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

Xianhang Xie

Spring 2023

## 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
# Load the necessary packages
library(tidyverse)
library(lubridate)
library(agricolae)
library(ggplot2)
library(cowplot)
# Verify the home directory
getwd()
```

```
## [1] "C:/Users/11764/Desktop/EDA-Spring2023/Assignments"
```

```
# import
NTL_LTER <- read_csv("../Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv")

#2
# Define the custom theme
custom_theme <- theme(
```

```
  plot.background = element_rect(fill = "White"),
  plot.title = element_text(size = 16, face = "bold", hjust = 0.5),
  panel.grid.major = element_line(colour = "gray", linetype = "dashed"),
  panel.grid.minor = element_line(colour = "gray", linetype = "dotted"),

  legend.title = element_text(face = "bold")
)

# Set the custom theme as the default theme
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: The mean lake temperature recorded during July is the same across all depths in all lakes.

Ha: The mean lake temperature recorded during July differs across different depths in 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)

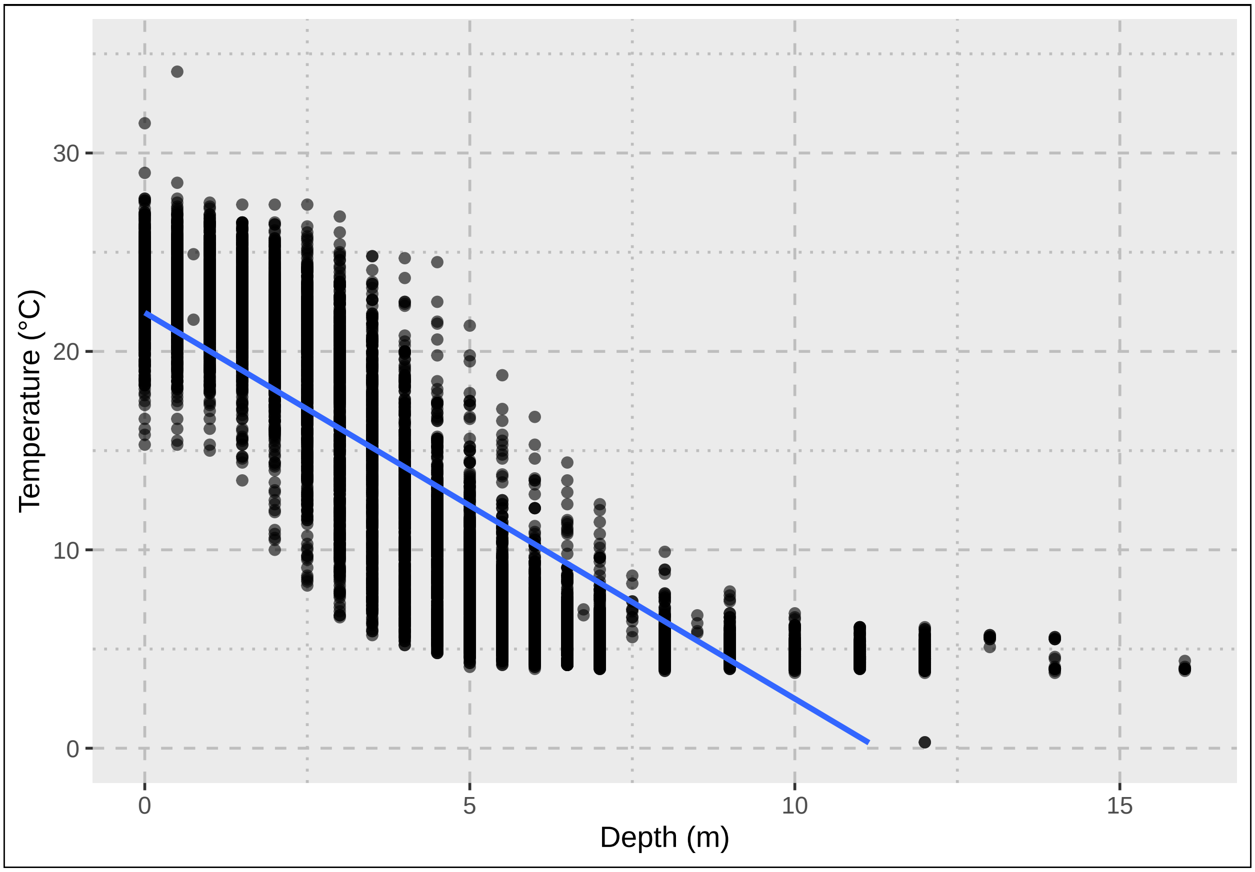
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```
#4
NTL_LTER_july <- NTL_LTER %>%
  mutate(sampledate = as.Date(sampledate, format = "%m/%d/%y")) %>%
  filter(format(sampledate, "%m") == "07") %>%  # filter for dates in July
  select(lakename, year4, daynum, depth, temperature_C) %>%  # select specific columns
  drop_na()  # remove rows with NAs

