Bollt_FinalProject_Thermocline

The crux of this project is to compare how the thermoclines on each of the 9 Wisconsin lakes in the NTL-LTER dataset have moved over the course of the 35 years of data. I am interested in this question because I have an interest in coldwater fisheries that rely on thermoclines to survive the summer weather. Perhaps climate change is affecting where the thermocline sets up, and therefore shrinking the available summer habitat of trout.

```
#Setting up session and loading all packages I think I might need
getwd()
```

```
## [1] "V:/ENV872BadgerThermoclines"
```

```
library(tidyverse)
```

```
## Warning: package 'tidyverse' was built under R version 3.5.2

## -- Attaching packages ------------------------------------------------------------------------------------

## v ggplot2 3.1.0     v purrr   0.2.5
## v tibble  1.4.2     v dplyr   0.7.8
## v tidyr   0.8.2     v stringr 1.3.1
## v readr   1.3.1     v forcats 0.3.0

## Warning: package 'ggplot2' was built under R version 3.5.2

## Warning: package 'tibble' was built under R version 3.5.2

## Warning: package 'tidyr' was built under R version 3.5.2

## Warning: package 'readr' was built under R version 3.5.2

## Warning: package 'purrr' was built under R version 3.5.2

## Warning: package 'dplyr' was built under R version 3.5.2

## Warning: package 'stringr' was built under R version 3.5.2

## Warning: package 'forcats' was built under R version 3.5.2

## -- Conflicts ---------------------------------------------------------------------------------------- ti
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(lubridate)
```

```
## Warning: package 'lubridate' was built under R version 3.5.2

##
## Attaching package: 'lubridate'

## The following object is masked from 'package:base':
##
##     date
```

```
library(ggplot2)
library(multcompView)
```

```
## Warning: package 'multcompView' was built under R version 3.5.2
```

```
library(nlme)
```

```
##
## Attaching package: 'nlme'

## The following object is masked from 'package:dplyr':
##
##     collapse
```

```
library(lsmeans)
```

```
## Warning: package 'lsmeans' was built under R version 3.5.2

## Loading required package: emmeans

## Warning: package 'emmeans' was built under R version 3.5.2

## The 'lsmeans' package is now basically a front end for 'emmeans'.
## Users are encouraged to switch the rest of the way.
## See help('transition') for more information, including how to
## convert old 'lsmeans' objects and scripts to work with 'emmeans'.
```

```
#install.packages("trend")
library(trend)
```

```
## Warning: package 'trend' was built under R version 3.5.3
```

```
#Reading in the raw lake dataset
NTLR_raw <- read.csv("V:/ENV_872_Project_Directory/Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv")
View(NTLR_raw)

#setting a theme for plots
mytheme <- mytheme <- theme_classic(base_size = 12.2696)+
  theme(axis.text = element_text(color = "Blue"),
  legend.position = "top")
theme_set(mytheme)
```

Next steps (document everything with comments as you work): Change the date column to dates Filter to generate a dataset for each of the nine lakes. Determine how to set a thermocline benchmark (July average?) Determine what data to compare to over time (see Kateri's comment) Run that comparison for each lake Figure out how to compare each of the lakes to eachother to look for overall trends - maybe correlated with maximum depth -maybe compare average temperature and temperature range? -Mann-Kendall to look for trends between lakes controlling for seasonality (o2 and temperature) -Look at each lake individually for both o2 and temperature to look for trends Make a bunch of graphs Write the report (you might have to knit it to Word for your own sanity) Go fishing

Change the date column to dates

```
#Changing the date column to read as a date
class(NTLR_raw$sampledate)
```

```
## [1] "factor"
```

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

```
## [1] "Date"
```

Filter to generate a dataset for each of the nine lakes.

```
unique(NTLR_raw$lakename)  # This data summary gives me the names of the nine lakes.
```

```
## [1] Paul Lake         Peter Lake        Tuesday Lake      East Long Lake
```

```
## [5] West Long Lake    Central Long Lake Hummingbird Lake  Crampton Lake
## [9] Ward Lake
## 9 Levels: Central Long Lake Crampton Lake ... West Long Lake
```

```r
Paullake_raw <- NTLR_raw %>%
  filter(lakename == "Paul Lake")
```

```
## Warning: package 'bindrcpp' was built under R version 3.5.2
```

```r
Peterlake_raw <- NTLR_raw %>%
  filter(lakename == "Peter Lake")
Tuesdaylake_raw <- NTLR_raw %>%
  filter(lakename == "Tuesday Lake")
Eastlonglake_raw <- NTLR_raw %>%
  filter(lakename == "East Long Lake")
Westlonglake_raw <- NTLR_raw %>%
  filter(lakename == "West Long Lake")
Centrallonglake_raw <- NTLR_raw %>%
  filter(lakename == "Central Long Lake")
Hummingbirdlake_raw <- NTLR_raw %>%
  filter(lakename == "Hummingbird Lake")
Cramptonlake_raw <- NTLR_raw %>%
  filter(lakename == "Crampton Lake")
Wardlake_raw <- NTLR_raw %>%
  filter(lakename == "Ward Lake")
```

Determine how to set a thermocline benchmark (July average?) "Keith, great idea. You might run into limitations answering this question due to sparse depth measurements and/or not enough temporal resolution. In that case, I might suggest a few options: (1) choose certain depths and compare along time series (i.e., hold depth constant and compare across time), (2) pay attention to the depth_id, which corresponds to a certain percent of surface irradiance (see NTL-LTER website for more info). Light could be used in addition to or separately from temperature data, (3) Analyze O2 in addition to temperature - this will give you an indication about development of hypoxia (when and at what depth) and how that might change over time. So, lots of places to pivot if you don't have enough resolution to answer your question at face value."

Determine how to set a thermocline benchmark: It looks like there is not enough temporal resolution to measure close-to-continuous change in thermocline depth over the course of a given season. Likewise, there is not enough close-to-continous depth measurements taken at each lake, nor is there consistant data taken below 10 meters of depth. As such, I will compare what is occurring at 7 meters depth at each lake over time. 7 meters, I know from my experience as a fisherman, is on the shallow end of where a thermocline sets up in a northern US lake. Therefore, evaluating what is happening at 7m depth in each lake will give a good idea what sorts of conditions trout are dealing with in these lakes in the summmer. I expect there to be more variation by year at 7 meters depth than at, say, 10 meters depth. Looking at 7 meters will give a better picture of whether the thermocline in these lakes is changing over time. Of course, this is more academic than practical if trout do not live in these lakes.

I will look at two indicators of thermocline establishment at 7 meters: temperature and dissolved oxygen content. I would expect water at or below the thermocline to have low temperatures and hypoxic conditions (low oxygen levels).

My research question, then, is as follows:

How have temperature and oxygen conditions changed at 7 meters depth in a series of Wisconsin Lakes? Is climate change affecting where the thermocline sets up in these lakes?

```r
#filtering for just the data at 7m depths in summer (June 20-September 21)
Paullake_processed <- Paullake_raw %>%
  filter(depth == 7, daynum %in% 172:264) %>%
```

```r
  select(lakename:dissolvedOxygen) %>%
  mutate(Week = week(sampledate)) %>%
  na.exclude()
dim(Paullake_processed)
```

```
## [1] 355   8
```

```r
#Enough datapoints to analyse this lake.

Peterlake_processed <- Peterlake_raw %>%
  filter(depth == 7, daynum %in% 172:264)%>%
  select(lakename:dissolvedOxygen) %>%
  mutate(Week = week(sampledate)) %>%
  na.exclude()
dim(Peterlake_processed)
```

```
## [1] 351   8
```

```r
#Enough datapoints to analyse this lake.

Tuesdaylake_processed <- Tuesdaylake_raw %>%
  filter(depth == 7, daynum %in% 172:264)%>%
  select(lakename:dissolvedOxygen) %>%
  mutate(Week = week(sampledate)) %>%
  na.exclude()
dim(Tuesdaylake_processed) #Enough datapoints to analyse this lake.
```

```
## [1] 197   8
```

```r
Eastlonglake_processed <- Eastlonglake_raw %>%
  filter(depth == 7, daynum %in% 172:264)%>%
  select(lakename:dissolvedOxygen) %>%
  mutate(Week = week(sampledate)) %>%
  na.exclude()
dim(Eastlonglake_processed)
```

```
## [1] 127   8
```

```r
#Enough datapoints to analyse this lake.

Westlonglake_processed <- Westlonglake_raw %>%
  filter(depth == 7, daynum %in% 172:264)%>%
  select(lakename:dissolvedOxygen) %>%
  mutate(Week = week(sampledate)) %>%
  na.exclude()
dim(Westlonglake_processed)
```

```
## [1] 136   8
```

```r
#Enough datapoints to analyse this lake.

Centrallonglake_processed <- Centrallonglake_raw %>%
  filter(depth == 7, daynum %in% 172:264)%>%
  select(lakename:dissolvedOxygen) %>%
  mutate(Week = week(sampledate)) %>%
  na.exclude()
dim(Centrallonglake_processed)
```

```
## [1] 0 8
```

```r
#There are 0 data points taken on Central Long Lake below 4 meters. Unfortunately, I am going to have t

Hummingbirdlake_processed <- Hummingbirdlake_raw %>%
  filter(depth == 7, daynum %in% 172:264)%>%
  select(lakename:dissolvedOxygen) %>%
  mutate(Week = week(sampledate)) %>%
  na.exclude()
dim(Hummingbirdlake_processed)
```

```
## [1] 1 8
```

```r
#Hummingbird lake only has one datapoint at 7 meters. Unfortunately, I am going to have to eliminate Hu

Cramptonlake_processed <- Cramptonlake_raw %>%
  filter(depth == 7, daynum %in% 172:264)%>%
  select(lakename:dissolvedOxygen) %>%
  mutate(Week = week(sampledate)) %>%
  na.exclude()
dim(Cramptonlake_processed)
```

```
## [1] 34  8
```

```r
#There are only 34 datapoints, not enough datapoints to analyse this lake.

Wardlake_processed <- Wardlake_raw %>%
  filter(depth == 7, daynum %in% 172:264)%>%
  select(lakename:dissolvedOxygen) %>%
  mutate(Week = week(sampledate)) %>%
  na.exclude()
dim(Wardlake_processed)
```

```
## [1] 11  8
```

```r
#Ward lake only has 11 datapoints at 7 meters. Unfortunately, I am going to have to eliminate Ward Lake
```

After deciding on what question I wanted to answer and what data I wanted to use to answer my question, I unfortunately had to eliminate three lakes from my analysis. I still have five lakes to perform my analysis on.

```r
#Combining the processed lake data into one file for later analysis
NTL_processed <- rbind(Paullake_processed, Peterlake_processed, Tuesdaylake_processed,
                          Eastlonglake_processed, Westlonglake_processed)
View(NTL_processed)
unique(NTL_processed$lakename)
```

```
## [1] Paul Lake      Peter Lake     Tuesday Lake   East Long Lake
## [5] West Long Lake
## 9 Levels: Central Long Lake Crampton Lake ... West Long Lake
```

```r
dim(NTL_processed)
```

```
## [1] 1166    8
```

