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

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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
# import packages
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
```

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

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

```r
here()
```

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

```r
# read the csv data
NTL_LTER_chem_phy <- read.csv(
  ("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"), stringsAsFactors = TRUE)
# Set date to date format
NTL_LTER_chem_phy$sampledate <- as.Date(NTL_LTER_chem_phy$sampledate ,
                                        format ="%m/%d/%y")
# head(NTL_LTER_chem_phy$sampledate)

#2
# Set theme
mytheme <- theme_classic(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: No difference between temperatures in different depths (or temp_deep - temp-shallow = 0) Ha: There is difference between temperatures in different depths (temp_deep-temp_shallow != 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 scatterplot 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
# Wrangle the data
head(NTL_LTER_chem_phy$sampledate)
```

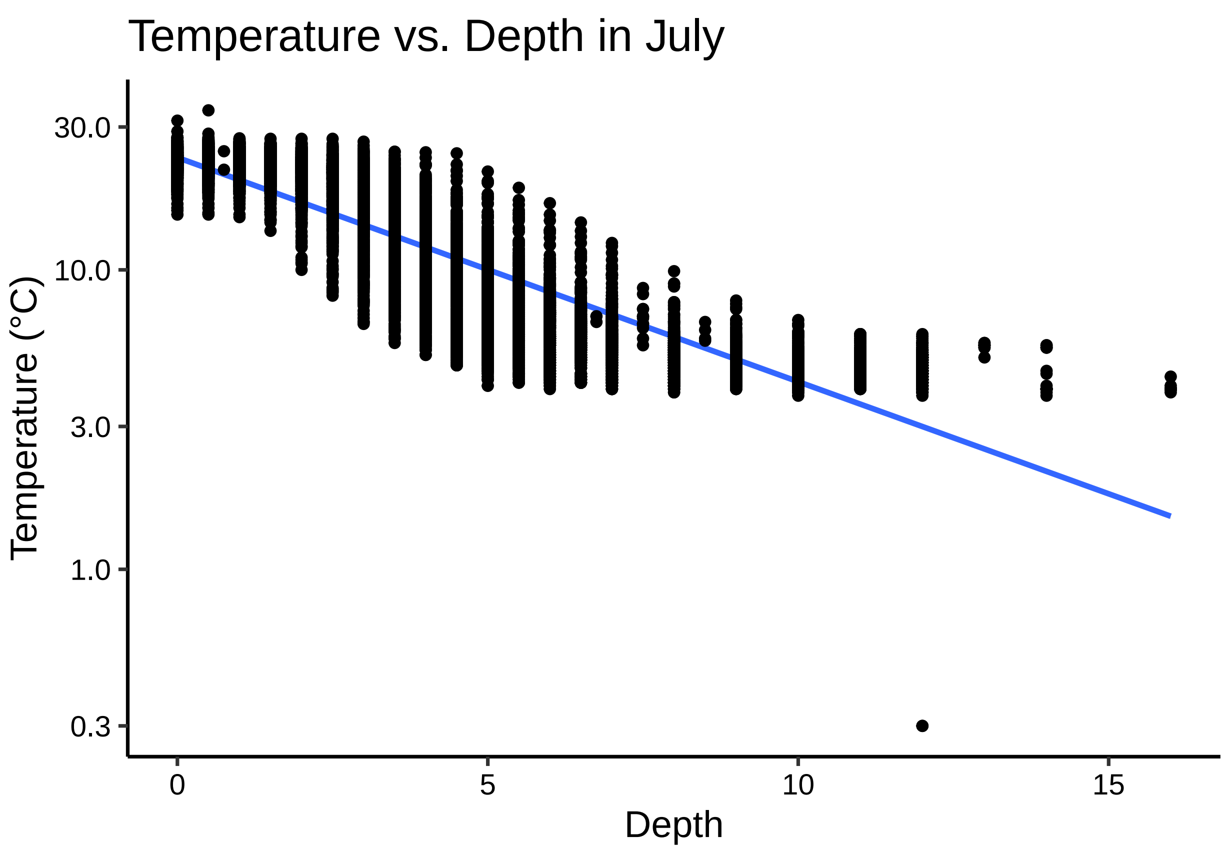
```
## [1] "1984-05-27" "1984-05-27" "1984-05-27" "1984-05-27" "1984-05-27"
## [6] "1984-05-27"
```

