Assignment 6: GLMs (Linear Regressios, 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
getwd()
```

```
## [1] "/Users/hbliska/Desktop/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
```

```
# importing raw data with read.csv
NTL.LTER.Lake.Chem.Phys <- read.csv("./Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv",
    stringsAsFactors = TRUE)

# using as.date to format my dates
NTL.LTER.Lake.Chem.Phys$sampledate <- as.Date(NTL.LTER.Lake.Chem.Phys$sampledate,
    format = "%m/%d/%y")

# 2 building my theme
mytheme <- theme_classic(base_size = 11) + theme(axis.text = element_text(color = "black"),
    legend.position = "right")
theme_set(mytheme)  #setting my theme
```

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 slope of the linear regression between depth and mean lake temperature across all lakes is equal to zero. Thus, depth has no effect on mean lake temperature across all lakes. Ha: The slope of the linear regression between depth and mean lake temperature is not equal to zero across all lakes. Thus, depth has an effect on mean lake temperature across all lakes.

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.

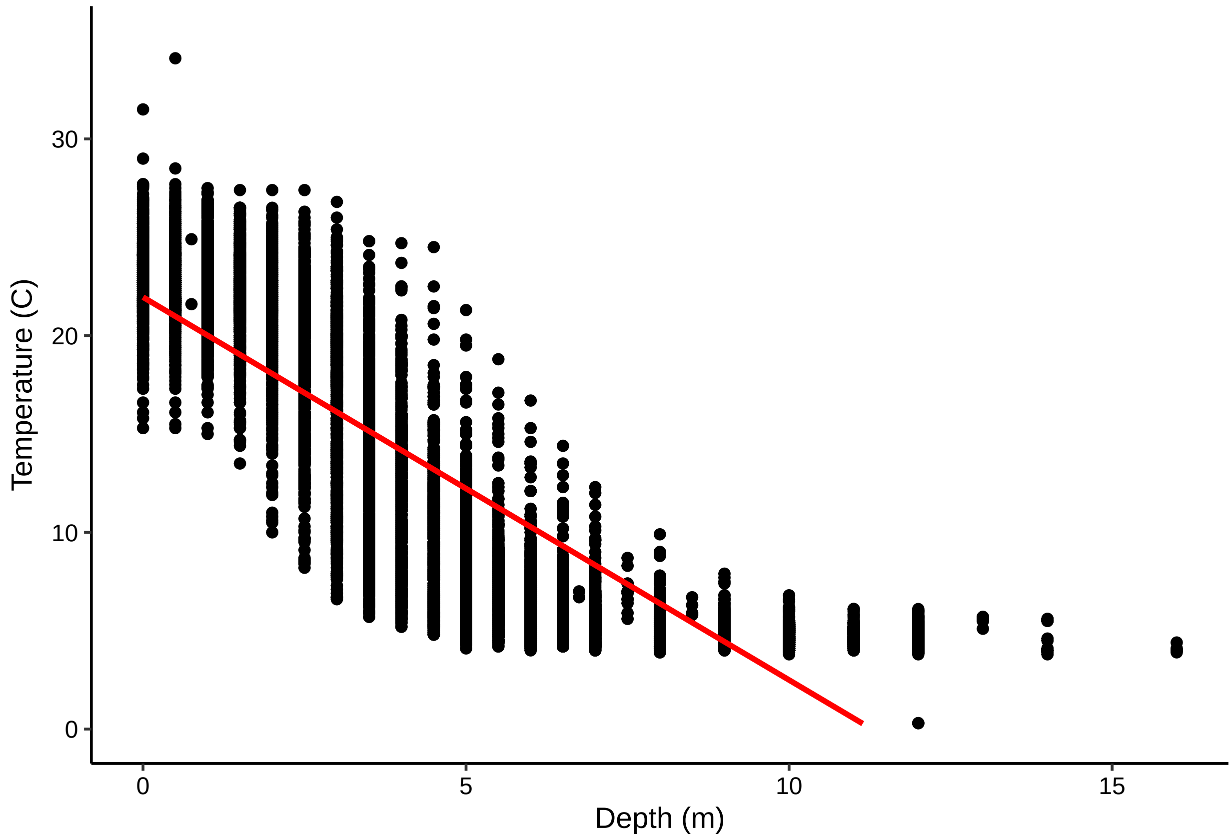
```
#4
Processed.NTL.LTER <-
  NTL.LTER.Lake.Chem.Phys %>%
  mutate(month = month(sampledate)) %>% #creating a month column
  filter(month=="7") %>% #including only July
  select(lakename, year4, daynum, depth, temperature_C) %>%
  #selecting only these columns
  drop_na(lakename, year4, daynum, depth, temperature_C) #using
  #drop_na to remove NAs in my columns

