mdi_pitchpine_analyses.R

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```
# script to analyze mdi pitch pine data

library(tidyverse)
library(emmeans)
library(lme4)
library(car)
library(circular)

multiplot <- function(..., plotlist=NULL, cols) {
  require(grid)

  # Make a list from the ... arguments and plotlist
  plots <- c(list(...), plotlist)

  numPlots = length(plots)

  # Make the panel
  plotCols = cols                          # Number of columns of plots
  plotRows = ceiling(numPlots/plotCols) # Number of rows needed, calculated from # of cols

  # Set up the page
  grid.newpage()
  pushViewport(viewport(layout = grid.layout(plotRows, plotCols)))
  vplayout <- function(x, y)
    viewport(layout.pos.row = x, layout.pos.col = y)

  # Make each plot, in the correct location
  for (i in 1:numPlots) {
    curRow = ceiling(i/plotCols)
    curCol = (i-1) %% plotCols + 1
    print(plots[[i]], vp = vplayout(curRow, curCol ))
  }

}

## read in cleaned data
data = read.csv('../data/mdi_all_clean.csv')
data$CN_foliar = data$C_foliar/data$N_foliar
data$CN_soil = data$C_soil/data$N_soil
data$fire[data$Name == 'CAD'] = 'fire'
data$fire[data$Name == 'CADCLIFFS'] = 'fire'
data$fire[data$Name == 'STSAUV'] = 'no fire'
data$fire[data$Name == 'WOND'] = 'no fire'
head(data)
```

```
##                  ID Name height canopy diam   d13C  d15N C_foliar N_foliar
## 1 PP-1-LOWELEV-DIST WOND  472.4  548.6 21.6 -28.52 -5.98    47.75     1.07
```

```
## 2 PP-2-LOWELEV-DIST WOND  152.4  167.6 19.4 -28.89 -1.78    48.58     1.79
## 3 PP-3-LOWELEV-DIST WOND  365.8  365.8 20.3 -29.14 -6.81    50.39    18.37
## 4 PP-4-LOWELEV-DIST WOND  365.8  609.6 20.3 -27.65 -6.81    47.37     1.05
## 5 PP-5-LOWELEV-DIST WOND  487.7  557.6 20.3 -28.19 -1.33    36.73     0.67
## 6 PP-6-LOWELEV-DIST WOND  762.0  731.5 21.6 -29.58  1.24    25.92     1.02
##   Ca_foliar P_foliar K_foliar Mg_foliar Al_foliar Zn_foliar Ca_soil P_soil
## 1      1860      830     3720       910       320      51.5    1506   19.1
## 2      1420     2260      540       330       176      27.7    1007   12.4
## 3      1710      930     3430       880       606      34.0     408    1.4
## 4      1220     2700      460       570       274      24.7     476    1.5
## 5      1480      810     3170       890       488      29.7     926   13.8
## 6      1230     2020      630       440       168      25.9     764    9.2
##   K_soil Mg_soil Al_soil Zn_soil  pH  CEC C_soil N_soil  ID1 longitude
## 1    627     635     270    10.9 3.9 34.3  47.27   0.95 PP-1 -68.32232
## 2    394     416      38     8.6 3.5 33.1  32.15   0.91 PP-2 -68.31530
## 3     79      71     124     1.9 4.5 15.9  27.17   0.64 PP-3 -68.32574
## 4    183     207      86     3.2 4.0 18.7  18.62   0.31 PP-4 -68.31498
## 5    475     327      92     6.4 3.6 33.9  12.70   0.34 PP-5 -68.31468
## 6    420     290      77     0.4 3.8 23.6  23.36   0.12 PP-6 -68.31465
##   latitude Label Elevation Slope Aspect retention CN_foliar   CN_soil
## 1 44.26728   PP1        40     2    343      25.4 44.626168  49.75789
## 2 44.23170   PP2        71     5    245      14.8 27.139665  35.32967
## 3 44.26817   PP3        37     5    325      19.1  2.743059  42.45312
## 4 44.23161   PP4        71     1    313       9.3 45.114286  60.06452
## 5 44.23154   PP5        58     4     94      18.6 54.820896  37.35294
## 6 44.23149   PP6        85     4     88      31.9 25.411765 194.66667
##      fire
## 1 no fire
## 2 no fire
## 3 no fire
## 4 no fire
## 5 no fire
## 6 no fire
```

```
data_density = read.csv('../data/mdi_stand_density.csv')
data_density$fire[data_density$site == 'CAD'] = 'fire'
data_density$fire[data_density$site == 'CADCLIFFS'] = 'fire'
data_density$fire[data_density$site == 'STSAUV'] = 'no fire'
data_density$fire[data_density$site == 'WOND'] = 'no fire'

## site means
data_group_by_Name = group_by(data, Name)
data_Name_means = summarise(data_group_by_Name,
                            Elevation_mean = mean(Elevation, na.rm = T),
                            Slope_mean = mean(Slope, na.rm = T),
                            Aspect_mean = mean(Aspect, na.rm = T))
```

```
## `summarise()` ungrouping output (override with `.groups` argument)
```

```
## create an elevation factor
data$elevation_fac[data$Name == 'CAD' | data$Name == 'STSAUV'] = 'high'
data$elevation_fac[data$Name == 'CADCLIFFS' | data$Name == 'WOND'] = 'low'
data_density$elevation_fac[data_density$site == 'CAD' | data_density$site == 'STSAUV'] = 'high'
data_density$elevation_fac[data_density$site == 'CADCLIFFS' | data_density$site == 'WOND'] = 'low'
```

```r
## create a generic variable set to pass to formula argument
ind_variables = c('elevation_fac', 'fire')
dep_variables = c("log(Elevation)", "log(height)", "log(canopy)", "log(diam)",
                  "d13C", "d15N", "C_foliar", "N_foliar", "CN_foliar", "Ca_foliar", "log(P_foliar)",
                  "log(K_foliar)", "Mg_foliar", "Al_foliar", "log(Zn_foliar)",
                  "Ca_soil", "log(P_soil)", "K_soil", "Mg_soil", "log(Al_soil)", "log(Zn_soil)",
                  "pH", "CEC", "C_soil", "N_soil", "log(CN_soil)", "asin(sqrt(0.01 * retention))")

## fit models and explore results

### elevation
Elevation_lm = lm(as.formula(paste("log(Elevation)",
                                   paste(ind_variables, collapse = "*"),
                                   sep = "~")), data = data)
#plot(resid(Elevation_lm) ~ fitted(Elevation_lm))
Anova(Elevation_lm)
```

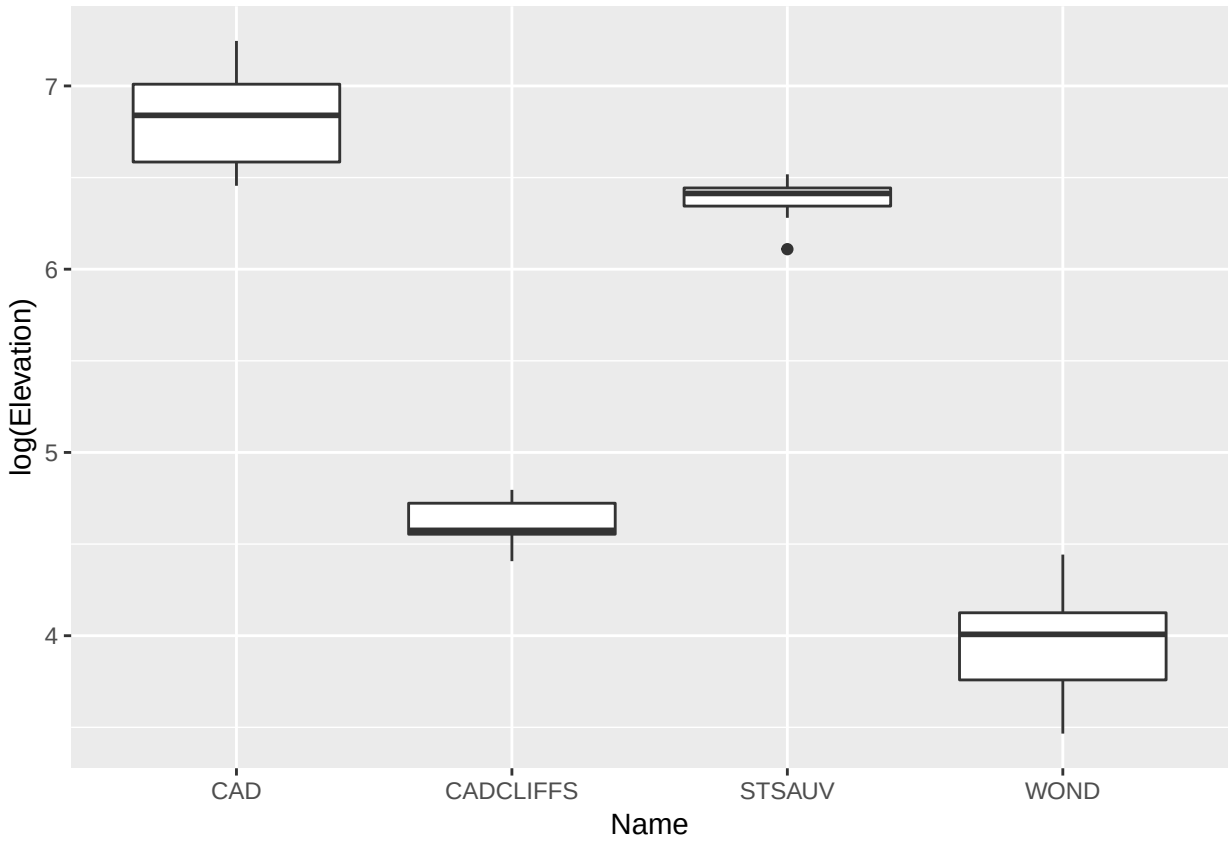
```
## Anova Table (Type II tests)
##
## Response: log(Elevation)
##                    Sum Sq Df  F value    Pr(>F)
## elevation_fac      81.138  1 1963.639 < 2.2e-16 ***
## fire                4.441  1  107.473 1.219e-14 ***
## elevation_fac:fire  0.222  1    5.375    0.0241 *
## Residuals           2.314 56
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
cld(emmeans(Elevation_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean     SE df lower.CL upper.CL .group
##  low           no fire   3.94 0.0525 56     3.83     4.05  1
##  low           fire      4.61 0.0525 56     4.50     4.71   2
##  high          no fire   6.39 0.0525 56     6.28     6.49    3
##  high          fire      6.81 0.0525 56     6.70     6.92     4
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```r
ggplot(data = data, aes(x = Name, y = log(Elevation))) +
  geom_boxplot()
```

```
## Warning: Removed 15 rows containing non-finite values (stat_boxplot).
```




```
### slope
Slope_lm = lm(as.formula(paste("Slope",
                               paste(ind_variables, collapse = "*"),
                               sep = "~")), data = data)
#plot(resid(Slope_lm) ~ fitted(Slope_lm))
Anova(Slope_lm)
```

```
## Anova Table (Type II tests)
##
## Response: Slope
##                     Sum Sq Df F value    Pr(>F)
## elevation_fac        620.8  1  29.981 1.066e-06 ***
## fire                2196.1  1 106.058 1.558e-14 ***
## elevation_fac:fire 3856.0  1 186.217 < 2.2e-16 ***
## Residuals          1159.6 56
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

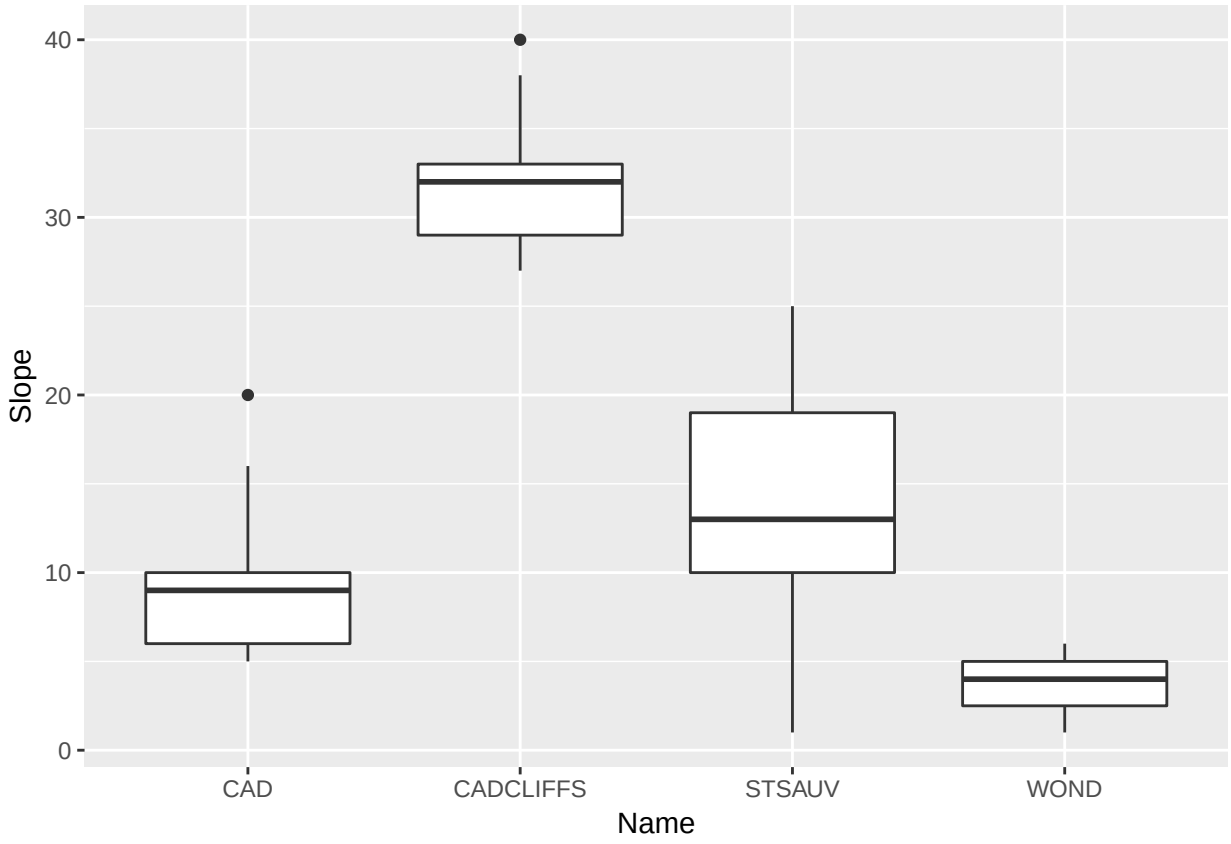
```
cld(emmeans(Slope_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean   SE df lower.CL upper.CL .group
##  low           no fire   3.73 1.17 56     1.38     6.09  1
##  high          fire      9.40 1.17 56     7.05    11.75   2
##  high          no fire  13.33 1.17 56    10.98    15.69   2
##  low           fire     31.87 1.17 56    29.51    34.22    3
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
```

```
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = Slope)) +
  geom_boxplot()
```

```
## Warning: Removed 15 rows containing non-finite values (stat_boxplot).
```




```
### aspect
#### watson tests following: https://bigdata.duke.edu/sites/bigdata.duke.edu/files/site-images/FullLess
aspect_CAD = circular(data$Aspect[data$Name == 'CAD'],
                      units="degrees", template="geographics")
aspect_CADCLIFFS = circular(data$Aspect[data$Name == 'CADCLIFFS'],
                            units="degrees", template="geographics")
aspect_STSAUV = circular(data$Aspect[data$Name == 'STSAUV'],
                         units="degrees", template="geographics")
aspect_WOND = circular(data$Aspect[data$Name == 'WOND'],
                       units="degrees", template="geographics")

watson.two.test(aspect_CAD, aspect_CADCLIFFS) # P >0.1
```

```
##
##       Watson's Two-Sample Test of Homogeneity
##
## Test Statistic: 0.1497
## P-value > 0.10
##
```

```
watson.two.test(aspect_CAD, aspect_STSAUV) # P < 0.001
```

```
##
##       Watson's Two-Sample Test of Homogeneity
##
## Test Statistic: 0.5186
## P-value < 0.001
##
```

```
watson.two.test(aspect_CAD, aspect_WOND) # P < 0.05
```

```
##
##       Watson's Two-Sample Test of Homogeneity
##
## Test Statistic: 0.1989
## 0.01 < P-value < 0.05
##
```

```
watson.two.test(aspect_CADCLIFFS, aspect_STSAUV) # P < 0.1
```

```
##
##       Watson's Two-Sample Test of Homogeneity
##
## Test Statistic: 0.3846
## 0.001 < P-value < 0.01
##
```

```
watson.two.test(aspect_CADCLIFFS, aspect_WOND) # P < 0.05
```

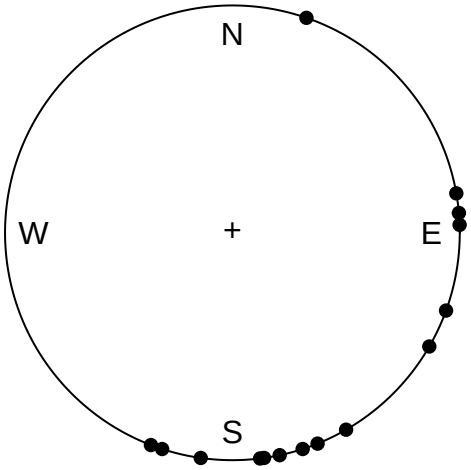
```
##
##       Watson's Two-Sample Test of Homogeneity
##
## Test Statistic: 0.2593
## 0.01 < P-value < 0.05
##
```

```
watson.two.test(aspect_STSAUV, aspect_WOND) # P <0.01
```

```
##
##       Watson's Two-Sample Test of Homogeneity
##
## Test Statistic: 0.2877
## 0.001 < P-value < 0.01
##
```

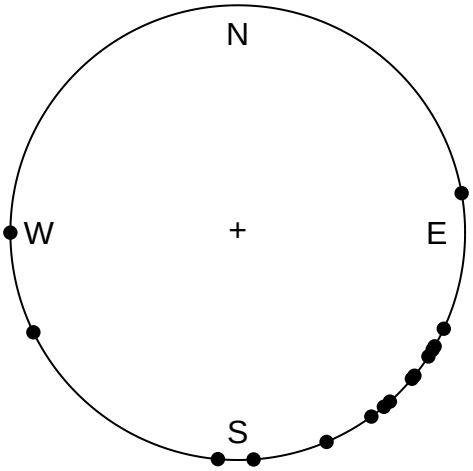
```
plot_aspect_CAD = plot.circular(aspect_CAD, main = 'CAD aspect')
```