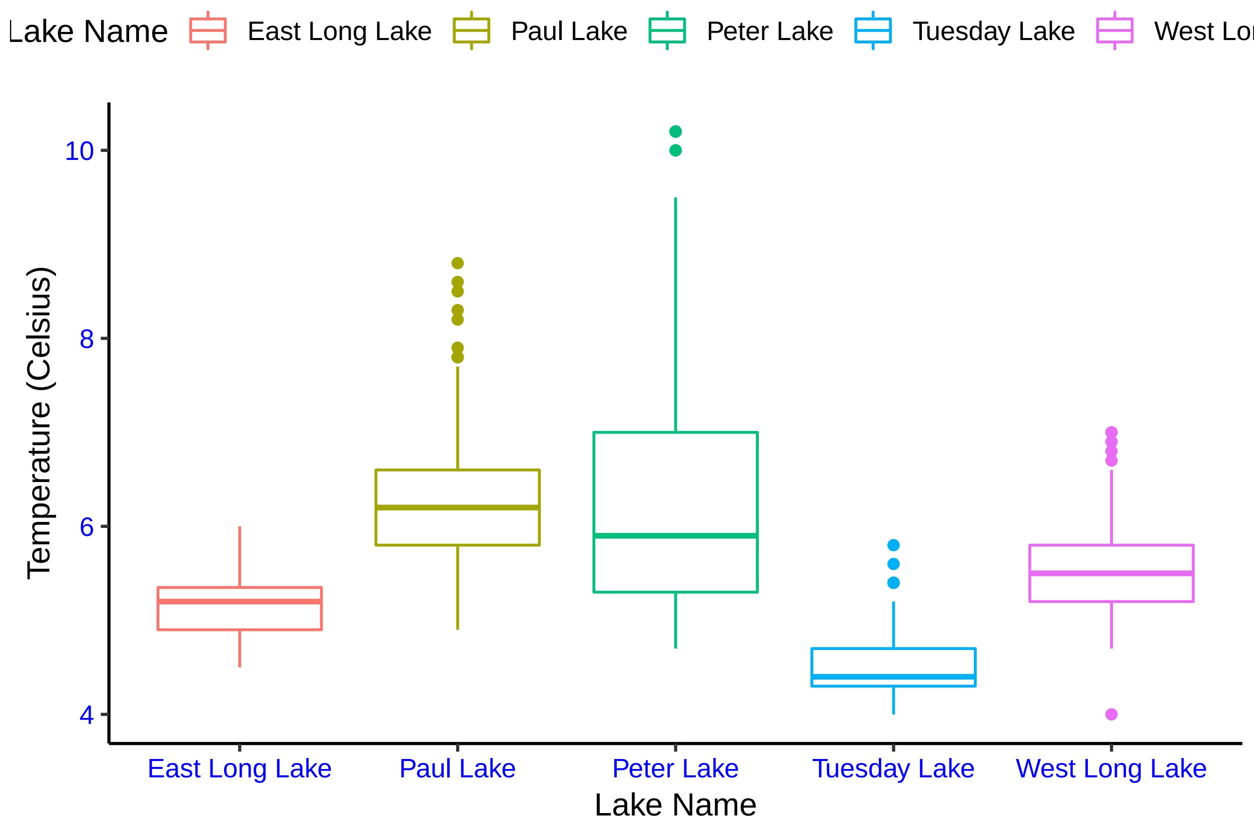
```r
head(NTL_processed)
```

```
##    lakename year4 daynum sampledate depth temperature_C dissolvedOxygen
## 1 Paul Lake  1984    176 1984-06-24     7           5.5             0.3
## 2 Paul Lake  1984    183 1984-07-01     7           5.7             0.5
```

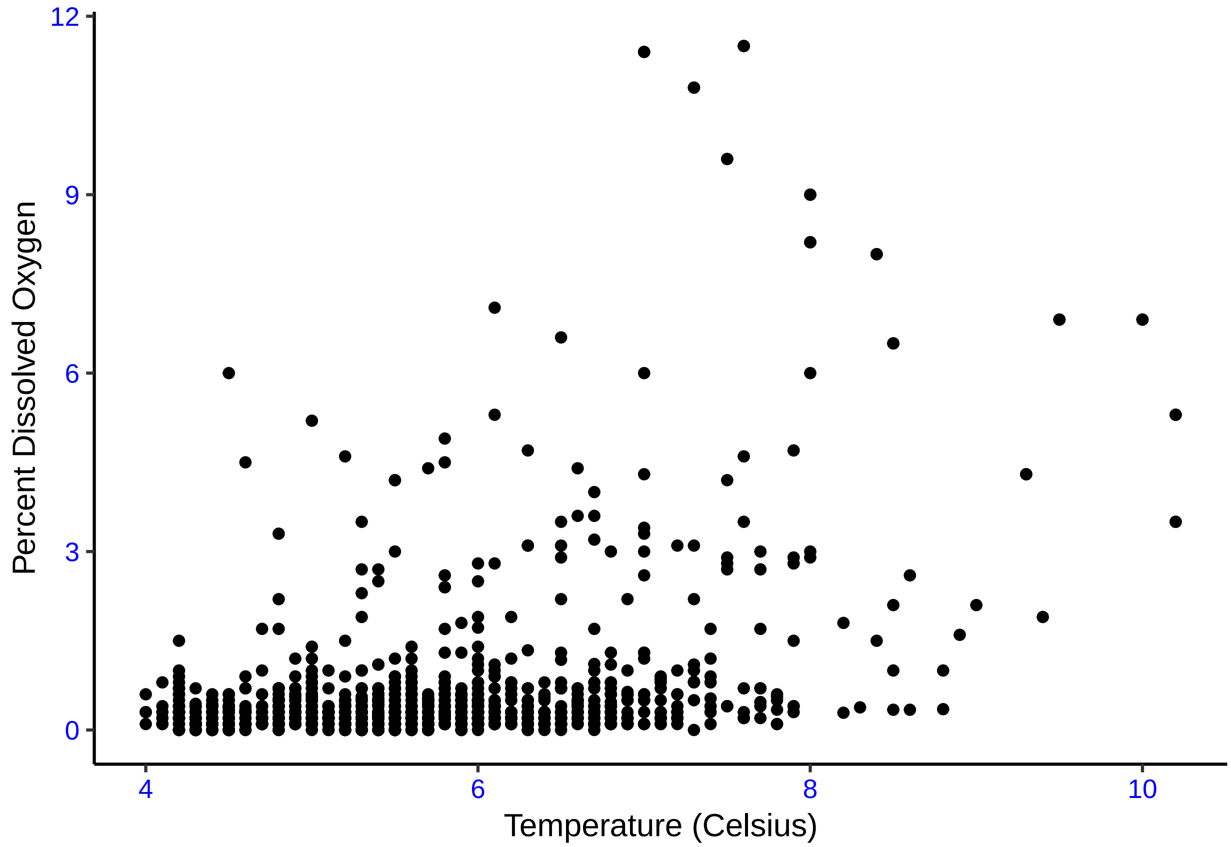
```
## 3 Paul Lake  1984    190 1984-07-08     7            5.9             0.5
## 4 Paul Lake  1984    197 1984-07-15     7            5.8             0.4
## 5 Paul Lake  1984    204 1984-07-22     7            5.9             0.4
## 6 Paul Lake  1984    211 1984-07-29     7            6.3             0.4
##   Week
## 1   26
## 2   27
## 3   28
## 4   29
## 5   30
## 6   31
```

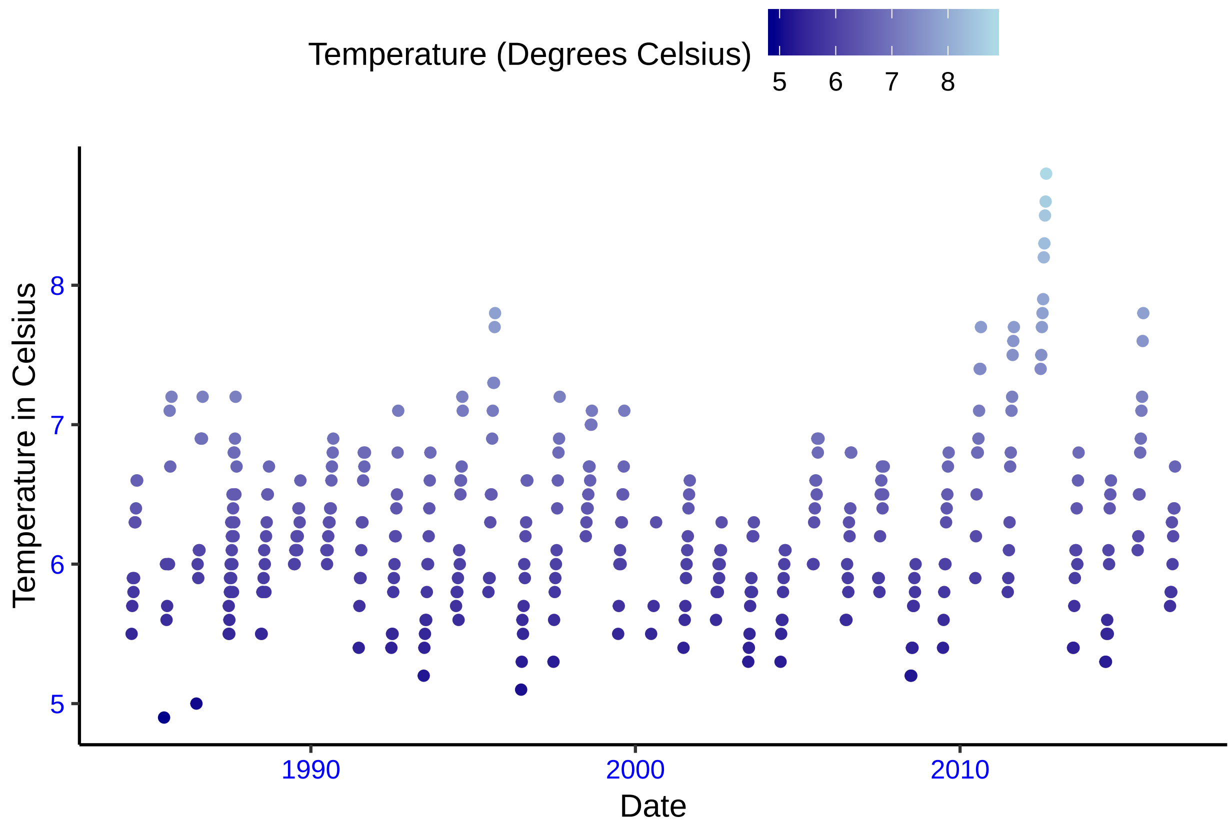
A little data visualization before my data analysis.

