Bloom or Bust: Influence of Harmful Algal Blooms on *Vibrio* Ecology in Florida’s Indian River Lagoon

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# Summary/Abstract

Through a genomics approach, this study examines the dynamics between *Vibrio* populations and harmful algal blooms in Florida’s Indian River Lagoon system. Surface water samples were collected from the Northern Indian River and St. Lucie Estuary weekly between June and July 2019. Samples were size fractionated to separate particle-attached and planktonic *Vibrio* bacteria. From each fraction, *Vibrio* abundance was estimated by culture-based methods as well as quantitative PCR (qPCR), targeting the RNA polymerase subunit A (rpoA). The abundance of phytoplankton was determined by flow cytometry. To characterize the species-specific associations between *Vibrio* and phytoplankton, the *Vibrio* hsp60 gene was amplified and sequenced from each fraction. This research demonstrates the correlations between *Vibrio* and phytoplankton abundance, while providing improved resolution of *Vibrio* assemblages associated with microalgae. By investigating bacterial-algal interactions, we may improve our understanding of how HAB events shape *Vibrio* ecology and microbial health risks.

# Introduction

## General Background Information

Harmful Algal Blooms (HABs) are an emerging global concern for ecosystem and public health. HAB events adversely affect water quality and deteriorate aquatic habitats. Contaminated waters pose public health risks, as HAB events may produce harmful toxins or promote the growth of pathogenic bacteria (Greenfield et al., 2017; Kazamia, Helliwell, Purton, & Smith, 2016).

Bacteria are increasingly recognized for their role in modulating HAB bloom dynamics (Cooper, Smith, Paszkowski, & Scott, 2015; Jones, Mikulski, Barnhorst, & Doucette, 2010; Laura B. Fandino, Lasse Riemann, Grieg F. Steward, Richard A. Long, 2001; Ramanan, Kim, Cho, Oh, & Kim, 2016; Seong & Jeong, 2013; Zhou et al., 2018). Similarly, algal blooms have been found to affect the activity of aquatic bacteria.

*Vibrio* spp. are a group of human pathogenic bacteria that are ubiquitous in estuary and marine environments. *Vibrio* illnesses are typically associated with the consumption of contaminated water and seafood, or with the infection of exposed wounds. *V. vulnificus* infection is the leading cause of seafood-borne deaths in the United States, usually the infection of exposed wounds by contaminated waters. Research has demonstrated that the distribution and dynamics of *Vibrio* populations are influenced by algal dynamics (Greenfield et al., 2017; Main, Salvitti, Whereat, & Coyne, 2015).Rapid algal growth may provide substrates and surfaces that stimulate *Vibrio* growth (Main et al., 2015).

Phytoplankton blooms may influence *Vibrio* ecology. In turn, *Vibrio* blooms may pose health risks to local populations.Investigating bacterial-algal interactions improves our understanding how HAB events shape microbial health risks.

Our research investigates *Vibrio* dynamics along Florida’s Indian River Lagoon (IRL), on Florida’s east coast. The IRL is an estuary of national significance and is protected by the USA National Estuaries Program. In recent years, the IRL has suffered from dense and damaging algal blooms, including those caused by the novel brown tide algae *Aureoumbra lagunensis* and by the toxic blue-green algae *Microcystis aeruginosa* (Kang, Koch, & Gobler, 2015; Oehrle, Rodriguez-Matos, Cartamil, Zavala, & Rein, 2017; Phlips, Badylak, & Grosskopf, 2002). Our research aims to investigate the interactions between bacteria and harmful algae during these HAB events.

We aimed to observe these dynamics during the summer of 2019. During this period, **we did not observe an algal bloom** at our field site, **but** we did collect a wealth of data on *Vibrio* populations and environmental variables. I am hoping to use this project as an opportunity to examine our data with these variables. With a reproducible analysis, I am hopeful that we can collect and analyze our data when a bloom event arises.

## Questions/Hypotheses to be addressed

Broadly, we aim to examine the associations between *Vibrio* spp. and harmful algal species during the succession of a bloom event. We ask: do harmful algal blooms promote *Vibrio* growth during a bloom event? We hypothesize that *Vibrio* populations will increase during brown tide blooms. The ecology of these two organisms are similar (they both thrive in warm, salty waters). In contrast, we predict that *Vibrio* populations will decrease during the toxic blue-green algae blooms caused by *Microcystis aeruginosa*. Microcystis thrives in freshwater and produces a harmful toxin that may damage *Vibrio* bacteria.

We’re still keeping a watchful eye for an algal bloom back in Florida, but until then, we hope to ask more exploratory questions to see if there are trends or relationships between *Vibrio* bacteria and other environmental variables.

In this analysis, we ask: how do environmental conditions influence *Vibrio* populations in Florida’s Indian River Lagoon? Can the patterns in our *Vibrio* data be explained by salinity, pH, water temperature, precipitation, or aerosol deposition?

During this field season, there was a notable “dust event,” where Saharan Dust was transported across the Atlantic to Florida’s coast. This dust may provide nutrients for rapid *Vibrio* growth. Are there associations between the dust patterns and *Vibrio* populations?

# Field and Laboratory Methods

Water samples were collected in triplicate from three locations in both the Northern Indian River Lagoon and the St. Lucie Estuary. Samples were collected weekly between June 2019 and July 2019 to monitor phytoplankton and *Vibrio* abundance (n = 144).

In the Northern Indian River Lagoon (IRL), samples were collected from three locations: Scottsmoor Landing (IRL 1), Titusville Pier (IRL 2), and the Beacon 42 Boat Ramp (IRL 3). Samples were collected on the following dates: 6/10, 6/17, 6/24, 7/1, 7/8, 7/15, 7/22, 7/29. The NIRL is not heavily influenced by tidal mixing.

In the St. Lucie Estuary (SLE), samples were collected from three locations: Snug Harbor Yacht Club (SLE 1), Stuart Boardwalk (SLE 2), and Leighton Park (SLE 3). Samples were collected on the following dates: 6/5, 6/12, 6/19, 6/26, 7/3, 7/17, 7/24, 7/31. The SLE is tidally influenced. Samples were collected during the outgoing tide.

Water samples were pre-filtered using a sterilized 200-µm filter to remove debris, detritus, and zooplankton. Physical parameters of the sampling sites were measured in-field using a YSI sonde. Salinity was determined using a refractometer. Data was collected on site at the time of sampling. Water samples will be analyzed for Chl a and nutrient composition. Water quality will be cross-referenced with the Continuous Sensor-based Water Quality Data from St. John’s Water Management District.

Samples were plated onto TCBS to culture and enumerate *Vibrio* bacteria. Cell density of phytoplankton will be determined from fixed samples using direct counts and flow cytometry.

Water samples were size fractionated in series onto polycarbonate filters (2.0 µm) and Sterivex filters (0.22 µm) to separate the particle-attached and planktonic bacterial communities. DNA will be extracted from stored filters using the Qiagen PowerSoil Pro Kit and phenol:chloroform:isoamyl extractions. Bacterial and phytoplankton DNA will be sequenced to characterize the aquatic microbial community.

Bacterial and cyanobacterial 16S rRNA will be amplified using universal 16S primers 515F/806R. Novel NGS sequencing of the *Vibrio* heat shock protein 60 (hsp60) will be sequenced to provide additional taxonomic resolution of the *Vibrio* community. 18S rRNA will be amplified using the universal 18S primers EukA/329R10 as described in to analyze the phytoplankton community.

## Data Aquisition

Daily averages for aerosol optical depth (AOD) were obtained from [AERONET Version 3](https://aeronet.gsfc.nasa.gov/new_web/data.html). The AOD is a measure of the blockage of sunlight by aerosolized particulate matter. The AOD is a unit less measure of atmospheric conditions and may be used to approximate the atmospheric transportation of dust from the Saharan desert. AOD values were obtained from AERONET stations at NASA Kennedy Space Center and Lake Okeechobee to approximate the aerosol optical depth in the Northern Indian River Lagoon (IRL), and the St. Lucie Estuary (SLE), respectively. The following data are cloud cleared and quality controls have been applied but these data may not have final calibration applied. For more information on this data, contact: PI Nima\_Pahlevan at [nima.pahlevan@nasa.gov](mailto:nima.pahlevan@nasa.gov).

Daily averages of precipitation were obtained from [U.S. Climate Data](https://www.usclimatedata.com/). Precipitation data was obtained for Titusville, FL (-80.8159, 28.6241) and Stuart, FL (-80.2397, 27.1897) to approximate precipitation in the Northern Indian River Lagoon (IRL), and the St. Lucie Estuary (SLE), respectively.