CAD aspect

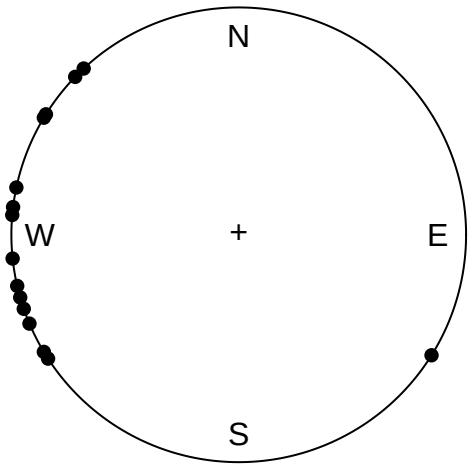



```
plot_aspect_CADCLIFFS = plot.circular(aspect_CADCLIFFS, main = 'CADCLIFFS aspect')
```

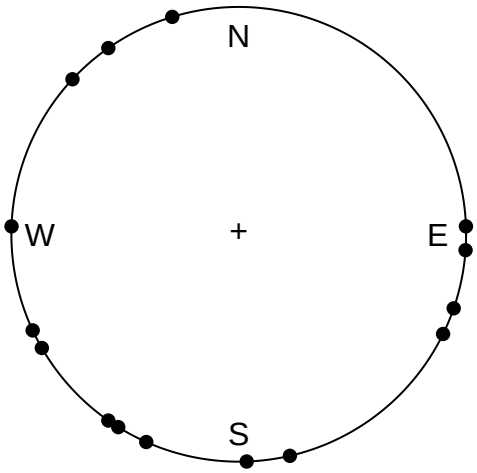
CADCLIFFS aspect




```
plot_aspect_STSAUV = plot.circular(aspect_STSAUV, main = 'STSAUV aspect')
```




```
plot_aspect_WOND = plot.circular(aspect_WOND, main = 'WOND aspect')
```




```
### height
height_lm = lm(as.formula(paste(dep_variables[2],
                                paste(ind_variables, collapse = "*"),
                                sep = "~")), data = data)
#plot(resid(height_lm) ~ fitted(height_lm))
Anova(height_lm)
```

```
## Anova Table (Type II tests)
##
## Response: log(height)
##                     Sum Sq Df F value   Pr(>F)
## elevation_fac       0.5238  1  2.2201 0.144934
## fire                0.1207  1  0.5116 0.479068
## elevation_fac:fire 1.9021  1  8.0628 0.007385 **
## Residuals          8.4928 36
```

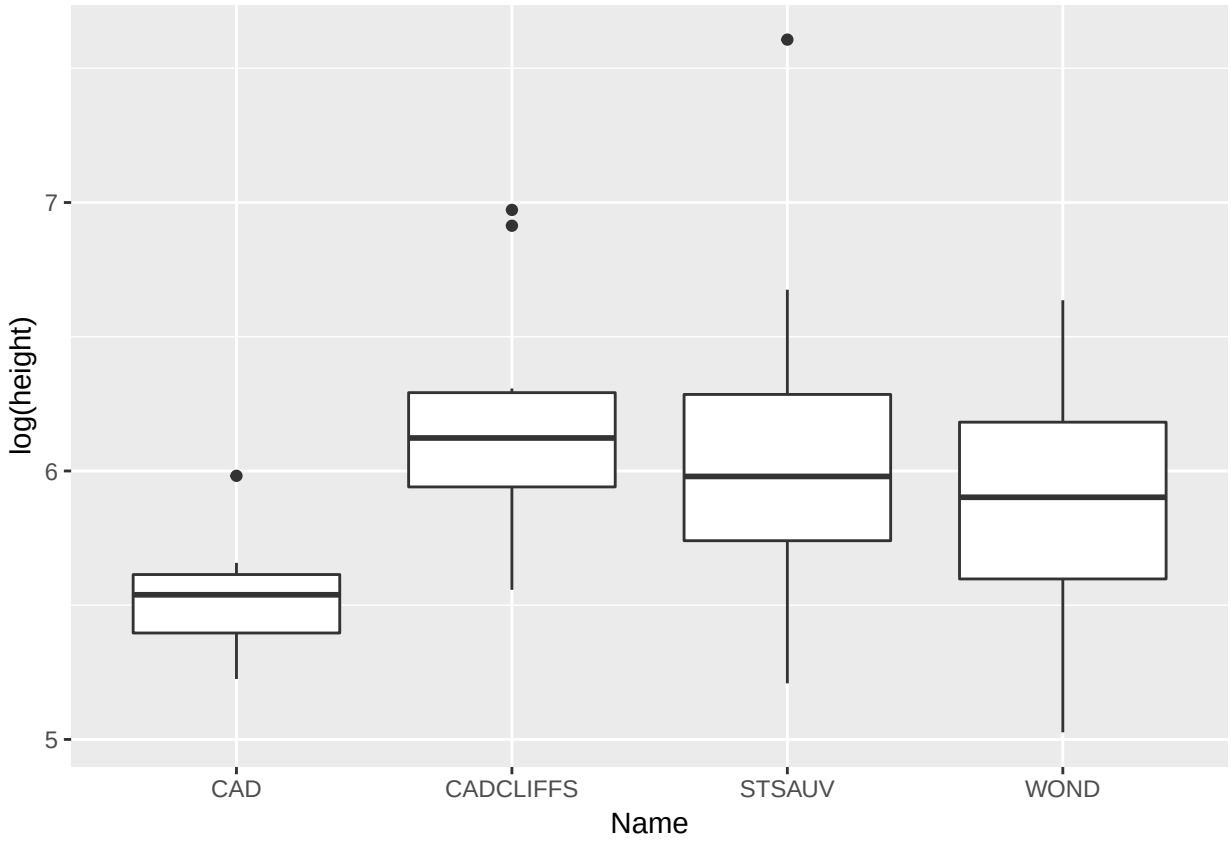
```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(height_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          fire      5.54 0.154 36     5.22     5.85  1
##  low           no fire   5.88 0.154 36     5.56     6.19  12
##  high          no fire   6.08 0.154 36     5.77     6.39  12
##  low           fire      6.20 0.154 36     5.89     6.51   2
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = log(height))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
# height_lmer_cont = lmer(log(height) ~ Elevation * fire + (1|Name), data = data)
# Anova(height_lmer_cont)
# test(emtrends(height_lmer_cont, ~fire, var = 'Elevation'))

# height_plot = ggplot(data = data, aes(x = Name, y = log(height), col = fire)) +
#   theme(legend.position = "none",
#         axis.title.y=element_text(size=rel(2.5), colour = 'black'),
#         axis.title.x=element_text(size=rel(2.5), colour = 'black'),
```

```
#         axis.text.x=element_text(size=rel(2), colour = 'black'),
#         axis.text.y=element_text(size=rel(2), colour = 'black'),
#         panel.background = element_rect(fill = 'white', colour = 'black'),
#         panel.grid.major = element_line(colour = "grey")) +
#   geom_boxplot(outlier.color = NA, fill = 'white') +
#   geom_dotplot(binaxis = 'y', binwidth = 0.07, stackdir = 'center', alpha = 0.5) +
#   # scale_x_discrete(labels = c('Ambient', 'Added N')) +
#   xlab('Site') +
#   ylab(expression('ln(Height)'))
#
# height_plot_elevation = ggplot(data = data, aes(x = Elevation, y = log(height), col = fire)) +
#   theme(legend.position = "right",
#         axis.title.y=element_text(size=rel(2.5), colour = 'black'),
#         axis.title.x=element_text(size=rel(2.5), colour = 'black'),
#         axis.text.x=element_text(size=rel(2), colour = 'black'),
#         axis.text.y=element_text(size=rel(2), colour = 'black'),
#         panel.background = element_rect(fill = 'white', colour = 'black'),
#         panel.grid.major = element_line(colour = "grey")) +
#   geom_point(size = 6) +
#   ylab(expression('ln(Height)'))
#
# jpeg(filename = "plots/height_plot.jpeg", width = 1000, height = 600, units = 'px')
# multiplot(height_plot, height_plot_elevation, cols = 2)
# dev.off()

### canopy
canopy_lm = lm(as.formula(paste(dep_variables[3],
                                paste(ind_variables, collapse = "*"),
                                sep = "~")), data = data)
#plot(resid(canopy_lm) ~ fitted(canopy_lm))
anova(canopy_lm)
```

```
## Analysis of Variance Table
##
## Response: log(canopy)
##                    Df  Sum Sq Mean Sq F value   Pr(>F)
## elevation_fac       1  2.3211 2.32110  8.3352 0.006538 **
## fire                1  0.0673 0.06729  0.2416 0.626008
## elevation_fac:fire  1  0.1170 0.11701  0.4202 0.520961
## Residuals          36 10.0249 0.27847
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

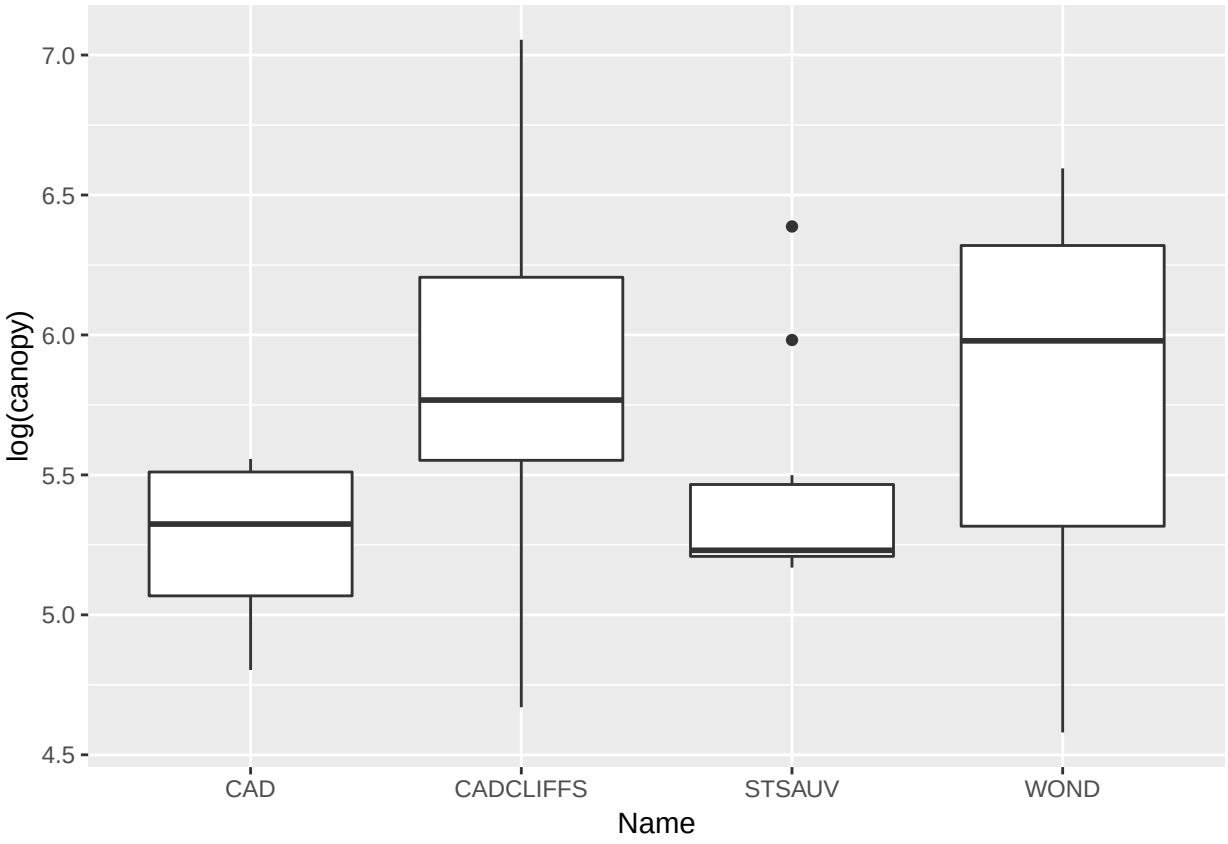
```
cld(emmeans(canopy_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          fire      5.26 0.167 36     4.92     5.60  1
##  high          no fire   5.45 0.167 36     5.11     5.79  1
##  low           no fire   5.82 0.167 36     5.48     6.16  1
##  low           fire      5.85 0.167 36     5.51     6.19  1
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
```

```
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = log(canopy))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
# canopy_lmer_cont = lmer(log(canopy) ~ Elevation * fire + (1|Name), data = data)
# Anova(canopy_lmer_cont)
# test(emtrends(canopy_lmer_cont, ~fire, var = 'Elevation'))

# canopy_plot = ggplot(data = data, aes(x = Name, y = log(canopy), col = fire)) +
#   theme(legend.position = "none",
#         axis.title.y=element_text(size=rel(2.5), colour = 'black'),
#         axis.title.x=element_text(size=rel(2.5), colour = 'black'),
#         axis.text.x=element_text(size=rel(2), colour = 'black'),
#         axis.text.y=element_text(size=rel(2), colour = 'black'),
#         panel.background = element_rect(fill = 'white', colour = 'black'),
#         panel.grid.major = element_line(colour = "grey")) +
#   geom_boxplot(outlier.color = NA, fill = 'white') +
#   geom_dotplot(binaxis = 'y', binwidth = 0.07, stackdir = 'center', alpha = 0.5) +
#   # scale_x_discrete(labels = c('Ambient', 'Added N')) +
#   xlab('Site') +
#   ylab(expression('ln(Canopy)'))
#
# canopy_plot_elevation = ggplot(data = data, aes(x = Elevation, y = log(canopy), col = fire)) +
#   theme(legend.position = "right",
#         axis.title.y=element_text(size=rel(2.5), colour = 'black'),
```

```
#         axis.title.x=element_text(size=rel(2.5), colour = 'black'),
#         axis.text.x=element_text(size=rel(2), colour = 'black'),
#         axis.text.y=element_text(size=rel(2), colour = 'black'),
#         panel.background = element_rect(fill = 'white', colour = 'black'),
#         panel.grid.major = element_line(colour = "grey")) +
#   geom_point(size = 6) +
#   ylab(expression('ln(Canopy)'))
#
# jpeg(filename = "plots/canopy_plot.jpeg", width = 1000, height = 600, units = 'px')
# multiplot(canopy_plot, canopy_plot_elevation, cols = 2)
# dev.off()

### diam
diam_lm = lm(as.formula(paste(dep_variables[4],
                              paste(ind_variables, collapse = "*"),
                              sep = "~")), data = data)
#plot(resid(diam_lm) ~ fitted(diam_lm))
anova(diam_lm)
```

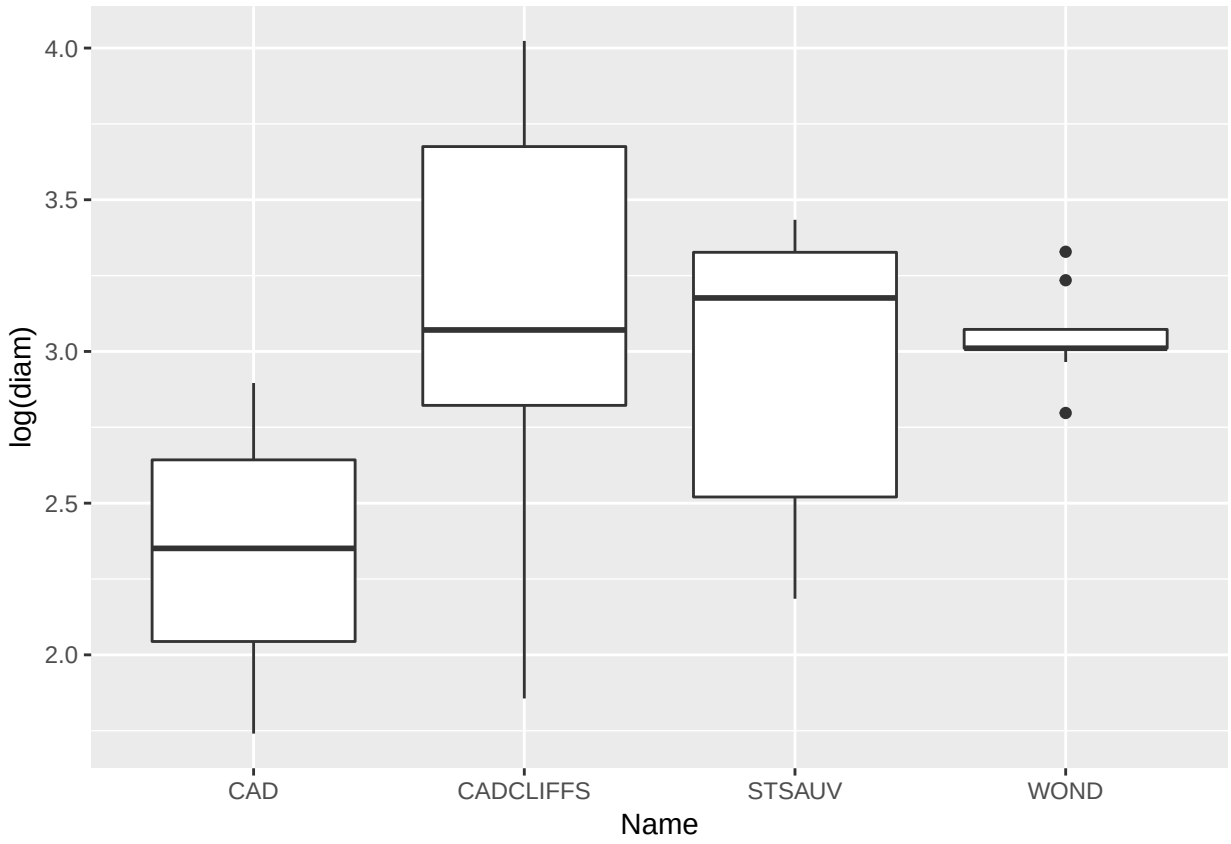
```
## Analysis of Variance Table
##
## Response: log(diam)
##                    Df Sum Sq Mean Sq F value   Pr(>F)
## elevation_fac       1 2.1167 2.11673 10.0838 0.003062 **
## fire                1 0.7177 0.71769  3.4190 0.072675 .
## elevation_fac:fire  1 1.2783 1.27835  6.0899 0.018483 *
## Residuals          36 7.5569 0.20991
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(diam_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          fire      2.32 0.145 36     2.03     2.62  1
##  high          no fire   2.95 0.145 36     2.66     3.24   2
##  low           no fire   3.05 0.145 36     2.76     3.35   2
##  low           fire      3.14 0.145 36     2.85     3.43   2
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = log(diam))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
# diam_lmer_cont = lmer(log(diam) ~ Elevation * fire + (1|Name), data = data)
# Anova(diam_lmer_cont)
# test(emtrends(diam_lmer_cont, ~fire, var = 'Elevation'))

