Moorings Bay Water Quality and Biological Analysis Report

Task #2

FINAL REPORT

Prepared for

City of Naples
Streets & Stormwater Department
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EXECUTIVE SUMMARY

Moorings Bay is a waterbody in the City of Naples, on the southwest coast of Florida. The Bay provides recreational and aesthetic value to residents and visitors as well as aquatic habitat. The adjacent land use is dominated by residential areas and Moorings Bay receives stormwater input from the surrounding watershed. The Bay is also connected at the north end to Clam Bay and the Gulf of Mexico via the inlet at Doctors Pass.

The City of Naples began a biological monitoring program in Moorings Bay in 2009 which involves fisheries and invertebrate monitoring through quarterly otter trawls; the City has also conducted monthly water quality monitoring since October 2008 in the surface waters of the Bay. In 2016, the first Moorings Bay Water Quality and Biological Data Analysis Report was prepared. In 2020, Wood was contracted to prepare the second Moorings Bay Water Quality and Biological Data Analysis Report and has conducted statistical analysis of the water quality and biological data to explore spatial and temporal trends. The primary questions driving the analysis are included below, with major findings:

- *Are statistically significant trends in Moorings Bay water quality data observed spatially and temporally?* Significantly increasing concentrations of total nitrogen, total phosphorus, and chlorophyll-a were observed in Moorings Bay. The water quality station farthest north in Moorings Bay (MB1) generally had poorer water quality compared to other Moorings Bay stations.
- *Are statistically significant trends in Moorings Bay biological data observed spatially and temporally?* Taxa richness at the most northern trawling zone (Zone 1) was significantly lower than the other zones, and diversity was also lower in this Zone. Over time, total abundances in the Bay have been relatively similar; in Zone 1, the diversity is more variable over time.
- *What correlations can be determined between water quality and biological data?* Conditions in the northern portion of Moorings Bay, including poorer water quality and less diverse biological community, are potentially affected by the stormwater and watershed inputs in this area and lack of flushing.
- *Are there statistically significant trends in the six stormwater lakes that drain to Moorings Bay?* Significantly increasing concentrations of Chlorophyll-a and copper were observed in some of the stormwater lakes discharging to the Bay. Generally, there are higher concentrations of total nitrogen, total phosphorus and chlorophyll-a in the stormwater lakes discharging to Moorings Bay compared to concentrations in the Bay itself.
- *What science-based management activities can be implemented by the City to achieve the City's overall goals of protecting and improving water quality, habitat, and resiliency?* Quantification of pollutant loadings into the Bay would be beneficial in identifying pollutant sources and potential water quality improvement projects. Water quality improvement projects can include traditional stormwater improvements (e.g., swales, baffle boxes), and living shoreline projects that provide both water quality treatment and habitat value.

In addition, Wood recommends several additions to the Moorings Bay water quality and biological monitoring program, including optimization of the current water quality monitoring (more comprehensive water quality sampling at the trawling locations) and several additions for benthic sampling (sediment and benthic organism sampling).

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LIST OF ACRONYMS AND ABBREVIATIONS

BEST	Bio-Env +Stepwise
CAP	Canonical analysis of principal coordinates
City	City of Naples
Cu	copper
DO	dissolved oxygen
DEAR	FDEP Division of Environmental Assessment and Restoration
FDEP	Florida Department of Environmental Protection
ft	feet
IWR	Impaired Waters Rule
µg/L	micrograms per liter
m	meter
mg/L	milligrams per liter
MK	Mann-Kendall
ml	milliliter
N	nitrogen
NM	nautical mile
NNC	Numeric Nutrient Criteria
PCA	Principal Components Analyses
P	phosphorus
POR	Period of record
rpm	revolutions per minute
SE	Standard Error
STORET	Storage and Retrieval
TDML	total maximum daily load
TN	total nitrogen
TP	total phosphorous
USGS	United States Geological Survey
WAVES	WIN Advanced View & Extraction System
WBID	Water Body Identification Number
WIN	Watershed Information Network
Wood	Wood Environment & Infrastructure Solutions, Inc.

1.0 INTRODUCTION

Wood Environment & Infrastructure Solutions, Inc. (Wood) was contracted by the City of Naples (the City) to prepare the 2021 Moorings Bay Water Quality and Biological Data Analysis Report. As described below, Wood has conducted statistical analysis of Moorings Bay (the Bay) environmental data (collected from 2008 through 2020) and biological data (collected from 2009 through 2020) to explore the following primary questions:

- *Are statistically significant trends in Moorings Bay water quality data observed spatially and temporally?*
- *Are statistically significant trends in Moorings Bay biological data observed spatially and temporally?*
- *What correlations can be determined between water quality and biological data?*
- *Are there statistically significant trends in the six stormwater lakes that drain to Moorings Bay?*
- *What science-based management activities can be implemented by the City to achieve the City's overall goals of protecting and improving water quality, habitat, and resiliency?*

We accessed water quality data from regulatory databases and performed univariate and multivariate analyses to better understand water quality in the Bay (e.g., temporal trend analysis using Mann-Kendall approach, Principal Components Analysis for spatial comparison). Biological data (otter trawls capturing fish and invertebrates in the lower water column) were provided by the City and PRIMER multivariate statistical software with the PERMANOVA+ Add-on was used to investigate potentially significant spatiotemporal trends. When possible, we explored the interactions and relationships between water quality and biological data. A discussion on the watershed setting, including the water quality of the City's stormwater lakes discharging to Moorings Bay, is also provided. The statistical analyses and watershed setting overview strengthen our understanding of the complex water quality and biological dynamics of Moorings Bay. This understanding was used to provide recommendations to enhance the current Moorings Bay monitoring program and recommendations aimed at improving habitat and water quality of the Bay.

1.1 Background

Moorings Bay (Water Body Identification Number [WBID] 3278Q2) is a waterbody in the City of Naples (**Figure 1**), providing recreation, natural systems, and aesthetic services to visitors and residents of the City and providing habitat to support aquatic biological diversity. The recreation and aesthetic services and habitat value contribute to the ecotourism draw of the City of Naples; ecotourism is a large component of the City of Naples economy, primarily based on the Everglades and Ten Thousand Islands, but aided by the Gulf of Mexico and Moorings and Naples Bays (AECOM, 2018). Moorings Bay is classified by the Florida Department of Environmental Protection (FDEP) as a Class II waterbody; Class II waterbodies include coastal waters that should support shellfish harvesting.[1] The FDEP regulatory criteria applicable to Moorings Bay include:

- Numeric Nutrient Criteria (NNC; (Rule Ch. 62-302.532, F.A.C.) define the maximum allowable levels of total phosphorus (TP), total nitrogen (TN), and chlorophyll-a (Chl-a).

[1] Surface Water Quality Standards Classes, Uses, Criteria, available at: https://floridadep.gov/dear/water-quality-standards/content/surface-water-quality-standards-classes-uses-criteria, accessed 2021-09-24.

- Class II Surface Water Quality Criteria (Rule Ch. 62-302.530, F.A.C.) define the maximum allowable levels of Enterococci and copper and the minimum allowable dissolved oxygen saturation.

The FDEP uses statewide water quality criteria to conduct impairment assessments and identify waterbodies with concentrations of pollutants that are exceeding regulatory criteria. The FDEP has verified Moorings Bay as impaired for total phosphorus[2]. When a waterbody is listed as impaired and a Total Maximum Daily Load (TMDL) is established, the entities (or municipalities) contributing to the impairment are responsible for implementing pollutant load reduction projects.

The City of Naples monitors water quality in Moorings Bay, which includes collecting samples for the parameters listed above (TN, TP, Chl-a, Enterococci, copper, and dissolved oxygen) and other parameters (described in **Section 2.1**)**.** Measuring TN and TP reveals the concentration of nutrients in the water and nutrients can fuel algal growth. Chl-a is a measure of the amount of algae in the water and under certain conditions, algal growth can sometimes result in an undesirable or harmful algae bloom. Enterococci is an indicator of fecal contamination (a fecal indicator bacteria) with potential human health concerns. Copper can be harmful to aquatic organisms while dissolved oxygen is essential to aquatic life.