## Data Import and Cleaning

Over the course of this study, 144 water samples were collected from eastern Florida. Water samples were collected in triplicate from six sample locations (IRL 1, IRL 2, IRL 3, SLE 1, SLE 2, SLE 3), during eight weekly sampling events. Vibrio count data sets each include 72 observations of Vibrio colonies enumerated from TCBS plates during this study. Triplicates were averaged, resulting in a total of 24 observations in each data set. The IRL and SLE environmental data sets each include 24 observations detailing the sampling time, water temperature, salinity, air temperature, and precipitation for each sampling event, at each sampling location.

The data imported from Aeronet includes 45 observations of the average AOD between 6/5/2019 and 7/31/2019. In this analysis, we use AOD measured at 1020nm to approximate aerosolized Saharan Dust.

The processing script provides code that imports and cleans the data included in this analysis.

# Results

## Univariate Analysis

In this univariate analysis, we aim to explore *Vibrio* concentrations and environmental variables in the IRL and SLE between June 5, 2019 and July 31, 2019. *Vibrio* was enumerated from two estuaries on Florida’s east coast, over a period of eight weeks.

### Indian River Lagoon

*Vibrio* abundance and environmental conditions between June 5, 2019 and July 31, 2019 in the IRL are presented in Figure 1.

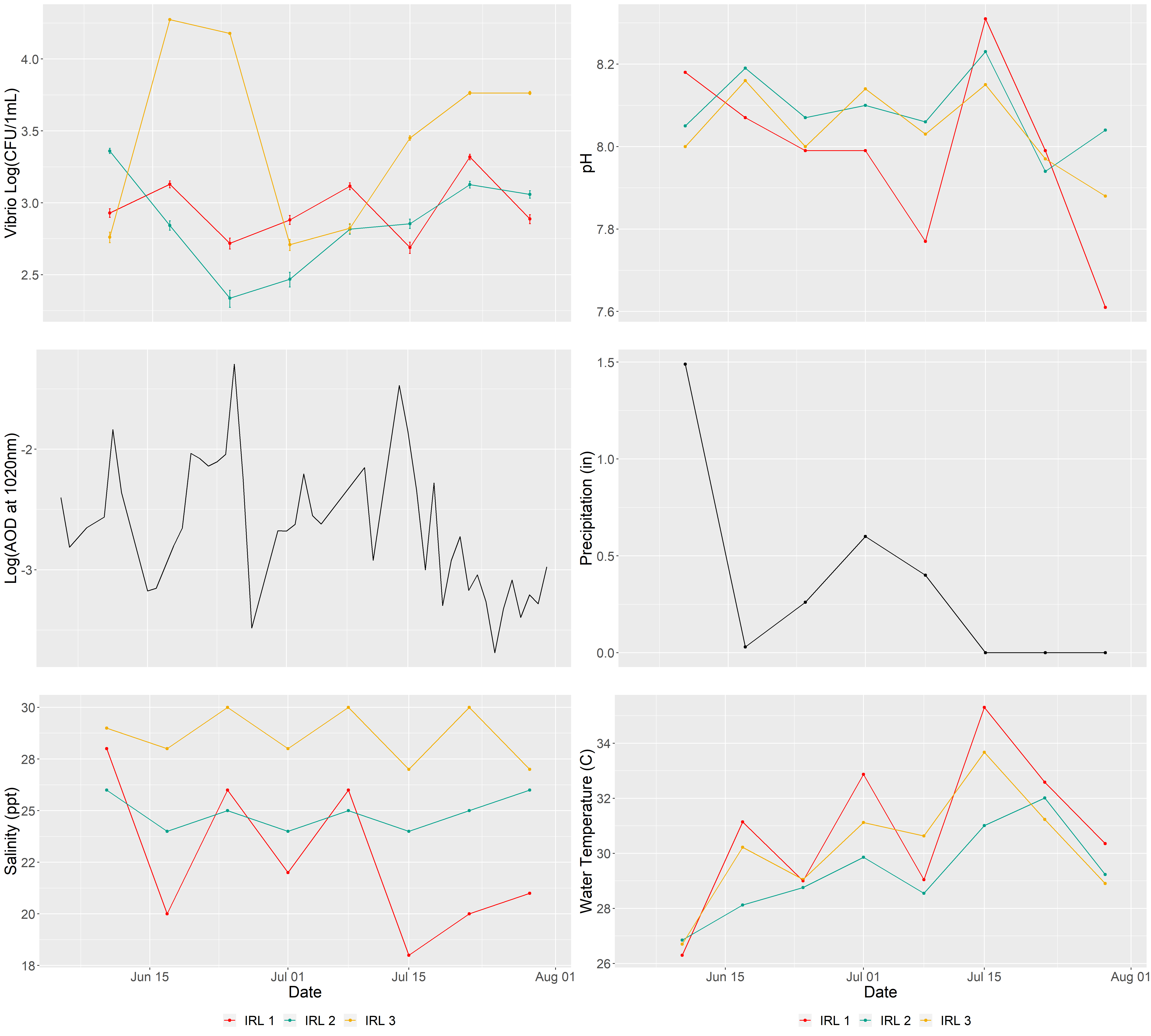


Figure 1: Enumeration of *Vibrio* spp. and environmental variables over time in the IRL. Water quality parameters including salinity, pH, and water temperature were determined in the field using a refractometer and YSI sonde. Aerosol optical density (AOD at 1020nm) was determined by the Aeronet Station at KSC.

In the IRL, *Vibrio* abundance bloomed between June 17 and June 24, 2019 at the IRL 3 sampling location. During this bloom, the maximum *Vibrio* abundance was recorded from the IRL, at 1.9 x 10^4 CFU/1mL. No bloom was observed at the IRL 1 or IRL 2 locations during this time. In fact, the lowest *Vibrio* abundance in the IRL was recorded at the IRL 2 location during this period, at 2.17 x 10^2 CFU/1mL on June 24, 2019. *Vibrio* abundance increased again, at all three locations, on July 22, 2019. Enumeration of bacteria from environmental samples do not typically conform to a normal distribution, but conform instead to a Poisson distribution. Results from the Shapiro-Wilk test for normality suggest that the *Vibrio* counts from the IRL do not follow a normal distribution (p < 0.01). Typically, counts will follow a normal distribution following log transformation. However, the Vibrio counts from the IRL do not follow a normal distribution when log-transformed (p = 0.0304).

In the IRL, the average AOD during this study period was 0.083. The AOD ranged between 0.025 and 0.274 over this period, peaking on June 25, 2019 (0.274) and again on July 14, 2019 (0.230). Results from the Shapiro-Wilk test for normality suggest that the AOD in the IRL does not follow a normal distribution (p = < 0.01). When log-transformed, the AOD can be assumed to follow a normal distribution (p = 0.552).

Salinity in the IRL ranged between 18 ppt and 30 ppt during this study period. Results from the Shapiro-Wilk test for normality suggest that salinity in the IRL does follow a normal distribution (p = 0.221). The salinity was distinctly different between the three IRL sampling locations (One-way ANOVA, p = < 0.01). At IRL 1, the average salinity was 23 ppt and ranged from 18 ppt to 28 ppt. At IRL 2, the average salinity was 25 ppt and ranged from 24 ppt to 26 ppt. At IRL 3, the average salinity was 29 ppt and ranged from 27 ppt to 30 ppt.

The average pH in the IRL was 8.03 and ranged between 7.61 and 8.31 during this study period. The pH is normally distributed in he IRL (Shapiro-Wilk, p = 0.137), and the pH is not distinctly different between the three locations (One-way ANOVA, p = 0.446 x 10^-1). The pH appeared to peak at all three sampling locations on July 15, 2019. The pH declined at location IRL 1 to 7.61 on July 29, 2019. This was the lowest pH observed in the IRL over the course of this study and corresponded with a drop in salinity at the same location.

The daily average precipitation in Titusville, FL ranged from 0.00 in. to 1.49 in. The average air temperature was 27.3 C and ranged from 26.4 C to 28.0 C. Precipitation and air temperature in Titusville, FL was used to approximate the precipitation in the IRL during this study period.

The average water temperature in the IRL was 30.10 and ranged from 26.3 C to 35.3 C. The water temperature is normally distributed (Shapiro-Wilk, p = 0.809) and does not differ significantly between sampling locations (One-way ANOVA, p = 0.400). The water temperature peaked at all three locations on July 15, 2019.

Water quality parameters appeared to follow a distinct pattern of fluctuating conditions, as though they were tidally influenced; however, this estuary is not influenced by tidal mixing. Examining the time of sampling in the IRL, it appears that time of sample collection fluctuates in the same or similar pattern. Samples were collected from each location in the following order: IRL 1, IRL 2, IRL 3. The average sampling time at the first location (IRL 1) was approximately 1100, but ranged from 0551 and 1455. Notably, sample collection finished latest on July 15, 2019. Sample times are included in the supplementary materials.