# diam_plot = ggplot(data = data, aes(x = Name, y = log(diam), col = fire)) +
#   theme(legend.position = "none",
#         axis.title.y=element_text(size=rel(2.5), colour = 'black'),
#         axis.title.x=element_text(size=rel(2.5), colour = 'black'),
#         axis.text.x=element_text(size=rel(2), colour = 'black'),
#         axis.text.y=element_text(size=rel(2), colour = 'black'),
#         panel.background = element_rect(fill = 'white', colour = 'black'),
#         panel.grid.major = element_line(colour = "grey")) +
#   geom_boxplot(outlier.color = NA, fill = 'white') +
#   geom_dotplot(binaxis = 'y', binwidth = 0.07, stackdir = 'center', alpha = 0.5) +
#   # scale_x_discrete(labels = c('Ambient', 'Added N')) +
#   xlab('Site') +
#   ylab(expression('ln(Diameter)'))
#
# diam_plot_elevation = ggplot(data = data, aes(x = Elevation, y = log(diam), col = fire)) +
#   theme(legend.position = "right",
#         axis.title.y=element_text(size=rel(2.5), colour = 'black'),
#         axis.title.x=element_text(size=rel(2.5), colour = 'black'),
#         axis.text.x=element_text(size=rel(2), colour = 'black'),
#         axis.text.y=element_text(size=rel(2), colour = 'black'),
#         panel.background = element_rect(fill = 'white', colour = 'black'),
#         panel.grid.major = element_line(colour = "grey")) +
#   geom_point(size = 6) +
```

```
#   ylab(expression('ln(Diameter)'))
#
# jpeg(filename = "plots/diam_plot.jpeg", width = 1000, height = 600, units = 'px')
# multiplot(diam_plot, diam_plot_elevation, cols = 2)
# dev.off()

### d13C
d13C_lm = lm(as.formula(paste(dep_variables[5],
                              paste(ind_variables, collapse = "*"),
                              sep = "~")), data = data)
#plot(resid(d13C_lm) ~ fitted(d13C_lm))
anova(d13C_lm)
```

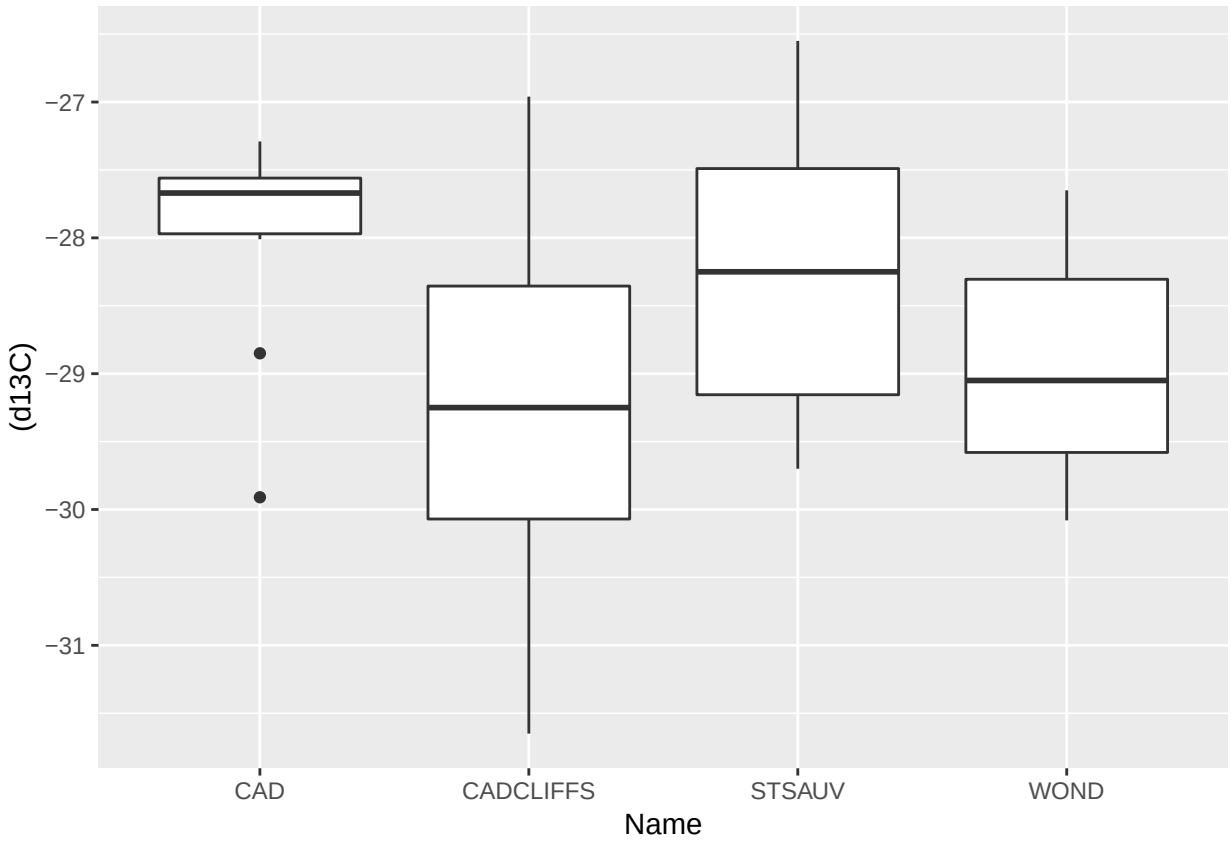
```
## Analysis of Variance Table
##
## Response: d13C
##                    Df Sum Sq Mean Sq F value    Pr(>F)
## elevation_fac       1 14.876 14.8761 14.1946 0.0004285 ***
## fire                1  0.321  0.3214  0.3067 0.5821471
## elevation_fac:fire  1  1.173  1.1735  1.1197 0.2949641
## Residuals          51 53.448  1.0480
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(d13C_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  low           fire     -29.3 0.264 51    -29.9    -28.8  1
##  low           no fire  -28.9 0.264 51    -29.5    -28.4  12
##  high          no fire  -28.2 0.264 51    -28.7    -27.6   2
##  high          fire     -28.0 0.324 51    -28.6    -27.3   2
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (d13C))) +
  geom_boxplot()
```

```
## Warning: Removed 20 rows containing non-finite values (stat_boxplot).
```




```
### d15N
d15N_lm = lm(as.formula(paste(dep_variables[6],
                              paste(ind_variables, collapse = "*"),
                              sep = "~")), data = data)
#plot(resid(d15N_lm) ~ fitted(d15N_lm))
anova(d15N_lm)
```

```
## Analysis of Variance Table
##
## Response: d15N
##                    Df Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac       1   2.80  2.8000  0.3337 0.56605
## fire                1  28.07 28.0714  3.3453 0.07325 .
## elevation_fac:fire  1   9.68  9.6787  1.1534 0.28789
## Residuals          51 427.96  8.3913
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

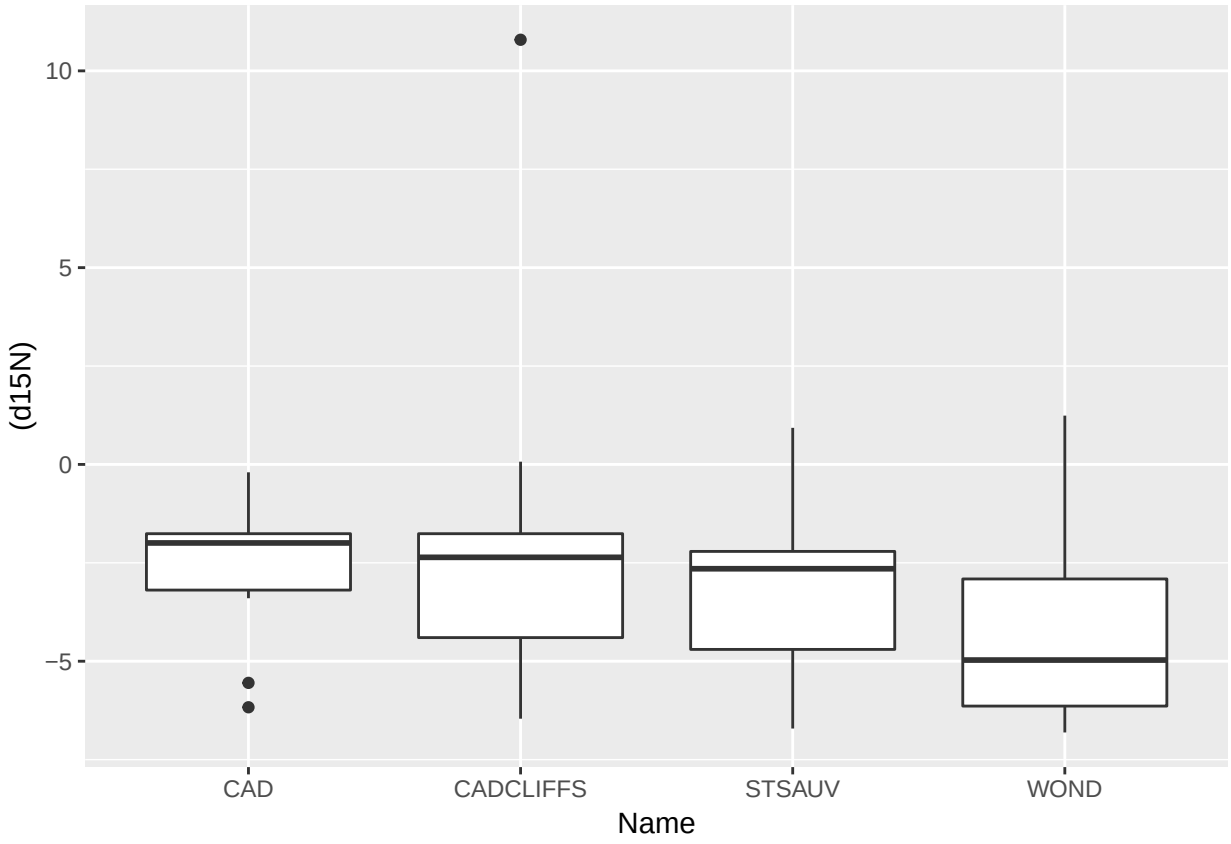
```
cld(emmeans(d15N_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  low           no fire  -4.42 0.748 51    -5.92   -2.918  1
##  high          no fire  -3.07 0.748 51    -4.57   -1.564  1
##  high          fire     -2.57 0.916 51    -4.41   -0.731  1
##  low           fire     -2.22 0.748 51    -3.72   -0.719  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
```

```
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (d15N))) +
  geom_boxplot()
```

```
## Warning: Removed 20 rows containing non-finite values (stat_boxplot).
```




```
### C_foliar
C_foliar_lm = lm(as.formula(paste(dep_variables[7],
                                  paste(ind_variables, collapse = "*"),
                                  sep = "~")), data = data)
#plot(resid(C_foliar_lm) ~ fitted(C_foliar_lm))
anova(C_foliar_lm)
```

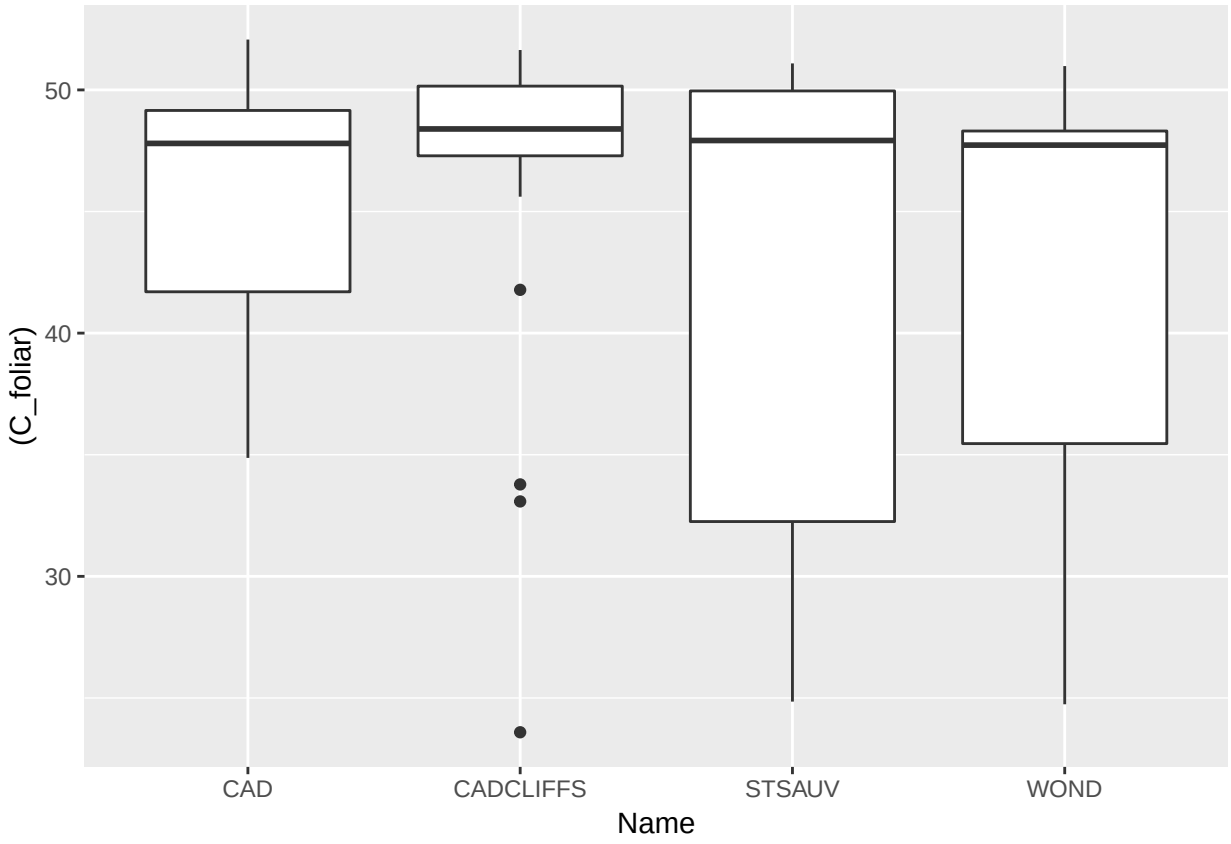
```
## Analysis of Variance Table
##
## Response: C_foliar
##                    Df Sum Sq Mean Sq F value Pr(>F)
## elevation_fac       1    0.9   0.901  0.0133 0.9084
## fire                1  172.2 172.173  2.5494 0.1148
## elevation_fac:fire  1    3.0   2.993  0.0443 0.8339
## Residuals          71 4794.9  67.534
```

```
cld(emmeans(C_foliar_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean   SE df lower.CL upper.CL .group
##  low           no fire   42.4 1.84 71     38.7     46.0  1
##  high          no fire   42.7 1.84 71     39.1     46.4  1
##  high          fire      45.3 2.12 71     41.1     49.6  1
```

```
##  low           fire      45.8 1.84 71     42.1     49.4  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (C_foliar))) +
  geom_boxplot()
```




```
### N_foliar
N_foliar_lm = lm(as.formula(paste(dep_variables[8],
                                  paste(ind_variables, collapse = "*"),
                                  sep = "~")), data = data)
#plot(resid(N_foliar_lm) ~ fitted(N_foliar_lm))
anova(N_foliar_lm)
```

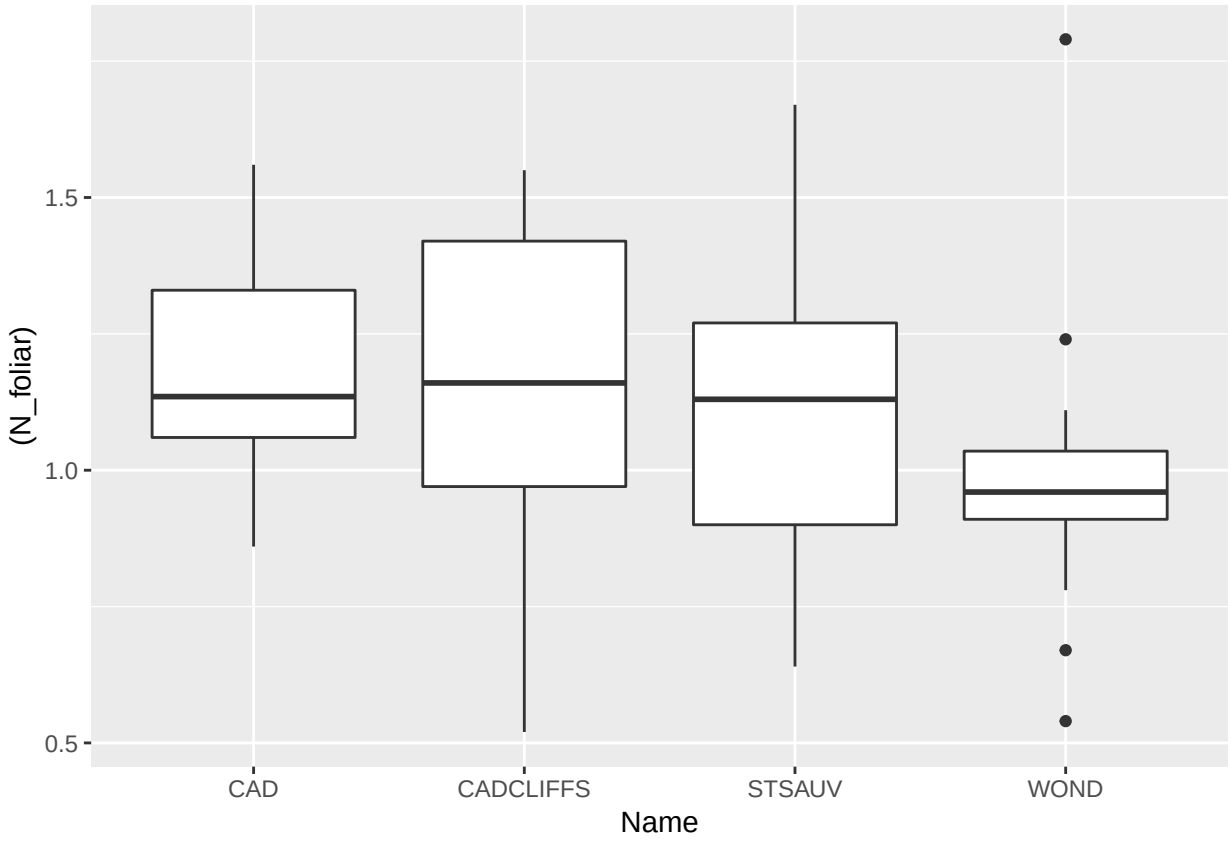
```
## Analysis of Variance Table
##
## Response: N_foliar
##                    Df  Sum Sq Mean Sq F value Pr(>F)
## elevation_fac       1    2.27  2.2713  0.1187 0.7315
## fire                1    2.09  2.0942  0.1094 0.7418
## elevation_fac:fire  1    0.54  0.5430  0.0284 0.8667
## Residuals          71 1358.82 19.1384
```

```
cld(emmeans(N_foliar_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  low           no fire   1.85 0.978 71  -0.0995     3.80  1
```

```
##  low           fire      2.03 0.978 71   0.0780     3.98  1
##  high          no fire   2.07 0.978 71   0.1150     4.02  1
##  high          fire      2.59 1.130 71   0.3337     4.84  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = subset(data, N_foliar < 5), aes(x = Name, y = (N_foliar))) +
  geom_boxplot()
```



