

# 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] "/Users/rachelgonsenhauser/Documents/Environmental_Data_Analytics_2020"

library(tidyverse)
library(cowplot)
#install.packages("agricolae")
library(agricolae)
PeterPaul.Processed <-
  read.csv("./Data/Processed/NTL-LTER_Lake_Nutrients_PeterPaul_Processed.csv")

#2
class(PeterPaul.Processed$sampldate)

## [1] "factor"

PeterPaul.Processed$sampldate <- as.Date(
  PeterPaul.Processed$sampldate, format = "%Y-%m-%d")
class(PeterPaul.Processed$sampldate)

## [1] "Date"

head(PeterPaul.Processed)

##   lakeid  lakename year4 daynum month sampldate 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
```

## 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.Wrangled <- filter(PeterPaul.Processed, depth == 0)
PeterPaul.Wrangled <- filter(PeterPaul.Wrangled, year4 %in% c(1993:1996))
PeterPaul.Wrangled$month <- as.factor(PeterPaul.Wrangled$month)
class(PeterPaul.Wrangled$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.

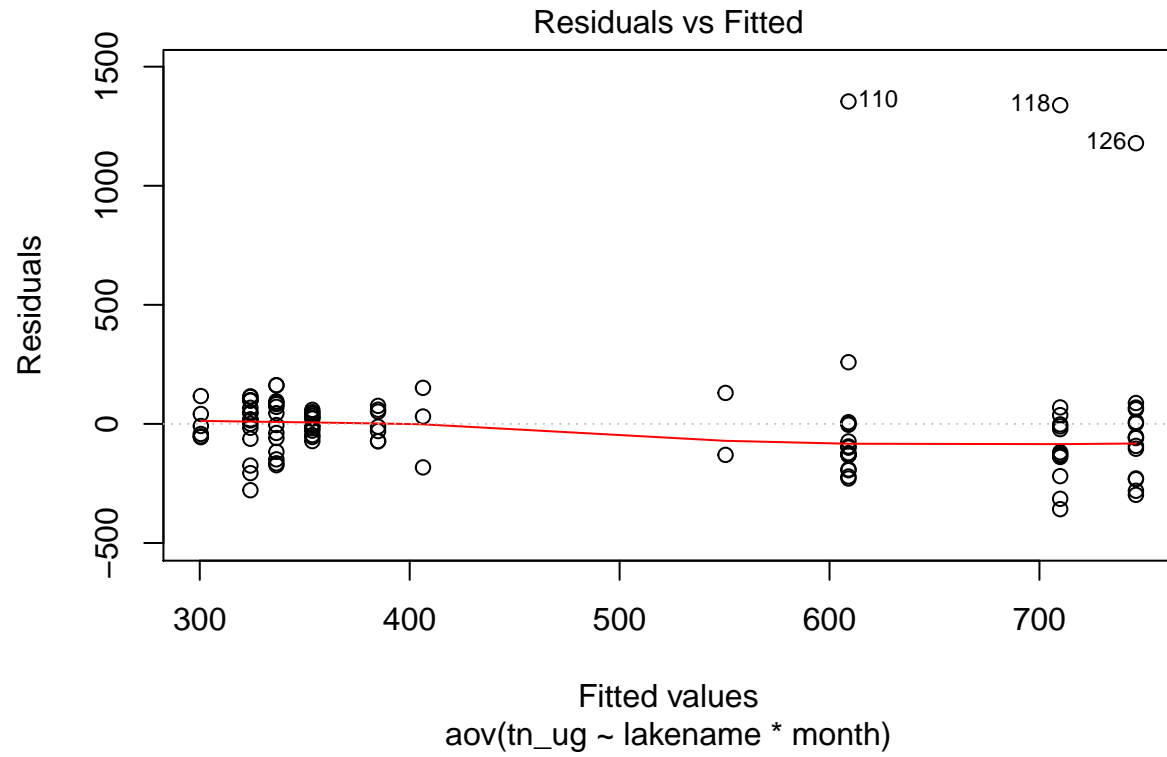
Answer: I chose to use a two-way ANOVA because in this case the explanatory variable (total nitrogen or total phosphorous) is continuous and the two explanatory variables (lake and month) are categorical. Specifically, I ran a two-way ANOVA with interaction effects to test whether there was an interaction between the explanatory variables on total nitrogen or phosphorous values.

