Are Oyster Restoration Sites Increasing Oyster Population Sizes and is Water Quality Improving in the James and the Rappahannock Rivers of Virginia?

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Lesson Objectives:

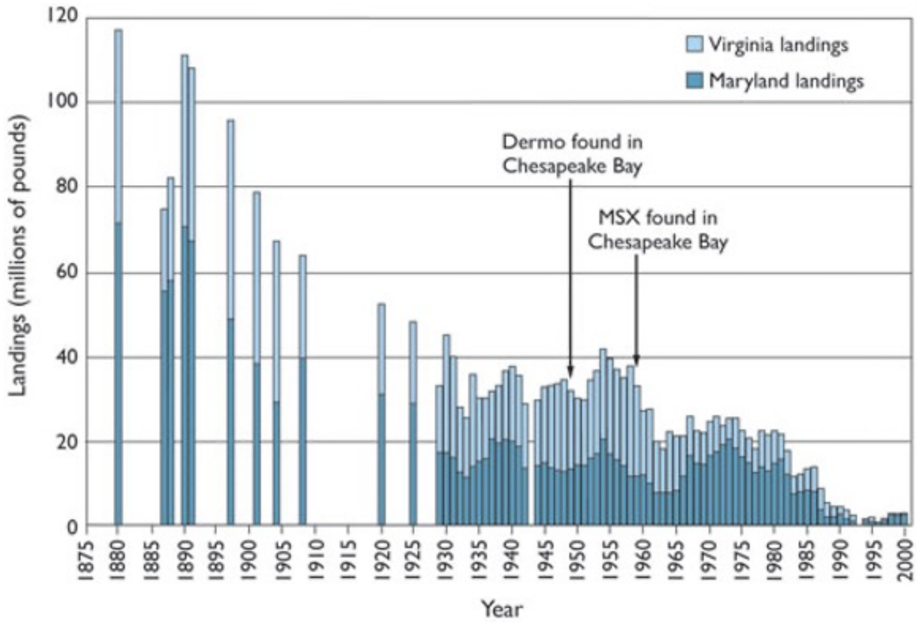
In this lesson, the students will learn about the population decline of the Eastern Oyster, the oyster's role in its ecosystem, and how the oyster improves its environment which in return improves the lives of humans. They will learn about oyster restoration projects and wild oyster populations. The students will learn about the current state of the water quality in the Chesapeake Bay and the cause of its pollution. The students will manipulate data in R-studio using Tidyverse, plot this data using GGPLOT, run Pearson correlation tests, and make linear regression models.

Research Background:

History of Environmental Stressors

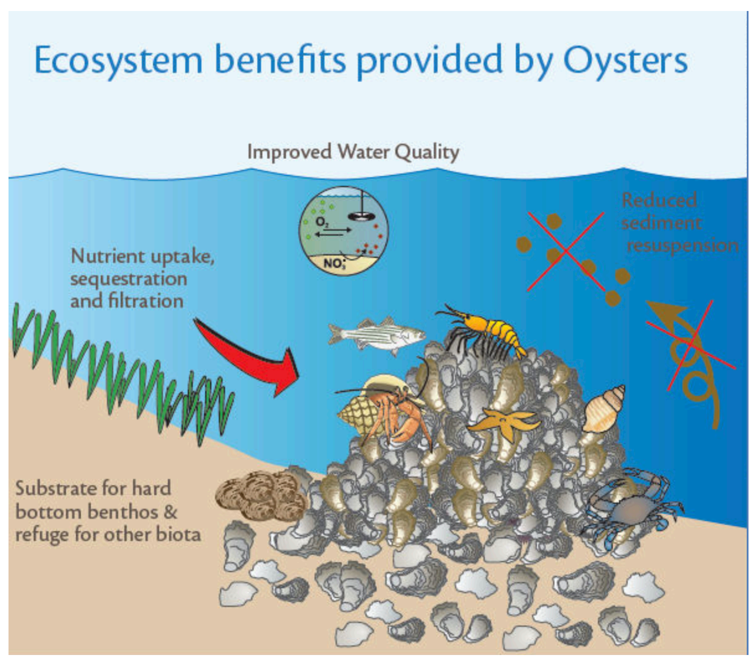
The **Eastern Oyster**, Crassostrea virginica, has been an important part of Virginia's history, culture, ecosystem, and economy since it first arrived in the Chesapeake Bay and its tributaries. The oyster populations in the Chesapeake Bay are at 1% of historic levels due to a long history of over-harvesting, habitat degradation, and disease- as shown in the graph below. Harvesters depleted oyster populations faster than they were able to replenish themselves. The oysters' habitat has been degraded due to human population influx and land use change to impervious surfaces in the

Chesapeake Bay watershed. MSX and Dermo, two parasitic diseases have also contributed to the oyster's decline.



Role in Ecosystem

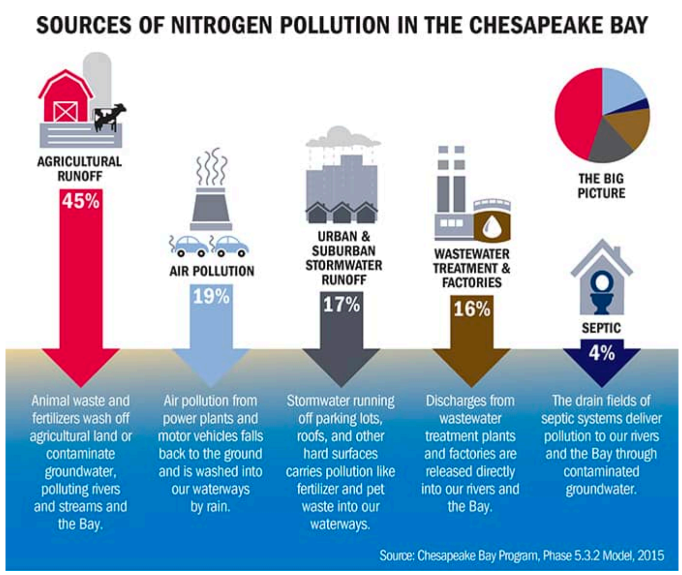
Oysters are a **keystone species** of the Chesapeake Bay because they support more than 300 other species and without them, ecosystems would collapse. Oyster reefs provide habitat for species like blue crabs, striped bass, and red drum. Oysters filter nitrogen, phosphorus, detritus, and sediments from the water column by using their cilia to draw them in. The particles become trapped in the mucus of the oysters' gills and travel to their mouths. There, the oysters eat the particles, digest them, and expel them in the form of pseudofeces, which gets buried in the bottom of the waterway and provides food for many species. Oysters improve water clarity in this same way by pulling sediment from the water, which aids in the growth of important seagrasses at the river bottom because the sunlight can reach them. Oysters consume excess algae and plankton, which keeps the water clear and healthy for other marine life. When algae grows out of control, it can harm fish, shellfish, marine mammals, and birds. **You can watch oysters filter the water here.**



Water Quality

The Chesapeake Bay and its watershed have a long history with poor water quality, pollutants, dead zones, and loss of species. In 2020, the Chesapeake Bay scored a 32 (D) on its watershed report card. Pollutants that enter the Bay and its estuaries create **dead zones**. Dead zones are areas in bodies of water that have little to no oxygen where aquatic life suffocates. They are caused by excess **nitrogen and phosphorous run-off from human activities.** This run-off can be from point or non-point source pollution. Point source pollution enters the environment from a confined place that is easy to identify like a pipe from a wastewater treatment plant. Non-point source pollution can come from many places and is impossible to trace like pesticides from a farm or dog waste from the street. Every year, 300 million pounds of nitrogen pollute the Bay, 40 percent of which comes from agriculture. Oysters are capable of filtering nitrogen, phosphorus, chlorophyll-A, and sediment (which can be measured through turbidity) from the water column. These four parameters are described in detail below.

1. **Total Nitrogen (TN)** is the sum of total kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite. Nitrogen is an essential nutrient for plants and animals, but an excess amount in our waterways is harmful for everyone- plants, animals, and humans. Too much nitrogen can lead to an overgrowth of algae. Most of the excess nitrogen comes from agricultural runoff. If you are interested in the subject, you can learn more about it here.



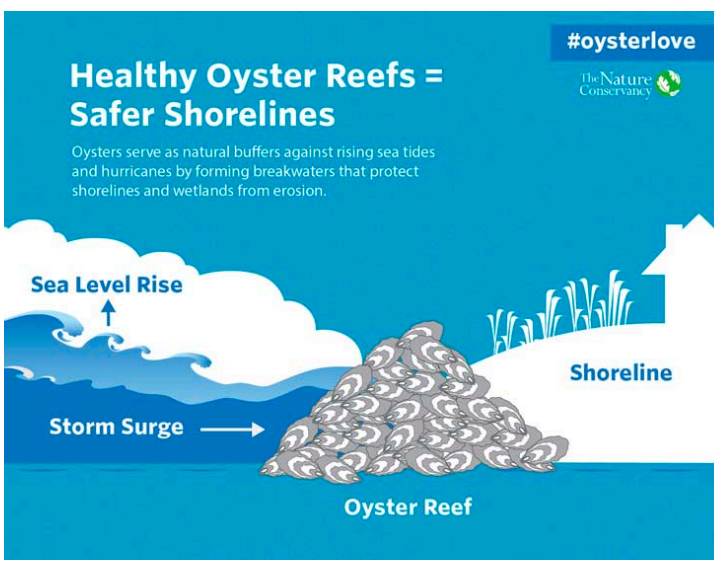
2. **Total Phosphorus (TP)** is a measure of all the forms of phosphorus, dissolved or particulate, that are found in a sample. Phosphorus is an essential nutrient for plants and animals but even a small amount introduced in a waterway has negative consequences like algae blooms and low dissolved oxygen. Sources come from wastewater treatment plants, runoff, drained wetlands, and commercial cleaning preparations.

3. **Chlorophyll-A (CHLA)** is the pigment that allows plants like algae to convert sunlight into organic compounds. Measuring chlorophyll-A is the same as measuring algae biomass. Excess algae can suffocate aquatic life by decreasing the levels of dissolved oxygen and creating dead zones. Some algae produces toxins that are harmful to humans and animals and can even cause death if consumed.

4. **Turbidity (TURB)** is a measure of how cloudy the water is - the cloudiness is caused by small particles of suspended matter. Turbid water is not harmful, but it can be an indicator of more serious problems. Turbidity particles can adsorb other harmful contaminants, and some turbidity particles are harmful themselves like asbestos, lead, bacteria and viruses, and protozoan cysts.

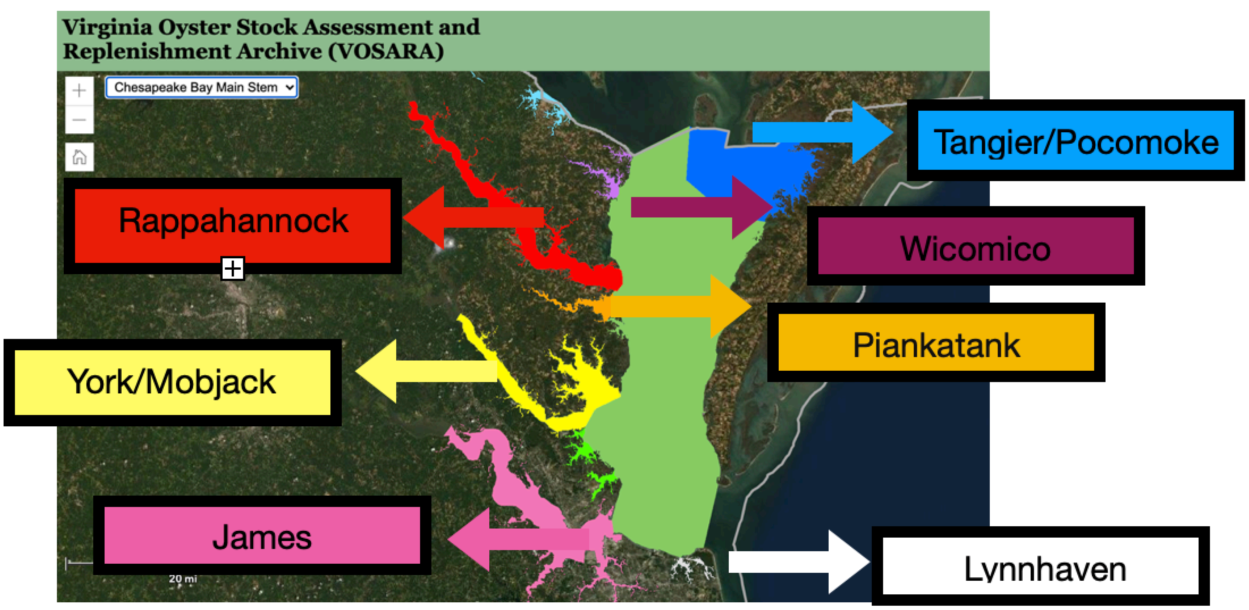
Human Benefit

Oyster reefs provide human protection by mitigating the impact of natural disasters. They buffer storm surges by absorbing wave energy which reduces coastal erosion. Oysters filter contaminants from our waterways. These pollutants cause harmful algal blooms that make humans extremely sick. Exposure to algal toxins through drinking water, seafood, salt spray, and other vectors can cause skin rashes, intestinal illness, respiratory failure, and death. Algae toxicity in dogs can cause seizures, respiratory and liver failure, and death. The pollutants that oysters filter out of the water column can contaminate the wells and reservoirs that humans rely on for clean drinking water. River basins with unsafe nitrate levels can lead to cancer, nervous system deformities in infants, hemorrhaging of the spleen, and other health problems if consumed.