See in **??** the temperature data distribution for each lake at 7m depth. This figure tells us which lakes are coldest

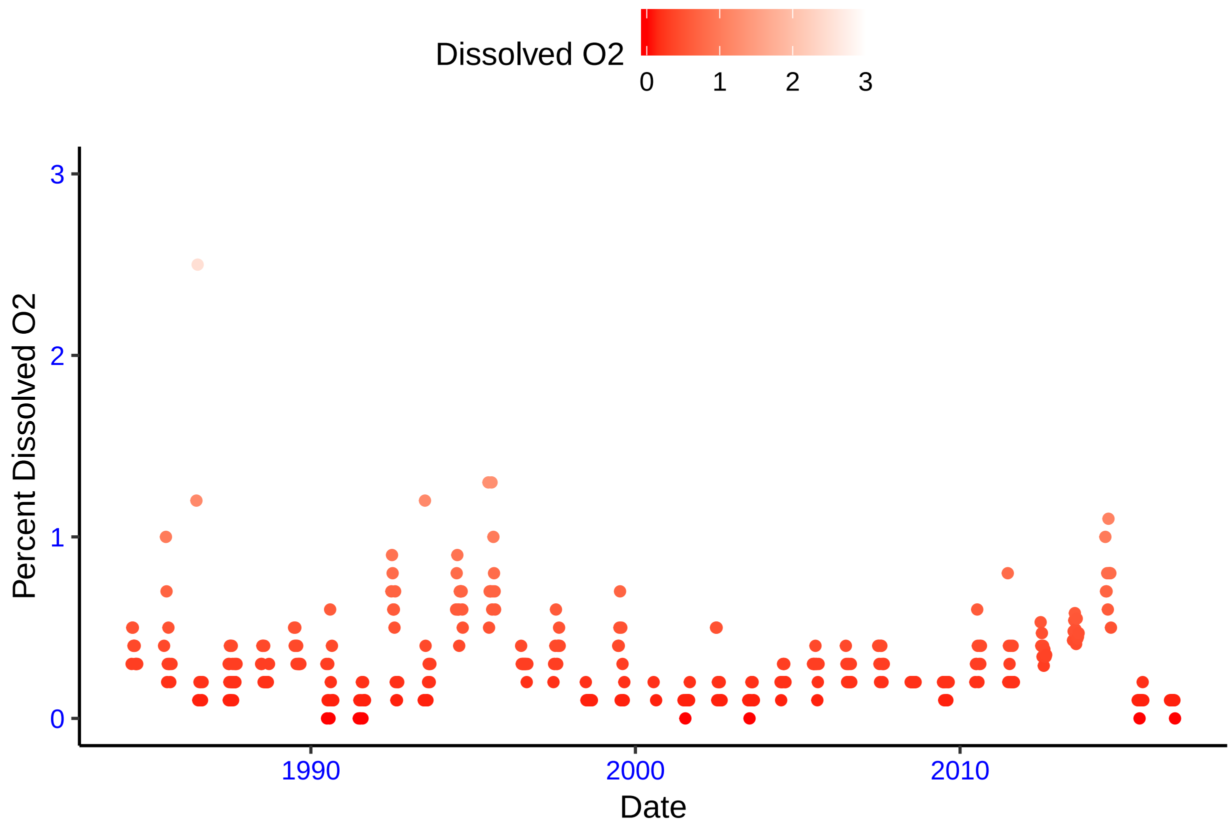


in the summer.

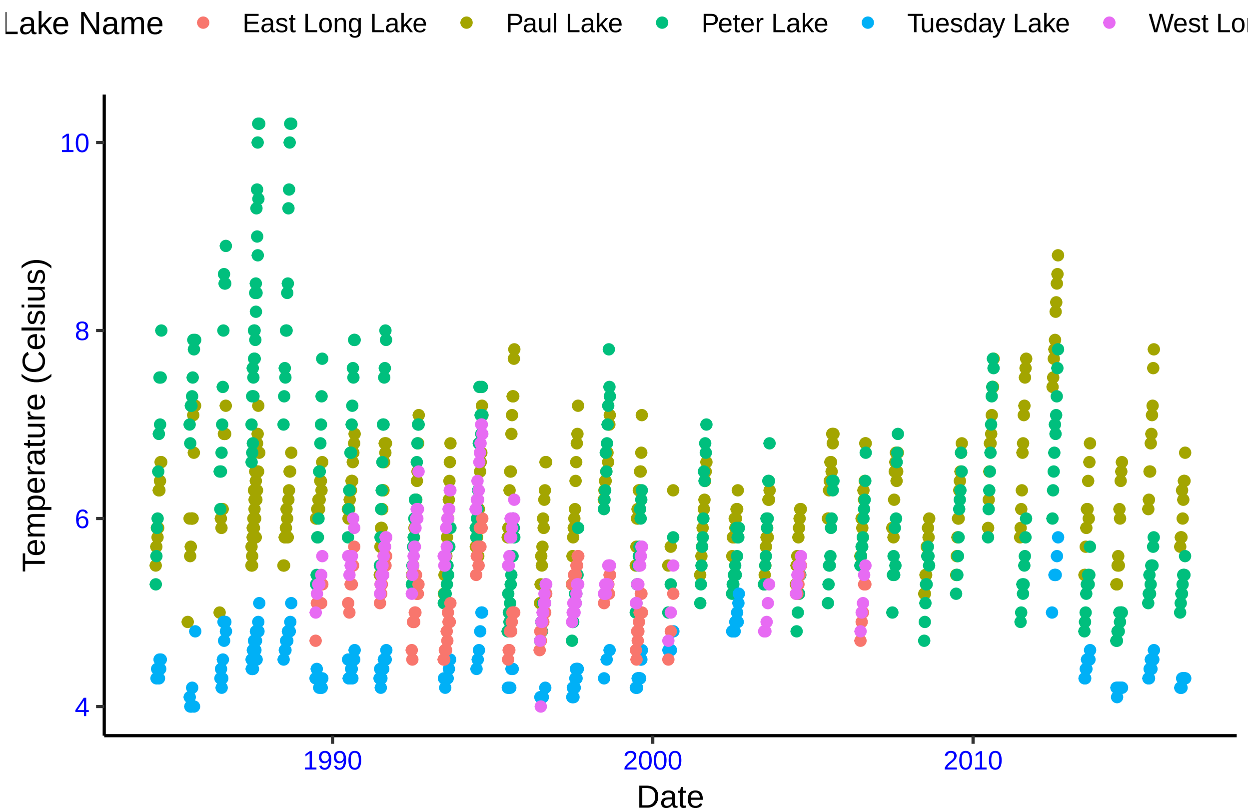

12
9
6
3
0
Percent Dissolved Oxygen
4
6
8
10
Temperature (Celsius)



Temperature (Degrees Celsius)
5
6
7
8
Temperature in Celsius
8
7
6
5
1990
2000
2010
Date



Dissolved O2
0
1
2
3
Percent Dissolved O2
Date
1990
2000
2010



Now that I have visualized my data, it is time to start running statistical tests on it in order to answer my research question. I am interested in two parameters at 7 meters depth, temperature and dissolved oxygen content. I will run a repeated measures ANOVA on the combined processed dataset, which contains data from five lakes. I will first run the test on temperature and then on dissolved oxygen. These two tests takes into account autocorrelation within a given year and within a given lake.

```
#Accounting for autocorrelation
Alllakestemptest.auto <- lme(data = NTL_processed,
                     temperature_C ~ sampledate * lakename, #fixed effects portion of model: response v
                     random = ~1|Week)  # this is the random effect portion of the model
Alllakestemptest.auto
```

```
## Linear mixed-effects model fit by REML
##   Data: NTL_processed
##   Log-restricted-likelihood: -1115.039
##   Fixed: temperature_C ~ sampledate * lakename
##                    (Intercept)                      sampledate
##                   5.272491e+00                   -2.594702e-06
##               lakenamePaul Lake              lakenamePeter Lake
##                   6.674286e-01                    2.857278e+00
##            lakenameTuesday Lake           lakenameWest Long Lake
##                  -7.952465e-01                    1.303065e+00
##      sampledate:lakenamePaul Lake     sampledate:lakenamePeter Lake
##                   4.527449e-05                   -1.592099e-04
##   sampledate:lakenameTuesday Lake sampledate:lakenameWest Long Lake
##                   1.436851e-05                   -9.102572e-05
##
```

```
## Random effects:
##  Formula: ~1 | Week
##         (Intercept)  Residual
## StdDev:   0.4782782 0.5869904
##
## Number of Observations: 1166
## Number of Groups: 14
```

```r
# we care about the Stddeviation between each week
ACF(Alllakestemptest.auto)
```

```
##    lag         ACF
## 1    0  1.00000000
## 2    1  0.30030325
## 3    2  0.17631594
## 4    3  0.16396185
## 5    4  0.09572205
## 6    5  0.02603781
## 7    6  0.04758664
## 8    7  0.01355097
## 9    8 -0.03009261
## 10   9 -0.01841401
## 11  10  0.01043748
## 12  11 -0.08491264
## 13  12 -0.02546651
## 14  13 -0.03374768
## 15  14 -0.11342657
## 16  15 -0.09191131
## 17  16 -0.02084283
## 18  17 -0.06995509
## 19  18 -0.14331117
## 20  19 -0.04230610
## 21  20  0.02734688
```

```r
# we care about the lag of 1's value. This tells us how much temperature is autocorrelated within a giv

#running the ANOVA
Alllakestemptest.mixed <- lme(data = NTL_processed,
                     temperature_C ~ sampledate * lakename,
                     random = ~1|Week,
                     correlation = corAR1(form = ~ sampledate/lakename|Week, value = 0.2323), #correlat
                     method = "REML")
```

```
## Warning in eval(aux[[2]], object): Incompatible methods ("Ops.Date",
## "Ops.factor") for "/"

## Warning in eval(aux[[2]], object): Incompatible methods ("Ops.Date",
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```

```
## "Ops.factor") for "/"

## Warning in eval(aux[[2]], object): Incompatible methods ("Ops.Date",
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## "Ops.factor") for "/"

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## "Ops.factor") for "/"

## Warning in eval(aux[[2]], object): Incompatible methods ("Ops.Date",
## "Ops.factor") for "/"
```

```r
summary(Alllakestemptest.mixed)
```

```
## Linear mixed-effects model fit by REML
##  Data: NTL_processed
##        AIC      BIC    logLik
##   2218.312 2283.998 -1096.156
##
## Random effects:
##  Formula: ~1 | Week
##         (Intercept)  Residual
## StdDev:   0.4868318 0.5787918
##
## Correlation Structure: ARMA(1,0)
##  Formula: ~sampledate/lakename | Week
##  Parameter estimate(s):
##      Phi1
## 0.6268315
## Fixed effects: temperature_C ~ sampledate * lakename
##                                   Value Std.Error   DF   t-value
## (Intercept)                    5.280447 0.3570871 1143 14.787559
## sampledate                    -0.000003 0.0000346 1143 -0.080810
## lakenamePaul Lake              0.630933 0.3475820 1143  1.815207
## lakenamePeter Lake             2.697730 0.3474224 1143  7.764987
## lakenameTuesday Lake          -0.835473 0.3526892 1143 -2.368865
## lakenameWest Long Lake         1.338440 0.4495996 1143  2.976961
## sampledate:lakenamePaul Lake   0.000048 0.0000358 1143  1.339615
```

