Assignment 7: GLMs (Linear Regressios, ANOVA, & t-tests)

Yufan Du

Fall 2024

OVERVIEW

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

Directions

1. Rename this file `<FirstLast>_A07_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
# check working directory
getwd()
```

```
## [1] "/home/guest/EDE_Fall2024"
```

```
# Load the required libraries
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v dplyr     1.1.4     v readr     2.1.5
## v forcats   1.0.0     v stringr   1.5.1
## v ggplot2   3.5.1     v tibble    3.2.1
## v lubridate 1.9.3     v tidyr     1.3.1
## v purrr     1.0.2
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```r
library(agricolae)
library(here)
```

```
## here() starts at /home/guest/EDE_Fall2024
```

```r
# Load the dataset
lake_data <- read_csv(here("Data", "Raw","NTL-LTER_Lake_ChemistryPhysics_Raw.csv"))
```

```
## Rows: 38614 Columns: 11
## -- Column specification --------------------------------------------------------
## Delimiter: ","
## chr (4): lakeid, lakename, sampledate, comments
## dbl (7): year4, daynum, depth, temperature_C, dissolvedOxygen, irradianceWat...
##
## i Use ‘spec()‘ to retrieve the full column specification for this data.
## i Specify the column types or set ‘show_col_types = FALSE‘ to quiet this message.
```

```r
# convert  Date type:
lake_data <- lake_data %>%
  mutate(sampledate = mdy(sampledate))

#2
# Define a custom ggplot theme
custom_theme <- theme_minimal() +
  theme(
    text = element_text(size = 12, color = "black"),
    plot.title = element_text(hjust = 0.5, face = "bold"),
    axis.title = element_text(size = 14),
    axis.text = element_text(size = 12),
    legend.position = "right",
    plot.background = element_rect(fill = "lightblue", color = NA)
  )

# Set this theme as the default for all ggplots
theme_set(custom_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: There is no relationship between lake temperature and depth in July; mean lake temperature does not change with depth across all lakes. Ha: There is a relationship between lake temperature and depth in July; mean lake temperature changes 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)

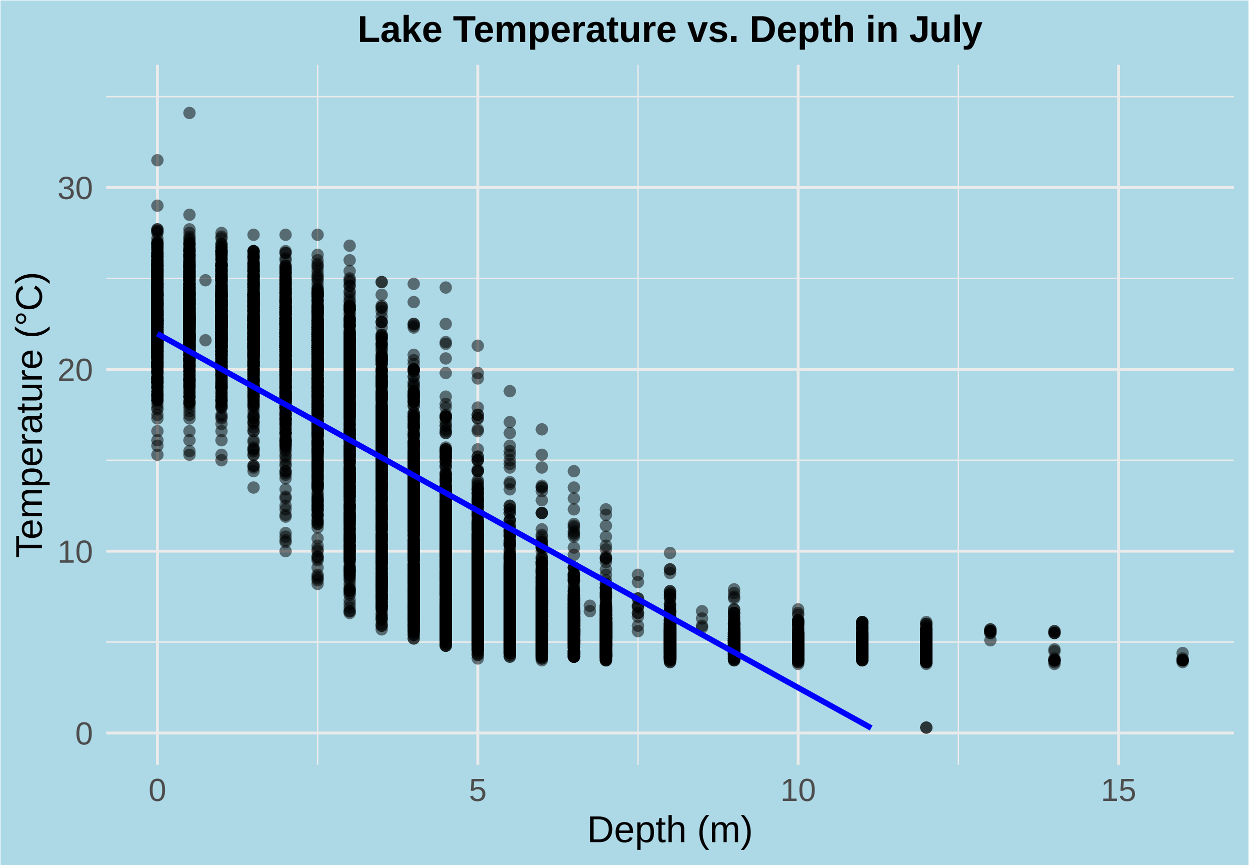
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```r
#4
# Filter data for July, select relevant columns, and remove rows with missing values
july_data <- lake_data %>%
  filter(month(sampledate) == 7) %>%  # Assuming 'date_column_name' is your date column
  select(lakename, year4, daynum, depth, temperature_C) %>%
  drop_na()  # Remove any rows with missing values


