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. Change "Student Name" on line 3 (above) with your name.
2. Work through the steps, **creating code and output** that fulfill each instruction.
3. Be sure to **answer the questions** in this assignment document.
4. When you have completed the assignment, **Knit** the text and code into a single PDF file.
5. After Knitting, submit the completed exercise (PDF file) to the dropbox in Sakai. Add your last name into the file name (e.g., "Fay_A06_GLMs.Rmd") prior to submission.

The completed exercise is due on Monday, February 28 at 7:00 pm.

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()

library(tidyverse)
library(ggplot2)
library(agricolae)
library(lubridate)

NTL_LTER <- read.csv("../Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv")

NTL_LTER$sampledate <- as.Date(NTL_LTER$sampledate, format = "%m/%d/%y")

#str(NTL_LTER)

#2
CalsTheme <- theme_classic(base_size = 16) +
  theme(axis.text = element_text(color = "gray"), legend.position = "left",
        legend.justification = 2)
theme_set(CalsTheme)
```

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 recorded during July does not change with depth (across all lakes) Ha: Mean lake temperature recorded during July 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)

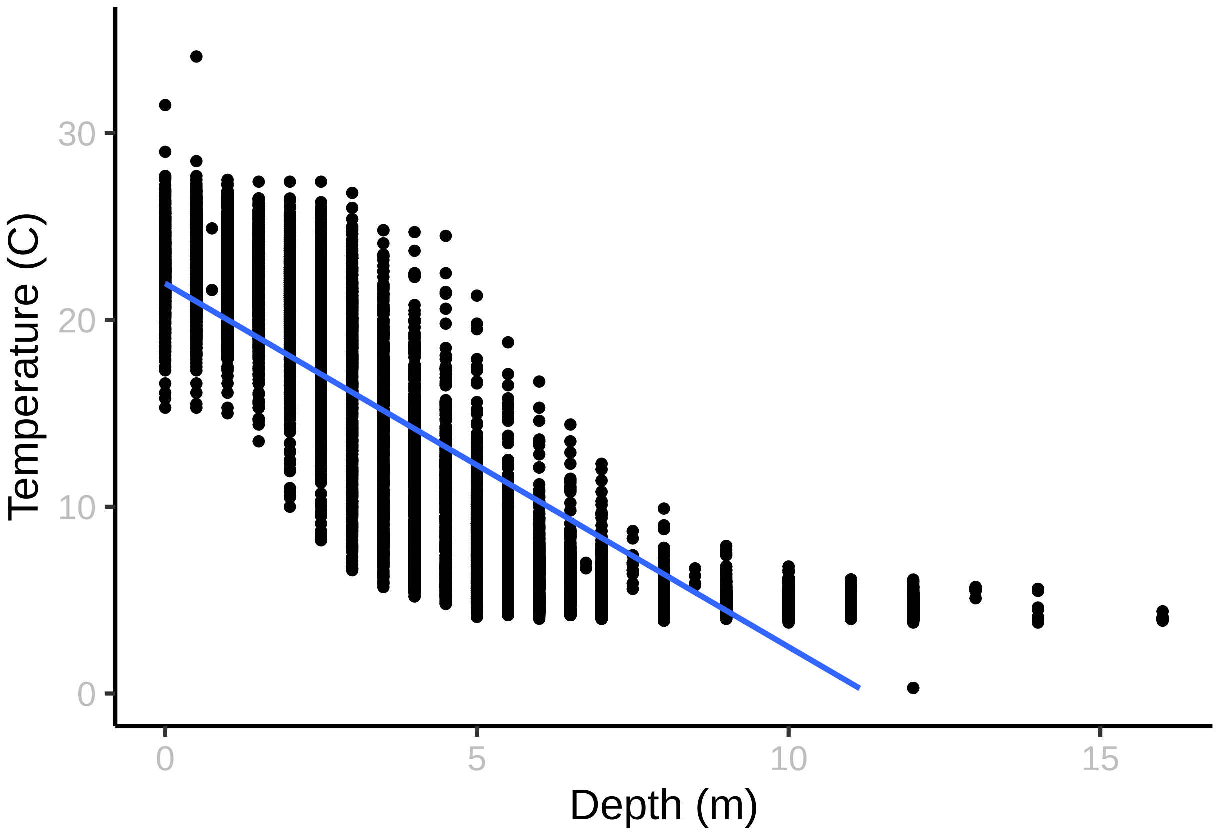
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```r
#4
NTL_LTERsubset <- NTL_LTER %>%
  separate(sampledate, c("Year", "Month", "Day")) %>%
  filter(Month == "07") %>%
  select(lakename:daynum, depth, temperature_C) %>%
  drop_na()

print(head(NTL_LTERsubset))
```

```
##    lakename year4 daynum depth temperature_C
## 1 Paul Lake  1984    183   0.0          22.8
## 2 Paul Lake  1984    183   0.5          22.9
## 3 Paul Lake  1984    183   1.0          22.8
## 4 Paul Lake  1984    183   1.5          22.7
## 5 Paul Lake  1984    183   2.0          21.7
## 6 Paul Lake  1984    183   2.5          20.3
```

```r
#5
A06_plot1 <- ggplot(NTL_LTERsubset, aes(x = depth, y = temperature_C)) +
  geom_point() +
  labs(x = "Depth (m)", y = "Temperature (C)") +
  ylim(0,35) +
  geom_smooth(method = lm)
print(A06_plot1)
```



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 as depth increases. This is evident from the negative slope of the smoothing line. The distribution of these points suggests that this relationship is not exactly linear. What I mean by this is that the point distribution has almost an 'S' shaped curve, so it may make sense to transform one of these variables to find a better linear relationship.