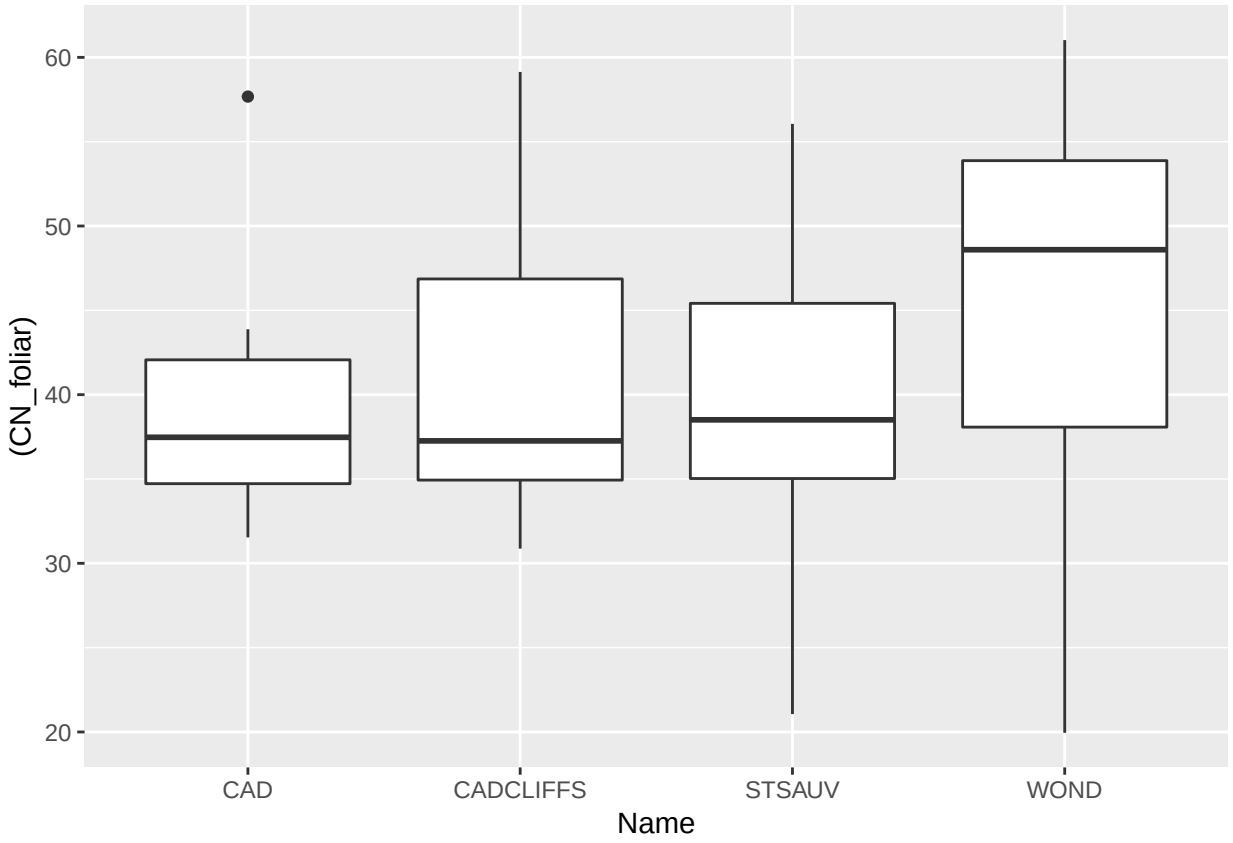

```
### CN_foliar
CN_foliar_lm = lm(as.formula(paste(dep_variables[9],
                                   paste(ind_variables, collapse = "*"),
                                   sep = "~")), data = data)
#plot(resid(CN_foliar_lm) ~ fitted(CN_foliar_lm))
anova(CN_foliar_lm)
```

```
## Analysis of Variance Table
##
## Response: CN_foliar
##                    Df  Sum Sq Mean Sq F value Pr(>F)
## elevation_fac       1   222.5 222.545  1.3821 0.2437
## fire                1   102.3 102.314  0.6354 0.4280
## elevation_fac:fire  1    21.6  21.552  0.1339 0.7156
## Residuals          71 11432.1 161.016
```

```
cld(emmeans(CN_foliar_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean   SE df lower.CL upper.CL .group
##  high          fire      36.7 3.28 71     30.2     43.2  1
##  high          no fire   37.9 2.84 71     32.2     43.5  1
##  low           fire      39.1 2.84 71     33.5     44.8  1
##  low           no fire   42.5 2.84 71     36.8     48.1  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = subset(data, N_foliar < 5), aes(x = Name, y = (CN_foliar))) +
  geom_boxplot()
```




```
### Ca_foliar
Ca_foliar_lm = lm(as.formula(paste(dep_variables[10],
                                   paste(ind_variables, collapse = "*"),
                                   sep = "~")), data = data)
#plot(resid(Ca_foliar_lm) ~ fitted(Ca_foliar_lm))
anova(Ca_foliar_lm)
```

```
## Analysis of Variance Table
##
## Response: Ca_foliar
##                    Df   Sum Sq Mean Sq F value    Pr(>F)
## elevation_fac       1  6814502 6814502 13.0259 0.0009267 ***
## fire                1  1556303 1556303  2.9749 0.0931449 .
## elevation_fac:fire  1   526703  526703  1.0068 0.3223708
## Residuals          36 18833470  523152
```

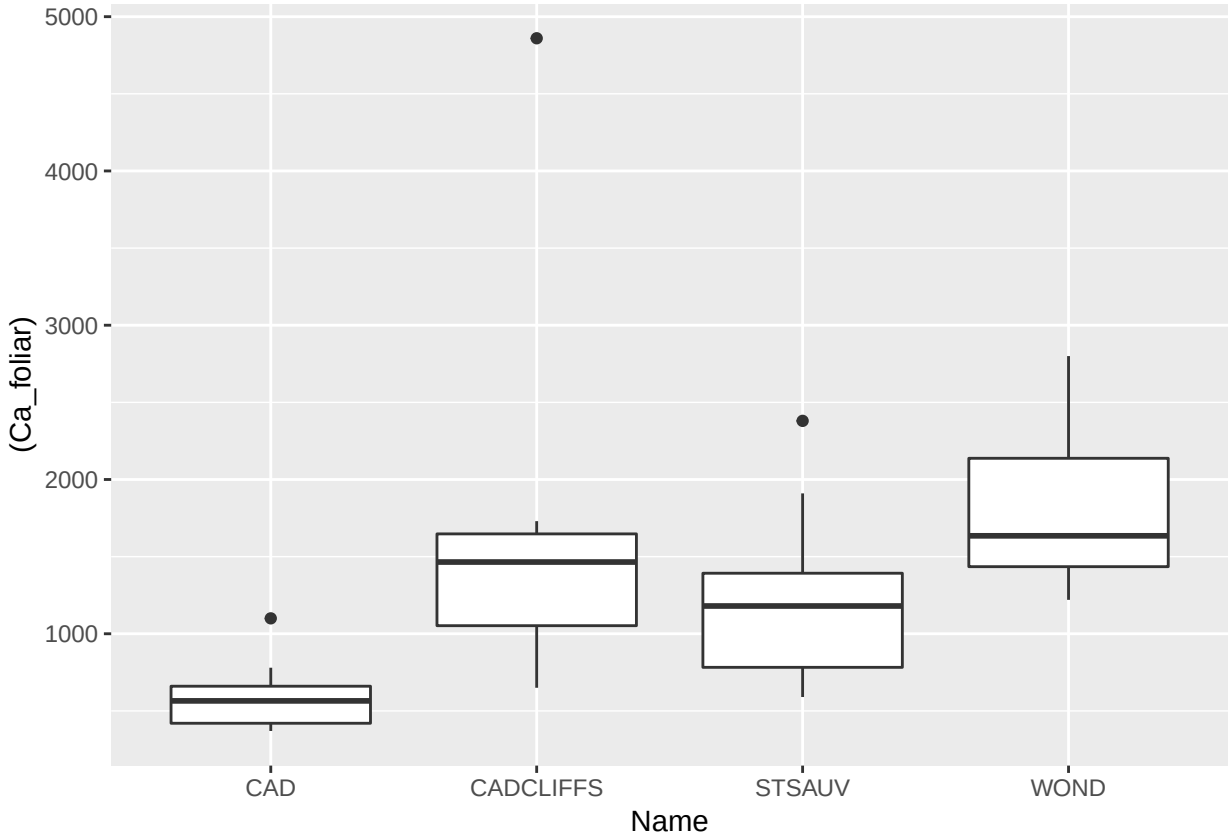
```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(Ca_foliar_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean  SE df lower.CL upper.CL .group
##  high          fire       597 229 36      133     1061  1
##  high          no fire   1221 229 36      757     1685  12
##  low           fire      1652 229 36     1188     2116   2
##  low           no fire   1817 229 36     1353     2281   2
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (Ca_foliar))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
### P_foliar
P_foliar_lm = lm(as.formula(paste(dep_variables[11],
                                  paste(ind_variables, collapse = "*"),
                                  sep = "~")), data = data)
#plot(resid(P_foliar_lm) ~ fitted(P_foliar_lm))
anova(P_foliar_lm)
```

```
## Analysis of Variance Table
##
```

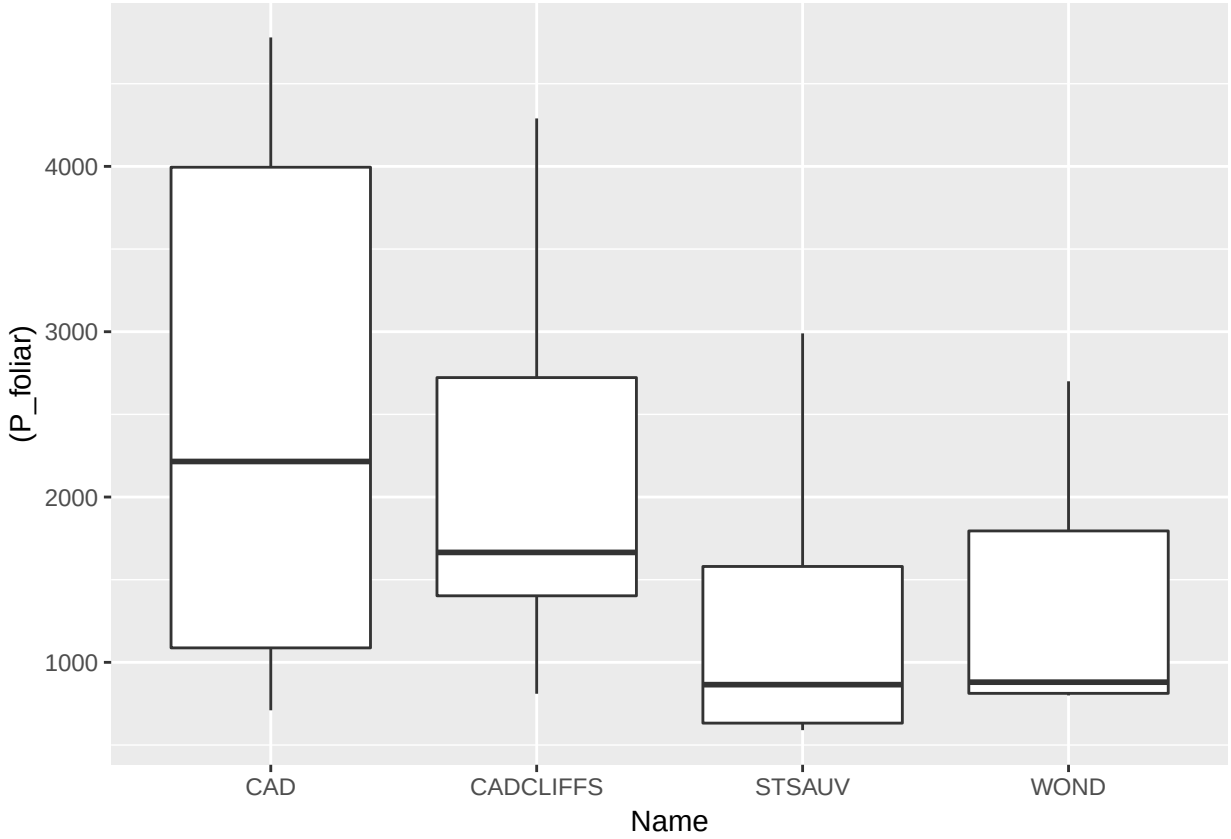
```
## Response: log(P_foliar)
##                     Df  Sum Sq Mean Sq F value   Pr(>F)
## elevation_fac        1  0.0296  0.0296  0.0796 0.779502
## fire                 1  3.2582  3.2582  8.7713 0.005391 **
## elevation_fac:fire   1  0.0514  0.0514  0.1382 0.712210
## Residuals           36 13.3724  0.3715
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(P_foliar_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          no fire   6.93 0.193 36     6.54     7.32  1
##  low           no fire   7.06 0.193 36     6.67     7.45  1
##  low           fire      7.56 0.193 36     7.17     7.95  1
##  high          fire      7.58 0.193 36     7.19     7.97  1
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (P_foliar))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
### K_foliar
K_foliar_lm = lm(as.formula(paste(dep_variables[12],
```

```
                                  paste(ind_variables, collapse = "*"),
                                  sep = "~")), data = data)
#plot(resid(K_foliar_lm) ~ fitted(K_foliar_lm))
anova(K_foliar_lm)
```

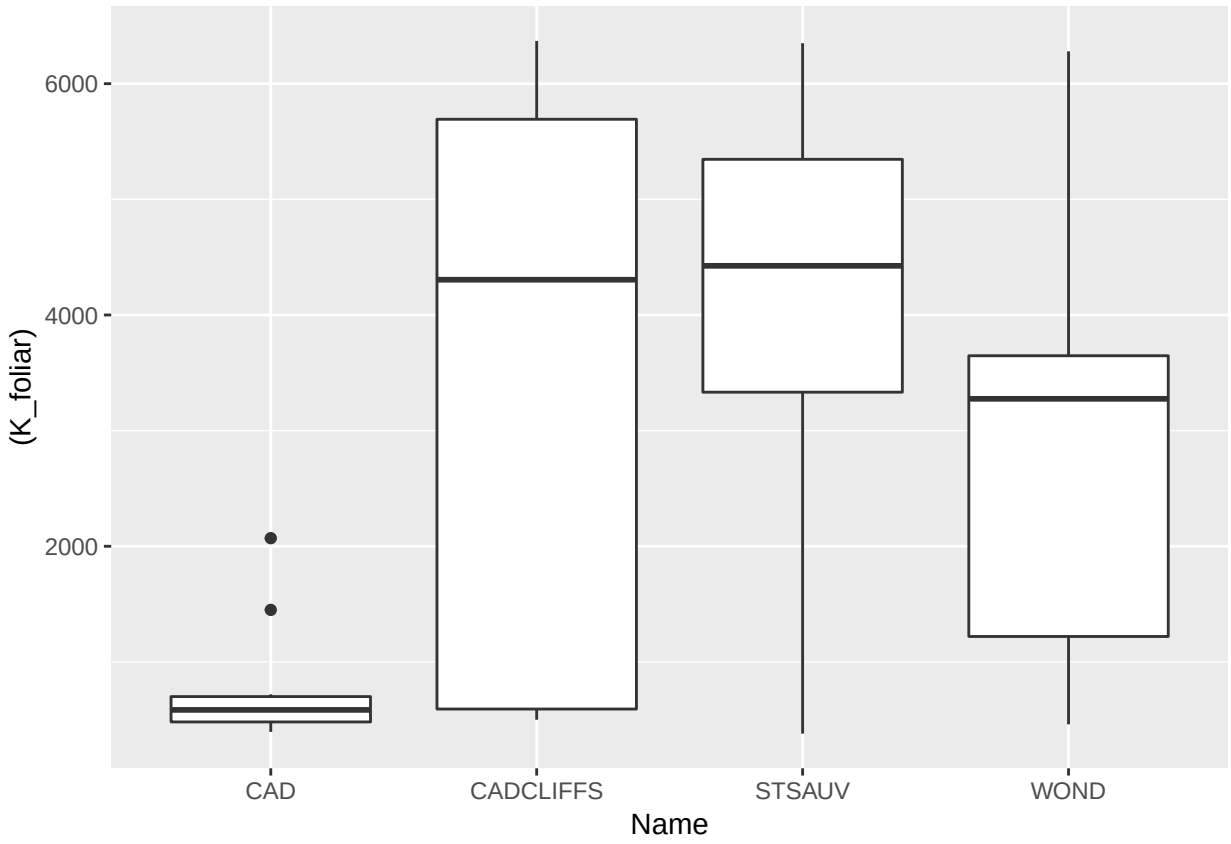
```
## Analysis of Variance Table
##
## Response: log(K_foliar)
##                    Df  Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac       1  1.6363  1.6363  1.8751 0.17938
## fire                1  5.2363  5.2363  6.0005 0.01930 *
## elevation_fac:fire  1  5.6572  5.6572  6.4828 0.01531 *
## Residuals          36 31.4152  0.8726
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(K_foliar_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          fire      6.52 0.295 36     5.92     7.12  1
##  low           no fire   7.65 0.295 36     7.05     8.25   2
##  low           fire      7.68 0.295 36     7.08     8.28   2
##  high          no fire   8.00 0.295 36     7.40     8.60   2
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (K_foliar))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
### Mg_foliar
Mg_foliar_lm = lm(as.formula(paste(dep_variables[13],
                                   paste(ind_variables, collapse = "*"),
                                   sep = "~")), data = data)
#plot(resid(Mg_foliar_lm) ~ fitted(Mg_foliar_lm))
anova(Mg_foliar_lm)
```

```
## Analysis of Variance Table
##
## Response: Mg_foliar
##                     Df  Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac        1  231040  231040  3.0242 0.09058 .
## fire                 1   11560   11560  0.1513 0.69957
## elevation_fac:fire   1      90      90  0.0012 0.97281
## Residuals           36 2750300   76397
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

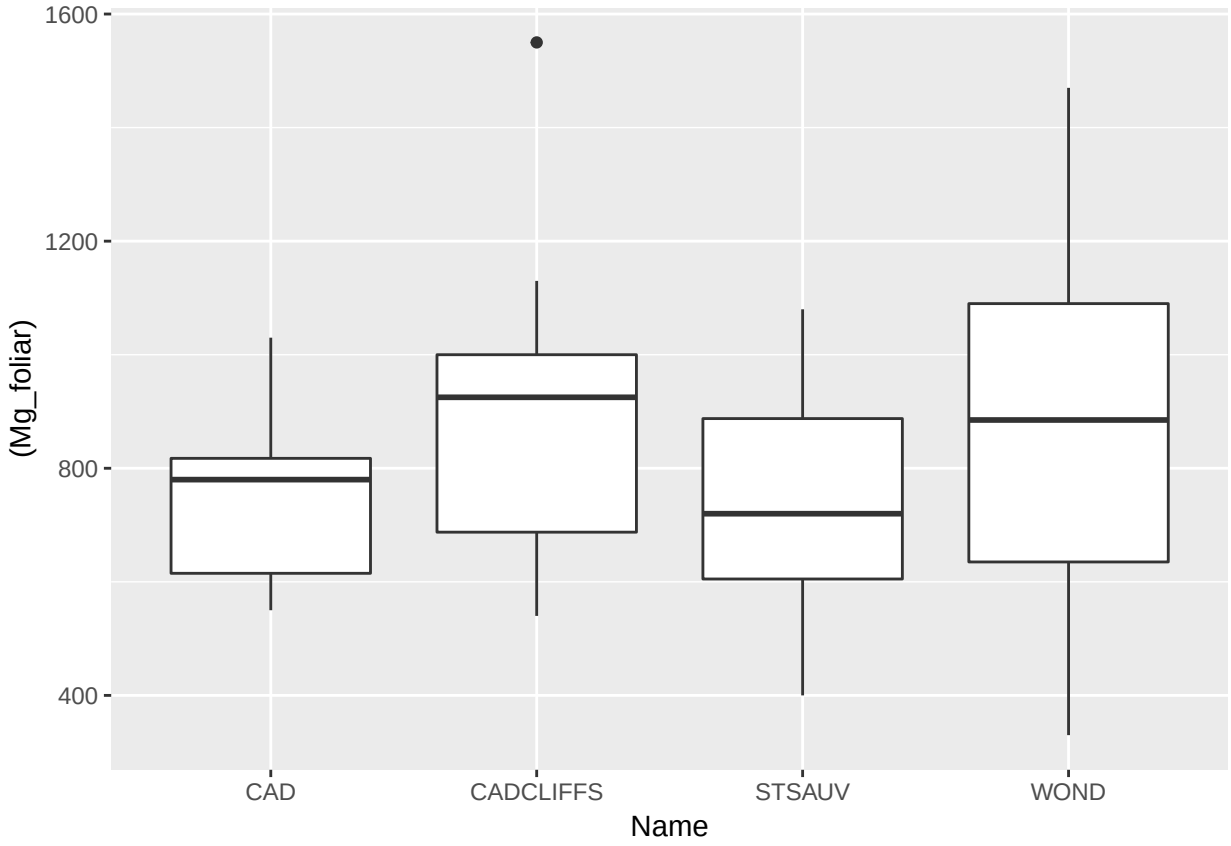
```
cld(emmeans(Mg_foliar_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean   SE df lower.CL upper.CL .group
##  high          no fire    725 87.4 36      548      902  1
##  high          fire       762 87.4 36      585      939  1
##  low           no fire    880 87.4 36      703     1057  1
##  low           fire       911 87.4 36      734     1088  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
```