#5
```

```
Plot.Depth.Temp <- ggplot(
  Processed.NTL.LTER, aes(x=depth, y=temperature_C)) +
  geom_point() + #creating a scatter plot
  ylab(expression("Temperature (C)")) + #setting y axis label
  xlab(expression("Depth (m)")) + #setting x axis label
  ylim(0,35) + #setting limit for y axis
  geom_smooth(method=lm, se = FALSE, color="red") #adding linear model
print(Plot.Depth.Temp)
```

```
## `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: This figure suggests that temperature decreases in response to increased depths. This is an intuitive result, as the load of light energy (which heats water) is high at shallow depths but decreases as light travels through water to deeper depths. The distribution of points suggests that the relationship between depth and temperature is a decreasing (negative) linear trend; however, there is some variation in the distribution of the temperature data, particularly in the shallower depths, and there are also fewer measurements of temperature recorded at deeper depths. The variation in the distribution of the temperature data suggests that the strength of the linear relationship may not be as strong (i.e., depth may not explain all of the variation in temperature) which we can test through performing a linear regression.

#less recordings deeper depths, more variability

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

```
# 7
temp.depth.regression <- lm(data = Processed.NTL.LTER,
    temperature_C ~ depth)
# linear regression between temperature and
# depth
summary(temp.depth.regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = Processed.NTL.LTER)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.5173 -3.0192  0.0633  2.9365 13.5834
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 21.95597    0.06792   323.3   <2e-16 ***
## depth       -1.94621    0.01174  -165.8   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.835 on 9726 degrees of freedom
## Multiple R-squared:  0.7387, Adjusted R-squared:  0.7387
## F-statistic: 2.75e+04 on 1 and 9726 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: 73.87% of the variability in temperature is explained by changes in depth, as indicated by the R^2 of my model (0.7387). The degrees of freedom for my model are 9726, which is the number of observations minus two (for two variables). I can reject the null hypothesis and establish that relationship between depth and temperature is negative and statistically significant because the p value of my model is less than 0.05. This indicates that deeper depths have significantly lower temperatures than shallower depths. Temperature is predicted to decrease -1.94621 degrees celcius for every 1m deeper change in depth.

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
AIC.Processed.NTL.LTER <- lm(data = Processed.NTL.LTER,
    temperature_C ~ depth + daynum + year4)  #considering all explanatory variables in AIC
step(AIC.Processed.NTL.LTER)
```

```
## Start:  AIC=26065.53
## temperature_C ~ depth + daynum + year4
##
##          Df Sum of Sq    RSS   AIC
## <none>                141687 26066
## - year4   1       101 141788 26070
## - daynum  1      1237 142924 26148
## - depth   1    404475 546161 39189
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + daynum + year4, data = Processed.NTL.LTER)
##
## Coefficients:
## (Intercept)        depth       daynum        year4
##    -8.57556     -1.94644      0.03978      0.01134
```

```
# 10
temp.mult.regression <- lm(data = Processed.NTL.LTER,
    temperature_C ~ depth + daynum + year4)
# running a multiple regression with
# variables recommended by AIC
summary(temp.mult.regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + daynum + year4, data = Processed.NTL.LTER)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.6536 -3.0000  0.0902  2.9658 13.6123
##
## Coefficients:
##              Estimate Std. Error  t value Pr(>|t|)
## (Intercept) -8.575564   8.630715   -0.994  0.32044
## depth       -1.946437   0.011683 -166.611  < 2e-16 ***
## daynum       0.039780   0.004317    9.215  < 2e-16 ***
## year4        0.011345   0.004299    2.639  0.00833 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.817 on 9724 degrees of freedom
## Multiple R-squared:  0.7412, Adjusted R-squared:  0.7411
## F-statistic:  9283 on 3 and 9724 DF,  p-value: < 2.2e-16
```

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 final set of explanatory variables are depth, daynum, and year4. This multiple regression model explains 74.12% of the variance in temperature, as indicated by the R^2 of 0.7412). This is a slight improvement in variance over using only depth, which explained 73.87% of the variance in temperature.