```
## sampledate:lakenamePeter Lake     -0.000147 0.0000358 1143 -4.124955
## sampledate:lakenameTuesday Lake    0.000017 0.0000363 1143  0.470521
## sampledate:lakenameWest Long Lake -0.000095 0.0000465 1143 -2.040667
##                                   p-value
## (Intercept)                        0.0000
## sampledate                         0.9356
## lakenamePaul Lake                  0.0698
## lakenamePeter Lake                 0.0000
## lakenameTuesday Lake               0.0180
## lakenameWest Long Lake             0.0030
## sampledate:lakenamePaul Lake       0.1806
## sampledate:lakenamePeter Lake      0.0000
## sampledate:lakenameTuesday Lake    0.6381
## sampledate:lakenameWest Long Lake  0.0415
##  Correlation:
##                                   (Intr) smpldt lknmPlL lknmPtL lknmTL
## sampledate                        -0.918
## lakenamePaul Lake                 -0.889  0.943
## lakenamePeter Lake                -0.889  0.943  0.912
## lakenameTuesday Lake              -0.875  0.929  0.898   0.899
## lakenameWest Long Lake            -0.683  0.726  0.701   0.702   0.692
## sampledate:lakenamePaul Lake       0.890 -0.968 -0.984  -0.913  -0.900
## sampledate:lakenamePeter Lake      0.889 -0.967 -0.913  -0.984  -0.899
## sampledate:lakenameTuesday Lake    0.876 -0.952 -0.899  -0.899  -0.982
## sampledate:lakenameWest Long Lake  0.681 -0.741 -0.699  -0.699  -0.690
##                                   lknWLL smpldt:lknmPlL smpldt:lknmPtL
## sampledate
## lakenamePaul Lake
## lakenamePeter Lake
## lakenameTuesday Lake
## lakenameWest Long Lake
## sampledate:lakenamePaul Lake      -0.703
## sampledate:lakenamePeter Lake     -0.703  0.937
## sampledate:lakenameTuesday Lake   -0.693  0.922          0.922
## sampledate:lakenameWest Long Lake -0.987  0.718          0.718
##                                   smp:TL
## sampledate
## lakenamePaul Lake
## lakenamePeter Lake
## lakenameTuesday Lake
## lakenameWest Long Lake
## sampledate:lakenamePaul Lake
## sampledate:lakenamePeter Lake
## sampledate:lakenameTuesday Lake
## sampledate:lakenameWest Long Lake  0.707
##
## Standardized Within-Group Residuals:
##         Min          Q1         Med          Q3         Max
## -2.87087159 -0.54707644 -0.05004423  0.44132449  5.00983807
##
## Number of Observations: 1166
## Number of Groups: 14
```

```r
#There is not a significant trend among all of the lakes at 7m.
```

The results from our mixed effects test demonstrates an important finding. Observe that the p-value for sampledate is 0.94. This means that we can reject the null hypothesis that there is a significant linear correlation between date and temperature of the combined dataset at 7 meters. This does not supports the idea that the temperature at 7 meters in these lakes as a group is changing.

```r
#oxygen may be autocorrelated with temperature
#copy from above, and plug in the oxygen data
#Accounting for autocorrelation
Alllakesoxygentest.auto <- lme(data = NTL_processed,
                     dissolvedOxygen ~ sampledate * lakename, #fixed effects portion of model: response
                     random = ~1|Week)  # this is the random effect portion of the model
Alllakesoxygentest.auto
```

```
## Linear mixed-effects model fit by REML
##   Data: NTL_processed
##   Log-restricted-likelihood: -1818.644
##   Fixed: dissolvedOxygen ~ sampledate * lakename
##                      (Intercept)                        sampledate
##                    -2.223387e-01                      5.794808e-05
##                 lakenamePaul Lake                lakenamePeter Lake
##                     6.045108e-01                      5.592896e+00
##              lakenameTuesday Lake            lakenameWest Long Lake
##                     3.712012e-01                      4.404329e-01
##       sampledate:lakenamePaul Lake      sampledate:lakenamePeter Lake
##                    -6.381108e-05                     -4.104614e-04
##    sampledate:lakenameTuesday Lake sampledate:lakenameWest Long Lake
##                    -4.852979e-05                     -5.360487e-05
##
## Random effects:
##  Formula: ~1 | Week
##         (Intercept) Residual
## StdDev:   0.1085113 1.098537
##
## Number of Observations: 1166
## Number of Groups: 14
```

```r
# we care about the Stddeviation between each week
ACF(Alllakesoxygentest.auto)
```

```
##    lag          ACF
## 1    0  1.000000000
## 2    1  0.064503074
## 3    2  0.287520890
## 4    3  0.152613685
## 5    4 -0.055392421
## 6    5  0.008574120
## 7    6 -0.039858173
## 8    7 -0.146340969
## 9    8 -0.146839546
## 10   9 -0.064558016
## 11  10 -0.135531947
## 12  11 -0.144567507
## 13  12 -0.084667262
```

```
## 14  13 -0.104176435
## 15  14 -0.035019680
## 16  15 -0.058042007
## 17  16 -0.041918323
## 18  17 -0.028473480
## 19  18 -0.044312102
## 20  19  0.014538690
## 21  20 -0.002689453
```

```
# we care about the lag of 1's value. This tells us how much temperature is autocorrelated within a giv

#running the ANOVA
Alllakesoxygentest.mixed <- lme(data = NTL_processed,
                     dissolvedOxygen ~ sampledate * lakename,
                     random = ~1|Week,
                     correlation = corAR1(form = ~ sampledate/lakename|Week, value = 0.0645), #correlat
                     method = "REML")
```

```
## Warning in eval(aux[[2]], object): Incompatible methods ("Ops.Date",
## "Ops.factor") for "/"

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```

```
## "Ops.factor") for "/"

## Warning in eval(aux[[2]], object): Incompatible methods ("Ops.Date",
## "Ops.factor") for "/"
```

```r
summary(Alllakesoxygentest.mixed)
```

```
## Linear mixed-effects model fit by REML
##  Data: NTL_processed
##        AIC      BIC    logLik
##   3913.639 3979.324 -1943.819
##
## Random effects:
##  Formula: ~1 | Week
##         (Intercept) Residual
## StdDev:   0.1024103 1.225626
##
## Correlation Structure: ARMA(1,0)
##  Formula: ~sampledate/lakename | Week
##  Parameter estimate(s):
##       Phi1
## -0.3060796
## Fixed effects: dissolvedOxygen ~ sampledate * lakename
##                                     Value Std.Error   DF   t-value
## (Intercept)                     -0.225185 0.7022547 1143 -0.320660
## sampledate                       0.000058 0.0000732 1143  0.795956
## lakenamePaul Lake                0.609414 0.7326343 1143  0.831812
## lakenamePeter Lake               5.783848 0.7333473 1143  7.886915
## lakenameTuesday Lake             0.382413 0.7440595 1143  0.513955
## lakenameWest Long Lake           0.443015 0.9451461 1143  0.468726
## sampledate:lakenamePaul Lake    -0.000064 0.0000755 1143 -0.850561
## sampledate:lakenamePeter Lake   -0.000424 0.0000755 1143 -5.617511
## sampledate:lakenameTuesday Lake -0.000049 0.0000767 1143 -0.643533
## sampledate:lakenameWest Long Lake -0.000053 0.0000976 1143 -0.543389
##                                 p-value
## (Intercept)                      0.7485
## sampledate                       0.4262
## lakenamePaul Lake                0.4057
## lakenamePeter Lake               0.0000
## lakenameTuesday Lake             0.6074
## lakenameWest Long Lake           0.6394
## sampledate:lakenamePaul Lake     0.3952
## sampledate:lakenamePeter Lake    0.0000
## sampledate:lakenameTuesday Lake  0.5200
## sampledate:lakenameWest Long Lake  0.5870
##  Correlation:
##                                 (Intr) smpldt lknmPlL lknmPtL lknmTL
## sampledate                      -0.987
## lakenamePaul Lake               -0.957  0.946
## lakenamePeter Lake              -0.956  0.945  0.916
## lakenameTuesday Lake            -0.942  0.931  0.903   0.902
## lakenameWest Long Lake          -0.741  0.732  0.710   0.709   0.699
## sampledate:lakenamePaul Lake     0.957 -0.969 -0.984  -0.916  -0.903
## sampledate:lakenamePeter Lake    0.956 -0.968 -0.916  -0.984  -0.902
## sampledate:lakenameTuesday Lake  0.941 -0.954 -0.902  -0.901  -0.982
```

```
## sampledate:lakenameWest Long Lake  0.739 -0.749 -0.709  -0.708  -0.698
##                                   lknWLL smpldt:lknmPlL smpldt:lknmPtL
## sampledate
## lakenamePaul Lake
## lakenamePeter Lake
## lakenameTuesday Lake
## lakenameWest Long Lake
## sampledate:lakenamePaul Lake      -0.710
## sampledate:lakenamePeter Lake     -0.710  0.939
## sampledate:lakenameTuesday Lake   -0.699  0.925          0.924
## sampledate:lakenameWest Long Lake -0.987  0.726          0.726
##                                   smp:TL
## sampledate
## lakenamePaul Lake
## lakenamePeter Lake
## lakenameTuesday Lake
## lakenameWest Long Lake
## sampledate:lakenamePaul Lake
## sampledate:lakenamePeter Lake
## sampledate:lakenameTuesday Lake
## sampledate:lakenameWest Long Lake  0.715
##
## Standardized Within-Group Residuals:
##         Min          Q1         Med          Q3         Max
## -2.56384702 -0.20032978 -0.06631274  0.10790173  6.81098115
##
## Number of Observations: 1166
## Number of Groups: 14
```

```
#There is not a significant trend among all of the lakes at 7m.
```

The results from our mixed effects test demonstrates an important finding. Observe that the p-value for sampledate is 0.43. This means that we can reject the null hypothesis that there is a significant linear correlation between date and dissolved oxygen content of combined dataset at 7 meters. This does not supports the idea that the dissolved oxygen at 7 meters in these lakes as a group is changing.

