Assignment 6: GLMs (Linear Regressions, ANOVA, & t-tests)

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OVERVIEW

This exercise accompanies the lessons in Environmental Data Analytics on generalized linear models.

Directions

1. Rename this file `<FirstLast>_A06_GLMs.Rmd` (replacing `<FirstLast>` with your first and last name).
2. Change "Student Name" on line 3 (above) with your name.
3. Work through the steps, **creating code and output** that fulfill each instruction.
4. Be sure to **answer the questions** in this assignment document.
5. When you have completed the assignment, **Knit** the text and code into a single PDF file.

Set up your session

1. Set up your session. Check your working directory. Load the tidyverse, agricolae and other needed packages. Import the *raw* NTL-LTER raw data file for chemistry/physics (`NTL-LTER_Lake_ChemistryPhysics_Raw.csv`). Set date columns to date objects.

2. Build a ggplot theme and set it as your default theme.

```
# 1
setwd("~/Documents/EDA-Fall2022")
getwd()
```

```
## [1] "/Users/laura/Documents/EDA-Fall2022"
```

```
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.2 --
## v ggplot2 3.3.6      v purrr   0.3.4
## v tibble  3.1.8      v dplyr   1.0.10
## v tidyr   1.2.1      v stringr 1.4.1
## v readr   2.1.2      v forcats 0.5.2
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(agricolae)
library(lubridate)
```

```
##
## Attaching package: 'lubridate'
##
## The following objects are masked from 'package:base':
##
##     date, intersect, setdiff, union
```

```
LTER_Chem <- read.csv("~/Documents/EDA-Fall2022/Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv",
    stringsAsFactors = TRUE)

LTER_Chem$sampledate <- as.Date(LTER_Chem$sampledate, format = "%m/%d/%y")

# 2
Laurastheme <- theme_classic(base_size = 12) + theme(axis.text = element_text(color = "black"),
    legend.position = "right")
theme_set(Laurastheme)
```

Simple regression

Our first research question is: Does mean lake temperature recorded during July change with depth across all lakes?

3. State the null and alternative hypotheses for this question: > Answer: H0: The mean lake temperatures recorded in July do not change with depth, the difference of means = 0. Ha: The mean lake temperatures recorded in July change with depth, the difference of means is != 0.

4. Wrangle your NTL-LTER dataset with a pipe function so that the records meet the following criteria:

- Only dates in July.
- Only the columns: `lakename`, `year4`, `daynum`, `depth`, `temperature_C`
- Only complete cases (i.e., remove NAs)

