Final Project

ENVIRON 872

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Contents

1. Rationale and Research Question **5**

2. Dataset Information **6**

3. Exploration of Raw Data **6**

4. Data Wrangling **6**

5. Exploration of Processed Data **7**
- 5.1 Dissolved Oxygen . . . 9
- 5.2 Chlorophyll . . . 14
- 5.3 Chlorophyll and Dissolved Oxygen . . . 19

6. Analysis **20**
- 6.1 Dissolved Oxygen Time Series Trend Analysis . . . 20
  - All Monitoring Stations have had statistically significant decreasing trends in their Dissolved Oxygen. . . . 24
- 6.2 Chlorophyll Time Series Trend Analysis . . . 24
- Multiple Regression . . . 28
- 6.4 Time Series Analysis of Relevant Variables . . . 30
  - 6.4.1 East Cribbing . . . 30
  - 6.4.2 Loosin Creek . . . 34
  - 6.4.3 Research Creek . . . 38
  - 6.4.4 Zeke's Basin . . . 42

7. Summary and Conclusion **46**

8. References **47**

List of Figures

1 Map of NC NERR Water Monitoring Stations . . . 7
2 Corrplot: Correlation Matrix of Variables . . . 8
3 Dissolved oxygen over time for each station . . . 9
4 Dissolved oxygen over time for each station separately . . . 9
5 Dissolved oxygen monthly averages at each monitoring station . . . 10
6 Relationship between Temperature and Dissolved Oxygen . . . 11
7 Relationship between Nitrate and Dissolved Oxygen . . . 11
8 Relationship between Phosphate and Dissolved Oxygen . . . 12

9 Relationship between Ammonium and Dissolved Oxygen . . . 12
10 Relationship between Depth and Dissolved Oxygen . . . 13
11 Chlorophyll Concentrations from 2002-2024 . . . 14
12 Chlorophyll concentrations from 2002-2024 for each monitoring station . . . 14
13 Chlorophyll Monthly Concentrations . . . 15
14 Relationship between Temperature and Chlorophyll . . . 16
15 Relationship between Nitrate and Chlorophyll . . . 16
16 Relationship between Phosphate and Chlorophyll . . . 17
17 Relationship between Ammonium and Chlorophyll . . . 17
18 Relationship between Depth and Chlorophyll . . . 18
19 Relationship between dissolved oxygen and chlorophyll . . . 19
20 Decomposed Components of East Cribbing Dissolved Oxygen Time Series . . . 20
21 Non-Seasonal Trend of East Cribbing Dissolved Oxygen . . . 20
22 Decomposed Components of East Cribbing Dissolved Oxygen Time Series . . . 21
23 Non-Seasonal Trend of Loosin Creek Dissolved Oxygen . . . 21
24 Decomposed Components of Research Creek Dissolved Oxygen Time Series . . . 22
25 Non-Seasonal Trend of Research Creek Dissolved Oxygen . . . 22
26 Decomposed Components of Zeke's Basin Dissolved Oxygen Time Series . . . 23
27 Non-Seasonal Trend of Zeke's Basin Dissolved Oxygen . . . 23
28 Decomposed Components of East Cribbing Chlorophyll Time Series . . . 24
29 Non-Seasonal Trend of East Cribbing Chlorophyll . . . 24
30 Decomposed Components of Loosin Creek Chlorophyll Time Series . . . 25
31 Non-Seasonal Trend of Loosin Creek Chlorophyll . . . 25
32 Decomposed Components of Research Creek Chlorophyll Time Series . . . 26
33 Non-Seasonal Trend of Research Creek Chlorophyll . . . 26
34 Decomposed Components of Zeke's Basin Chlorophyll Time Series . . . 27
35 Non-Seasonal Trend of Zeke's Basin Chlorophyll . . . 27
36 Decomposed Components of East Cribbing PO4 Time Series . . . 30
37 Non-Seasonal Trend of East Cribbing PO4 . . . 30
38 Decomposed Components of East Cribbing NH4 Time Series . . . 31
39 Non-Seasonal Trend of East Cribbing NH4 . . . 31
40 Decomposed Components of East Cribbing NO3 Time Series . . . 32
41 Non-Seasonal Trend of East Cribbing NO3 . . . 32
42 Decomposed Components of East Cribbing Temperature Time Series . . . 33
43 Non-Seasonal Trend of East Cribbing Temperature . . . 33
44 Decomposed Components of Loosin Creek PO4 Time Series . . . 34
45 Non-Seasonal Trend of Loosin Creek Temperature . . . 34
46 Decomposed Components of Loosin Creek NH4 Time Series . . . 35
47 Non-Seasonal Trend of Loosin Creek NH4 . . . 35
48 Decomposed Components of Loosin Creek NO3 Time Series . . . 36
49 Non-Seasonal Trend of Loosin Creek NO3 . . . 36
50 Decomposed Components of Loosin Creek Temperature Time Series . . . 37
51 Non-Seasonal Trend of Loosin Creek Temperature . . . 37
52 Decomposed Components of Research Creek PO4 Time Series . . . 38
53 Non-Seasonal Trend of Research Creek PO4 . . . 38
54 Decomposed Components of Research Creek NH4 Time Series . . . 39
55 Non-Seasonal Trend of Research Creek NH4 . . . 39
56 Decomposed Components of Research Creek NO3 Time Series . . . 40
57 Non-Seasonal Trend of Research Creek NO3 . . . 40
58 Decomposed Components of Research Creek Temperature Time Series . . . 41
59 Non-Seasonal Trend of Research Creek Temperature . . . 41
60 Decomposed Components of Zeke's Basin PO4 Time Series . . . 42
61 Non-Seasonal Trend of Zeke's Basin PO4 . . . 42
62 Decomposed Components of Zeke's Basin NH4 Time Series . . . 43

63 Non-Seasonal Trend of Zeke's Basin NH4 43
64 Decomposed Components of Zeke's Basin NO3 Time Series 44
65 Non-Seasonal Trend of Zeke's Basin NO3 44
66 Decomposed Components of Zeke's Basin Temperature Time Series 45
67 Non-Seasonal Trend of Zeke's Basin Temperature 45




1. Rationale and Research Question

Human development and global environmental change have put strain on aquatic ecosystems world wide. One of the biggest impacts on coastal estuarine systems is the rise in frequency of eutrophication, when excess nutrients cause phytoplankton populations to soar. When nutrients like phosphorus and nitrogen are moved through waterways and accumulate at the mouths of streams and rivers, algal blooms cause foul odors, block light, and remove dissolved oxygen in the water as the large numbers of phytoplankton die (Chislock et al., 2013).

The National Atmospheric and Oceanic Association has 4 water quality and nutrients monitoring stations in southern North Carolina as part of its water monitoring open data portal. Components of the North Carolina National Estuarine Research Reserve (NCNERR) located in the Cape Fear River basin, the monitoring stations in Research Creek, Loosin Creek, Zeke's Basin, and East Cribbing each collect data on water quality and nutrients. We wanted to know if dissolved oxygen and chlorophyll (key indicators of algal blooms) have changed over time in this region, and if a relationship can be found between nutrient variables associated with eutrophication.

Our research questions are:

1. Has there been significant statistical trends in the dissolved oxygen and chlorophyll a concentrations at the water quality monitoring stations over time?

2.0. Which water nutrient variables are most strongly predictive of dissolved oxygen and chlorophyll a?

2.1. Have these strongly predictive variables had significant statistical trends in their concentrations at the water quality monitoring stations over time?

2. Dataset Information

The data set was collected through the National Estuarine Research Reserve System's (NERR) National Monitoring Program. NERR was established by the Coastal Zone Management Act and was in paid partnership with National Oceanic and Atmospheric Administration. The data set is public information and meets the quality assurance and quality control protocols of the Estuarine Reserve Division.

We collected the data from the National Estuarine Research Reserve System's Centralized Data Management Office. Specifically, we collected nutrient and water quality data from four stations in North Carolina: East Cribbing, Loosin Creek, Research Creek, and Zeke's Basin.

3. Exploration of Raw Data

Exploration of the raw data consisted of understanding the number of files and contents of those files for each Station. Originally, the water quality data and the nutrient data were separate for each station we are studying. We uploaded all of the files with nutrient and water quality data from the four stations we are studying for the years 2002-2024. We obtained a separate file with information about the stations in which the data was collected.

4. Data Wrangling

After the conclusion of exploring the raw data, we began to wrangle the data by choosing the variables we wished to keep for our study.

For the nutrient data sets we kept:

- Station Code
- Date and Time
- Orthophosphate (PO4F) (mg/L)
- Ammonium (NH4F) (mg/L)
- Nitrite (NO2F) (mg/L)
- Nitrate (NO3F) (mg/L)
- Nitrite + Nitrate (NO23F) (mg/L)
- Chlorophyll a (ug/L)

For the water quality data sets we kept the variables:

- Station Code
- Date and Time
- Temperature (degrees Celsius)
- Salinity (ppt)
- Dissolved Oxygen (%)
- Dissolved Oxygen in milligrams per Liter (mg/L)
- Depth (m)
- pH (standard units)
- Turbidity (NTU)

After cleaning, preparing, and combining all of the files into one data set for nutrients and one data set for water quality, we added the sampling station data to each. This allowed us to create two large data sets which we will use for our study. With so multiple samples taken per day, we decided to get a monthly average of the data since our study focuses on the changes in nutrients and water quality over a 12 year period (2002-2024). Finally, we saved our new completed datasets as new csv files to ensure they were saved properly and could be used in future studies if need be.

5. Exploration of Processed Data

To explore the processed data, we begin our study by exploring the variables and identifying which are correlated and have varied throughout the 12 year period we are studying.

Our 4 water monitoring stations are located around the Cape Fear River basin, North Carolina.

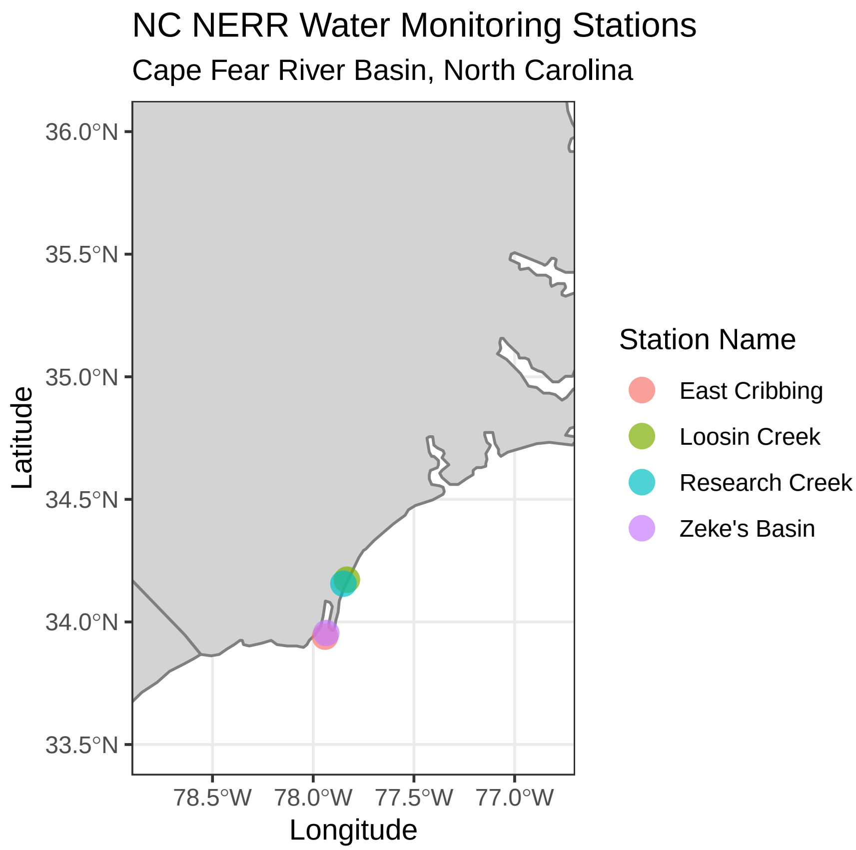

Figure 1: Map of NC NERR Water Monitoring Stations

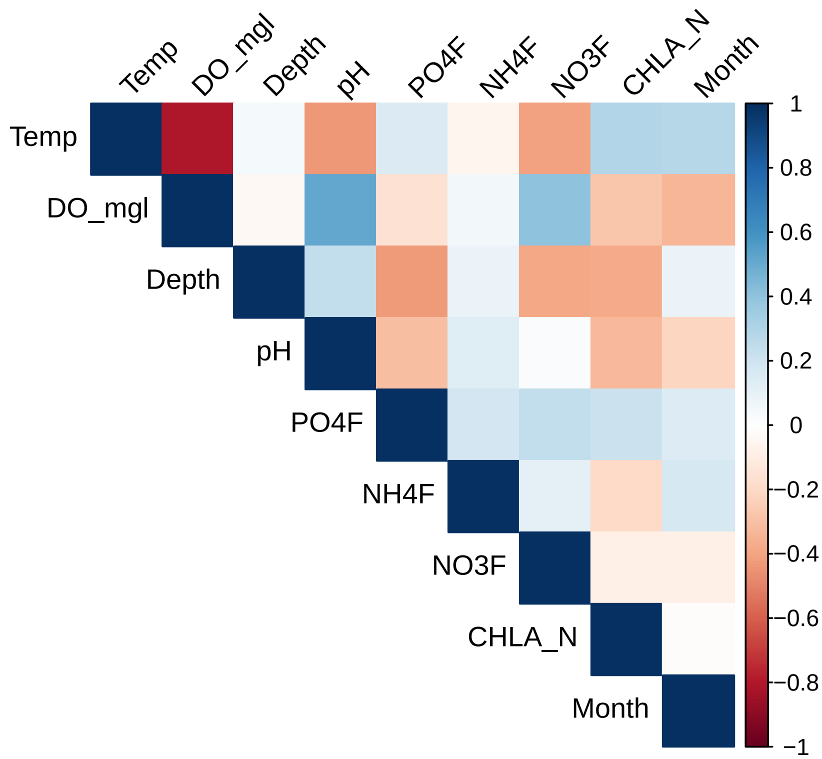

Figure 2: Corrplot: Correlation Matrix of Variables

5.1 Dissolved Oxygen

Relationships between different nutrients is important to understand water quality and ecosystem health, so we will look at the different variables and see how they relate to each other based on our initial comparison. We're most interested in dissolved oxygen across the four monitoring stations. We will start with seeing how the other variables relate to dissolved oxygen. Is there consistent data for us to analyze? Could we identify trends over time?

Although plotting dissolved oxygen is helpful for seeing consistent patterns and concentrations across all four stations, let's look at them separately to see gaps and data coverage.

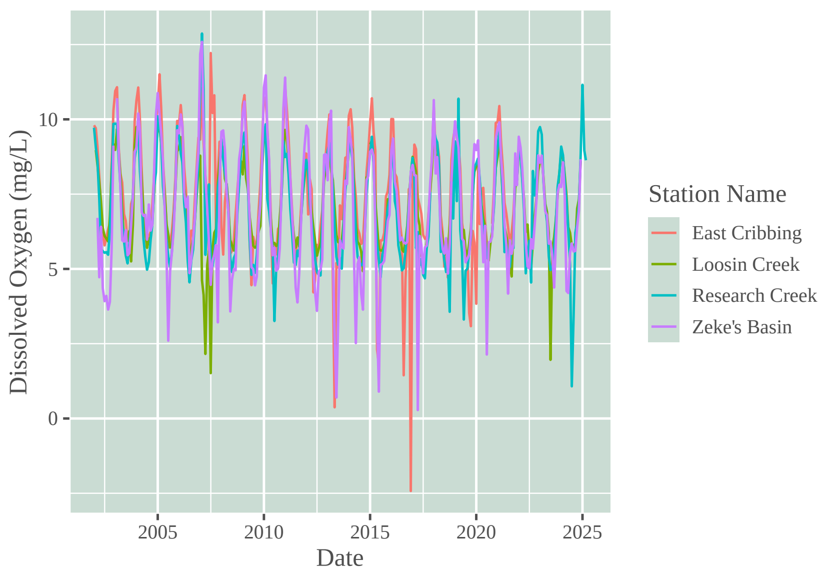

Figure 3: Dissolved oxygen over time for each station

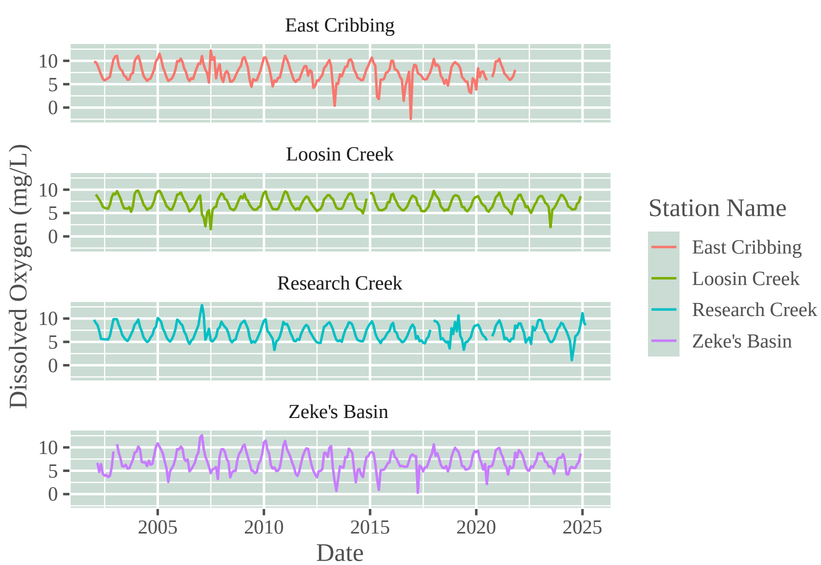

Figure 4: Dissolved oxygen over time for each station separately

It is important to note that the East Cribbing's data seems to end by 2022.