The peak in *Vibrio* abundance appears to correspond with increases in AOD at 1020nm. In the IRL, the AOD peaked on June 25, 2019 and again on July 14, 2019. Samples were collected from the IRL on June 24 and July 15, 2019.

### St. Lucie Estuary

*Vibrio* abundance and environmental conditions between June 5, 2019 and July 31, 2019 in the SLE are presented in Figure 2.

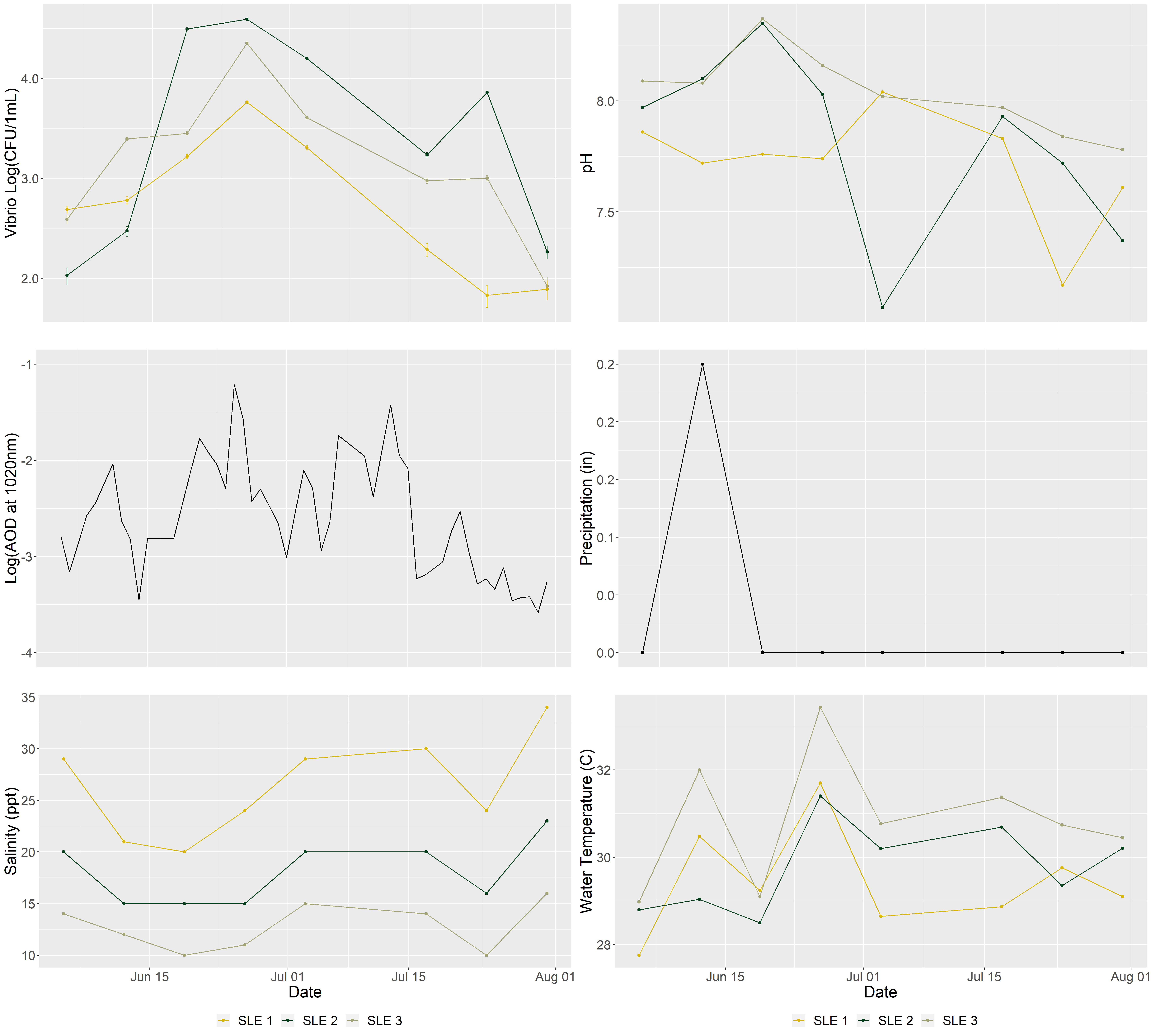


Figure 2: Enumeration of *Vibrio* spp. and water quality parameters over time in the SLE. Salinity, pH, and water temperature were determined in field using refractometer and YSI sonde. Aerosol optical density (AOD at 1020nm) over time in the Indian River Lagoon and St. Lucie Estuary, as determined by Aeronet Station at Lake Okechobee.

In the SLE, *Vibrio* abundance bloomed between June 19 and July 3, 2019 at SLE 1, SLE 2, and SLE 3. *Vibrio* abundance peaked at all three locations on June 26, 2019 (3.9 x 10^3 CFU/1mL, 2.3 x 10^3 CFU/1mL,5.8 x 10^3 CFU/1mL, respectively). Results from the Shapiro-Wilk test for normality suggest that the *Vibrio* counts from the SLE do not follow a normal distribution (p < 0.01), but do follow a normal distribution when log-transformed (p = 0.406). The enumeration of total Vibrio does not differ between sampling locations in the SLE (One-way ANOVA, p = 0.281).

The average AOD in the SLE during this study period was 8.8294 x 10^-2. The AOD ranged between 2.7799 x 10^-2 and 2.97130 x 10^-1 over this period. The AOD peaked on June 25, 2019 (2.97130 x 10^-1) and again on July 13, 2019 (2.4067 x 10^-1). Results from the Shapiro-Wilk test for normality suggest that the AOD in the SLE does not follow a normal distribution (p < 0.01). When log-transformed, the AOD can be assumed to follow a normal distribution (p = 0.223).

Salinity in the SLE follows a normal distribution (Shapiro-Wilk, p = 0.119), but average salinity is significantly different between the three sampling locations (One-way ANOVA, p < 0.01). At SLE 1, the average salinity was 26 ppt and ranged from 20 ppt to 34 ppt. At SLE 2, the average salinity was 18 ppt and ranged from 15 ppt to 23 ppt. At SLE 3, the average salinity was 13 ppt and ranged from 10 ppt to 16 ppt.

The average pH in the SLE was 7.86 and ranged between 7.07 and 8.37 during this study period. The pH is normally distributed in the SLE (Shapiro-Wilk, p = 0.091), and the pH is not distinctly different between the three locations (One-way ANOVA, p = 0.115).

The average precipitation in Stuart, FL ranged from 0.00 in. to 0.25 in on the days of sample collection. The average air temperature was 29.5 C, and ranged from 28.3 and 30.6 C. Precipitation and air temperature in Stuart, FL was used to approximate the precipitation in the SLE during this study period.

The average water temperature in the SLE was 30.02 and ranged from 27.76 C to 33.43 C. The water temperature is normally distributed (Shapiro-Wilk, 0.354) and does not differ significantly between sampling locations (One-way ANOVA, 0.0819).

The peak in *Vibrio* abundance appears again to correspond with increases in AOD at 1020nm. In the SLE, the AOD peaked on June 25, 2019 and again on July 13, 2019. As previously noted, the peak of *Vibrio* abundance in the SLE was recorded on June 26, 2019, 24h following the peak AOD.

## Bivariate Analysis

In this analysis, we are interested in understanding how environmental variables influence *Vibrio* abundance, our outcome of interest.

The correlation plots in Figures 3 and 4 demonstrate the correlations between *Vibrio* abundance and environmental variables and factors in methodology that may influence *Vibrio* enumeration. These correlation plots provide a brief overview of the relationships that might be important in determining our recorded *Vibrio* abundance. Specifically, these correlation plots suggest that we may want to keep a watchful eye on the relationships between *Vibrio* abundance and the AOD 24 hours prior to sampling. Additionally, we will want to consider the relationships between *Vibrio* abundance and precipitation 24 hours prior to sampling. We see some interesting correlations between air temperature and precipitation and between water temperature and salinity.