Restoration

The wild oyster restoration sites are shown below. They include the Chesapeake Bay Main Stem, Great/Little Wicomico Rivers, James River, Lynnhaven Bay, Piankatank River, Rappahannock River, Tangier/Pocomoke Sound, York River, and Mobjack Bay. Some of these sites are able to be harvested while others are protected reefs that cannot be harvested. There are many oyster restoration programs in Virginia, like the Virginia Oyster Shell Recycling Program (VOSRP)- they plant oyster shells and larvae off of Gwynn Island in the Piankatank. The Army Corps of Engineers are responsible for the oyster restoration sites in this research paper. **Read more about the program here.** Restoration sites are completed in different ways. VOSRP through Virginia Commonwealth University takes used oyster shells from restaurants, cleans, bags, and stores them at the Rice Rivers Center (RRC) until the summer months. In May they are hauled to Gwynn Island where they are put into tanks with millions of oyster larvae purchased from hatcheries. The larvae attach to the recycled shell and are brought by boat to the oyster restoration reefs. You can see the process in the pictures below.



1. The used oyster shells are collected by volunteers from restaurants.

2. and 3. The oysters are hauled to the RRC and stay there for at least one year to cure.

4. 10 million oyster larvae are in each of these bags- they are put into tanks with the recycled shells and attach to them after a few days.

5. Successful **recruitment** (addition of new individuals to populations) is 10-12 larvae per shell. Once attached, the larvae is referred to as "spat on shell".

6. The spat on shell is brought by boat to the restoration reef site.

Research Paper:

This research paper inspired this QUBES lesson because it found that oyster aquaculture in the Chesapeake Bay has minimal effects on the surrounding water quality. **Aquaculture** is the process of cultivating oysters, clams, mussels or other shellfish for food. It is important to differentiate aquaculture from wild oyster sanctuaries/restoration sites. One is farmed while the other is wild. Some of these wild sites include oyster sanctuaries which are protected, so it is prohibited to harvest these oysters for food. This study focuses on wild oyster restoration sites (both protected and able to be harvested) and wild oyster populations. It is interesting to read about the study's experiment and analysis inside and outside of farmed oyster cages. The low density of the farmed oyster sites could be why they did not find that the oysters affected the water quality. Oysters deserve credibility for all that they do for us, so I wanted to create a lesson that highlights their importance.

Research Question:
Have the oyster restoration sites successfully increased the total number of oysters present over the years? Has the water quality at the restoration sites improved over the years, meaning is there a reduction of nitrogen, phosphorus, algae, and sediment?

Research Data:

Meet the Researcher in charge of the data:

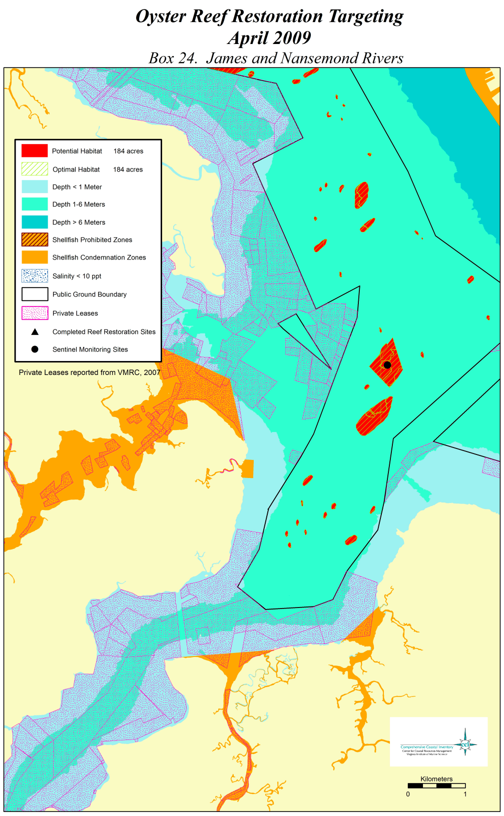
Melissa Southworth works for **VIMS, the Virginia Institute of Marine Science.** The oyster data used in this paper is visible to the public here, but it is not downloadable, so Melissa shared the files with me. VIMS partners with the Virginia Marine Resources Commission (VMRC) and the Chesapeake Bay Program (CBP). The oyster reef station management is funded by the National Oceanic and Atmospheric Association (NOAA). The data comes from the Virginia Oyster Stock and Replenishment Archive (VOSARA).

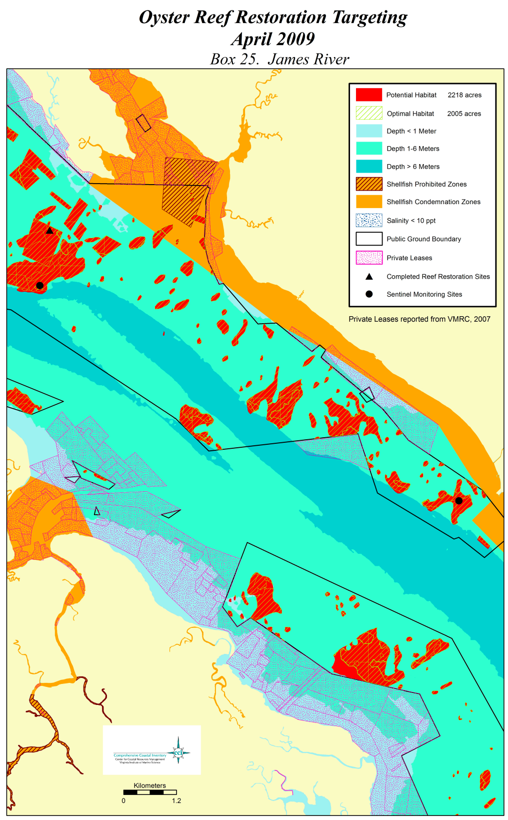
You can read Melissa Southworth's research paper on oyster population sizes here.

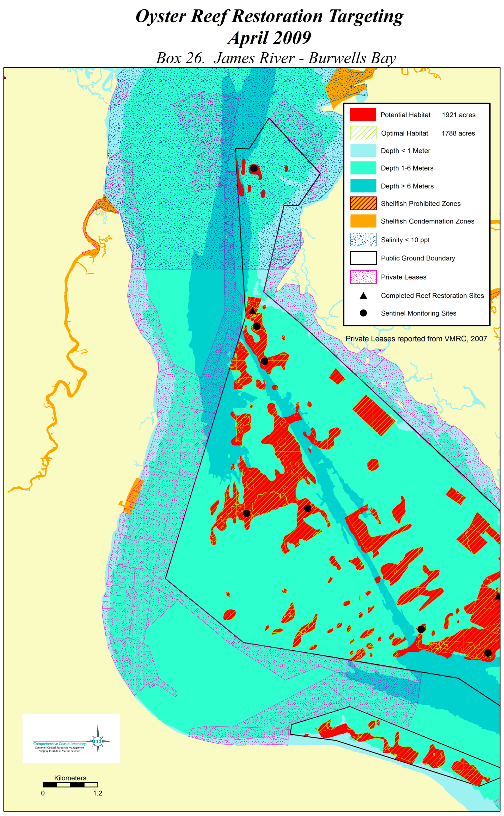
Melissa Southworth - Missy is a senior marine scientist in the Molluscan Ecology Lab and also received an M.S. from VIMS. She runs the field program for the Molluscan Ecology Lab and is the lead scientist on the oyster patent tong, dredge, and shellstring surveys. Her interests include stock assessment of commercially viable shellfish species in the Chesapeake Bay, the development of best management practices in support of shellfish aquaculture in the Bay, restoration of oyster populations and oyster reef ecology and biology.

Oyster Data
The oyster data includes the **year of collection, the number of oysters counted, and the location of the collection site.** Oyster populations are described in units of density, oysters per unit area, for each of these three size classes:

1. spat are young of the year
2. small are submarket size (< 76mm length)
3. market size (> 76mm length)



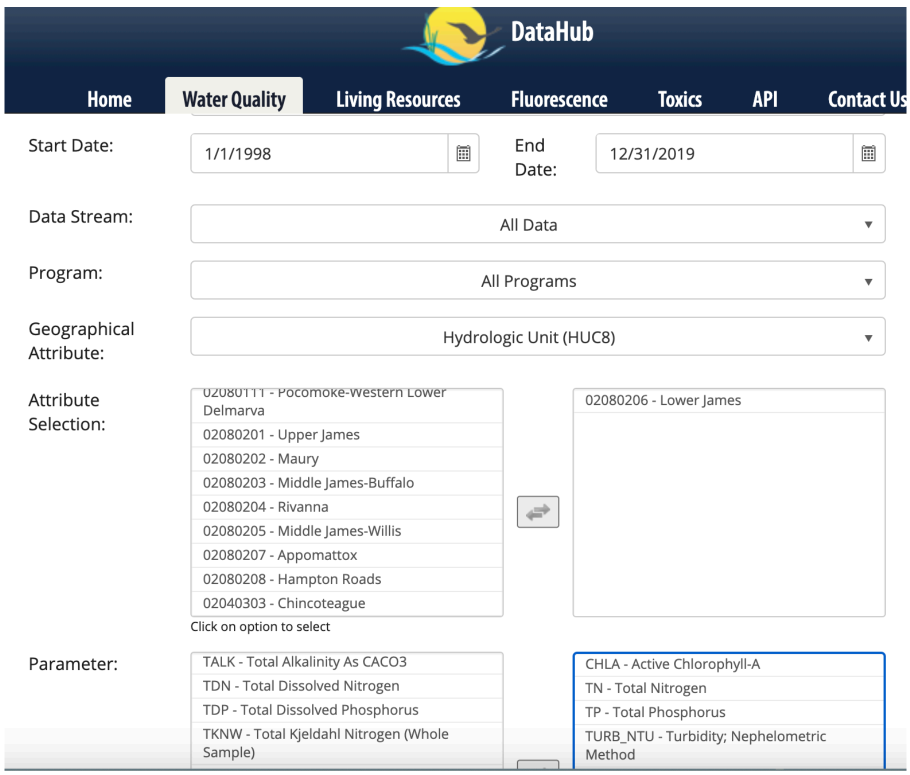




The data includes the "total" which is all three class sizes together- the number I will be using in this research. The oysters are collected from October through December from natural oyster reefs in the Virginia portion of the Chesapeake Bay with a quantitative sampling program that uses a stratified random grid with documented oyster reefs (bars) forming the strata. A hydraulic patent tong (pictured on the previous page) is used to collect the oysters from the 43-ft long VMRC research vessel *J.B. Baylor.* The tong samples one square meter of the bottom of the site. From each sample, oysters are counted and categorized. The procedures of Bros and Cowell were used to assure adequacy of sampling within each strata (reef). Shown to the right are the locations and years of the oyster data. Pictured above are the oyster reef restoration sites in the James River - they are all located below the fall line, which puts them in the lower James. The red dots in the picture to the left are the oyster reef restoration sites in the Rappahannock River- they are all located in the lower Rappahannock. There are 34 oyster reefs spanning across 6,809 acres monitored in the James River and 57 reefs spanning across 583 acres in the Rappahannock River.

James River	**1998-2019**
Lynnhaven	2007-2019
Piankatank	1998 - 2019
Great Wicomico	2002 - 2019
Chesapeake Bay	2002- 2019
Mobjack	2005 - 2019
Pocomoke	2002 - 2019
York	2009 - 2019
Tangier	2002 - 2019
Rappahannock	**2000 - 2019**

Water Quality
The water quality data comes from the Chesapeake Bay Program. It is publicly available. **You can access it here.** The Chesapeake Bay monitoring program is carried out by Maryland, Virginia and the EPA. Water quality parameters are measured at over 100 stations once a month. Trends are analyzed by using a Generalized Additive Model (GAM) statistical approach. First, we are going to look at the water quality from the James River, pictured below. We will only be using the lower James River data because that is where the oyster stations are located. We want to look at how the water quality parameters that oysters are capable of filtering are fluctuating through the same time period and area as the oysters.



