

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() #verify working directory

## [1] "C:/Users/sierr/Documents/Duke University/ENVIRON-872L/Environmental_Data_Analytics_2020"

library(tidyverse) #load tidyverse packages
library(cowplot) #load cowplot package
library(agricolae) #load agricolae package
PeterPaul.nutrients <-
  read.csv("../Data/Processed/NTL-LTER_Lake_Nutrients_PeterPaul_Processed.csv")
  #import the NTL-LTER lake nutrients processed dataset

#2
class(PeterPaul.nutrients$sampleddate) #check class of 'sampleddate' column

## [1] "factor"

PeterPaul.nutrients$sampleddate <-
  as.Date(PeterPaul.nutrients$sampleddate, format = "%Y-%m-%d")
  #format 'sampleddate' column as date
head(PeterPaul.nutrients$sampleddate)

## [1] "1991-05-20" "1991-05-20" "1991-05-20" "1991-05-20" "1991-05-20"
## [6] "1991-05-20"
```

```
#call up head of 'sampledate' column to verify date formatting
```

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.

```
PeterPaul.nutrients <- filter(PeterPaul.nutrients,  
                              depth < 0.25 &  
                              year4 > 1992 & year4 < 1997)  
#select only surface depth data from years 1993-1996  
PeterPaul.nutrients$month <- as.factor(PeterPaul.nutrients$month) #set month as a 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: I will use a two-way ANOVA with interaction effects, as we are examining the effects of two categorical explanatory variables (lake name and month) on a continuous response variable (TN and TP). We want to know how TN and TP (separately) vary across lakes (location) and months (seasonality). I expect the effects of lake name and month may be dependent on one another, so I have chosen to run a two-way ANOVA with interaction effects.