```r
library(dplyr)
NTL_LTER_chem_phy.July <- NTL_LTER_chem_phy %>%
  mutate(month = month(sampledate)) %>%  # Extract month from the date column
```

```
  filter(month == 7) %>%  # filter out only July
  select(lakename, year4, daynum, depth, temperature_C) %>%
  na.omit()

#5 make a scatter plot with methods in lab and add a line
# the two variables: x is depth, y is temperature_C
NTL_LTER_July_plot <-
  ggplot(NTL_LTER_chem_phy.July, aes(x = depth, y = temperature_C)) +
  geom_smooth(method = "lm") +
  scale_y_log10() +
  geom_point() +
  labs(
    title = "Temperature vs. Depth in July",
    x = "Depth",
    y = "Temperature (°C)"
  ) +
  theme_set(mytheme)
print(NTL_LTER_July_plot)
```

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



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: From visual oberservation, there is a visual trend of correlation between depth and temperature of the lake. And the points concentrate around the line of best fit. The distribution should suggest that there could be a significant negative linearity of this trend.

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

```
#7
# Fit the linear regression model
lm_model <- lm(temperature_C ~ depth, data = NTL_LTER_chem_phy.July)
# Check the summary of the model
summary(lm_model)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = NTL_LTER_chem_phy.July)
##
## 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: According to the results output: - The coefficient of the depth in the regression of depth vs temperature is -1.94621, which means each unit (1m) increase of depth will result in about 2 degrees decrease in temperature in the lake. - Degrees of freedom: df = n - k (sample size - # of parameters) = 9726, which means we have a pretty high df, which could mean a robust estimate of the model parameters and better fit of the model to the data. - Statistical significance: The F-stat is 2.75e+04 on 1 and 9726 DF. This is a large value, which suggests that the model explains a significant amount of the variability in the y variable (temperature_C). Typically, the higher the F-statistic, the better the model fits the data. Also the p-value: $< 2.2e-16$, which is very low, almost 0, which means the result is significant and we can reject the H0 null hypothesis of no difference in temperature by 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.

```r
#9
# Fit the full model with all predictors
full_model <- lm(temperature_C ~ year4 + daynum + depth,
                 data = NTL_LTER_chem_phy.July)

# step
step(full_model)
```