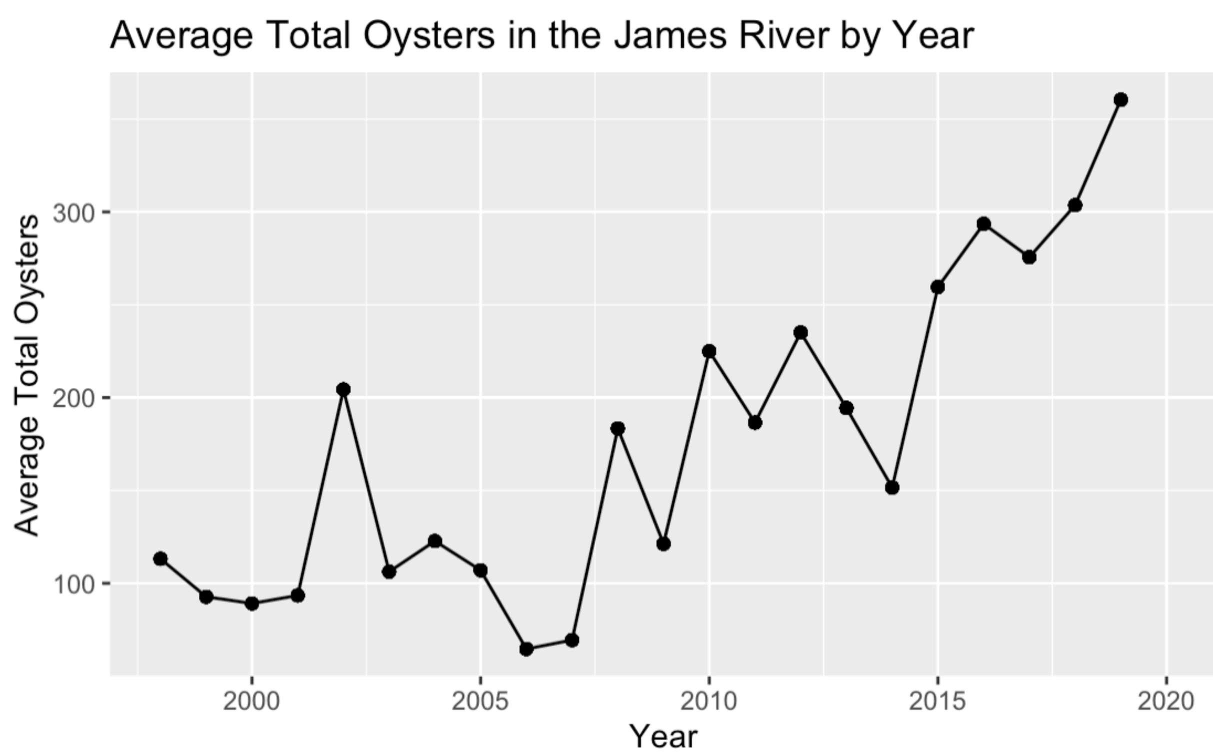
Hypothesis:
Oyster reef restoration stations in the lower James River and the lower Rappahannock River have increased wild oyster population sizes over the years, and the surrounding water quality has improved in the form of reduced total nitrogen, total phosphorus, chlorophyll-A, and turbidity.

The Analysis:
Site #1: The Lower James River
Oyster Data

We are going to analyze the lower James River oyster data. Follow along with the explanations and instructions in the R-studio (.rmd) file.

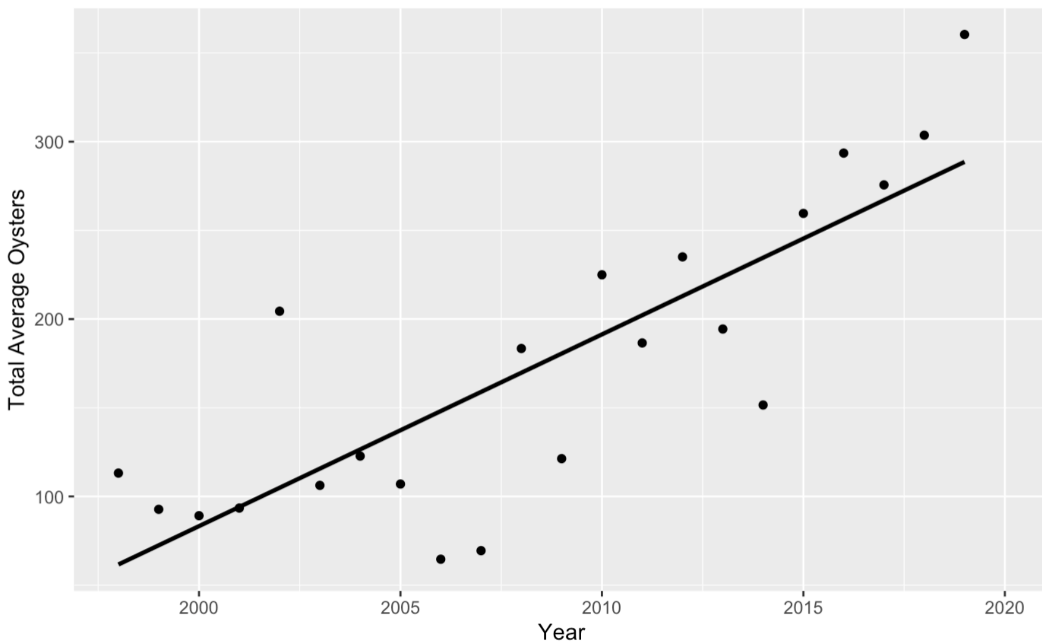
1. Open the .rmd file in R-studio and make sure the oyster data (.csv) is in the same folder.
2. Take a look at the data in R-studio.
3. Manipulate the data using **Tidyverse** to extract only what we need.
4. Separate out the columns “Year” and “Total” by using the function “select”.
5. Convert the data from character to numeric by using the function “mutate_if”.
6. Arrange the column by year by using the “arrange” function.
7. Calculate the average number of oysters per year by using the “group_by” and “mutate” functions. Rename the column’s title by using the “rename” function.
8. Remove the duplicate rows.
8. Plot the data with **GGPLOT**.

We are going to create two **scatterplots**, shown below, in order to visually see the relationship between the two variables, total oysters and year. We must do this **before** running the other statistical tests because if the plot does not show any increasing or decreasing trends, a linear regression model will not be useful.



Do you see any trends?

Answer: Yes, the average total number of oysters is generally increasing through time, meaning there is an upward trend.



A **linear relationship** is where the relationship between variables is represented as a line. In this plot above, we are looking at the relationship between year and number of oysters. Visually, it appears as if the two variables have a positive relationship, meaning when one increases, the other increases.

Now that we have visualized the relationship and can see a positive trend, we can move forward with the tests.

Pearson's Correlation Test

First, we will run a Pearson's correlation test which measures a relationship between two variables. The resulting correlation coefficient is a numerical measure of association between two variables. The coefficient is a value between -1 and 1, indicating the strength of the association of the observed data for the two variables.

+1 = perfect positive relationship, for every positive increase in one variable, there is a positive increase in the other

-1 = perfect negative relationship, for every positive increase in one variable, there is a negative decrease in the other

0 = no relationship, for every increase, there is no positive or negative increase- the two variables are not related

The correlation test between total average oysters and year resulted with a correlation coefficient of .82 which is very close to +1, meaning there is a strong positive relationship. The number of oysters are increasing through time.

Linear regression model

Now that we have visualized a positive relationship and calculated the numerical measure of association between the two variables with the correlation test, we can attempt to fit a linear model to the observed data by making a linear regression model. **Linear regression** is a statistical analysis that tries to model a relationship between two variables by fitting a linear equation to the observed data. The equation is ***Y = a + bX***, where ***X*** is the explanatory variable and ***Y*** is the dependent variable. The slope of the line is ***b***, and ***a*** is the intercept (the value of ***y*** when ***x*** = 0). R-squared measures how close the data is to the fitted regression line. The higher the R-squared, the better the model fits your data. The lower the p-value, the better the model fits your data. The more evenly distributed the residuals are, the better the model fits your data.

$$R^2 = 1 - \frac{Explained\,Variation}{Total\,Variation}$$

For this linear regression model, between the total average oysters and the year, (shown below) the residuals are evenly distributed, the p-value (2.765e-06) is low, and the multiple R-squared is high at 0.675 which means the model explains 68% of the variability of the response data around its mean.

```
Call:
lm(formula = Year ~ average, data = oystersjamesave2)

Residuals:
    Min      1Q  Median      3Q     Max 
-8.3287 -1.5155 -0.0686  2.1151  6.9728 

Coefficients:
             Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 1.998e+03  1.880e+00 1062.580  < 2e-16 ***
average     6.245e-02  9.690e-03    6.444 2.76e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 3.794 on 20 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared:  0.675,	Adjusted R-squared:  0.6587 
F-statistic: 41.53 on 1 and 20 DF,  p-value: 2.765e-06
```

What can you say about the two variables after completing the model?

Answer: We can confidently say that there is a significant and positive relationship between the number of oysters and the year.

How does this answer the hypothesis?

Answer: This analysis confirms the hypothesis that the oyster restoration sites are successfully increasing the number of oysters in the James River.

As a marine biologist, what would you think about this plot and analysis? Would you support these restoration efforts?

I would be excited about the increase in the number of oysters through time and would fully support these restoration efforts because they are successfully increasing the oyster population sizes.