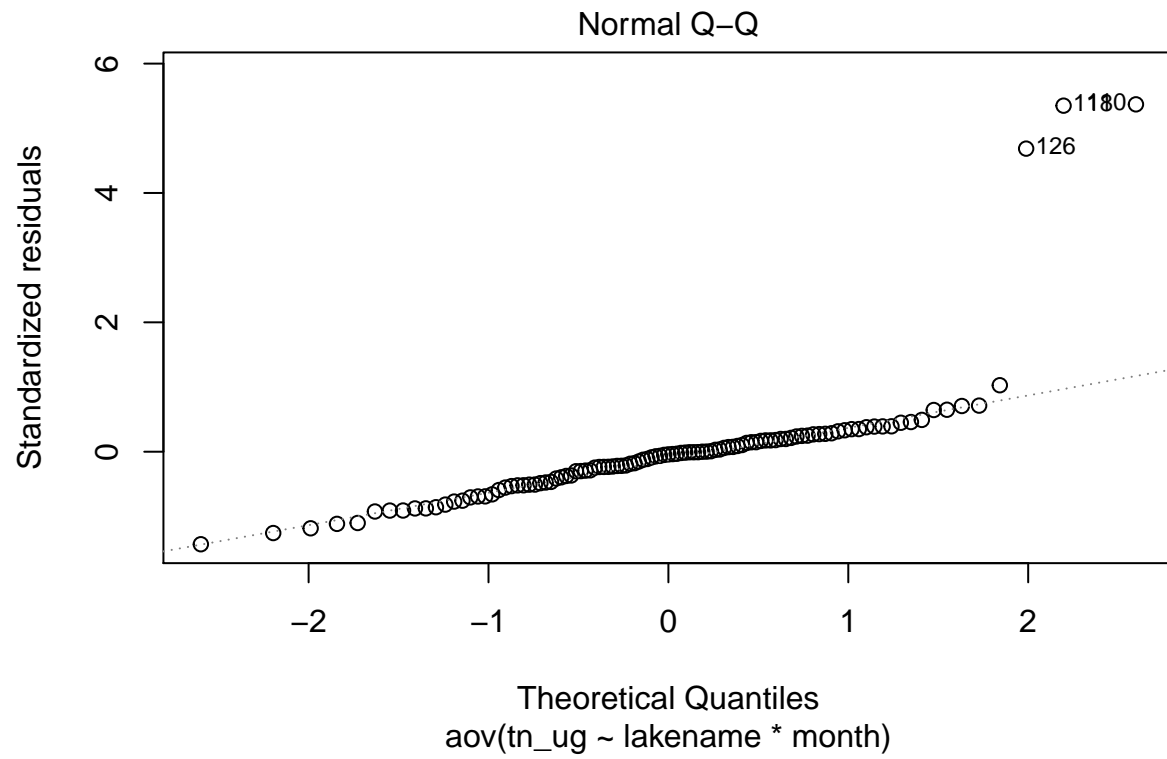
5. Run your test for TN. Include examination of groupings and consider interaction effects, if relevant.
6. Run your test for TP. Include examination of groupings and consider interaction effects, if relevant.

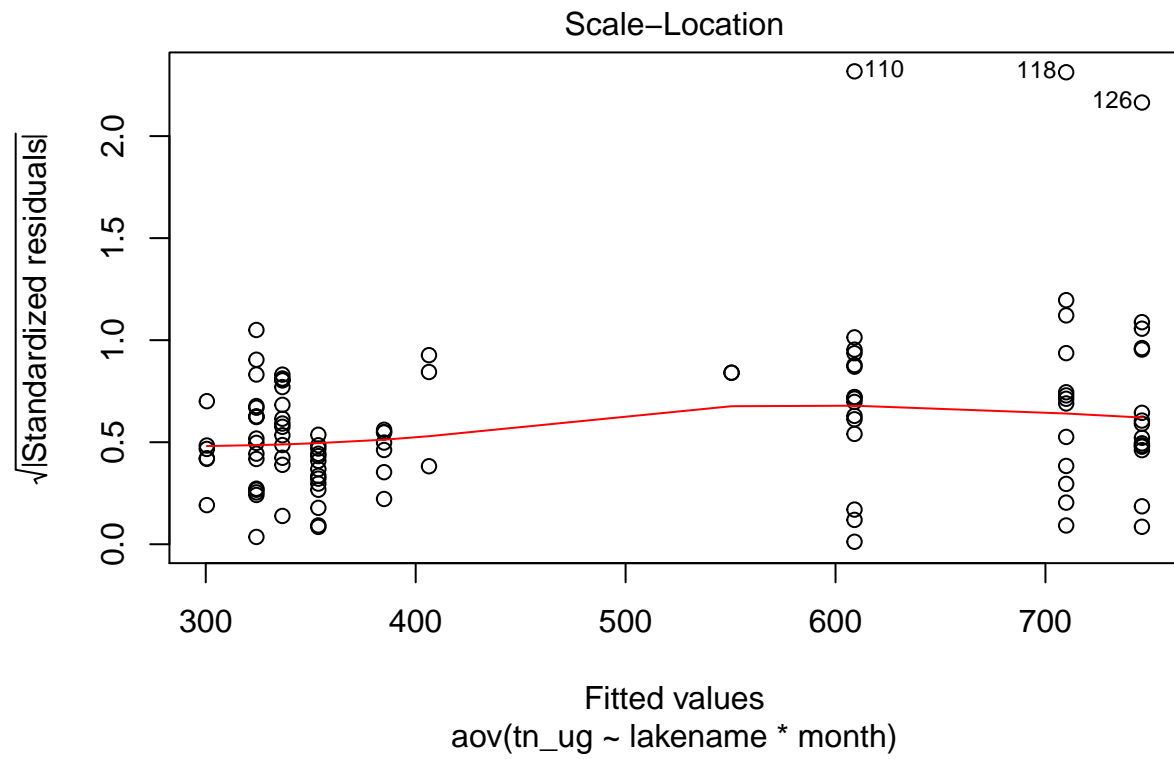
```
#5
PeterPaul.TN.anova.2way <-
  aov(data = PeterPaul.Wrangled, tn_ug ~ lakename * month)
summary(PeterPaul.TN.anova.2way)
```

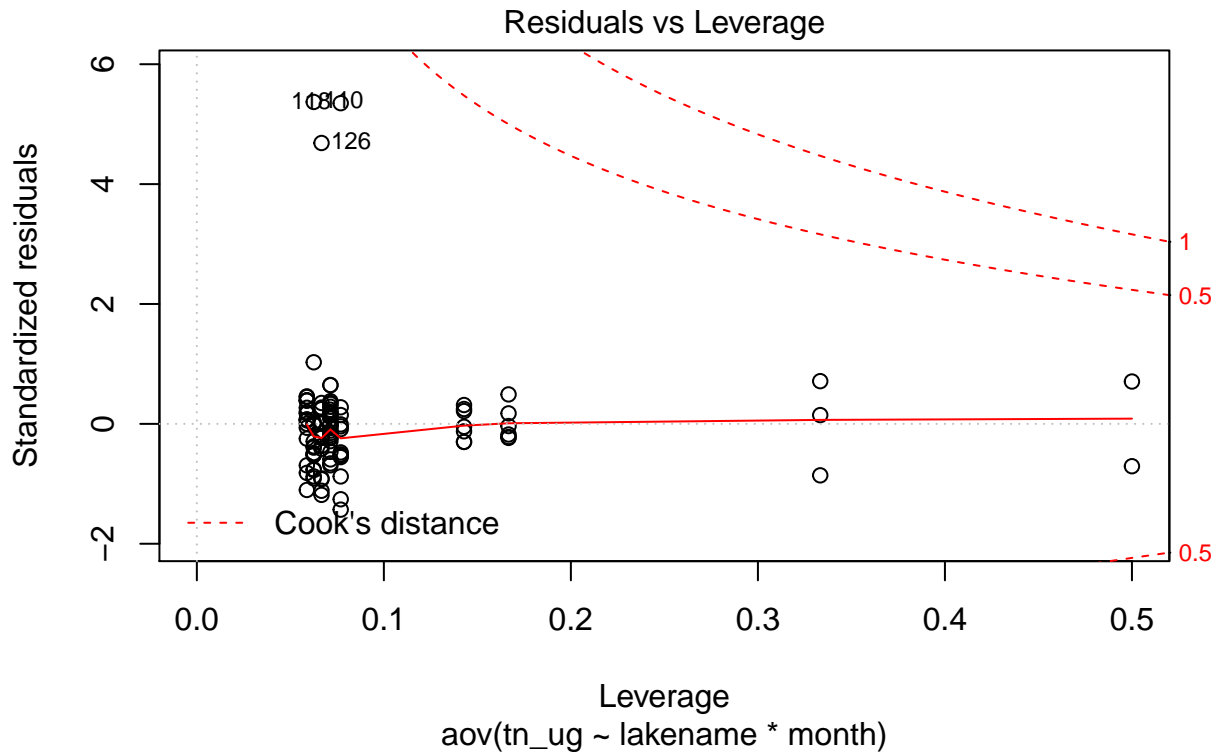
```
##              Df Sum Sq Mean Sq F value    Pr(>F)
## lakename      1 2468595 2468595    36.414 2.91e-08 ***
## month         4  459542   114885     1.695   0.157
## lakename:month 4   288272    72068     1.063   0.379
## Residuals    97 6575834    67792
## ---
## Signif. codes:  0 '***' 0.001 '**'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

```
plot(PeterPaul.TN.anova.2way)
```









```
TukeyHSD(PeterPaul.TN.anova.2way)
```

```
## Tukey multiple comparisons of means
## 95% family-wise confidence level
##
## Fit: aov(formula = tn_ug ~ lakename * month, data = PeterPaul.Wrangled)
##
## $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.groupings <- HSD.test(PeterPaul.TN.anova.2way,
                          "lakename", group = TRUE)
```

```
TN.groupings
```

```
## $statistics
##   MSerror Df      Mean      CV
##   67792.1 97 487.4077 53.41917
##
## $parameters
```