The watershed around Moorings Bay is highly developed, allowing for contaminants typical of urban stormwater to be introduced to the Bay. These contaminants include nutrients, metals, suspended solids, and pathogens (Harper, 1998). Nutrient contamination can threaten waterbodies by driving algal blooms, anoxic conditions, fish kills, changes in the fish community, disturbances to seagrass and shellfish habitats, and economic losses to the tourism, recreation, real estate, and fishing industries. Before the urbanization of the surrounding watershed, Moorings Bay's undeveloped shoreline included mangrove swamps (Cardno, 2016) and the Bay was connected to the Gulf of Mexico via a dynamic inlet, Doctors Pass, that migrated along the coast (FDEP, 1997). Shoreline stabilization measures were implemented at Doctors Pass and the surrounding area became developed, making Moorings Bay a completely artificial waterbody[3]. The shoreline now consists of seawalls and riprap (Cardno, 2016). Several stormwater lakes (Lakes 1, 2, 3 4, 5, and 23) discharge to the Bay and the Bay is hydrologically connected to Clam Bay to the north via culverts.

Due to the importance of Moorings Bay as a natural resource, the City of Naples conducts rigorous water quality, fish, and invertebrate sampling programs to monitor ecosystem health. The City has been monitoring water quality in Moorings Bay since 2008 and collecting biological sampling since 2009 and the previous Moorings Bay Water Quality and Biological Data Analysis Report was prepared in 2016 by Cardno. Cardno (2016) found increasing trends in copper, turbidity, fecal coliform bacteria, and Chl-a, and decreasing trends in TN in Moorings Bay. The report concluded that the northern end of Moorings Bay generally had poorer water quality and the lowest fish diversity, which was thought to be driven by low dissolved oxygen.

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[2] Comprehensive Verified List, FDEP, available at: https://floridadep.gov/dear/watershed-assessment-section/documents/comprehensive-verified-list, accessed 2021-07-23.

[3] Moorings Bay, City of Naples, available at: https://www.naplesgov.com/naturalresources/page/moorings-bay; accessed 2021-07-23.

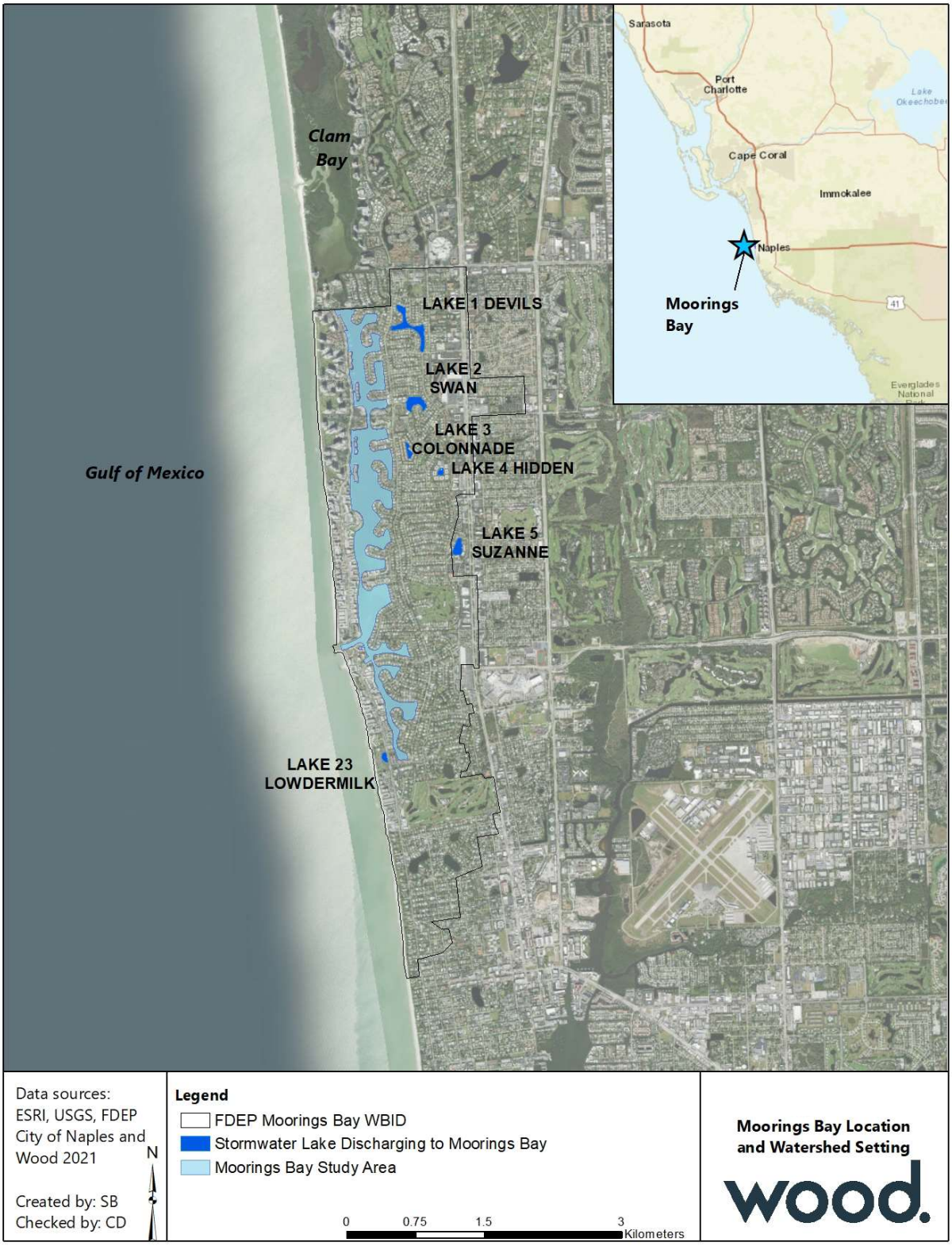

Figure 1. Moorings Bay Location and Watershed Setting.

1.2 Watershed Setting

The Moorings Bay watershed is dominated by residential land uses, including high density/high rise development on lands between the Gulf of Mexico and Moorings Bay and single-family residential areas to the east of the Bay (AECOM, 2018). There are also six stormwater lakes within the Moorings Bay watershed (**Figure 2**): Devils Lake (Lake 1, Sample Location 1SE-B), Swan Lake (Lake 2, Sample Location 2B), Colonnade Lake (Lake 3, Sample Location 3B), Hidden Lake (Lake 4, Sample Location 4B), Lake Suzanne (Lake 5, Sample Location 5B), and Lowdermilk Lake (Lake 23, Sample Location 23B). These lakes are monitored as part of the City's stormwater lakes monitoring program. While regulatory criteria are not applicable to these stormwater lakes, statistically significant trends for parameters that are regulated in Moorings Bay (TN, TP, Chl-a, Enterococci, and copper) are included below:

- Devils Lake (from February 2015 to September 2021): significantly increasing concentrations of Chl-a, decreasing concentrations of Enterococci and copper.
- Swan Lake (from February 2015 to September 2021): significantly decreasing concentrations of TP.
- Colonnade Lake (from February 2015 to September 2021): significantly decreasing concentrations of TP and copper.
- Lake Suzanne (from February 2015 to September 2021): significantly increasing copper concentrations, significantly decreasing TN and TP concentrations.

Hidden Lake and Lowdermilk Lake were recently included in the monitoring program and have limited water quality data (October 2020 to September 2021). In Hidden Lake, data suggest potential increasing concentrations of TN, TP, Chl-a, Enterococci, and copper. In Lowdermilk Lake, data suggest potential increasing concentrations of TP and Enterococci and potential decreasing concentrations of TN, Chl-a, and copper.