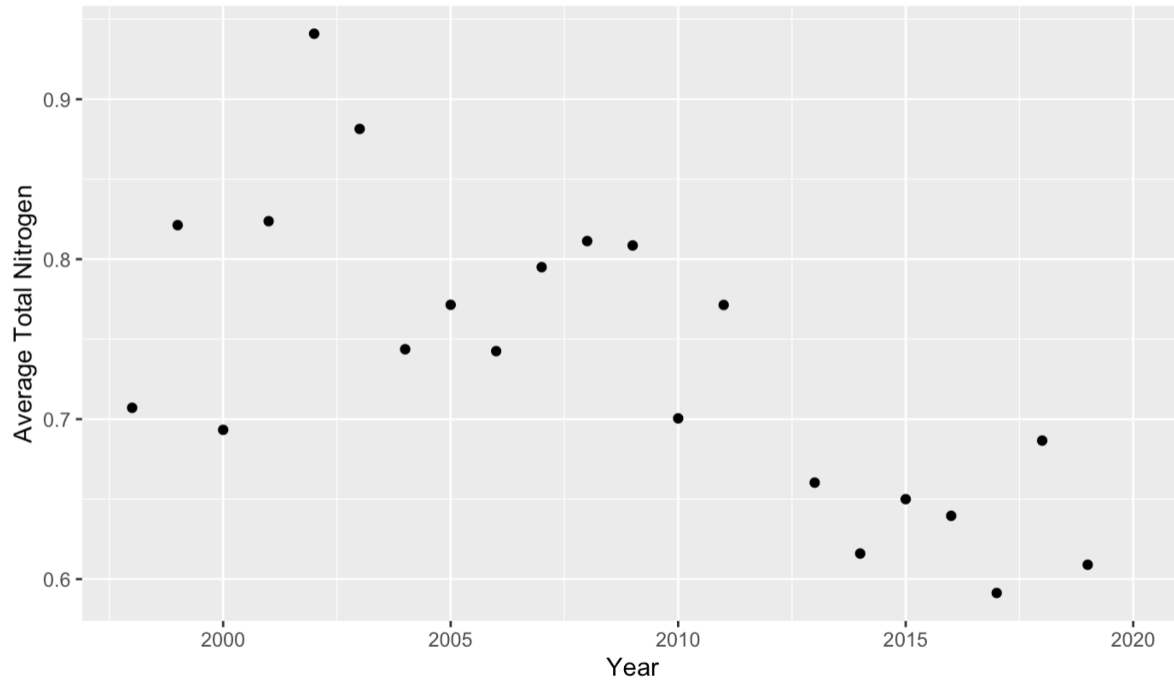
Water Quality- Total Nitrogen

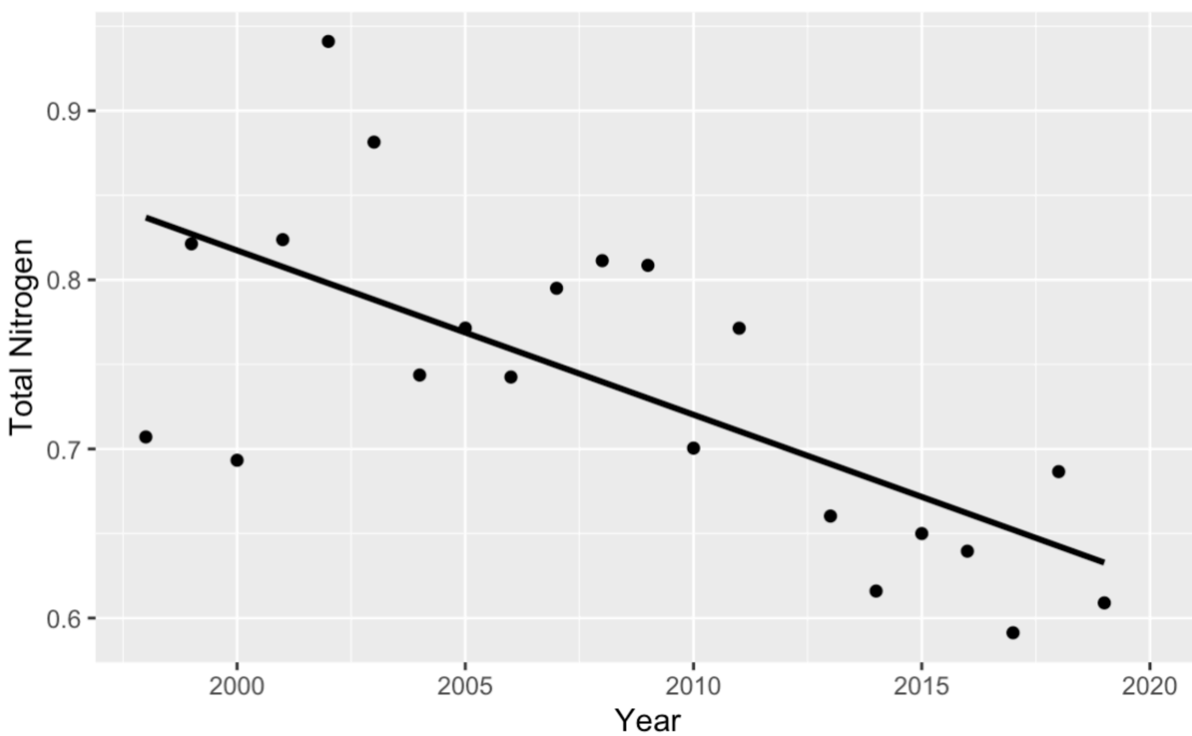
Now, let's look at the water quality data for the James River, beginning with total nitrogen. We have to manipulate the water quality data to make sure it matches the oyster data.

1. Select the columns of data that we need to simplify things - Parameter, MeasureValue, and SampleDate.
2. Isolate the parameter that we are working with - Total Nitrogen (TN).
3. Since the date is in the form of month/day/year, isolate these into separate columns.
4. Make the data numeric.
5. Group the data by year so it goes in chronological order.
6. Find the average (mean) MeasureValue for each year.
7. Remove the duplicate rows.

Now we have the data that we need to plot- the average total nitrogen of each year as shown below. Let's see how the total nitrogen changes through time and what their relationship looks like.

Total Nitrogen in the James River by Year





Do you see any trends? As an environmentalist would you say this is good or bad?

Answer: The total nitrogen is decreasing through time, meaning there is a downward trend. This is a good sign because too much nitrogen in the waterways is harmful.

After looking at these plots, we can say that the two variables might be related, and we can move forward with the correlation test and the linear regression model.

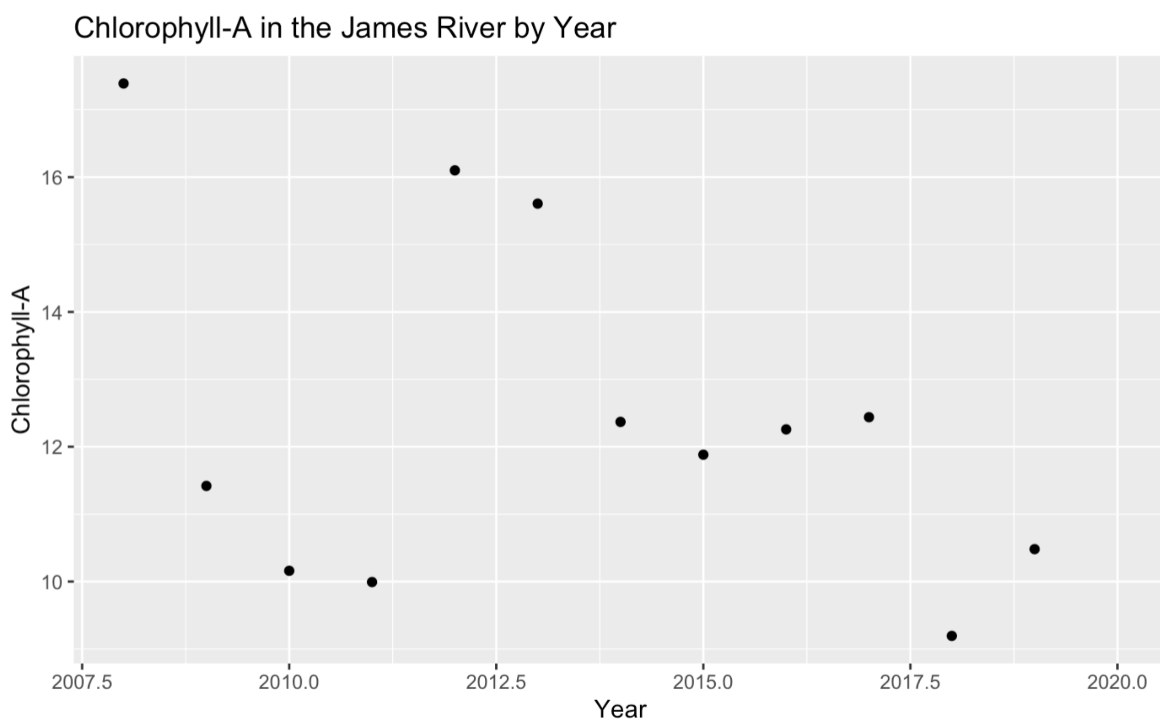
The correlation coefficient is -0.69, which is very close to -1 meaning yes, there is a strong, negative relationship between year and total nitrogen. Remember that the coefficient is negative because as one variable increases (year), the other variable decreases (total nitrogen).

The linear regression model tells us that the two variables, year and total nitrogen, are related because the p-value is low (0.000608) and the R-squared is almost 50% (0.4696).

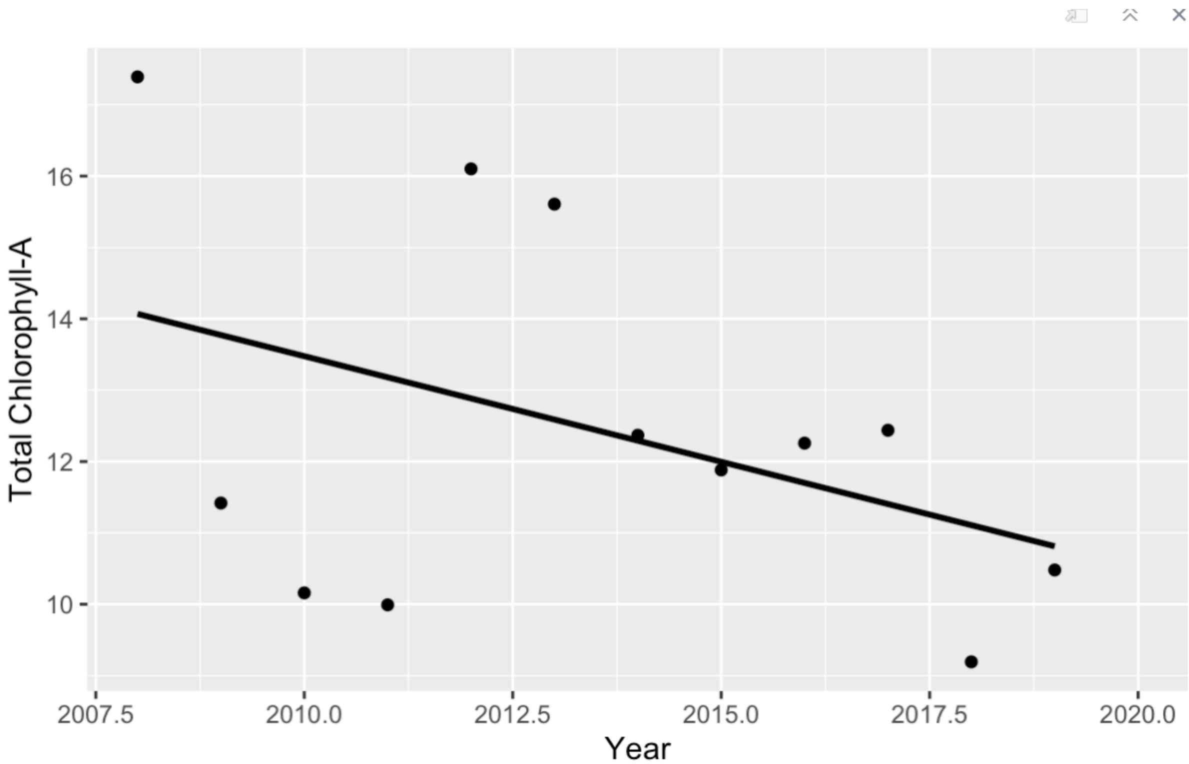
Water Quality - Chlorophyll-A

Now let's find out how chlorophyll-A changes through time. The chlorophyll-A dataset has missing data for the years 2001- 2007, so we are going to only use the chlorophyll-A data from 2008- 2019. Remember the steps-

1. Manipulate the data with Tidyverse to pull out only the data that we need.
2. Plot the parameter to visualize it through time and to visualize the relationship between the two variables.



As you can see in the plot above, the amount of chlorophyll-A in the lower James is decreasing through time.



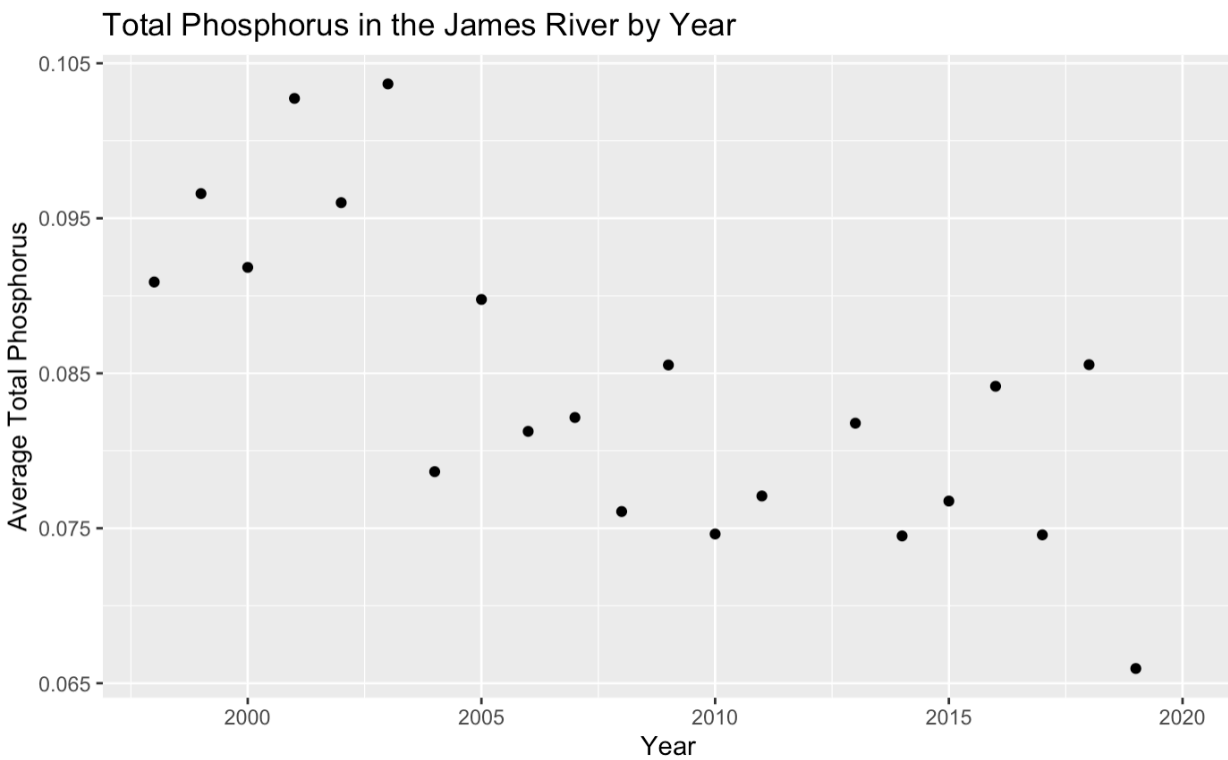
As you can see in the plot above, it looks like there is a negative relationship between chlorophyll-A and year. So let's move forward with the analysis.