While we have rejected the null hypothesis that there is a significant linear trend between the five lakes for either temperature or dissolved oxygen, we can still look at trends in the individual lakes. In order to do this, a seasonal Mann-Kendall test is appropriate. I will run 10 seasonal Mann Kendall tests (five lakes and two parameters per lake). I will set each year's summer as its own season.

```
#Paul Lake
length(unique(Paullake_processed$year4)) #Tells me how many summers are in the dataset.
```

```
## [1] 33
```

```
Paullaketemp_ts <- ts(Paullake_processed$temperature_C,
                      start = c(1984), frequency = 33)
Paullaketemp_ts
```

```
## Time Series:
## Start = c(1984, 1)
## End = c(1994, 25)
## Frequency = 33
##   [1] 5.5 5.7 5.9 5.8 5.9 6.3 6.3 6.4 6.6 6.6 4.9 6.0 5.6 5.7 6.0 6.0 6.0
##  [18] 7.1 6.7 7.2 5.0 6.0 5.9 6.1 6.1 6.9 6.9 6.9 7.2 5.5 5.7 5.5 5.6 5.8
##  [35] 5.9 5.8 6.0 5.9 6.3 6.1 6.2 6.0 6.5 5.8 6.4 6.2 6.8 6.3 6.8 6.5 6.9
```

```
##  [52] 6.5 7.2 6.7 5.5 5.5 5.8 5.8 5.9 6.1 6.0 5.8 6.2 6.3 6.5 6.5 6.7 6.0
##  [69] 6.0 6.1 6.1 6.2 6.1 6.2 6.4 6.4 6.3 6.6 6.1 6.0 6.1 6.2 6.3 6.3 6.4
##  [86] 6.4 6.6 6.7 6.8 6.9 5.4 5.7 5.9 5.9 6.1 6.3 6.3 6.6 6.8 6.7 6.8 5.4
## [103] 5.5 5.5 5.8 5.9 6.0 6.2 6.2 6.4 6.5 6.8 7.1 5.2 5.4 5.5 5.6 5.6 5.8
## [120] 6.0 6.0 6.2 6.4 6.6 6.8 5.7 5.8 5.8 5.9 5.6 6.1 6.0 6.5 6.6 6.6 6.7
## [137] 7.2 7.1 5.8 5.9 5.9 6.3 6.5 6.5 6.9 7.1 7.3 7.3 7.7 7.8 5.1 5.3 5.6
## [154] 5.5 5.7 6.0 5.9 6.2 6.3 6.6 6.6 5.3 5.6 5.8 5.9 6.0 6.1 6.4 6.6 6.8
## [171] 6.9 7.2 6.2 6.3 6.4 6.4 6.5 6.7 6.7 6.6 7.0 7.0 7.1 5.5 5.7 6.0 6.1
## [188] 6.0 6.3 6.3 6.5 6.5 6.7 7.1 5.5 5.7 6.3 5.4 5.6 5.7 5.9 6.0 6.1 6.2
## [205] 6.4 6.5 6.6 5.6 5.8 5.8 5.8 6.0 5.9 6.0 6.1 6.1 6.3 5.3 5.4 5.5 5.7
## [222] 5.8 5.9 5.8 6.2 6.2 6.3 5.3 5.5 5.6 5.6 5.8 5.9 6.0 6.1 6.1 6.0 6.0
## [239] 6.3 6.4 6.6 6.6 6.5 6.9 6.8 6.9 5.6 5.6 6.0 5.9 5.8 6.3 6.2 6.4 6.8
## [256] 6.8 5.9 5.9 5.8 6.2 6.5 6.6 6.7 6.4 6.5 6.7 5.2 5.2 5.4 5.4 5.7 5.7
## [273] 5.9 5.8 6.0 5.4 5.6 5.8 6.0 6.0 6.3 6.4 6.5 6.7 6.8 5.9 6.2 6.5 6.8
## [290] 6.8 6.9 7.1 7.4 7.4 7.7 5.8 5.9 6.1 6.3 6.7 6.8 7.1 7.2 7.5 7.6 7.7
## [307] 7.4 7.5 7.7 7.8 7.9 8.2 8.3 8.5 8.6 8.8 5.4 5.4 5.7 5.9 6.1 6.1 6.4
## [324] 6.0 6.6 6.8 5.3 5.3 5.5 5.6 5.5 6.1 6.0 6.4 6.5 6.6 6.1 6.2 6.5 6.5
## [341] 6.8 6.9 7.1 7.2 7.6 7.8 5.7 5.8 5.8 6.3 6.0 6.2 6.4 6.4 6.7
```

```
Paul_temp_smk <- smk.test(Paullaketemp_ts)
Paul_temp_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data:  Paullaketemp_ts
## z = 2.2304, p-value = 0.02572
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##        S     varS
##  159.000 5018.333
```

```
summary(Paul_temp_smk) #The seasonal Mann Kendall test for temperature at Paul Lake had an overall z-sc
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Paullaketemp_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                      S  varS    tau      z Pr(>|z|)
## Season 1:   S = 0   -7 161.0 -0.132 -0.473 0.636309
## Season 2:   S = 0   12 162.0  0.224  0.864 0.387455
## Season 3:   S = 0    9 160.3  0.170  0.632 0.527519
## Season 4:   S = 0   13 163.0  0.241  0.940 0.347262
## Season 5:   S = 0   11 160.3  0.208  0.790 0.429675
## Season 6:   S = 0   -1 163.0 -0.019  0.000 1.000000
## Season 7:   S = 0   -2 161.3 -0.037 -0.079 0.937248
## Season 8:   S = 0    1 156.3  0.019  0.000 1.000000
## Season 9:   S = 0    8 162.0  0.150  0.550 0.582339
## Season 10:   S = 0  -2 162.0 -0.037 -0.079 0.937377
## Season 11:   S = 0  31 163.0  0.574  2.350 0.018784 *
```

```
## Season 12:   S = 0  11 156.3  0.212  0.800 0.423834
## Season 13:   S = 0  21 163.0  0.389  1.567 0.117227
## Season 14:   S = 0  16 162.0  0.299  1.179 0.238593
## Season 15:   S = 0  20 164.0  0.367  1.484 0.137902
## Season 16:   S = 0  12 161.3  0.224  0.866 0.386476
## Season 17:   S = 0   2 164.0  0.037  0.078 0.937759
## Season 18:   S = 0  -8 164.0 -0.147 -0.547 0.584648
## Season 19:   S = 0  -4 164.0 -0.073 -0.234 0.814783
## Season 20:   S = 0 -16 162.0 -0.299 -1.179 0.238593
## Season 21:   S = 0  -1 160.3 -0.019  0.000 1.000000
## Season 22:   S = 0   4 159.3  0.076  0.238 0.812140
## Season 23:   S = 0  11 161.0  0.208  0.788 0.430632
## Season 24:   S = 0   6 162.0  0.112  0.393 0.694440
## Season 25:   S = 0  22 162.0  0.411  1.650 0.098960 .
## Season 26:   S = 0  -1 123.0 -0.023  0.000 1.000000
## Season 27:   S = 0  -1 123.0 -0.023  0.000 1.000000
## Season 28:   S = 0   3 123.0  0.068  0.180 0.856890
## Season 29:   S = 0  12 124.0  0.270  0.988 0.323236
## Season 30:   S = 0  -1 120.3 -0.023  0.000 1.000000
## Season 31:   S = 0  -4 122.0 -0.092 -0.272 0.785924
## Season 32:   S = 0  -7 123.0 -0.159 -0.541 0.588506
## Season 33:   S = 0 -11 120.3 -0.256 -0.912 0.361976
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
Paullakeo2_ts <- ts(Paullake_processed$dissolvedOxygen,
                    start = c(1984), frequency = 33)
Paullakeo2_ts
```

```
## Time Series:
## Start = c(1984, 1)
## End = c(1994, 25)
## Frequency = 33
##   [1] 0.30 0.50 0.50 0.40 0.40 0.40 0.30 0.30 0.30 0.30 0.40 1.00 0.70 0.20
##  [15] 0.30 0.50 0.30 0.30 0.20 0.30 1.20 2.50 0.10 0.10 0.20 0.20 0.10 0.10
##  [29] 0.20 0.30 0.10 0.30 0.20 0.40 0.10 0.40 0.10 0.20 0.10 0.40 0.20 0.20
##  [43] 0.30 0.20 0.10 0.20 0.20 0.20 0.30 0.20 0.20 0.20 0.30 0.30 0.30 0.30
##  [57] 0.40 0.40 0.20 0.40 0.20 0.20 0.20 0.20 0.20 0.20 0.30 0.50 0.40 0.50
##  [71] 0.40 0.30 0.40 0.30 0.30 0.30 0.30 0.30 0.30 0.00 0.10 0.30 0.10 0.00
##  [85] 0.60 0.20 0.10 0.40 0.10 0.10 0.00 0.10 0.00 0.00 0.10 0.20 0.00 0.20
##  [99] 0.10 0.10 0.10 0.70 0.90 0.80 0.60 0.60 0.50 0.70 0.20 0.10 0.10 0.20
## [113] 0.20 0.10 0.10 1.20 0.40 0.10 0.10 0.10 0.20 0.30 0.30 0.20 0.30 0.60
## [127] 0.80 0.90 0.60 0.60 0.40 0.70 0.70 0.70 0.70 0.70 0.60 0.50 1.30 0.50
## [141] 0.70 0.70 0.70 1.30 0.60 0.70 1.00 0.80 0.70 0.60 0.40 0.30 0.30 0.30
## [155] 0.30 0.30 0.30 0.30 0.30 0.20 0.30 0.20 0.30 0.30 0.40 0.60 0.30 0.30
## [169] 0.40 0.40 0.50 0.40 0.20 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10
## [183] 0.10 0.40 0.40 0.50 0.70 0.10 0.50 0.10 0.30 0.10 0.10 0.20 3.00 0.20
## [197] 0.10 0.10 0.10 0.00 0.10 0.10 0.10 0.10 0.10 0.10 0.20 0.50 0.50 0.10
## [211] 0.20 0.10 0.20 0.20 0.10 0.10 0.10 0.10 0.10 0.00 0.10 0.10 0.20 0.20
## [225] 0.20 0.10 0.10 0.20 0.10 0.20 0.20 0.30 0.30 0.30 0.20 0.20 0.30 0.30
## [239] 0.30 0.30 0.40 0.30 0.30 0.10 0.20 0.30 0.40 0.30 0.20 0.30 0.20 0.30
## [253] 0.20 0.20 0.30 0.20 0.40 0.40 0.30 0.20 0.40 0.40 0.30 0.20 0.30 0.30
## [267] 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.10 0.20 0.10
## [281] 0.20 0.10 0.10 0.20 0.20 0.20 0.30 0.30 0.60 0.40 0.20 0.30 0.40 0.30
## [295] 0.40 0.80 0.20 0.40 0.30 0.20 0.40 0.20 0.20 0.40 0.20 0.20 0.53 0.40
```

```
## [309] 0.47 0.34 0.40 0.29 0.38 0.34 0.34 0.35 0.43 0.48 0.54 0.58 0.49 0.41
## [323] 0.55 0.44 0.45 0.47 1.00 0.70 0.70 0.80 0.60 1.10 0.80 0.80 0.80 0.50
## [337] 0.10 0.10 0.10 0.00 0.10 0.10 0.10 0.10 0.20 0.10 0.10 0.10 0.10 0.10
## [351] 0.10 0.10 0.10 0.10 0.00
```

```
Paul_o2_smk <- smk.test(Paullakeo2_ts)
Paul_o2_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data:  Paullakeo2_ts
## z = -0.43408, p-value = 0.6642
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##        S     varS
##  -31.000 4776.333
```

```
summary(Paul_o2_smk) #The seasonal Mann Kendall test for dissolved oxygen at Paul Lake had an overall z
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Paullakeo2_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                       S  varS    tau      z Pr(>|z|)
## Season 1:   S = 0    8 153.3  0.159  0.565 0.571869
## Season 2:   S = 0    5 154.3  0.098  0.322 0.747467
## Season 3:   S = 0  -13 161.0 -0.245 -0.946 0.344285
## Season 4:   S = 0    2 159.3  0.038  0.079 0.936856
## Season 5:   S = 0   -5 151.7 -0.101 -0.325 0.745333
## Season 6:   S = 0   -3 158.3 -0.058 -0.159 0.873713
## Season 7:   S = 0  -15 154.3 -0.295 -1.127 0.259771
## Season 8:   S = 0  -20 150.7 -0.407 -1.548 0.121645
## Season 9:   S = 0  -18 150.7 -0.366 -1.385 0.166062
## Season 10:   S = 0  -5 160.3 -0.094 -0.316 0.752079
## Season 11:   S = 0  -7 158.3 -0.135 -0.477 0.633482
## Season 12:   S = 0  -4 147.3 -0.081 -0.247 0.804788
## Season 13:   S = 0 -18 152.7 -0.358 -1.376 0.168862
## Season 14:   S = 0  -3 147.7 -0.062 -0.165 0.869271
## Season 15:   S = 0   3 151.7  0.060  0.162 0.870991
## Season 16:   S = 0 -14 155.3 -0.272 -1.043 0.296919
## Season 17:   S = 0  -7 154.3 -0.138 -0.483 0.629116
## Season 18:   S = 0  -6 155.3 -0.117 -0.401 0.688289
## Season 19:   S = 0 -11 154.3 -0.216 -0.805 0.420847
## Season 20:   S = 0  -6 154.0 -0.119 -0.403 0.687013
## Season 21:   S = 0  -8 152.7 -0.159 -0.567 0.571031
## Season 22:   S = 0 -19 160.3 -0.359 -1.422 0.155158
## Season 23:   S = 0   7 139.7  0.151  0.508 0.611666
## Season 24:   S = 0   5 147.7  0.103  0.329 0.742028
## Season 25:   S = 0   4 155.3  0.078  0.241 0.809782
```