Median concentrations of TN, TP, Chl-a, Enterococci, and copper for these lakes are included in **Figure 3** through **Figure 7**. Although the water quality criteria applicable to Moorings Bay are not applicable to the stormwater lakes (and therefore the criteria are not included on the figures), lakes that are discharging at concentrations above the Moorings Bay criteria could be considered more of a source to Moorings Bay than lakes contributing lower concentrations. Note however, that, as described above, the discharge volumes are not captured in the concentrations and are an important factor. However, analyses of TN, TP, Chl-a and Enterococci have revealed the following:

- Median TN concentration (**Figure 3**) in excess of the Moorings Bay NNC (0.85 mg/L) were observed in the monitored stormwater lakes except Hidden Lake (4B) and Lowdermilk Lake (23B). However, Hidden and Lowdermilk lakes had a much more limited dataset (data from 2020 – 2021 only)**.** Individual samples with concentrations greater than 0.85 mg/L were observed in Devils Lake (1SE-B), Swan Lake (2B), Colonnade Lake (3B), and Lake Suzanne (5B), with over 75% of samples exceeding the NNC in each lake. Individual samples also exceeded the TN NNC in more limited datasets of Hidden Lake (4B) and Lowdermilk Lake (23B).
- Median TP concentration (**Figure 4**) in excess of the Moorings Bay NNC (0.04 mg/L) were observed in the monitored lakes (though the Devils Lake [1SE-B] median was borderline). The most individual samples exceedances were observed in Swan Lake (2B), Colonnade Lake (3B), and Lake Suzanne (5B), with more than 85% of samples exceeding the NNC. In Devils Lake (1SE-

B), 47% of samples exceeded the NNC. The majority of samples exceeded the NNC in the more limited datasets from Hidden (4B) and Lowdermilk (23B) lakes.

- Individual Chl-a concentrations were in excess of the AGM based criteria (though not directly comparable) at the six lakes (**Figure 5**). 100% of the AGMs calculated for Swan Lake (2B) Colonnade Lake (3B), and Lake Suzanne (5B) exceeded the Moorings Bay AGM criteria of 8.1 ug/L while the Devils Lake AGMs did not exceed the Moorings Bay criteria. In the more limited datasets from Hidden (4B) and Lowdermilk (23B) lakes, the AGM exceeded the Moorings Bay criteria.
- Median Enterococci counts exceeded the Class II Criteria of 130 (#/100 mL) at Colonnade Lake (3B), Hidden Lake (4B), and Lake Suzanne (5B) (**Figure 6**). The most individual samples exceedances were observed in Colonnade Lake (3B), and Lake Suzanne (5B), with 52 to 63% of samples exceeding the NNC. In Devils Lake (1SE-B) and Swan Lake (2B), 27 to 36% of samples exceeded the NNC. In the more limited dataset, the majority of samples exceeded the criteria in Hidden Lake (4B) and 4 samples exceeded the criteria in Lowdermilk Lake (23B).
- Copper concentrations exceeded the Class II Criteria (3.7 ug/L) in the six stormwater lakes (**Figure 7**). In Devils Lake (1SE-B), over 90% of samples exceeded the criteria. 70% of samples exceeded the criteria in Lake Suzanne (5B). Exceedances ranged from 55 to 60% in Colonnade Lake (3B) and Swan Lake (2B). In the more limited dataset, the majority of samples exceeded the criteria in Hidden Lake (4B) and 5 samples exceeded the criteria in Lowdermilk Lake (23B).

Based on the analysis above, samples exceeding the non-applicable criteria for Moorings Bay (TN, TP, Chl-a, Enterococci, and copper) were frequently observed in Devils Lake (1SE-B), Swan Lake (2B), Colonnade Lake (3B), and Lake Suzanne (5B).

The full data analysis of stormwater lake water quality data is available in the 2020 - 2021 Annual Surface water and Pump Station Monitoring and Analysis Report. The City monitors additional parameters in the stormwater lakes, including parameters that are regulated in freshwater lakes (though, as stated previously, regulatory criteria are not applicable to the City's stormwater lakes). For example, Enterococci, a fecal indicator bacteria, with only an FDEP marine criterion, is monitored in the City's stormwater lakes. *Escherichia coli* (E. coli), another fecal indicatory bacteria is regulated in freshwater and is also monitored in the City's stormwater lakes. The City has also included fecal coliform in their stormwater lakes monitoring program.

Figure 2. Stormwater Lake and Sampling Locations.

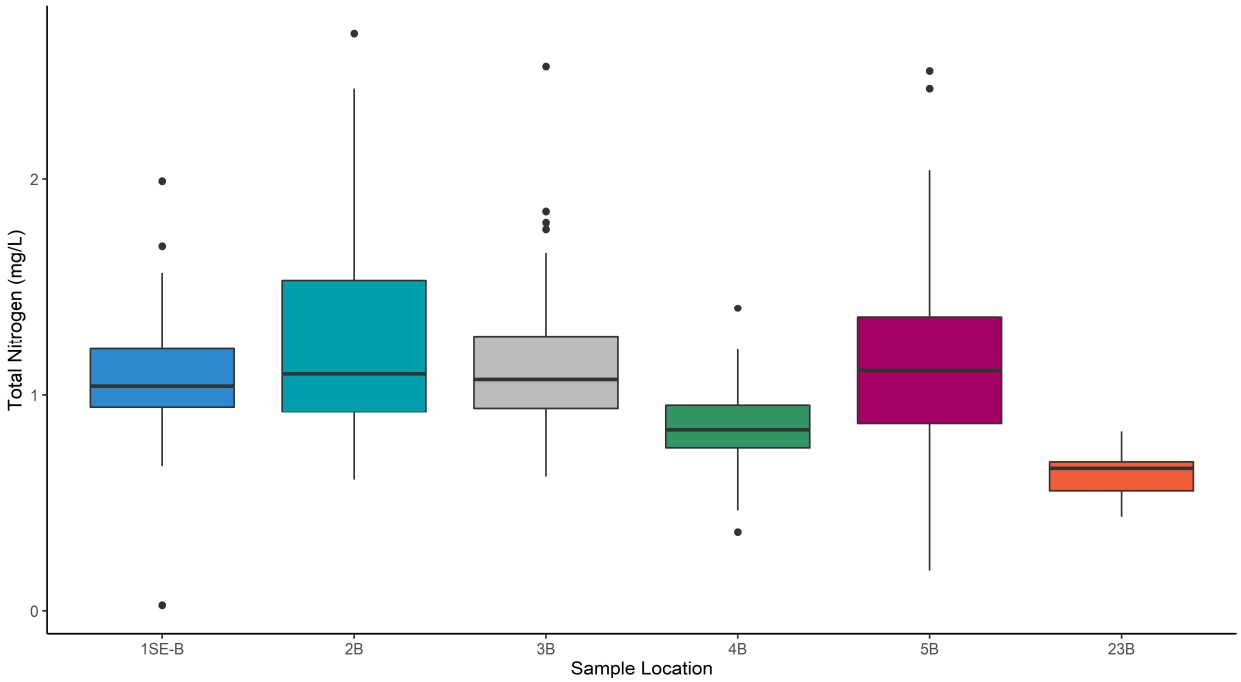

Figure 3. Box plots of total nitrogen concentrations among locations (2014 through 2021, except for 4B and 23B which are 2020-2021). Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges.

