Assignment 6: GLMs week 1 (t-test and ANOVA)

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OVERVIEW

This exercise accompanies the lessons in Environmental Data Analytics on t-tests and ANOVAs.

Directions

1. Change "Student Name" on line 3 (above) with your name.
2. Work through the steps, **creating code and output** that fulfill each instruction.
3. Be sure to **answer the questions** in this assignment document.
4. When you have completed the assignment, **Knit** the text and code into a single PDF file.
5. After Knitting, submit the completed exercise (PDF file) to the dropbox in Sakai. Add your last name into the file name (e.g., "Salk_A06_GLMs_Week1.Rmd") prior to submission.

The completed exercise is due on Tuesday, February 18 at 1:00 pm.

Set up your session

1. Check your working directory, load the `tidyverse`, `cowplot`, and `agricolae` packages, and import the NTL-LTER_Lake_Nutrients_PeterPaul_Processed.csv dataset.

2. Change the date column to a date format. Call up `head` of this column to verify.

```
#1
getwd()
```

```
## [1] "C:/Users/senam/Box Sync/My Documents/MEM classes/Duke Spring 2020/DataAnalytics/Environmental_Da
```

```
library(tidyverse)
library(cowplot)
library(agricolae)
library(scales)

NTL.nutrients.PP <- read.csv("./Data/Processed/NTL-LTER_Lake_Nutrients_PeterPaul_Processed.csv")

#2
NTL.nutrients.PP$sampledate <- as.Date(NTL.nutrients.PP$sampledate, format = "%Y-%m-%d")
head(NTL.nutrients.PP)
```

```
##   lakeid  lakename year4 daynum month sampledate depth_id depth tn_ug tp_ug
## 1      L Paul Lake  1991    140     5 1991-05-20        1  0.00   538    25
## 2      L Paul Lake  1991    140     5 1991-05-20        2  0.85   285    14
## 3      L Paul Lake  1991    140     5 1991-05-20        3  1.75   399    14
## 4      L Paul Lake  1991    140     5 1991-05-20        4  3.00   453    14
## 5      L Paul Lake  1991    140     5 1991-05-20        5  4.00   363    13
## 6      L Paul Lake  1991    140     5 1991-05-20        6  6.00   583    37
##   nh34 no23 po4 comments
## 1   NA   NA  NA       NA
```

```
## 2   NA   NA  NA       NA
## 3   NA   NA  NA       NA
## 4   NA   NA  NA       NA
## 5   NA   NA  NA       NA
## 6   NA   NA  NA       NA
```

```
str(NTL.nutrients.PP)
```

```
## 'data.frame':    2406 obs. of  14 variables:
##  $ lakeid    : Factor w/ 2 levels "L","R": 1 1 1 1 1 1 2 2 2 2 ...
##  $ lakename  : Factor w/ 2 levels "Paul Lake","Peter Lake": 1 1 1 1 1 1 2 2 2 2 ...
##  $ year4     : int  1991 1991 1991 1991 1991 1991 1991 1991 1991 1991 ...
##  $ daynum    : int  140 140 140 140 140 140 140 140 140 140 ...
##  $ month     : int  5 5 5 5 5 5 5 5 5 5 ...
##  $ sampledate: Date, format: "1991-05-20" "1991-05-20" ...
##  $ depth_id  : int  1 2 3 4 5 6 1 2 3 4 ...
##  $ depth     : num  0 0.85 1.75 3 4 6 0 1 2.25 3.5 ...
##  $ tn_ug     : num  538 285 399 453 363 583 352 356 364 582 ...
##  $ tp_ug     : num  25 14 14 14 13 37 11 15 28 14 ...
##  $ nh34      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ no23      : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ po4       : num  NA NA NA NA NA NA NA NA NA NA ...
##  $ comments  : logi  NA NA NA NA NA NA ...
```