It seems that there's variation in dissolved oxygen across the year. What do the monthly spreads look like?

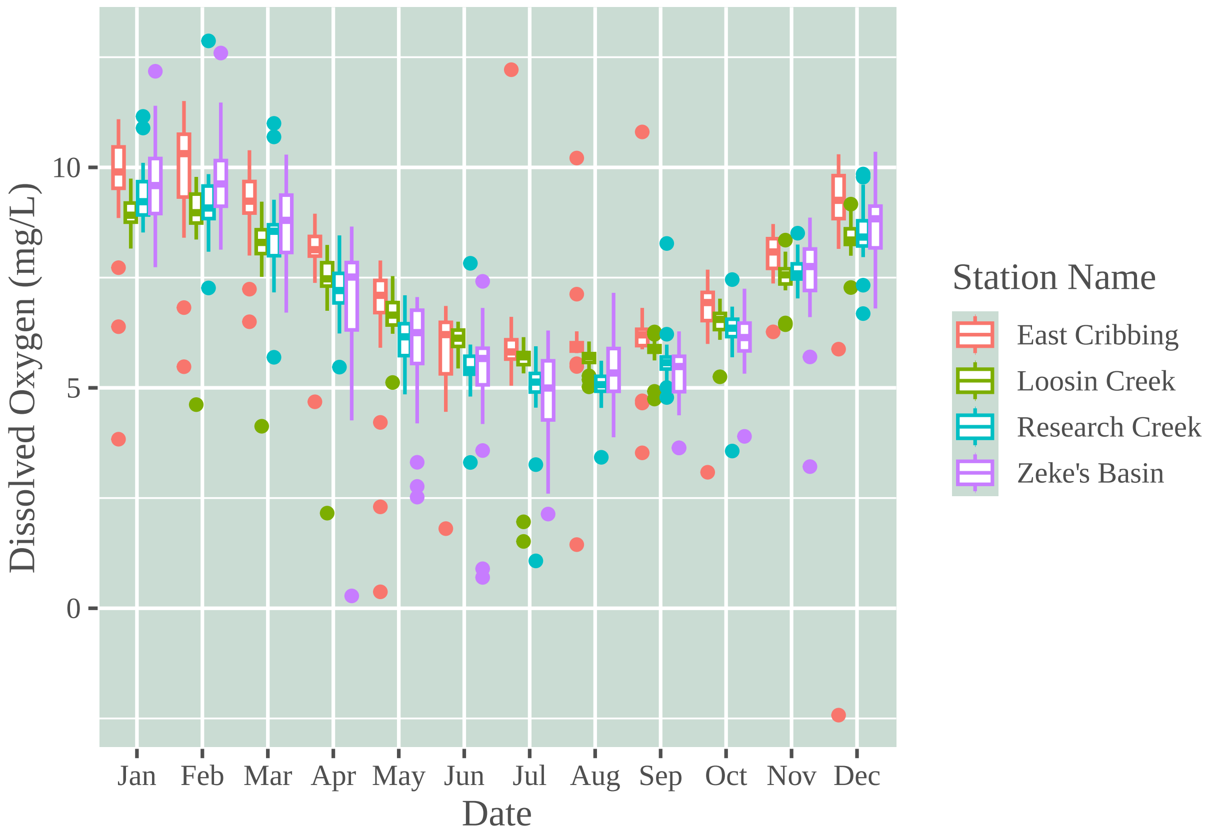

Figure 5: Dissolved oxygen monthly averages at each monitoring station

Now we want to look at how dissolved oxygen relates to the other variables.

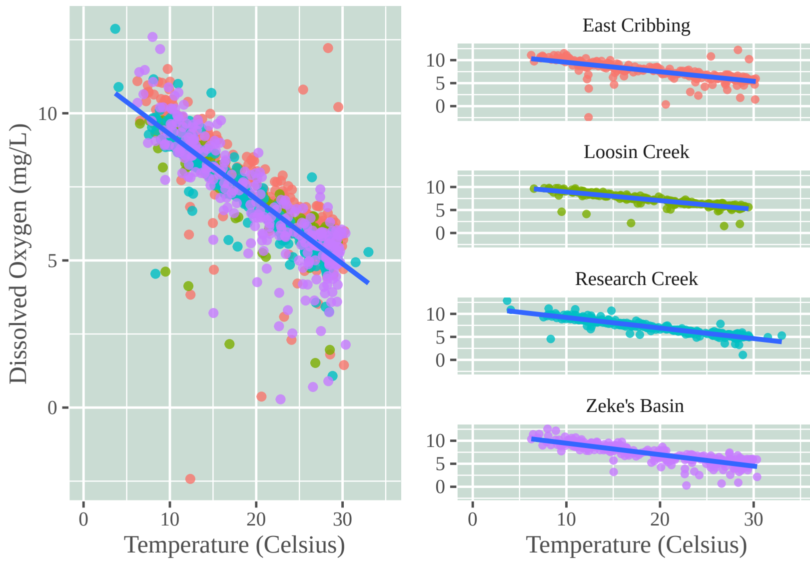

Figure 6: Relationship between Temperature and Dissolved Oxygen

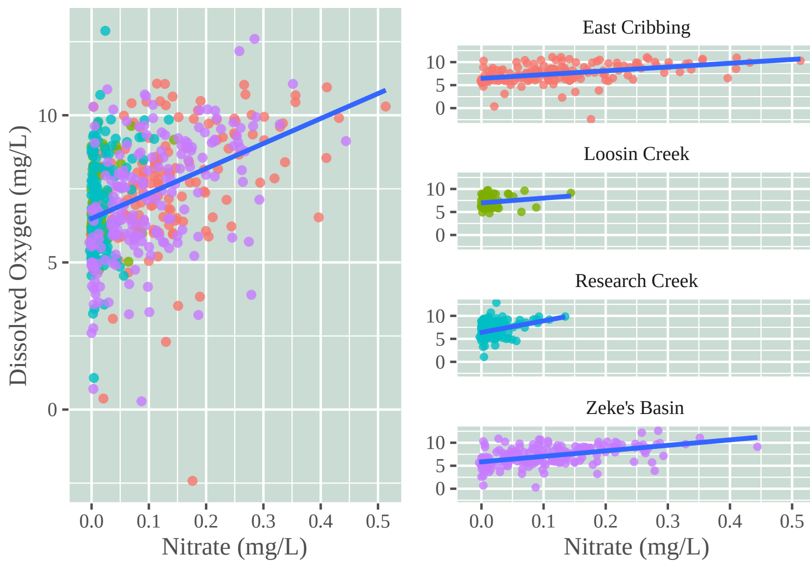

Figure 7: Relationship between Nitrate and Dissolved Oxygen

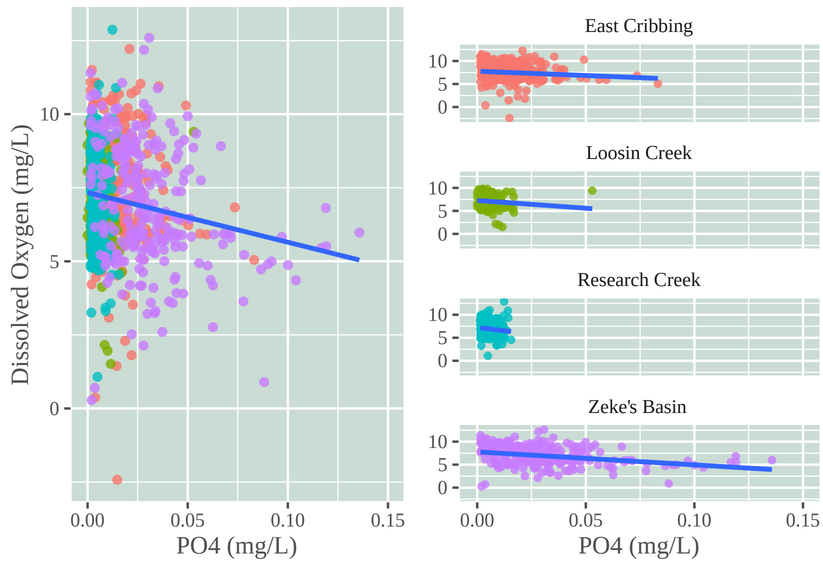

Figure 8: Relationship between Phosphate and Dissolved Oxygen

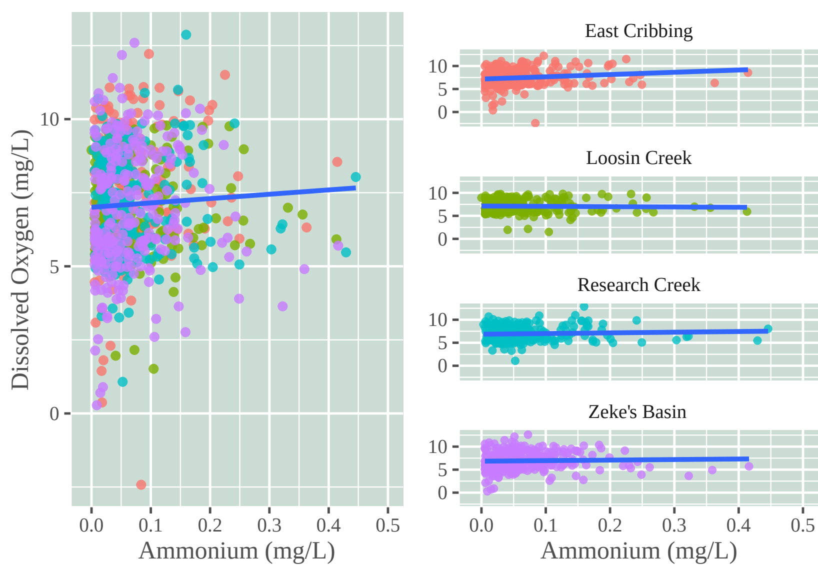

Figure 9: Relationship between Ammonium and Dissolved Oxygen

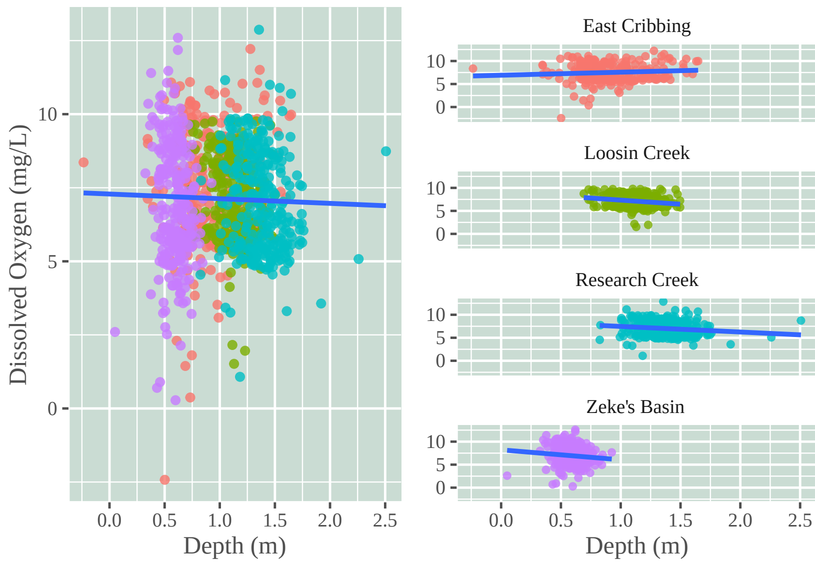

Figure 10: Relationship between Depth and Dissolved Oxygen

5.2 Chlorophyll

The other variable we are interested in is chlorophyll. Chlorophyll is essential in many aquatic ecosystems as it is crucial for photosynthesis, is an indicator for algal blooms, and supports food chains.

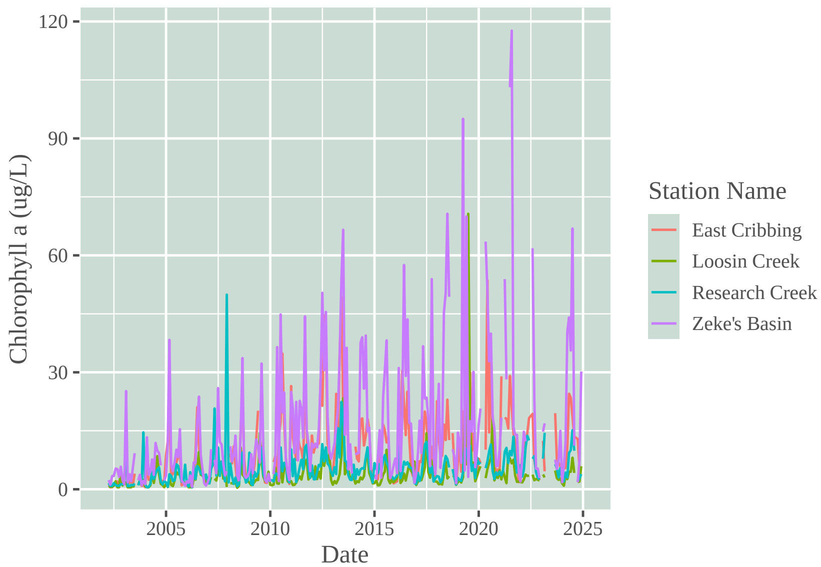

Figure 11: Chlorophyll Concentrations from 2002-2024

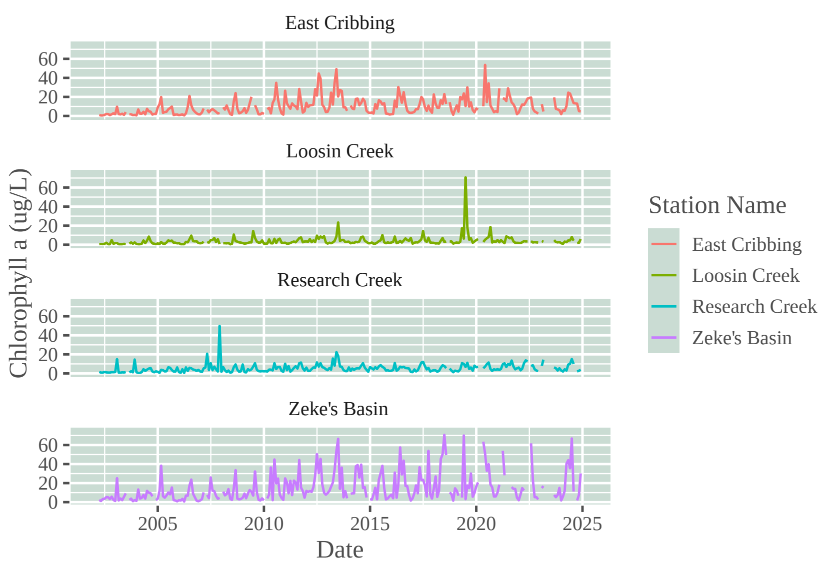

Figure 12: Chlorophyll concentrations from 2002-2024 for each monitoring station

Although plotting Chlorophyll is helpful for seeing consistent patterns and concentrations across all four stations, let's look at them separately to see gaps and data coverage.

Loosin Creek and Research Creek seem to have less fluctuation in their Chlorophyll than East Cribbbing and Zeke's Basin. Could it do with differences in depth or other variables?

It seems that there's variation in chlorophyll across the year. What do the monthly spreads look like?