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).

```
# 12 running anova between temperature of
# lakes and lake name with aov
Lake.temp.anova <- aov(data = Processed.NTL.LTER,
    temperature_C ~ lakename)
summary(Lake.temp.anova)
```

```
##                Df Sum Sq Mean Sq F value Pr(>F)
## lakename        8  21642  2705.2      50 <2e-16 ***
## Residuals    9719 525813    54.1
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# running anova between temperature of lakes
# and lake name with lm
Lake.temp.anova2 <- lm(data = Processed.NTL.LTER,
    temperature_C ~ lakename)
summary(Lake.temp.anova2)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = Processed.NTL.LTER)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -10.769  -6.614  -2.679   7.684  23.832
##
## Coefficients:
##                          Estimate Std. Error t value Pr(>|t|)
## (Intercept)               17.6664     0.6501  27.174  < 2e-16 ***
## lakenameCrampton Lake     -2.3145     0.7699  -3.006 0.002653 **
## lakenameEast Long Lake    -7.3987     0.6918 -10.695  < 2e-16 ***
## lakenameHummingbird Lake  -6.8931     0.9429  -7.311 2.87e-13 ***
## lakenamePaul Lake         -3.8522     0.6656  -5.788 7.36e-09 ***
```

```
## lakenamePeter Lake        -4.3501     0.6645  -6.547 6.17e-11 ***
## lakenameTuesday Lake      -6.5972     0.6769  -9.746  < 2e-16 ***
## lakenameWard Lake         -3.2078     0.9429  -3.402 0.000672 ***
## lakenameWest Long Lake    -6.0878     0.6895  -8.829  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.355 on 9719 degrees of freedom
## Multiple R-squared:  0.03953,    Adjusted R-squared:  0.03874
## F-statistic:    50 on 8 and 9719 DF,  p-value: < 2.2e-16
```

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

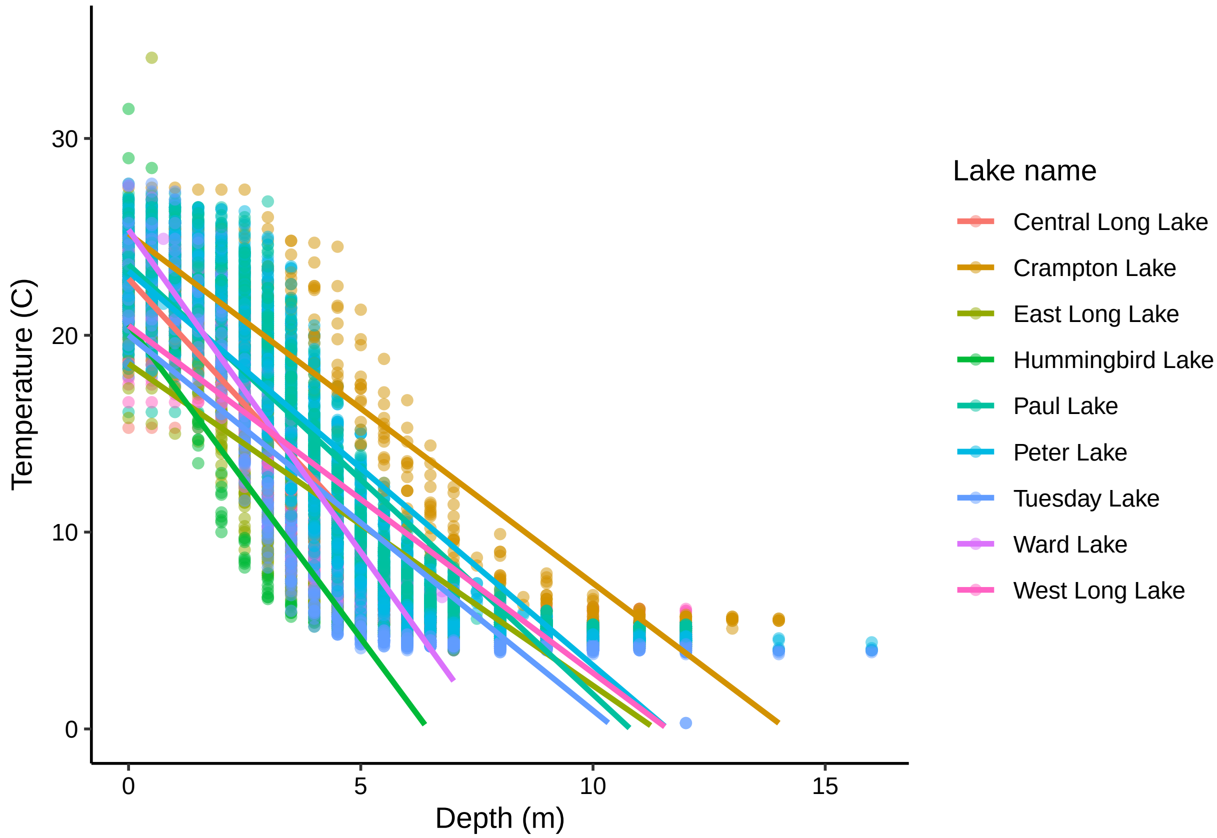
    Answer: Yes, there is a significant difference in mean temperature among the lakes (p<0.001).