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

```r
summary(full_model)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL_LTER_chem_phy.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
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 2e-16 ***
## depth       -1.946437   0.011683 -166.611  < 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
```

```r
# According to the results, full_model with all the predictor variables
# seem to give the best result and is best suited for prediction, since the
# lowest AIC value occurs at "none" with all of the variables included.
# When taking out one each variable, the AIC value increases a little, and
# depth being dropped causing the highest increase in AIC.
# Also from the results summary, it shows all p-value < 0.05 or 0.01, which means
# they are all significant variables for the regression.

#10
# Fit the multiple regression model with the 3 variables determined earlier
multiple_regression_model <- lm(temperature_C ~ year4 + daynum + depth, data = NTL_LTER_chem_phy.July)

# View the summary of the model
summary(multiple_regression_model)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL_LTER_chem_phy.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
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 2e-16 ***
## depth       -1.946437   0.011683 -166.611  < 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: A set with all three variables year4, daynum, depth are the explanatory variables for the mutiple regression. - The adjusted r-squared is about 0.7411, which means 0.7411 (about 74%) of variance explained by the model. - Before adding the mutiple variables, when there was just depth as the explanatory variable, the adjusted r-squared was 0.7387, whereas now the adjusted r-squared is 0.7411, then the r-squared slightly improved.

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
# anova
# Run ANOVA model
anova_model <- aov(temperature_C ~ lakename, data = NTL_LTER_chem_phy.July)

# Print ANOVA summary
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
```

```r
# Format ANOVA as lm (linear)
anova2_linear <- lm(temperature_C ~ lakename, data = NTL_LTER_chem_phy.July)

# Print summary of linear model
summary(anova2_linear)
```

```
## 
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL_LTER_chem_phy.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: The F-stat is 50 on 8 and 9719 degrees of freedom, p-value: < 2.2e-16. Since it has a high F-stat and low, close to 0 p-value, it means we can reject the null of no significant difference in mean temperature among lakes.

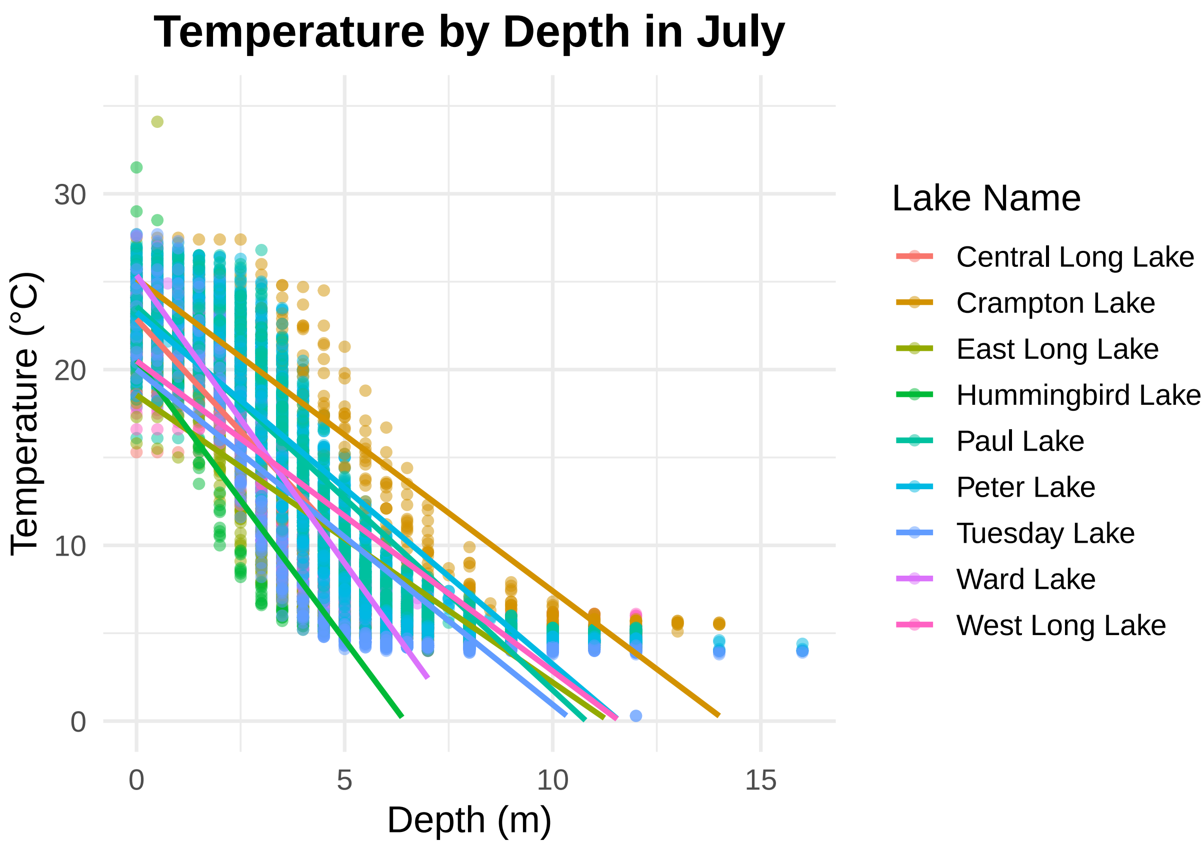
14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = “lm”, se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```
#14.Similar to the first scatterplot done previously, but change colors
# Create the plot
NTL_LTER_July_plot_2 <- ggplot(NTL_LTER_chem_phy.July, aes(x = depth,
                                      y = temperature_C, color = lakename)) +
  # Plot points with 50% transparency
  geom_point(alpha = 0.5) +
  # Add linear regression lines for each lake
  geom_smooth(method = "lm", se = FALSE) +
  # Set y-axis limits
  ylim(0, 35) +
  # Customize labels
  labs(
    title = "Temperature by Depth in July",
    x = "Depth (m)",
    y = "Temperature (°C)",
    color = "Lake Name"
  ) +
  # Apply a clean theme
  theme_minimal(base_size = 14) +
  theme(
    plot.title = element_text(hjust = 0.5, face = "bold"),
    legend.position = "right"
  )

# Print the plot
print(NTL_LTER_July_plot_2)
```

```
## `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
# Post-hoc test
# TukeyHSD() computes Tukey Honest Significant Differences, use anova model
TukeyHSD(anova_model)
```