#5
# Create the plot
ggplot(data = NTL_LTER_july, aes(x = depth, y = temperature_C)) +
  geom_point(alpha = 0.6) +  # add scatter points with transparency
  geom_smooth(method = "lm", se = FALSE) +  # add linear line
  scale_y_continuous(limits = c(0, 35)) +  # set limits for temperature
  labs(x = "Depth (m)", y = "Temperature (°C)") # set axis labels
```

```
## `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 scatter plot suggests a decreasing trend in temperature with increasing depth. The distribution of the points does not suggest a linear model though, as we can clearly observe the shape of the point distribution follows a curve. Therefore, it is important to consider other statistical methods to fit the data.

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

```
#7
lm_depth_temp <- lm(temperature_C ~ depth, data = NTL_LTER_july)
# Display the model summary
summary(lm_depth_temp)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = NTL_LTER_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: The model accounts for 73.87% of the variability in temperature_C and is highly statistically significant (p-value < 2.2e-16), based on a F distribution of degree of freedom 1 and 9726. The model estimates that for every additional meter of depth in the lakes, the temperature decreases by approximately 1.95 °C on average.

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## 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 multiple linear regression models with all combinations of predictors
model1 <- lm(temperature_C ~ year4, data = NTL_LTER_july)
model2 <- lm(temperature_C ~ daynum, data = NTL_LTER_july)
model3 <- lm(temperature_C ~ depth, data = NTL_LTER_july)
model4 <- lm(temperature_C ~ year4 + daynum, data = NTL_LTER_july)
model5 <- lm(temperature_C ~ year4 + depth, data = NTL_LTER_july)
model6 <- lm(temperature_C ~ daynum + depth, data = NTL_LTER_july)
model7 <- lm(temperature_C ~ year4 + daynum + depth, data = NTL_LTER_july)

# Calculate AIC for each model
AIC1 <- AIC(model1)
AIC2 <- AIC(model2)
AIC3 <- AIC(model3)
AIC4 <- AIC(model4)
AIC5 <- AIC(model5)
AIC6 <- AIC(model6)
AIC7 <- AIC(model7)
```

```r
# Combine AIC values into a data frame
AIC_df <- data.frame(models = c("model1", "model2", "model3", "model4", "model5", "model6", "model7"),
                     AIC = c(AIC1, AIC2, AIC3, AIC4, AIC5, AIC6, AIC7))
AIC_df <- AIC_df[order(AIC_df$AIC), ]

# Print the AIC results
print(AIC_df)
```

```
##   models      AIC
## 7 model7 53674.39
## 6 model6 53679.36
## 5 model5 53756.97
## 3 model3 53762.12
## 2 model2 66796.54
## 4 model4 66798.34
## 1 model1 66819.14
```

```r
#10
fit <- lm(temperature_C ~ year4 + daynum + depth, data = NTL_LTER_july)
summary(fit)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, 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