Wrangle your data

3. Wrangle your dataset so that it contains only surface depths and only the years 1993-1996, inclusive. Set month as a factor.

```
NTL.nutrients.PP_surface_93to96 <- NTL.nutrients.PP %>%
  filter(depth == 0) %>%
  filter(year4 >= 1993 & year4 <= 1996)

NTL.nutrients.PP_surface_93to96$month <- as.factor(NTL.nutrients.PP_surface_93to96$month)

class(NTL.nutrients.PP_surface_93to96$month)
```

```
## [1] "factor"
```

Analysis

Peter Lake was manipulated with additions of nitrogen and phosphorus over the years 1993-1996 in an effort to assess the impacts of eutrophication in lakes. You are tasked with finding out if nutrients are significantly higher in Peter Lake than Paul Lake, and if these potential differences in nutrients vary seasonally (use month as a factor to represent seasonality). Run two separate tests for TN and TP.

4. Which application of the GLM will you use (t-test, one-way ANOVA, two-way ANOVA with main effects, or two-way ANOVA with interaction effects)? Justify your choice.

   Answer: Two-way anova with interactions is needed to assess the differences in mean nutrient level by lake and also by month. An interaction between lake and time of year can also be considered because specific characteristics of the lake (size, depth, lake chemistry, inflows, etc) may result in different seasonal effects on tp and tn, and therefore the effect of season on nutrient concentrations may depend on the lake.