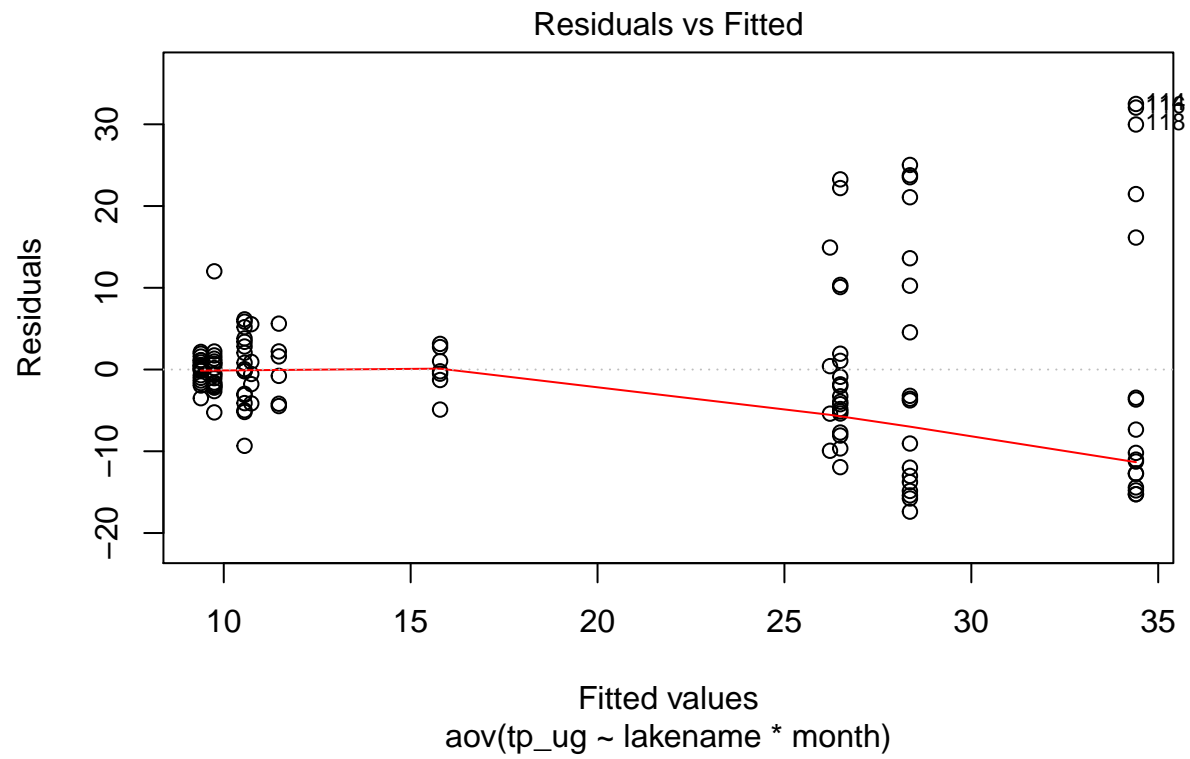
```
## test name.t ntr StudentizedRange alpha
## Tukey lakename 2 2.806822 0.05
##
## $means
## tn_ug std r Min Max Q25 Q50 Q75
## Paul Lake 336.9293 100.2745 54 45.670 557.812 284.0107 344.243 411.5165
## Peter Lake 640.7253 361.3738 53 312.133 2048.151 448.0490 571.092 692.4860
##
## $comparison
## NULL
##
## $groups
## tn_ug groups
## Peter Lake 640.7253 a
## Paul Lake 336.9293 b
##
## attr("class")
## [1] "group"
```