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.

```
#5  
sierratheme <- theme_classic(base_size = 14) +  
  theme(axis.text = element_text(color = "black"),  
        legend.position = "top")  
#build new theme 'sierratheme' and define its parameters  
theme_set(sierratheme) #set sierratheme as default plot theme  
  
# Format as aov  
TN.anova.2way <- aov(data = PeterPaul.nutrients, tn_ug ~ lakename * month)  
summary(TN.anova.2way)
```

```
##              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
```

```
# Run a post-hoc test for pairwise differences  
TukeyHSD(TN.anova.2way)
```

```
##    Tukey multiple comparisons of means
```

```
##      95% family-wise confidence level
##
## Fit: aov(formula = tn_ug ~ lakename * month, data = PeterPaul.nutrients)
##
## $lakename
##              diff      lwr      upr p adj
## Peter Lake-Paul Lake 303.796 203.8773 403.7146      0
##
## $month
##      diff      lwr      upr      p adj
## 6-5 132.58168 -104.4173 369.5807 0.5296645
## 7-5 196.50011  -47.8276 440.8278 0.1755245
## 8-5 208.77984  -32.7942 450.3539 0.1234174
## 9-5 160.08048 -220.7887 540.9497 0.7692917
## 7-6  63.91843 -123.8978 251.7346 0.8780820
## 8-6  76.19815 -108.0216 260.4179 0.7795574
## 9-6  27.49879 -319.8343 374.8318 0.9994702
## 8-7  12.27972 -181.2775 205.8370 0.9997797
## 9-7 -36.41964 -388.7941 315.9548 0.9984863
## 9-8 -48.69936 -399.1701 301.7714 0.9952106
##
## $`lakename:month`
##              diff      lwr      upr      p adj
## Peter Lake:5-Paul Lake:5    84.42736 -384.695091 553.54981 0.9998802
## Paul Lake:6-Paul Lake:5    23.61297 -376.795278 424.02122 1.0000000
## Peter Lake:6-Paul Lake:5   308.53119  -95.128061 712.19044 0.2949521
## Paul Lake:7-Paul Lake:5    53.12257 -358.325034 464.57018 0.9999929
## Peter Lake:7-Paul Lake:5   409.37327  -6.794730 825.54127 0.0577843
## Paul Lake:8-Paul Lake:5    35.99664 -375.450962 447.44425 0.9999998
## Peter Lake:8-Paul Lake:5   445.47177   38.159418 852.78411 0.0206524
## Paul Lake:9-Paul Lake:5   105.82450 -490.419726 702.06873 0.9998933
## Peter Lake:9-Paul Lake:5   249.95650 -438.527028 938.44003 0.9743614
## Paul Lake:6-Peter Lake:5   -60.81439 -439.493476 317.86470 0.9999541
## Peter Lake:6-Peter Lake:5   224.10383 -158.011173 606.21883 0.6694487
## Paul Lake:7-Peter Lake:5   -31.30479 -421.638257 359.02869 0.9999999
## Peter Lake:7-Peter Lake:5   324.94591  -70.360160 720.25198 0.2042224
## Paul Lake:8-Peter Lake:5   -48.43071 -438.764185 341.90276 0.9999950
## Peter Lake:8-Peter Lake:5   361.04441  -24.927657 747.01648 0.0870846
## Paul Lake:9-Peter Lake:5    21.39714 -560.477640 603.27193 1.0000000
## Peter Lake:9-Peter Lake:5   165.52914 -510.548261 841.60655 0.9985431
## Peter Lake:6-Paul Lake:6   284.91822  -8.787028 578.62346 0.0650344
## Paul Lake:7-Paul Lake:6    29.50960 -274.811140 333.83034 0.9999994
## Peter Lake:7-Paul Lake:6   385.76030   75.087182 696.43342 0.0043241
## Paul Lake:8-Paul Lake:6    12.38367 -291.937068 316.70441 1.0000000
## Peter Lake:8-Paul Lake:6   421.85880  123.152702 720.56489 0.0005774
## Paul Lake:9-Paul Lake:6    82.21153 -445.831232 610.25429 0.9999647
## Peter Lake:9-Paul Lake:6   