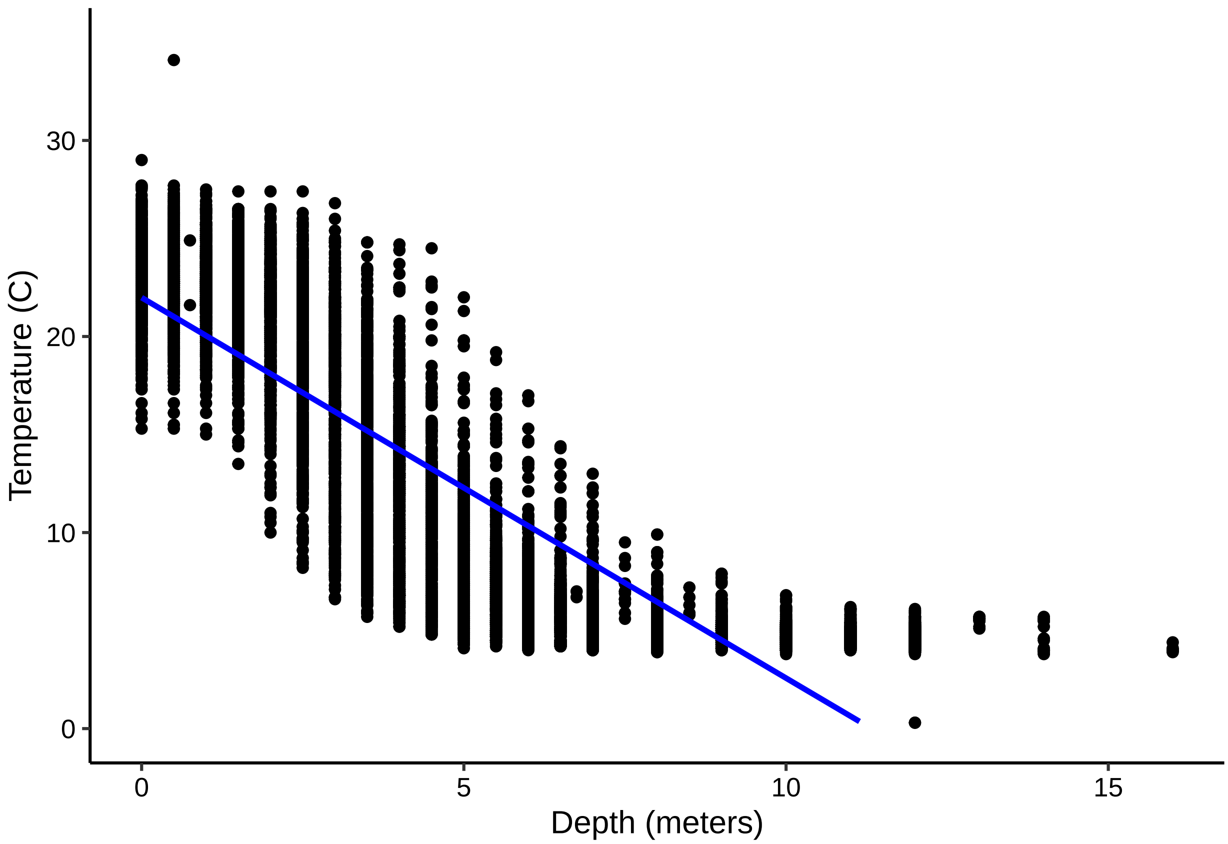
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```
# 4
LTER_July <- LTER_Chem %>%
    filter(daynum %in% c(183:213)) %>%
    select(lakename:daynum, depth:temperature_C) %>%
    drop_na()

# 5
plot_tempbydepth <- ggplot(LTER_July, aes(x = depth, y = temperature_C)) +
    geom_point() + geom_smooth(method = "lm", se = FALSE, color = "Blue") +
    ylim(0, 35) + ylab("Temperature (C)") + xlab("Depth (meters)")
print(plot_tempbydepth)
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 24 rows containing missing values (geom_smooth).
```



6. Interpret the figure. What does it suggest with regards to the response of temperature to depth? Do the distribution of points suggest about anything about the linearity of this trend?

   Answer: The distribution of points suggests that there is a negative relationship between depth and temperature. As depth increases, temperature values decrease. This pattern is observable in ocean and water bodies where temperature decreases as we dive deeper. Furthermore, this trend is shown by the negative linear regression plotted.

7. Perform a linear regression to test the relationship and display the results

```
# 7

July.regression <- lm(LTER_July$temperature_C ~ LTER_July$depth)
print(July.regression)
```

```
##
## Call:
## lm(formula = LTER_July$temperature_C ~ LTER_July$depth)
##
## Coefficients:
##     (Intercept)  LTER_July$depth
##          21.983           -1.941
```

```
summary(July.regression)
```

```
##
## Call:
## lm(formula = LTER_July$temperature_C ~ LTER_July$depth)
##
## Residuals:
```

```
##      Min       1Q   Median       3Q      Max
## -9.5606 -3.0380  0.0872  2.9872 13.4706
##
## Coefficients:
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)      21.98318    0.06840   321.4   <2e-16 ***
## LTER_July$depth -1.94086    0.01179  -164.7   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.852 on 9671 degrees of freedom
## Multiple R-squared:  0.7371, Adjusted R-squared:  0.7371
## F-statistic: 2.712e+04 on 1 and 9671 DF,  p-value: < 2.2e-16
```

8. Interpret your model results in words. Include how much of the variability in temperature is explained by changes in depth, the degrees of freedom on which this finding is based, and the statistical significance of the result. Also mention how much temperature is predicted to change for every 1m change in depth.

   Answer: The overall R-squared is about 73.71%, which means that 73.71% of the values for temperature can be explained due to the depth variable. This shows a strong relationship between depth and temperature. The degrees of freedom is 9671, which is the number of values that can vary in the dataset minus 1. The linear regression model estimates that for every 1m, temperature will decrease by 0.38 degrees Celcius.

Multiple regression

Let's tackle a similar question from a different approach. Here, we want to explore what might the best set of predictors for lake temperature in July across the monitoring period at the North Temperate Lakes LTER.

9. Run an AIC to determine what set of explanatory variables (year4, daynum, depth) is best suited to predict temperature.

10. Run a multiple regression on the recommended set of variables.