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

```r
#7
A06_lm1 <- lm(NTL_LTERsubset$temperature_C ~ NTL_LTERsubset$depth)
print(summary(A06_lm1))
```

```
##
## Call:
## lm(formula = NTL_LTERsubset$temperature_C ~ NTL_LTERsubset$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_LTERsubset$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 summary of this linear model indicates that ~73% of the variability in temperature is explained by changes in depth (R^2 = 0.7387, p-value < 2.2e-16, df = 9726).It also indicates that temperature is expected to drop by 1.946 degrees Celcius for every 1m increase 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
#normally I would explore a correlation plot prior to running an AIC, but since
#you've already suggested which variables to explore I'm going to skip that
#step and go straight to the AIC.
A06_lm2 <- lm(data = NTL_LTERsubset, temperature_C ~ year4 + daynum + depth)

step(A06_lm2)
```

```
## 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_LTERsubset)
##
## Coefficients:
## (Intercept)        year4       daynum        depth
##    -8.57556      0.01134      0.03978     -1.94644
```

```
#10
##since the AIC said I should use all the same variables I'm not re-running the
#model I generated in Question #9
summary(A06_lm2)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL_LTERsubset)
```

```
##
## 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 AIC method suggests including all three of the suggested variables (year4, daynum, depth). This model explains ~74% of the variability in temperature (R^2 = 0.7412, p-value < 2.2e-16, df = 9724). I would not go so far as to say this is an improvement over the model that only used depth as an explanatory variable. More variablity is explained, but with a trade off in clarity. What I mean by this is that there may now be covariation occuring that we haven't teased apart yet, so limiting the model to a single explanatory variable would make interpretation simpler.

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
A06_2Wanov1 <- aov(data = NTL_LTERsubset, temperature_C ~ lakename)
print(summary(A06_2Wanov1))
```

```
##               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
```

```
A06_2Wanov2 <- lm(data = NTL_LTERsubset, temperature_C ~ lakename)
print(summary(A06_2Wanov2))
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL_LTERsubset)
##
## Residuals:
```

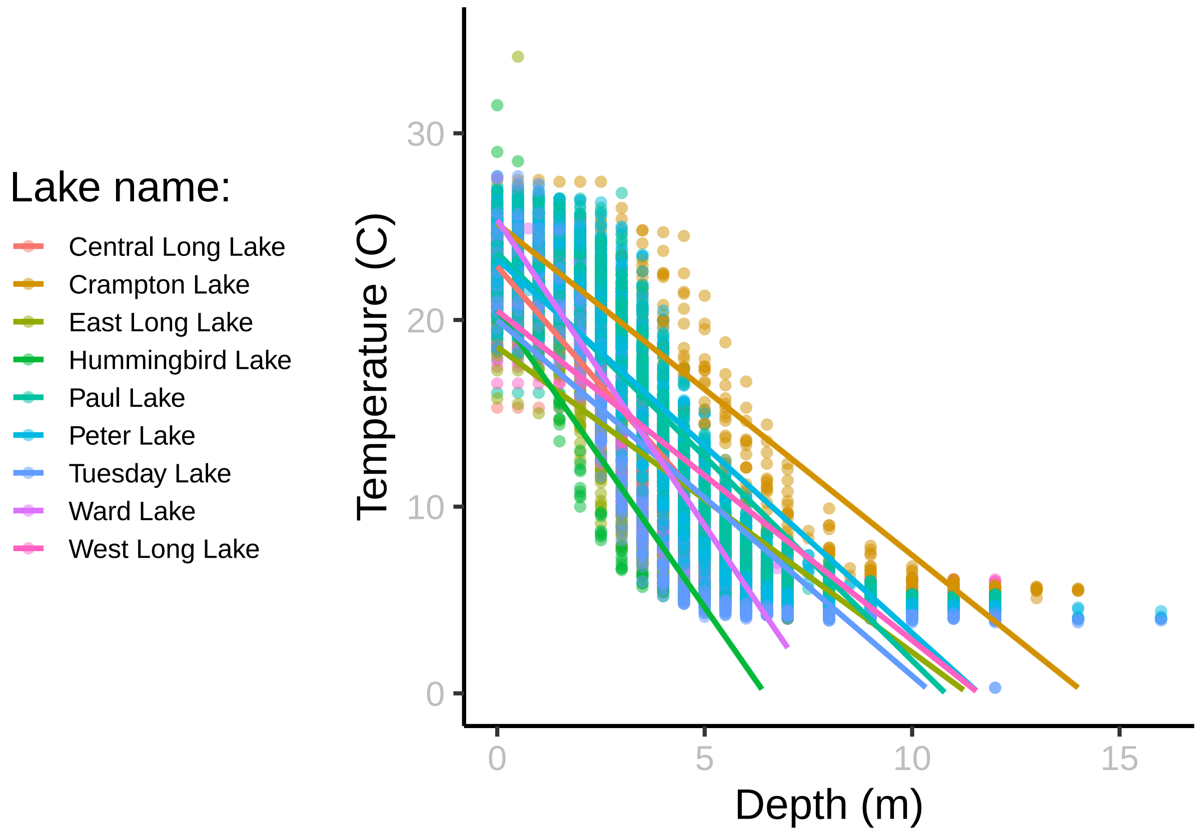
```
##     Min      1Q  Median      3Q     Max
## -10.769  -6.614  -2.679   7.684  23.832
##
## Coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)                17.6664     0.6501  27.174  < 2e-16 ***
## lakenameCrampton Lake      -2.3145     0.7699  -3.006 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 significant difference in mean temperature among the lakes (R^2 = 0.03953, p-value < 2.2e-16, df = 9719).

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.
A06_plot2 <- ggplot(NTL_LTERsubset, aes(x = depth, y = temperature_C,
                                        color = lakename)) +
  geom_point(alpha = .5) +
  labs(x = "Depth (m)", y = "Temperature (C)", color = "Lake name:") +
  ylim(0,35) +
  geom_smooth(method = lm, se = FALSE) +
  theme(legend.key.size = unit(0.5, "cm"),
        legend.text = element_text(size = 10))
print(A06_plot2)
```



