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 Loading necessary packages
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.2 --
## v ggplot2 3.4.0      v purrr   1.0.0
## v tibble  3.1.8      v dplyr   1.0.10
## v tidyr   1.2.1      v stringr 1.5.0
## v readr   2.1.3      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
```

```
library(here)
```

```
## here() starts at /home/guest/ENVR872-RepositoryClone
```

```
library(dplyr)
library(tidyr)
library(corrplot)
```

```
## corrplot 0.92 loaded
```

```
here()
```

```
## [1] "/home/guest/ENVR872-RepositoryClone"
```

```
# Importing raw NTL-LTER data
NTL.LTER.raw <- read.csv(here("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"),
                         stringsAsFactors = TRUE)

# Setting dates to date objects
NTL.LTER.raw$sampledate <- as.Date(NTL.LTER.raw$sampledate, format = "%m/%d/%y")

#2 Defining and setting a theme
mytheme <- theme_light(base_size = 14) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "top")
theme_set(mytheme)
```

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: Mean lake temperature during July does not change with depth across all lakes (in other words, mean lake temperatures are the same for all lakes during July). Ha: Mean lake temperature during July varies with depth 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.

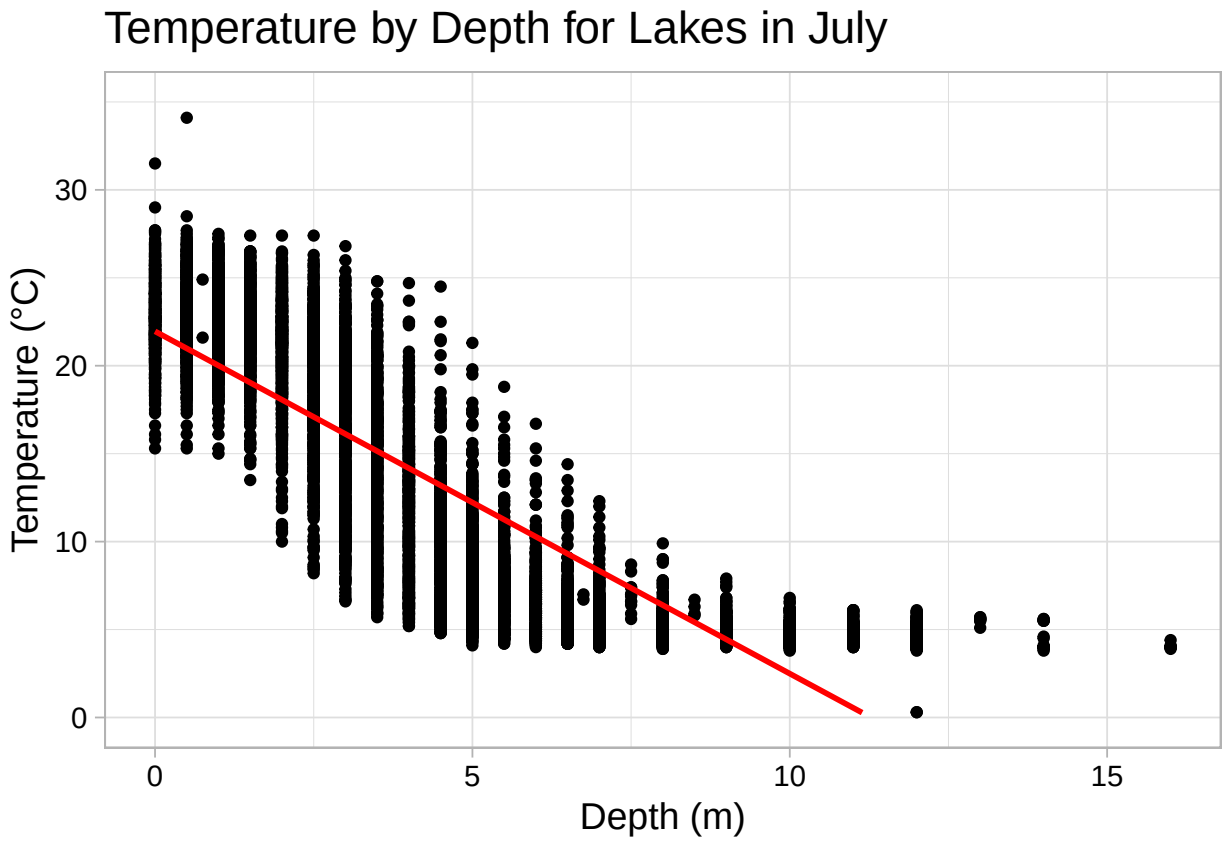
```r
#4 Wrangling data
NTL.LTER.July <- NTL.LTER.raw %>%
  filter(month(sampledate)==7) %>%
  select(lakename:daynum, depth:temperature_C) %>%
  drop_na()

#5 Visualizing relationships with scatterplot
temp.depth.plot <- NTL.LTER.July %>%
  ggplot(aes(x = depth, y = temperature_C)) +
  geom_point() +
  geom_smooth(method = "lm", color = "red", se = FALSE) +
  xlim(0, 16) + ylim(0, 35) +
  labs(x = "Depth (m)", y = "Temperature (\u00B0C)",
  title ="Temperature by Depth for Lakes in July")

print(temp.depth.plot)
```

```
## `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 anything about the linearity of this trend?