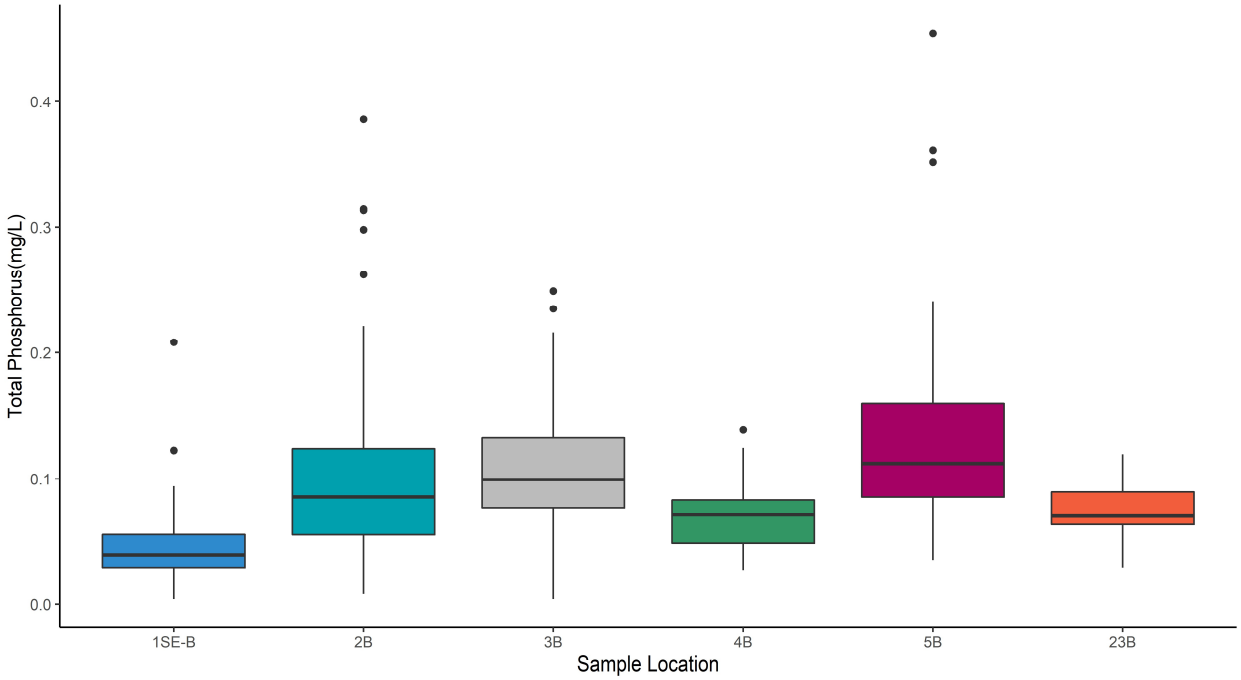

Figure 4. Box plots of total phosphorous concentrations among locations (2014 through 2021, except for 4B and 23B which are 2020-2021). Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges.

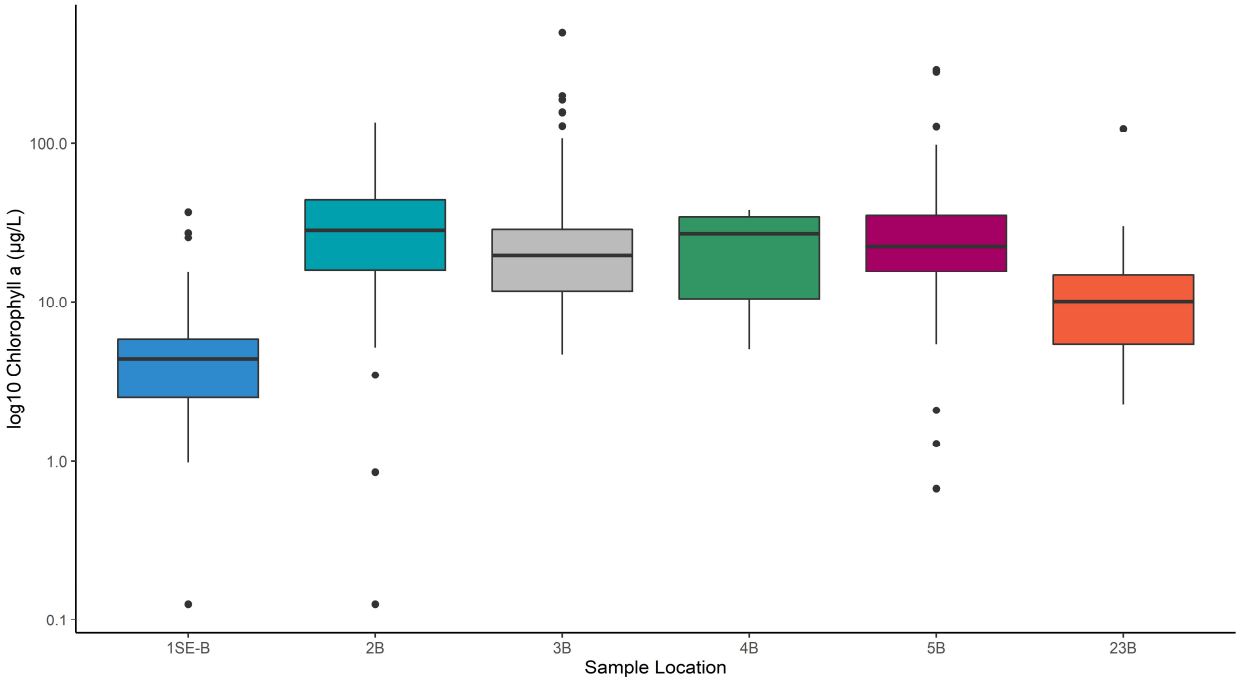

Figure 5. Box plots of chlorophyll-a concentrations among locations (2014 through 2021, except for 4B and 23B which are 2020-2021). Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges.

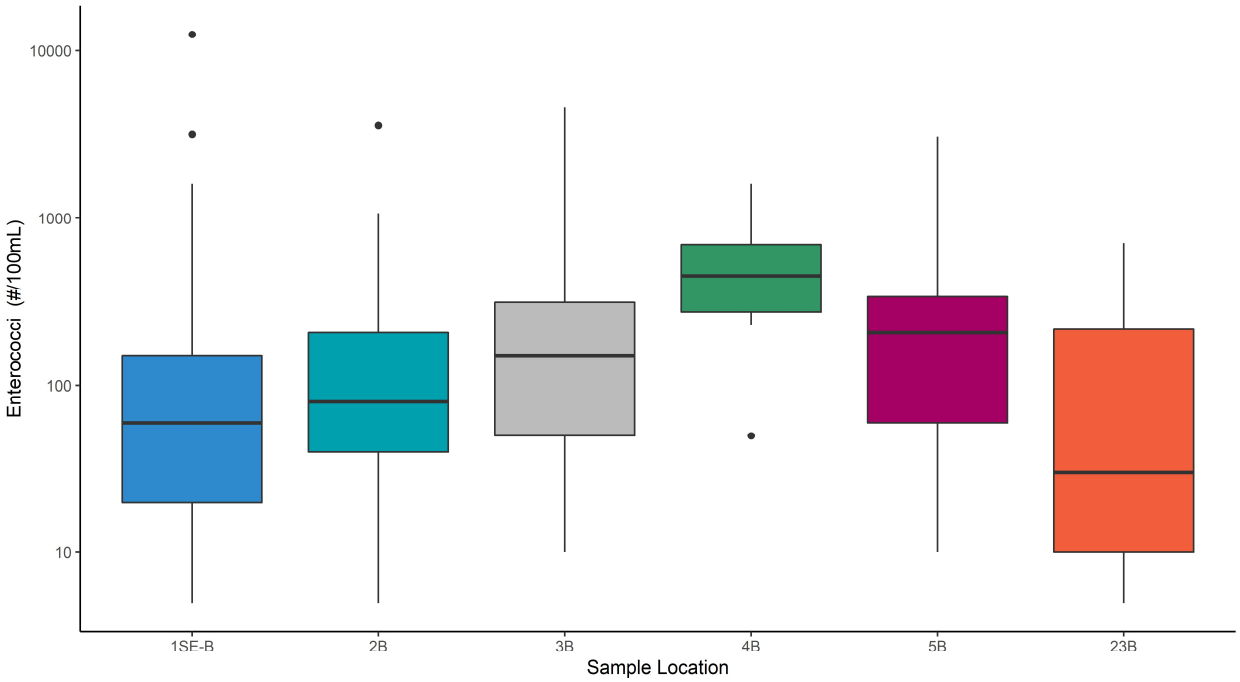

Figure 6. Box plots of Enterococci counts among locations (2014 through 2021, except for 4B and 23B which are 2020-2021). Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges.