```
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (Mg_foliar))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
### Al_foliar
Al_foliar_lm = lm(as.formula(paste(dep_variables[14],
                                   paste(ind_variables, collapse = "*"),
                                   sep = "~")), data = data)
#plot(resid(Al_foliar_lm) ~ fitted(Al_foliar_lm))
anova(Al_foliar_lm)
```

```
## Analysis of Variance Table
##
## Response: Al_foliar
##                    Df  Sum Sq Mean Sq F value Pr(>F)
## elevation_fac       1    4928    4928  0.1266 0.7241
## fire                1    2856    2856  0.0733 0.7881
## elevation_fac:fire  1   14440   14440  0.3708 0.5464
## Residuals          36 1401817   38939
```

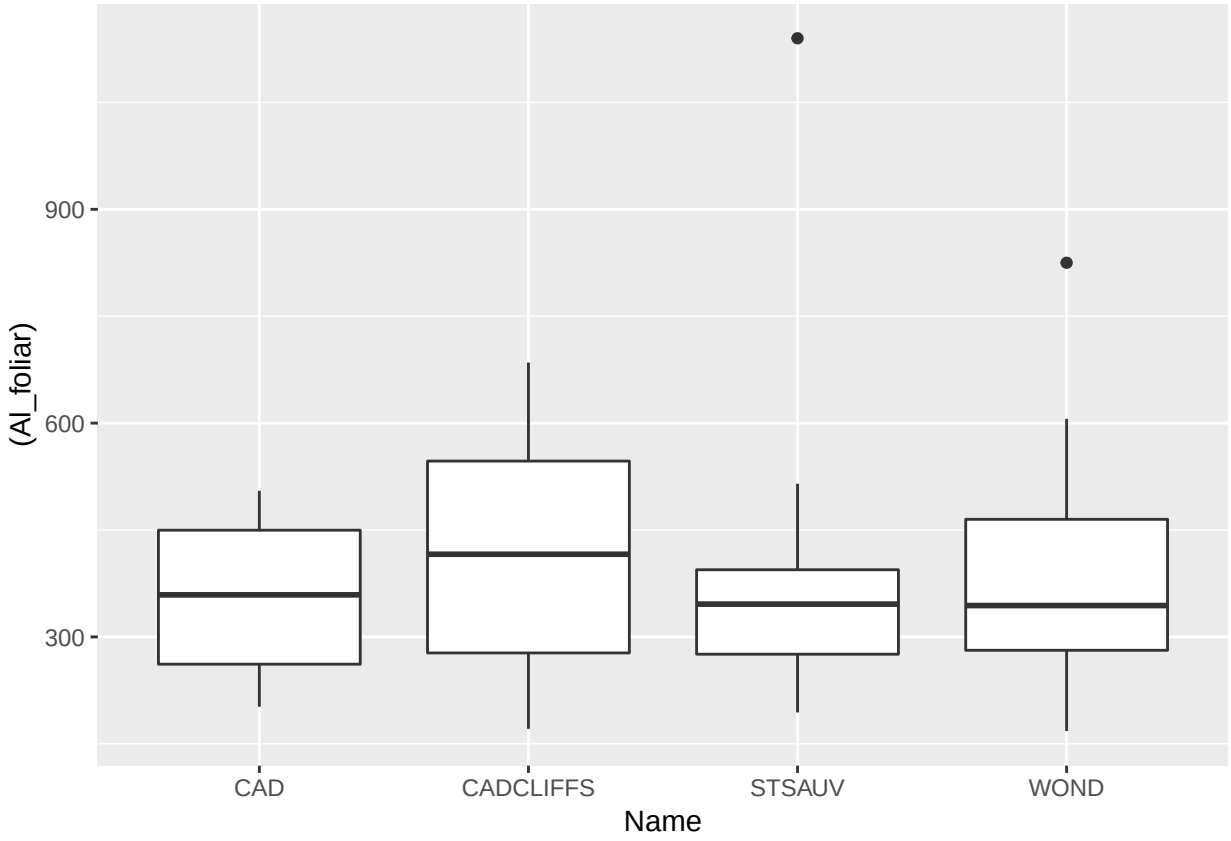
```
cld(emmeans(Al_foliar_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean   SE df lower.CL upper.CL .group
##  high          fire       353 62.4 36      227      480  1
##  low           no fire    392 62.4 36      266      519  1
##  high          no fire    408 62.4 36      282      535  1
```

```
##  low           fire       414 62.4 36      287      540  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (Al_foliar))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
### Zn_foliar
Zn_foliar_lm = lm(as.formula(paste(dep_variables[15],
                                   paste(ind_variables, collapse = "*"),
                                   sep = "~")), data = data)
#plot(resid(Zn_foliar_lm) ~ fitted(Zn_foliar_lm))
anova(Zn_foliar_lm)
```

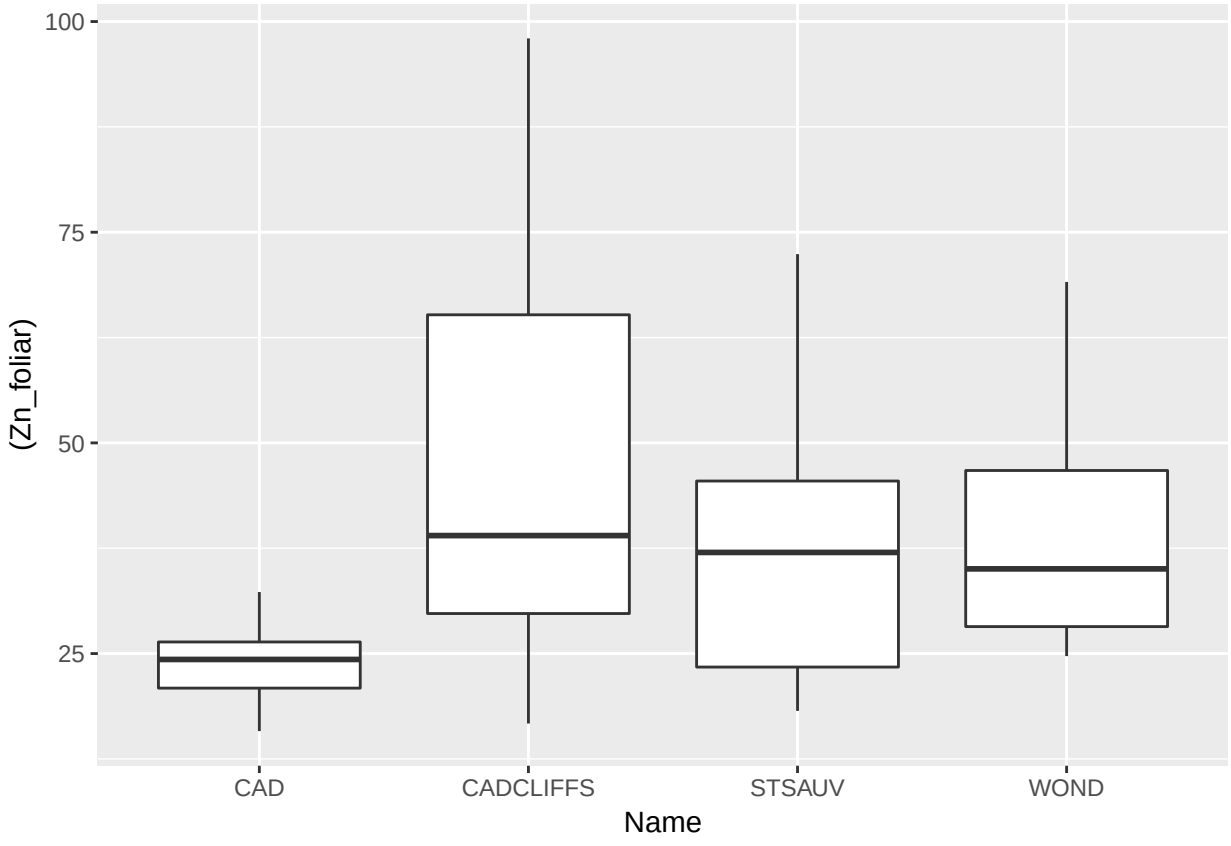
```
## Analysis of Variance Table
##
## Response: log(Zn_foliar)
##                    Df Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac       1 1.0906 1.09060  6.7570 0.01345 *
## fire                1 0.1143 0.11428  0.7080 0.40565
## elevation_fac:fire  1 0.6502 0.65022  4.0286 0.05229 .
## Residuals          36 5.8105 0.16140
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(Zn_foliar_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          fire      3.16 0.127 36     2.90     3.42  1
##  high          no fire   3.52 0.127 36     3.27     3.78  12
##  low           no fire   3.60 0.127 36     3.34     3.86  12
##  low           fire      3.75 0.127 36     3.49     4.01   2
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (Zn_foliar))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
### Ca_soil
Ca_soil_lm = lm(as.formula(paste(dep_variables[16],
                                 paste(ind_variables, collapse = "*"),
                                 sep = "~")), data = data)
#plot(resid(Ca_soil_lm) ~ fitted(Ca_soil_lm))
anova(Ca_soil_lm)
```

```
## Analysis of Variance Table
##
## Response: Ca_soil
```

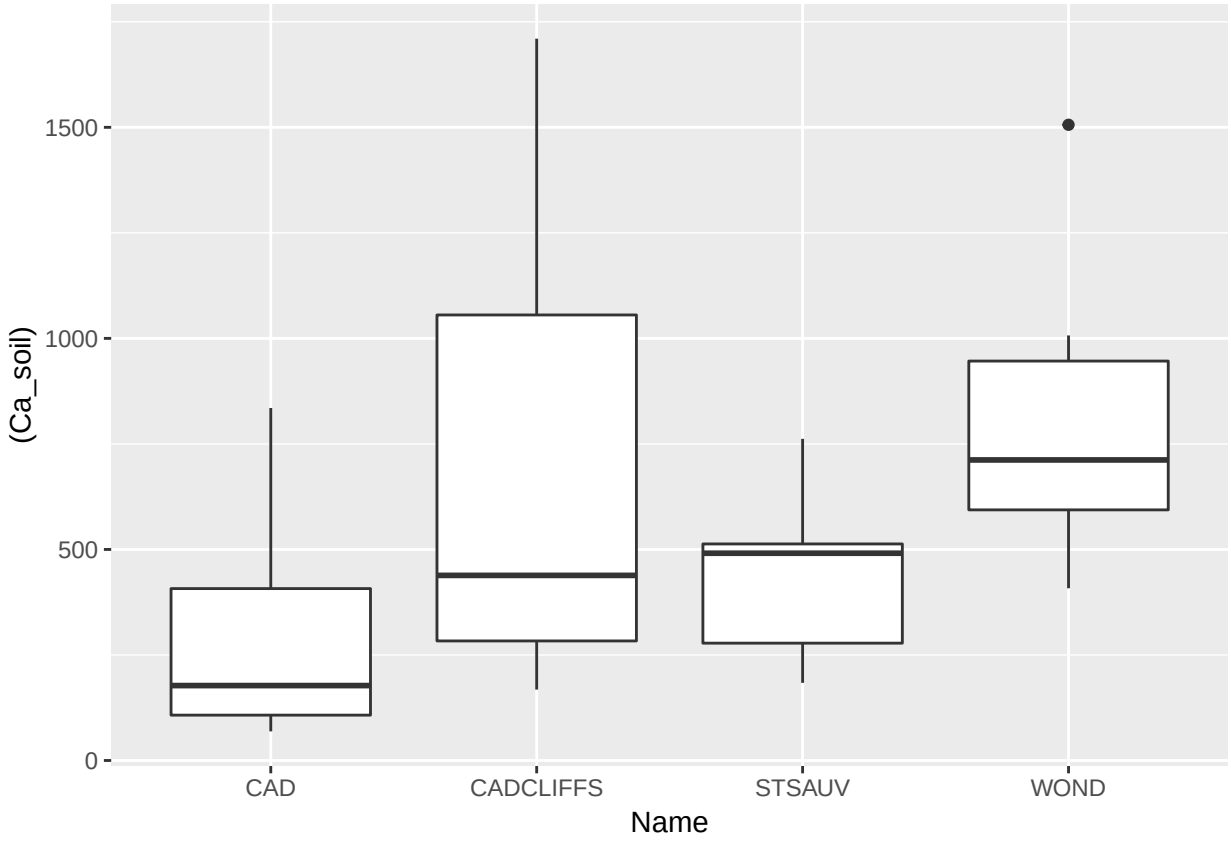
```
##                    Df  Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac       1 1131016 1131016  7.4816 0.01088 *
## fire                1   88710   88710  0.5868 0.45030
## elevation_fac:fire  1    1116    1116  0.0074 0.93218
## Residuals          27 4081653  151172
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(Ca_soil_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean  SE df lower.CL upper.CL .group
##  high          fire       312 137 27     29.7      594  1
##  high          no fire    431 147 27    129.8      733  1
##  low           fire       702 137 27    419.9      984  1
##  low           no fire    798 137 27    515.4     1080  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (Ca_soil))) +
  geom_boxplot()
```

```
## Warning: Removed 44 rows containing non-finite values (stat_boxplot).
```




```
### P_soil
P_soil_lm = lm(as.formula(paste(dep_variables[17],
                                paste(ind_variables, collapse = "*"),
                                sep = "~")), data = data)
```

```r
#plot(resid(P_soil_lm) ~ fitted(P_soil_lm))
anova(P_soil_lm)
```

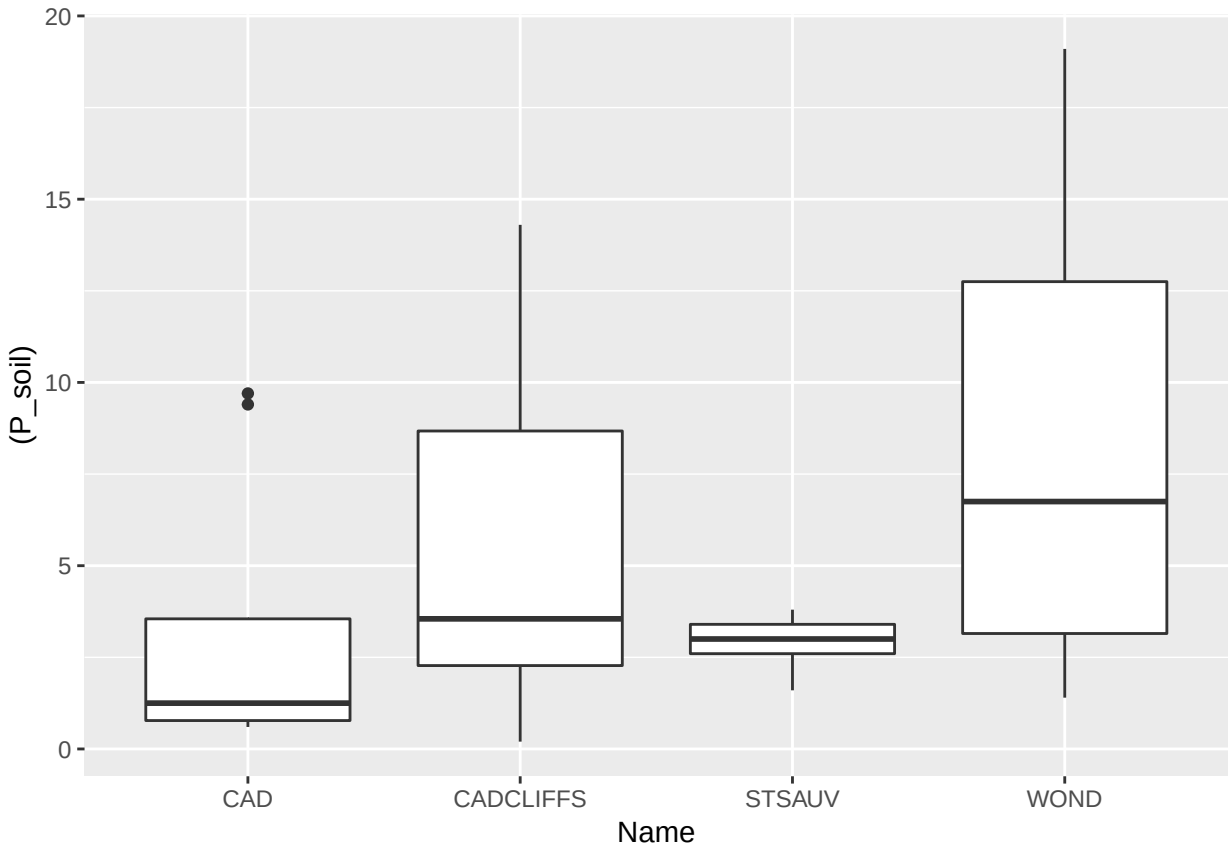
```
## Analysis of Variance Table
##
## Response: log(P_soil)
##                    Df  Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac       1  3.5797  3.5797  3.2947 0.08063 .
## fire                1  2.1276  2.1276  1.9582 0.17309
## elevation_fac:fire  1  0.0072  0.0072  0.0066 0.93593
## Residuals          27 29.3360  1.0865
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
cld(emmeans(P_soil_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          fire      0.54 0.369 27   -0.216     1.30  1
##  high          no fire   1.03 0.394 27    0.225     1.84  1
##  low           fire      1.17 0.369 27    0.417     1.93  1
##  low           no fire   1.73 0.369 27    0.971     2.48  1
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```r
ggplot(data = data, aes(x = Name, y = (P_soil))) +
  geom_boxplot()
```