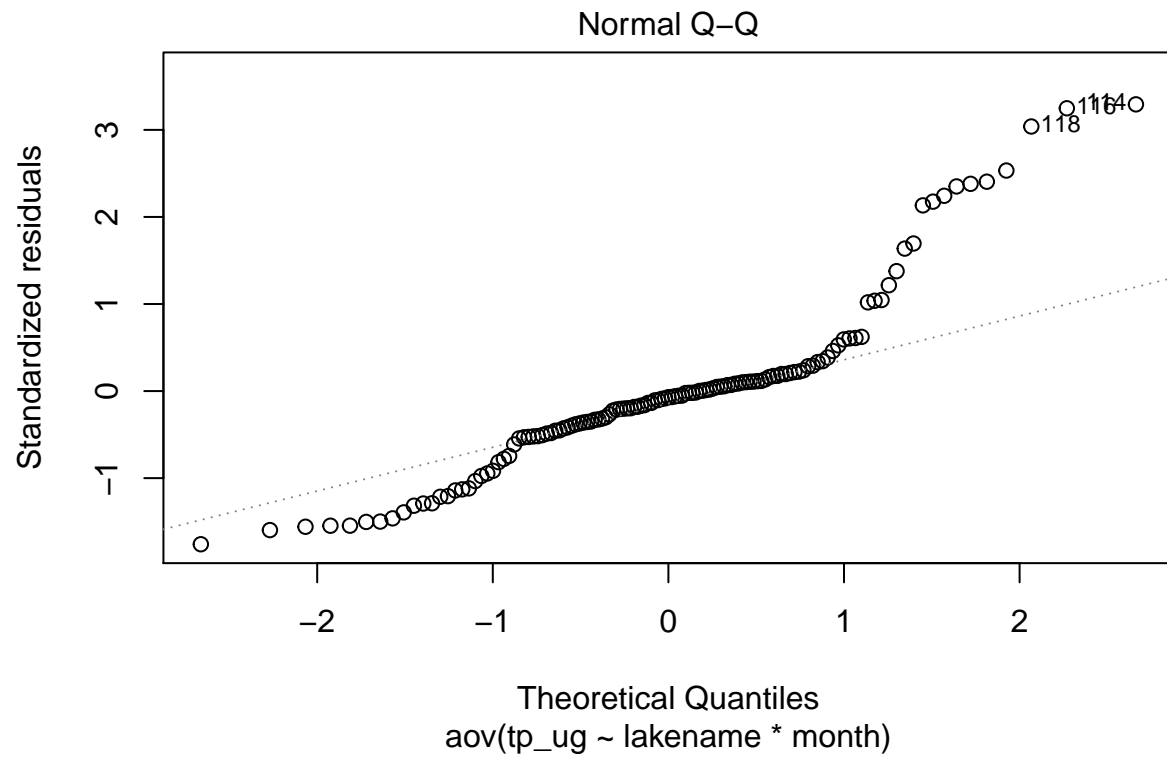
Total nitrogen differs significantly across the two lakes but does not differ significantly seasonally (two-way ANOVA with interaction effects,  $F_{1,4,4} = 36.41$ ,  $p < 0.0001$ ). Additionally, there is not a significant interaction effect between lake and month on total nitrogen.