#5
# Scatter plot with a linear model line
ggplot(july_data, aes(x = depth, y = temperature_C)) +
  geom_point(alpha = 0.5) +  # Points with 50% transparency
  geom_smooth(method = "lm", se = FALSE, color = "blue") +  # Linear trend line
  scale_y_continuous(limits = c(0, 35)) +  # Limit y-axis to 0 - 35 °C
  labs(
    title = "Lake Temperature vs. Depth in July",
    x = "Depth (m)",
    y = "Temperature (°C)"
  ) +
  custom_theme
```

```
## ‘geom_smooth()‘ using formula = ’y ~ x’

## Warning: Removed 24 rows containing missing values or values outside the scale range
## (‘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 temperature decreases as depth increases. The data points has downward trend and the line has negative slope. The distribution of points suggests a relatively linear trend, where the temperature consistently declines with depth. The linear model seems appropriate for this trend.Most points cluster relatively close to the line, suggesting a strong inverse relationship between depth and temperature.

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

```
#7
# Linear regression model of temperature by depth
temperature_depth_model <- lm(temperature_C ~ depth, data = july_data)

# Display the summary of the model to check coefficients and statistics
summary(temperature_depth_model)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = july_data)
##
## 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: The model has an R-squared of 0.7387, meaning approximately 73.87% of the variability in lake temperature is explained by changes in depth. The model is based on 9726 degrees of freedom. The p-value for the depth coefficient is < 2e-16, indicating that the relationship between depth and temperature is highly significant. The slope coefficient for depth is -1.94621, meaning that for each additional meter of depth, the temperature is predicted to decrease by about 1.95 °C. —

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.