```
# 9
July.AIC <- lm(data = LTER_July, temperature_C ~ year4 + daynum +
    depth)
step(July.AIC)
```

```
## Start:  AIC=25998.22
## temperature_C ~ year4 + daynum + depth
##
##          Df Sum of Sq    RSS   AIC
## <none>                142056 25998
## - year4   1       201 142257 26010
## - daynum  1      1237 143293 26080
## - depth   1    402549 544605 38995
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = LTER_July)
##
## Coefficients:
## (Intercept)        year4       daynum        depth
##   -18.19700      0.01611      0.04024     -1.94133
```

```r
summary(July.AIC)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = LTER_July)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.6857 -3.0267  0.1055  2.9937 13.6038
##
## Coefficients:
##               Estimate Std. Error  t value Pr(>|t|)
## (Intercept) -18.196998   8.741236   -2.082 0.037392 *
## year4         0.016113   0.004353    3.701 0.000216 ***
## daynum        0.040237   0.004385    9.176  < 2e-16 ***
## depth        -1.941328   0.011728 -165.528  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.833 on 9669 degrees of freedom
## Multiple R-squared:  0.7398, Adjusted R-squared:  0.7397
## F-statistic:  9162 on 3 and 9669 DF,  p-value: < 2.2e-16
```

```r
# 10
AIC(July.regression, July.AIC)
```

```
##                 df      AIC
## July.regression  3 53544.72
## July.AIC         5 53451.00
```

11. What is the final set of explanatory variables that the AIC method suggests we use to predict temperature in our multiple regression? How much of the observed variance does this model explain? Is this an improvement over the model using only depth as the explanatory variable?

    Answer: The overall AIC decreases when including more variables. The first model that only had depth had an AIC of 53544.72. By including additional variables such as year4 and daynum, the overall AIC drops down to 53451. This is a reduction of 93.72, and lower AIC values are indicative of models that better explain the variability of the dependent varaible due to the indepenedent variables. In this case, the temperature is better explained by a model that has more varaibles: depth, daynum, and year4.

Analysis of Variance

12. Now we want to see whether the different lakes have, on average, different temperatures in the month of July. Run an ANOVA test to complete this analysis. (No need to test assumptions of normality or similar variances.) Create two sets of models: one expressed as an ANOVA models and another expressed as a linear model (as done in our lessons).

```r
# 12

Lakes.anova <- aov(data = LTER_July, temperature_C ~ lakename)
summary(Lakes.anova)
```

```
##               Df Sum Sq Mean Sq F value Pr(>F)
## lakename       8  22188  2773.5   51.18 <2e-16 ***
```

```
## Residuals   9664 523706    54.2
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# Format ANOVA as lm
Lakes.anova2 <- lm(data = LTER_July, temperature_C ~ lakename)
summary(Lakes.anova2)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = LTER_July)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -10.773  -6.612  -2.673   7.657  23.813
##
## Coefficients:
##                          Estimate Std. Error t value Pr(>|t|)
## (Intercept)               17.6664     0.6507  27.151  < 2e-16 ***
## lakenameCrampton Lake     -2.1851     0.7565  -2.889 0.003879 **
## lakenameEast Long Lake    -7.3795     0.6915 -10.671  < 2e-16 ***
## lakenameHummingbird Lake  -6.6828     0.9571  -6.982 3.09e-12 ***
## lakenamePaul Lake         -3.8234     0.6666  -5.735 1.00e-08 ***
## lakenamePeter Lake        -4.3162     0.6652  -6.489 9.08e-11 ***
## lakenameTuesday Lake      -6.5937     0.6777  -9.730  < 2e-16 ***
## lakenameWard Lake         -3.2078     0.9437  -3.399 0.000679 ***
## lakenameWest Long Lake    -6.0542     0.6893  -8.783  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.361 on 9664 degrees of freedom
## Multiple R-squared:  0.04064,    Adjusted R-squared:  0.03985
## F-statistic: 51.18 on 8 and 9664 DF,  p-value: < 2.2e-16
```