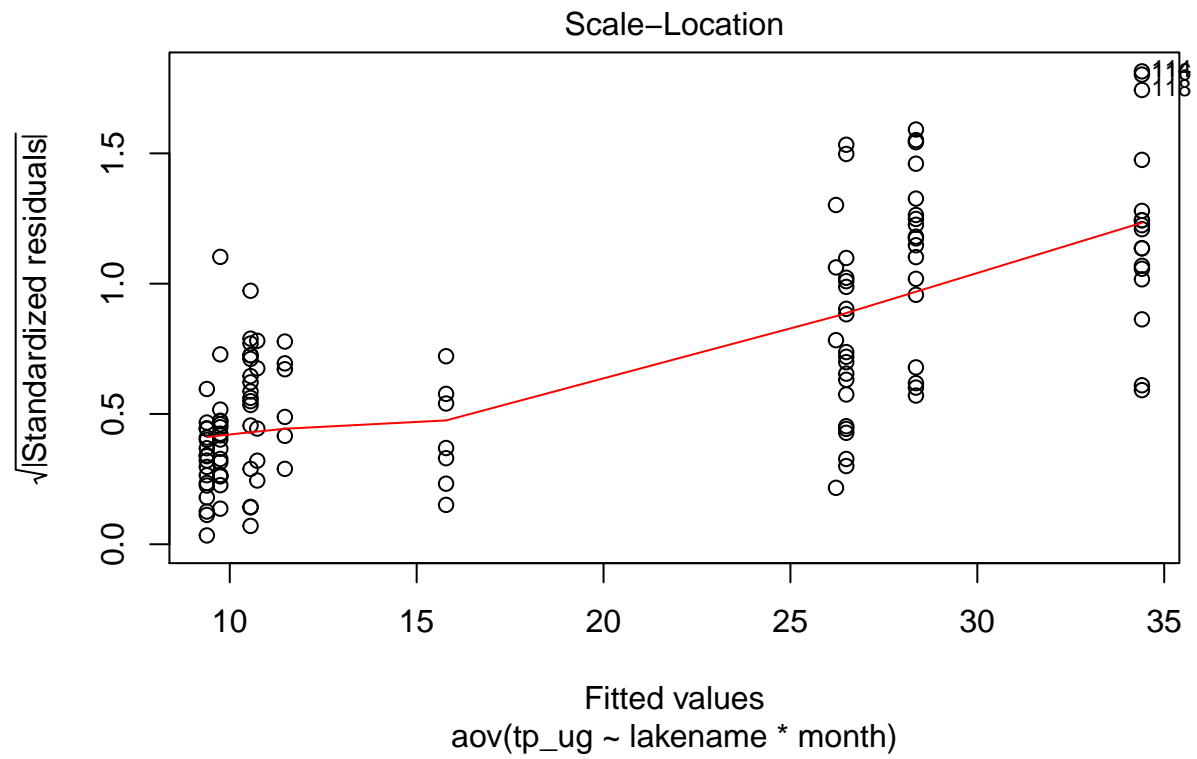
```
#6
PeterPaul.TP.anova.2way <- aov(data = PeterPaul.Wrangled, tp_ug ~ lakename * month)
summary(PeterPaul.TP.anova.2way)
```