```r
#9

# Creating models with different combinations of predictors
model1 <- lm(temperature_C ~ depth, data = july_data)               # Only depth
model2 <- lm(temperature_C ~ depth + year4, data = july_data)       # Depth and year
model3 <- lm(temperature_C ~ depth + daynum, data = july_data)      # Depth and daynum
model4 <- lm(temperature_C ~ depth + year4 + daynum, data = july_data)  # Depth, year, and daynum

# Compare models using AIC
AIC(model1, model2, model3, model4)
```

```
##        df      AIC
## model1  3 53762.12
## model2  4 53756.97
## model3  4 53679.36
## model4  5 53674.39
```

```r
#10
# Multiple regression with the best predictor set identified by AIC
best_model <- lm(temperature_C ~ depth + year4 + daynum, data = july_data)

# Display the summary of the best model
summary(best_model)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = july_data)
##
## 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 AIC analysis recommended using depth, year4, and daynum to predict temperature. The R-squared for this model is 0.7412, indicating that 74.12% of the variance in lake temperature is explained by the combination of depth, year, and day of the year. Still highly significant with a p-value < 2e-16, and a slope of -1.946437, showing that depth is a strong predictor. Statistically significant with a p-value of 0.00833, indicating a minor effect of the year on temperature. Highly significant with a p-value < 2e-16, indicating that the day of the year also affects lake temperature. Compared to the single-variable model with only depth (R-squared = 0.7387), this multiple regression model explains slightly more variance (R-squared = 0.7412), suggesting a modest 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
# ANOVA model to test for differences in lake temperature
anova_model <- aov(temperature_C ~ lakename, data = july_data)

# Display the summary of the ANOVA model
summary(anova_model)
```

```
##               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
```

```
# Linear model for the same test
lm_model <- lm(temperature_C ~ lakename, data = july_data)

# Display the summary of the linear model
summary(lm_model)
```

```
## 
## Call:
## lm(formula = temperature_C ~ lakename, data = july_data)
## 
## 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.

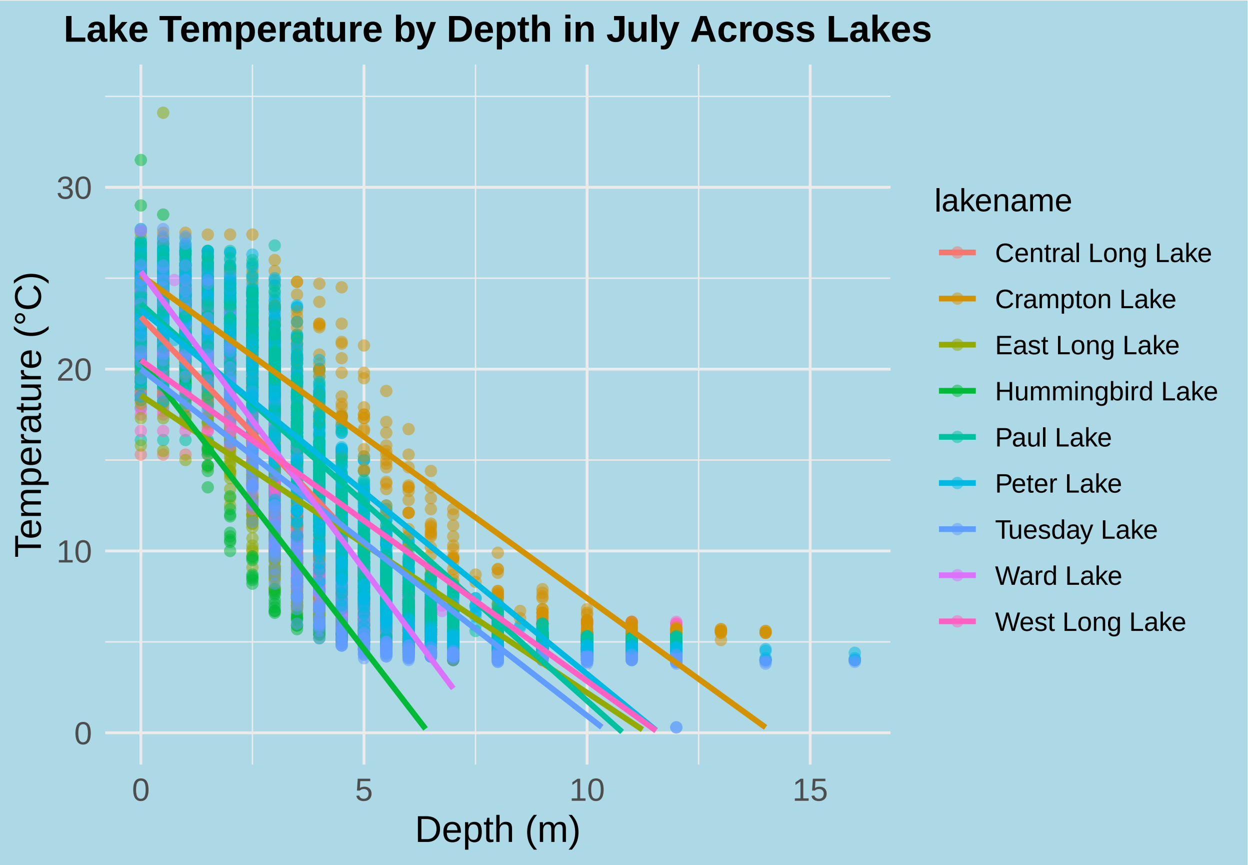
    Answer: There is a statistically significant difference in mean temperature among the lakes in July, as indicated by the ANOVA test (F(8, 9719) = 50, p < 2e-16). This result suggests that lake temperature varies significantly across the different lakes. Based on the linear model, several lakes show significantly different mean temperatures compared to the reference lake, as evidenced by the significant p-values for each lake’s coefficient. This detailed comparison confirms that specific lakes have distinct mean temperatures, contributing to the overall difference detected by the ANOVA.