5. Run your test for TN. Include examination of groupings and consider interaction effects, if relevant.

6. Run your test for TP. Include examination of groupings and consider interaction effects, if relevant.

```r
#5
#ggplot(data = NTL.nutrients.PP_surface_93to96, aes(x=as.factor(month), y = tn_ug, color = lakename))+
#  geom_boxplot()

# two-way anova with interaction effect
tn.anova.int <- aov(data = NTL.nutrients.PP_surface_93to96, tn_ug ~ lakename * month)
summary(tn.anova.int)
```

```
##                Df  Sum Sq Mean Sq F value   Pr(>F)
## lakename        1 2468595 2468595  36.414 2.91e-08 ***
## month           4  459542  114885   1.695    0.157
## lakename:month  4  288272   72068   1.063    0.379
## Residuals      97 6575834   67792
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 23 observations deleted due to missingness
```

```r
# interaction is not significant, so remove from the model

# two-way anova with main effects only
tn.anova.noint <- aov(data = NTL.nutrients.PP_surface_93to96, tn_ug ~ lakename + month)
summary(tn.anova.noint)
```

```
##              Df  Sum Sq Mean Sq F value   Pr(>F)
## lakename      1 2468595 2468595   36.32 2.75e-08 ***
## month         4  459542  114885    1.69    0.158
## Residuals   101 6864107   67961
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 23 observations deleted due to missingness
```

```r
TukeyHSD(tn.anova.noint)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = tn_ug ~ lakename + month, data = NTL.nutrients.PP_surface_93to96)
##
## $lakename
##                           diff      lwr      upr p adj
## Peter Lake-Paul Lake 303.796 203.8026 403.7894     0
##
## $month
##          diff        lwr      upr     p adj
## 6-5 132.58168 -104.53533 369.6987 0.5307817
## 7-5 196.50011  -47.94924 440.9495 0.1761663
## 8-5 208.77984  -32.91447 450.4741 0.1238871
## 9-5 160.08048 -220.97835 541.1393 0.7701126
## 7-6  63.91843 -123.99128 251.8281 0.8785969
## 8-6  76.19815 -108.11330 260.5096 0.7803543
## 9-6  27.49879 -320.00718 375.0048 0.9994732
## 8-7  12.27972 -181.37388 205.9333 0.9997809
## 9-7 -36.41964 -388.96950 316.1302 0.9984948
## 9-8 -48.69936 -399.34457 301.9458 0.9952369
```

```r
#groups
tn.anova.lakegroups <- HSD.test(tn.anova.noint, trt = "lakename", group = TRUE)
tn.anova.lakegroups
```

```
## $statistics
##    MSerror  Df     Mean       CV
##   67961.45 101 487.4077 53.48585
##
## $parameters
##    test   name.t ntr StudentizedRange alpha
##   Tukey lakename   2         2.805419  0.05
##
## $means
##               tn_ug      std  r     Min      Max      Q25     Q50      Q75
## Paul Lake  336.9293 100.2745 54  45.670  557.812 284.0107 344.243 411.5165
## Peter Lake 640.7253 361.3738 53 312.133 2048.151 448.0490 571.092 692.4860
##
## $comparison
## NULL
##
## $groups
##               tn_ug groups
## Peter Lake 640.7253      a
## Paul Lake  336.9293      b
##
## attr(,"class")
## [1] "group"
```

```r
#month is not significant, so groups do not depend on month


#6
#ggplot(data = NTL.nutrients.PP_surface_93to96, aes(x=as.factor(month), y = tp_ug, color = lakename))+
#  geom_boxplot()

tp.anova.int <- aov(data = NTL.nutrients.PP_surface_93to96, tp_ug ~ lakename * month)
summary(tp.anova.int)
```

```