Answer: The scatterplot suggests that temperature tends to decrease as depth increases. However, as the distribution of points for the deepest depths drastically condenses beyond 10 m, a linear trendline cannot explain the entirety of this relationship. Thus, it appears as though this is a non-linear trend/relationship overall.

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

```
#7 Running a linear regression model
temp.depth.lm <- lm(NTL.LTER.July$temperature_C ~ NTL.LTER.July$depth)
summary(temp.depth.lm)
```

```
##
## Call:
## lm(formula = NTL.LTER.July$temperature_C ~ NTL.LTER.July$depth)
##
## 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 ***
## NTL.LTER.July$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: The reported p-values for the coefficients fall below the alpha value of 0.05. Therefore, depth should be considered as a predictor variable of temperature of lakes (during the month of July). Further, the reported R-squared value was fairly strong (0.7387), a good indicator of the model's ability to explain approximately 73.87% of the variation of July lake temperatures based on depth and 9,726 degrees of freedom.Temperature is predicted to decrease by 1.94621 degrees Celsius for every 1-m 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 Running an AIC to determine what set of explanatory variables are best at predicting temperature
temp.depth.AIC <- lm(data = NTL.LTER.July, temperature_C ~ depth + year4 + daynum)
summary(temp.depth.AIC)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = NTL.LTER.July)
##
## 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 ***
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 2e-16 ***
## ---
## 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
```

```
step(temp.depth.AIC)
```

```
## Start:  AIC=26065.53
## temperature_C ~ depth + year4 + daynum
##
##          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 + year4 + daynum, data = NTL.LTER.July)
##
## Coefficients:
## (Intercept)        depth        year4       daynum
##    -8.57556     -1.94644      0.01134      0.03978
```

```
# Results: The stepwise algorithm maintained all 3 variables due to their statistical
#significance with reported p-values below the 0.05 alpha value. Therefore, these 3
#variables should be included as explanatory variables for their influence on
#temperature, with depth and daynum tied as the strongest two.

#10 Running a multiple regression
```

```
temp.depth.multiple <- lm(data = NTL.LTER.July, temperature_C ~ depth + year4 + daynum)
summary(temp.depth.multiple)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = NTL.LTER.July)
##
## 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 ***
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 2e-16 ***
## ---
## 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 that the AIC method suggests we use includes all three: depth, day number, and year. This model explains approximately 74.11% of the observed variance. When we considered only depth alone as an explanatory variable, our model was able to explain 73.87% of the observed variance. Therefore, our new model is an improvement!

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 an ANOVA to see if different lakes have different temperatures during the month of July
#Set 1: ANOVA as an ANOVA (aov) model
temp.depth.ANOVA <- aov(data = NTL.LTER.July, temperature_C ~ lakename)
summary(temp.depth.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
```

```r
#Set 2: ANOVA as a linear (lm) model
temp.depth.ANOVA.2 <- lm(data = NTL.LTER.July,
                         temperature_C ~ lakename)
summary(temp.depth.ANOVA.2)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL.LTER.July)
##
## 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.

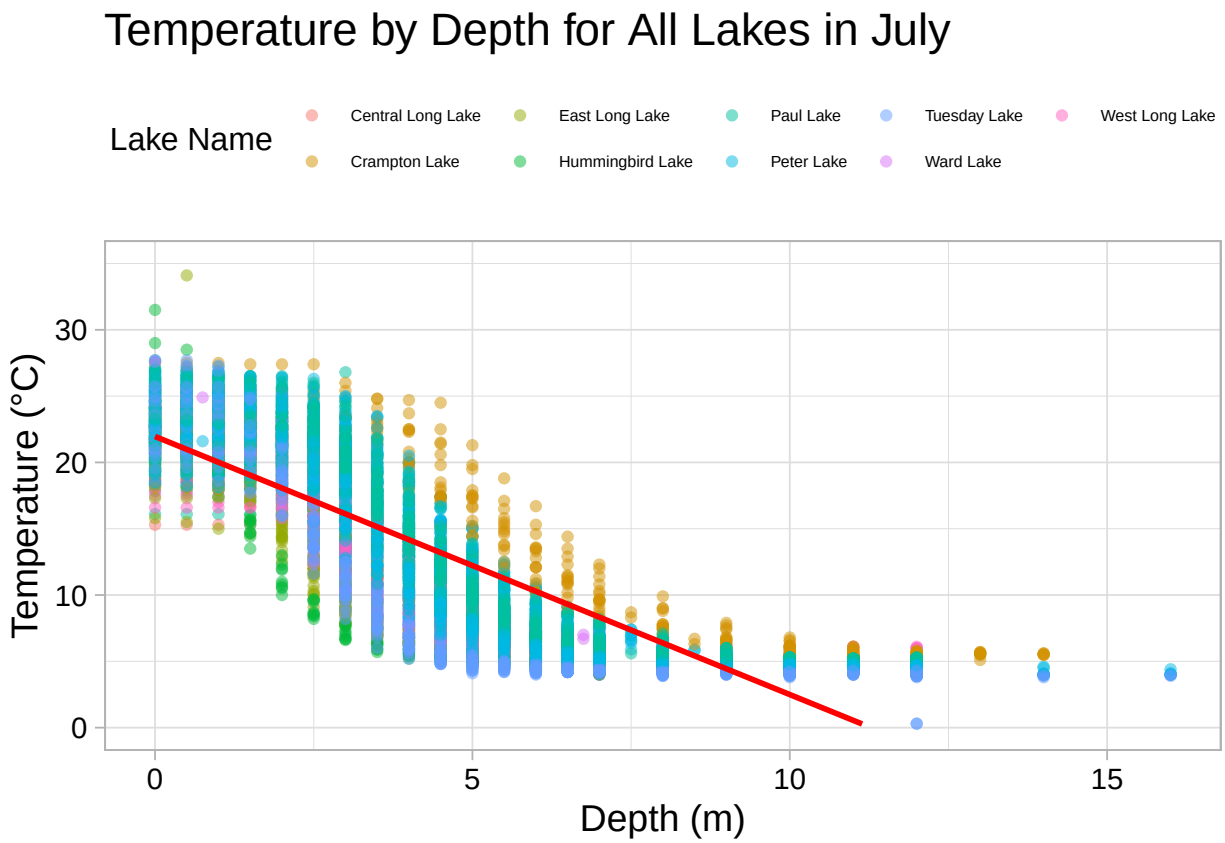
    Answer: Yes, the ANOVA reported a statistically significant p-value associated with "lakename" (<2e-16), suggesting that there is a significant difference in mean temperature among the lakes during the month of July.

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. Scatterplot for temperature by depth for each lake
temp.depth.lakes.plot <- NTL.LTER.July %>%
  ggplot(aes(x = depth, y = temperature_C, color = lakename)) +
  geom_point(alpha = .5) +
  theme(legend.text = element_text(size = 6),
        legend.title = element_text(size = 12)) +
  labs(title = "Temperature by Depth for All Lakes in July",
       x = "Depth (m)", y = "Temperature (\u00B0C)") +
  geom_smooth(method = "lm", color = "red", se = FALSE) +
  ylim(0,35) +
  scale_color_discrete(name = "Lake Name")
print(temp.depth.lakes.plot)
```