```
## Season 26:   S = 0  28 116.7  0.677  2.500 0.012429 *
## Season 27:   S = 0  10 122.0  0.230  0.815 0.415174
## Season 28:   S = 0  16 119.3  0.377  1.373 0.169713
## Season 29:   S = 0  10 115.3  0.242  0.838 0.402008
## Season 30:   S = 0  12 115.3  0.290  1.024 0.305707
## Season 31:   S = 0  20 122.0  0.460  1.720 0.085400 .
## Season 32:   S = 0  13 117.7  0.310  1.106 0.268617
## Season 33:   S = 0   8 107.3  0.205  0.676 0.499254
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
#Peter Lake
length(unique(Peterlake_processed$year4)) #Tells me how many summers are in the dataset.
```

```
## [1] 33
```

```r
Peterlaketemp_ts <- ts(Peterlake_processed$temperature_C,
                       start = c(1984), frequency = 33)
Peterlaketemp_ts
```

```
## Time Series:
## Start = c(1984, 1)
## End = c(1994, 21)
## Frequency = 33
##   [1]  5.3  5.6  5.9  6.0  6.5  6.9  7.5  7.0  7.5  8.0  7.0  6.8  7.2  7.2
##  [15]  7.3  7.5  7.9  7.8  7.9  6.5  6.1  6.5  6.7  7.0  7.4  8.0  8.6  8.5
##  [29]  8.5  8.9  7.0  6.6  7.3  6.7  7.6  6.8  7.5  7.3  8.0  7.7  8.0  7.7
##  [43]  8.4  7.9  8.5  8.2  9.3  8.4  9.5  9.0 10.0  8.8 10.2  9.4 10.2  7.0
##  [57]  7.3  7.6  7.5  8.0  8.0  8.4  8.5  9.3  9.5 10.0 10.2 10.2  5.3  5.4
##  [71]  5.8  5.8  6.0  6.5  6.5  6.8  7.0  7.3  7.7  5.8  6.1  6.3  6.3  6.7
##  [85]  6.7  7.0  7.2  7.6  7.5  7.9  7.9  5.5  5.8  6.1  6.3  6.6  7.0  7.0
##  [99]  7.5  7.6  8.0  7.9  5.3  5.5  5.7  5.8  6.0  6.2  6.2  6.2  6.6  6.8
## [113]  7.0  7.0  5.1  5.2  5.2  5.2  5.1  5.3  5.5  5.4  5.7  5.7  5.9  5.9
## [127]  5.9  5.8  6.0  6.1  6.3  6.8  7.4  6.8  7.1  6.9  7.4  7.1  4.8  5.2
## [141]  5.0  4.9  5.1  5.3  5.4  5.9  5.6  6.0  5.9  5.8  4.7  4.8  4.9  4.8
## [155]  4.9  5.1  5.0  5.0  5.1  5.3  5.2  4.7  4.9  4.9  5.1  5.1  5.2  5.1
## [169]  5.2  5.3  5.4  5.9  6.1  6.2  6.3  6.7  6.5  6.8  7.0  7.2  7.8  7.4
## [183]  7.3  5.0  5.1  5.3  5.3  5.5  5.6  5.7  6.1  6.0  6.2  6.3  5.0  5.3
## [197]  5.8  5.1  5.3  5.5  5.7  5.8  6.0  6.5  6.4  6.8  6.7  7.0  5.2  5.3
## [211]  5.3  5.4  5.4  5.5  5.4  5.9  5.6  5.8  5.8  5.9  5.3  5.3  5.5  5.6
## [225]  6.0  5.9  6.0  6.4  6.4  6.8  4.8  5.0  5.2  5.4  5.1  5.3  5.5  5.5
## [239]  5.6  5.9  6.0  6.4  6.3  6.4  5.5  5.6  5.7  5.7  5.8  6.0  6.1  6.2
## [253]  6.4  6.7  5.0  5.4  5.6  5.4  5.9  5.5  6.0  6.6  6.7  6.9  4.7  4.9
## [267]  5.1  5.3  5.3  5.6  5.7  5.6  5.5  5.2  5.4  5.4  5.6  5.8  6.1  6.2
## [281]  6.3  6.7  6.5  5.8  6.1  6.3  6.5  6.7  7.0  7.3  7.4  7.7  7.6  4.9
## [295]  5.0  5.3  5.2  5.3  5.5  5.6  5.8  6.0  6.0  6.3  6.5  6.7  7.0  6.9
## [309]  7.1  7.3  7.6  7.8  4.8  4.9  5.0  5.2  5.3  5.3  5.4  5.3  5.4  5.7
## [323]  4.7  4.7  4.8  4.8  4.8  5.0  4.9  5.0  5.0  5.0  5.1  5.2  5.4  5.2
## [337]  5.3  5.5  5.5  5.5  5.7  5.8  5.0  5.1  5.2  5.2  5.3  5.4  5.4  5.4
## [351]  5.6
```

```r
Peter_temp_smk <- smk.test(Peterlaketemp_ts)
Peter_temp_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
```

```
##
## data:  Peterlaketemp_ts
## z = -9.637, p-value < 2.2e-16
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##    S varS
## -676 4906
```

```r
summary(Peter_temp_smk) #The seasonal Mann Kendall test for temperature at Peter Lake had an overall z-
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Peterlaketemp_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                      S  varS    tau      z Pr(>|z|)
## Season 1:   S = 0  -27 160.3 -0.510 -2.053 0.040039 *
## Season 2:   S = 0  -31 163.0 -0.574 -2.350 0.018784 *
## Season 3:   S = 0  -22 161.3 -0.411 -1.653 0.098266 .
## Season 4:   S = 0  -22 162.0 -0.411 -1.650 0.098960 .
## Season 5:   S = 0  -19 160.3 -0.359 -1.422 0.155158
## Season 6:   S = 0  -25 165.0 -0.455 -1.868 0.061707 .
## Season 7:   S = 0  -21 165.0 -0.382 -1.557 0.119471
## Season 8:   S = 0  -23 163.0 -0.426 -1.723 0.084857 .
## Season 9:   S = 0  -22 162.0 -0.411 -1.650 0.098960 .
## Season 10:   S = 0 -20 164.0 -0.367 -1.484 0.137902
## Season 11:   S = 0 -18 164.0 -0.330 -1.327 0.184351
## Season 12:   S = 0 -20 164.0 -0.367 -1.484 0.137902
## Season 13:   S = 0 -26 164.0 -0.477 -1.952 0.050918 .
## Season 14:   S = 0 -21 163.0 -0.389 -1.567 0.117227
## Season 15:   S = 0 -19 163.0 -0.352 -1.410 0.158578
## Season 16:   S = 0 -25 165.0 -0.455 -1.868 0.061707 .
## Season 17:   S = 0 -26 164.0 -0.477 -1.952 0.050918 .
## Season 18:   S = 0 -25 163.0 -0.463 -1.880 0.060132 .
## Season 19:   S = 0 -14 164.0 -0.257 -1.015 0.310044
## Season 20:   S = 0 -13 163.0 -0.241 -0.940 0.347262
## Season 21:   S = 0 -11 160.3 -0.208 -0.790 0.429675
## Season 22:   S = 0 -13 125.0 -0.289 -1.073 0.283131
## Season 23:   S = 0 -13 123.0 -0.296 -1.082 0.279251
## Season 24:   S = 0 -19 125.0 -0.422 -1.610 0.107405
## Season 25:   S = 0 -14 121.3 -0.322 -1.180 0.237923
## Season 26:   S = 0 -16 124.0 -0.360 -1.347 0.177967
## Season 27:   S = 0 -16 124.0 -0.360 -1.347 0.177967
## Season 28:   S = 0 -20 121.3 -0.460 -1.725 0.084546 .
## Season 29:   S = 0 -22 124.0 -0.494 -1.886 0.059314 .
## Season 30:   S = 0 -28 124.0 -0.629 -2.425 0.015322 *
## Season 31:   S = 0 -21 123.0 -0.477 -1.803 0.071335 .
## Season 32:   S = 0 -20 124.0 -0.449 -1.706 0.087961 .
## Season 33:   S = 0 -24 124.0 -0.539 -2.065 0.038879 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
Peterlakeo2_ts <- ts(Peterlake_processed$dissolvedOxygen,
                     start = c(1984), frequency = 33)
Peterlakeo2_ts
```

```
## Time Series:
## Start = c(1984, 1)
## End = c(1994, 21)
## Frequency = 33
##   [1]  1.90  1.40  1.80  1.40  2.20  2.20  2.90  2.60  2.80  3.00  1.30
##  [12]  1.10  0.60  1.00  0.50  0.40  0.40  0.50  0.30  6.60  7.10  3.10
##  [23]  3.20  3.00  1.70  2.90  2.60  2.10  1.00  1.60 11.40  3.60 10.80
##  [34]  1.70 11.50  1.30  9.60  2.20  9.00  2.70  8.20  1.70  8.00  1.50
##  [45]  6.50  1.80  4.30  1.50  6.90  2.10  6.90  1.00  5.30  1.90  3.50
##  [56] 11.40 10.80 11.50  9.60  9.00  8.20  8.00  6.50  4.30  6.90  6.90
##  [67]  5.30  3.50  2.70  2.50  2.40  2.60  2.80  3.50  2.90  3.00  3.40
##  [78]  3.10  3.00  2.40  2.80  3.10  3.10  4.00  3.60  3.30  3.10  3.50
##  [89]  2.70  2.80  2.90  4.20  4.90  5.30  4.70  4.40  6.00  4.30  4.20
## [100]  4.60  6.00  4.70  3.50  4.20  4.40  4.50  1.90  1.90  1.20  0.30
## [111]  0.50  0.40  0.50  0.60  0.40  0.10  0.90  0.50  0.40  0.20  0.30
## [122]  0.30  0.40  0.40  0.40  0.40  0.50  1.70  1.20  0.90  0.70  0.70
## [133]  0.90  0.80  0.90  1.00  1.20  0.80  1.70  4.60  1.40  1.20  1.00
## [144]  2.30  1.10  1.30  0.90  1.10  0.60  0.70  0.40  0.40  0.40  0.30
## [155]  0.30  0.30  0.30  0.30  0.30  0.20  0.30  0.20  0.30  0.30  0.70
## [166]  0.30  0.20  0.20  0.40  0.40  0.30  0.30  0.20  0.30  0.20  0.50
## [177]  0.30  0.10  0.10  0.20  0.10  0.10  0.00  0.50  0.40  0.20  0.20
## [188]  0.20  0.20  0.20  0.20  0.20  0.30  0.30  5.20  1.00  0.20  0.10
## [199]  0.10  0.10  0.20  0.30  0.10  0.20  0.00  0.10  0.10  0.30  0.30
## [210]  0.70  0.20  0.10  0.20  0.20  0.20  0.10  0.10  0.10  0.20  0.20
## [221]  0.10  0.10  0.30  0.20  0.10  0.30  0.40  0.20  0.30  0.80  0.20
## [232]  0.20  0.30  0.50  0.30  0.30  0.20  0.30  0.20  0.20  0.30  0.30
## [243]  0.20  0.30  0.30  0.30  0.20  0.30  0.30  0.40  0.40  0.30  0.30
## [254]  0.30  1.00  2.70  1.20  0.70  0.60  0.90  0.80  0.60  0.30  0.50
## [265]  0.20  0.30  0.20  0.20  0.20  0.30  0.30  0.30  0.20  0.30  0.40
## [276]  0.60  1.00  0.40  0.90  0.80  0.70  0.80  0.70  0.30  0.30  0.50
## [287]  0.70  1.00  1.30  1.10  0.80  0.70  0.30  0.20  0.20  0.20  0.20
## [298]  0.10  0.20  0.30  0.40  0.50  1.72  1.34  1.18  1.11  1.20  0.64
## [309]  0.85  0.81  0.70  0.56  0.52  0.56  0.55  0.43  0.52  0.49  0.52
## [320]  0.56  0.52  0.44  1.00  0.60  0.70  0.70  0.70  0.80  0.90  0.80
## [331]  0.90  0.40  0.10  0.10  0.30  0.10  0.10  0.10  0.20  0.00  0.10
## [342]  0.10  0.20  0.10  0.10  0.10  0.00  0.10  0.10  0.10  0.10
```