## 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: The final set of explanatory variables that the AIC method suggests we use to predict temperature in our multiple regression are year4, daynum, depth. It explain 74.12% of the observed variance. Compared to the 73.87% of the model using only depth as the explanatory variable, there is a slightly improvement.

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## 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
# Run ANOVA
anova_fit <- aov(temperature_C ~ lakename, data = NTL_LTER_july)
summary(anova_fit)
```

```
##                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
```

```
# Run linear regression
lm_fit <- lm(temperature_C ~ lakename, data = NTL_LTER_july)
summary(lm_fit)
```

```
##
## 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.

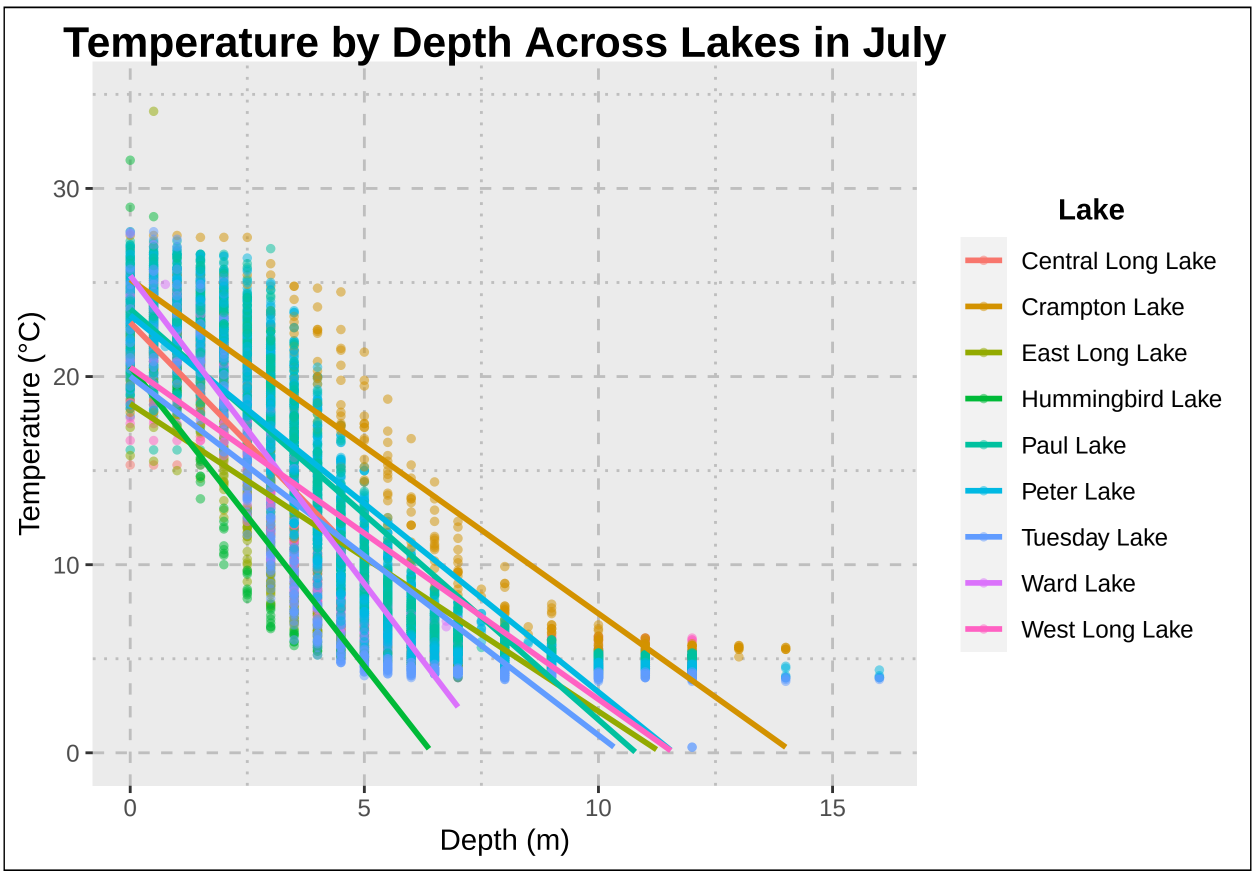
    Answer: As the F statistic is 50 with degrees of freedom 8 and 9719, p value smaller than 2.2e-16. So we can conclude that there are significant differences in mean temperature among the different lakes.

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.
ggplot(NTL_LTER_july, aes(x = depth, y = temperature_C, color = lakename)) +
  geom_point(alpha = 0.5, size = 1) +
  # Add separate linear regression lines
  geom_smooth(method = "lm", se = FALSE) +
  # Adjust y-axis limits to 0-35 degrees
  scale_y_continuous(limits = c(0, 35)) +
  # Add axis labels and legend title
  xlab("Depth (m)") +
  ylab("Temperature (°C)") +
  labs(color = "Lake") +
  # Customize plot title and subtitle
  ggtitle("Temperature by Depth Across Lakes in July")
```

```
## `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.

```r
#15
TukeyHSD(anova_fit)
```

```
##   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
```

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: According to the Tukey's HSD test results, the only lake with a pairwise comparison p-value greater than 0.05 are Ward lake and Paul Lake. Therefore, statistically speaking, Peter Lake and Ward Lake have the same mean temperature.

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 can use a two-sample t test to 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?

```
NTL_LTER_july_CW <- NTL_LTER_july %>%
  filter(lakename %in% c("Crampton Lake", "Ward Lake"))
t.test(temperature_C ~ lakename, data = NTL_LTER_july_CW)
```

```
##
##  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: The p-value for the test is 0.2649, which is greater than the significance level of 0.05. So we cannot reject the null hypothesis that the mean temperatures of Crampton Lake and Ward Lake are equal. In part 16, the Tukey's HSD test, Crampton Lake and Ward Lake has the p value of 0.97, which means their pairwise difference is not significant. So it match the answer.