2.201
##	(2003-11-27) - (2023-11-27)	-0.0398	0.0560	35.0	-0.2010	0.1213	-0.711
##	(2004-11-27) - (2013-11-27)	-0.0388	0.0579	35.1	-0.2053	0.1278	-0.669
##	(2004-11-27) - (2023-11-27)	0.0489	0.0560	35.0	-0.1122	0.2101	0.873
##	(2013-11-27) - (2023-11-27)	0.0877	0.0579	35.1	-0.0788	0.2542	1.514
##	p.value						
##	<.0001						
##	0.0001						
##	0.0010						
##	<.0001						
##	0.5174						
##	0.2031						
##	0.9527						
##	0.9618						
##	0.9049						
##	0.5609						

```
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## Conf-level adjustment: tukey method for comparing a family of 5 estimates
## P value adjustment: tukey method for comparing a family of 5 estimates

kableone=tidy(contrast(fuels_lmer_One_emm, "pairwise", infer=TRUE), conf.int=TRUE)
kableone$Size_class="One"

tidy(contrast(fuels_lmer_One_emm, "pairwise", infer=TRUE), conf.int=TRUE) %>%
  select(Contrast=contrast, Estimate=estimate,
         SE=std.error, df=df, `CI-low`=conf.low, `CI-high`=conf.high,
         `P-value`='adj.p.value') %>%
  kable(digits=c(2, 2, 2, 2, 2, 6), booktabs=T)
```

Contrast	Estimate	SE	df	CI-low	CI-high	P-value
(2001-11-27) - (2003-11-27)	0.38	0.06	35.00	0.22	0.54	0.000001
(2001-11-27) - (2004-11-27)	0.29	0.06	35.00	0.13	0.45	0.000087
(2001-11-27) - (2013-11-27)	0.25	0.06	35.13	0.09	0.42	0.001017
(2001-11-27) - (2023-11-27)	0.34	0.06	35.00	0.18	0.50	0.000006
(2003-11-27) - (2004-11-27)	-0.09	0.06	35.00	-0.25	0.07	0.517448
(2003-11-27) - (2013-11-27)	-0.13	0.06	35.13	-0.29	0.04	0.203065
(2003-11-27) - (2023-11-27)	-0.04	0.06	35.00	-0.20	0.12	0.952693
(2004-11-27) - (2013-11-27)	-0.04	0.06	35.13	-0.21	0.13	0.961763
(2004-11-27) - (2023-11-27)	0.05	0.06	35.00	-0.11	0.21	0.904873
(2013-11-27) - (2023-11-27)	0.09	0.06	35.13	-0.08	0.25	0.560870

```
fuels_lmer_Ten_emm <- emmeans(fuels_lmer_Ten, ~year)
contrast(fuels_lmer_Ten_emm, "pairwise", infer=TRUE, conf.int=TRUE)
```

```
## contrast      estimate    SE   df lower.CL upper.CL t.ratio
## (2001-11-27) - (2003-11-27)  0.774 0.392 35.0  -0.353   1.901   1.976
## (2001-11-27) - (2004-11-27)  0.481 0.392 35.0  -0.646   1.608   1.227
## (2001-11-27) - (2013-11-27)  0.143 0.405 35.3  -1.021   1.306   0.352
## (2001-11-27) - (2023-11-27) -0.470 0.392 35.0  -1.597   0.657  -1.199
## (2003-11-27) - (2004-11-27) -0.293 0.392 35.0  -1.420   0.834  -0.748
## (2003-11-27) - (2013-11-27) -0.632 0.405 35.3  -1.795   0.532  -1.560
## (2003-11-27) - (2023-11-27) -1.244 0.392 35.0  -2.371  -0.117  -3.175
## (2004-11-27) - (2013-11-27) -0.338 0.405 35.3  -1.502   0.825  -0.836
## (2004-11-27) - (2023-11-27) -0.951 0.392 35.0  -2.078   0.176  -2.427
## (2013-11-27) - (2023-11-27) -0.613 0.405 35.3  -1.776   0.551  -1.513
## p.value
## 0.2987
## 0.7356
## 0.9965
## 0.7518
## 0.9434
## 0.5316
## 0.0243
## 0.9175
## 0.1320
```

```
##    0.5610
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## Conf-level adjustment: tukey method for comparing a family of 5 estimates
## P value adjustment: tukey method for comparing a family of 5 estimates

kableten=tidy(contrast(fuels_lmer_Ten_emm, "pairwise", infer=TRUE), conf.int=TRUE)
kableten$Size_class="Ten"

tidy(contrast(fuels_lmer_Ten_emm, "pairwise", infer=TRUE), conf.int=TRUE) %>%
  select(Contrast=contrast, Estimate=estimate,
         SE=std.error, df=df, `CI-low`=conf.low, `CI-high`=conf.high,
         `P-value`='adj.p.value') %>%
  kable(digits=c(2, 2, 2, 2, 2, 6), booktabs=T)
```