226.34353 -403.998878 856.68594 0.9761624
## Paul Lake:7-Peter Lake:6  -255.40862 -563.994320  53.17709 0.1964898
## Peter Lake:7-Peter Lake:6   100.84208 -214.009961 415.69412 0.9891274
## Paul Lake:8-Peter Lake:6  -272.53454 -581.120248  36.05116 0.1316086
## Peter Lake:8-Peter Lake:6   136.94058 -166.109506 439.99066 0.9029804
## Paul Lake:9-Peter Lake:6  -202.70669 -733.218875 327.80550 0.9642843
## Peter Lake:9-Peter Lake:6  -58.57469 -690.987190 573.83782 0.9999996
## Peter Lake:7-Paul Lake:7   356.25070   31.473618 681.02778 0.0200027
```

```

## Paul Lake:8-Paul Lake:7    -17.12593 -335.831873 301.58002 1.0000000
## Peter Lake:8-Paul Lake:7   392.34920   79.000035 705.69836 0.0038467
## Paul Lake:9-Paul Lake:7    52.70193 -483.760115 589.16397 0.9999994
## Peter Lake:9-Paul Lake:7   196.83393 -440.577960 834.24582 0.9916222
## Paul Lake:8-Peter Lake:7   -373.37663 -698.153706 -48.59955 0.0116944
## Peter Lake:8-Peter Lake:7    36.09850 -283.423597 355.62059 0.9999978
## Paul Lake:9-Peter Lake:7   -303.54877 -843.639684 236.54215 0.7209271
## Peter Lake:9-Peter Lake:7 -159.41677 -799.885807 481.05227 0.9983429
## Peter Lake:8-Paul Lake:8    409.47512   96.125963 722.82428 0.0020552
## Paul Lake:9-Paul Lake:8     69.82786 -466.634186 606.28990 0.9999924
## Peter Lake:9-Paul Lake:8    213.95986 -423.452032 851.37175 0.9849047
## Paul Lake:9-Peter Lake:8   -339.64727 -872.944314 193.64978 0.5579223
## Peter Lake:9-Peter Lake:8 -195.51527 -830.265716 439.23518 0.9917740
## Peter Lake:9-Paul Lake:9    144.13200 -625.615985 913.87999 0.9998333

TN.interaction <- with(PeterPaul.nutrients, interaction(lakename, month))
TN.anova.2way2 <- aov(data = PeterPaul.nutrients, tn_ug ~ TN.interaction)

TN.groups <- HSD.test(TN.anova.2way2, "TN.interaction", group = TRUE)
TN.groups

## $statistics
##   MSerror Df      Mean      CV
## 67792.1 97 487.4077 53.41917
##
## $parameters
##      test      name.t ntr StudentizedRange alpha
##  Tukey TN.interaction 10          4.579991 0.05
##
## $means
##           tn_ug      std  r      Min      Max      Q25      Q50      Q75
## Paul Lake.5 300.5115 67.85647 6 244.870 417.345 251.0738 275.0400 329.5267
## Paul Lake.6 324.1245 117.32193 17 45.670 439.984 307.8120 342.8260 422.2600
## Paul Lake.7 353.6341 40.78474 14 281.421 412.669 328.0188 351.6630 385.5945
## Paul Lake.8 336.5081 118.22435 14 163.148 499.251 233.8633 356.6185 423.1365
## Paul Lake.9 406.3360 169.15898 3 223.799 557.812 330.5980 437.3970 497.6045
## Peter Lake.5 384.9389 62.65797 7 312.133 460.791 333.7260 373.0810 440.5575
## Peter Lake.6 609.0427 379.99046 16 379.781 1962.902 462.9225 497.8530 606.3447
## Peter Lake.7 709.8848 422.31321 13 352.001 2048.151 571.0920 590.7920 707.7710
## Peter Lake.8 745.9833 349.34126 15 448.049 1924.631 579.3500 688.5110 781.0950
## Peter Lake.9 550.4680 183.97504 2 420.378 680.558 485.4230 550.4680 615.5130
##
## $comparison
## NULL
##
## $groups
##           tn_ug groups
## Peter Lake.8 745.9833 a
## Peter Lake.7 709.8848 a
## Peter Lake.6 609.0427 ab
## Peter Lake.9 550.4680 ab
## Paul Lake.9 406.3360 ab
## Peter Lake.5 384.9389 ab
## Paul Lake.7 353.6341 b
## Paul Lake.8 336.5081 b