##                 Df Sum Sq Mean Sq F value Pr(>F)
## lakename         1  10228   10228  98.914 <2e-16 ***
## month            4    813     203   1.965 0.1043
## lakename:month   4   1014     254   2.452 0.0496 *
## Residuals      119  12305     103
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 1 observation deleted due to missingness
```

```r
# lake and interaction are significant, but month on its own is not

TukeyHSD(tp.anova.int)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = tp_ug ~ lakename * month, data = NTL.nutrients.PP_surface_93to96)
```

```
##
## $lakename
##                            diff      lwr      upr p adj
## Peter Lake-Paul Lake 17.80939 14.26365 21.35513     0
##
## $month
##           diff         lwr       upr     p adj
## 6-5  6.3451786  -2.8038335 15.494191 0.3119085
## 7-5  8.8661326  -0.2828796 18.015145 0.0622967
## 8-5  4.8191843  -4.2626118 13.900980 0.5839528
## 9-5  5.4951391  -6.7194172 17.709695 0.7243206
## 7-6  2.5209540  -4.2125367  9.254445 0.8376355
## 8-6 -1.5259943  -8.1678685  5.115880 0.9688094
## 9-6 -0.8500395 -11.3776631  9.677584 0.9994372
## 8-7 -4.0469483 -10.6888225  2.594926 0.4453729
## 9-7 -3.3709935 -13.8986170  7.156630 0.9012092
## 9-8  0.6759548  -9.7933076 11.145217 0.9997679
##
## $`lakename:month`
##                                      diff         lwr         upr     p adj
## Peter Lake:5-Paul Lake:5    4.3135714 -13.9293175  22.5564604 0.9989515
## Paul Lake:6-Paul Lake:5    -0.9178824 -16.4886641  14.6528993 1.0000000
## Peter Lake:6-Paul Lake:5   16.8838889   1.4263507  32.3414270 0.0206973
## Paul Lake:7-Paul Lake:5    -1.7271111 -17.1846493  13.7304270 0.9999981
## Peter Lake:7-Paul Lake:5   22.9304706   7.3596889  38.5012523 0.0002415
## Paul Lake:8-Paul Lake:5    -2.0872222 -17.5447604  13.3703159 0.9999902
## Peter Lake:8-Paul Lake:5   15.0200000  -0.3355071  30.3755071 0.0607728
## Paul Lake:9-Paul Lake:5    -0.7380000 -20.5935673  19.1175673 1.0000000
## Peter Lake:9-Paul Lake:5   14.7452500  -6.4208558  35.9113558 0.4316694
## Paul Lake:6-Peter Lake:5   -5.2314538 -19.9572479   9.4943403 0.9787107
## Peter Lake:6-Peter Lake:5  12.5703175  -2.0356832  27.1763181 0.1571717
## Paul Lake:7-Peter Lake:5   -6.0406825 -20.6466832   8.5653181 0.9437275
## Peter Lake:7-Peter Lake:5  18.6168992   3.8911050  33.3426933 0.0032014
## Paul Lake:8-Peter Lake:5   -6.4007937 -21.0067943   8.2052070 0.9208652
## Peter Lake:8-Peter Lake:5  10.7064286  -3.7915495  25.2044066 0.3464892
## Paul Lake:9-Peter Lake:5   -5.0515714 -24.2516579  14.1485150 0.9975850
## Peter Lake:9-Peter Lake:5  10.4316786 -10.1207861  30.9841433 0.8273658
## Peter Lake:6-Paul Lake:6   17.8017712   6.7120688  28.8914737 0.0000401
## Paul Lake:7-Paul Lake:6    -0.8092288 -11.8989312  10.2804737 1.0000000
## Peter Lake:7-Paul Lake:6   23.8483529  12.6013419  35.0953640 0.0000000
## Paul Lake:8-Paul Lake:6    -1.1693399 -12.2590423   9.9203626 0.9999989
## Peter Lake:8-Paul Lake:6   15.9378824   4.9908457  26.8849190 0.0003006
## Paul Lake:9-Paul Lake:6     0.1798824 -16.5021309  16.8618956 1.0000000
## Peter Lake:9-Paul Lake:6   15.6631324  -2.5591082  33.8853729 0.1584032
## Paul Lake:7-Peter Lake:6  -18.6110000 -29.5411300  -7.6808700 0.0000101
## Peter Lake:7-Peter Lake:6   6.0465817  -5.0431207  17.1362841 0.7595330
## Paul