```
Lakes.groups <- HSD.test(Lakes.anova, "lakename", group = TRUE)
Lakes.groups
```

```
## $statistics
##    MSerror   Df     Mean       CV
##   54.19142 9664 12.74849 57.74396
##
## $parameters
##    test   name.t ntr StudentizedRange alpha
##   Tukey lakename   9          4.38751  0.05
##
## $means
##                    temperature_C      std    r Min  Max    Q25   Q50    Q75
## Central Long Lake       17.66641 4.196292  128 8.9 26.8 14.400 18.40 21.000
## Crampton Lake           15.48132 7.347999  364 5.0 27.5  7.500 17.05 22.400
## East Long Lake          10.28694 6.765204  988 4.2 34.1  5.000  6.50 16.025
## Hummingbird Lake        10.98364 6.779212  110 4.0 29.0  5.225  7.80 16.600
## Paul Lake               13.84304 7.314316 2575 4.7 27.7  6.500 12.40 21.400
## Peter Lake              13.35016 7.670045 2835 4.0 26.9  5.600 11.50 21.500
## Tuesday Lake            11.07267 7.715792 1511 0.3 27.7  4.400  6.80 19.400
## Ward Lake               14.45862 7.409079  116 5.7 27.6  7.200 12.55 23.200
```

```
## West Long Lake         11.61224 6.989346 1046 4.0 25.7  5.400  8.10 18.800
##
## $comparison
## NULL
##
## $groups
##                     temperature_C groups
## Central Long Lake      17.66641      a
## Crampton Lake          15.48132     ab
## Ward Lake              14.45862     bc
## Paul Lake              13.84304      c
## Peter Lake             13.35016      c
## West Long Lake         11.61224      d
## Tuesday Lake           11.07267     de
## Hummingbird Lake       10.98364     de
## East Long Lake         10.28694      e
##
## attr(,"class")
## [1] "group"
```

13. Is there a significant difference in mean temperature among the lakes? Report your findings.

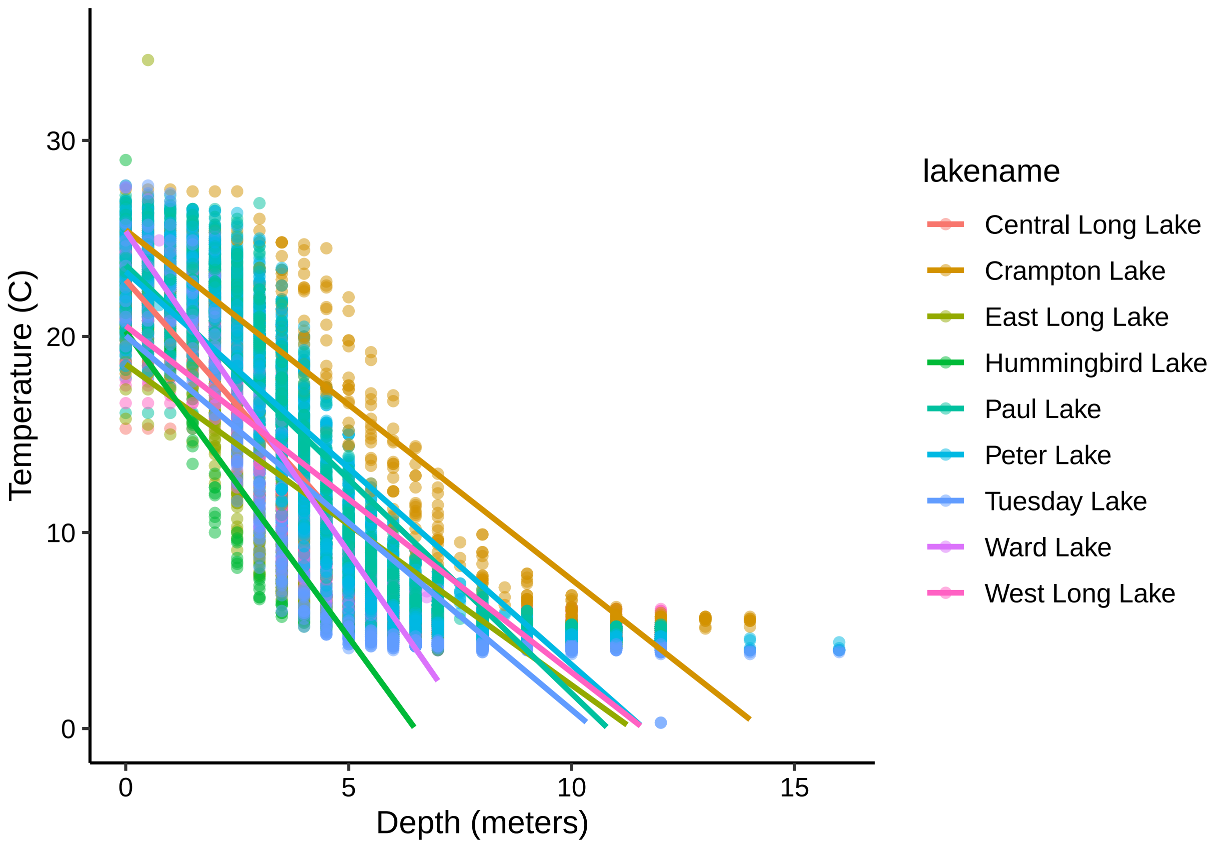
    Answer: There is a significant difference in mean temperatures among the lakes. This is especially true when analyzing the groups. Based on the mean temperatures, there are 5 groups that were divided up and share similar means.

14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```
# 14.
plot_lakes <- ggplot(LTER_July, aes(x = depth, y = temperature_C)) +
    geom_point(aes(color = lakename), alpha = 0.5) + geom_smooth(method = "lm",
    se = FALSE, aes(color = lakename)) + ylim(0, 35) + ylab("Temperature (C)") +
    xlab("Depth (meters)")
print(plot_lakes)
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 72 rows containing missing values (geom_smooth).
```