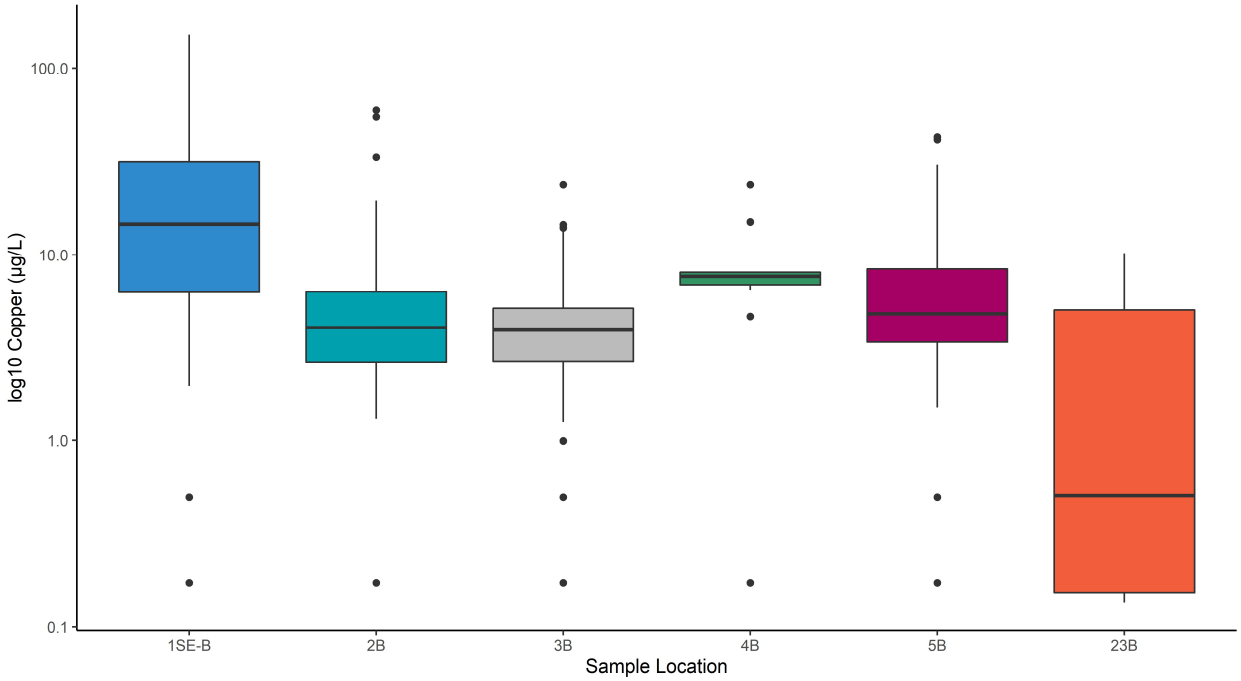

Figure 7. Box plots of copper concentrations among locations (2014 through 2021, except for 4B and 23B which are 2020-2021). Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges. Y-axis is log-transformed.

In previous work conducted by Wood (formerly AMEC), the annual average runoff volumes entering the lakes were computed (Amec, 2012). Lakes with larger volume lakesheds conceivably have greater discharges to a receiving waterbody and higher potential for contributing pollutants via higher pollutant loads, if left untreated and unmanaged. According to Amec (2012), of the lakes discharging to Moorings Bay, Swan Lake (Lake 2) has the highest annual lakeshed volume (171 acre-feet) followed by Devils Lake (a combined 88 acre-feet), Lake Suzanne (85 acre-feet), Hidden Lake (27 acre-feet), Colonnade Lake (26 acre-feet), and Lowdermilk Lake (6 acre-feet). These lakeshed runoff volumes can provide context for the trends in concentrations described above. For example, the increasing concentration of Chl-a in Devils Lake has a potentially larger impact on Moorings Bay water quality than the increasing concentrations of Chl-a at Lake Suzanne, with a much smaller potential runoff volume. Compared to the other lakes, Devils Lake also discharges in the most northern portion of the Bay, farthest from Doctors Pass and potential benefits from flushing. While these lakeshed data are older, they illustrate the importance of knowing the volume of the discharging waterbody, in addition to the trends in concentration.

The stormwater lakes are not the only contributors of stormwater to Moorings Bay. As described in the 2018 Stormwater Master Plan Update (AECOM, 2018), the majority of Moorings Bay is located in Basin 1, which is primarily residential land uses, with high-rise residential areas concentrated along the Gulf of Mexico and commercial development to the east. Within Basin 1, swales, inlets, and pipes route stormwater to both stormwater lakes and directly to Moorings Bay. South of Basin 1 is Basin 2, dominated by residential land uses; the northern portion of Basin 2 discharges stormwater via a system of swales, inlets, and pipes that discharge to stormwater lakes and Moorings Bay. AECOM (2018) reported that in North Naples, there are 97 outfalls that discharge to tidal waters, including Moorings Bay, Outer Doctors Bay, Inner Doctors Bay, Venetian Bay, and Hurricane Harbor.

Moorings Bay is also connected to Clam Bay (WBID 3278Q1) to the north via culverts under Seagate Dr. PBS&J (2009) reported that there is a net southerly exchange of water from Clam Bay to Moorings Bay, indicating that water quality in Clam Bay has the potential to effect Moorings Bay. The hydrology of the Clam Bay – Moorings Bay system was impacted by the construction of Seagate Drive south of Clam Bay, which originally closed tidal connections south to Moorings Bay. However, culverts placed under Seagate Drive in the 1970s in response to water quality concerns re-established connectivity between Clam and Moorings Bay. PBS&J (2009) found that the maximum current velocities around Seagate Drive were ten times greater going south towards Moorings Bay than going north towards Clam Bay, and that water levels at low tide were higher on the Clam Bay side.

In the most recent FDEP list of verified impaired waters (dated 6/21/2021)[4], Clam Bay is listed as impaired for copper. Additionally, a 2020 report on Clam Bay NNC Criteria found increasing TP and TN concentrations in recent years (ESA, 2020). Also, ESA (2020) noted that "while nutrients are increasing in most of the stations in Outer Clam Bay, there does not yet appear to be evidence of a similar system-wide increase in algal populations." Both Cardno (2012) and ESA (2020) also observed depressed DO in Clam Bay.

An analysis of water quality in Clam Bay, the stormwater lakes discharging to Moorings Bay, and Moorings Bay was conducted to explore water quality trends within the watershed. Water quality data (TN, TP, Chl-a, and copper) for five Clam Bay stations (21FLPBSDCB5, 21FLPBSDCB6, 21FLPBSDCB7, 21FLPBSDCB8, 21FLPBSDCB9), Moorings Bay (MB1, MB2, MB3, and MB4) and the contributing stormwater lakes with available data were reviewed for the years November 2017 through September 2020. The parameters and time span were selected based on overlapping timeframes of available data at the different stations to provide for more direct comparisons. These parameters and dates were primarily restricted to the more limited Clam Bay dataset (which did not include, for example, bacteriological data); Hidden Lake and Lowdermilk Lake were not included because sampling began in October 2020. Using the available data, the average concentrations of TN, TP, Chl-a, and copper from November 2017 through September 2020 were mapped with symbology indicating lower concentrations to higher concentrations:

- Average TN concentrations were higher in the stormwater lakes, followed by Clam Bay stations, and lower in Moorings Bay (**Figure 8)**.
- Average TP (**Figure 9**) and Chl-a (**Figure 10**) concentrations were higher in the stormwater lakes, followed by Clam Bay stations (with the exception of Devils Lake, which had lower concentrations compared to other lakes and Clam Bay), and lower in Moorings Bay.
- Average copper concentrations (**Figure 11**) were higher in the stormwater lakes, with lower concentrations in Clam Bay and Moorings Bay.

While these data show that the relative concentrations of TN, TP, Chl-a, and copper are lower in Moorings Bay compared to Clam Bay and the upstream stormwater lakes, it should be noted that these are average values from 2017 through 2020 and do not account for the specific flow regime between Moorings Bay and Clam Bay and the varying runoff volumes from the stormwater lakes.

[4] Comprehensive Verified List, FDEP, available at: https://floridadep.gov/dear/watershed-assessment-section/documents/comprehensive-verified-list, accessed 2021-07-23.