Lake:8-Peter Lake:6  -18.9711111 -29.9012412  -8.0409811 0.0000062
## Peter Lake:8-Peter Lake:6  -1.8638889 -12.6492426   8.9214648 0.9999197
## Paul Lake:9-Peter Lake:6  -17.6218889 -34.1982518  -1.0455259 0.0276305
## Peter Lake:9-Peter Lake:6  -2.1386389 -20.2642090  15.9869312 0.9999970
## Peter Lake:7-Paul Lake:7   24.6575817  13.5678793  35.7472841 0.0000000
## Paul Lake:8-Paul Lake:7    -0.3601111 -11.2902412  10.5700189 1.0000000
## Peter Lake:8-Paul Lake:7   16.7471111   5.9617574  27.5324648 0.0000827
## Paul Lake:9-Paul Lake:7     0.9891111 -15.5872518  17.5654741 1.0000000
```

```
## Peter Lake:9-Paul Lake:7   16.4723611  -1.6532090  34.5979312 0.1087387
## Paul Lake:8-Peter Lake:7  -25.0176928 -36.1073952 -13.9279904 0.0000000
## Peter Lake:8-Peter Lake:7  -7.9104706 -18.8575073   3.0365661 0.3778093
## Paul Lake:9-Peter Lake:7  -23.6684706 -40.3504838  -6.9864574 0.0004851
## Peter Lake:9-Peter Lake:7  -8.1852206 -26.4074611  10.0370199 0.9089776
## Peter Lake:8-Paul Lake:8   17.1072222   6.3218685  27.8925759 0.0000523
## Paul Lake:9-Paul Lake:8     1.3492222 -15.2271407  17.9255852 0.9999999
## Peter Lake:9-Paul Lake:8   16.8324722  -1.2930979  34.9580424 0.0926020
## Paul Lake:9-Peter Lake:8  -15.7580000 -32.2392597   0.7232597 0.0735733
## Peter Lake:9-Peter Lake:8  -0.2747500 -18.3133864  17.7638864 1.0000000
## Peter Lake:9-Paul Lake:9   15.4832500  -6.5132124  37.4797124 0.4163366
```

```
tp.interaction <- with(NTL.nutrients.PP_surface_93to96, interaction(lakename, month))
tp.anova.interactionterm <- aov(data = NTL.nutrients.PP_surface_93to96, tp_ug ~ tp.interaction)

# groups with interaction
tp.anova.groups <- HSD.test(tp.anova.interactionterm, "tp.interaction", group = TRUE)
tp.anova.groups
```

```
## $statistics
##    MSerror  Df     Mean      CV
##   103.4055 119 19.07347 53.3141
##
## $parameters
##    test         name.t ntr StudentizedRange alpha
##   Tukey tp.interaction  10         4.560262  0.05
##
## $means
##                  tp_ug       std  r    Min    Max     Q25     Q50      Q75
## Paul Lake.5  11.474000  3.928545  6  7.001 17.090  8.1395 11.8885 13.53675
## Paul Lake.6  10.556118  4.416821 17  1.222 16.697  7.4430 10.6050 13.94600
## Paul Lake.7   9.746889  3.525120 18  4.501 21.763  7.8065  9.1555 10.65700
## Paul Lake.8   9.386778  1.478062 18  5.879 11.542  8.4495  9.6090 10.45050
## Paul Lake.9  10.736000  3.615978  5  6.592 16.281  8.9440 10.1920 11.67100
## Peter Lake.5 15.787571  2.719954  7 10.887 18.922 14.8915 15.5730 17.67400
## Peter Lake.6 28.357889 15.588507 18 10.974 53.388 14.7790 24.6840 41.13000
## Peter Lake.7 34.404471 18.285568 17 19.149 66.893 21.6640 24.2070 50.54900
## Peter Lake.8 26.494000  9.829596 19 14.551 49.757 21.2425 23.2250 27.99350
## Peter Lake.9 26.219250 10.814803  4 16.281 41.145 19.6845 23.7255 30.26025
##
## $comparison
## NULL
##
## $groups
##                  tp_ug groups
## Peter Lake.7 34.404471      a
## Peter Lake.6 28.357889     ab
## Peter Lake.8 26.494000    abc
## Peter Lake.9 26.219250   abcd
## Peter Lake.5 15.787571    bcd
## Paul Lake.5  11.474000     cd
## Paul Lake.9  10.736000     cd
## Paul Lake.6  10.556118      d
## Paul Lake.7   9.746889      d
## Paul Lake.8   9.386778      d
```

```
##
## attr(,"class")
## [1] "group"
```