15. Use the Tukey's HSD test to determine which lakes have different means.

```
# 15
TukeyHSD(Lakes.anova)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = LTER_July)
##
## $lakename
##                                            diff        lwr        upr     p adj
## Crampton Lake-Central Long Lake    -2.18508757 -4.5319912  0.1618160 0.0915179
## East Long Lake-Central Long Lake   -7.37946293 -9.5249061 -5.2340198 0.0000000
## Hummingbird Lake-Central Long Lake -6.68276989 -9.6520798 -3.7134600 0.0000000
## Paul Lake-Central Long Lake        -3.82336936 -5.8915944 -1.7551443 0.0000004
## Peter Lake-Central Long Lake       -4.31624752 -6.3799766 -2.2525184 0.0000000
## Tuesday Lake-Central Long Lake     -6.59373914 -8.6961647 -4.4913136 0.0000000
## Ward Lake-Central Long Lake        -3.20778556 -6.1355040 -0.2800671 0.0195251
## West Long Lake-Central Long Lake   -6.05416916 -8.1927792 -3.9155591 0.0000000
## East Long Lake-Crampton Lake       -5.19437536 -6.5946962 -3.7940545 0.0000000
## Hummingbird Lake-Crampton Lake     -4.49768232 -6.9825914 -2.0127732 0.0000007
## Paul Lake-Crampton Lake            -1.63828179 -2.9171590 -0.3594045 0.0023129
## Peter Lake-Crampton Lake           -2.13115995 -3.4027534 -0.8595665 0.0000072
## Tuesday Lake-Crampton Lake         -4.40865157 -5.7421303 -3.0751729 0.0000000
## Ward Lake-Crampton Lake            -1.02269799 -3.4577560  1.4123600 0.9307880
## West Long Lake-Crampton Lake       -3.86908159 -5.2589107 -2.4792525 0.0000000
## Hummingbird Lake-East Long Lake     0.69669304 -1.5988991  2.9922852 0.9905616
```

```
## Paul Lake-East Long Lake           3.55609357  2.7014024  4.4107847 0.0000000
## Peter Lake-East Long Lake          3.06321541  2.2194620  3.9069688 0.0000000
## Tuesday Lake-East Long Lake        0.78572379 -0.1486934  1.7201409 0.1828556
## Ward Lake-East Long Lake           4.17167737  1.9301428  6.4132120 0.0000003
## West Long Lake-East Long Lake      1.32529377  0.3120836  2.3385039 0.0016418
## Paul Lake-Hummingbird Lake         2.85940053  0.6358062  5.0829949 0.0021745
## Peter Lake-Hummingbird Lake        2.36652237  0.1471092  4.5859355 0.0263810
## Tuesday Lake-Hummingbird Lake      0.08903074 -2.1664094  2.3444709 1.0000000
## Ward Lake-Hummingbird Lake         3.47498433  0.4355186  6.5144501 0.0117238
## West Long Lake-Hummingbird Lake    0.62860073 -1.6606065  2.9178079 0.9952002
## Peter Lake-Paul Lake              -0.49287816 -1.1146082  0.1288519 0.2521516
## Tuesday Lake-Paul Lake            -2.77036979 -3.5104805 -2.0302590 0.0000000
## Ward Lake-Paul Lake                0.61558380 -1.5521583  2.7833259 0.9939613
## West Long Lake-Paul Lake          -2.23079980 -3.0681906 -1.3934090 0.0000000
## Tuesday Lake-Peter Lake           -2.27749162 -3.0049438 -1.5500394 0.0000000
## Ward Lake-Peter Lake               1.10846196 -1.0549910  3.2719149 0.8108720
## West Long Lake-Peter Lake         -1.73792164 -2.5641457 -0.9116976 0.0000000
## Ward Lake-Tuesday Lake             3.38595358  1.1855572  5.5863500 0.0000641
## West Long Lake-Tuesday Lake        0.53956999 -0.3790495  1.4581895 0.6673292
## West Long Lake-Ward Lake          -2.84638360 -5.0813788 -0.6113884 0.0025399
```