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

```
# Extract groupings for pairwise relationships
anova_model.groups <- HSD.test(anova_model, "lakename", group = TRUE)
anova_model.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        se Min  Max    Q25   Q50
## Central Long Lake      17.66641 4.196292  128 0.6501298 8.9 26.8 14.400 18.40
## Crampton Lake          15.35189 7.244773  318 0.4124692 5.0 27.5  7.525 16.90
## East Long Lake         10.26767 6.766804  968 0.2364108 4.2 34.1  4.975  6.50
## Hummingbird Lake       10.77328 7.017845  116 0.6829298 4.0 31.5  5.200  7.00
## Paul Lake              13.81426 7.296928 2660 0.1426147 4.7 27.7  6.500 12.40
## Peter Lake             13.31626 7.669758 2872 0.1372501 4.0 27.0  5.600 11.40
## Tuesday Lake           11.06923 7.698687 1524 0.1884137 0.3 27.7  4.400  6.80
## Ward Lake              14.45862 7.409079  116 0.6829298 5.7 27.6  7.200 12.55
## West Long Lake         11.57865 6.980789 1026 0.2296314 4.0 25.7  5.400  8.00
##                      Q75
## Central Long Lake 21.000
## Crampton Lake     22.300
## East Long Lake    15.925
## Hummingbird Lake  15.625
```

```
## Paul Lake         21.400
## Peter Lake        21.500
## Tuesday Lake      19.400
## Ward Lake         23.200
## West Long Lake    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"
```

```
# Results listed would be lakes ground by different means of Temperature_C
```

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: Observing the mean groups listed for each lake, Paul lake seems to have similar mean as Peter Lake. Also, according to the groups, none of the groups are completely distinct from all other groups, and each of them has a mean kind of related/ close to at least one other group, so there is no lake with a mean temperature that is statistically distinct from all the 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: The t-test hypothesis testing can help explore whether they have distinct mean temperatures.

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?

```
July_CW <- NTL_LTER_chem_phy.July %>%
  filter(lakename %in% c("Crampton Lake", "Ward Lake"))
# Run two-sample T-test on temperature by lake
t_test_result <- t.test(
  temperature_C ~ lakename,
  data = July_CW)

# Print the T-test result
print(t_test_result)
```

```
##
##  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 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: According to the t-test result, the t-stat for hypothesis testing whether means of Crampton and Ward have statistical difference is 1.1298, which is lower than the t-stat for 95% confidence level, and the p-value is 0.2592, which is much higher than 0.05. Therefore, we cannot reject the null of no statistical difference between the means of the two lakes.