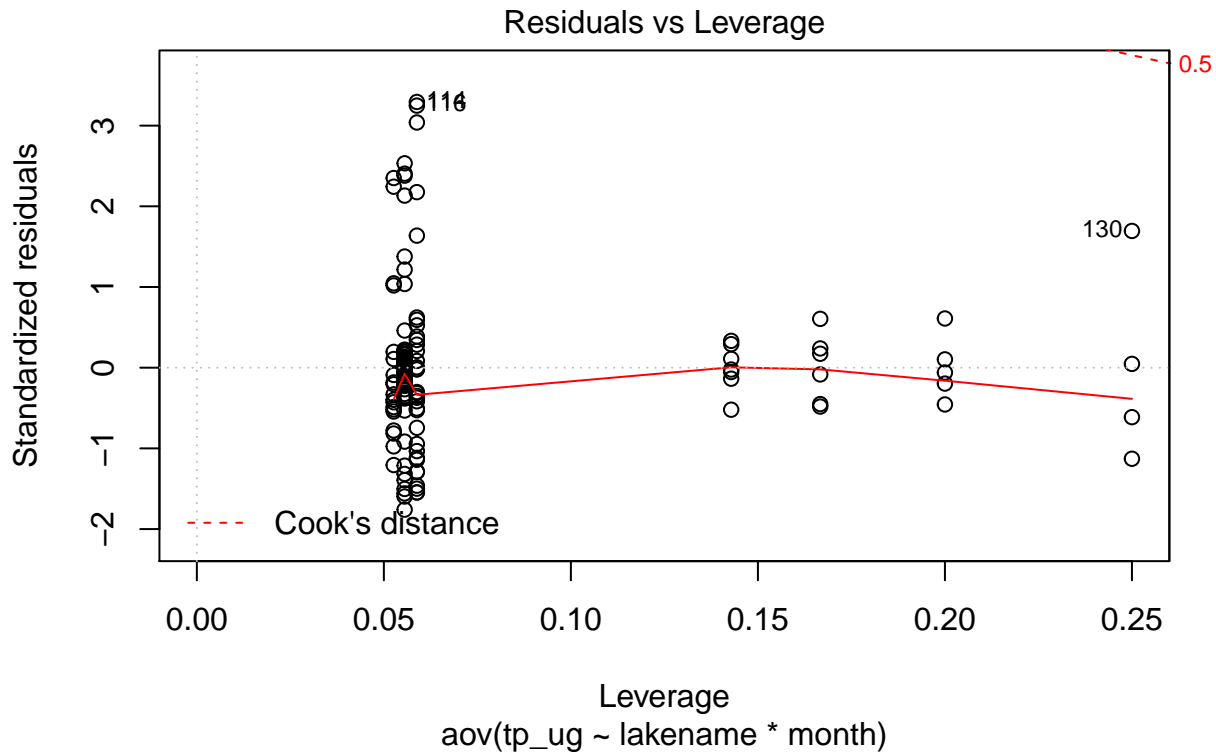
```
## Df Sum Sq Mean Sq F value Pr(>F)
## lakename 1 10228 10228 98.914 <2e-16 ***
## month 4 813 203 1.965 0.1043
## lakename:month 4 1014 254 2.452 0.0496 *
## Residuals 119 12305 103
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 1 observation deleted due to missingness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











```
TukeyHSD(PeterPaul.TP.anova.2way)
```

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

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

```
## $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"
```

Total phosphorous differs significantly across the two lakes but does not differ significantly seasonally (two-way ANOVA with interaction effects,  $F_{1,4,4}$ : 98.914,  $p < 0.0001$ ). Additionally, there is a significant interaction between lake and month on total phosphorous (two-way ANOVA with interaction effects,  $F_{1,4,4}$ : 2.452,  $p < 0.05$ ).

““

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.

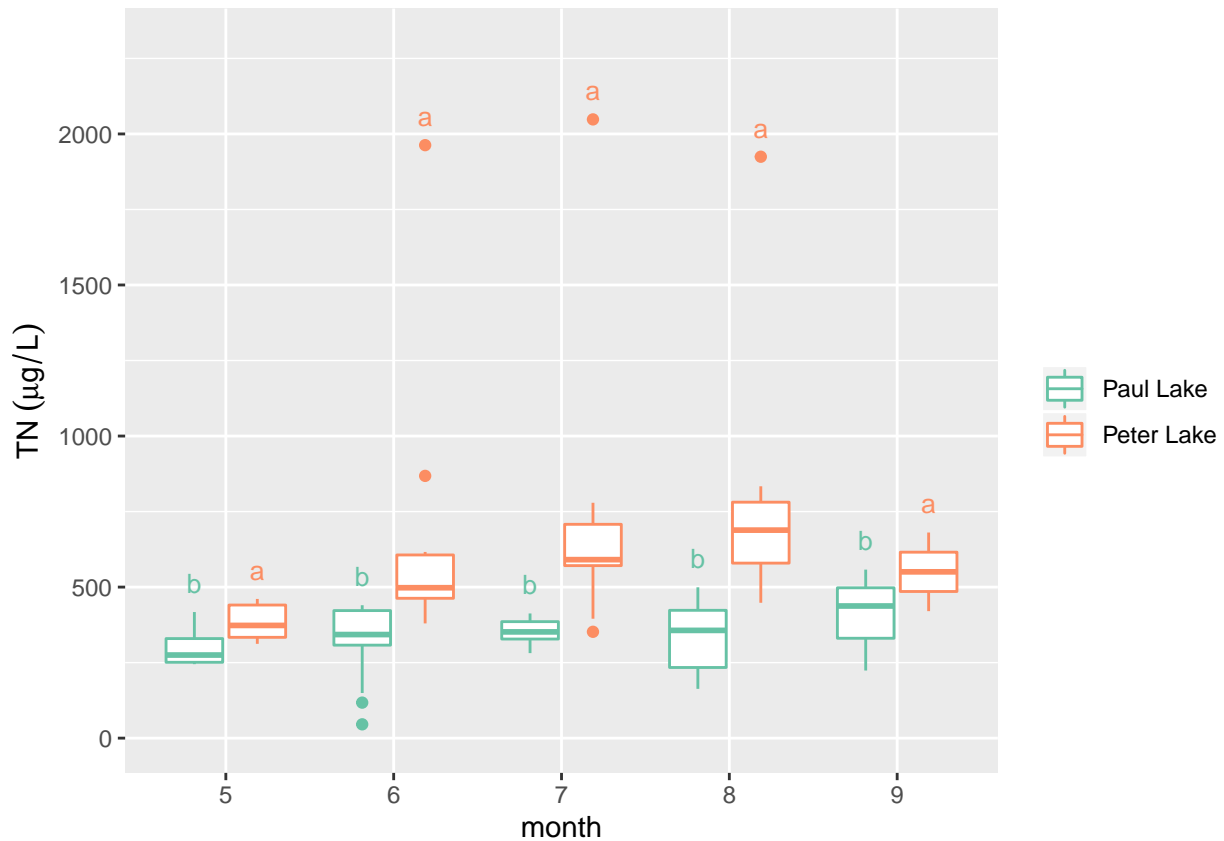
```