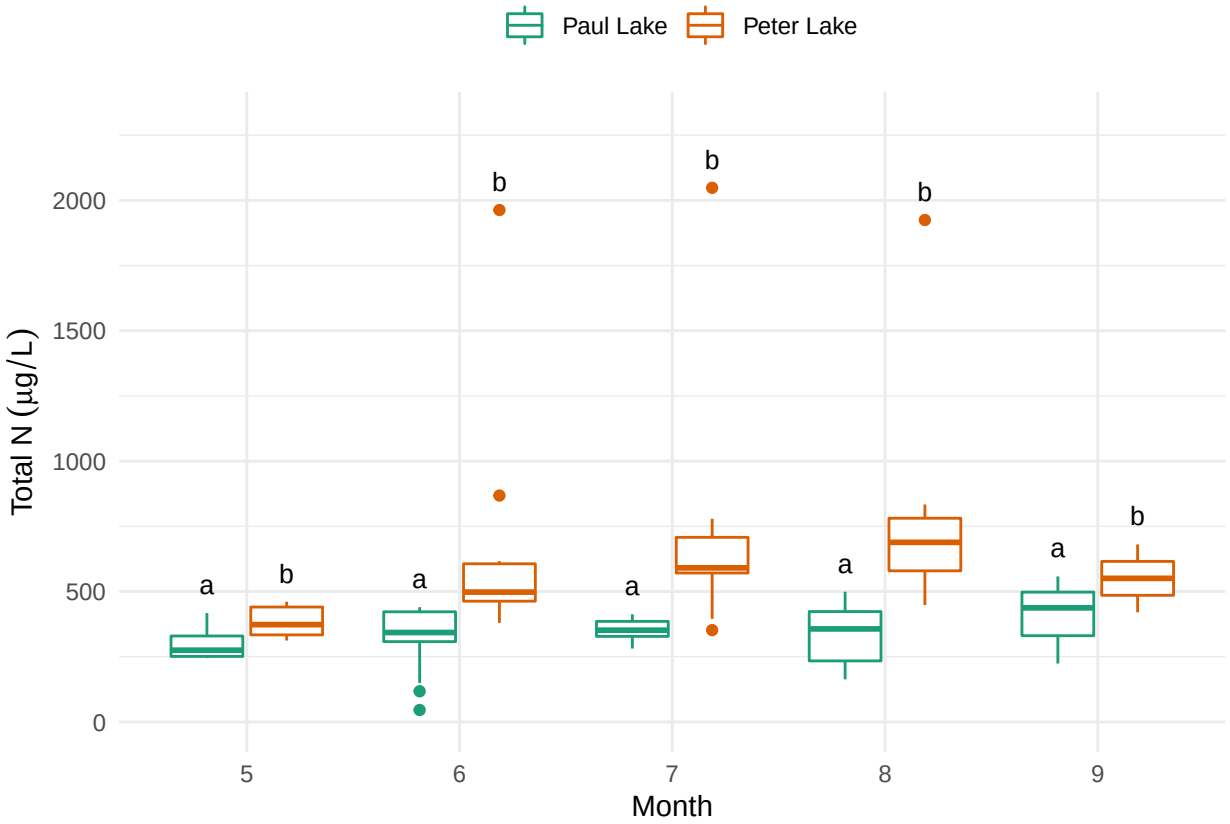
7. Create two plots, with TN (plot 1) or TP (plot 2) as the response variable and month and lake as the predictor variables. Hint: you may use some of the code you used for your visualization assignment. Assign groupings with letters, as determined from your tests. Adjust your axes, aesthetics, and color palettes in accordance with best data visualization practices.