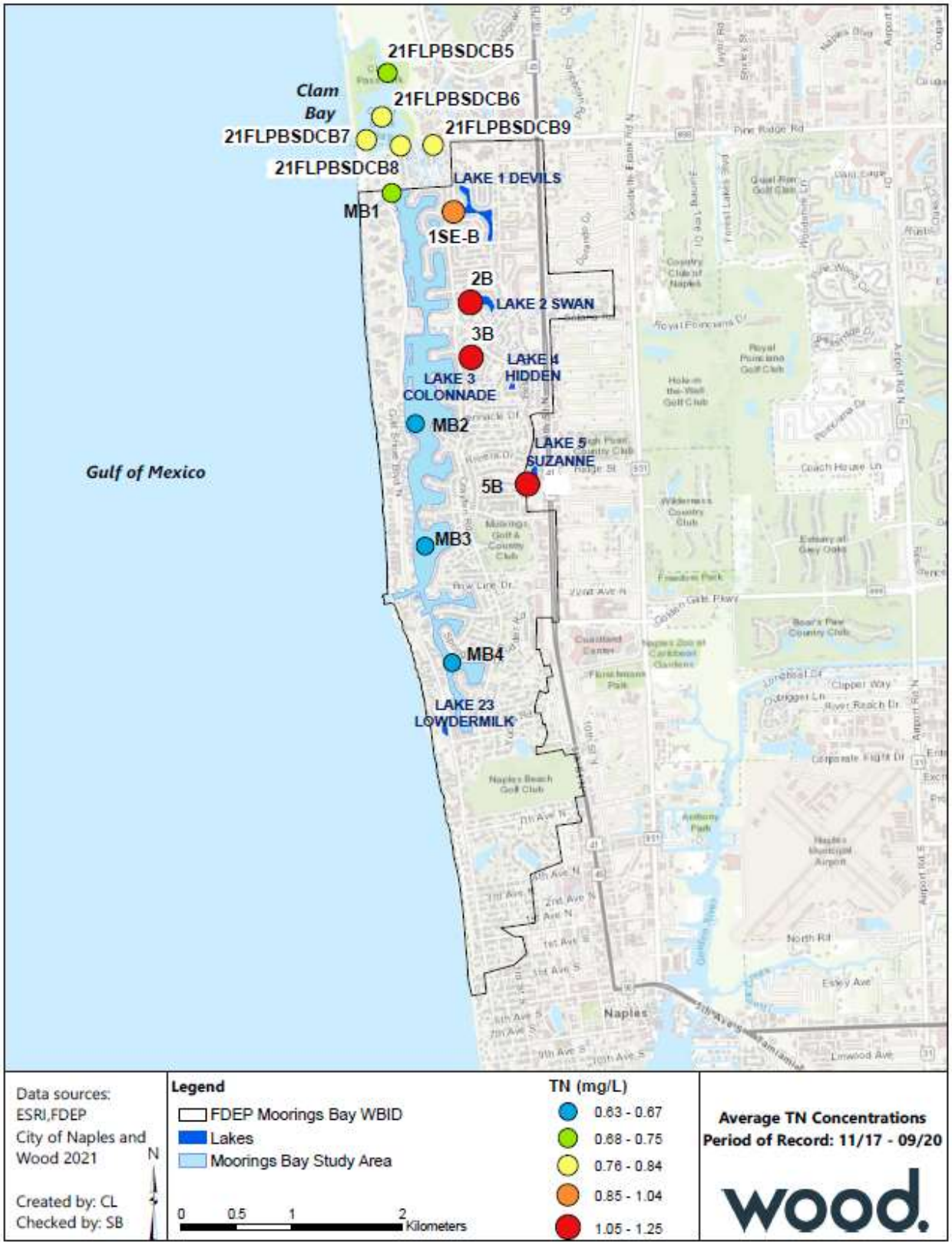

Figure 8. Average total nitrogen concentrations at water quality monitoring stations in Clam Bay, Moorings Bay, and stormwater lakes (November 2017 through September 2020).

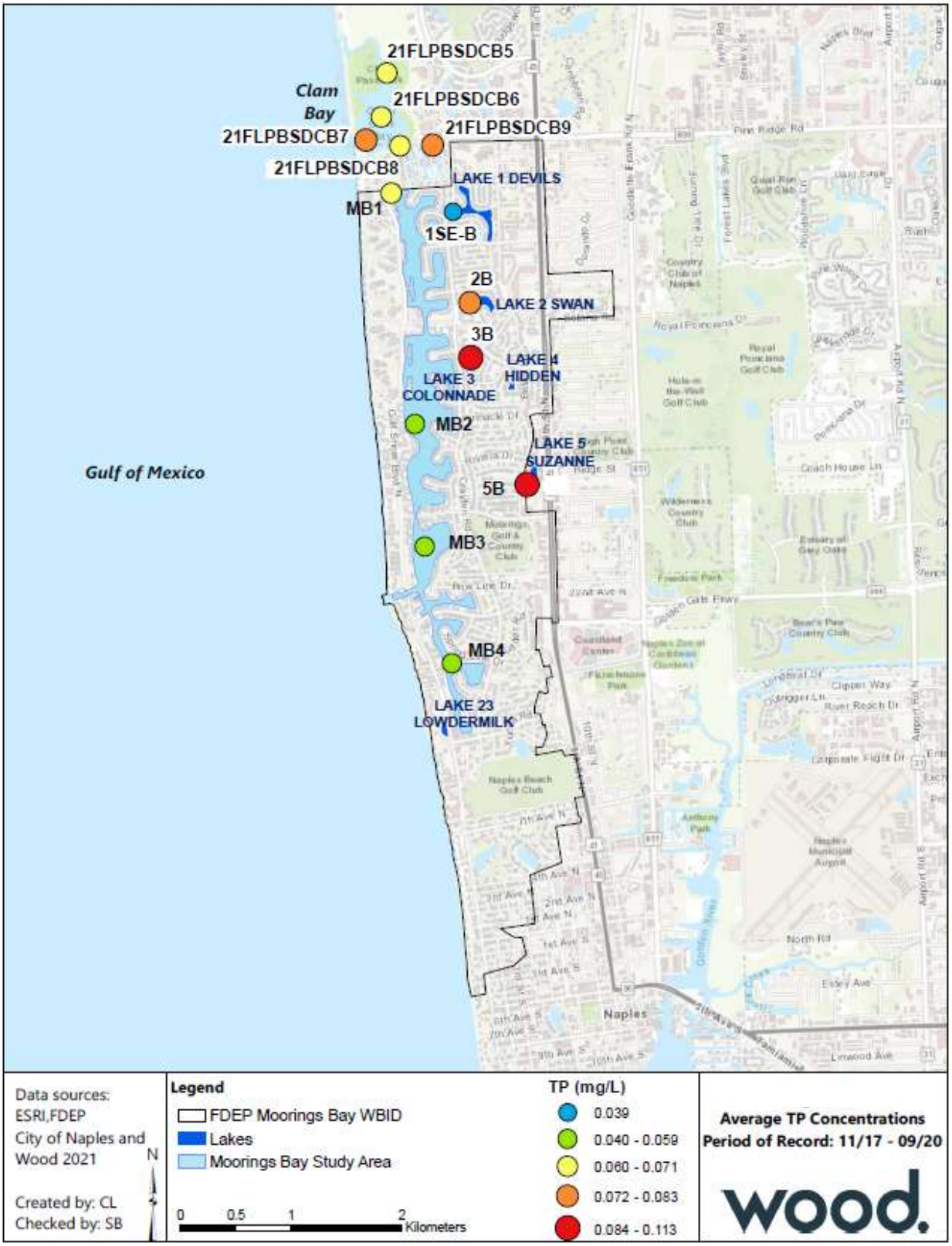

Figure 9. Average total phosphorus concentrations at water quality monitoring stations in Clam Bay, Moorings Bay, and stormwater lakes (November 2017 through September 2020).