16.From the findings above, which lakes have the same mean temperature, statistically speaking, as Peter Lake? Does any lake have a mean temperature that is statistically distinct from all the other lakes?

> Answer: Peter Lake has the same mean temperature as Ward Lake and Paul Lake. This is shown by their grouping in category "c" and by Tukey's test that shows a difference that is less than 0.5 for Paul Lake and 1.1 for Ward Lake when compared. There is not a lake that has a statistically distinct mean from all other lakes. This can be seen in the lake groupings which show that all lakes are grouped with at least one other lake.

17. If we were just looking at Peter Lake and Paul Lake. What's another test we might explore to see whether they have distinct mean temperatures?

    > Answer: Antoher test we can perfrom is the Bartlett's test, which tests if the variances in each of the groups (in this case Peter and Paul lake) are the same.

18. Wrangle the July data to include only records for Crampton Lake and Ward Lake. Run the two-sample T-test on these data to determine whether their July temperature are same or different. What does the test say? Are the mean temperatures for the lakes equal? Does that match you answer for part 16?

```r
LTER.subset <- filter(LTER_July, lakename %in% c("Crampton Lake",
    "Ward Lake"))


July.twosample <- t.test(LTER.subset$temperature_C ~ LTER.subset$lakename)
July.twosample
```

```
##
##  Welch Two Sample t-test
##
## data:  LTER.subset$temperature_C by LTER.subset$lakename
## t = 1.2972, df = 192.4, p-value = 0.1961
## alternative hypothesis: true difference in means between group Crampton Lake and group Ward Lake is n
## 95 percent confidence interval:
##  -0.5323014  2.5776973
## sample estimates:
## mean in group Crampton Lake     mean in group Ward Lake
```

```
##                    15.48132                     14.45862
```

Answer: Based on the T-test, Crampton Lake has a mean temperature of 15.48 and Ward Lake has a mean temperature of 14.45. These resulst are the same reported values as the aov. The mean temperatures of both lakes are statistically the same because they both are grouped under “b” and have a difference of -1.02269799.