8. Combine your plots with cowplot, with a common legend at the top and the two graphs stacked vertically. Your x axes should be formatted with the same breaks, such that you can remove the title and text of the top legend and retain just the bottom legend.

```
theme_set(theme_minimal()+
            theme(legend.position = "top"))
#7
TN.plot <- ggplot(NTL.nutrients.PP_surface_93to96, aes(y = tn_ug, x = month, color = lakename)) +
  geom_boxplot()+
  scale_y_continuous(limits = c(0,2300))+
  labs(x= "Month", y = expression("Total N" ~ (mu*g / L)), color = "")+
  stat_summary(aes(x=month, y = tn_ug, group = lakename), color = "black", position = position_dodge(0.
               geom = "text", fun.y = max, vjust = -1, size = 3.5,
               label = c("b", "a","b","a",
                         "b", "a","b", "a"
                         ,"b", "a"),
               show.legend = FALSE)+
  scale_color_brewer(type = "qual", palette = 2)
print(TN.plot)
```

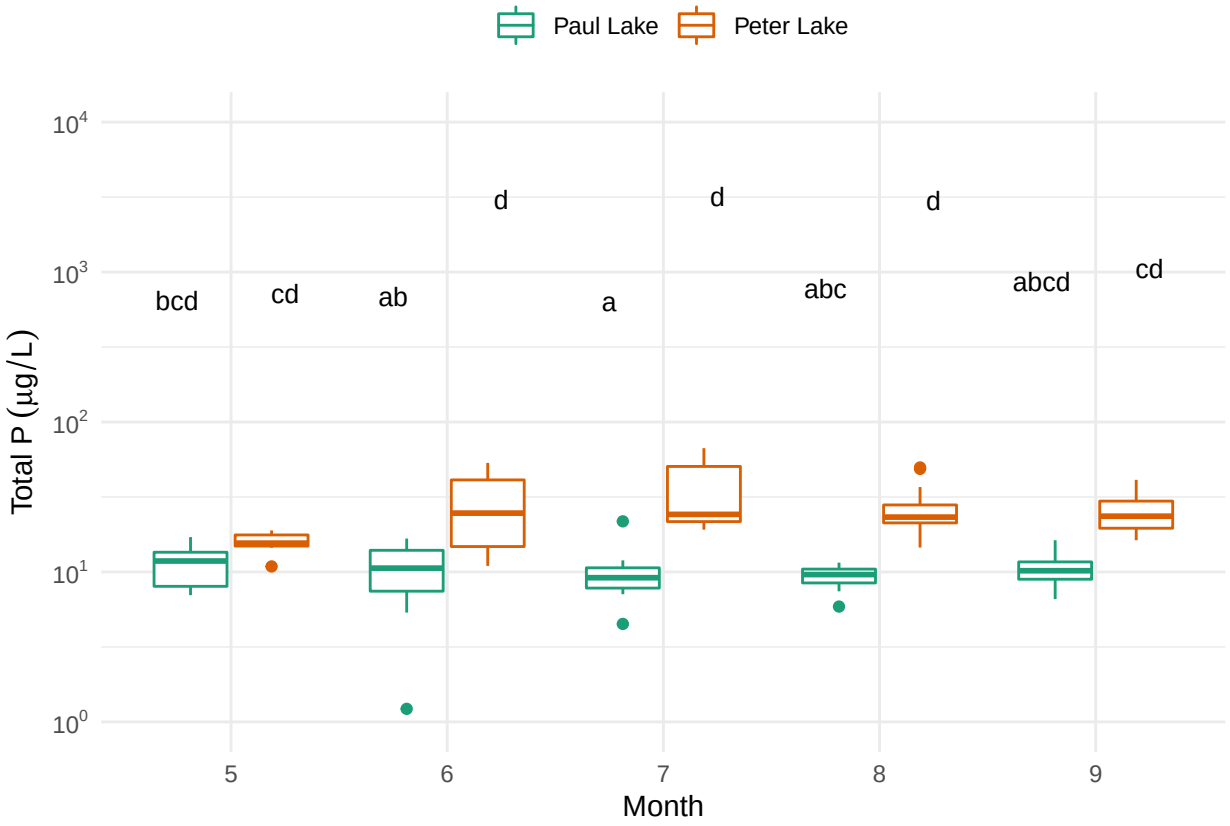
```
## Warning: Removed 23 rows containing non-finite values (stat_boxplot).
```

```
## Warning: Removed 23 rows containing non-finite values (stat_summary).
```




```
TP.plot <- ggplot(NTL.nutrients.PP_surface_93to96, aes(y = tp_ug, x = month, color = lakename)) +
  geom_boxplot()+
  scale_y_log10(limits = c(1, 10^4), labels = trans_format("log10", math_format(10^.x)))+
  labs(x= "Month", y = expression("Total P" ~ (mu*g / L)), color = "")+
  stat_summary(aes(x=month, y = tn_ug, group = lakename), color = "black", position = position_dodge(1)
               geom = "text", fun.y = max, vjust = -1, size = 3.5,
               label = c("cd", "bcd", "d", "ab", "d", "a",
                         "d", "abc", "cd", "abcd"),
               show.legend = FALSE)+
  scale_color_brewer(type = "qual", palette = 2)
print(TP.plot)
```

```
## Warning: Removed 1 rows containing non-finite values (stat_boxplot).

## Warning: Removed 23 rows containing non-finite values (stat_summary).
```