The correlation coefficient is -0.41, which is closer to 0 than to -1, so there is not a strong relationship present.
The linear regression model resulted with a p-value of 0.000608, which is still low and a multiple R-squared of 0.4696 which means it explains 47% of the variability.

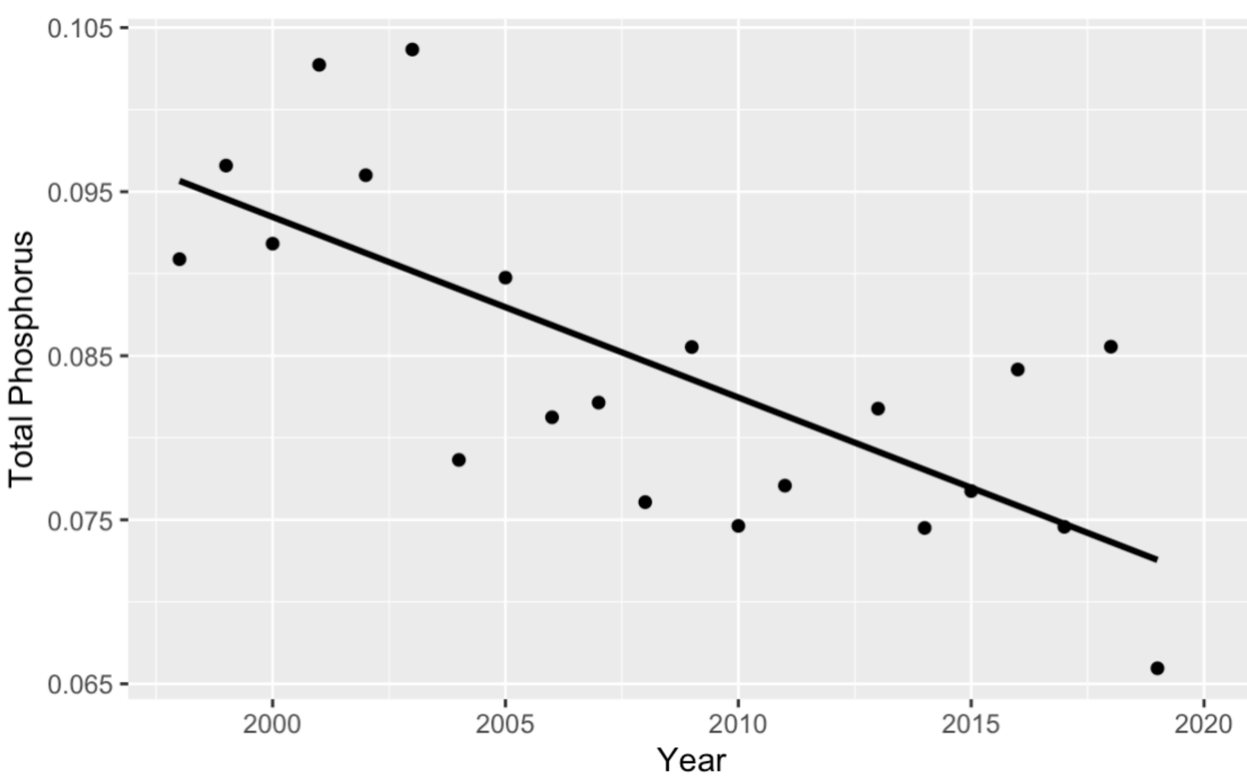
Although we could not establish a strong, negative relationship, chlorophyll-A is still appears to be decreasing through time which is another positive finding for environmentalists and marine scientists because remember that too much algae can lead to dead zones which can suffocate aquatic life and harm humans. The amount of chlorophyll-A could be decreasing for a number of reasons, but no matter the reason, we are on the right track if the number of oysters are increasing while the total chlorophyll-A is decreasing during the same time period and at the same location.

Water Quality - Total Phosphorus

As we can see from the plots below and just like the other parameters, the amount of total phosphorus is decreasing through time, and there seems to be a negative relationship between total phosphorus and year.



Total Phosphorus in the James River by Year
Average Total Phosphorus
0.105
0.095
0.085
0.075
0.065
2000
2005
2010
2015
2020
Year



Total Phosphorus
0.105
0.095
0.085
0.075
0.065
2000
2005
2010
2015
2020
Year

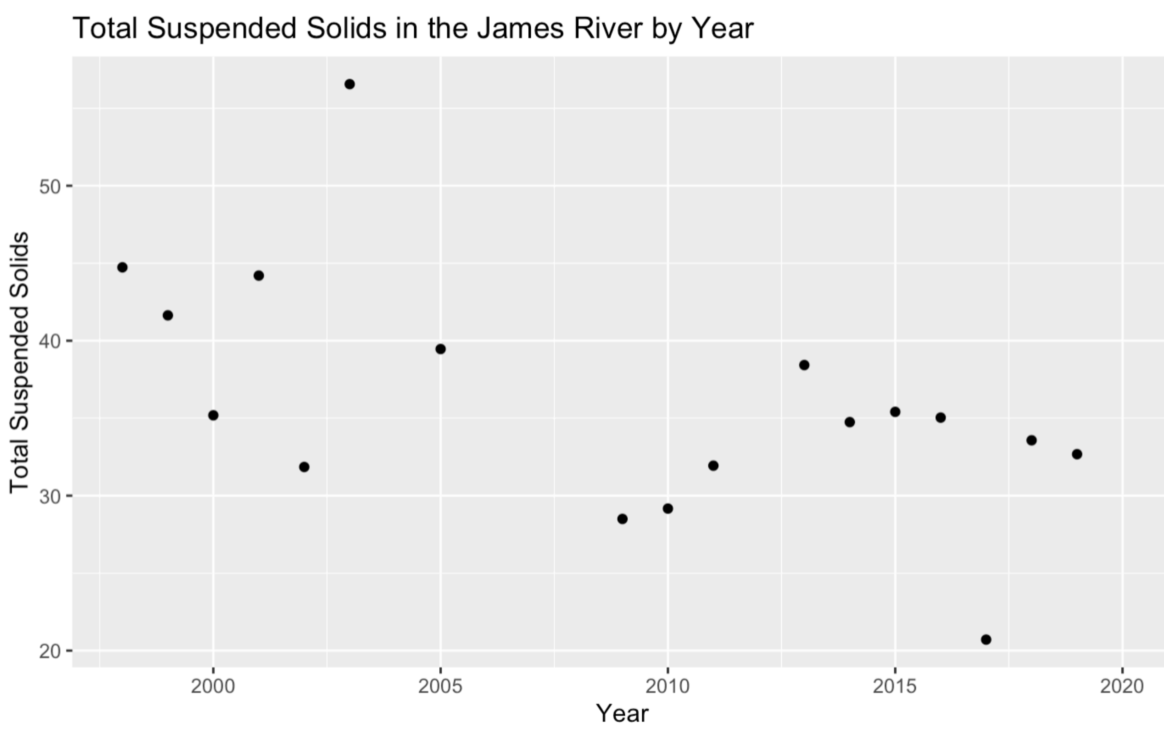
The correlation test between total phosphorus and year resulted in a -0.73 which is very close to -1, so we are statistically sure that there is a strong, negative relationship present. Remember that the number is negative because the relationship is negative - as one goes up, the other goes down. As the years increase, total phosphorus decreases.

The linear regression model resulted in a low p-value (0.000175) and a high multiple R-squared (0.5322), so we can confidently say through statistical analysis that the two variables are related. The average total phosphorus in the lower James River is decreasing through time.

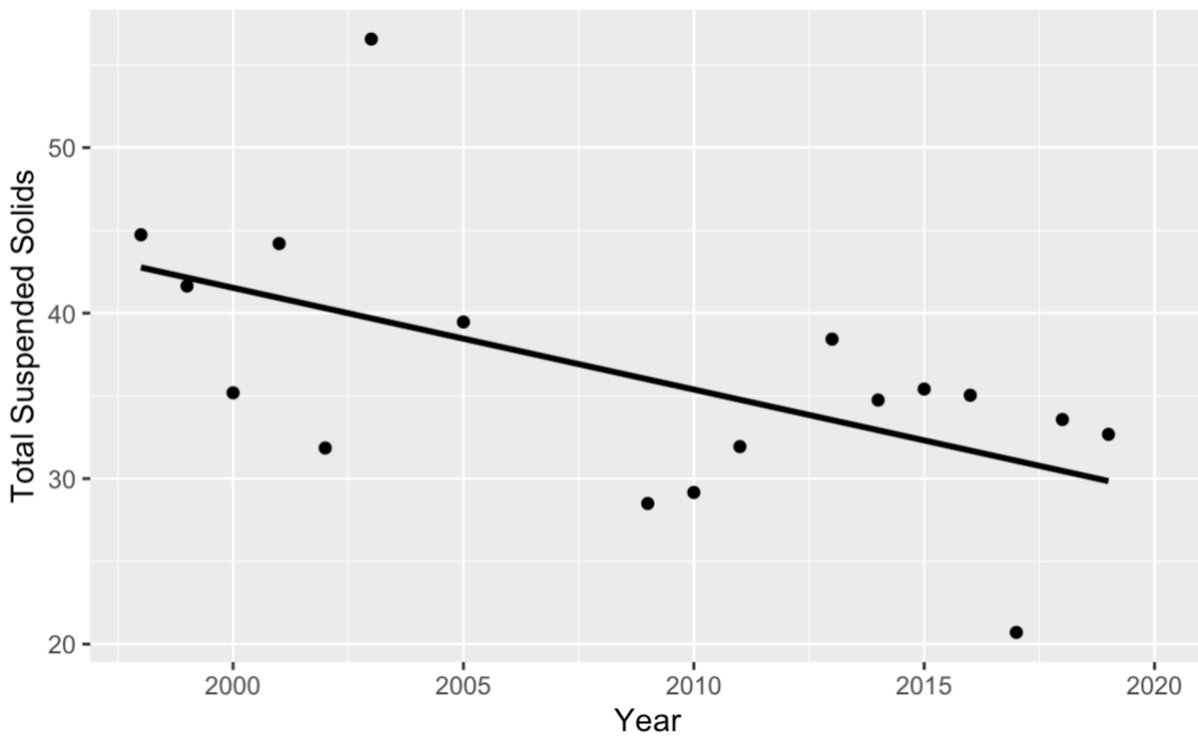
Water Quality - Turbidity

Because there is so much missing data from the turbidity dataset, we are going to use the total suspended solids parameter. Remember that we have to bring in the new data using the read.csv function.

Total suspended solids (TSS) are particles that are larger than 2 microns found in the water column. You can read more about them here.



Visually, it doesn't look like the total suspended solids are decreasing through time as dramatically as the other parameters, but there is still a downward trend present.



Visually, it appears as though the two variables have a negative relationship.

The correlation coefficient through the correlation test is -0.56, which is closer to -1 than to 0, so we can say that year and total suspended solids have a negative relationship. Remember, as time goes by (increases), total suspended solids decreases. The linear regression model, however, resulted in a lower multiple R-squared of 0.3161 and a higher p-value of 0.01881, so the model does not show a significant relationship.

Conclusion:

In conclusion, **the average total number of oysters has increased over time at the oyster reef restoration sites** in the lower James River, and the **total nitrogen, total phosphorus, chlorophyll-A, and turbidity have decreased over time in this area.**

What does this mean for oyster restoration programs?

The oyster restoration efforts are successfully increasing the number of oysters at the oyster reef stations and should receive annual grants so that they can continue to restore the population. The restoration programs not only deserve more financial award, they also deserve recognition by the state of Virginia as successful programs that should become a permanent part of the environmental efforts in the Chesapeake Bay and its tributaries.

As an aquaculturist, would you support these programs? Why or why not?