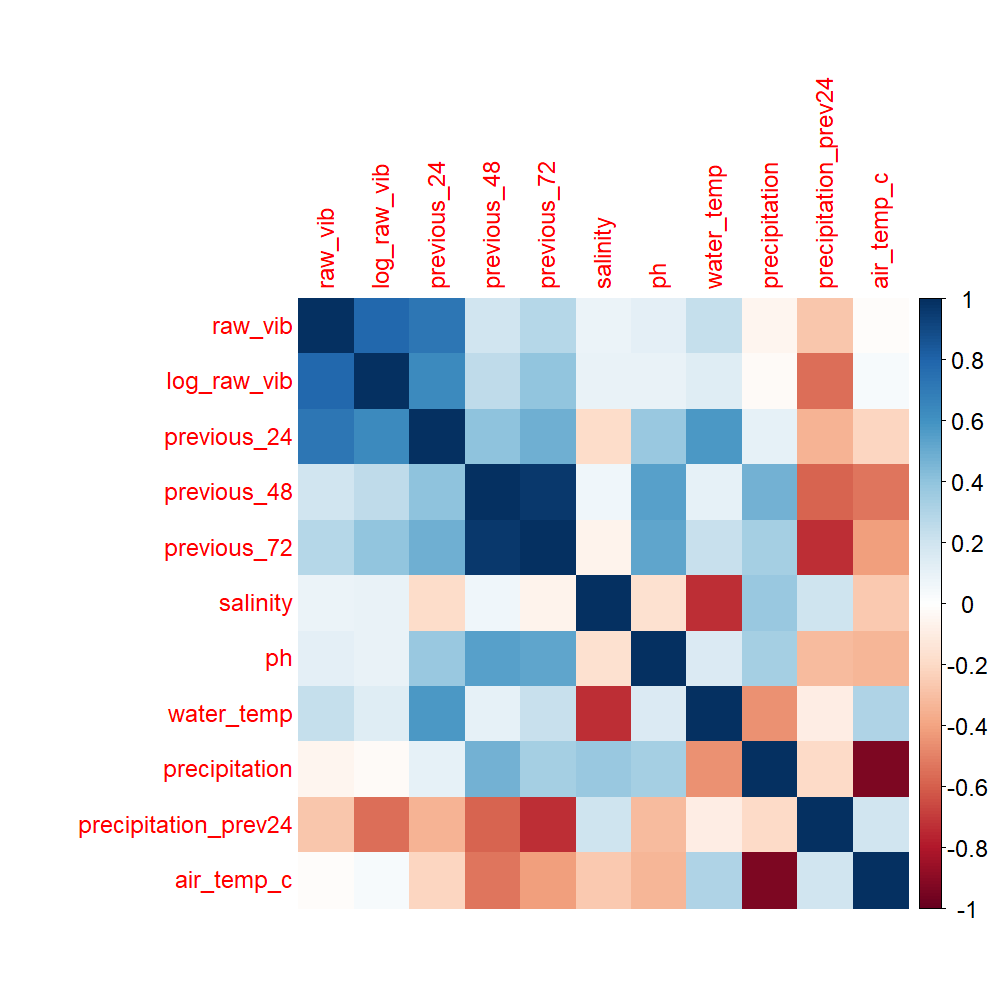


Figure 3: Correlation between *Vibrio* abundance and environmental variables.

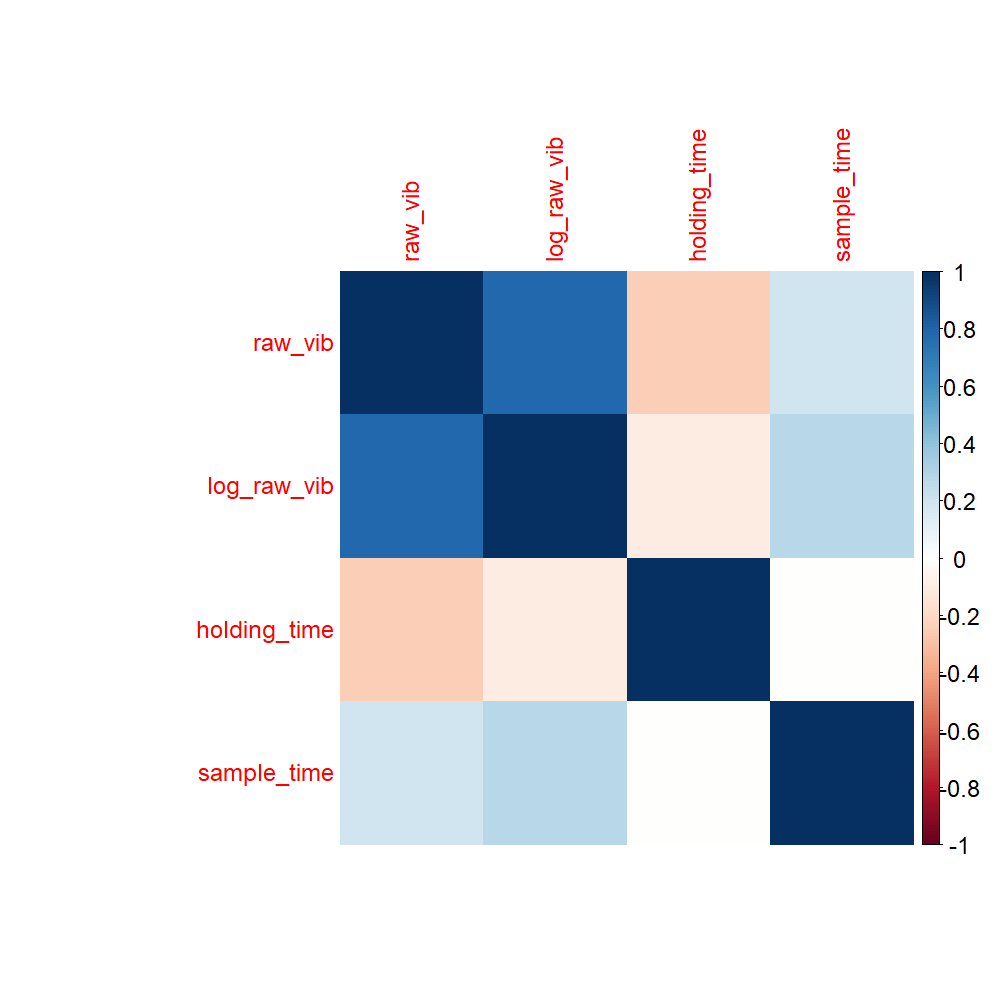


Figure 4: Correlation between *Vibrio* abundance and methodological variables, such as sampling time and sample holding time.

### Influence of Environmental Varibales on *Vibrio* Abundance in the Indian River Lagoon

The relationship between *Vibrio* abundance and environmental variables was examined using simple linear regression.

The plots in Figure 5 assess the linear relationship between log-transformed *Vibrio* abundance in the IRL and pH, salinity, water temperature and air temperature measured on the day of sampling. Additionally, this plot evaluates the linear relationship between *Vibrio* abundance and precipitation the day of and day before sampling. There does not appear to be a statistically significant relationship between any of these variables and *Vibrio* abundance.