```

```
## Paul Lake.6 324.1245      b
## Paul Lake.5 300.5115      b
##
## attr("class")
## [1] "group"

#6

# Format as aov
TP.anova.2way <- aov(data = PeterPaul.nutrients, tp_ug ~ lakename * month)
summary(TP.anova.2way)

##              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

# Run a post-hoc test for pairwise differences
TukeyHSD(TP.anova.2way)

##      Tukey multiple comparisons of means
##      95% family-wise confidence level
##
## Fit: aov(formula = tp_ug ~ lakename * month, data = PeterPaul.nutrients)
##
## $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(PeterPaul.nutrients, interaction(lakename, month))
TP.anova.2way2 <- aov(data = PeterPaul.nutrients, tp Ug ~ TP.interaction)
```

```
TP.groups <- HSD.test(TP.anova.2way2, "TP.interaction", group = TRUE)
TP.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
```

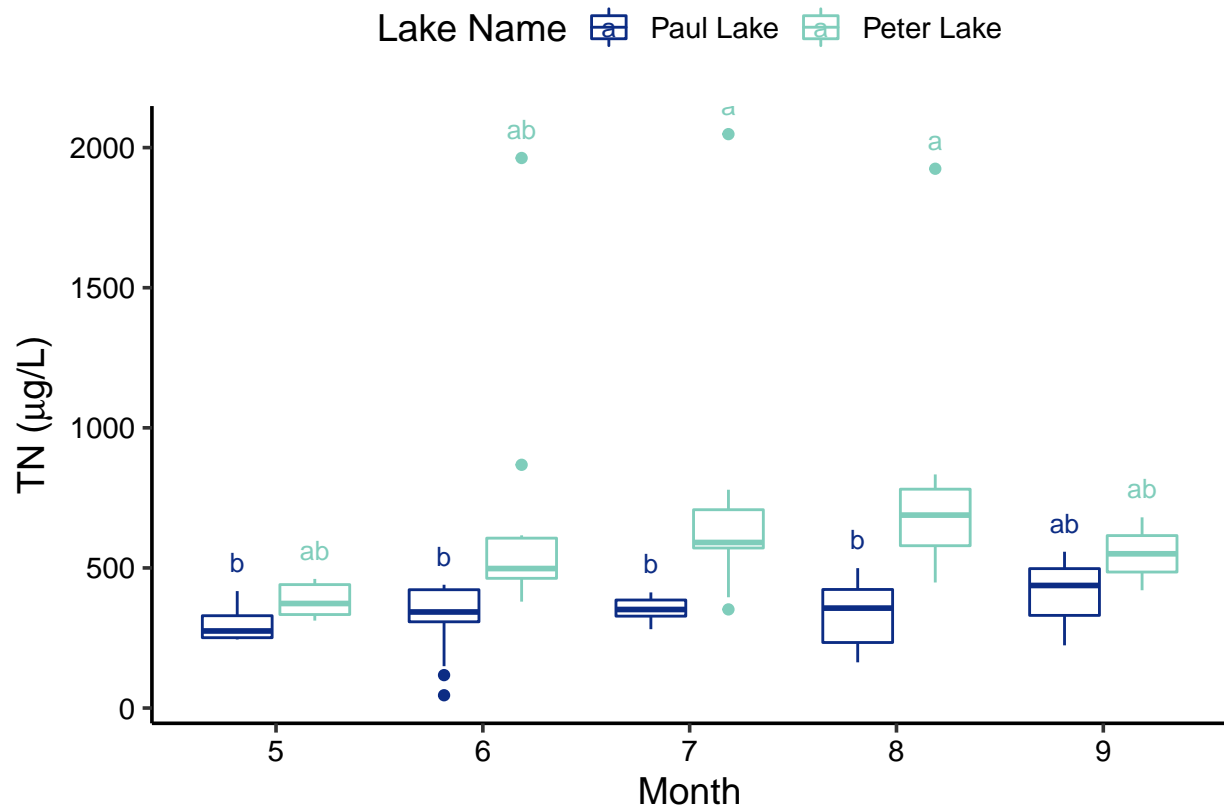
```
## Paul Lake.6 10.556118 4.416821 17 1.222 16.697 7.4430 10.6050 13.94600
## Paul Lake.7 9.746889 3.525120 18 4.501 21.763 7.8065 9.1555 10.65700
## Paul Lake.8 9.386778 1.478062 18 5.879 11.542 8.4495 9.6090 10.45050
## Paul Lake.9 10.736000 3.615978 5 6.592 16.281 8.9440 10.1920 11.67100
## Peter 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.