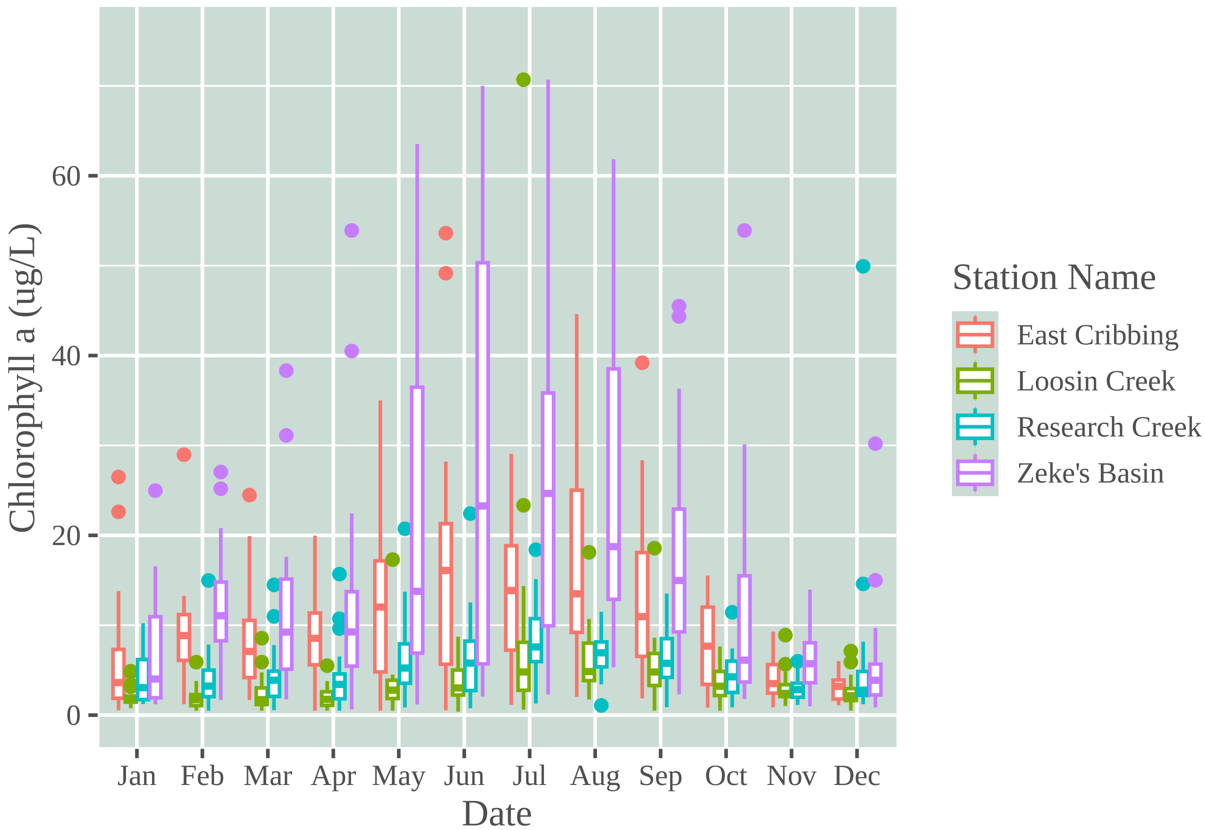

Figure 13: Chlorophyll Monthly Concentrations

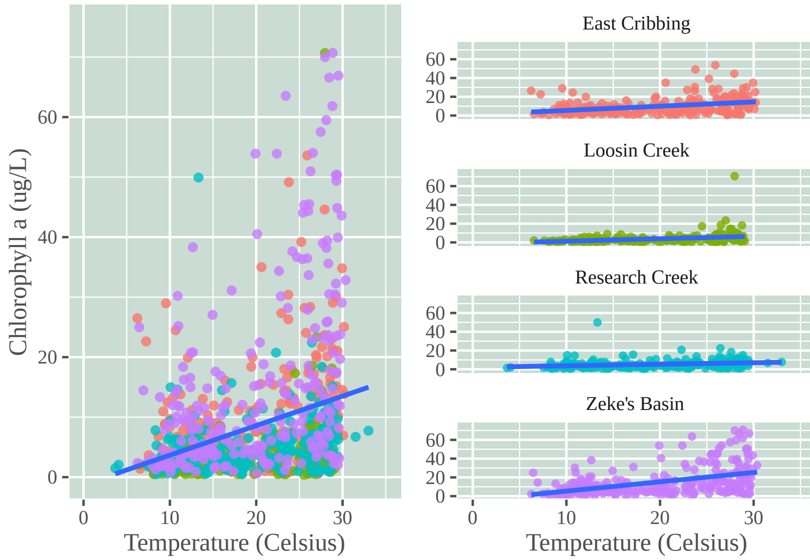

Figure 14: Relationship between Temperature and Chlorophyll

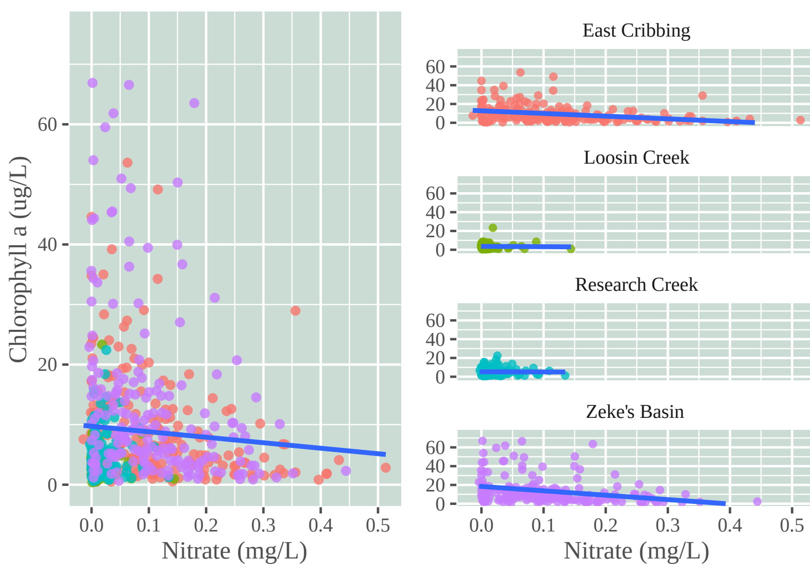

Figure 15: Relationship between Nitrate and Chlorophyll

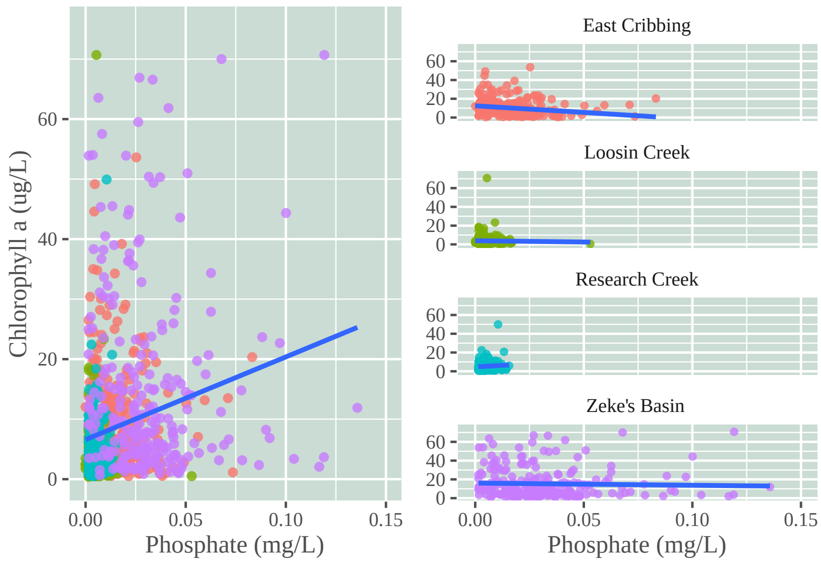

Figure 16: Relationship between Phosphate and Chlorophyll

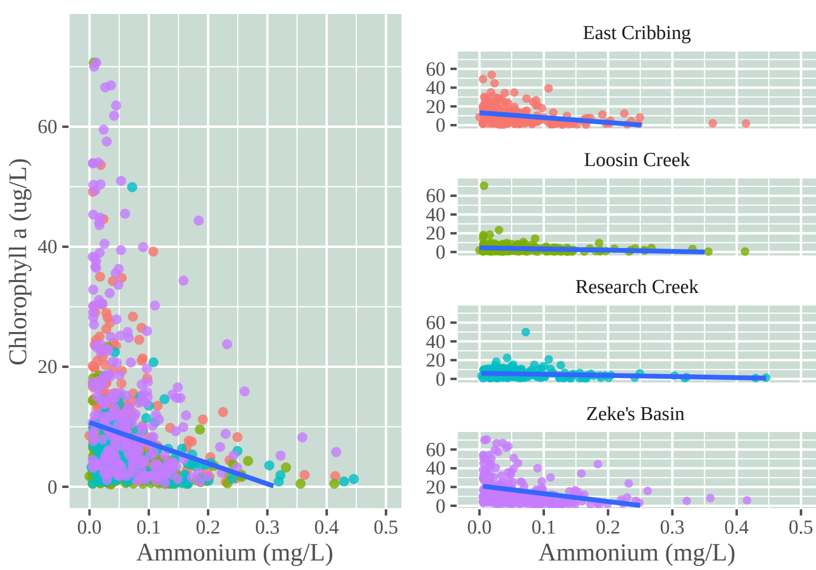

Figure 17: Relationship between Ammonium and Chlorophyll

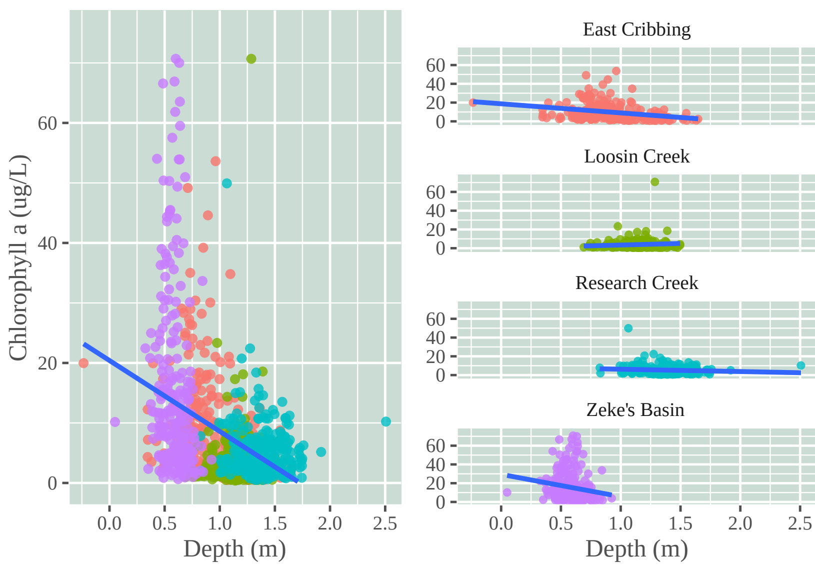

Figure 18: Relationship between Depth and Chlorophyll

5.3 Chlorophyll and Dissolved Oxygen

Now to see if there is a relationship between the two variables we care the most about:

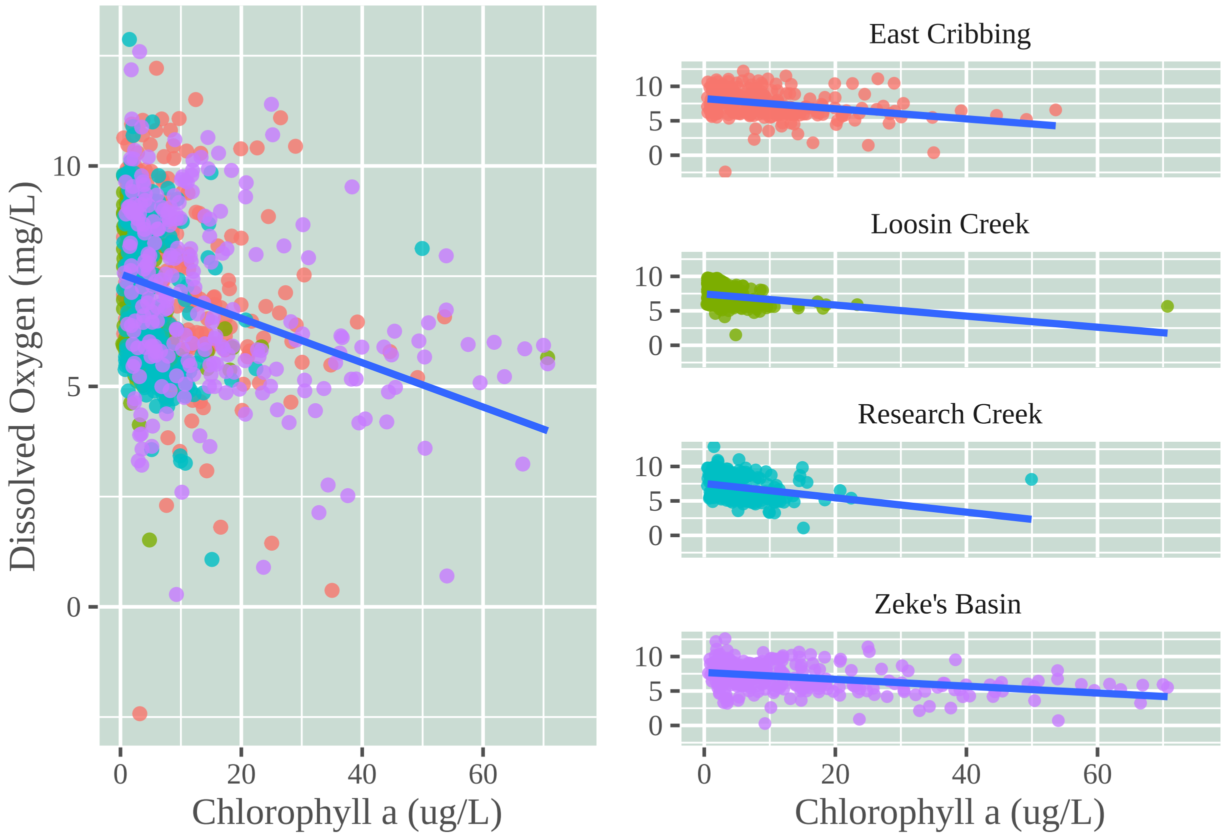

Figure 19: Relationship between dissolved oxygen and chlorophyll

6. Analysis

TO answer our research questions, we want to do two main things: 1) Identify if there is a trend in decreasing dissolved oxygen and increasing chlorophyll across time, and 2) identify the variables most strongly correlated with possible changes.

First, we must turn dissolved oxygen into a time series across each station.

6.1 Dissolved Oxygen Time Series Trend Analysis

East Cribbing

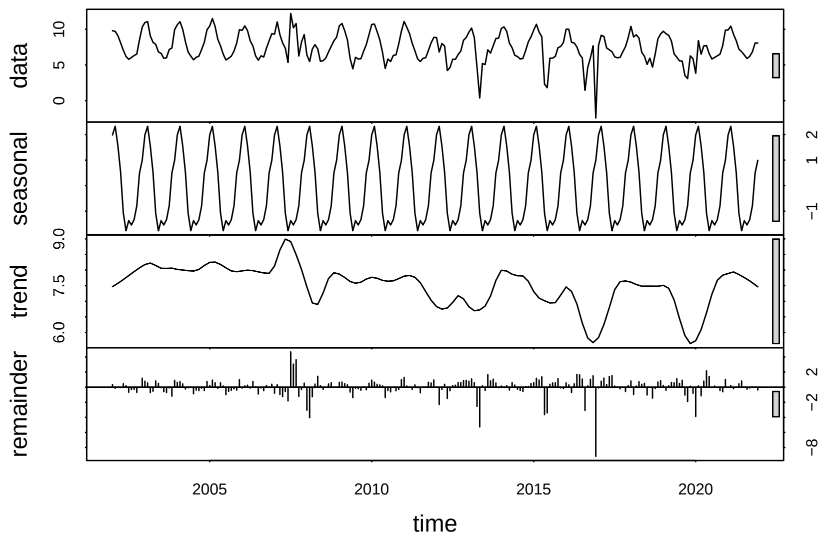

Figure 20: Decomposed Components of East Cribbing Dissolved Oxygen Time Series

```
## Score =  -456 , Var(Score) = 11400
## denominator =  2280
## tau = -0.2, 2-sided pvalue =1.9475e-05
```

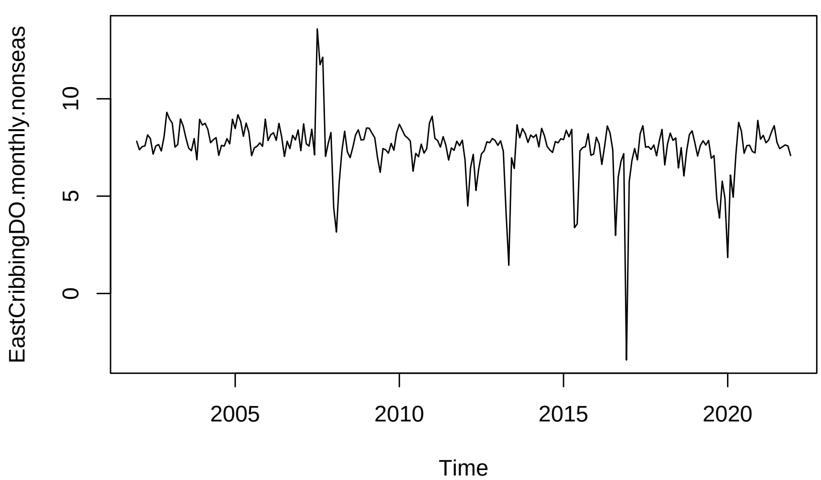

Figure 21: Non-Seasonal Trend of East Cribbing Dissolved Oxygen

```
##
##  Mann-Kendall trend test
```

```
##
## data:  EastCribbingDO.monthly.nonseas
## z = -3.9037, n = 240, p-value = 9.475e-05
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -4.854000e+03  1.545533e+06 -1.692469e-01
```