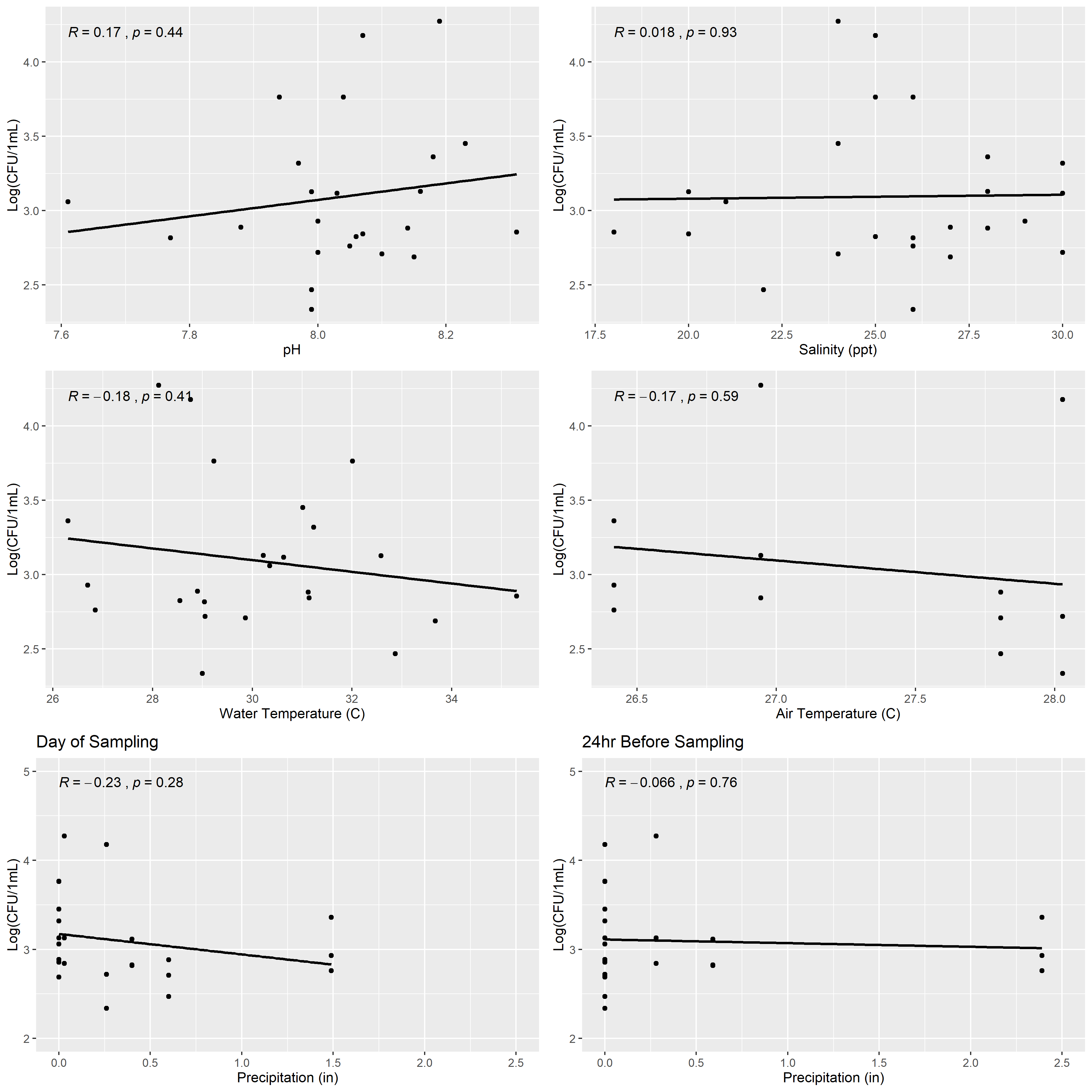


Figure 5: Enumeration of *Vibrio* spp. from the Indian River Lagoon in relation to environmental variables. Pearson’s correlation coefficient (R) and p-value (p) presented for each relationship.

The plots in Figure 6 assess the linear relationship between log-transformed *Vibrio* abundance and normalized AOD in the IRL. The correlation is examined between *Vibrio* abundance and the AOD measured on the day of sampling, 24 hours before sampling, 48 hours before sampling, and 72 hours before sampling. There appears to be no statistically significant linear relationship between AOD and *Vibrio* abundance in the IRL.

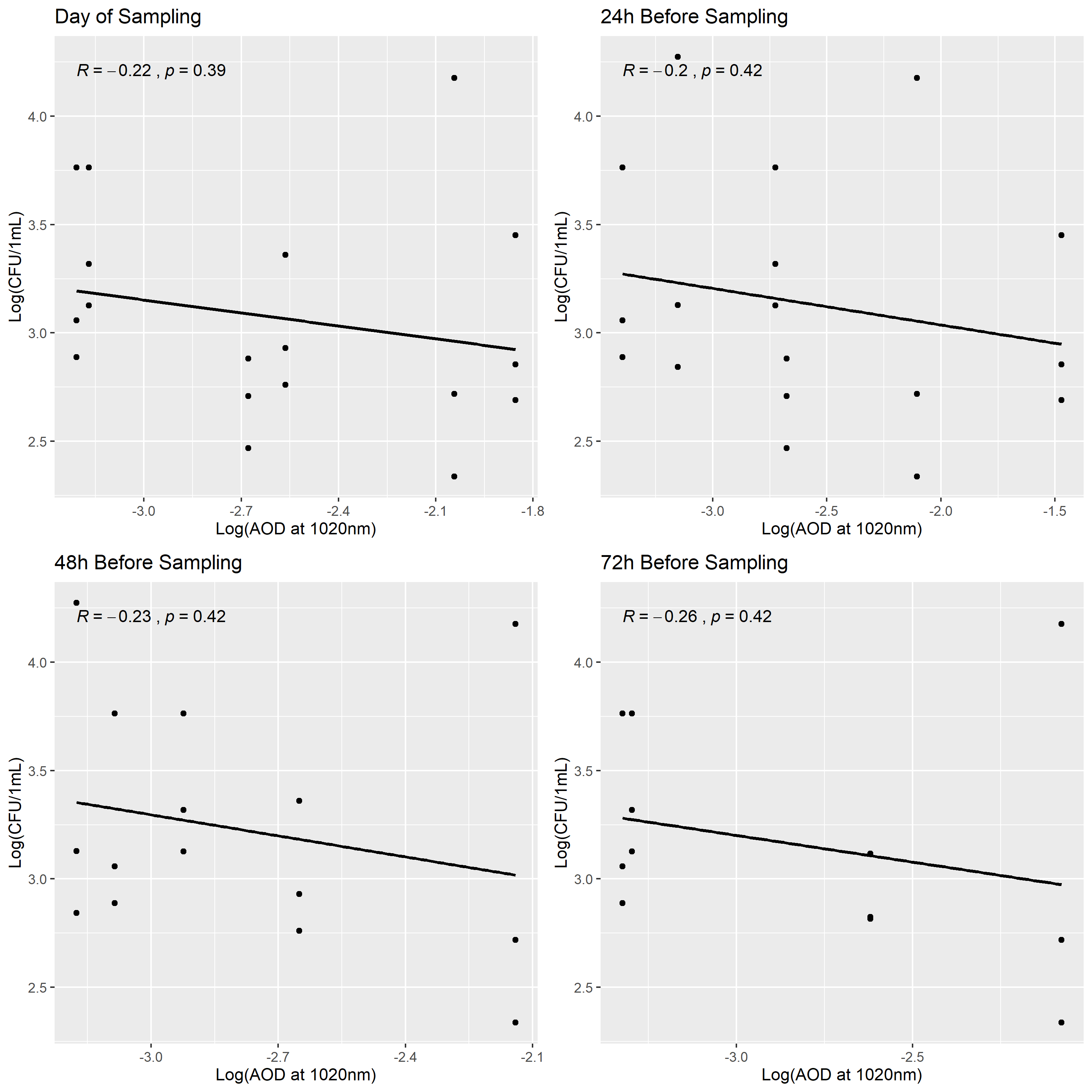


Figure 6: Enumeration of *Vibrio* spp. from the Indian River Lagoon in relation to AOD on the day of sampling, 24 hours before sampling, 48 hours before sampling, and 72 hours before sampling. Pearson’s correlation coefficient (R) and p-value (p) presented for each relationship.

### Influence of Environmental Varibales on *Vibrio* Abundance in the St. Lucie Estuary

The plots in Figure 7 assess the linear relationship between normalized *Vibrio* abundance in the SLE and pH, salinity, water temperature and air temperature measured on the day of sampling. Additional plots evaluate the linear relationship between *Vibrio* abundance and salinity measured between 0 ppt to 15 ppt separately from the salinity measured at 15 ppt and 30 ppt. Precipitation the day of and day before sampling are examined in relation to *Vibrio* abundance. There does not appear to be a statistically significant relationship between any of these environmental variables and *Vibrio* abundance.