#7
# Plot 1
NitrogenPlot <- ggplot(PeterPaul.Wrangled, aes(y = tn_ug, x = month, color = lakename)) +
  geom_boxplot() +
  stat_summary(geom = "text", fun.y = max,
    show.legend = FALSE,
    vjust = -1, size = 3.5,
    position = position_dodge(0.75),
    label = c("a", "b", "a", "b", "a", "b", "a", "b", "a", "b")) +
  labs(x = "month", y = expression(TN ~ (mu*g / L)),
    color = "") +
  ylim(0,2300) +
  scale_color_brewer(palette = "Set2")
print(NitrogenPlot)

```

## Warning: Removed 23 rows containing non-finite values (stat\_boxplot).

## Warning: Removed 23 rows containing non-finite values (stat\_summary).



```

# Plot 2
PhosphorousPlot <- ggplot(PeterPaul.Wrangled,
  aes(y = tp_ug, x = month,
    color = lakename)) +
  geom_boxplot() +
  stat_summary(geom = "text", fun.y = max,
    show.legend = FALSE, vjust = -1,
    size = 3.5, position = position_dodge(0.75),

```

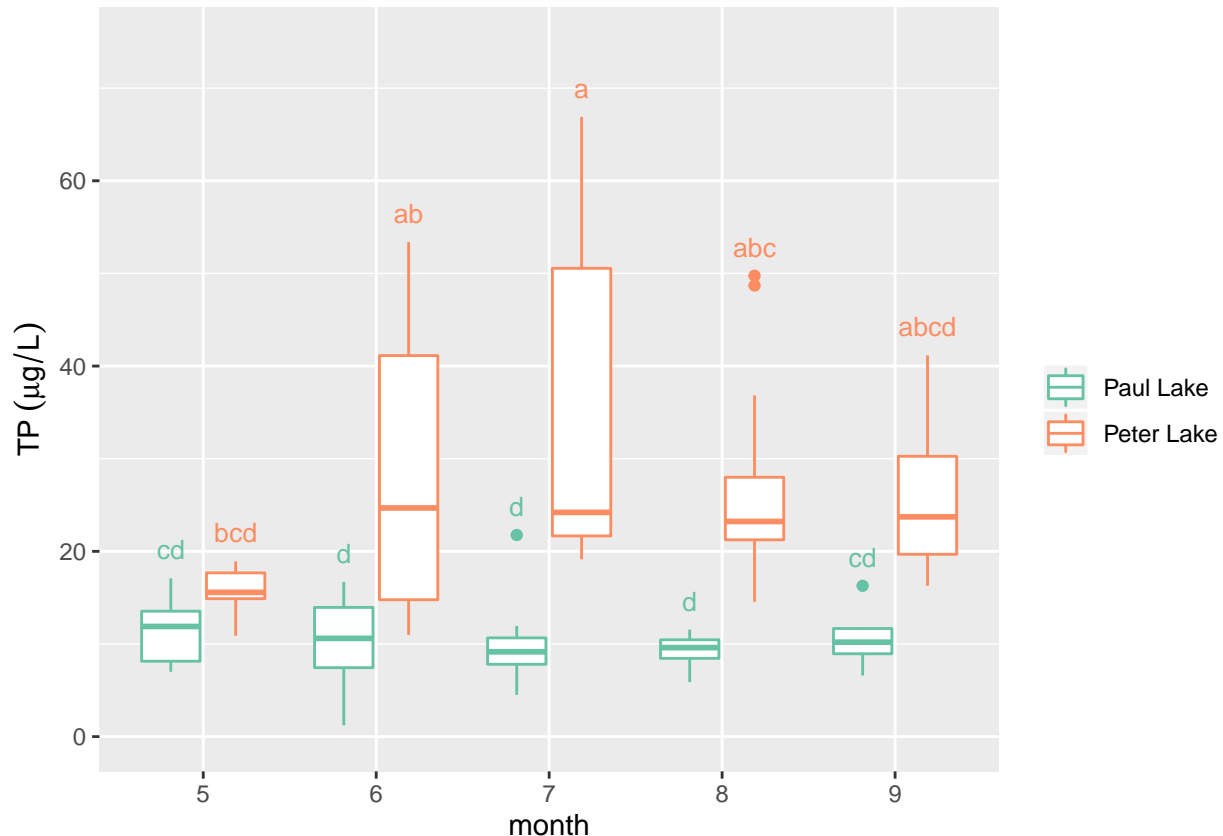
```