```
## Warning: Removed 44 rows containing non-finite values (stat_boxplot).
```




```
### K_soil
K_soil_lm = lm(as.formula(paste(dep_variables[18],
                                paste(ind_variables, collapse = "*"),
                                sep = "~")), data = data)
#plot(resid(K_soil_lm) ~ fitted(K_soil_lm))
anova(K_soil_lm)
```

```
## Analysis of Variance Table
##
## Response: K_soil
##                    Df Sum Sq Mean Sq F value   Pr(>F)
## elevation_fac       1  51608   51608  2.7943 0.106149
## fire                1 164484  164484  8.9061 0.005971 **
## elevation_fac:fire  1    470     470  0.0255 0.874394
## Residuals          27 498657   18469
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

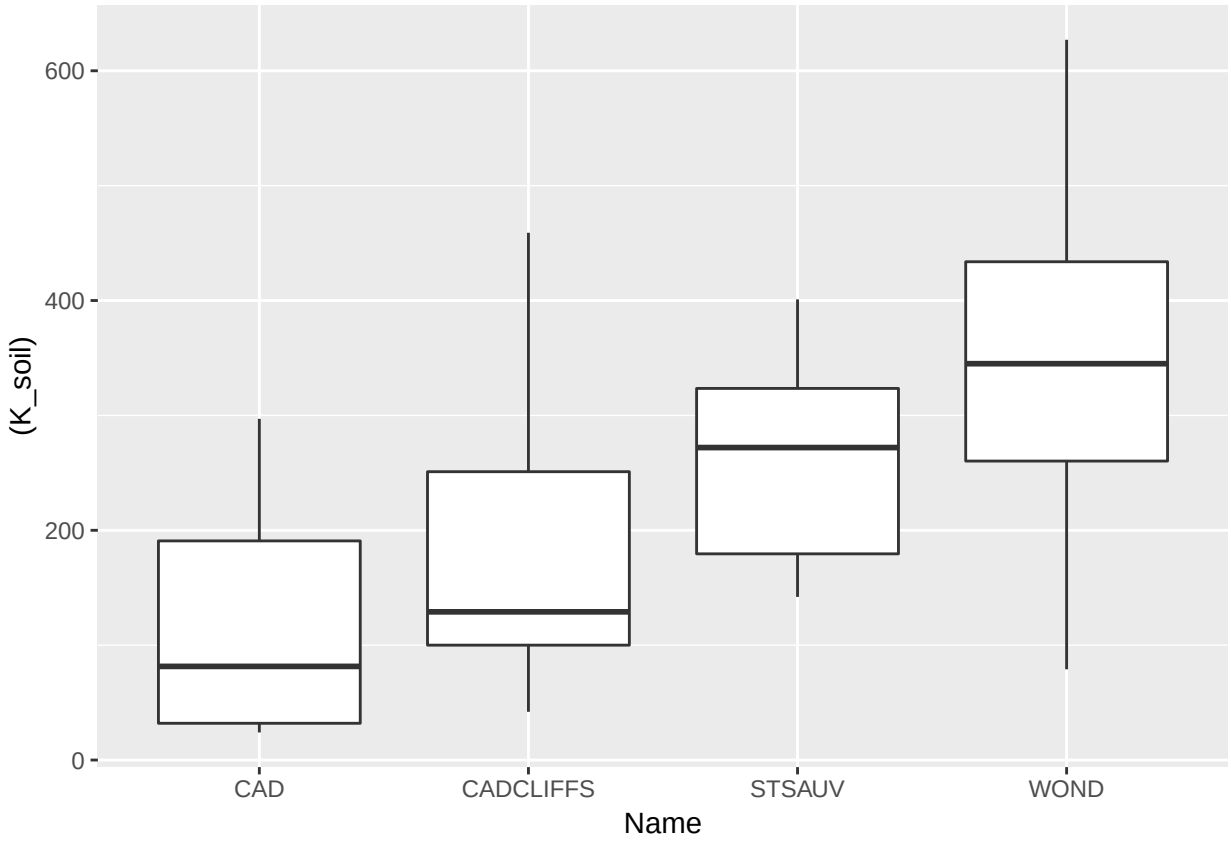
```
cld(emmeans(K_soil_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean   SE df lower.CL upper.CL .group
##  high          fire       122 48.0 27     23.8      221  1
##  low           fire       192 48.0 27     93.0      290  12
##  high          no fire    260 51.4 27    154.7      366  12
##  low           no fire    345 48.0 27    246.4      444   2
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
```

```
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (K_soil))) +
  geom_boxplot()
```

```
## Warning: Removed 44 rows containing non-finite values (stat_boxplot).
```




```
### Mg_soil
Mg_soil_lm = lm(as.formula(paste(dep_variables[19],
                                 paste(ind_variables, collapse = "*"),
                                 sep = "~")), data = data)
#plot(resid(Mg_soil_lm) ~ fitted(Mg_soil_lm))
anova(Mg_soil_lm)
```

```
## Analysis of Variance Table
##
## Response: Mg_soil
##                    Df Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac       1  89281   89281  2.9207 0.09892 .
## fire                1  22475   22475  0.7352 0.39874
## elevation_fac:fire  1   1447    1447  0.0473 0.82939
## Residuals          27 825345   30568
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

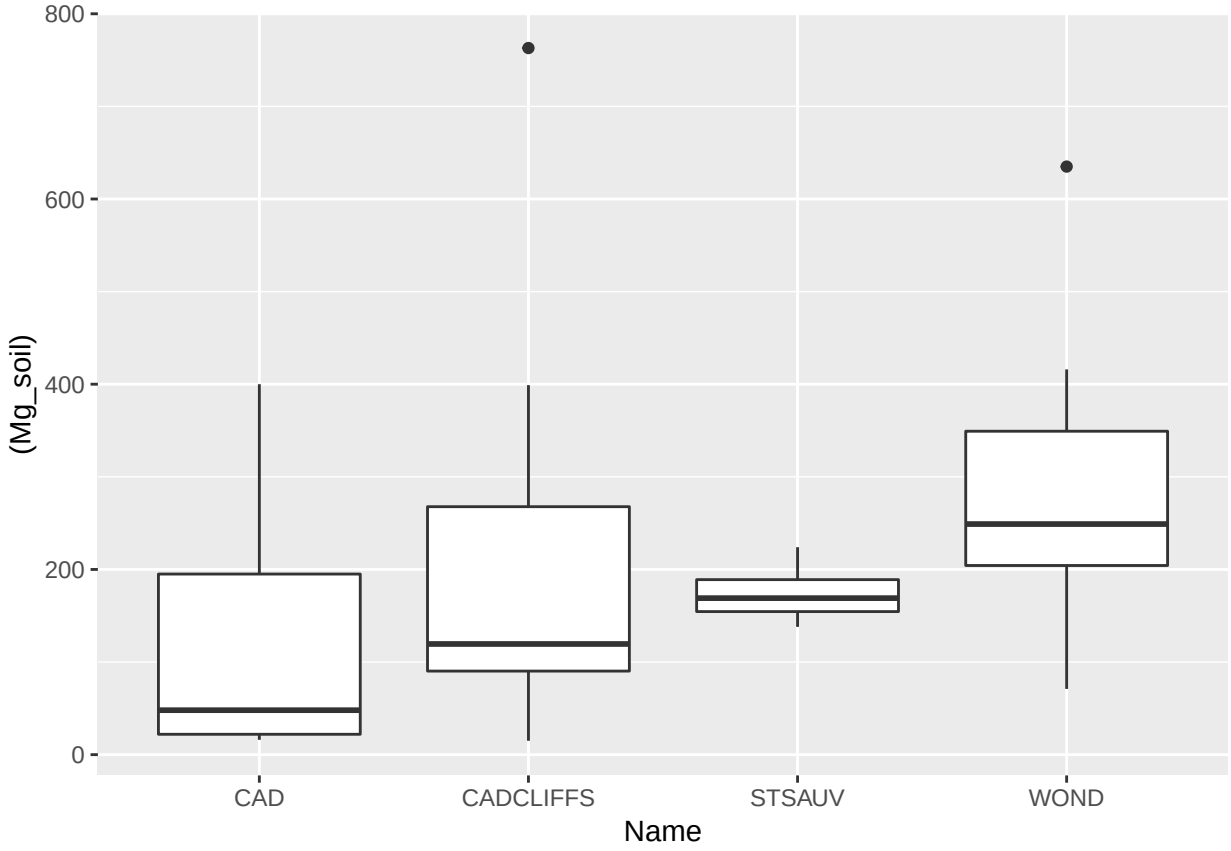
```
cld(emmeans(Mg_soil_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean   SE df lower.CL upper.CL .group
##  high          fire       134 61.8 27     7.42      261  1
```

```
##  high          no fire    174 66.1 27    38.41      310  1
##  low           fire       227 61.8 27    99.79      353  1
##  low           no fire    294 61.8 27   166.92      421  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (Mg_soil))) +
  geom_boxplot()
```

```
## Warning: Removed 44 rows containing non-finite values (stat_boxplot).
```




```
### Al_soil
Al_soil_lm = lm(as.formula(paste(dep_variables[20],
                                 paste(ind_variables, collapse = "*"),
                                 sep = "~")), data = data)
#plot(resid(Al_soil_lm) ~ fitted(Al_soil_lm))
anova(Al_soil_lm)
```

```
## Analysis of Variance Table
##
## Response: log(Al_soil)
##                    Df Sum Sq Mean Sq F value   Pr(>F)
## elevation_fac       1 0.1771  0.1771  0.5440 0.467135
## fire                1 0.0021  0.0021  0.0065 0.936542
## elevation_fac:fire  1 3.3022  3.3022 10.1414 0.003637 **
## Residuals          27 8.7915  0.3256
```

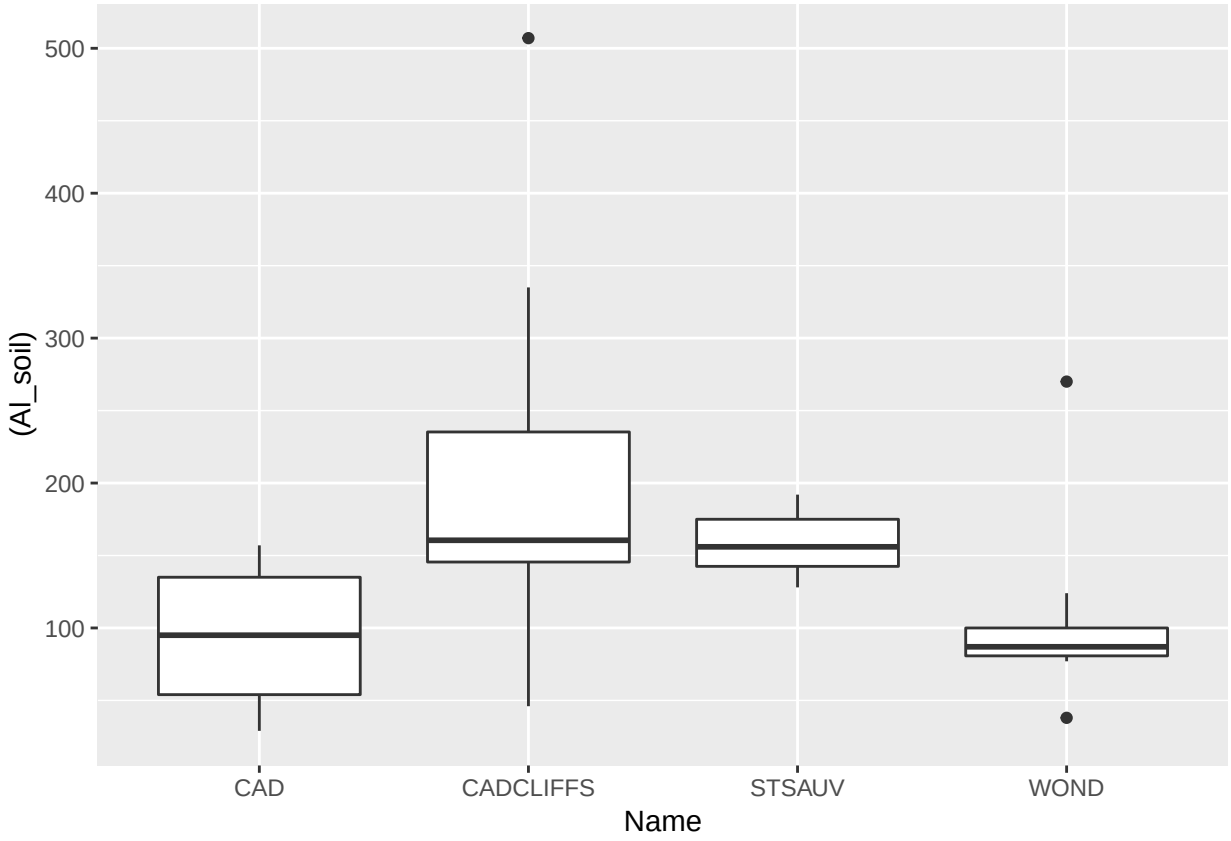
```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(Al_soil_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          fire      4.37 0.202 27     3.95     4.78  1
##  low           no fire   4.53 0.202 27     4.12     4.95  12
##  high          no fire   5.06 0.216 27     4.62     5.50  12
##  low           fire      5.15 0.202 27     4.73     5.56   2
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (Al_soil))) +
  geom_boxplot()
```

```
## Warning: Removed 44 rows containing non-finite values (stat_boxplot).
```




```
### Zn_soil
Zn_soil_lm = lm(as.formula(paste(dep_variables[21],
                                 paste(ind_variables, collapse = "*"),
                                 sep = "~")), data = data)
#plot(resid(Zn_soil_lm) ~ fitted(Zn_soil_lm))
anova(Zn_soil_lm)
```

```
## Analysis of Variance Table
```

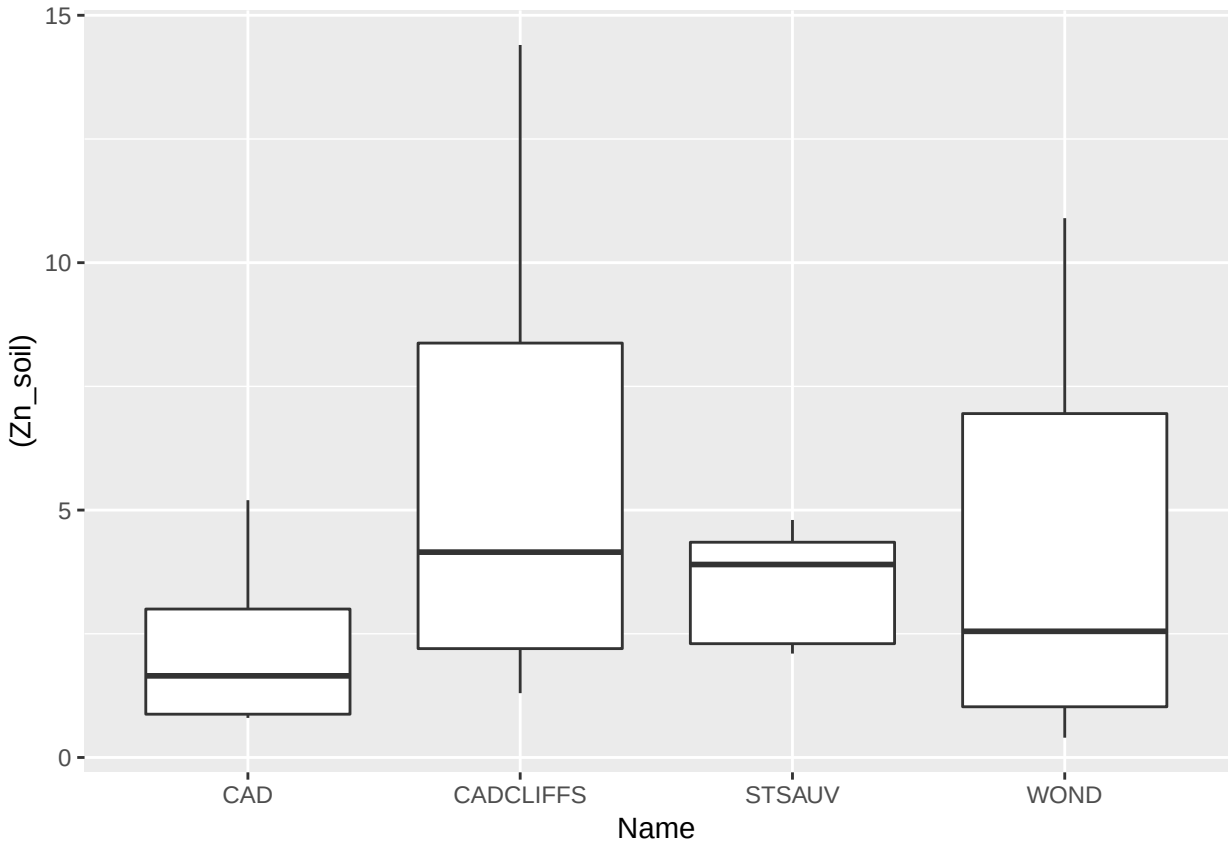
```
##
## Response: log(Zn_soil)
##                    Df  Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac       1  0.7821 0.78207  1.0531 0.31389
## fire                1  0.0005 0.00051  0.0007 0.97934
## elevation_fac:fire  1  2.6387 2.63871  3.5533 0.07023 .
## Residuals          27 20.0504 0.74261
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(Zn_soil_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          fire     0.569 0.305 27  -0.0561     1.19  1
##  low           no fire  0.895 0.305 27   0.2696     1.52  1
##  high          no fire  1.182 0.326 27   0.5135     1.85  1
##  low           fire     1.451 0.305 27   0.8258     2.08  1
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (Zn_soil))) +
  geom_boxplot()
```