Loosin Creek

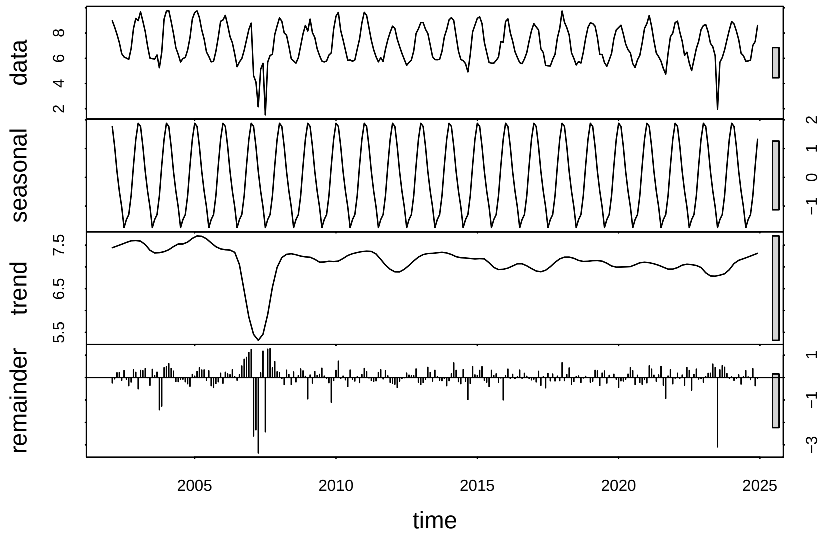

Figure 22: Decomposed Components of East Cribbing Dissolved Oxygen Time Series

```
## Score =  -824 , Var(Score) = 17028
## denominator =  3014
## tau = -0.273, 2-sided pvalue =2.7087e-10
```

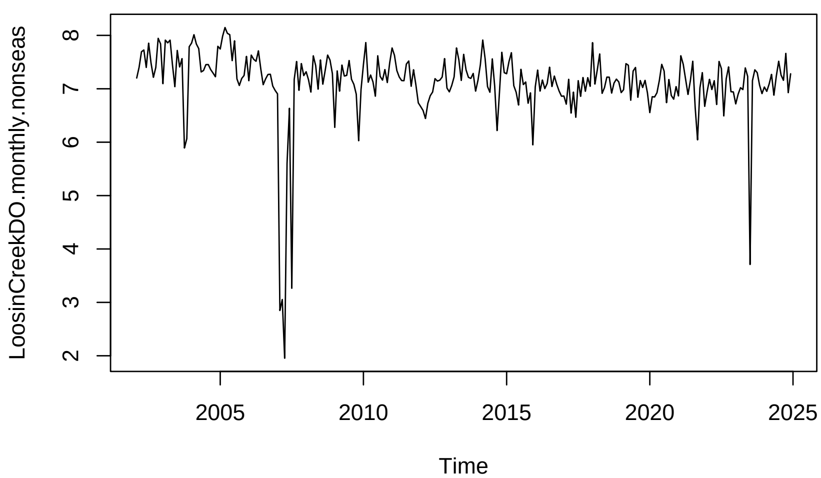

Figure 23: Non-Seasonal Trend of Loosin Creek Dissolved Oxygen

```
##
##  Mann-Kendall trend test
##
## data:  LoosinCreekDO.monthly.nonseas
```

```
## z = -6.0621, n = 275, p-value = 1.344e-09
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -9.241000e+03  2.323292e+06 -2.452820e-01
```

Research Creek

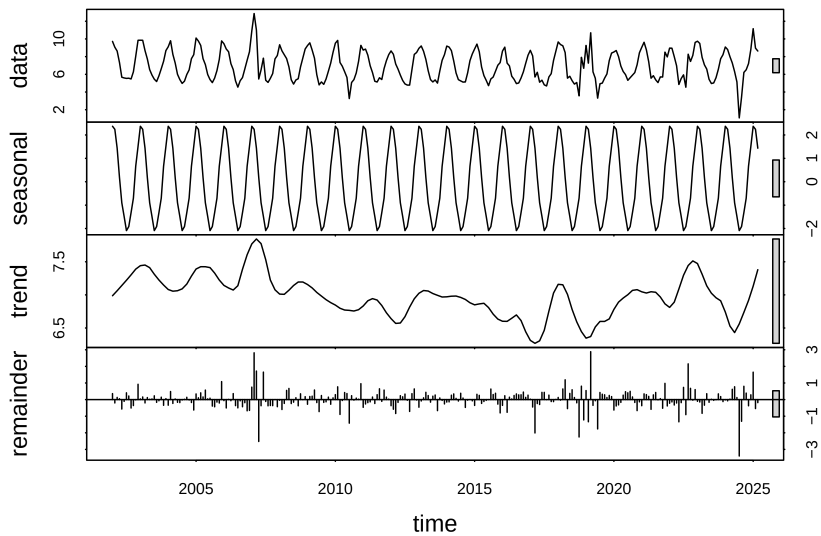

Figure 24: Decomposed Components of Research Creek Dissolved Oxygen Time Series

```
## Score =  -513 , Var(Score) = 17779
## denominator =  3105
## tau = -0.165, 2-sided pvalue =0.00011939
```

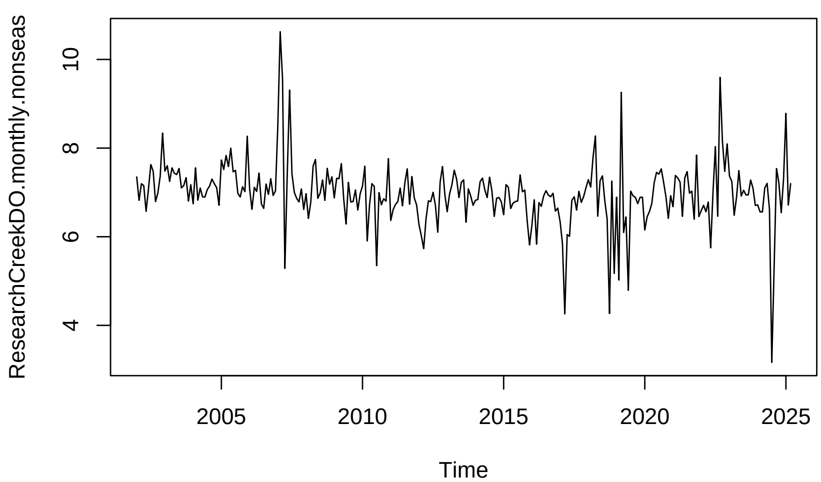

Figure 25: Non-Seasonal Trend of Research Creek Dissolved Oxygen

```
##
##  Mann-Kendall trend test
##
## data:  ResearchCreekDO.monthly.nonseas
## z = -3.8702, n = 279, p-value = 0.0001088
## alternative hypothesis: true S is not equal to 0
```

```
## sample estimates:
##             S          varS           tau
## -6.029000e+03  2.425967e+06 -1.554627e-01
```

Zeke's Basin

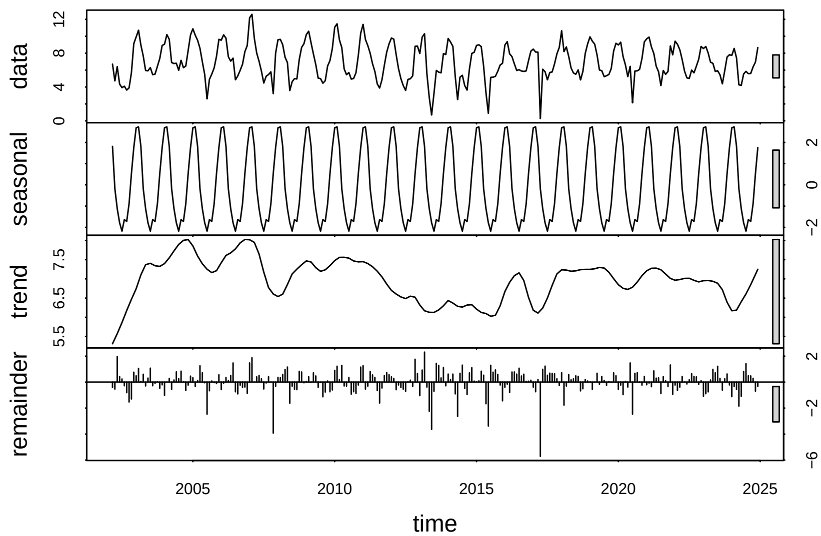

Figure 26: Decomposed Components of Zeke's Basin Dissolved Oxygen Time Series

```
## Score =  -388 , Var(Score) = 16852
## denominator =  2992
## tau = -0.13, 2-sided pvalue =0.0028002
```

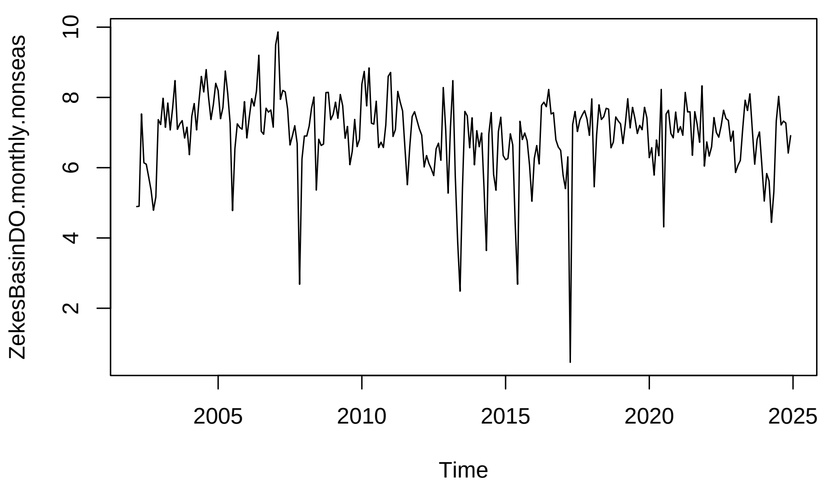

Figure 27: Non-Seasonal Trend of Zeke's Basin Dissolved Oxygen

```
##
##  Mann-Kendall trend test
##
## data:  ZekesBasinDO.monthly.nonseas
## z = -2.8985, n = 274, p-value = 0.003749
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
```

```
## -4.395000e+03  2.298084e+06 -1.175102e-01
```

All Monitoring Stations have had statistically significant decreasing trends in their Dissolved Oxygen.

6.2 Chlorophyll Time Series Trend Analysis

East Cribbing

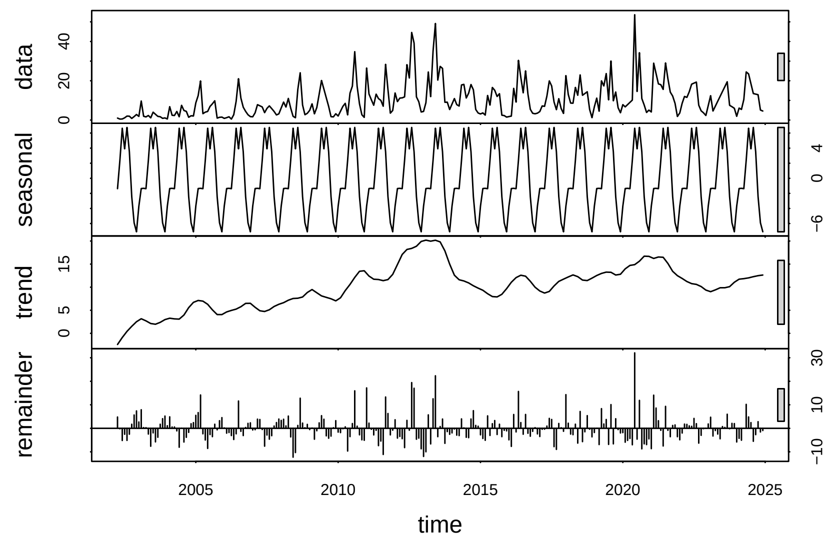

Figure 28: Decomposed Components of East Cribbing Chlorophyll Time Series

```
## Score =  1074 , Var(Score) = 16676
## denominator =  2970
## tau = 0.362, 2-sided pvalue =< 2.22e-16
```

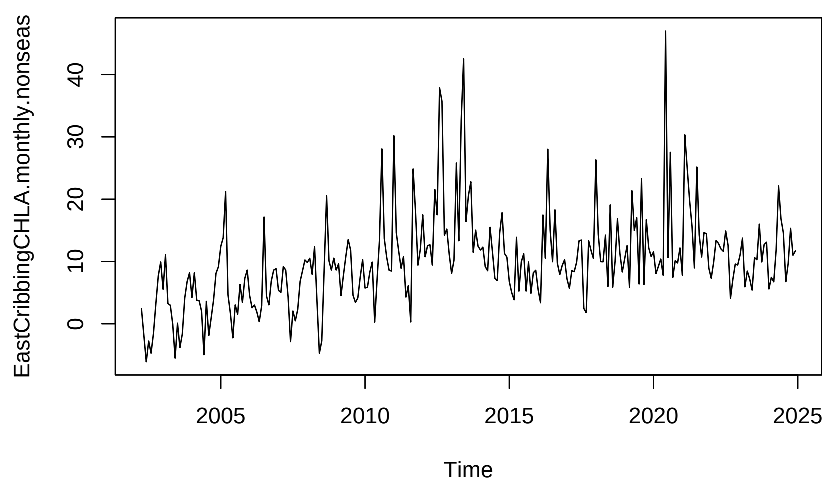

Figure 29: Non-Seasonal Trend of East Cribbing Chlorophyll

```
##
##  Mann-Kendall trend test
##
## data:  EastCribbingCHLA.monthly.nonseas
## z = 7.8432, n = 273, p-value = 4.39e-15
```

```
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 1.182600e+04 2.273059e+06 3.185197e-01
```

Loosin Creek

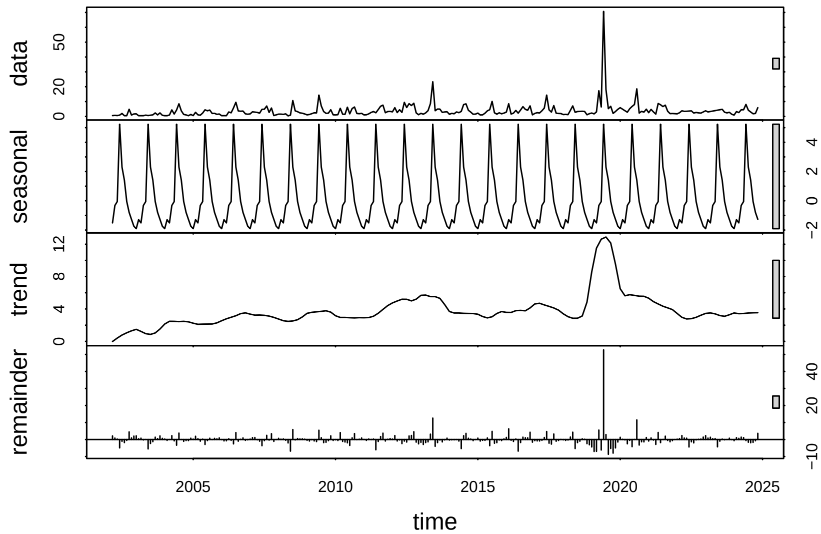

Figure 30: Decomposed Components of Loosin Creek Chlorophyll Time Series

```
## Score =  842 , Var(Score) = 16666
## denominator =  2964.991
## tau = 0.284, 2-sided pvalue =6.9268e-11
```

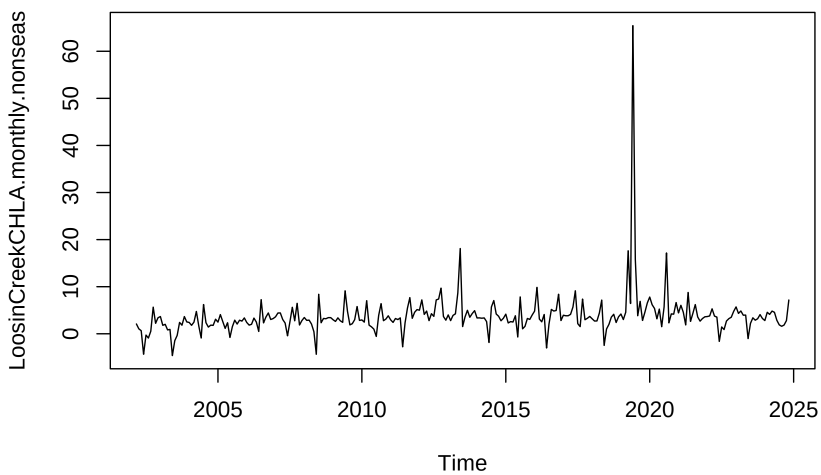

Figure 31: Non-Seasonal Trend of Loosin Creek Chlorophyll

```
##
##  Mann-Kendall trend test
##
## data:  LoosinCreekCHLA.monthly.nonseas
## z = 5.7738, n = 273, p-value = 7.749e-09
## alternative hypothesis: true S is not equal to 0
## sample estimates:
```

```
##             S          varS           tau
## 8.706000e+03 2.273049e+06 2.345177e-01
```