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.

```r
#14.
Plot.Temp.Lakes <-
  ggplot(Processed.NTL.LTER, aes(x=depth, y=temperature_C, color=lakename)) +
  geom_point(alpha=0.5) + #adding lake name
  #aesthetics and transparency to scatter plot
  geom_smooth(method=lm, se = FALSE) + #adding linear
  #model to the graph in red
  xlab(expression("Depth (m)")) + #setting x axis label
  ylab(expression("Temperature (C)")) + #setting y axis label
  ylim(0,35) + #setting limit for y axis
  labs(color="Lake name") #setting legend label
print(Plot.Temp.Lakes)
```

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

## Warning: Removed 73 rows containing missing values (geom_smooth).
```



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

```
# 15
TukeyHSD(Lake.temp.anova)  #creating Tukey HSD test
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = Processed.NTL.LTER)
##
## $lakename
##                                      diff        lwr        upr     p adj
## Crampton Lake-Central Long Lake    -2.3145195 -4.7031913  0.0741524 0.0661566
## East Long Lake-Central Long Lake   -7.3987410 -9.5449411 -5.2525408 0.0000000
## Hummingbird Lake-Central Long Lake -6.8931304 -9.8184178 -3.9678430 0.0000000
## Paul Lake-Central Long Lake        -3.8521506 -5.9170942 -1.7872070 0.0000003
## Peter Lake-Central Long Lake       -4.3501458 -6.4115874 -2.2887042 0.0000000
## Tuesday Lake-Central Long Lake     -6.5971805 -8.6971605 -4.4972005 0.0000000
## Ward Lake-Central Long Lake        -3.2077856 -6.1330730 -0.2824982 0.0193405
## West Long Lake-Central Long Lake   -6.0877513 -8.2268550 -3.9486475 0.0000000
## East Long Lake-Crampton Lake       -5.0842215 -6.5591700 -3.6092730 0.0000000
## Hummingbird Lake-Crampton Lake     -4.5786109 -7.0538088 -2.1034131 0.0000004
## Paul Lake-Crampton Lake            -1.5376312 -2.8916215 -0.1836408 0.0127491
## Peter Lake-Crampton Lake           -2.0356263 -3.3842699 -0.6869828 0.0000999
## Tuesday Lake-Crampton Lake         -4.2826611 -5.6895065 -2.8758157 0.0000000
```

```
## Ward Lake-Crampton Lake           -0.8932661 -3.3684639  1.5819317 0.9714459
## West Long Lake-Crampton Lake      -3.7732318 -5.2378351 -2.3086285 0.0000000
## Hummingbird Lake-East Long Lake    0.5056106 -1.7364925  2.7477137 0.9988050
## Paul Lake-East Long Lake           3.5465903  2.6900206  4.4031601 0.0000000
## Peter Lake-East Long Lake          3.0485952  2.2005025  3.8966879 0.0000000
## Tuesday Lake-East Long Lake        0.8015604 -0.1363286  1.7394495 0.1657485
## Ward Lake-East Long Lake           4.1909554  1.9488523  6.4330585 0.0000002
## West Long Lake-East Long Lake      1.3109897  0.2885003  2.3334791 0.0022805
## Paul Lake-Hummingbird Lake         3.0409798  0.8765299  5.2054296 0.0004495
## Peter Lake-Hummingbird Lake        2.5429846  0.3818755  4.7040937 0.0080666
## Tuesday Lake-Hummingbird Lake      0.2959499 -1.9019508  2.4938505 0.9999752
## Ward Lake-Hummingbird Lake         3.6853448  0.6889874  6.6817022 0.0043297
## West Long Lake-Hummingbird Lake    0.8053791 -1.4299320  3.0406903 0.9717297
## Peter Lake-Paul Lake              -0.4979952 -1.1120620  0.1160717 0.2241586
## Tuesday Lake-Paul Lake            -2.7450299 -3.4781416 -2.0119182 0.0000000
## Ward Lake-Paul Lake                0.6443651 -1.5200848  2.8088149 0.9916978
## West Long Lake-Paul Lake          -2.2356007 -3.0742314 -1.3969699 0.0000000
## Tuesday Lake-Peter Lake           -2.2470347 -2.9702236 -1.5238458 0.0000000
## Ward Lake-Peter Lake               1.1423602 -1.0187489  3.3034693 0.7827037
## West Long Lake-Peter Lake         -1.7376055 -2.5675759 -0.9076350 0.0000000
## Ward Lake-Tuesday Lake             3.3893950  1.1914943  5.5872956 0.0000609
## West Long Lake-Tuesday Lake        0.5094292 -0.4121051  1.4309636 0.7374387
## West Long Lake-Ward Lake          -2.8799657 -5.1152769 -0.6446546 0.0021080
```