Contrast	Estimate	SE	df	CI-low	CI-high	P-value
(2001-11-27) - (2003-11-27)	0.77	0.39	35.01	-0.35	1.90	0.298704
(2001-11-27) - (2004-11-27)	0.48	0.39	35.01	-0.65	1.61	0.735647
(2001-11-27) - (2013-11-27)	0.14	0.40	35.32	-1.02	1.31	0.996544
(2001-11-27) - (2023-11-27)	-0.47	0.39	35.01	-1.60	0.66	0.751827
(2003-11-27) - (2004-11-27)	-0.29	0.39	35.01	-1.42	0.83	0.943443
(2003-11-27) - (2013-11-27)	-0.63	0.40	35.32	-1.79	0.53	0.531636
(2003-11-27) - (2023-11-27)	-1.24	0.39	35.01	-2.37	-0.12	0.024350
(2004-11-27) - (2013-11-27)	-0.34	0.40	35.32	-1.50	0.82	0.917470
(2004-11-27) - (2023-11-27)	-0.95	0.39	35.01	-2.08	0.18	0.132037
(2013-11-27) - (2023-11-27)	-0.61	0.40	35.32	-1.78	0.55	0.561029

```
fuels_lmer_Hun_emm <- emmeans(fuels_lmer_Hun, ~year)
contrast(fuels_lmer_Hun_emm, "pairwise", infer=TRUE, conf.int=TRUE)
```

```
## contrast          estimate    SE   df lower.CL upper.CL t.ratio
## (2001-11-27) - (2003-11-27)  1.164 0.502 35.0  -0.280  2.6069  2.318
## (2001-11-27) - (2004-11-27)  0.778 0.502 35.0  -0.665  2.2212  1.550
## (2001-11-27) - (2013-11-27) -0.191 0.517 35.8  -1.676  1.2935 -0.370
## (2001-11-27) - (2023-11-27) -1.607 0.502 35.0  -3.050 -0.1633 -3.200
## (2003-11-27) - (2004-11-27) -0.386 0.502 35.0  -1.829  1.0576 -0.768
## (2003-11-27) - (2013-11-27) -1.355 0.517 35.8  -2.840  0.1298 -2.621
## (2003-11-27) - (2023-11-27) -2.770 0.502 35.0  -4.213 -1.3270 -5.518
## (2004-11-27) - (2013-11-27) -0.969 0.517 35.8  -2.454  0.5155 -1.875
## (2004-11-27) - (2023-11-27) -2.385 0.502 35.0  -3.828 -0.9413 -4.750
## (2013-11-27) - (2023-11-27) -1.415 0.517 35.8  -2.900  0.0695 -2.737
## p.value
## 0.1633
## 0.5384
## 0.9958
## 0.0228
## 0.9380
## 0.0878
## <.0001
## 0.3490
```

```
## 0.0003
## 0.0679
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## Conf-level adjustment: tukey method for comparing a family of 5 estimates
## P value adjustment: tukey method for comparing a family of 5 estimates

kablehun=tidy(contrast(fuels_lmer_Hun_emm, "pairwise", infer=TRUE), conf.int=TRUE)
kablehun$Size_class="Hun"

tidy(contrast(fuels_lmer_Hun_emm, "pairwise", infer=TRUE), conf.int=TRUE) %>%
  select(Contrast=contrast, Estimate=estimate,
         SE=std.error, df=df, `CI-low`=conf.low, `CI-high`=conf.high,
         `P-value`='adj.p.value') %>%
  kable(digits=c(2, 2, 2, 2, 2, 6), booktabs=T)
```

Contrast	Estimate	SE	df	CI-low	CI-high	P-value
(2001-11-27) - (2003-11-27)	1.16	0.50	35.04	-0.28	2.61	0.163318
(2001-11-27) - (2004-11-27)	0.78	0.50	35.04	-0.67	2.22	0.538383
(2001-11-27) - (2013-11-27)	-0.19	0.52	35.78	-1.68	1.29	0.995823
(2001-11-27) - (2023-11-27)	-1.61	0.50	35.04	-3.05	-0.16	0.022832
(2003-11-27) - (2004-11-27)	-0.39	0.50	35.04	-1.83	1.06	0.938000
(2003-11-27) - (2013-11-27)	-1.35	0.52	35.78	-2.84	0.13	0.087796
(2003-11-27) - (2023-11-27)	-2.77	0.50	35.04	-4.21	-1.33	0.000031
(2004-11-27) - (2013-11-27)	-0.97	0.52	35.78	-2.45	0.52	0.348989
(2004-11-27) - (2023-11-27)	-2.38	0.50	35.04	-3.83	-0.94	0.000311
(2013-11-27) - (2023-11-27)	-1.42	0.52	35.78	-2.90	0.07	0.067937

```
sum_table=rbind(kableone,kableten,kablehun)

ggplot(sum_table, aes(Size_class, contrast)) +
  geom_tile(aes(fill = adj.p.value), colour = "white") +
  scale_fill_gradient(low = "steelblue", high = "white")
```