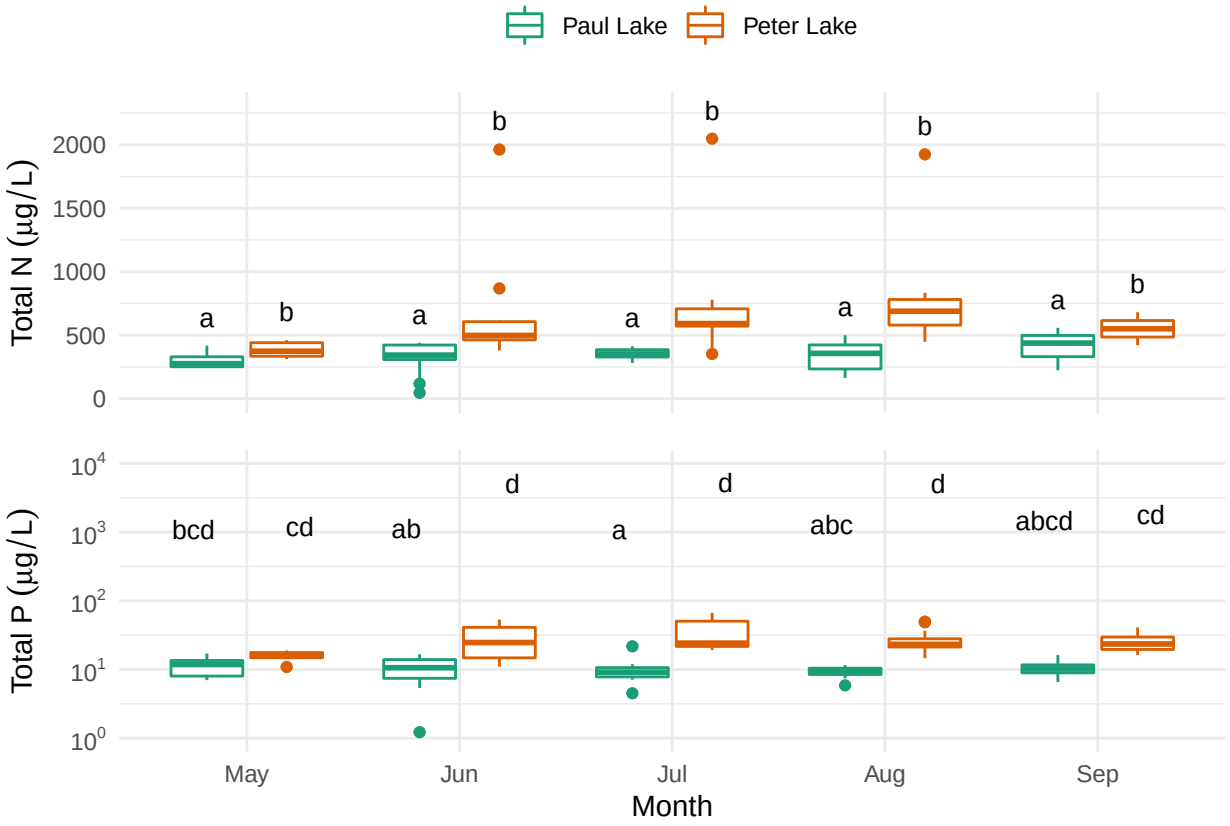

```
#8
TN.cowplot <- TN.plot +
  theme(axis.title.x = element_blank(),
        axis.text.x = element_blank())
TP.cowplot <- TP.plot +
  theme(legend.position = "none")+
  scale_x_discrete(labels = c("May", "Jun", "Jul", "Aug", "Sep"))

plot_grid(TN.cowplot, TP.cowplot, nrow = 2, align = "v", rel_heights = c(1.15, 1))
```

```
## Warning: Removed 23 rows containing non-finite values (stat_boxplot).
```

```
## Warning: Removed 23 rows containing non-finite values (stat_summary).
```

```
## Warning: Removed 1 rows containing non-finite values (stat_boxplot).
```

```
## Warning: Removed 23 rows containing non-finite values (stat_summary).
```


Paul Lake
Peter Lake
Total N (µg/L)
2000
1500
1000
500
0
a
b
a
b
a
b
a
b
a
b
Total P (µg/L)
10^4
10^3
10^2
10^1
10^0
bcd
cd
ab
d
a
d
abc
d
abcd
cd
May
Jun
Jul
Aug
Sep
Month