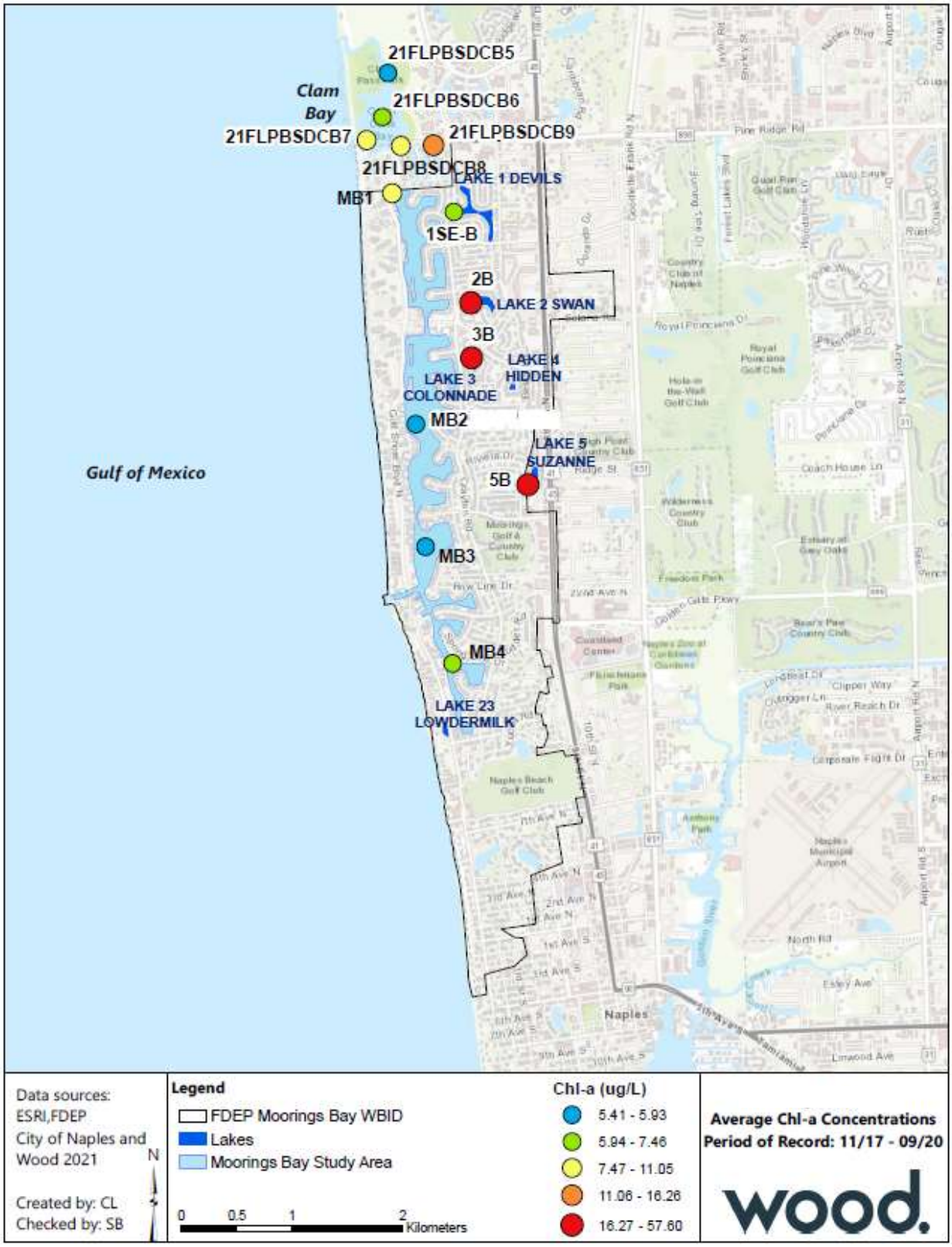

Figure 10. Average chlorophyll-a concentrations at water quality monitoring stations in Clam Bay, Moorings Bay, and stormwater lakes (November 2017 through September 2020).

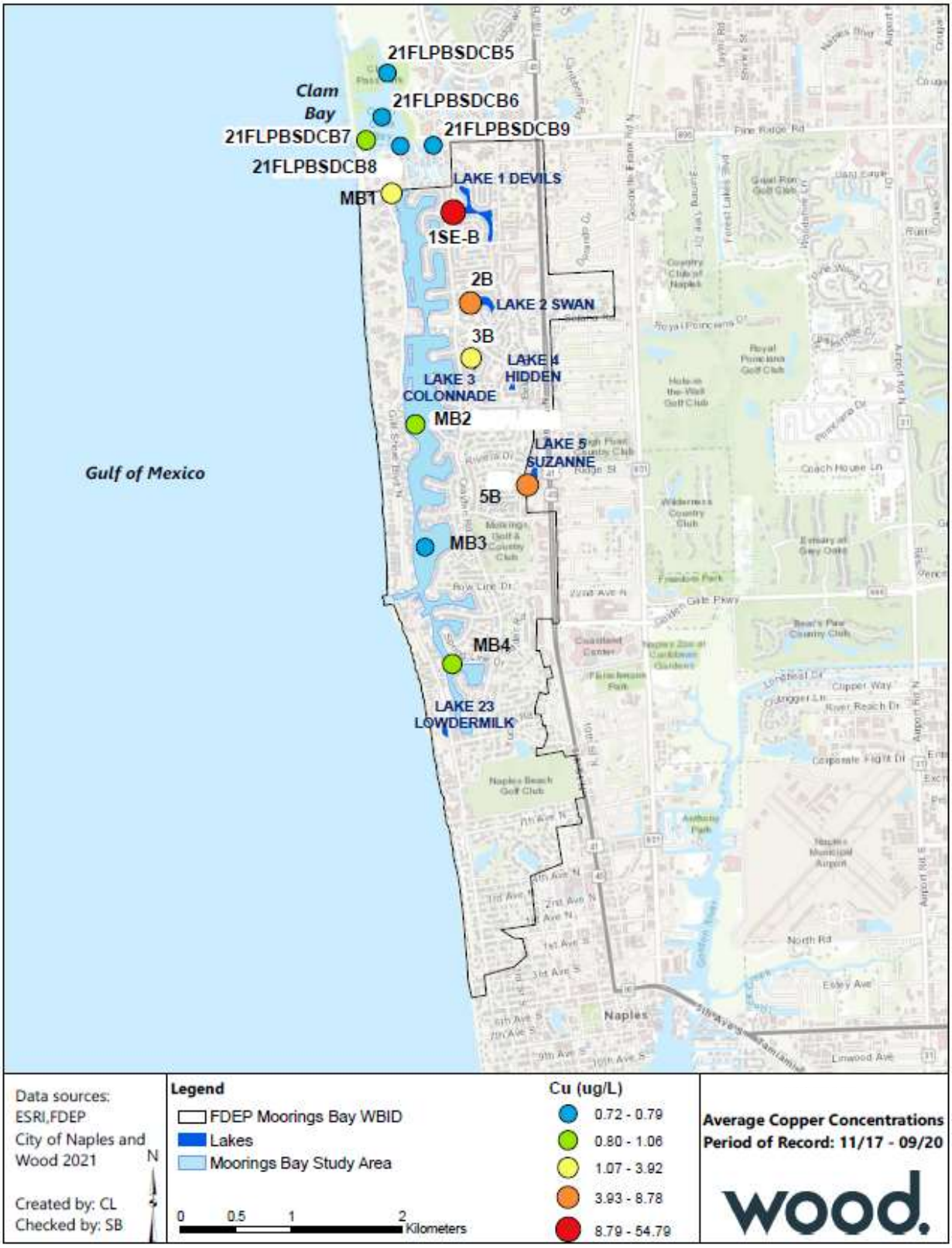

Figure 11. Average copper concentrations at water quality monitoring stations in Clam Bay, Moorings Bay, and stormwater lakes (November 2017 through September 2020).