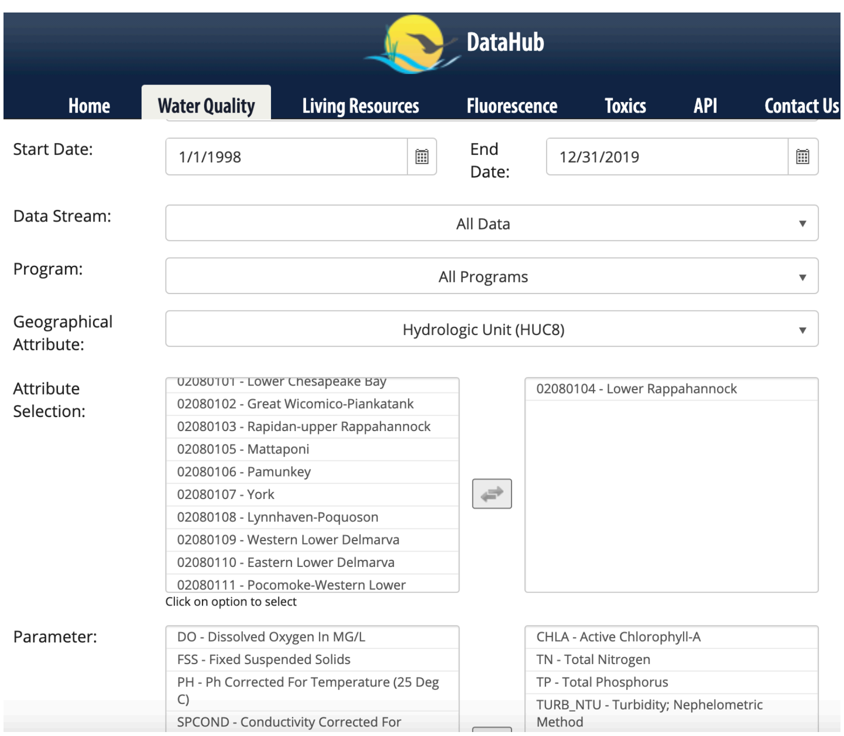
Yes, because an increase in wild oyster populations benefits everyone. When wild oysters reproduce, the oyster larvae may travel to nearby oyster farms. More oyster reefs means more aquatic wildlife like fish and crabs, so the fishery industry benefits as well. More oyster reefs, whether they are protected or able to be harvested, mean that there are more oysters filtering more water in the tributaries of the Chesapeake Bay. Oysters filter pollutants and algae, creating a better environment for both humans and wildlife.

Our hypothesis was right in that the oyster restoration sites in the James are increasing the number of oysters over the years. Our hypothesis was also right in that nitrogen, phosphorus, chlorophyll-A, and turbidity are all decreasing during this same time period and in the same location. It is important to remember the oysters' importance in their ecosystem and environment. An increase in oyster population sizes and a decrease in pollutants in our waterways means we are on the right track in regards to species conservation, environmentalism, and protecting human lives.

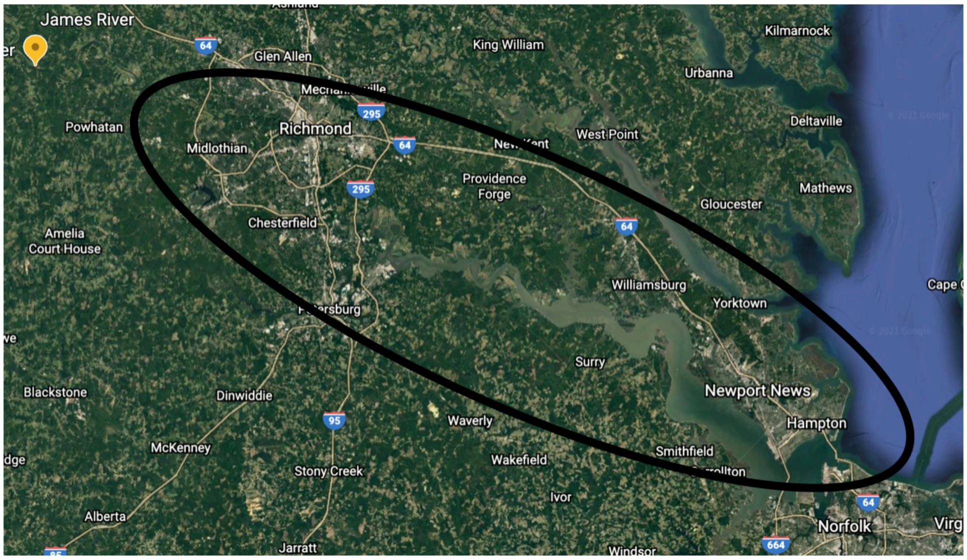
Homework:

Site #2: The Lower Rappahannock River

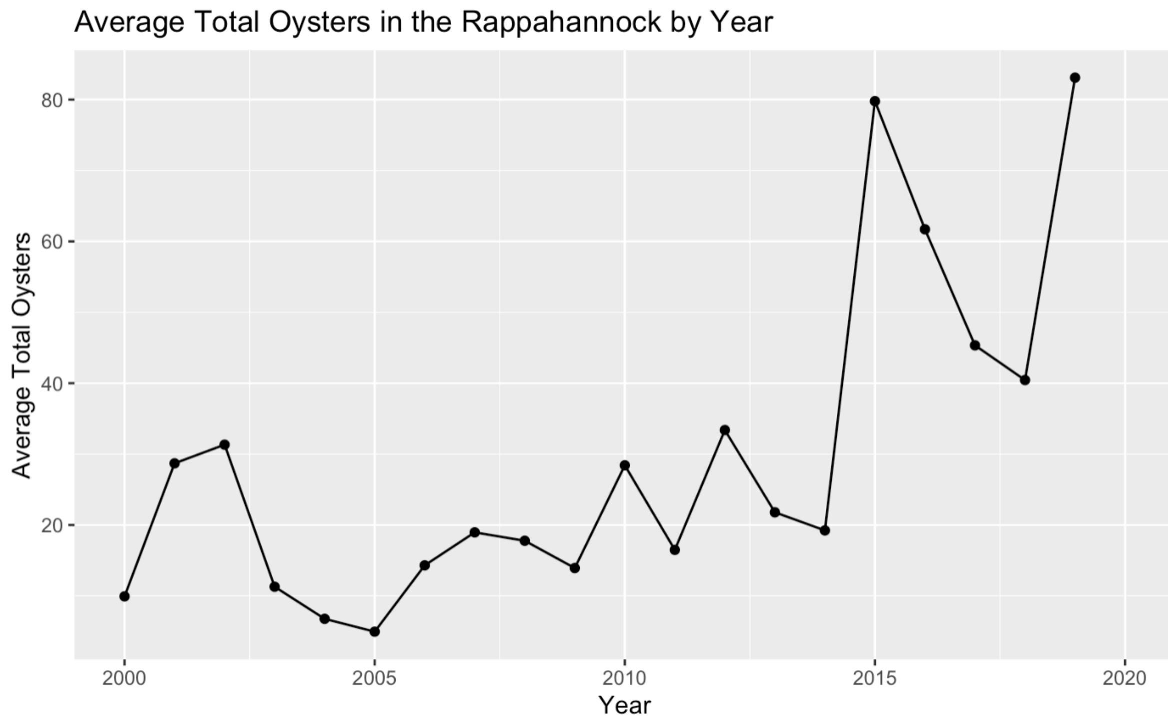
The students are going to do the same statistical analysis on the Rappahannock River that we just did on the James River. The source of the water quality data is pictured below. There are 57 public oyster reefs (approximately 583 acres) monitored in the Rappahannock River- 18 of those are designated as sanctuary reefs with the remaining 39 located in the rotational harvest areas. The oyster stations are all located in the lower Rappahannock.



The students will look at these google earth pictures of the James River and the Rappahannock River.



Then the students will look at the location of the rivers in retrospect to each other.



The students will answer the following questions.

Think about where the James River is located compared to the Rappahannock River. Based off of this location, what is your hypothesis? Do you think the Rappahannock River will have similar success in the increase in the amount of oysters? What about in the amount of TN, TP, CHL, and TURB? How might the water quality be different between the two rivers? Why?

Answer: The Rappahannock River is north of the James River, so since the water flows from north to south, there might be less pollution in the Rappahannock. This could mean more success in oyster restoration efforts. The James River runs through Richmond, Virginia, so there could be more pollution going into the James in the form of urban runoff. However, the Rappahannock is located in a more rural area, so there might be more pollutants coming from agricultural runoff.

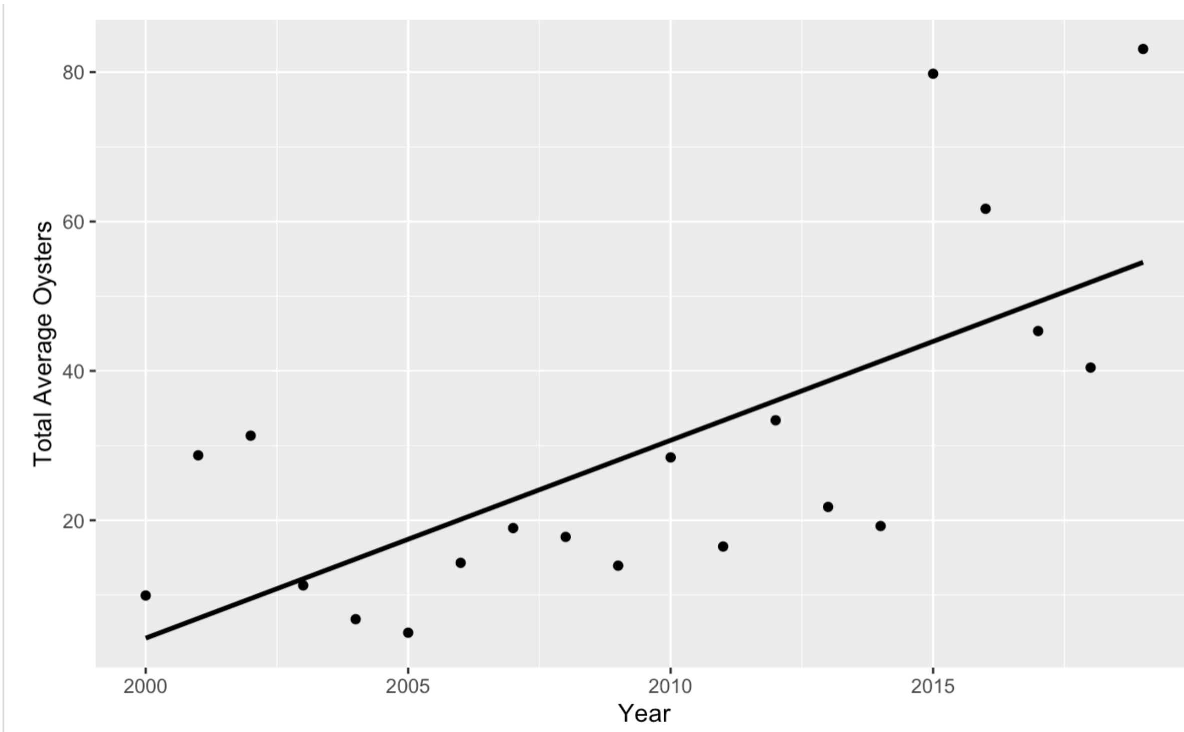
Oyster Data

Remember that this is a new .csv file, so you have to bring in the data using the "read.csv" function.
Execute the same analysis as we did for the James oyster data.

Make a plot using GGPLOT as we did before showing how the total number of oysters changes through time. How does the total number of oysters visually change through time?

Answer: The total number of oysters appears to be increasing through time.

Make a plot as we did before showing the linear relationship between year and total number of oysters. Are there any trends present? Should we continue with the analysis?



Answer: It appears that there is a positive relationship between year and total oysters, so yes we can continue.

What is the correlation coefficient between year and total oysters?

Answer: The correlation coefficient is 0.69 which is close to +1 so we can confidently say that a positive relationship exists.

What does the linear regression model say about the two variables?

Answer: The p-value is low 0.0007101 and the multiple R-squared is high 0.4799- the model explains 48% of variability. There is a significant relationship between the two variables.