```
#7
TN.anova.plot <- ggplot(PeterPaul.nutrients, aes(y = tn_ug, x = month, color = lakename)) +
  geom_boxplot() +
  xlab(expression(paste("Month")))) + #change x-label
  ylab(expression(paste("TN (", mu, "g/L)")))) + #change y-label
  labs(color = "Lake Name") +
  scale_color_manual(values = c("#0c2c84", "#7fcdbb")) + #assign colors to lakes
  stat_summary(geom = "text", fun.y = max, position = position_dodge(width = 0.75,
    preserve = "total"), vjust = -1, size = 3.5,
    label = c("ab", "b", "ab", "b", "a", "b", "a", "b", "ab", "ab"))
  #add group labels to plot
print(TN.anova.plot)
```

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

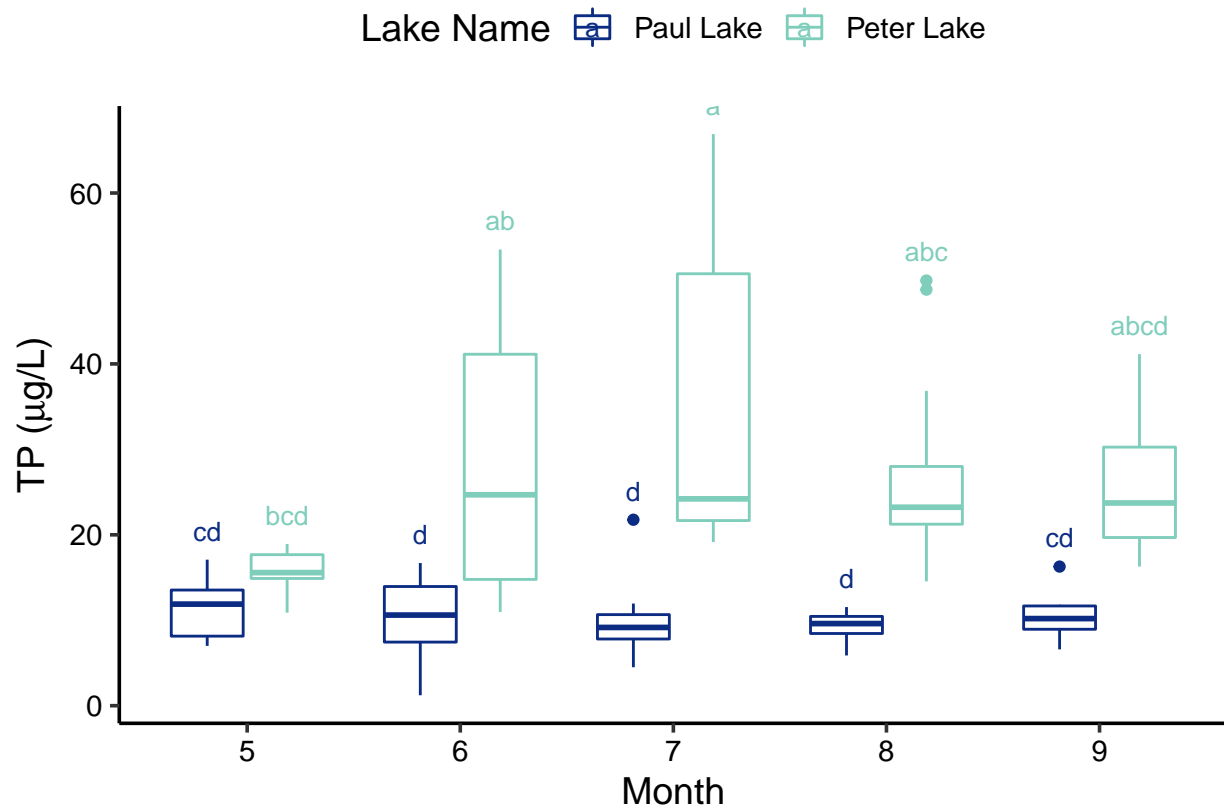
```
## Warning: Removed 23 rows containing non-finite values (stat_summary).
```