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.
# Scatter plot of temperature by depth, with each lake in a different color
ggplot(july_data, aes(x = depth, y = temperature_C, color = lakename)) +
  geom_point(alpha = 0.5) +  # 50% transparency for points
  geom_smooth(method = "lm", se = FALSE) +  # Linear trend line for each lake
  scale_y_continuous(limits = c(0, 35)) +  # Y-axis limits from 0 to 35°C
  labs(
    title = "Lake Temperature by Depth in July Across Lakes",
    x = "Depth (m)",
    y = "Temperature (°C)"
  ) +
  custom_theme  # Apply custom theme with background color
```

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

```
## Warning: Removed 73 rows containing missing values or values outside the scale range
## ('geom_smooth()').
```



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

```r
#15
# Perform Tukey's HSD test to determine which lakes have different mean temperatures
tukey_result <- TukeyHSD(anova_model)

# Display the Tukey test results
print(tukey_result)
```

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

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: Lakes with statistically similar mean temperatures to Peter Lake include Paul Lake and Ward Lake, as their temperature differences were not significant in the Tukey's HSD test. Conversely, East Long Lake stands out as having a statistically distinct mean temperature from all other lakes.

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 focused solely on comparing the mean temperatures between Peter Lake and Paul Lake, a two-sample t-test would be an appropriate choice. This test would allow us to directly test the hypothesis of whether there is a significant difference between the mean temperatures of these two lakes.

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
# Filter data to include only records for Crampton Lake and Ward Lake
crampton_ward_data <- july_data %>%
  filter(lakename %in% c("Crampton Lake", "Ward Lake"))

# Perform the two-sample t-test on temperature data for Crampton Lake and Ward Lake
t_test_result <- t.test(
  temperature_C ~ lakename,
  data = crampton_ward_data,
  var.equal = TRUE  # Assume equal variance; change to FALSE if variances are suspected to differ
)

# Display the t-test results
t_test_result
```

```
##
##  Two Sample t-test
##
## data:  temperature_C by lakename
## t = 1.1298, df = 432, p-value = 0.2592
## alternative hypothesis: true difference in means between group Crampton Lake and group Ward Lake is n
## 95 percent confidence interval:
##  -0.660656  2.447188
## sample estimates:
## mean in group Crampton Lake     mean in group Ward Lake
##                    15.35189                    14.45862
```

> Answer: The two-sample t-test results indicate that there is no statistically significant difference in mean temperatures between Crampton Lake and Ward Lake in July (t = 1.1298, p = 0.2592). The 95% confidence interval (-0.66, 2.45) includes zero, further suggesting that any observed difference in means is likely due to random variation rather than a true difference. This finding aligns with the Tukey's HSD result, which also indicated no significant difference between these lakes.