```r
Peter_o2_smk <- smk.test(Peterlakeo2_ts)
Peter_o2_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data:  Peterlakeo2_ts
## z = -10.557, p-value < 2.2e-16
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##        S     varS
## -738.000 4873.333
```

```r
summary(Peter_o2_smk) #The seasonal Mann Kendall test for dissolved oxygen at Peter Lake had an overall
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Peterlakeo2_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                        S  varS    tau      z  Pr(>|z|)
## Season 1:   S = 0  -30 162.0 -0.561 -2.278 0.0226995  *
## Season 2:   S = 0  -25 163.0 -0.463 -1.880 0.0601319  .
## Season 3:   S = 0  -32 161.3 -0.598 -2.441 0.0146622  *
## Season 4:   S = 0  -39 163.0 -0.722 -2.976 0.0029166 **
## Season 5:   S = 0  -27 163.0 -0.500 -2.036 0.0417025  *
## Season 6:   S = 0  -31 163.0 -0.574 -2.350 0.0187844  *
## Season 7:   S = 0  -30 161.3 -0.561 -2.283 0.0224211  *
## Season 8:   S = 0  -27 163.0 -0.500 -2.036 0.0417025  *
## Season 9:   S = 0  -32 161.3 -0.598 -2.441 0.0146622  *
## Season 10:   S = 0 -32 156.7 -0.623 -2.477 0.0132603  *
## Season 11:   S = 0 -26 161.3 -0.486 -1.968 0.0490405  *
## Season 12:   S = 0 -27 165.0 -0.491 -2.024 0.0429601  *
## Season 13:   S = 0 -16 164.0 -0.294 -1.171 0.2414769
## Season 14:   S = 0 -24 161.3 -0.449 -1.811 0.0701749  .
## Season 15:   S = 0 -19 163.0 -0.352 -1.410 0.1585784
## Season 16:   S = 0 -20 162.0 -0.374 -1.493 0.1354945
## Season 17:   S = 0 -12 164.0 -0.220 -0.859 0.3903650
## Season 18:   S = 0 -20 164.0 -0.367 -1.484 0.1379016
## Season 19:   S = 0 -14 162.0 -0.262 -1.021 0.3070761
## Season 20:   S = 0 -32 155.3 -0.623 -2.487 0.0128714  *
## Season 21:   S = 0 -23 160.3 -0.434 -1.737 0.0823089  .
## Season 22:   S = 0 -10 119.3 -0.236 -0.824 0.4100103
## Season 23:   S = 0 -16 121.3 -0.368 -1.362 0.1732730
## Season 24:   S = 0 -18 124.0 -0.405 -1.527 0.1268493
## Season 25:   S = 0 -12 124.0 -0.270 -0.988 0.3232363
## Season 26:   S = 0 -16 124.0 -0.360 -1.347 0.1779674
## Season 27:   S = 0 -15 125.0 -0.333 -1.252 0.2104977
## Season 28:   S = 0  -7 123.0 -0.159 -0.541 0.5885064
## Season 29:   S = 0 -18 121.3 -0.414 -1.543 0.1227507
## Season 30:   S = 0 -20 121.3 -0.460 -1.725 0.0845458  .
## Season 31:   S = 0 -26 124.0 -0.584 -2.245 0.0247639  *
## Season 32:   S = 0 -19 123.0 -0.432 -1.623 0.1045883
## Season 33:   S = 0 -23 123.0 -0.523 -1.984 0.0472923  *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
#Tuesday Lake
unique(Tuesdaylake_processed$year4) # There are too many gaps in the data, including a 10 year gap from
```

```
##  [1] 1984 1985 1986 1987 1988 1989 1990 1991 1993 1994 1995 1996 1997 1998
## [15] 1999 2000 2002 2012 2013 2014 2015 2016
```

```r
Tuesday_smk <- Tuesdaylake_processed %>%
  filter(year4 >= 1984, year4 <= 1991)
Tuesdaylaketemp_ts <- ts(Tuesday_smk$temperature_C,
                         start = c(1984), frequency = 8)
Tuesdaylaketemp_ts
```

```
## Time Series:
## Start = c(1984, 1)
## End = c(1995, 6)
## Frequency = 8
##  [1] 4.3 4.4 4.3 4.5 4.4 4.5 4.1 4.0 4.0 4.2 4.0 4.8 4.3 4.4 4.2 4.3 4.5
## [18] 4.9 4.7 4.9 4.9 4.8 4.5 4.4 4.4 4.6 4.4 4.6 4.5 4.7 4.7 4.7 4.5 4.7
## [35] 4.6 4.8 4.7 4.8 4.5 4.8 4.8 4.8 4.8 4.9 4.8 5.1 4.5 4.6 4.6 4.7 4.7
## [52] 4.7 4.8 4.8 4.8 4.8 4.9 5.1 4.3 4.3 4.4 4.3 4.3 4.3 4.2 4.3 4.3 4.2
## [69] 4.2 4.3 4.5 4.3 4.3 4.3 4.3 4.4 4.4 4.3 4.5 4.5 4.5 4.6 4.3 4.4 4.2
## [86] 4.3 4.4 4.4 4.4 4.5 4.5 4.5 4.5 4.6
```

```r
Tuesday_temp_smk <- smk.test(Tuesdaylaketemp_ts)
Tuesday_temp_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data:  Tuesdaylaketemp_ts
## z = -0.56165, p-value = 0.5744
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##        S     varS
##  -23.000 1534.333
```

```r
summary(Tuesday_temp_smk) #The seasonal Mann Kendall test for temperature at Tuesday Lake had an overal
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Tuesdaylaketemp_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                       S  varS    tau      z Pr(>|z|)
## Season 1:   S = 0  11 207.0  0.173  0.695  0.48703
## Season 2:   S = 0  -1 209.7 -0.016  0.000  1.00000
## Season 3:   S = 0  -1 195.0 -0.017  0.000  1.00000
## Season 4:   S = 0 -22 208.7 -0.344 -1.454  0.14601
## Season 5:   S = 0 -12 206.0 -0.191 -0.766  0.44343
## Season 6:   S = 0 -15 200.3 -0.245 -0.989  0.32260
## Season 7:   S = 0   9 148.3  0.181  0.657  0.51127
## Season 8:   S = 0   8 159.3  0.153  0.555  0.57920
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
Tuesdaylakeo2_ts <- ts(Tuesday_smk$dissolvedOxygen,
                       start = c(1984), frequency = 8)
Tuesdaylakeo2_ts
```

```
## Time Series:
## Start = c(1984, 1)
## End = c(1995, 6)
## Frequency = 8
##  [1] 0.3 0.3 0.2 0.3 0.4 0.3 0.2 0.3 0.6 0.2 0.1 0.2 0.1 0.1 0.1 0.1 0.1
## [18] 0.1 0.1 0.1 0.1 0.1 0.2 0.1 0.1 0.3 0.1 0.3 0.1 0.2 0.1 0.1 0.2 0.1
## [35] 0.1 0.0 0.1 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.2 0.3 0.2 0.3 0.3 0.2 0.1
## [52] 0.1 0.0 0.2 0.1 0.1 0.1 0.3 0.3 0.2 0.2 0.1 0.1 0.2 0.3 0.7 0.2 0.2
## [69] 0.3 0.2 0.2 0.0 0.0 0.0 0.1 0.1 0.4 0.1 0.0 0.2 0.0 0.0 0.0 0.0 0.0
## [86] 0.0 0.0 0.1 0.0 0.0 0.0 0.1 0.1 0.2
```

```
Tuesday_o2_smk <- smk.test(Tuesdaylakeo2_ts)
Tuesday_o2_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data:  Tuesdaylakeo2_ts
## z = -3.3862, p-value = 0.0007088
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##        S     varS
## -128.000 1406.667
```

```
summary(Tuesday_o2_smk) #The seasonal Mann Kendall test for dissolved oxygen at Tuesday Lake had an ove
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Tuesdaylakeo2_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                     S  varS    tau      z Pr(>|z|)
## Season 1:   S = 0 -30 196.7 -0.503 -2.068 0.038648 *
## Season 2:   S = 0 -20 200.7 -0.329 -1.341 0.179833
## Season 3:   S = 0 -17 166.3 -0.319 -1.241 0.214755
## Season 4:   S = 0 -21 190.3 -0.362 -1.450 0.147147
## Season 5:   S = 0  -1 193.0 -0.017  0.000 1.000000
## Season 6:   S = 0 -13 186.3 -0.229 -0.879 0.379350
## Season 7:   S = 0 -20 138.7 -0.437 -1.613 0.106637
## Season 8:   S = 0  -6 134.7 -0.131 -0.431 0.666567
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#East Long Lake
unique(Eastlonglake_processed$year4) #There are too many gaps in the data, including no data after 2006
```

```
##  [1] 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2004 2006
```

```
Eastlong_smk <- Eastlonglake_processed %>%
  filter(year4 >= 1989, year4 <= 2000)
Eastlonglaketemp_ts <- ts(Eastlong_smk$temperature_C,
```

```r
                       start = c(1989), frequency = 12)
Eastlonglaketemp_ts
```

```
##      Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
## 1989 4.7 5.1 5.1 5.1 5.1 5.3 5.1 5.0 5.3 5.3 5.5 5.7
## 1990 5.1 5.3 5.2 5.3 5.5 5.4 5.6 5.6 5.7 5.5 5.6 4.6
## 1991 4.5 4.9 4.9 4.9 5.0 5.0 5.4 5.2 5.2 5.2 5.3 4.5
## 1992 4.5 4.6 4.6 4.6 4.8 4.7 5.0 4.9 4.9 4.9 5.1 5.4
## 1993 5.6 5.7 5.7 5.5 5.7 5.9 5.7 5.9 5.9 6.0 4.5 4.6
## 1994 4.6 4.8 4.8 4.8 4.9 5.0 5.0 5.0 5.0 4.6 4.8 4.7
## 1995 4.8 4.9 4.9 4.9 5.0 5.1 5.0 5.2 5.2 5.3 5.3 5.3
## 1996 5.4 5.4 5.3 5.4 5.5 5.5 5.6 5.6 5.1 5.2 5.2 5.2
## 1997 5.3 5.3 5.3 5.3 5.2 5.4 5.4 4.6 4.5 4.8 4.7 4.8
## 1998 4.9 5.0 5.0 5.2 5.2 5.0 4.5 4.8 5.2
```

```r
Eastlong_temp_smk <- smk.test(Eastlonglaketemp_ts)
Eastlong_temp_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data:  Eastlonglaketemp_ts
## z = -0.83753, p-value = 0.4023
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##    S varS
##  -32 1370
```

```r
summary(Eastlong_temp_smk) #The seasonal Mann Kendall test for temperature at East Long Lake had an ove
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Eastlonglaketemp_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                         S  varS    tau      z Pr(>|z|)
## Season 1:   S = 0   12 124.0  0.270  0.988 0.323236
## Season 2:   S = 0    3 123.0  0.068  0.180 0.856890
## Season 3:   S = 0    5 123.0  0.114  0.361 0.718348
## Season 4:   S = 0    5 123.0  0.114  0.361 0.718348
## Season 5:   S = 0    4 122.0  0.092  0.272 0.785924
## Season 6:   S = 0    1 120.3  0.023  0.000 1.000000
## Season 7:   S = 0  -10 119.3 -0.236 -0.824 0.410010
## Season 8:   S = 0  -10 122.0 -0.230 -0.815 0.415174
## Season 9:   S = 0  -14 121.3 -0.322 -1.180 0.237923
## Season 10:   S = 0 -12  90.0 -0.343 -1.160 0.246252
## Season 11:   S = 0 -17  91.0 -0.479 -1.677 0.093492 .
## Season 12:   S = 0   1  91.0  0.028  0.000 1.000000
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