```r
Lake.temp.anova.groups <- HSD.test(Lake.temp.anova,
    "lakename", group = TRUE)
# evaluating the groups from Tukey HSD test
# results
Lake.temp.anova.groups  #printing the groups
```

```
## $statistics
##   MSerror   Df     Mean       CV
##   54.1016 9719 12.72087 57.82135
##
## $parameters
##    test   name.t ntr StudentizedRange alpha
##   Tukey lakename   9         4.387504  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           15.35189 7.244773  318 5.0 27.5  7.525 16.90 22.300
## East Long Lake          10.26767 6.766804  968 4.2 34.1  4.975  6.50 15.925
## Hummingbird Lake        10.77328 7.017845  116 4.0 31.5  5.200  7.00 15.625
## Paul Lake               13.81426 7.296928 2660 4.7 27.7  6.500 12.40 21.400
## Peter Lake              13.31626 7.669758 2872 4.0 27.0  5.600 11.40 21.500
## Tuesday Lake            11.06923 7.698687 1524 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          11.57865 6.980789 1026 4.0 25.7  5.400  8.00 18.800
##
## $comparison
## NULL
##
## $groups
```

```
##                     temperature_C groups
## Central Long Lake      17.66641      a
## Crampton Lake          15.35189     ab
## Ward Lake              14.45862     bc
## Paul Lake              13.81426      c
## Peter Lake             13.31626      c
## West Long Lake         11.57865      d
## Tuesday Lake           11.06923     de
## Hummingbird Lake       10.77328     de
## East Long Lake         10.26767      e
##
## attr(,"class")
## [1] "group"
```

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: Ward Lake, Paul Lake, and Peter lake have the same mean temperature; their mean temperatures are not statistically different. No lake has a mean temperature that is statistically distinct from all other lakes; we see in the results of the test that there is at least two lakes in each group (for a, n=2; for b, n=2; for c, n=3; for d, n=3; for e, n=3).

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: We could use a two sample t-test to explore if Peter and Paul Lake have distinct mean temperatures. The null hypothesis of this test would be that there is no difference between the mean of the lakes' temperatures. The alternative hypothesis would be that there is a significant difference between the temperatures of Peter and Paul Lake.

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?

```
Crampton.Ward.Lakes <- Processed.NTL.LTER %>%
    filter(lakename == "Crampton Lake" | lakename ==
        "Ward Lake")
# filtering by Crampton Lake and Ward Lake

Crampton.Ward.Lakes.Ttest <- t.test(data = Crampton.Ward.Lakes,
    temperature_C ~ lakename)  #running t-test
Crampton.Ward.Lakes.Ttest  #printing results of t-test
```

```
##
##  Welch Two Sample t-test
##
## data:  temperature_C by lakename
## t = 1.1181, df = 200.37, p-value = 0.2649
## alternative hypothesis: true difference in means between group Crampton Lake and group Ward Lake is r
## 95 percent confidence interval:
##  -0.6821129  2.4686451
```

```
## sample estimates:
## mean in group Crampton Lake     mean in group Ward Lake
##                     15.35189                    14.45862
```

Answer: There is not a significant difference in lake temperatures between Crampton and Ward Lakes (p=0.2649). Therefore, we accept the null hypothesis and can infer that the mean lake temperatures of Crampton and Ward lakes in July are statiscally the same. This does match my answer for part 16, as Crampton and Ward Lake were a part of the same group (b) produced by the Tukey HSD test and comparison of means.