```
## Warning: Removed 44 rows containing non-finite values (stat_boxplot).
```



```r
### pH
pH_lm = lm(as.formula(paste(dep_variables[22],
                            paste(ind_variables, collapse = "*"),
                            sep = "~")), data = data)
#plot(resid(pH_lm) ~ fitted(pH_lm))
anova(pH_lm)
```

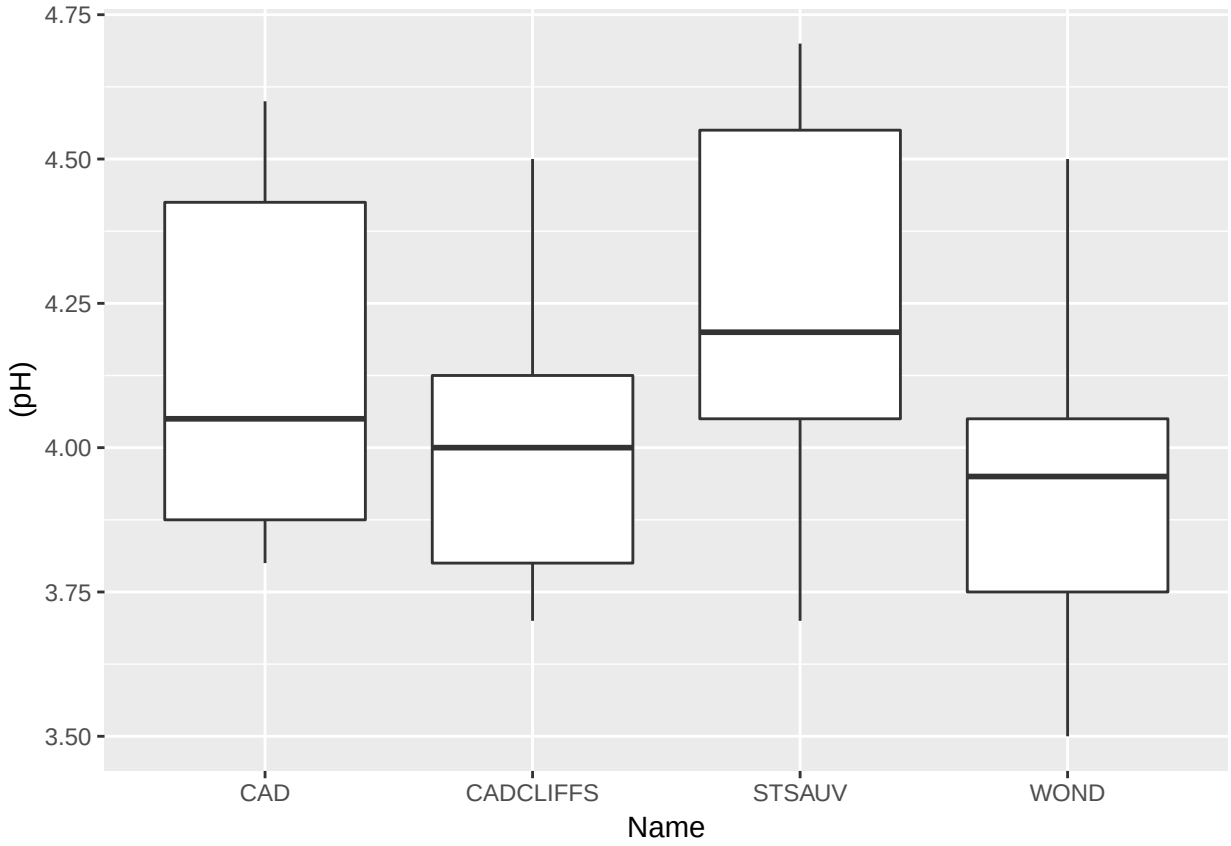
```
## Analysis of Variance Table
##
## Response: pH
##                     Df  Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac        1 0.36905 0.36905  3.6059 0.06831 .
## fire                 1 0.00278 0.00278  0.0272 0.87028
## elevation_fac:fire   1 0.07316 0.07316  0.7148 0.40528
## Residuals           27 2.76339 0.10235
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
cld(emmeans(pH_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  low           no fire   3.94 0.113 27     3.71     4.17  1
##  low           fire      4.01 0.113 27     3.78     4.24  1
##  high          fire      4.14 0.113 27     3.91     4.37  1
##  high          no fire   4.26 0.121 27     4.01     4.51  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```r
ggplot(data = data, aes(x = Name, y = (pH))) +
  geom_boxplot()
```

```
## Warning: Removed 44 rows containing non-finite values (stat_boxplot).
```




```
### CEC
CEC_lm = lm(as.formula(paste(dep_variables[23],
                             paste(ind_variables, collapse = "*"),
                             sep = "~")), data = data)
#plot(resid(CEC_lm) ~ fitted(CEC_lm))
anova(CEC_lm)
```

```
## Analysis of Variance Table
##
## Response: CEC
##                     Df  Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac        1  318.02  318.02  4.8714 0.03599 *
## fire                 1    0.73    0.73  0.0112 0.91666
## elevation_fac:fire   1   28.92   28.92  0.4429 0.51136
## Residuals           27 1762.65   65.28
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

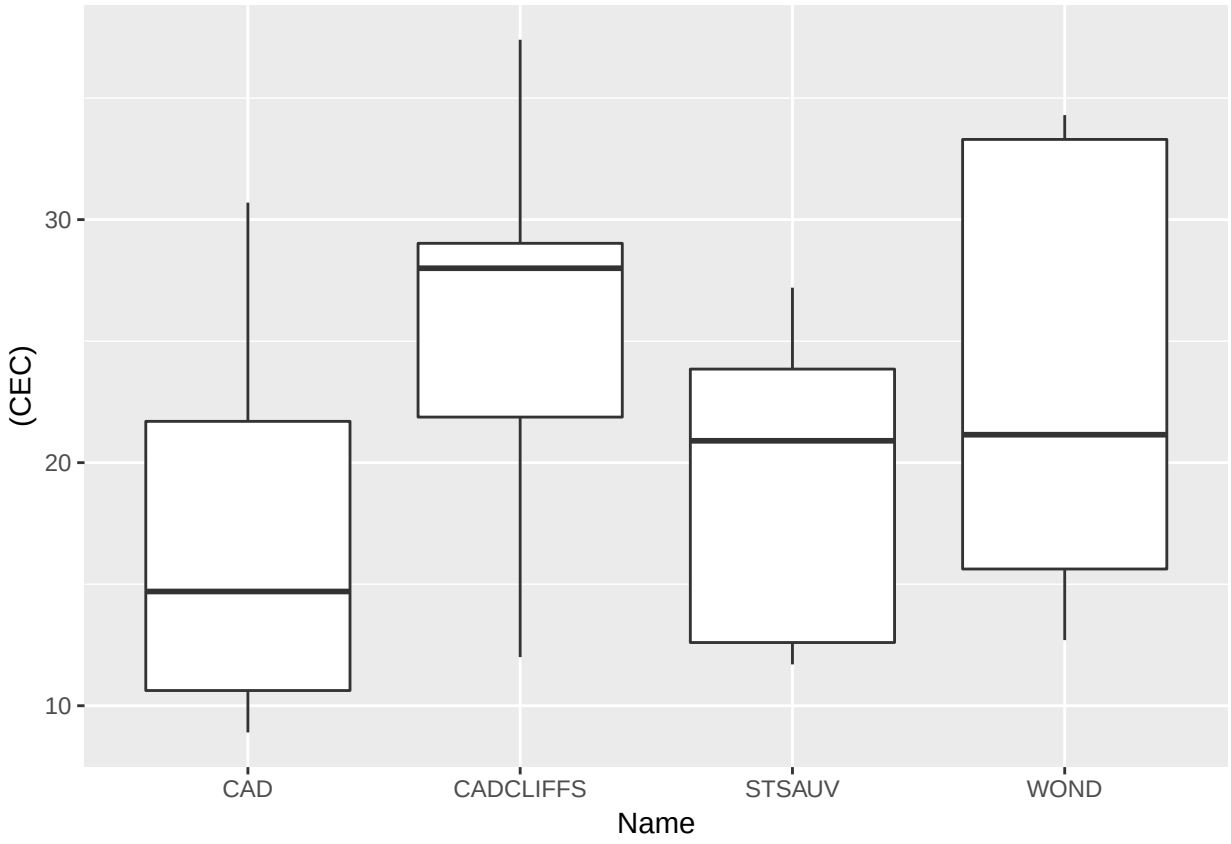
```
cld(emmeans(CEC_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean   SE df lower.CL upper.CL .group
##  high          fire      17.3 2.86 27     11.4     23.1  1
##  high          no fire   19.0 3.05 27     12.7     25.2  1
##  low           no fire   23.4 2.86 27     17.5     29.2  1
##  low           fire      25.6 2.86 27     19.7     31.4  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
```

```
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (CEC))) +
  geom_boxplot()
```

```
## Warning: Removed 44 rows containing non-finite values (stat_boxplot).
```




```
### C_soil
C_soil_lm = lm(as.formula(paste(dep_variables[24],
                                paste(ind_variables, collapse = "*"),
                                sep = "~")), data = data)
#plot(resid(C_soil_lm) ~ fitted(C_soil_lm))
anova(C_soil_lm)
```

```
## Analysis of Variance Table
##
## Response: C_soil
##                    Df  Sum Sq Mean Sq F value  Pr(>F)
## elevation_fac       1  640.83  640.83  6.3631 0.01785 *
## fire                1  480.00  480.00  4.7661 0.03789 *
## elevation_fac:fire  1    4.90    4.90  0.0487 0.82705
## Residuals          27 2719.18  100.71
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

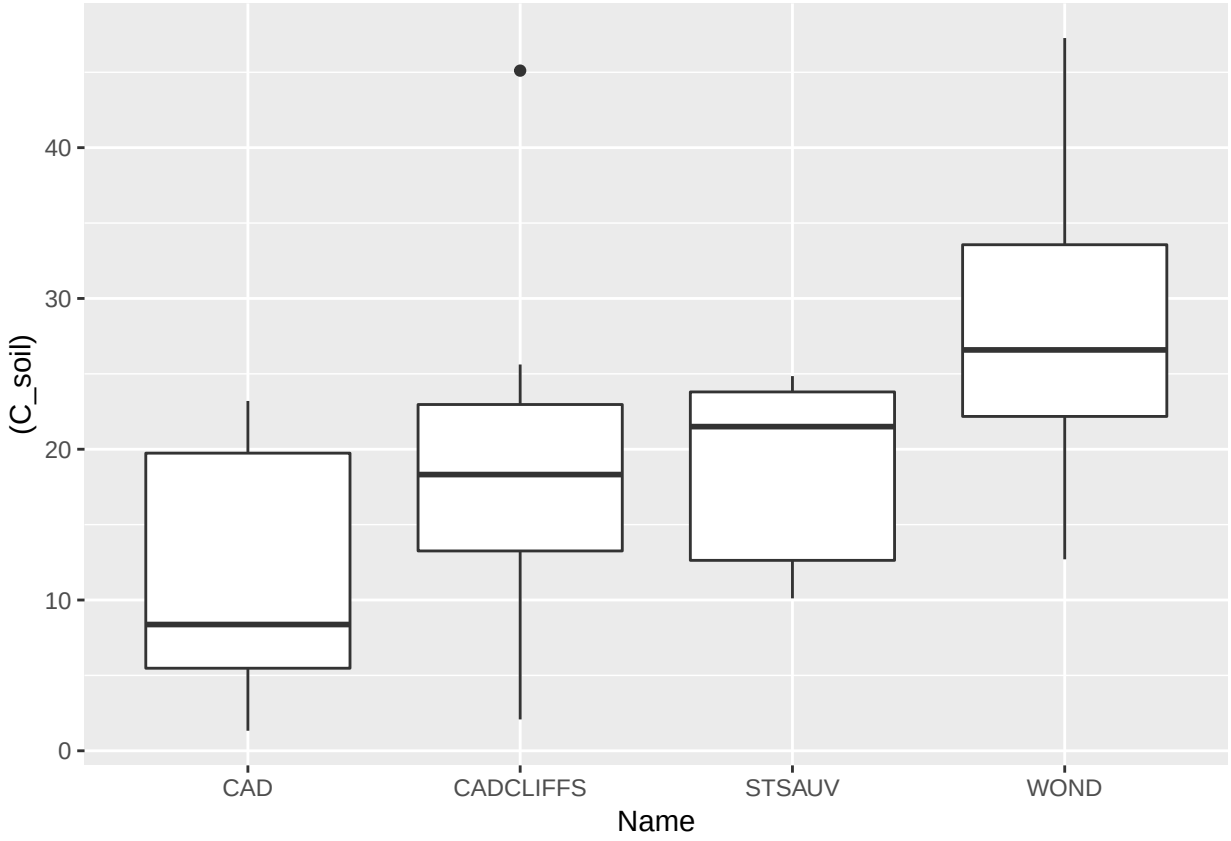
```
cld(emmeans(C_soil_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean   SE df lower.CL upper.CL .group
##  high          fire      11.4 3.55 27     4.14     18.7  1
```

```
##  high          no fire   18.5 3.79 27    10.69     26.3  12
##  low           fire      19.5 3.55 27    12.21     26.8  12
##  low           no fire   28.1 3.55 27    20.85     35.4   2
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (C_soil))) +
  geom_boxplot()
```

```
## Warning: Removed 44 rows containing non-finite values (stat_boxplot).
```




```
### N_soil
N_soil_lm = lm(as.formula(paste(dep_variables[25],
                                paste(ind_variables, collapse = "*"),
                                sep = "~")), data = data)
#plot(resid(N_soil_lm) ~ fitted(N_soil_lm))
anova(N_soil_lm)
```

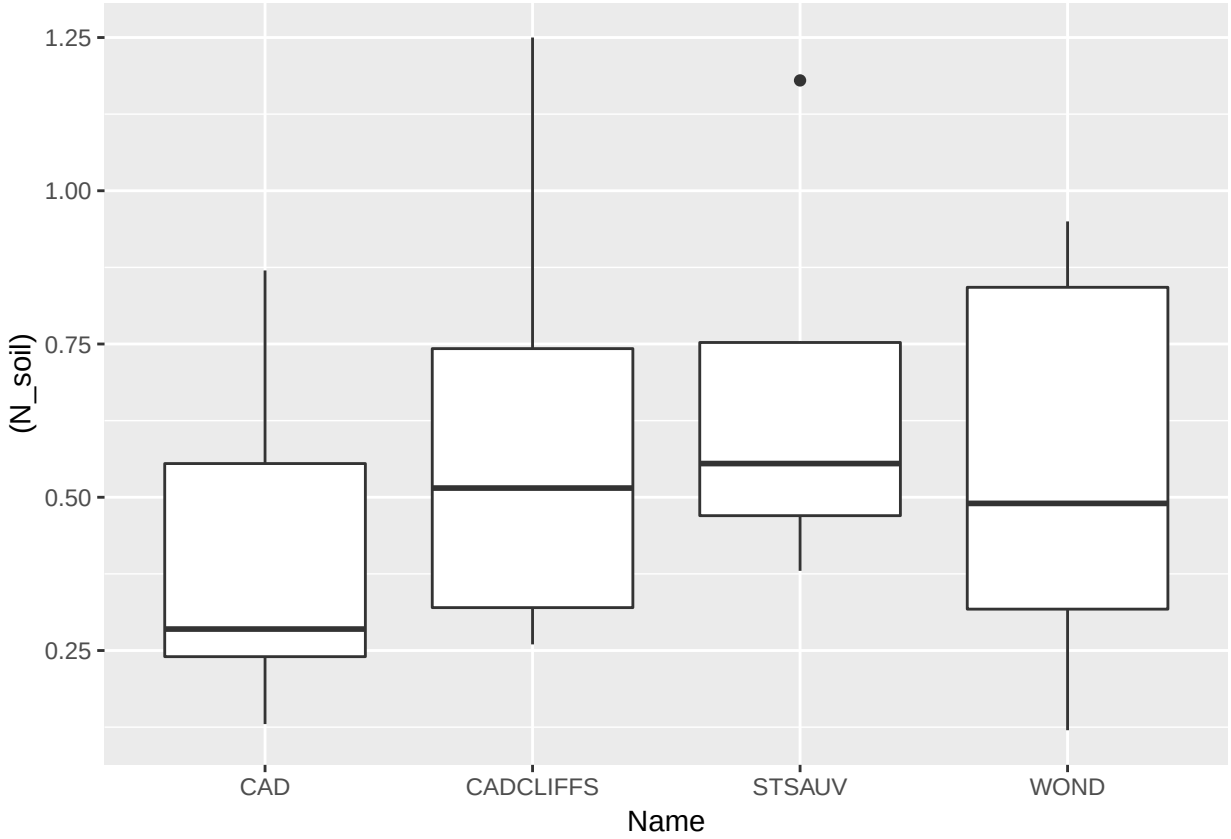
```
## Analysis of Variance Table
##
## Response: N_soil
##                    Df  Sum Sq  Mean Sq F value Pr(>F)
## elevation_fac       1 0.04513 0.045129  0.4138 0.5267
## fire                1 0.03916 0.039162  0.3591 0.5551
## elevation_fac:fire  1 0.15121 0.151209  1.3864 0.2516
## Residuals          22 2.39950 0.109068
```

```
cld(emmeans(N_soil_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          fire     0.409 0.117 22    0.167    0.651  1
##  low           no fire  0.545 0.135 22    0.265    0.825  1
##  low           fire     0.604 0.117 22    0.362    0.846  1
##  high          no fire  0.667 0.165 22    0.325    1.010  1
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (N_soil))) +
  geom_boxplot()
```

```
## Warning: Removed 49 rows containing non-finite values (stat_boxplot).
```




```
### CN_soil
CN_soil_lm = lm(as.formula(paste(dep_variables[26],
                                 paste(ind_variables, collapse = "*"),
                                 sep = "~")), data = data)
#plot(resid(CN_soil_lm) ~ fitted(CN_soil_lm))
anova(CN_soil_lm)
```