    label = c("bcd", "cd", "ab", "d", "a", "d", "abc", "d", "abcd", "cd")) +
  labs(x = "month", y = expression(TP ~ (mu*g / L)),
       color = "") +
  ylim(0,75) +
  scale_color_brewer(palette = "Set2")
print(PhosphorousPlot)

```

## Warning: Removed 1 rows containing non-finite values (stat\_boxplot).

## Warning: Removed 1 rows containing non-finite values (stat\_summary).



```

#8
library(cowplot)
TN.cowplot <- NitrogenPlot +
  theme(legend.position = "top") +
  theme(axis.title.x = element_blank()) +
  theme(axis.text.x = element_blank())

TP.cowplot <- PhosphorousPlot +
  theme(legend.position = "none") +
  scale_x_discrete(labels = c("May", "June", "July", "Aug", "Sept"))

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

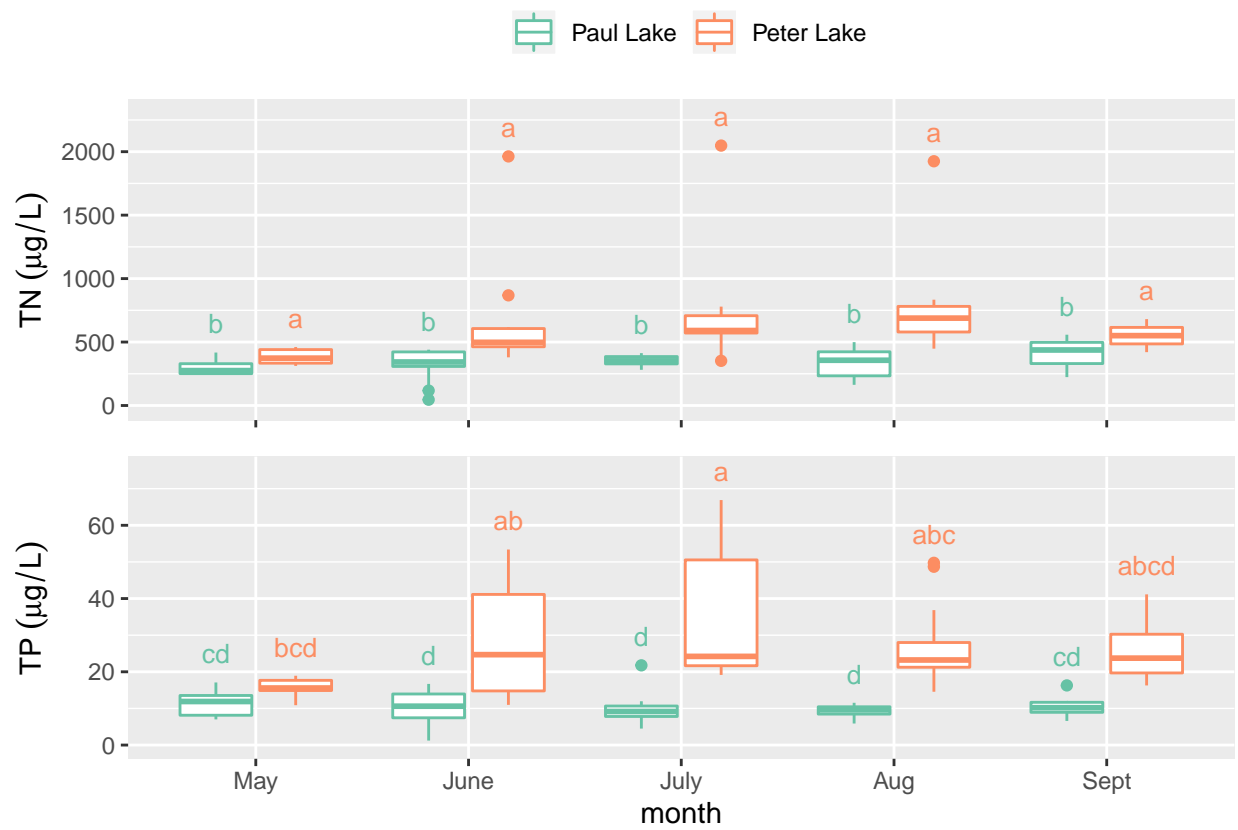
```

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



```
print
```

```
## function (x, ...)
## UseMethod("print")
## <bytecode: 0x7f88d0edae48>
## <environment: namespace:base>
```