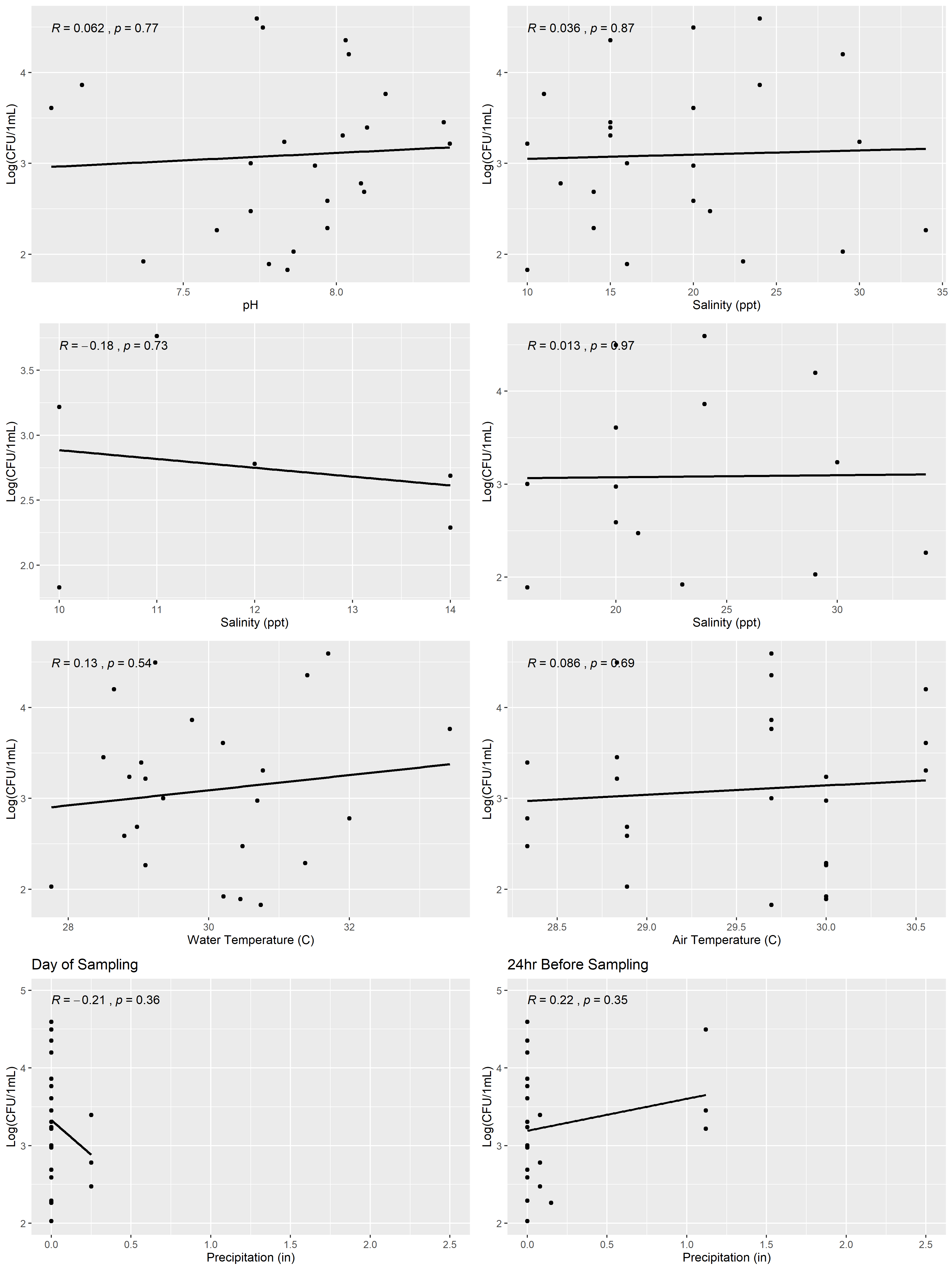


Figure 7: Enumeration of *Vibrio* spp. from the St. Lucie Estuary in relation to environmental variables. Pearson’s correlation coefficient (R) and p-value (p) presented for each relationship.

The linear relationship between normalized *Vibrio* abundance and normalized AOD in the SLE are examined in Figure 8. There does appears to be a statistically significant linear relationship between *Vibrio* abundance in the SLE and the normalized AOD measurement on the day of sampling (p < 0.01), the day before sampling (p < 0.01), and 72 hours before sampling (p = .06).



Figure 8: Enumeration of *Vibrio* spp. from the St. Lucie Estuary in relation to AOD. Pearson’s correlation coefficient (R) and p-value (p) presented for each relationship.

### Influence of Environmental Varibales on *Vibrio* Abundance, with Combined Analysis from the Indian River Lagoon and St. Lucie Estuary

Although the IRL and SLE are separated by 150 miles, it may be of interest to combine the two data sets to improve the number of observations included in the linear regression models. Based on this combined data set, there does not appear to be a linear relationship between *Vibrio* abundance and environmental variables pH, salinity, water temperature, air temperature, or precipitation (Supplemental Materials). There does, however, appear to be a statistically significant linear relationship between log-transformed *Vibrio* abundance in the IRL and SLE and normalized AOD measured the day of sampling (p < 0.01). The relationship between *Vibrio* abundance and AOD is demonstrated in Figure 9.

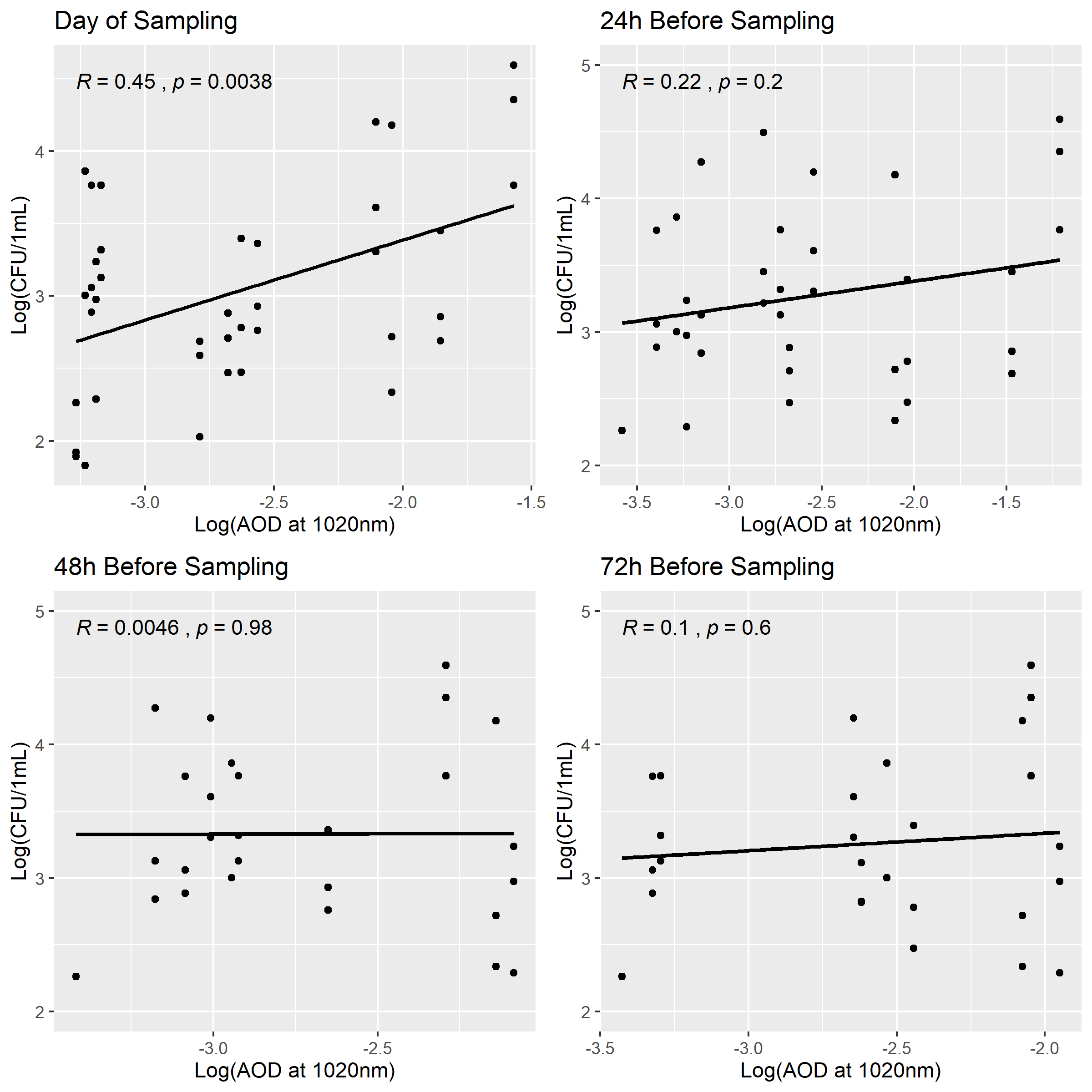


Figure 9: Enumeration of *Vibrio* spp. from the Indian River Lagoon and St. Lucy Estuary in relation to AOD at 1020nm.

## Full Analysis

In this section of the analysis, we use statistical models to analyze the relationship between our environmental variables and *Vibrio* abundance. We begin with a single predictor model with the outcome of *Vibrio* abundance and the following predictors: normalized AOD day of sampling, normalized AOD the day before sampling, salinity, pH, water temperature, sampling time, and precipitation. When filtering for missing values, our data set contains 33 observations. These observations are then divided into a training set (25 observations) and a test set (8) observations.

Using the ‘lm’ linear model function, we can examine the RMSE of each single predictor (Table 1. According to the RMSE values, the models that include the the normalized values of the AOD on the day of sampling and day before sampling may perform better than the other single-predictor models.

Table 1: RMSE of the simple linear regression between *Vibrio* abundance and environmental variables as measured from the Indian River Lagoon and St. Lucy Estuary.

|  |  |
| --- | --- |
| Variable | RMSE |
| AOD\_1020nm | 0.6191808 |
| previous\_24 | 0.6254623 |
| salinity | 0.7728044 |
| ph | 0.7501033 |
| water\_temp | 0.7209808 |
| sample\_time | 0.7265205 |
| precipitation | 0.7353341 |

When examining the full model in the training data set, with all seven predictors, the RMSE was 0.8358849. The RMSE of the model with the test data set was 0.8522869. The full model did not perform as well as any of the single-predictor models. The predicted outcomes are plotted against the measured *Vibrio* abundance in Figure 10.