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

```
#15
print(TukeyHSD(A06_2Wanov1)) #check to see if different lakes have different
```

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

#group them so that it's easier to interpret the results of the HSD test
interaction_check <- with(NTL_LTERsubset, interaction(lakename, lakename))
#^create interactions between lakes
A06_2Wanov3 <- aov(data = NTL_LTERsubset, temperature_C ~ interaction_check)
#^model that
lakename_groups <- HSD.test(A06_2Wanov3, "interaction_check", group = TRUE)
#^group them using TukeyHSD
print(lakename_groups)
```

```
## $statistics
##   MSerror   Df     Mean       CV
##   54.1016 9719 12.72087 57.82135
##
## $parameters
##    test             name.t ntr StudentizedRange alpha
##   Tukey interaction_check   9         4.387504  0.05
##
## $means
##                                     temperature_C      std    r Min  Max    Q25
## Central Long Lake.Central Long Lake      17.66641 4.196292  128 8.9 26.8 14.400
## Crampton Lake.Crampton Lake              15.35189 7.244773  318 5.0 27.5  7.525
## East Long Lake.East Long Lake            10.26767 6.766804  968 4.2 34.1  4.975
## Hummingbird Lake.Hummingbird Lake        10.77328 7.017845  116 4.0 31.5  5.200
## Paul Lake.Paul Lake                      13.81426 7.296928 2660 4.7 27.7  6.500
## Peter Lake.Peter Lake                    13.31626 7.669758 2872 4.0 27.0  5.600
## Tuesday Lake.Tuesday Lake                11.06923 7.698687 1524 0.3 27.7  4.400
## Ward Lake.Ward Lake                      14.45862 7.409079  116 5.7 27.6  7.200
## West Long Lake.West Long Lake            11.57865 6.980789 1026 4.0 25.7  5.400
##                                       Q50    Q75
## Central Long Lake.Central Long Lake 18.40 21.000
## Crampton Lake.Crampton Lake         16.90 22.300
```

```
## East Long Lake.East Long Lake         6.50 15.925
## Hummingbird Lake.Hummingbird Lake     7.00 15.625
## Paul Lake.Paul Lake                  12.40 21.400
## Peter Lake.Peter Lake                11.40 21.500
## Tuesday Lake.Tuesday Lake             6.80 19.400
## Ward Lake.Ward Lake                  12.55 23.200
## West Long Lake.West Long Lake         8.00 18.800
##
## $comparison
## NULL
##
## $groups
##                                      temperature_C groups
## Central Long Lake.Central Long Lake       17.66641      a
## Crampton Lake.Crampton Lake               15.35189     ab
## Ward Lake.Ward Lake                       14.45862     bc
## Paul Lake.Paul Lake                       13.81426      c
## Peter Lake.Peter Lake                     13.31626      c
## West Long Lake.West Long Lake             11.57865      d
## Tuesday Lake.Tuesday Lake                 11.06923     de
## Hummingbird Lake.Hummingbird Lake         10.77328     de
## East Long Lake.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:Paul Lake (p-value (adj.) = 0.2242) and Ward Lake (p-value (adj.) = 0.7827) have the same mean temperature as Peter Lake.There is no single lake with a mean temperature that is statisticaly distinct from all other lakes, this is evidenced from the fact that there is no interaction group that does not overlap with all the others.

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: A two-sample t-test would also be able to tell us if Peter Lake and Paul Lake have different mean temperatures.