Research Creek

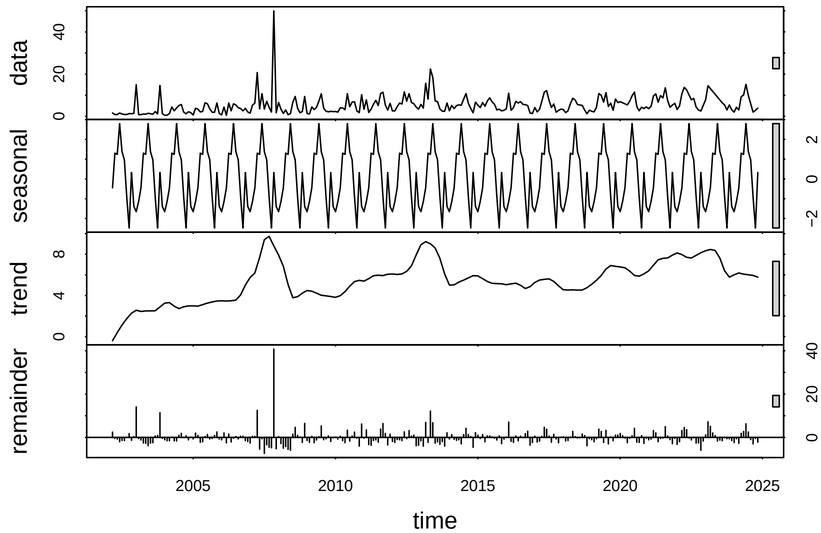

Figure 32: Decomposed Components of Research Creek Chlorophyll Time Series

```
## Score =  1140 , Var(Score) = 16676
## denominator =  2970
## tau = 0.384, 2-sided pvalue =< 2.22e-16
```

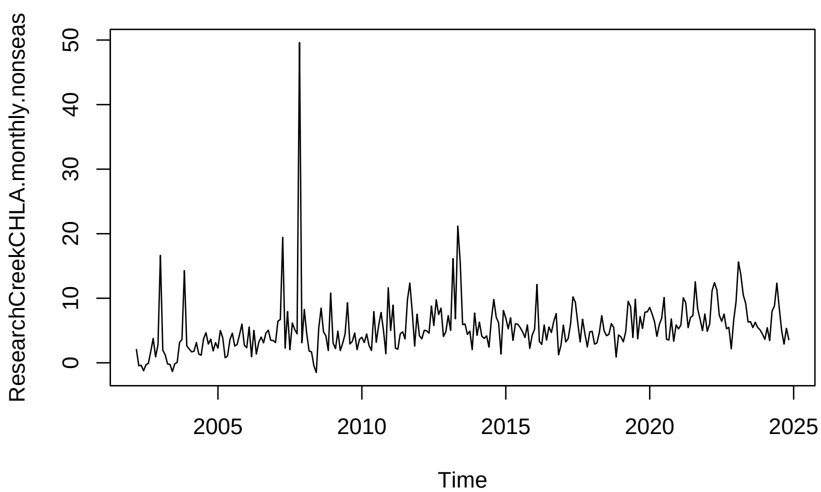

Figure 33: Non-Seasonal Trend of Research Creek Chlorophyll

```
##
##  Mann-Kendall trend test
##
## data:  ResearchCreekCHLA.monthly.nonseas
## z = 8.342, n = 273, p-value < 2.2e-16
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## 1.257800e+04 2.273059e+06 3.387740e-01
```

Zeke's Basin

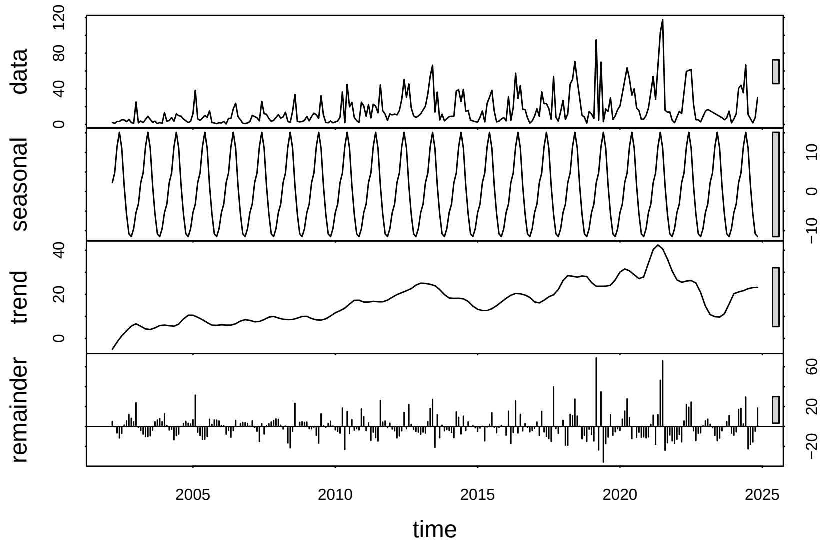

Figure 34: Decomposed Components of Zeke's Basin Chlorophyll Time Series

```
## Score =  1106 , Var(Score) = 16676
## denominator =  2970
## tau = 0.372, 2-sided pvalue =< 2.22e-16
```

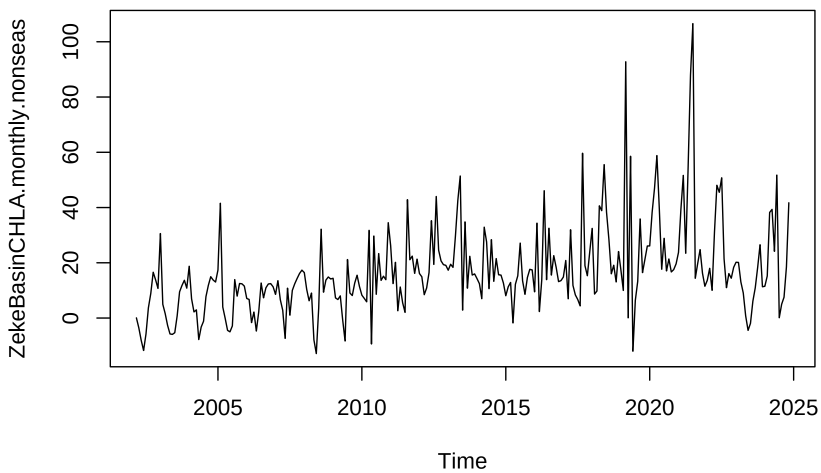

Figure 35: Non-Seasonal Trend of Zeke's Basin Chlorophyll

```
##
##  Mann-Kendall trend test
##
## data:  ZekeBasinCHLA.monthly.nonseas
## z = 8.0489, n = 273, p-value = 8.357e-16
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 1.213600e+04 2.273059e+06 3.268692e-01
```

All stations have statistically significant increasing trends in their Chlorophyll levels as well. Since all of the stations have statistically significant trends in their DO and Chlorophyll levels, now we ask, which variables are most responsible for these changes?

Multiple Regression

```
## Start:  AIC=205.96
## DO_mgl ~ Temp + PO4F + NH4F + NO3F
##
##        Df Sum of Sq     RSS    AIC
## - NH4F  1      0.26  786.60 204.15
## <none>               786.34 205.96
## - PO4F  1      7.53  793.87 209.22
## - NO3F  1     24.34  810.68 220.76
## - Temp  1    791.98 1578.32 587.86
##
## Step:  AIC=204.15
## DO_mgl ~ Temp + PO4F + NO3F
##
##        Df Sum of Sq     RSS    AIC
## <none>               786.60 204.15
## - PO4F  1      7.27  793.87 207.22
## - NO3F  1     24.65  811.25 219.15
## - Temp  1    792.99 1579.59 586.31

##
## Call:
## lm(formula = DO_mgl ~ Temp + PO4F + NO3F, data = stations_wo_na)
##
## Coefficients:
## (Intercept)         Temp         PO4F         NO3F
##     10.7545      -0.1899      -6.3340       2.6928

##
## Call:
## lm(formula = DO_mgl ~ Temp + PO4F + NO3F, data = stations_wq_nutr_cleaned)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -11.2111  -0.2374   0.1538   0.5269   2.8577
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 10.715193   0.184085  58.208  < 2e-16 ***
## Temp        -0.188493   0.008049 -23.419  < 2e-16 ***
## PO4F        -6.363718   2.812901  -2.262   0.0241 *
## NO3F         2.816014   0.647443   4.349 1.62e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.2 on 555 degrees of freedom
##   (541 observations deleted due to missingness)
## Multiple R-squared:  0.6032, Adjusted R-squared:  0.601
## F-statistic: 281.2 on 3 and 555 DF,  p-value: < 2.2e-16
```

```r
CHLA.AIC <- lm(data = stations_wo_na, CHLA_N~ Temp + PO4F + NH4F + NO3F)
step(CHLA.AIC)
```

```
## Start:  AIC=2664.49
## CHLA_N ~ Temp + PO4F + NH4F + NO3F
##
##        Df Sum of Sq   RSS    AIC
## - NO3F  1      90.3 68231 2663.2
## <none>               68140 2664.5
## - PO4F  1     668.0 68808 2667.9
## - NH4F  1    4170.6 72311 2695.2
## - Temp  1    4676.3 72816 2699.1
##
## Step:  AIC=2663.22
## CHLA_N ~ Temp + PO4F + NH4F
##
##        Df Sum of Sq   RSS    AIC
## <none>               68231 2663.2
## - PO4F  1     899.9 69130 2668.4
## - NH4F  1    4120.1 72351 2693.5
## - Temp  1    5150.5 73381 2701.3
```

```
##
## Call:
## lm(formula = CHLA_N ~ Temp + PO4F + NH4F, data = stations_wo_na)
##
## Coefficients:
## (Intercept)         Temp         PO4F         NH4F
##      2.5118       0.4324      68.6214     -38.6696
```

```
CHLA.regression <- lm(data = stations_wq_nutr_cleaned, CHLA_N~ Temp + PO4F
                      + NH4F)
summary(CHLA.regression)
```

```
##
## Call:
## lm(formula = CHLA_N ~ Temp + PO4F + NH4F, data = stations_wq_nutr_cleaned)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -33.806  -5.134  -2.478   1.559  94.158
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   1.19024    1.09055   1.091    0.275
## Temp          0.40908    0.04887   8.371  < 2e-16 ***
## PO4F        146.58494   19.64113   7.463 1.86e-13 ***
## NH4F        -39.84771    5.31967  -7.491 1.53e-13 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.85 on 978 degrees of freedom
##   (118 observations deleted due to missingness)
## Multiple R-squared:  0.1661, Adjusted R-squared:  0.1636
## F-statistic: 64.95 on 3 and 978 DF,  p-value: < 2.2e-16
```

From these multiple regressions we find that temperature, phosphorus, and nitrate are the best variables for predicting DO and temperature, phosphorus, and ammonium are the best variables for predicting Chlorophyll. Both of these relationships are significant, although the R-squared for the Chlorophyll regression is 0.1661 which indicates a weaker correlation.

Temperature is the most impactful variable in both of the models, with PO4 being the least impactful.

6.4 Time Series Analysis of Relevant Variables

From here, we perform time series analyses on these variables to determine if their trends are in line with what we expect.

6.4.1 East Cribbing

PO4

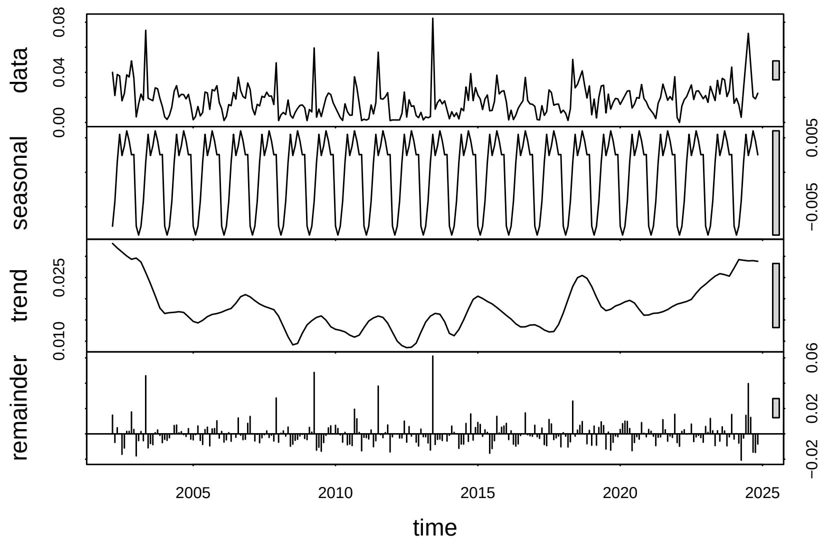

Figure 36: Decomposed Components of East Cribbing PO4 Time Series

```
## Score =  239 , Var(Score) = 16664.33
## denominator =  2964.485
## tau = 0.0806, 2-sided pvalue =0.06411
```

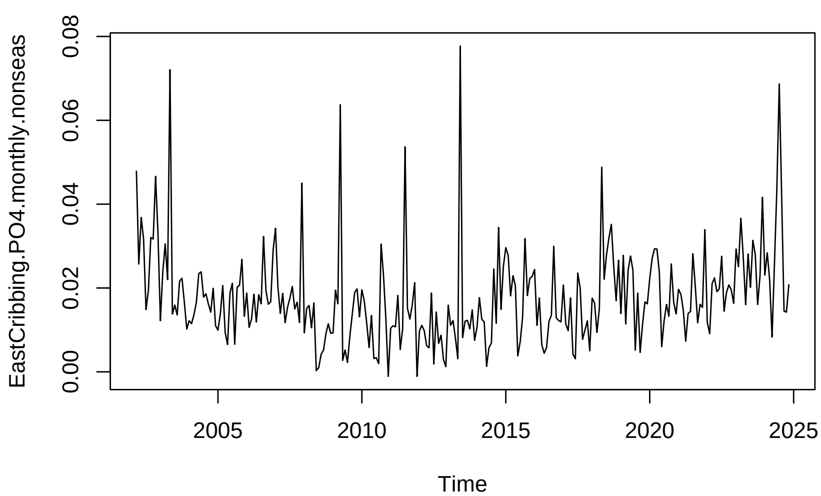

Figure 37: Non-Seasonal Trend of East Cribbing PO4

```
##
##  Mann-Kendall trend test
##
## data:  EastCribbing.PO4.monthly.nonseas
## z = 1.7385, n = 273, p-value = 0.08213
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 2.622000e+03 2.273047e+06 7.063102e-02
```

NH4

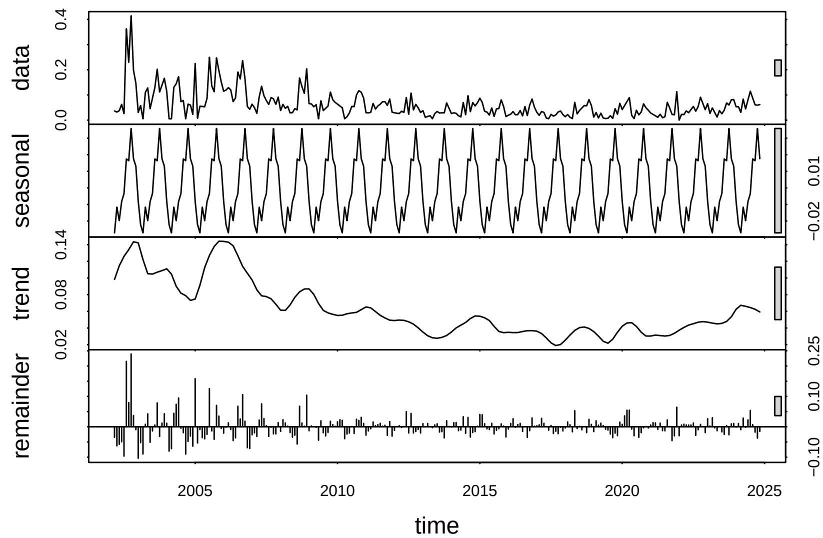

Figure 38: Decomposed Components of East Cribbing NH4 Time Series

```
## Score =  -901 , Var(Score) = 16671
## denominator =  2967.496
## tau = -0.304, 2-sided pvalue =2.9896e-12
```

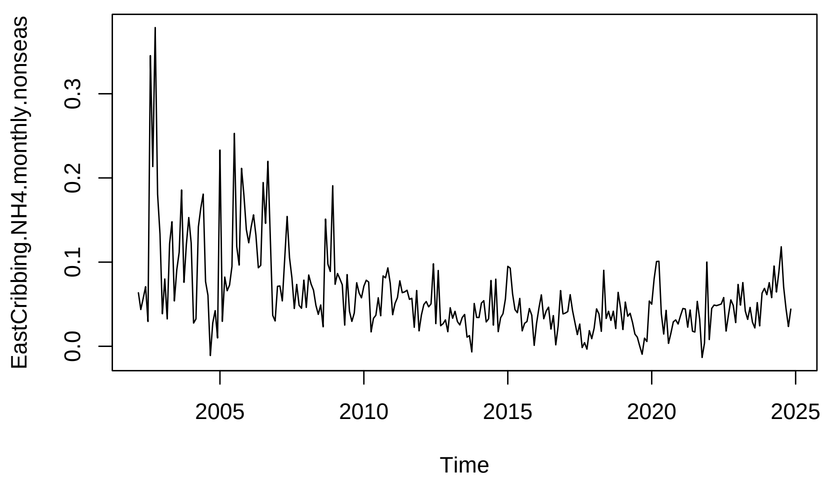

Figure 39: Non-Seasonal Trend of East Cribbing NH4

```
##
##  Mann-Kendall trend test
```

```
##
## data:  EastCribbing.NH4.monthly.nonseas
## z = -7.4546, n = 273, p-value = 9.016e-14
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -1.124000e+04  2.273054e+06 -3.027569e-01
```