Eastlonglakeo2_ts <- ts(Eastlong_smk$dissolvedOxygen,
                        start = c(1989), frequency = 12)
Eastlonglakeo2_ts
```

```
##      Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
## 1989 0.4 0.2 0.2 0.2 0.2 0.2 0.3 0.0 0.0 0.3 0.0 0.0
## 1990 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.2 0.0 0.1 0.1 0.7
## 1991 0.6 0.7 0.6 0.5 0.3 0.3 0.3 0.1 0.1 0.1 0.1 0.1
## 1992 0.0 0.0 0.9 0.1 0.1 0.1 0.1 0.2 0.3 0.3 0.3 1.1
## 1993 0.8 0.4 0.5 0.5 0.3 0.5 0.5 0.4 0.4 0.6 0.6 0.3
## 1994 0.3 0.2 0.4 0.7 0.7 0.6 0.5 0.4 0.3 0.3 0.4 0.1
## 1995 0.3 0.3 0.3 0.2 0.3 0.3 0.3 0.2 0.3 0.3 0.2 0.2
## 1996 0.1 0.2 0.2 0.2 0.4 0.3 0.3 0.3 0.0 0.0 0.1 0.0
## 1997 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.3 0.4 0.5 0.1 0.1
## 1998 0.1 0.1 0.1 0.1 0.1 0.1 6.0 3.3 0.6
```

```r
Eastlong_o2_smk <- smk.test(Eastlonglakeo2_ts)
Eastlong_o2_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data:  Eastlonglakeo2_ts
## z = 0.82562, p-value = 0.409
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##        S     varS
##   31.000 1320.333
```

```r
summary(Eastlong_o2_smk) #The seasonal Mann Kendall test for dissolved oxygen at East Long Lake had an
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Eastlonglakeo2_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                      S  varS    tau      z Pr(>|z|)
## Season 1:   S = 0  -10 119.3 -0.236 -0.824 0.410010
## Season 2:   S = 0   -7 117.7 -0.167 -0.553 0.580177
## Season 3:   S = 0  -15 123.0 -0.341 -1.262 0.206827
## Season 4:   S = 0   -5 118.3 -0.119 -0.368 0.713089
## Season 5:   S = 0    4 119.3  0.094  0.275 0.783604
## Season 6:   S = 0    0 119.3  0.000  0.000 1.000000
## Season 7:   S = 0    9 114.3  0.221  0.748 0.454354
## Season 8:   S = 0   26 119.3  0.613  2.289 0.022106 *
## Season 9:   S = 0   24 116.7  0.580  2.129 0.033222 *
## Season 10:   S = 0   5  82.3  0.155  0.441 0.659335
## Season 11:   S = 0   6  83.3  0.183  0.548 0.583882
## Season 12:   S = 0  -6  87.3 -0.177 -0.535 0.592628
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
#West Long Lake
unique(Westlonglake_processed$year4) #There are too many gaps in the data, including no data after 2006
```

```
##  [1] 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2003 2004
## [15] 2006
```

```r
Westlong_smk <- Westlonglake_processed %>%
  filter(year4 >= 1989, year4 <= 2000)
Westlonglaketemp_ts <- ts(Westlong_smk$temperature_C,
                      start = c(1989), frequency = 12)
Westlonglaketemp_ts
```

```
##      Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
## 1989 5.0 5.2 5.3 5.3 5.4 5.6 5.6 5.4 5.5 5.6 6.0 5.9
## 1990 5.2 5.3 5.4 5.5 5.5 5.4 5.6 5.7 5.7 5.8 5.8 5.2
## 1991 5.4 5.5 5.6 5.7 5.7 5.9 6.0 6.1 6.0 6.1 6.5 5.6
## 1992 5.5 5.5 5.6 5.9 5.7 6.0 6.0 6.1 6.1 6.3 6.3 6.1
## 1993 6.1 6.2 6.4 6.2 6.3 6.6 6.7 6.8 7.0 7.0 6.9 5.5
## 1994 5.5 5.6 5.8 6.0 5.8 5.9 6.0 6.0 6.0 6.2 4.7 4.0
## 1995 4.9 4.9 5.0 5.0 5.1 5.2 5.1 5.3 5.3 4.9 5.0 5.1
## 1996 5.1 5.0 5.1 5.1 5.2 5.3 5.3 5.3 5.2 5.2 5.3 5.2
## 1997 5.3 5.3 5.3 5.5 5.5 5.5 5.5 5.1 5.1 5.3 5.3 5.3
## 1998 5.5 5.5 5.5 5.6 5.7 5.7 4.7 5.0 5.5
```

```r
Westlong_temp_smk <- smk.test(Westlonglaketemp_ts)
Westlong_temp_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data:  Westlonglaketemp_ts
## z = -1.646, p-value = 0.09975
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##        S     varS
##  -62.000 1373.333
```

```r
summary(Westlong_temp_smk) #The seasonal Mann Kendall test for temperature at West Long Lake had an ove
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Westlonglaketemp_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                       S  varS    tau      z Pr(>|z|)
## Season 1:   S = 0     8 121.3  0.184  0.635 0.525110
## Season 2:   S = 0     3 120.3  0.070  0.182 0.855331
## Season 3:   S = 0    -1 123.0 -0.023  0.000 1.000000
## Season 4:   S = 0     2 124.0  0.045  0.090 0.928444
## Season 5:   S = 0     3 120.3  0.070  0.182 0.855331
## Season 6:   S = 0    -4 124.0 -0.090 -0.269 0.787616
## Season 7:   S = 0   -15 120.3 -0.349 -1.276 0.201868
```

```
## Season 8:   S = 0  -21 123.0 -0.477 -1.803 0.071335 .
## Season 9:   S = 0  -13 123.0 -0.296 -1.082 0.279251
## Season 10:   S = 0  -4  92.0 -0.111 -0.313 0.754454
## Season 11:   S = 0  -9  91.0 -0.254 -0.839 0.401678
## Season 12:   S = 0 -11  91.0 -0.310 -1.048 0.294507
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Westlonglakeo2_ts <- ts(Westlong_smk$dissolvedOxygen,
                      start = c(1989), frequency = 12)
Westlonglakeo2_ts
```

```
##      Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
## 1989 0.2 0.2 0.2 0.3 0.2 0.2 0.2 0.3 0.0 0.6 0.1 0.0
## 1990 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.1 0.5
## 1991 0.6 0.7 0.6 0.4 0.5 0.4 0.3 0.1 0.1 0.1 0.1 0.0
## 1992 0.0 0.1 0.4 0.1 0.1 0.1 0.1 0.2 0.3 0.1 0.4 0.5
## 1993 1.0 0.8 0.5 0.5 0.4 0.5 0.4 0.6 0.6 0.5 0.6 0.3
## 1994 0.2 0.3 0.3 0.5 0.6 0.5 0.3 0.4 0.3 0.6 0.3 0.3
## 1995 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.2 0.2 0.2 0.2
## 1996 0.1 0.2 0.1 0.1 0.4 0.4 0.3 0.3 0.1 0.1 0.1 0.1
## 1997 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.3 0.2 0.4 0.1 0.1
## 1998 0.1 0.1 0.1 0.1 0.1 0.1 1.7 0.2 0.1
```

```
Westlong_o2_smk <- smk.test(Westlonglakeo2_ts)
Westlong_o2_smk
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data:  Westlonglakeo2_ts
## z = -0.46921, p-value = 0.6389
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##        S     varS
##  -18.000 1312.667
```

```
summary(Westlong_o2_smk) #The seasonal Mann Kendall test for dissolved oxygen at West Long Lake had an
```

```
##
##  Seasonal Mann-Kendall trend test (Hirsch-Slack test)
##
## data: Westlonglakeo2_ts
## alternative hypothesis: two.sided
##
## Statistics for individual seasons
##
## H0
##                      S  varS    tau      z Pr(>|z|)
## Season 1:   S = 0   -6 119.3 -0.141 -0.458  0.64716
## Season 2:   S = 0   -6 119.3 -0.141 -0.458  0.64716
## Season 3:   S = 0  -14 122.0 -0.322 -1.177  0.23921
## Season 4:   S = 0   -7 118.3 -0.167 -0.552  0.58125
## Season 5:   S = 0   -2 122.0 -0.046 -0.091  0.92786
## Season 6:   S = 0   -1 121.0 -0.023  0.000  1.00000
## Season 7:   S = 0   12 115.3  0.290  1.024  0.30571
```

```
## Season 8:   S = 0    6 115.3  0.145  0.466  0.64152
## Season 9:   S = 0    5 114.3  0.123  0.374  0.70834
## Season 10:   S = 0   1  82.3  0.031  0.000  1.00000
## Season 11:   S = 0   0  75.3  0.000  0.000  1.00000
## Season 12:   S = 0  -6  88.0 -0.177 -0.533  0.59403
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

My data does not appear to be showing a significant change in the thermocline of any of the five individual lakes, as defined by both higher temperatures and lower oxygen levels at 7 meters depth. Let's visualize the temperature and oxygen over the period of the ten tests I just ran to see if the naked eye agrees with my statistical analysis.

Discussion: The results of my tests seem to run contrary to the idea that climate change is affecting the water temperatures of the lakes in this study. However, it may be the case that my tests are inconclusive by design. I am testing whether the thermocline on these lakes is moving over time. The location of a lake's thermocline is a product of water chemistry and physics, especially water density. It may be the case that the basic physics of water that determine where a thermocline sets up are not affected by 1 °C of global warming. Perhaps, given relatively modest warming, it is the relative water density that determines where the thermocline location sets up. It may be the case that the steepness and not the location of the thermocline is what is changing under relatively small amounts of warming. If I were to test surface water temperature or water temperature at, say, 15 meters, I would likely see evidence of climate change. It might require larger levels of warming for the thermocline itself to also move. Unfortunately, testing this hypothesis is beyond the scope of the dataset I am analyzing.