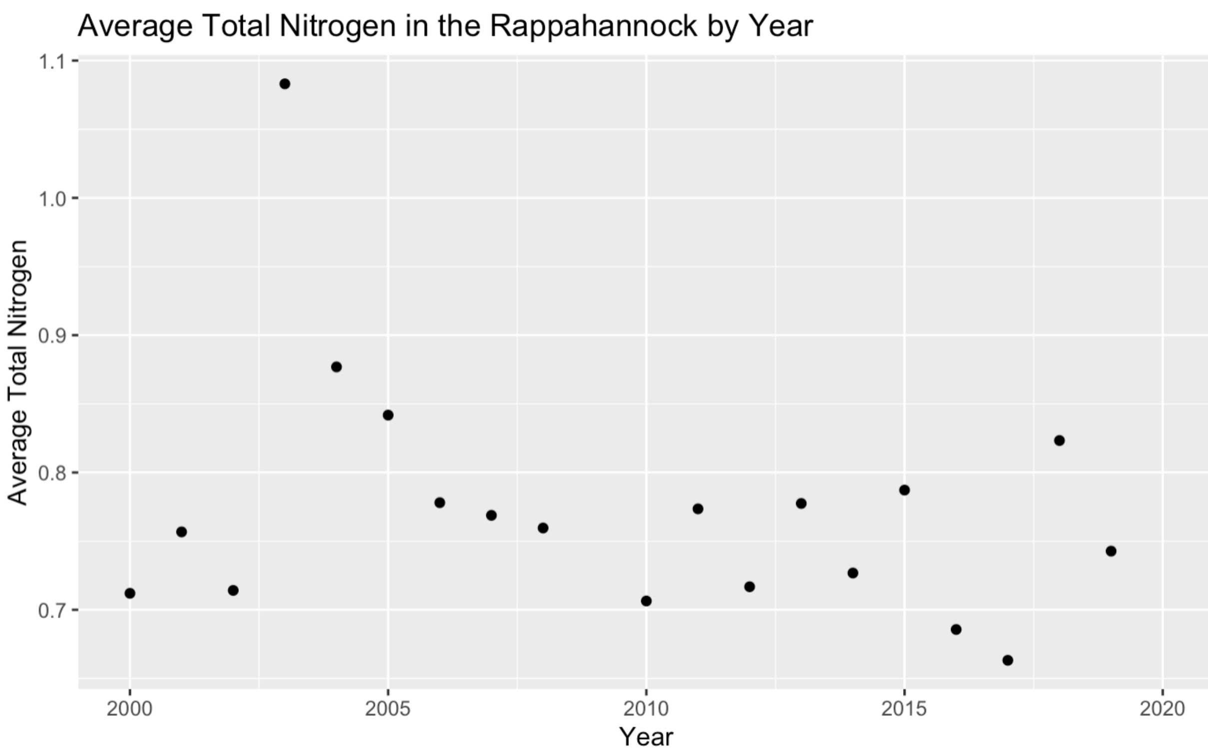
What is your conclusion?

Answer: The number of oysters in the lower Rappahannock River is visually increasing through time. From my statistical analysis, I can confidently say that there is a positive relationship between year and number of oysters in the lower Rappahannock River.

Water Quality- Total Nitrogen

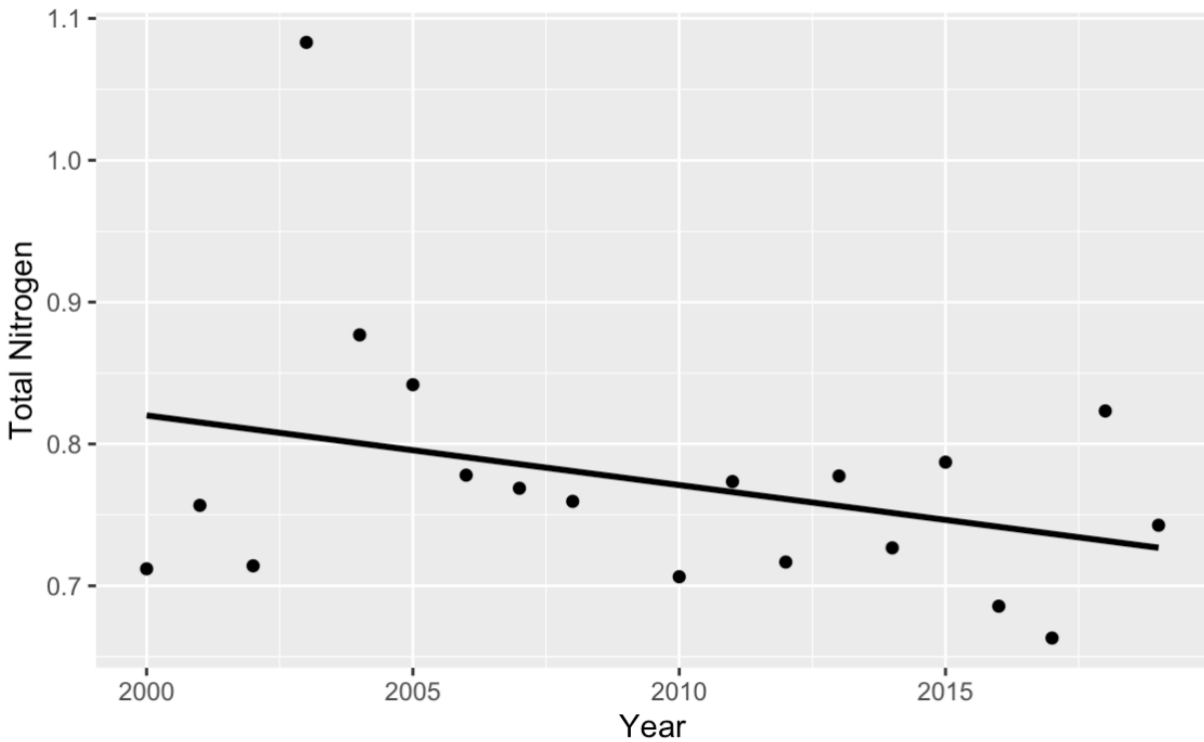
Look at the water quality data to see if TN, TP, CHL, and TURB are increasing or decreasing through the same time and space as the oyster numbers.
Hint - the Rappahannock oyster data starts in 2000, so you will have to manipulate the Rappahannock water quality data to start in 2000 as well.

Make a plot using GGPLOT as we did before showing how total nitrogen changes through time.
How does the total nitrogen visually change through time?



Answer: The total nitrogen does not appear to be increasing or decreasing through time. There is no obvious trend present.

Make a plot as we did before showing the linear relationship between year and total nitrogen. Are there any trends present? Should we continue with the analysis?

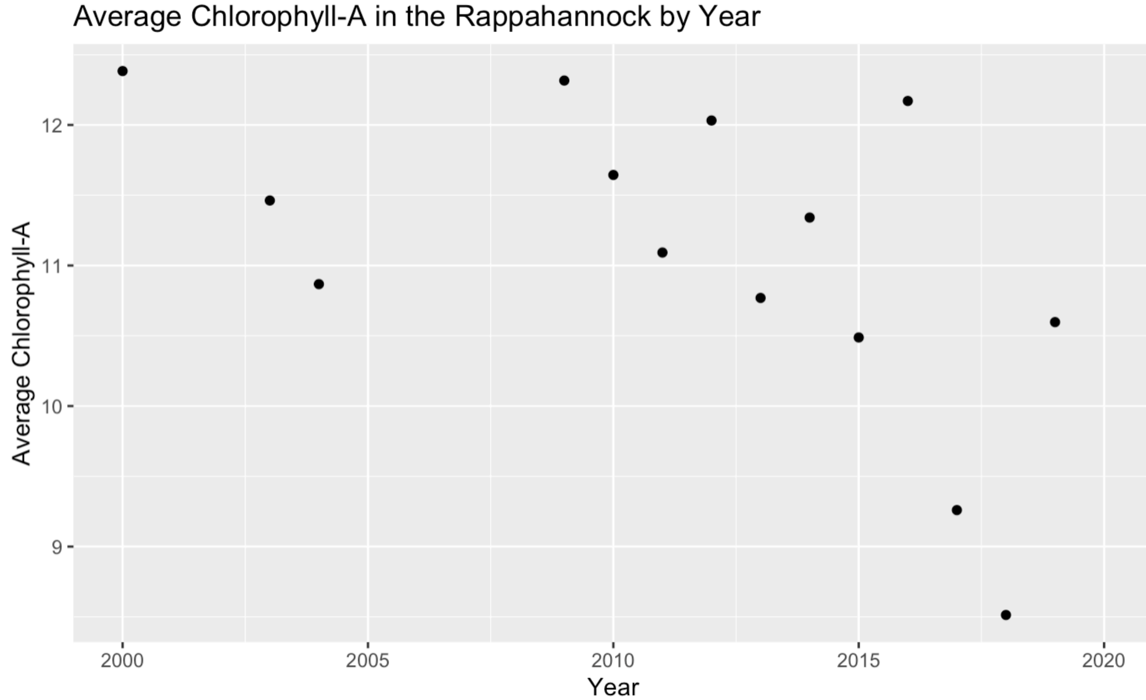


Answer: The plot does not show any increasing or decreasing trends so a linear regression model will not be useful. No, we will not run the correlation test or make a linear regression model.

Water Quality - Chlorophyll-A

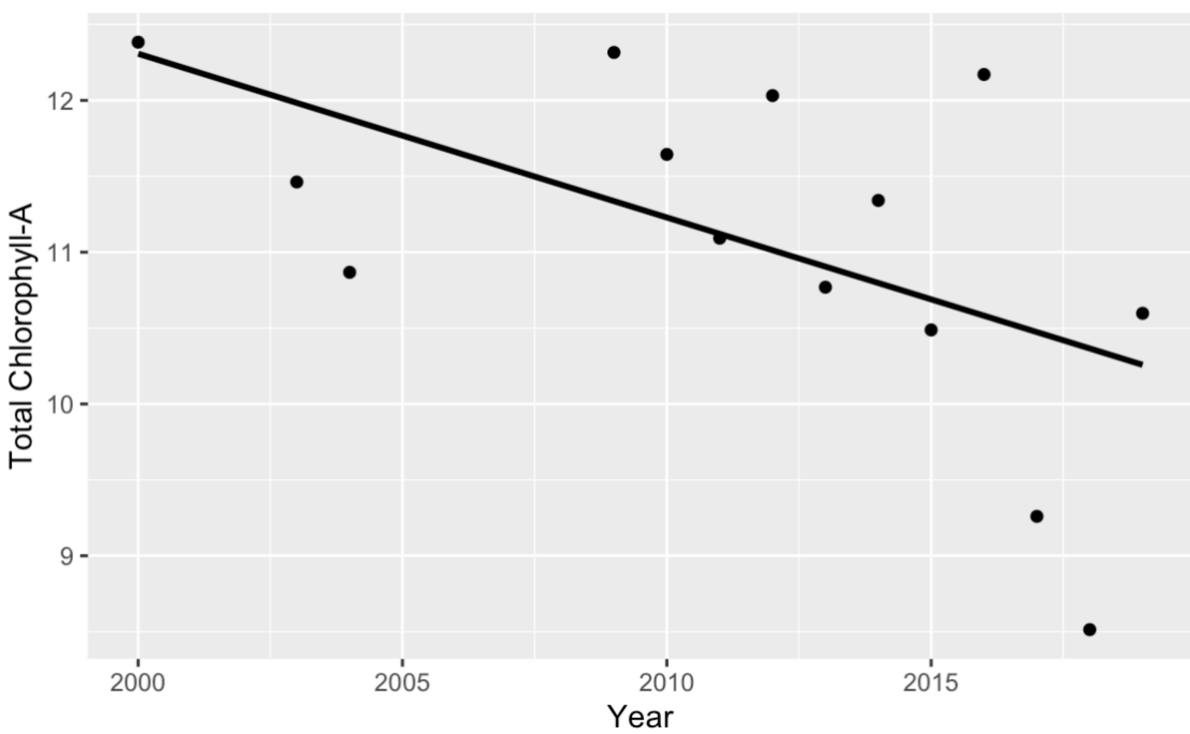
Make a plot using GGPLOT as we did before showing how total nitrogen changes through time. How does the chlorophyll-A visually change through time?

Average Chlorophyll-A in the Rappahannock by Year



Answer: The chlorophyll-A appears to be decreasing through time.

Make a plot as we did before showing the linear relationship between year and total nitrogen. Are there any trends present? Should we continue with the analysis?



Answer: There does appear to be a negative relationship between the two variables, so we can continue with the analysis.

As an environmentalist what can you infer from this plot? Why does the amount of chlorophyll-A in our waterways matter?