NO3

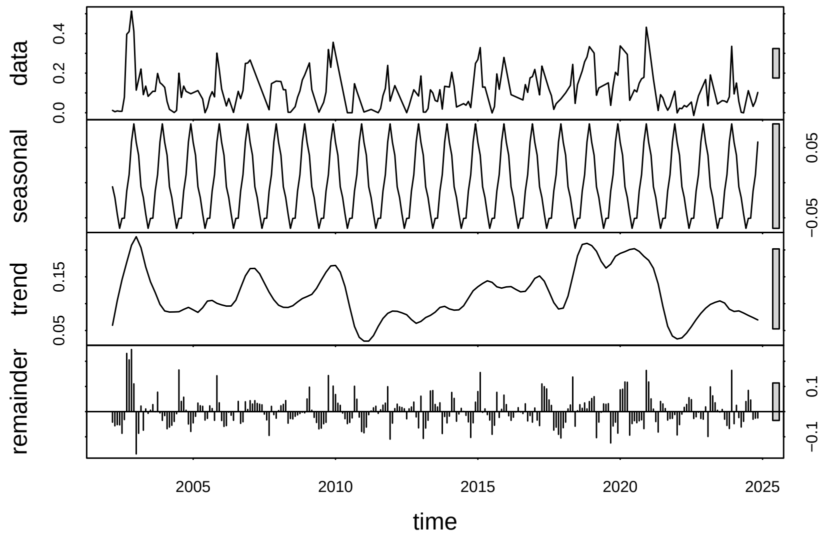

Figure 40: Decomposed Components of East Cribbing NO3 Time Series

```
## Score =  90 , Var(Score) = 16669.33
## denominator =  2966.994
## tau = 0.0303, 2-sided pvalue =0.48575
```

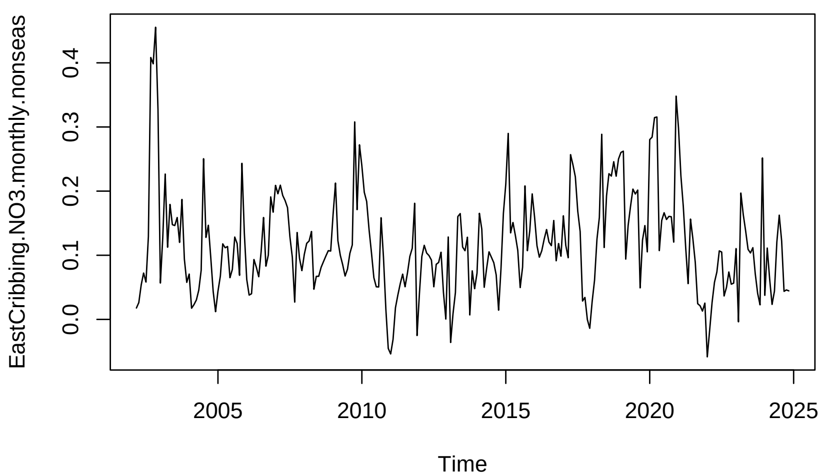

Figure 41: Non-Seasonal Trend of East Cribbing NO3

```
##
##  Mann-Kendall trend test
##
## data:  EastCribbing.NO3.monthly.nonseas
```

```
## z = 0.45832, n = 273, p-value = 0.6467
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 6.920000e+02 2.273052e+06 1.863973e-02
```

Temperature

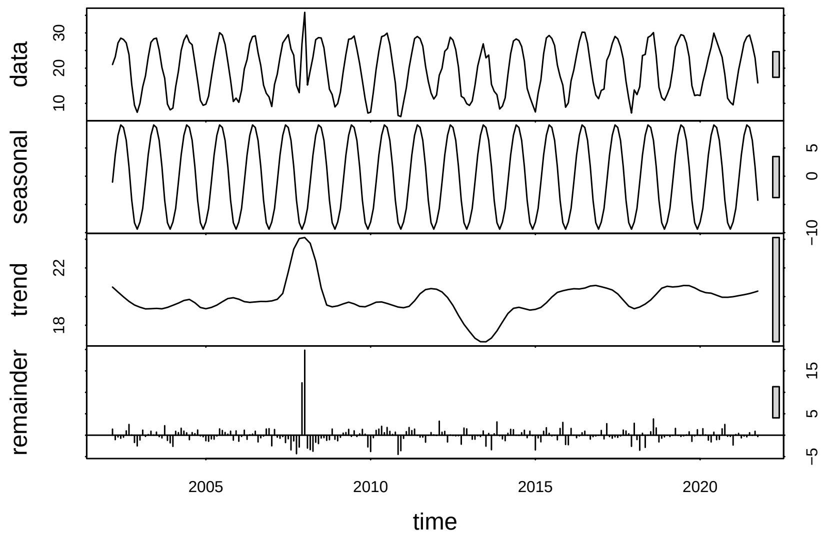

Figure 42: Decomposed Components of East Cribbing Temperature Time Series

```
## Score =  194 , Var(Score) = 10868
## denominator =  2204
## tau = 0.088, 2-sided pvalue =0.062756
```

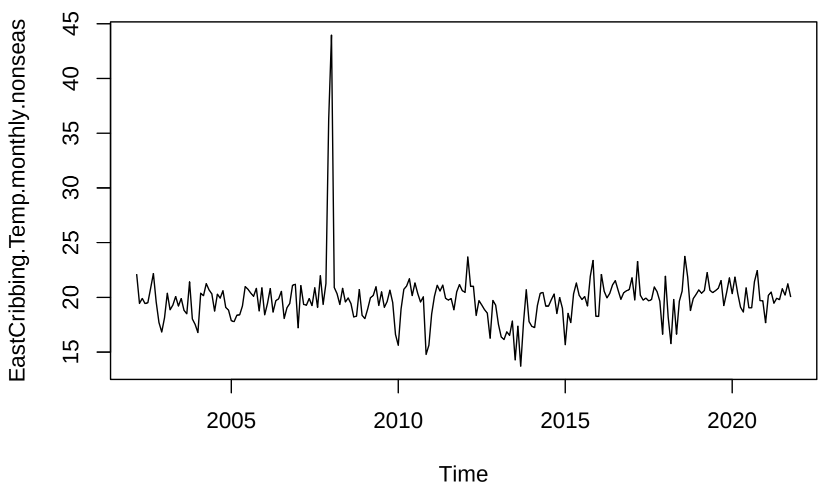

Figure 43: Non-Seasonal Trend of East Cribbing Temperature

```
##
##  Mann-Kendall trend test
##
## data:  EastCribbing.Temp.monthly.nonseas
## z = 2.0564, n = 236, p-value = 0.03974
## alternative hypothesis: true S is not equal to 0
```

```
## sample estimates:
##             S          varS           tau
## 2.494000e+03 1.469690e+06 8.993869e-02
```

For East Cribbing, PO4 had a significant increasing trend, NH4 had a significant decreasing trend, and NO3 and temperature did not have statistically significant trends.

6.4.2 Loosin Creek

PO4

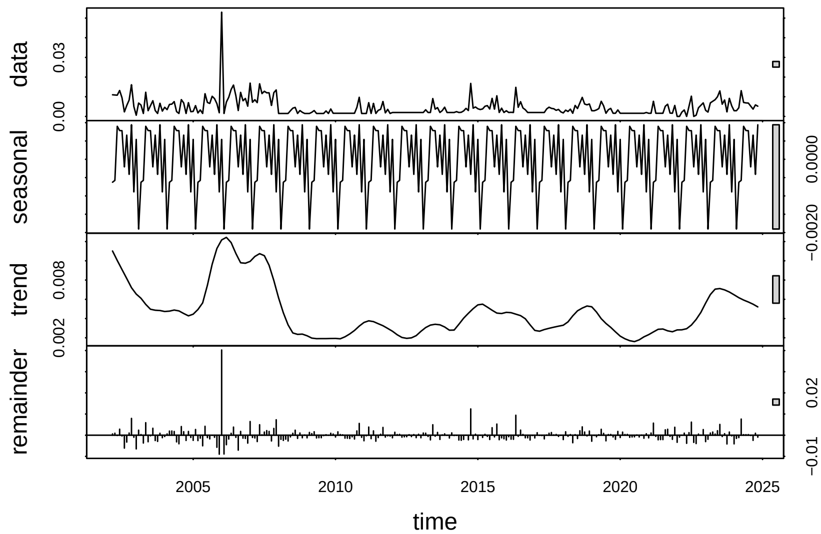

Figure 44: Decomposed Components of Loosin Creek PO4 Time Series

```
## Score =  -139 , Var(Score) = 16529
## denominator =  2914.783
## tau = -0.0477, 2-sided pvalue =0.27962
```

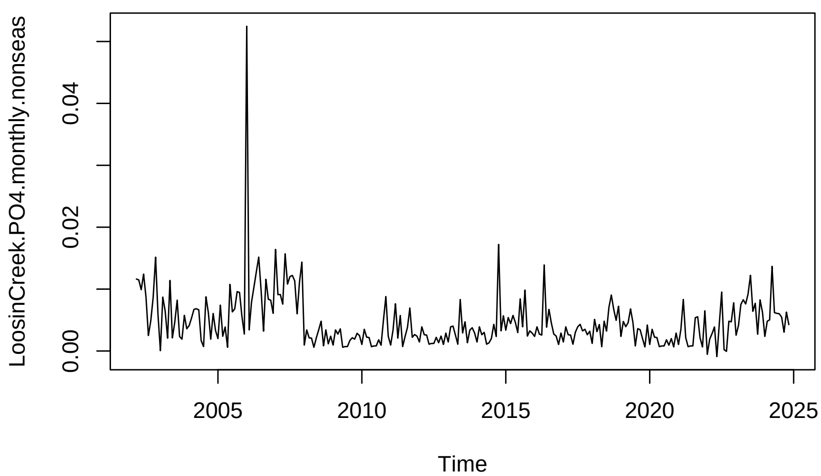

Figure 45: Non-Seasonal Trend of Loosin Creek Temperature

```
##
##  Mann-Kendall trend test
##
```

```
## data:  LoosinCreek.PO4.monthly.nonseas
## z = -2.0854, n = 273, p-value = 0.03703
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -3.145000e+03  2.272912e+06 -8.483158e-02
```

NH4

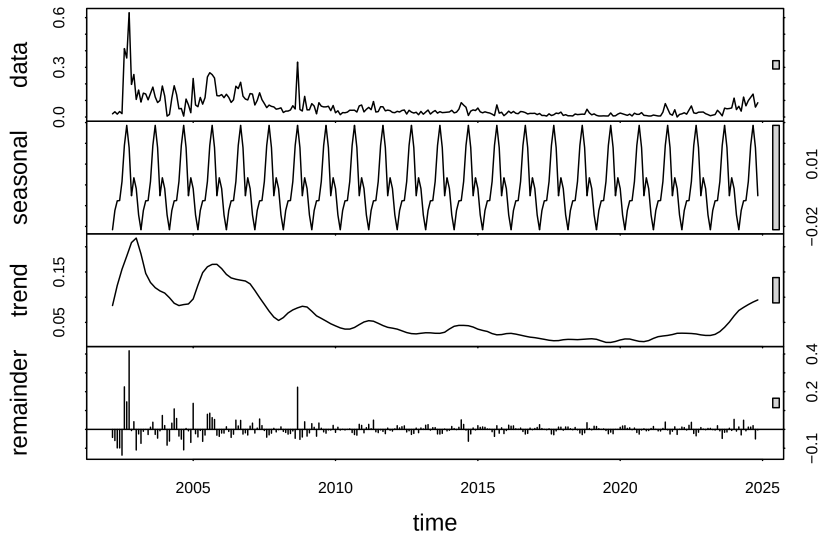

Figure 46: Decomposed Components of Loosin Creek NH4 Time Series

```
## Score =  -1345 , Var(Score) = 16668.33
## denominator =  2966.493
## tau = -0.453, 2-sided pvalue =< 2.22e-16
```

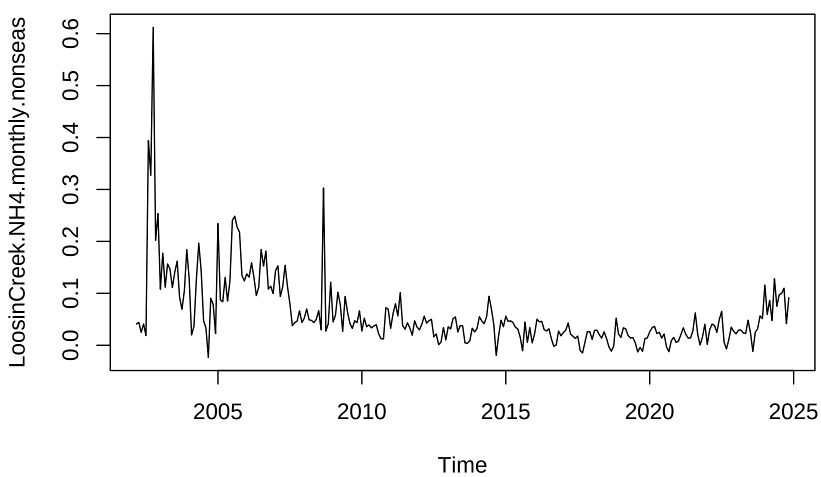

Figure 47: Non-Seasonal Trend of Loosin Creek NH4

```
##
##  Mann-Kendall trend test
##
## data:  LoosinCreek.NH4.monthly.nonseas
## z = -9.9386, n = 273, p-value < 2.2e-16
```

```
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -1.498500e+04  2.273051e+06 -4.036418e-01
```

NO3

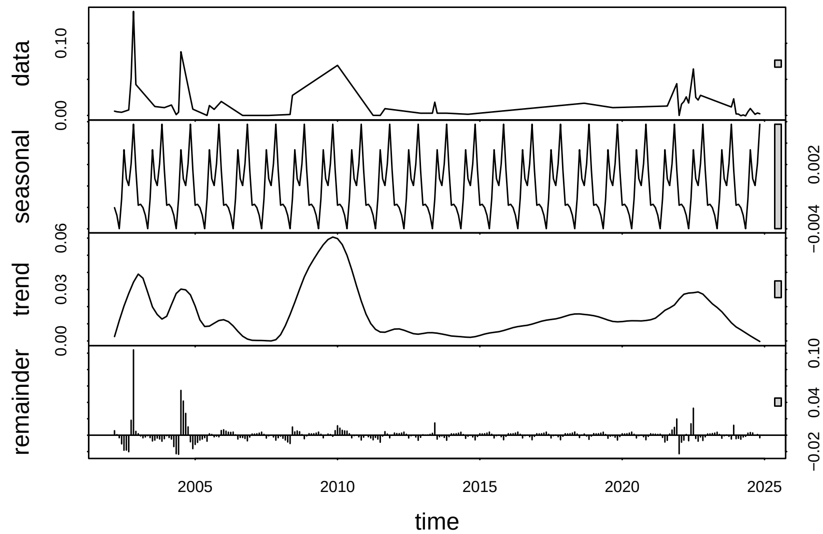

Figure 48: Decomposed Components of Loosin Creek NO3 Time Series

```
## Score =  255 , Var(Score) = 16673
## denominator =  2968.498
## tau = 0.0859, 2-sided pvalue =0.048286
```

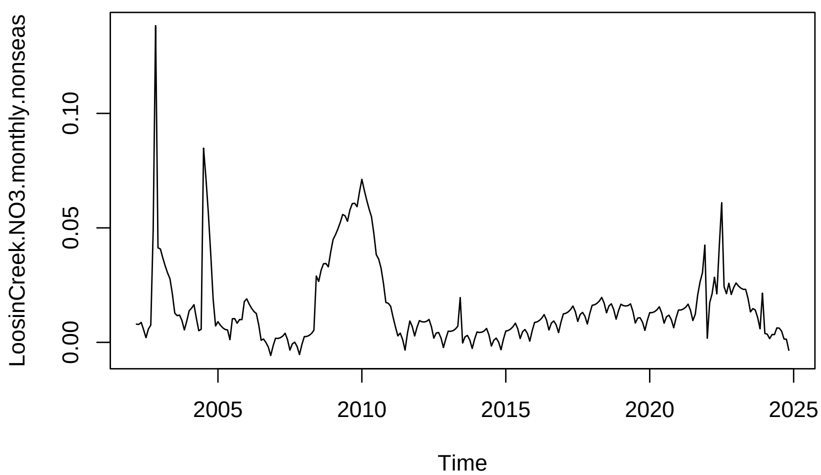

Figure 49: Non-Seasonal Trend of Loosin Creek NO3

```
##
##  Mann-Kendall trend test
##
## data:  LoosinCreek.NO3.monthly.nonseas
## z = 1.3159, n = 273, p-value = 0.1882
## alternative hypothesis: true S is not equal to 0
## sample estimates:
```

```
##              S           varS            tau
## 1.985000e+03 2.273056e+06 5.346585e-02
```