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

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



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

```
#15 Using Tukey's HSD test to identify different lake means
Lake.means.Tukey <- TukeyHSD(temp.depth.ANOVA)
print(Lake.means.Tukey)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = NTL.LTER.July)
##
## $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
```

```
# Another way to look at results:
Lake.means.groups <- HSD.test(temp.depth.ANOVA, "lakename", group = TRUE)
Lake.means.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: Statistically speaking, Paul Lake and Ward Lake have the same mean temperature as Peter Lake. These lakes have adjusted p-values that are larger than the alpha value of 0.05 that serves as a threshold for the determination of statistically significant difference between the lakes' reported mean temperatures. No lake has a mean temperature that is statistically distinct from all other lakes. The reported adjusted p-value for every pairwise combination surpassed the statistically significant threshold (< 0.05) in at least one pairwise combination with another 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: If we were just looking at the temperature difference between Peter Lake and Paul Lake, we could use a two-sample t-test.

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 temperatures are the same or different. What does the test say? Are the mean temperatures for the lakes equal? Does that match your answer for part 16?

```
# Wrangling July dataset to only include records from Crampton and Ward lakes
Crampton.Ward.July <- NTL.LTER.July %>%
  filter(lakename == "Crampton Lake" | lakename == "Ward Lake")

# Running 2-sample t-test to determine if July temperatures for each lake differ
Crampton.Ward.July.t.test <- t.test(Crampton.Ward.July$temperature_C ~ Crampton.Ward.July$lakename)
Crampton.Ward.July.t.test
```

```
##
##  Welch Two Sample t-test
##
## data:  Crampton.Ward.July$temperature_C by Crampton.Ward.July$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 n
## 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: The two-sample t-test reveals that the mean temperatures for Crampton and Ward lakes during the month of July are not statistically significant in their difference based on their reported p-value of 0.2649. Therefore, we fail to reject the null hypothesis that states that the mean temperatures for these two lakes during July are the same. This finding does indeed match my answer from question 16! From this previous question, the HSD.test() function grouped the mean July temperatures of Crampton and Ward lakes by the letter "b" while the TukeyHSD() function reported a p-value of 0.9714459 for the pairwise combination of the two lakes's mean temperatures. The closeness of the adjusted p-value to the value of 1.0000 suggests that the two means are very similar and close to being equal!