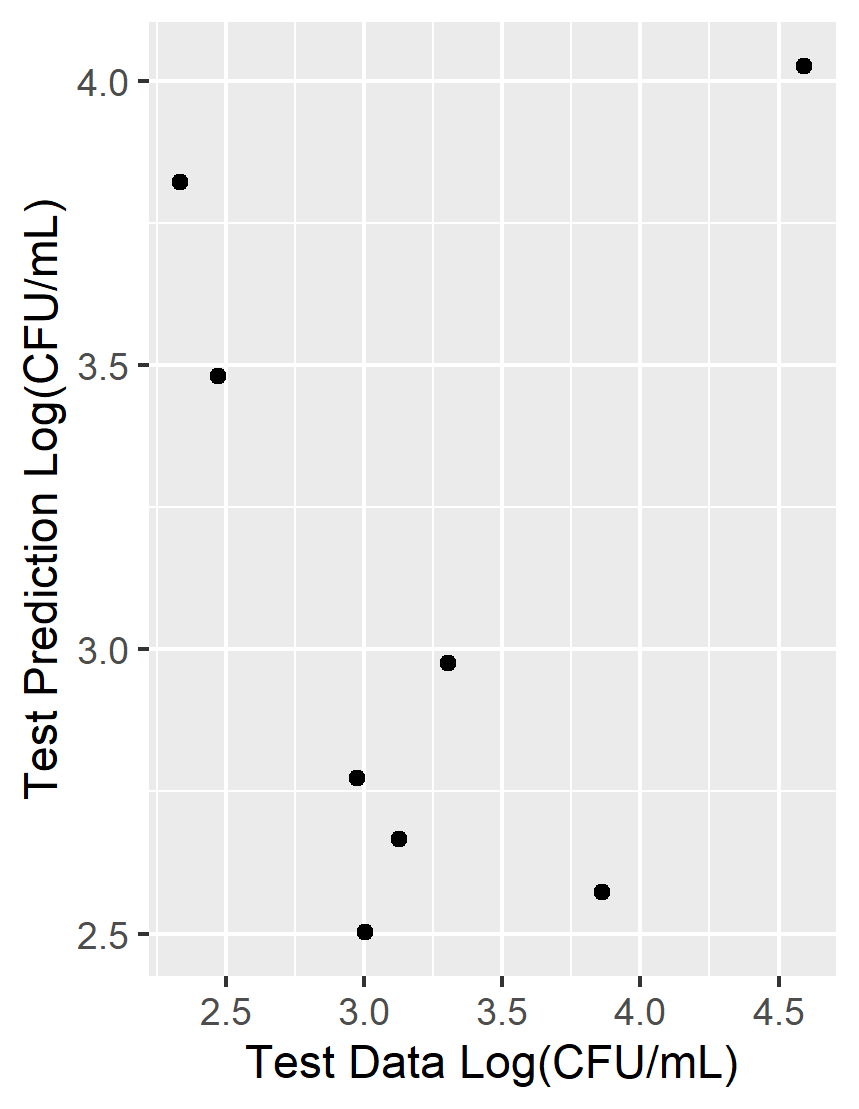


Figure 10: *Vibrio* abundance predicted by the full linear regression model with all predictors, in relation to *Vibrio* abundance in the test data set.

The next step in this analysis would be to complete a variable or feature selection. This data set contains one continuous outcome and seven continuous predictors. Based on this data set, it is appropriate to use filter methods for feature selection. Features may be selected based on Pearson’s Correlation. None of our variables are strongly correlated with the outcome (R > 0.7 or R < -0.7); only normalized AOD is significantly correlated with *Vibrio* abundance.

Using the Boruta algorithm for feature ranking and selection, the potential or tentative variables of importance are: pH, water temperature, sampling time, and the normalized AOD on the day of sampling and 24 hours before sampling. The importance scores for each variable are presented in Figure 11. Based on these scores, the normalized AOD on the day of sampling, day before sampling, and sample time are all confirmed variables of importance.

In a multiple regression including the normalized AOD on the day of sampling and the normalized AOD on the day before sampling, the RMSE is 0.62891. In a model including the AOD on the day of sampling and sample time, the RMSE is 0.6301921. Including all three predictors, the RMSE is 0.6186559. This model performs with only a slight improvement over the model with the normalized AOD on the day of sampling as a single predictor.

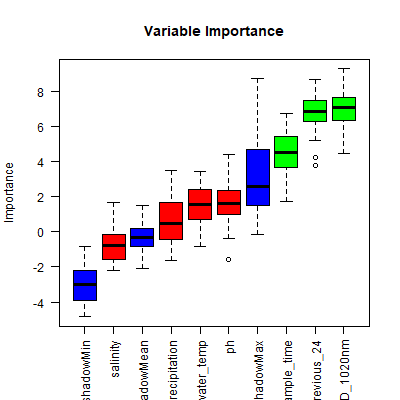


Figure 11: Variable importance as determined by the Boruta algorithm.

We explored a tree model to further explore the predictor variables and the *Vibrio* abundance outcome. In this model, we included all 33 observations to improve the resolution of the tree model. The results from the tree model suggest once more, that the normalized AOD on the day of sampling is a significant predictor of *Vibrio* abundance.

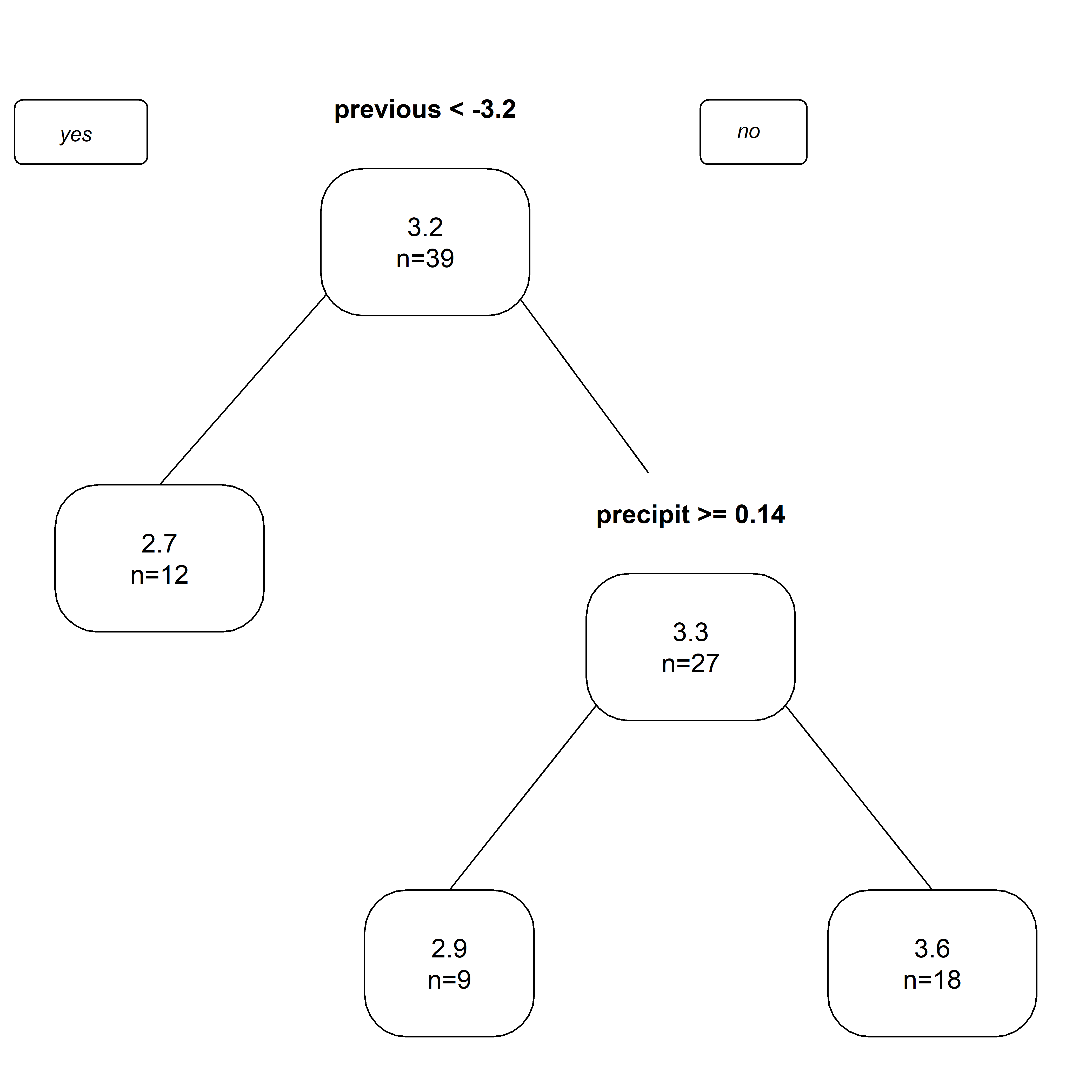


Figure 12: *Vibrio* abundance predicted by a tree model with all predictors.

# Discussion

## Summary and Interpretation

In this analysis, we examine the relationship between environmental variables and *Vibrio* abundance in Florida’s eastern estuaries. We monitored *Vibrio* abundance from three locations in the IRL and three locations in the SLE. We measured or collected data on water temperature, air temperature, pH, salinity, aerosol optical density, precipitation at each location or watershed. In our analysis, it appears that among these environmental variables, the AOD is significantly correlated with *Vibrio* abundance.