Temperature

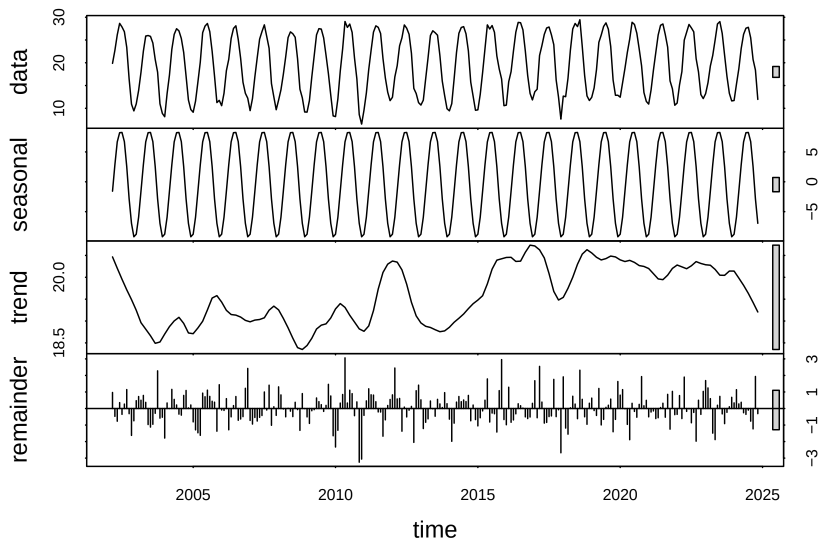

Figure 50: Decomposed Components of Loosin Creek Temperature Time Series

```
## Score =  784 , Var(Score) = 16676
## denominator =  2970
## tau = 0.264, 2-sided pvalue =1.2701e-09
```

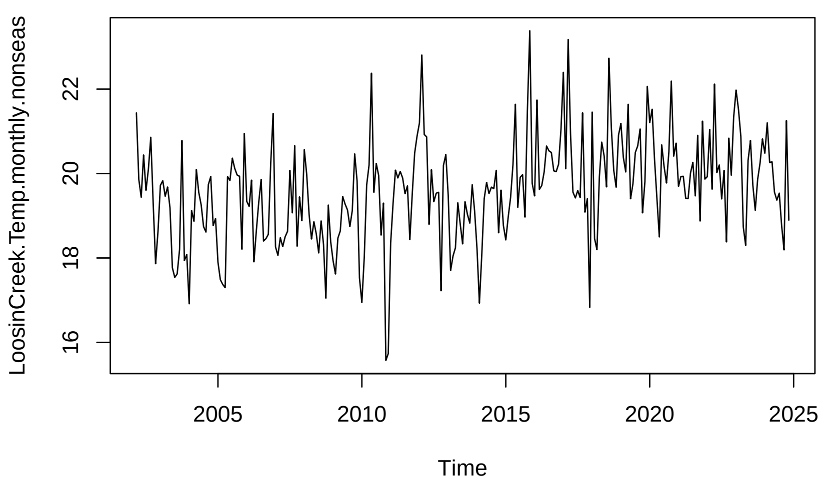

Figure 51: Non-Seasonal Trend of Loosin Creek Temperature

```
##
##  Mann-Kendall trend test
##
## data:  LoosinCreek.Temp.monthly.nonseas
## z = 6.2819, n = 273, p-value = 3.345e-10
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##              S           varS            tau
## 9.472000e+03 2.273059e+06 2.551174e-01
```

For Loosin Creek, PO4 and NH4 showed significant decreasing trends and temperature showed a significant increasing trend. NO3 did not have a significant trend.

6.4.3 Research Creek

PO4

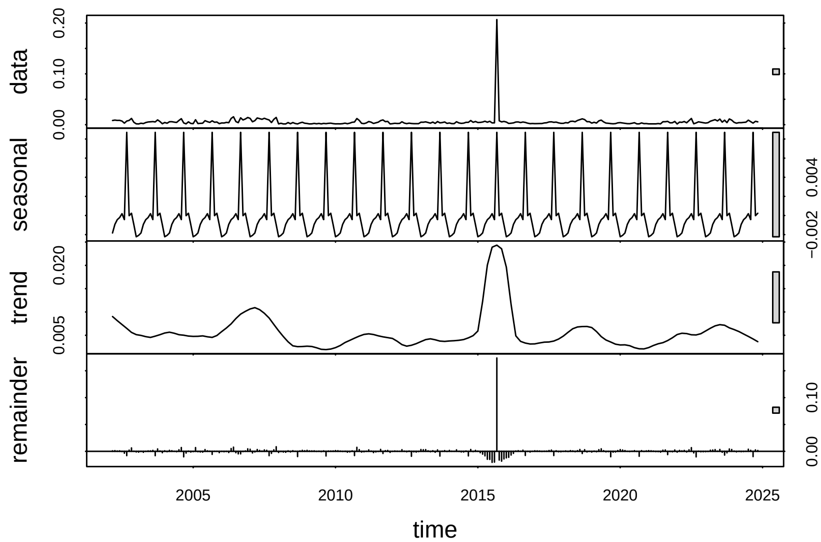

Figure 52: Decomposed Components of Research Creek PO4 Time Series

```
## Score =  -36 , Var(Score) = 16674
## denominator =  2968.999
## tau = -0.0121, 2-sided pvalue =0.7804
```

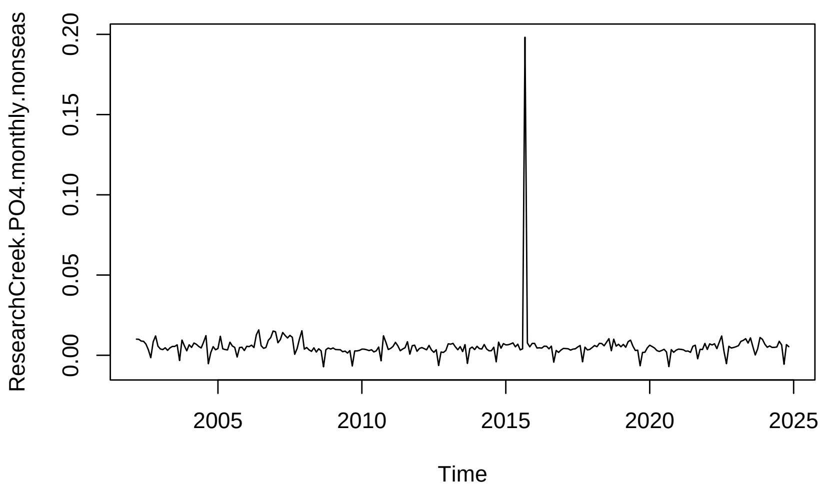

Figure 53: Non-Seasonal Trend of Research Creek PO4

```
##
##  Mann-Kendall trend test
##
## data:  ResearchCreek.PO4.monthly.nonseas
## z = -0.58302, n = 273, p-value = 0.5599
## alternative hypothesis: true S is not equal to 0
```

```
## sample estimates:
##             S          varS           tau
## -8.800000e+02  2.273057e+06 -2.370243e-02
```

NH4

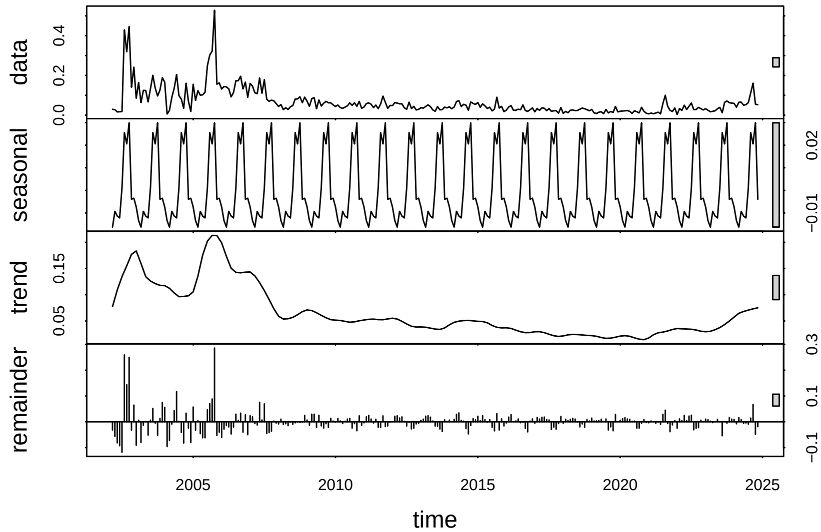

Figure 54: Decomposed Components of Research Creek NH4 Time Series

```
## Score =  -1368 , Var(Score) = 16676
## denominator =  2970
## tau = -0.461, 2-sided pvalue =< 2.22e-16
```

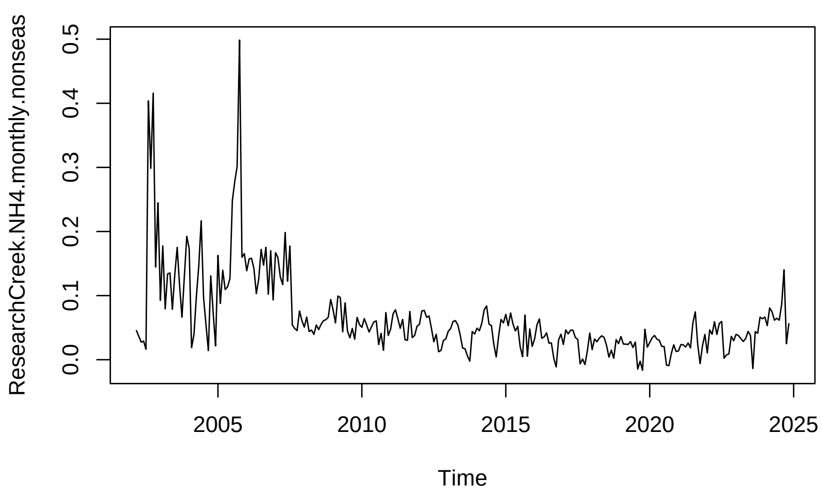

Figure 55: Non-Seasonal Trend of Research Creek NH4

```
##
##  Mann-Kendall trend test
##
## data:  ResearchCreek.NH4.monthly.nonseas
## z = -10.08, n = 273, p-value < 2.2e-16
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
```

```
## -1.519800e+04  2.273059e+06 -4.093407e-01
```

NO3

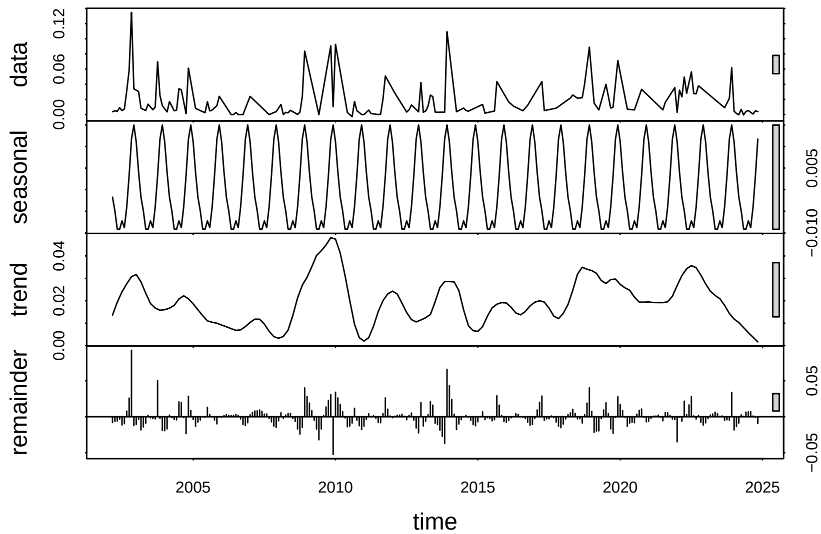

Figure 56: Decomposed Components of Research Creek NO3 Time Series

```
## Score =  426 , Var(Score) = 16670
## denominator =  2966.997
## tau = 0.144, 2-sided pvalue =0.00096874
```

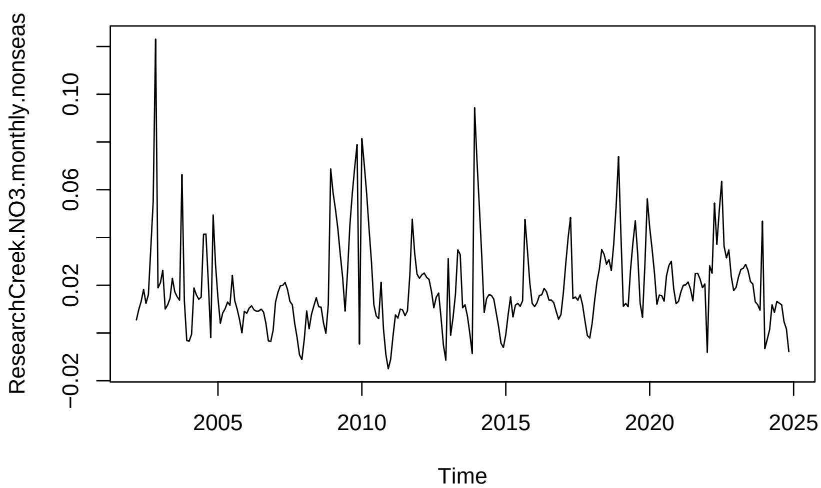

Figure 57: Non-Seasonal Trend of Research Creek NO3

```
##
##  Mann-Kendall trend test
##
## data:  ResearchCreek.NO3.monthly.nonseas
## z = 2.4926, n = 273, p-value = 0.01268
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS           tau
## 3.759000e+03 2.273054e+06 1.012512e-01
```

Temperature

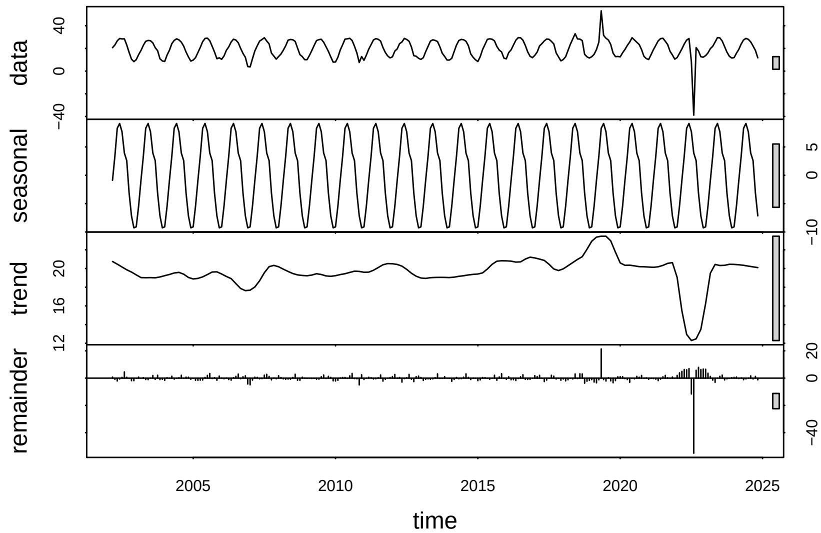

Figure 58: Decomposed Components of Research Creek Temperature Time Series

```
## Score =  700 , Var(Score) = 16676
## denominator =  2970
## tau = 0.236, 2-sided pvalue =5.938e-08
```

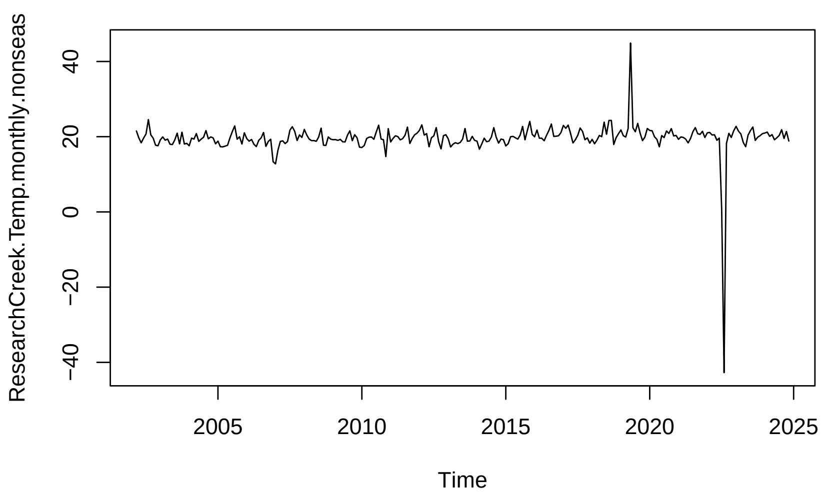

Figure 59: Non-Seasonal Trend of Research Creek Temperature

```
##
##  Mann-Kendall trend test
##
## data:  ResearchCreek.Temp.monthly.nonseas
## z = 4.8612, n = 273, p-value = 1.167e-06
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 7.330000e+03 2.273059e+06 1.974251e-01
```

For Research Creek, NH4 had a significant decreasing trend and NO3 and temperature had significant increasing trends (for temperature, this is still despite a significant outlier that can likely be attributed to human error in data collection). PO4 did not have a significant trend.