```
## Analysis of Variance Table
##
## Response: log(CN_soil)
##                    Df Sum Sq Mean Sq F value  Pr(>F)
```

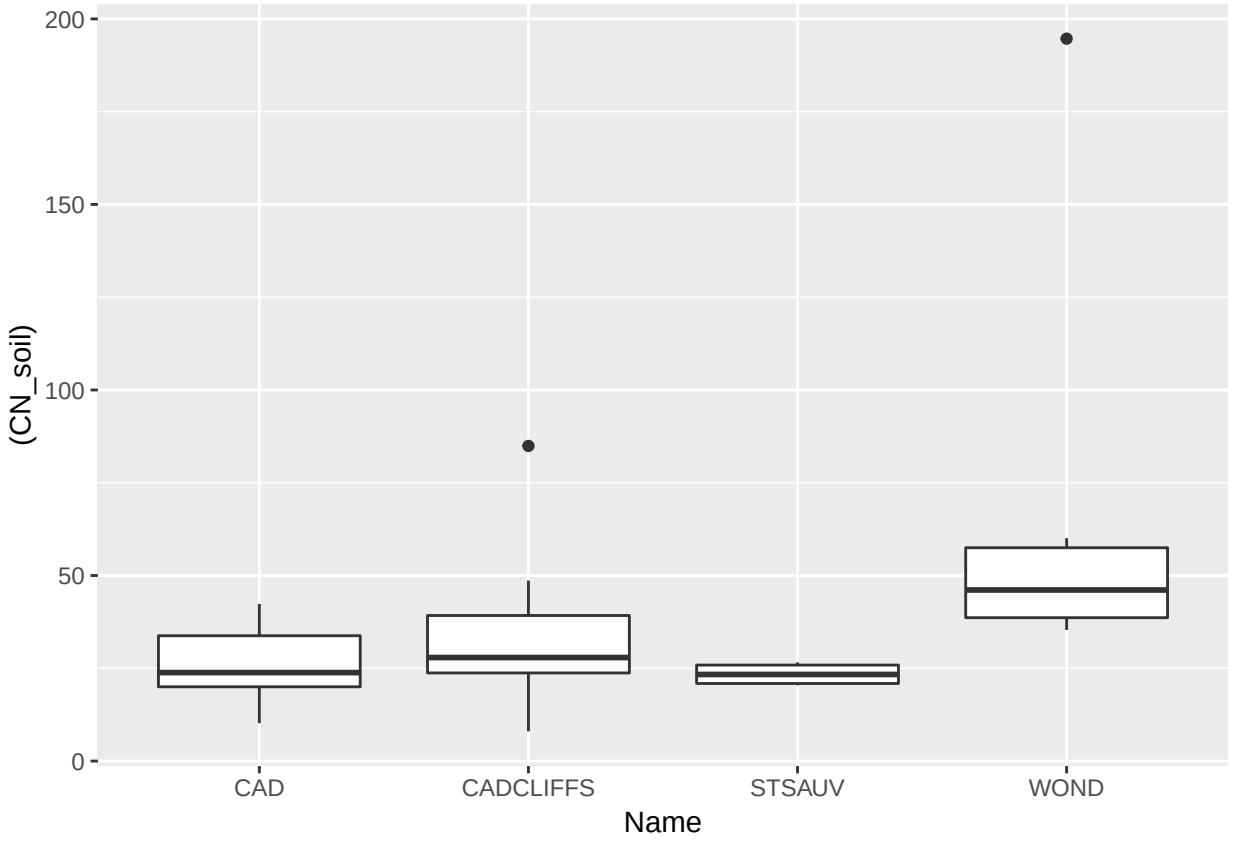
```
## elevation_fac       1 1.5999 1.59986  5.0654 0.03474 *
## fire                1 0.8234 0.82341  2.6070 0.12064
## elevation_fac:fire  1 0.6937 0.69367  2.1962 0.15253
## Residuals          22 6.9485 0.31584
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(CN_soil_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  high          no fire   3.15 0.281 22     2.56     3.73  12
##  high          fire      3.16 0.199 22     2.75     3.57  1
##  low           fire      3.37 0.199 22     2.96     3.78  12
##  low           no fire   4.03 0.229 22     3.56     4.51   2
##
## Results are given on the log (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data, aes(x = Name, y = (CN_soil))) +
  geom_boxplot()
```

```
## Warning: Removed 49 rows containing non-finite values (stat_boxplot).
```




```
### retention
retention_lm = lm(as.formula(paste(dep_variables[27],
                                   paste(ind_variables, collapse = "*"),
                                   sep = "~")), data = data)
```

```r
#plot(resid(retention_lm) ~ fitted(retention_lm))
anova(retention_lm)
```

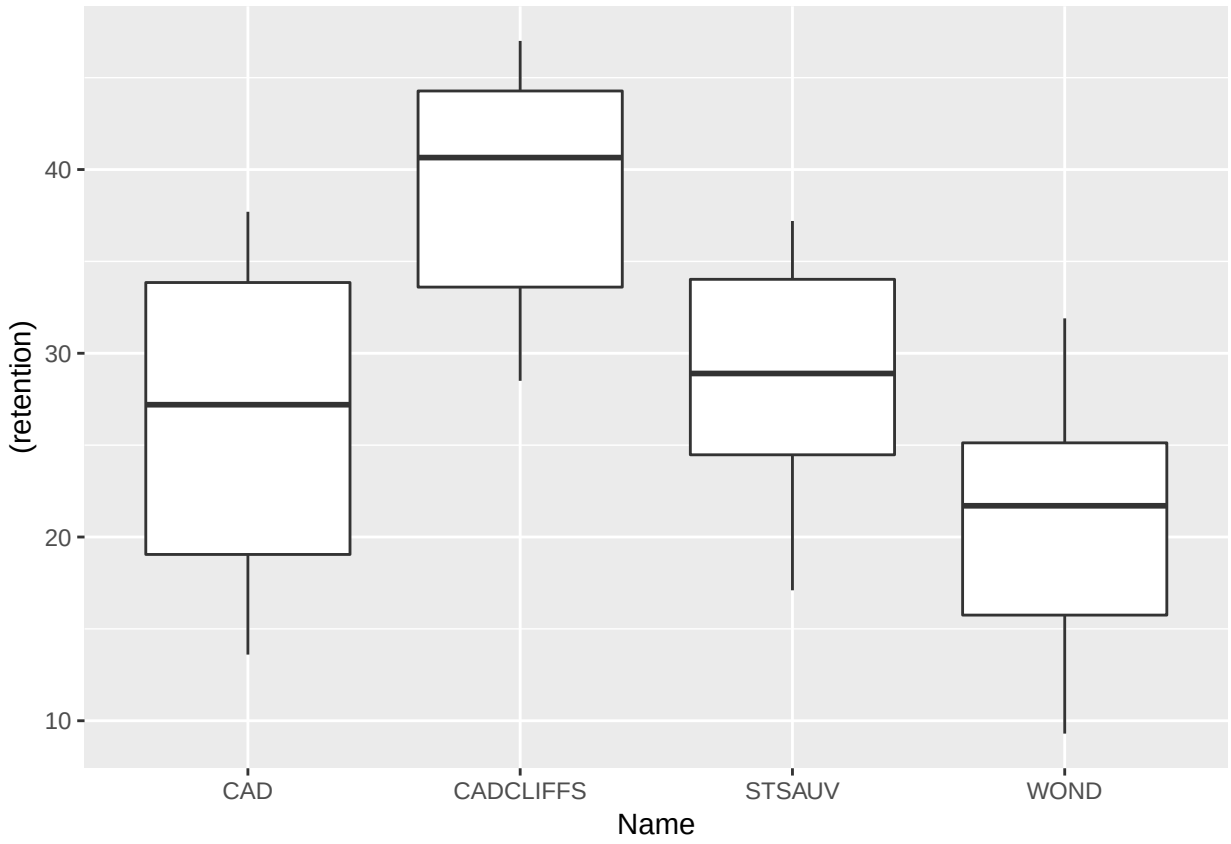
```
## Analysis of Variance Table
##
## Response: asin(sqrt(0.01 * retention))
##                     Df   Sum Sq  Mean Sq F value    Pr(>F)
## elevation_fac        1 0.006536 0.006536  0.8661 0.3582460
## fire                 1 0.084133 0.084133 11.1488 0.0019655 **
## elevation_fac:fire   1 0.128378 0.128378 17.0119 0.0002093 ***
## Residuals           36 0.271670 0.007546
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
cld(emmeans(retention_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean     SE df lower.CL upper.CL .group
##  low           no fire  0.470 0.0275 36    0.414    0.526  1
##  high          fire     0.536 0.0275 36    0.480    0.592  1
##  high          no fire  0.558 0.0275 36    0.502    0.613  1
##  low           fire     0.675 0.0275 36    0.619    0.731   2
##
## Results are given on the asin(sqrt(mu)) (not the response) scale.
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```r
ggplot(data = data, aes(x = Name, y = (retention))) +
  geom_boxplot()
```

```
## Warning: Removed 35 rows containing non-finite values (stat_boxplot).
```




```
### density
head(data_density)
```

```
##   site rep distance_1 distance_2 distance_3 distance_4 distance_5
## 1 WOND   1        0.0        0.0        0.0        0.0          0
## 2 WOND   2        4.1        4.3        0.0        0.0          0
## 3 WOND   3        3.2        3.3        4.1        4.1          0
## 4 WOND   4        1.6        2.7        2.8        2.8          0
## 5 WOND   5        2.7        2.8        3.9        4.8          5
## 6 WOND   6        2.8        3.2        3.8        3.9          0
##   mean_distance    fire elevation_fac
## 1          0.00 no fire           low
## 2          4.20 no fire           low
## 3          3.60 no fire           low
## 4          1.98 no fire           low
## 5          3.84 no fire           low
## 6          3.40 no fire           low
```

```
density_lm = lm(mean_distance ~ elevation_fac * fire, data = data_density)
#plot(resid(density_lm) ~ fitted(density_lm))
anova(density_lm)
```

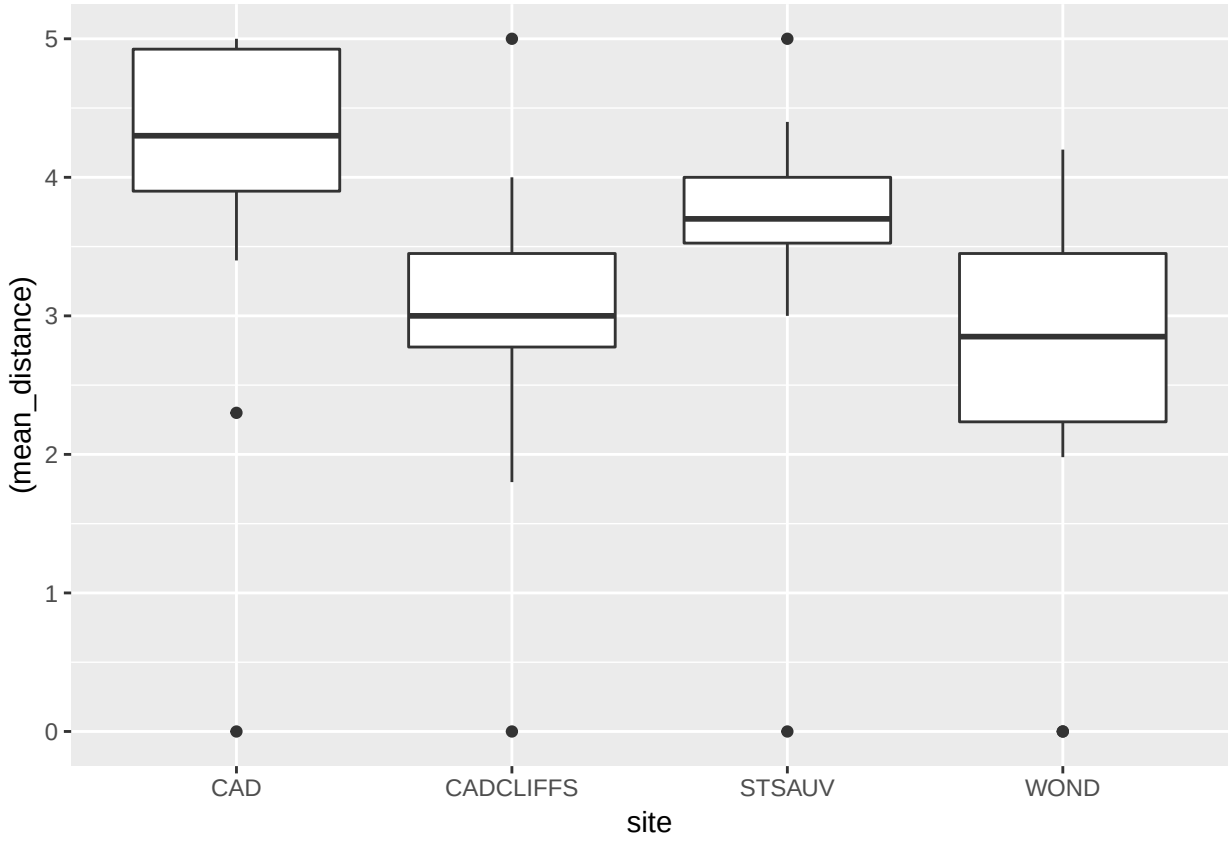
```
## Analysis of Variance Table
##
## Response: mean_distance
##                   Df Sum Sq Mean Sq F value   Pr(>F)
## elevation_fac      1 14.211 14.2107  9.9257 0.002616 **
## fire               1  2.121  2.1206  1.4812 0.228692
```

```
## elevation_fac:fire  1  0.014  0.0135  0.0094 0.922990
## Residuals          56 80.176  1.4317
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
cld(emmeans(density_lm, ~elevation_fac * fire))
```

```
##  elevation_fac fire    emmean    SE df lower.CL upper.CL .group
##  low           no fire   2.63 0.309 56     2.01     3.25  1
##  low           fire      2.98 0.309 56     2.36     3.60  12
##  high          no fire   3.57 0.309 56     2.96     4.19  12
##  high          fire      3.98 0.309 56     3.36     4.60   2
##
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 4 estimates
## significance level used: alpha = 0.05
```

```
ggplot(data = data_density, aes(x = site, y = (mean_distance))) +
  geom_boxplot()
```




```
# rmarkdown::render("mdi_pitchpine_analyses.R", output_format = "pdf_document")

## tables and posthoc
### soil organics
write.csv(cbind(as.matrix(anova(C_soil_lm)[, c(1, 4, 5)]),
      as.matrix(anova(N_soil_lm)[, c(4, 5)]),
      as.matrix(anova(CN_soil_lm)[, c(4, 5)])),
      'tables/soil_organics.csv')
```

```
(summary(emmeans(C_soil_lm, ~fire))[1,2] - summary(emmeans(C_soil_lm, ~fire))[2,2])/ summary(emmeans(C_s
```

```
## NOTE: Results may be misleading due to involvement in interactions
```

```
## NOTE: Results may be misleading due to involvement in interactions
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```

```
## [1] -0.3368901
```

```
(summary(emmeans(C_soil_lm, ~elevation_fac))[1,2] - summary(emmeans(C_soil_lm, ~elevation_fac))[2,2])/ s
```

```
## NOTE: Results may be misleading due to involvement in interactions
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## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] -0.3722326
```

```
(summary(emmeans(CN_soil_lm, ~elevation_fac))[1,2] - summary(emmeans(CN_soil_lm, ~elevation_fac))[2,2])/
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] -0.1479162
```

```
write.csv(cbind(as.matrix(anova(Ca_soil_lm)[, c(1, 4, 5)]),
                as.matrix(anova(P_soil_lm)[, c(4, 5)]),
                as.matrix(anova(K_soil_lm)[, c(4, 5)]),
                as.matrix(anova(Mg_soil_lm)[, c(4, 5)]),
                as.matrix(anova(Al_soil_lm)[, c(4, 5)]),
                as.matrix(anova(Zn_soil_lm)[, c(4, 5)])),
          'tables/soil_inorganics.csv')

(summary(emmeans(K_soil_lm, ~fire))[1,2] - summary(emmeans(K_soil_lm, ~fire))[2,2])/ summary(emmeans(K_s
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] -0.4811143
```

```
(summary(emmeans(Ca_soil_lm, ~elevation_fac))[1,2] - summary(emmeans(Ca_soil_lm, ~elevation_fac))[2,2])/
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] -0.5044777
```

```
write.csv(as.matrix(anova(retention_lm)[, c(1, 4, 5)]),
          'tables/retention.csv')

write.csv(cbind(as.matrix(anova(C_foliar_lm)[, c(1, 4, 5)]),
                as.matrix(anova(N_foliar_lm)[, c(4, 5)]),
                as.matrix(anova(CN_foliar_lm)[, c(4, 5)])),
          'tables/foliar_cn.csv')

write.csv(cbind(as.matrix(anova(d13C_lm)[, c(1, 4, 5)]),
                as.matrix(anova(d15N_lm)[, c(4, 5)])),
          'tables/foliar_isotope.csv')
```

```
(summary(emmeans(d13C_lm, ~elevation_fac))[1,2] - summary(emmeans(d13C_lm, ~elevation_fac))[2,2])/ summa
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] -0.03645517
```

```
write.csv(cbind(as.matrix(anova(Ca_foliar_lm)[, c(1, 4, 5)]),
                as.matrix(anova(P_foliar_lm)[, c(4, 5)]),
                as.matrix(anova(K_foliar_lm)[, c(4, 5)]),
                as.matrix(anova(Mg_foliar_lm)[, c(4, 5)]),
                as.matrix(anova(Al_foliar_lm)[, c(4, 5)]),
                as.matrix(anova(Zn_foliar_lm)[, c(4, 5)])),
          'tables/foliar_inorganics.csv')

(summary(emmeans(P_foliar_lm, ~fire))[1,2] - summary(emmeans(P_foliar_lm, ~fire))[2,2])/ summary(emmeans
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] 0.08157756
```

```
(summary(emmeans(K_foliar_lm, ~fire))[1,2] - summary(emmeans(K_foliar_lm, ~fire))[2,2])/ summary(emmeans
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] -0.09249996
```

```
(summary(emmeans(Ca_foliar_lm, ~elevation_fac))[1,2] - summary(emmeans(Ca_foliar_lm, ~elevation_fac))[2
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] -0.4759297
```

```
(summary(emmeans(Zn_foliar_lm, ~elevation_fac))[1,2] - summary(emmeans(Zn_foliar_lm, ~elevation_fac))[2
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] -0.08989564
```

```
write.csv(cbind(as.matrix(anova(height_lm)[, c(1, 4, 5)]),
                as.matrix(anova(canopy_lm)[, c(4, 5)]),
                as.matrix(anova(diam_lm)[, c(4, 5)])),
          'tables/allometry.csv')

(summary(emmeans(canopy_lm, ~elevation_fac))[1,2] - summary(emmeans(canopy_lm, ~elevation_fac))[2,2])/ s
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] -0.08255594
```

```r
write.csv(anova(density_lm)[, c(1, 4, 5)],
          'tables/density.csv')

(summary(emmeans(density_lm, ~elevation_fac))[1,2] - summary(emmeans(density_lm, ~elevation_fac))[2,2])
```

```
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
## NOTE: Results may be misleading due to involvement in interactions
```

```
## [1] 0.3471644
```