Results of the linear regression models indicate that the normalized values of AOD on the day of sampling and day before sampling are significantly correlated with *Vibrio* abundance. During this study, the AOD peaked in the IRL on June 25, 2019 and again on July 14, 2019. The increases in AOD corresponded with a marked increases in *Vibrio* abundance in the eastern sampling location, IRL 3. Similarly, the AOD peaked in the SLE on June 25, 2019 and July 13, 2019 with a marked increase in *Vibrio* abundance at all three sampling locations in the SLE during the same period.

An increase in AOD approximates the increase in particle matter suspended in the atmosphere. The average AOD in the U.S. is between 0.1 and 0.15 (US Department of Commerce, NOAA, n.d.). The AOD reached 0.27413 and 0.229634 during the two peak events in the IRL. In the SLE, the AOD reached 0.29713 and 0.240665 during the two peak events.

Peaks in AOD may be used to approximate the transport and deposition of dust from the Saharan desert. These dust events provide pulses of nutrients that can affect the microbial community of the marine environment (Borchardt et al., 2019; Westrich et al., 2016; Westrich, Griffin, Westphal, & Lipp, 2018). Previous research demonstrates that the abundance of *Vibrio* increases significantly within 14-24h of dust deposition in oligotrophic marine waters (Westrich et al., 2016). These results suggest that dust events may limited, but essential nutrients for bacterial growth, such as iron. In a eutrophic system, such as the IRL and SLE estuaries, the nutrients from Saharan dust may not drive *Vibrio* blooms; instead, particulate matter from the dust may provide substrates for opportunistic, particle-attached *Vibrios*.

In response to Saharan dust events, *Vibrio* blooms may pose public health risks. Within a short period of time, the abundance of pathogenic *Vibirio* spp. may quickly exceed an infectious dose for vibriosis, skin infections, or other *Vibrio*-associated illnesses. As such, *Vibrio* blooms may have implications for aquaculture and recreational use of estuarine and marine waters.

## Strengths and Limitations

In this study, we aimed to examine the relationship between *Vibrio* abundance and HAB events. We conducted intensive weekly sampling from two watersheds that suffer from reoccurring HAB events. Unfortunately, we did not observe an algal bloom during this sampling period. The results of this data analysis suggest, however, that there are still interesting relationships between environmental variables and *Vibrio* abundance in the IRL and SLE.

This data analysis focused on the linear relationship between *Vibrio* abundance and several environmental variables. However, our study design includes time series data for our outcome and each predictor variable. Linear models may not be sufficient to explain the dynamic relationship between microbes and their physical environment. Future analyses should explore this data with time-series-specific modeling.

Our study design allowed for the collection and analysis of water samples across space and time. However, in this analysis, we have discovered that the watersheds and sampling locations may be distinctly different based on environmental and biological factors. Future analyses should explore this data using mixed-effects or multilevel modeling.

This analysis considers the environmental variables that were measured in-situ or retrieved from publicly available sources. We are still collecting data on other environmental and biological variables, including chlorophyll a concentration, nutrient levels, and phytoplankton abundance in these water samples. Our data collection and data analysis are still evolving.

## Conclusions

The transport and deposition of Saharan dust may influence *Vibrio* populations in Eastern Florida. The dynamics in *Vibrio* abundance in the IRL and SLE were explained by AOD moreso than salinity, pH, water temperature, air temperature, and precipitation. Peaks in AOD in late-June and mid-July correspond with peaks in *Vibrio* abundance in the IRL and SLE.

# References

Borchardt, T., Fisher, K. V., Ebling, A. M., Westrich, J. R., Xian, P., Holmes, C. D., … Ottesen, E. A. (2019). Saharan dust deposition initiates successional patterns among marine microbes in the Western Atlantic. *Limnology and Oceanography*. <https://doi.org/10.1002/lno.11291>

Cooper, M. B., Smith, A. G., Paszkowski, U., & Scott, B. (2015). Exploring mutualistic interactions between microalgae and bacteria in the omics age. *Current Opinion in Plant Biology*, *26*, 147–153. <https://doi.org/10.1016/j.pbi.2015.07.003>

Greenfield, D. I., Gooch Moore, J., Stewart, J. R., Hilborn, E. D., George, B. J., Li, Q., … Sandifer, P. A. (2017). Temporal and environmental factors driving <i>Vibrio vulnificus</i> and <i>V. parahaemolyticus</i> populations and their associations with harmful algal blooms in South Carolina detention ponds and receiving tidal creeks. *GeoHealth*, 306–317. <https://doi.org/10.1002/2017GH000094>

Jones, K. L., Mikulski, C. M., Barnhorst, A., & Doucette, G. J. (2010). Comparative analysis of bacterioplankton assemblages from Karenia brevis bloom and nonbloom water on the west Florida shelf (Gulf of Mexico, USA) using 16S rRNA gene clone libraries. *FEMS Microbiology Ecology*, *73*(3), 468–485. <https://doi.org/10.1111/j.1574-6941.2010.00914.x>

Kang, Y., Koch, F., & Gobler, C. J. (2015). The interactive roles of nutrient loading and zooplankton grazing in facilitating the expansion of harmful algal blooms caused by the pelagophyte, Aureoumbra lagunensis, to the Indian River Lagoon, FL, USA. *Harmful Algae*, *49*, 162–173. <https://doi.org/10.1016/j.hal.2015.09.005>

Kazamia, E., Helliwell, K. E., Purton, S., & Smith, A. G. (2016). How mutualisms arise in phytoplankton communities: building eco-evolutionary principles for aquatic microbes. *Ecology Letters*, *19*(7), 810–822. <https://doi.org/10.1111/ele.12615>

Laura B. Fandino, Lasse Riemann, Grieg F. Steward, Richard A. Long, F. A. (2001). Variations in bacterial community structure during a dinoflagellate bloom analyzed by DGGE and 16S rDNA sequencing. *Aquat Microb Ecol*, *23*, 119–130. Retrieved from <https://www.int-res.com/articles/ame/23/a023p119.pdf>

Main, C. R., Salvitti, L. R., Whereat, E. B., & Coyne, K. J. (2015). Community-Level and species-specific associations between phytoplankton and particle-associated Vibrio species in delaware’s inland bays. *Applied and Environmental Microbiology*, *81*(17), 5703–5713. <https://doi.org/10.1128/AEM.00580-15>

Oehrle, S., Rodriguez-Matos, M., Cartamil, M., Zavala, C., & Rein, K. S. (2017). Toxin composition of the 2016 Microcystis aeruginosa bloom in the St. Lucie Estuary, Florida. *Toxicon*, *138*, 169–172. <https://doi.org/10.1016/j.toxicon.2017.09.005>

Phlips, E. J., Badylak, S., & Grosskopf, T. (2002). Factors Affecting the Abundance of Phytoplankton in a Restricted Subtropical Lagoon, the Indian River Lagoon, Florida, USA. *Estuarine, Coastal and Shelf Science*, *55*, 385–402. <https://doi.org/10.1006/ecss.2001.0912>

Ramanan, R., Kim, B.-H., Cho, D.-H., Oh, H.-M., & Kim, H.-S. (2016). Algae-bacteria interactions: Evolution, ecology and emerging applications-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/). *Biotechnology Advances*, *34*, 14–29. <https://doi.org/10.1016/j.biotechadv.2015.12.003>

Seong, K. A., & Jeong, H. J. (2013). Interactions between marine bacteria and red tide organisms in Korean waters. *Algae*, *28*(4), 297–305. <https://doi.org/10.4490/algae.2013.28.4.297>

US Department of Commerce, NOAA, E. S. R. L. (n.d.). *ESRL Global Monitoring Division - GRAD - Surface Radiation Budget Network (SURFRAD)*.

Westrich, J. R., Ebling, A. M., Landing, W. M., Joyner, J. L., Kemp, K. M., Griffin, D. W., & Lipp, E. K. (2016). Saharan dust nutrients promote Vibrio bloom formation in marine surface waters. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(21), 5964–5969. <https://doi.org/10.1073/pnas.1518080113>

Westrich, J. R., Griffin, D. W., Westphal, D. L., & Lipp, E. K. (2018). Vibrio Population Dynamics in Mid-Atlantic Surface Waters during Saharan Dust Events. *Frontiers in Marine Science*, *5*. <https://doi.org/10.3389/fmars.2018.00012>

Zhou, J., Richlen, M. L., Sehein, T. R., Kulis, D. M., Anderson, D. M., & Cai, Z. (2018). Microbial Community Structure and Associations During a Marine Dinoflagellate Bloom. *Frontiers in Microbiology*, *9*, 1201. <https://doi.org/10.3389/fmicb.2018.01201>