6.4.4 Zeke's Basin

PO4

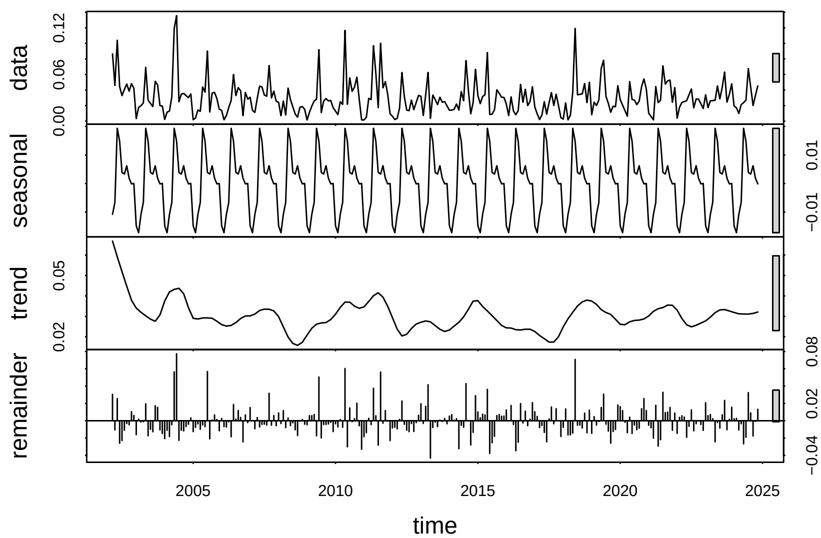

Figure 60: Decomposed Components of Zeke's Basin PO4 Time Series

```
## Score =  -44 , Var(Score) = 16668
## denominator =  2965.995
## tau = -0.0148, 2-sided pvalue =0.73325
```

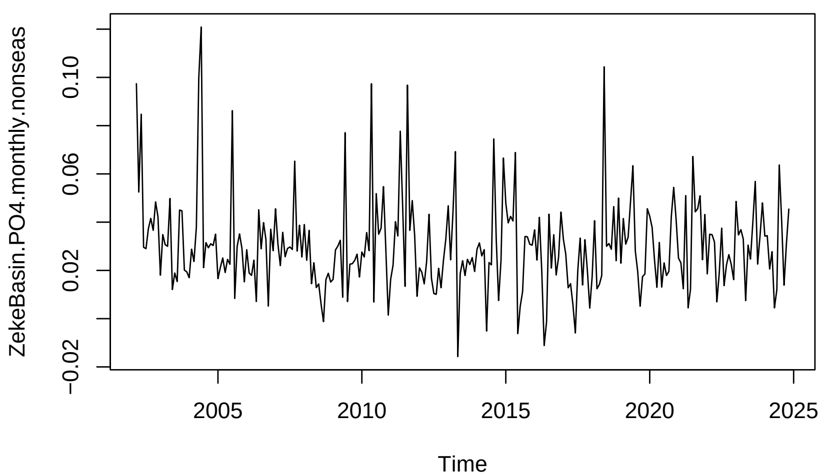

Figure 61: Non-Seasonal Trend of Zeke's Basin PO4

```
##
##  Mann-Kendall trend test
##
## data:  ZekeBasin.PO4.monthly.nonseas
## z = -0.51935, n = 273, p-value = 0.6035
## alternative hypothesis: true S is not equal to 0
## sample estimates:
```

```
##              S           varS           tau
## -7.840000e+02  2.273051e+06 -2.111841e-02
```

NH4

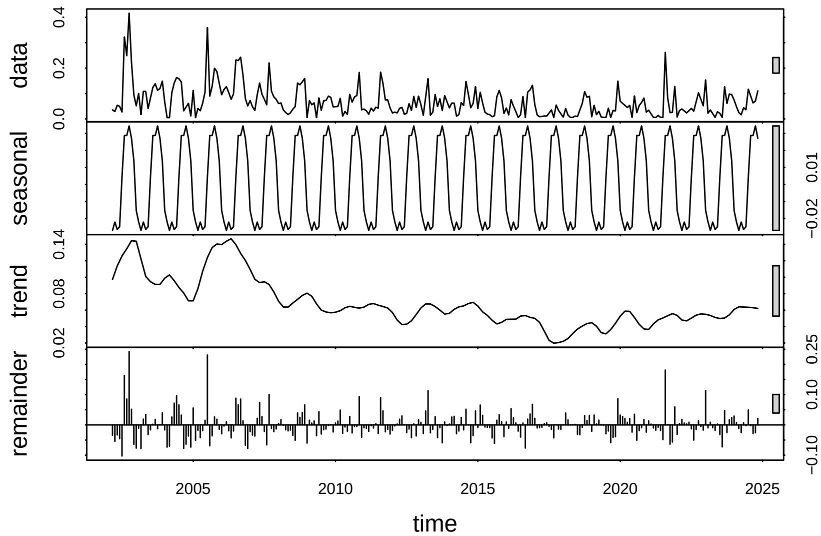

Figure 62: Decomposed Components of Zeke's Basin NH4 Time Series

```
## Score =  -857 , Var(Score) = 16666.33
## denominator =  2965.491
## tau = -0.289, 2-sided pvalue =3.1719e-11
```

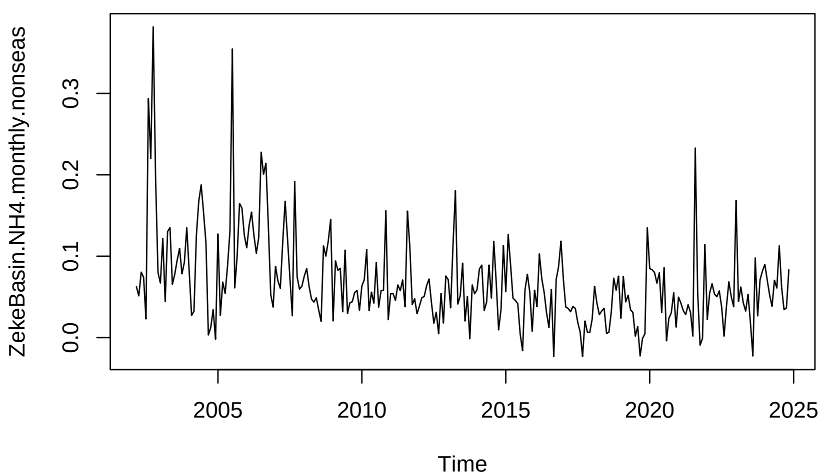

Figure 63: Non-Seasonal Trend of Zeke's Basin NH4

```
##
##  Mann-Kendall trend test
##
## data:  ZekeBasin.NH4.monthly.nonseas
## z = -6.4643, n = 273, p-value = 1.018e-10
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##              S           varS           tau
## -9.747000e+03  2.273049e+06 -2.625561e-01
```

NO3

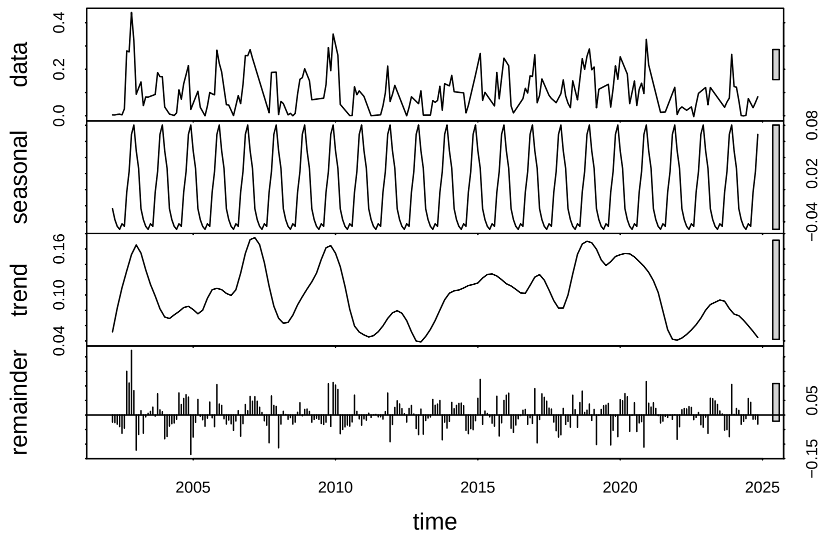

Figure 64: Decomposed Components of Zeke's Basin NO3 Time Series

```
## Score =  -48 , Var(Score) = 16674
## denominator =  2968.999
## tau = -0.0162, 2-sided pvalue =0.7101
```

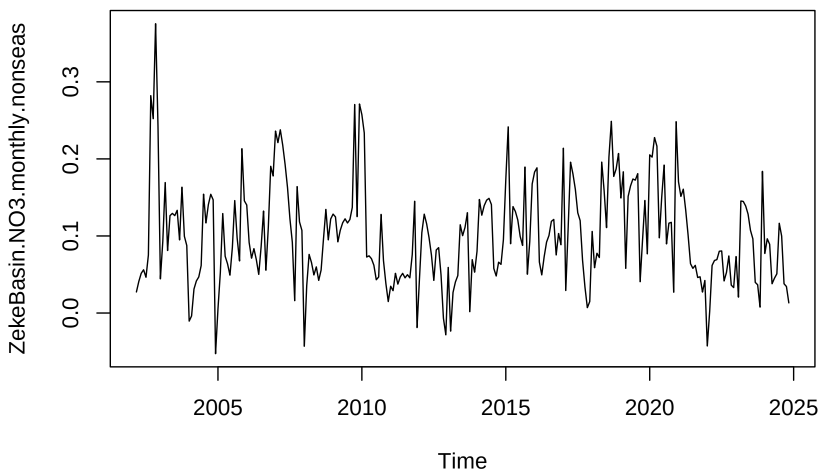

Figure 65: Non-Seasonal Trend of Zeke's Basin NO3

```
##
##  Mann-Kendall trend test
##
## data:  ZekeBasin.NO3.monthly.nonseas
## z = -0.48486, n = 273, p-value = 0.6278
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##             S          varS           tau
## -7.320000e+02  2.273057e+06 -1.971611e-02
```

Temperature

```
## Score =  546 , Var(Score) = 16676
```

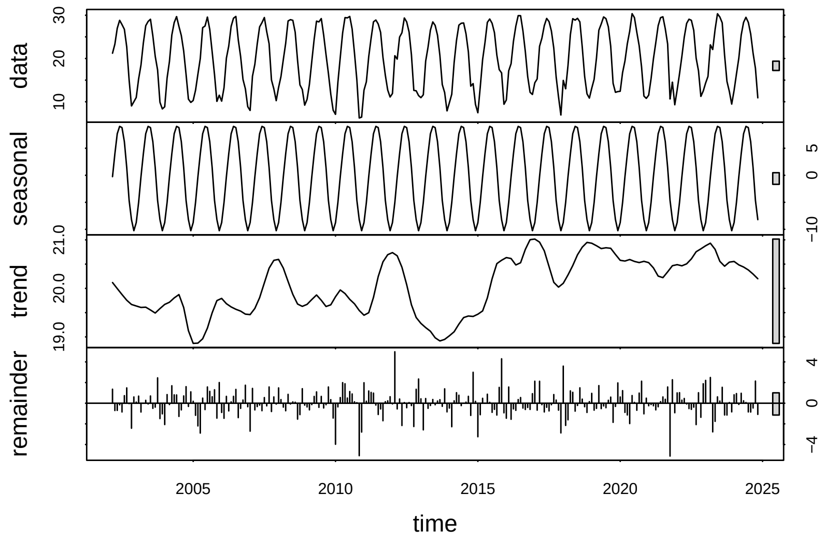

Figure 66: Decomposed Components of Zeke's Basin Temperature Time Series

```
## denominator =  2970
## tau = 0.184, 2-sided pvalue =2.3566e-05
```

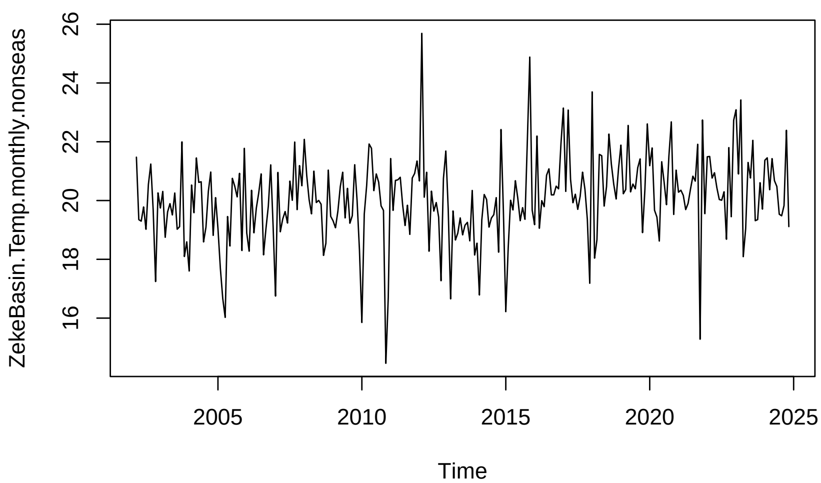

Figure 67: Non-Seasonal Trend of Zeke's Basin Temperature

```
##
##  Mann-Kendall trend test
##
## data:  ZekeBasin.Temp.monthly.nonseas
## z = 4.434, n = 273, p-value = 9.25e-06
## alternative hypothesis: true S is not equal to 0
## sample estimates:
##            S         varS          tau
## 6.686000e+03 2.273059e+06 1.800797e-01
```

For Zeke's Basin, NH4 had a significant decreasing trend, temperature had a significant increasing trend, and PO4 and NO3 had insignificant trends.

7. Summary and Conclusion

After conducting time series trend analyses on the dissolved oxygen and chlorophyll concentrations across each research station, we found that dissolved oxygen has indeed decreased over time across all monitoring stations, and that Chlorophyll has indeed increased over time across all monitoring stations. This leads us to believe that phytoplankton populations have grown over time in the Cape Fear River basin, and could be contributing to decreasing dissolved oxygen available in the water. After this part of our analysis, we decided to run a step-wise multiple regression for dissolved oxygen and chlorophyll on the water nutrient variables and temperature across all monitoring stations. We found that temperature, phosphate, and ammonium are the best variables for predicting chlorophyll. On the other hand, we found that temperature, phosphate, and nitrate are the best variables for predicting dissolved oxygen.

We decided to conduct time series analyses on the temperature, phosphate, nitrate, and ammonium as they best predicted dissolved oxygen and chlorophyll trends. We found the following results for each monitoring station:

East Cribbing: Phosphate had a significant decreasing trend, ammonium had a significant increasing trend, while nitrate and temperature had insignificant trends.

Loosin Creek: Phosphate had a significant decreasing trend, ammonium had a significant decreasing trend, nitrate had a insignificant trend, and temperature had a significant increasing trend.

Research Creek: Phosphate had an insignificant trend, ammonium had a significant decreasing trend, nitrate had a significant increasing trend, and temperature had a significant increasing trend.

Zeke's Basin: Phosphate had an insignificant trend, ammonium had a significant decreasing trend, nitrate had an insignificant trend, and temperature had a significant increasing trend.

From these results, what is consistent across each monitoring station is that temperature has been increasing, which decreases the amount of oxygen available in liquid water while improving conditions for the proliferation of phytoplanktonic communities in the river basin. Additionally, ammonium has a significant decreasing trend across all stations, but this could be a result of phytoplankton uptaking ammonium rapidly. Similarly, in half of the monitoring stations phosphate is also significantly decreasing (also a potential consequence of phytoplankton uptake). Lastly, nitrate's lack of significant trends leads us to find its role in eutrophication for the river basin inconclusive. Our takeaways are that temperature is absolutely increasing and potentially affecting the dissolved oxygen and phytoplankton communities in the Cape Fear River basin, but the impacts on nutrients are inconclusive – further research is needed to understand the mechanisms and temporal lag between nutrient concentrations like phosphate and ammonium and phytoplankton populations. Temporal lag and hysteresis need to be more deeply looked into, as it's difficult to make assumptions about the relationship between phosphate and ammonium nutrient use efficiency in phytoplankton populations just from chlorophyll a concentration data. Overall, it's difficult to assess conclusions based off of nutrients, as we have a chicken and the egg scenario with our data. However, it is clear that climate change and increasing temperatures are putting the Cape Fear River basin at risk for anoxic conditions as a consequence of warmer water and increasing phytoplanktonic activity, and should be heavily considered in the future coastal management of the region.

8. References

Chislock, M. F., Doster, E., Zitomer, R. A. & Wilson, A. E. (2013) Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems. Nature Education Knowledge 4(4):10

NOAA National Estuarine Research Reserve System (NERRS). System-wide Monitoring Program. Data accessed from the NOAA NERRS Centralized Data Management Office website: http://www.nerrsdata.org; accessed 12 October 2025. doi:10.25921/vw8a-8031.