```
TP.anova.plot <- ggplot(PeterPaul.nutrients, aes(y = tp_ug, x = month, color = lakename)) +
  geom_boxplot() +
  xlab(expression(paste("Month")))) + #change x-label
  ylab(expression(paste("TP (", mu, "g/L)")))) + #change y-label
  labs(color = "Lake Name") +
  scale_color_manual(values = c("#0c2c84", "#7fcdbb")) + #assign colors to lakes
  stat_summary(geom = "text", fun.y = max, position = position_dodge(width = 0.75,
    preserve = "total"), vjust = -1, size = 3.5,
    label = c("bcd", "cd", "ab", "d", "a", "d", "abc", "d", "abcd", "cd"))
  #add group labels to plot
print(TP.anova.plot)
```

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

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

#8

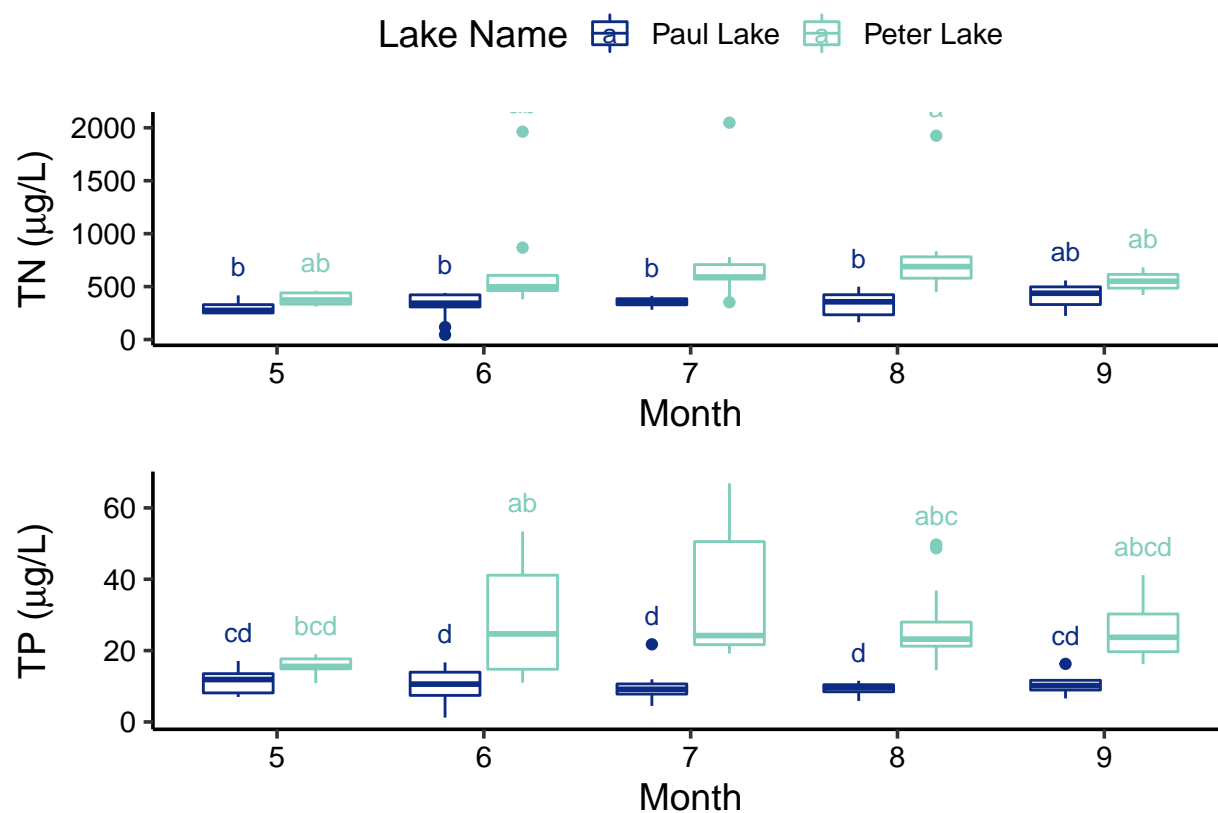
```
plot_grid(TN.anova.plot, TP.anova.plot + theme(legend.position = "none"), nrow = 2,
  align = 'v', rel_heights = c(1.25, 1))
```

```
## 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 1 rows containing non-finite values (stat_summary).
```



#combine two previous graphs into one couplot with one legend and vertically aligned axes