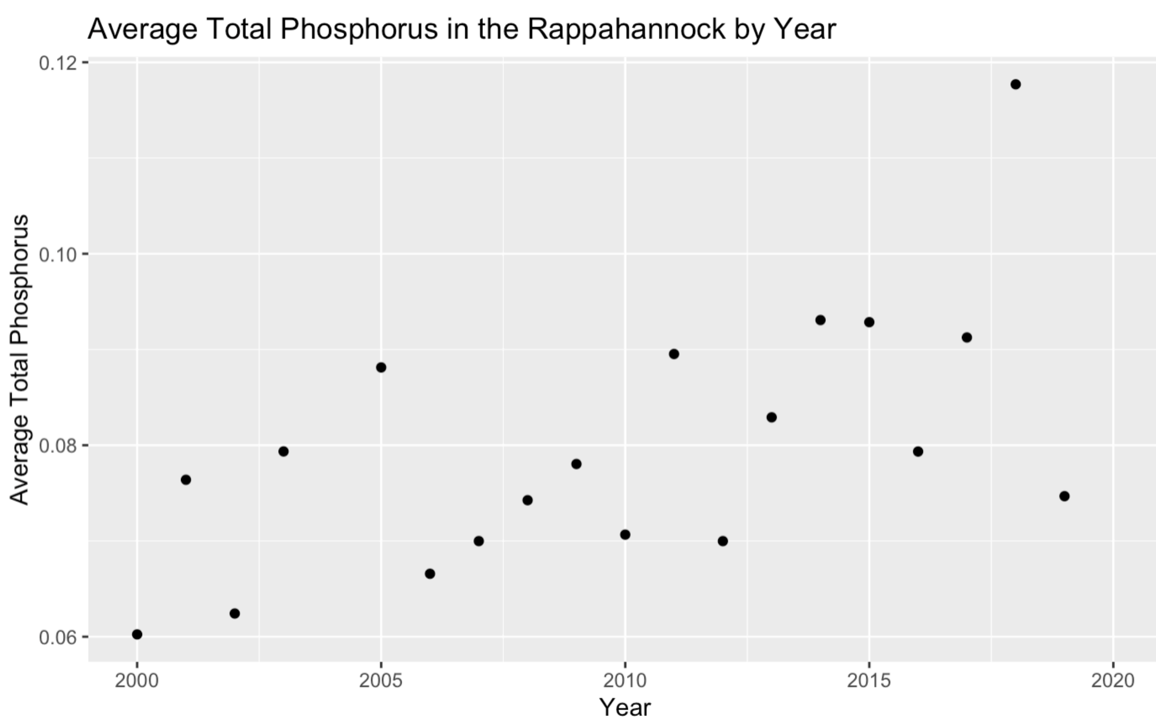
Answer: Lower amounts of chlorophyll-A are a good sign because too much algae can lead to dead zones which suffocate aquatic life. Certain types of algae are harmful to humans and dogs and can even cause death.

What is the correlation coefficient, p-value, and multiple R-squared? What do they mean? Can we confidently say that the two variables are related?

Answer: The correlation coefficient is -0.56, the p-value is 0.03851, and the multiple R-squared is 0.3103. Since the correlation coefficient is closer to -1 than 0 we can statistically say there is a negative relationship. Since the p-value is high and the multiple R-squared is low, the model does not show a relationship between the two variables.

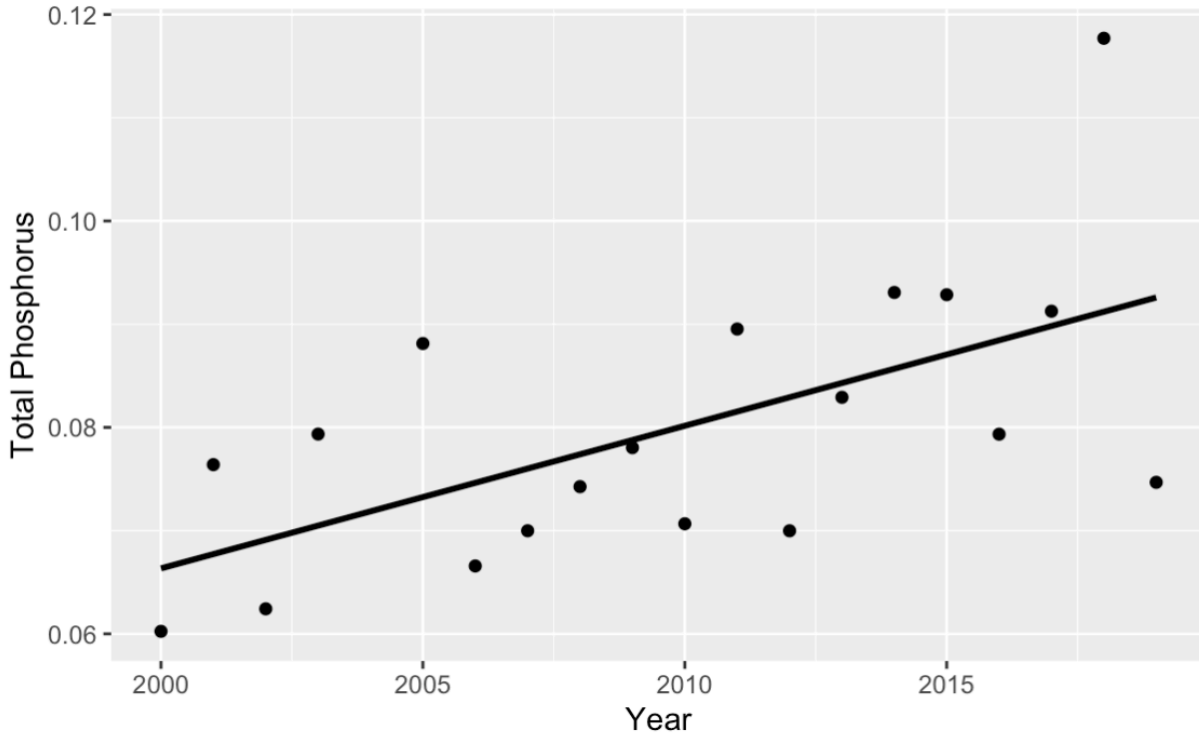
Water Quality - Total Phosphorous

Make a plot using GGPLOT as we did before showing how total phosphorus changes through time. How does the total phosphorus change through time?



Answer: The total phosphorus appears to be increasing through time.

Make a plot as we did before showing the linear relationship between year and total phosphorus. Are there any trends present? Should we continue with the analysis?



Answer: There appears to be a positive relationship between the variables, so we can continue with the analysis.

Why might there be an increase in the amount of phosphorus in the Rappahannock River over time?

Answer: The proximity of the Rappahannock River to farms and agriculture could be the reason for this increase since agricultural runoff includes phosphorus.

What are two ways we can regulate the amount of phosphorus that goes into our waterways?

Answer: We can vote on policy to regulate the amount of fertilizers that contain phosphorus permitted to be used by farmers and farmers can create buffers and barriers to stop runoff pollution from entering the waterways.

What is the correlation coefficient, p-value, and multiple R-squared? What do they mean? Can we confidently say that the two variables are related?

Answer: The correlation coefficient is -0.32, the p-value is 0.1757, and the multiple R-squared is 0.1051. Since the correlation coefficient is closer to 0 than -1 we can not statistically say there is a negative relationship. Since the p-value is high and the multiple R-squared is low, the model does not show a relationship between the two variables. Therefore we can not confidently say the two variables are related.

Water Quality - Turbidity

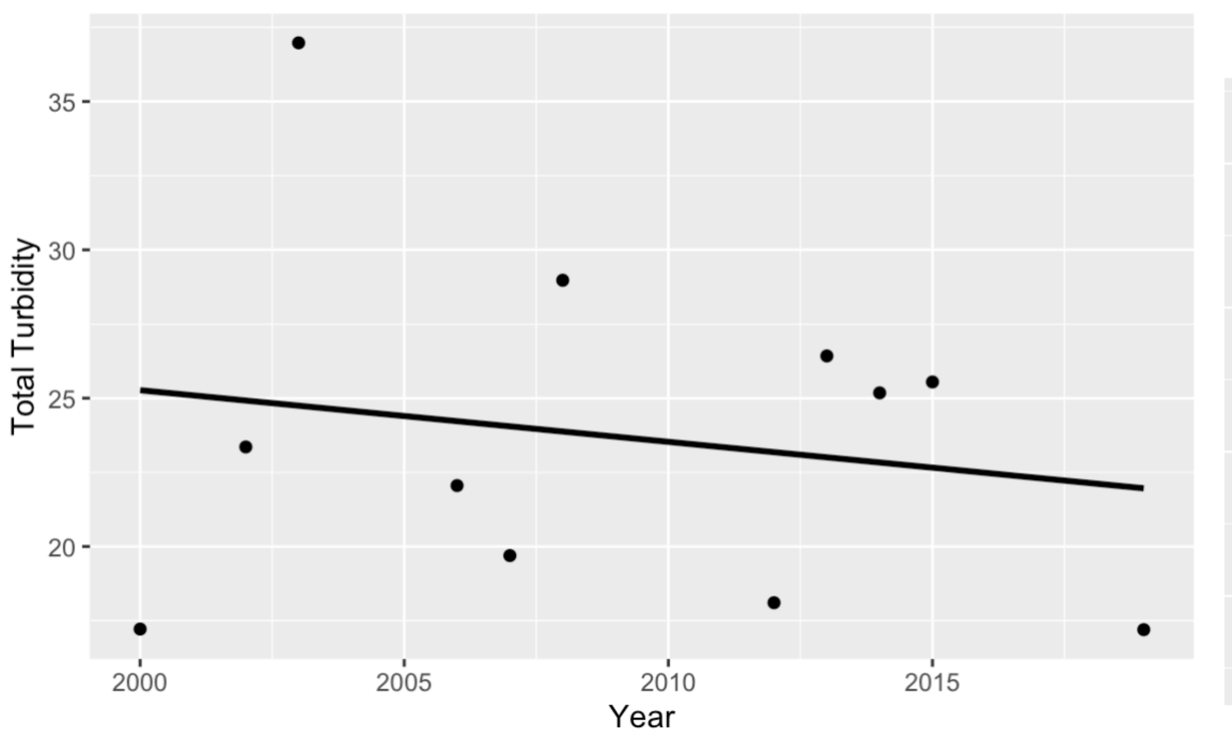
Visually, how does the turbidity change through time? Is this positive or negative?

Answer: The turbidity looks like it is decreasing through time. This is a positive because turbidity is the measure of cloudiness in the water column. Too much turbidity can block sunlight from reaching seagrass which is an important food source and habitat for many species.

As a marine scientist, how do you feel about this plot?

Answer: I would be happy about the decrease in the amount of turbidity in the water column over the years because cloudy water can be harmful to many aquatic species.

Make a plot as we did before showing the linear relationship between year and total turbidity. Are there any trends present? Should we continue with the analysis?



Answer: The plot does not show any increasing or decreasing trends so a linear regression model will not be useful. No, we will not run the correlation test or make a linear regression model.

Bringing it all together

Through our analysis, we have found that despite a long history of over-harvesting, disease, and habitat degradation, the Eastern Oyster population size has been increasing in the lower James and Rappahannock Rivers throughout the 21st century. These wild oyster population sizes are located on restored reefs. The combined efforts of many organizations like VIMS, VOSRP, NOAA, CBP, and VMRC are the reason the oyster numbers are rising, along with policies like the Oyster Management Plan. **You can find out more about the policies behind oyster restoration here.** If you are interested in oyster recycling, you can find a bin near you and read more about VOSRP **here** or **watch this video.**

Through our analysis, we have found that the water quality in the lower James River has improved through time in the 21st century. There is evidence that the average total nitrogen, phosphorus, chlorophyll-A, and turbidity per year has gone down from the early 2000s through 2019. However, nitrogen and phosphorus agricultural runoff is still a prominent issue in the Chesapeake Bay, as we found in our analysis of the lower Rappahannock River. It is important that we continue to monitor the levels of these nutrients in our waterways because as you have read about in this lesson, excess nitrogen and phosphorus leads to excess algae which can create dead zones. These dead zones suffocate aquatic life and can harm humans and other species, like dogs. Below you can read about how you can help save the Bay.

1. **Don't Litter** – Reduce the amount of trash that ends up in the Chesapeake Bay.
2. **Use Fertilizer Sparingly** – Limit the amount of fertilizer used on your lawn and garden. Excessive levels of nutrients in the Bay lead to lower levels of oxygen needed for aquatic life.
3. **Build a Rain Garden or Rain Barrel** – Stormwater carries pollutants such as lawn chemicals from our yards into the Bay. Creating backyard habitats can minimize runoff and reduce yard work.

4. **Scoop the Poop** – Make your neighbors happy and keep harmful nitrogen out of the Bay by always cleaning up after your pet.
5. **Drive Less** – More than one-third of the nitrogen pollution entering the Chesapeake Bay originates from air pollution. Consider carpooling, using public transportation, biking or walking whenever possible.
6. **Reduce Electricity** - Coal-burning power plants are among the largest sources of nitrogen compounds in air pollution.
7. **Grab a Friend and Volunteer** – Cleaning up the Bay begins in your hometown. Find a local watershed group, grab some friendsand volunteer for a clean-up.
8. **Make an Appointment to Service Your Septic System** – Septic systems should be inspected yearly to ensure proper functioning. Failing systems can leak into the groundwater and eventually end up in the Bay.
9. **Dispose Properly of Hazardous Household Items** – Oils, anti-freeze, paint, cleaners and prescription drugs shouldn't be poured down a household or storm drain. Check with your local waste management service to find out what hazardous materials they accept.
10. **Recycle Oyster Shells** – A healthy oyster population can help filter and clean Chesapeake Bay waterways. A recycled oyster shell can return 10 new oysters back into the Bay.

Note- I included histograms of the data throughout the R script because it is always helpful to look at a histogram of the data first to see if it is normally distributed. If it isn't, you can log it to make it more normally distributed.

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