2.0 MOORINGS BAY WATER QUALITY METHODS

Water quality data for Moorings Bay was obtained from publicly available FDEP water quality databases. Data from four locations within Moorings Bay were available. After data were processed, data analysis was conducted and consisted of the following:

- An analysis of the Bay-wide water quality, including an exceedance analysis with comparison to regulatory criteria (to ascertain whether Bay-wide concentrations are exceeding criteria) and estimation of long-term water quality trends (e.g., increasing or decreasing concentrations over time).
- An analysis of the water quality at individual stations, including comparisons among stations (for a spatial analysis of Bay water quality), long-term trends at the individual stations (e.g., temporal trends, increasing or decreasing concentrations over time), and an analysis of seasonal patterns.
- Correlation analysis to assess the relationships among water quality parameters at the individual stations and rainfall.
- Principal Components Analysis (PCA) to simultaneously compare water quality among the individual stations and examine annual changes in water quality.

The analysis largely focused on the following parameters:

- Regulated parameters:
  - TN, TP, and Chl-a: elevated nutrient (TN and TP) concentrations can contribute to increased algae (measured as Chl-a) and harmful algal blooms.
  - Enterococci: Enterococci indicates contamination from fecal sources.
  - Copper and DO: high copper concentrations and low DO can be harmful to aquatic life.
- Additional parameters useful to evaluating water quality conditions:
  - Total Kjeldahl nitrogen (TKN) and nitrate + nitrite (NOx), which are components of TN.
  - Secchi depth, turbidity, and total suspended solids, which are indicators of water clarity; higher water clarity is desirable for submerged aquatic vegetation (SAV).
  - Salinity: salinity regimes are important for estuarine life, and can indicate freshwater inputs.

Additional parameters were incorporated in the correlation and PCA. This data analysis is described in detail below.

2.1 Data Acquisition

Water quality data for Moorings Bay were obtained from two primary sources: 1) FDEP Division of Environmental Assessment and Restoration (DEAR) Impaired Waters Rule (IWR) Run 60 Database (STORET), and 2) data collected from 2017 – 2020 is from the FDEP's Watershed Information Network (WIN) WAVES (WIN Advanced View & Extraction System) database. Both databases are available online for public access through the Florida Department of Environmental Protection. These data included information for four monitoring stations: MB1, MB2, MB3, MB4 (**Figure 12**).

Available water quality data included 23 parameters (**Table 1**). Most of these parameters had a 12-year period of record (POR) from 2008 through 2020. Apparent color data were available from 2008 through 2017. True color data were only available from 2017 through 2020. The two color methods are not directly comparable. The number of samples per year ranged from 3 to 48. Water quality data included parameters measured in the field using a hand-held water quality meter (temperature, pH, specific conductance, dissolved oxygen [concentration and %], and salinity) and analytical data from surface water grab samples (**Table 1).** In-situ measurements included readings from the surface (0.3 m) and bottom water (0.3m above the bottom) at each site. Maximum bottom depths varied by station with the deepest station being MB1 (3.4 m) followed by MB2 (3.1 m), MB4 (2.5 m) and MB3 (2.3m).

Rainfall data from Naples, Florida were obtained from the Climate Data Online Portal from the NOAA National Centers for Environmental Information[5]. The daily rainfall data were obtained from station USW000012897 (Lat: 26.155°, Long: -81.7752°). This station has the most complete period of record for this area and is about 2.3 miles southeast from the southern end of Moorings Bay. For the analyses in this report, the total rainfall over the 30 days preceding the sample event was calculated.

[5] NOAA Climate Data Online, available at: https://www.ncdc.noaa.gov/cdo-web/.

Figure 12. Locations of Moorings Bay water quality monitoring stations.

Table 1. Summary of available water quality data period of record by parameter for Moorings Bay water quality stations (MB1, MB2, MB3, and MB4).

Parameter	Water Quality Significance	Units	Period of Record	Number of Samples Per Year
Chlorophyll a	Measure of algae	µg/L	2008-2020	3 to 24
Apparent Color	Indicator of water clarity	PCU	2009-2017	3 to 13
True Color	Indicator of water clarity	PCU	2017-2020	12 to 24
Copper	Regulated parameter, aquatic toxicity	µg/L	2008-2020	3 to 24
Dissolved Oxygen	Essential to aquatic life	mg/L	2008-2020	6 to 24
Dissolved Oxygen (%)	Regulated parameter, essential to aquatic life	%	2008-2020	6 to 48
Enterococci	Regulated parameter, indicator of fecal contamination	#/100ml	2008-2020	3 to 13
Fecal Coliform	Indicator of fecal contamination	#/100ml	2008-2018	3 to 22
Total Nitrogen	Regulated nutrient, contributes to algal growth	mg/L	2008-2020	3 to 24
Total Ammonia	Component of total nitrogen	mg/L	2008-2020	3 to 24
Total Kjeldahl Nitrogen	Component of total nitrogen	mg/L	2008-2020	3 to 24
Nitrate + Nitrite	Component of total nitrogen	mg/L	2008-2020	3 to 24
Orthophosphate	Component of total phosphorus	mg/L	2008-2020	3 to 24
pH (Field)	Field measurement	SU	2008-2020	6 to 24
Total Phosphorus	Regulated nutrient, contributes to algal growth	mg/L	2008-2020	3 to 24
Salinity	Field measurement, regime important to estuarine life	ppt	2008-2020	6 to 24
Secchi Disk Depth	Indicator of water clarity	m	2008-2020	3 to 24
Specific Conductance	Field measurement	µmhos/cm	2008-2020	6 to 24
Temperature	Field measurement	deg C	2008-2020	6 to 24
Total Organic Carbon	Measure of organic material	mg/L	2008-2020	3 to 24
Total Suspended Solids (TSS)	Indicator of water clarity	mg/L	2008-2020	3 to 13
Turbidity	Indicator of water clarity	NTU	2008-2020	3 to 24

2.2 Data Processing

Data were processed by first conducting an initial overview of the data. Then, lab and field qualified data were processed by the following: First, data with the following codes were removed: "A", "F", "G", "H", "K", "L", "N", "O", "T", "V", "Y", "?", which is consistent with the FDEP's impairment assessment approach for handling qualifier codes[6]. Additional qualifiers were reviewed and retained consistent with FDEP methodology.

[6] Definitions of the data qualifiers removed from the dataset: A=value reported is mean (average) of multiple determinations, F=indicated female for species data, G=parameter detected in sample and blank (field, lab, equipment,

Measurement units for water quality parameters were checked for consistency and, if different, standardized to the same scale. For data collected on the same day, the values were averaged. Duplicates were then removed. Since bacterial data (Fecal and Enterococci) ranged over several orders of magnitude, these data were log10(x+1) transformed for graphical presentations.

2.3 Data Analyses

Water quality data analysis was conducted using the R statistical program (R Core Team, 2021) and Rstudio (Rstudio Team, 2021) and PRIMER v7 and PERMANOVA + (PRIMER-e ltd, Quest Research Limited; Anderson et al., 2008; Clarke et al., 2014; Clarke and Gorley, 2015). Both univariate and multivariate approaches were used, as described below.

2.3.1 Bay-Wide Water Quality

The Bay-wide water quality analysis included the following water quality parameters with regulatory criteria: TN, TP, DO (%), Enterococci, Chl-a, and copper. For the Bay-wide water quality analysis, DO saturation was averaged for top and bottom values.

For the exceedance analysis, the Moorings Bay water quality data were compared to regulatory criteria during the period of FDEP's Verified Period (January 1, 2013 through June 30, 2020). To be consistent with the FDEP's impairment assessment methodology, data qualifiers were treated as follows: data with "U" qualifier codes (indicating that the concentration in the sample could not be detected above the method detection limit) were transformed by taking one-half the reported method detection limit (MDL) and "I" qualified data (indicating that the result is in between the MDL and practical quantitation limit [PQL]) were adjusted down to the MDL. Exceedances of the regulatory criteria were calculated, consistent with the impairment analysis used by FDEP to identify impaired waterbodies:

- Numeric Nutrient Criteria (NNC, Rule Ch. 62-302.532, F.A.C.):
  - No more than 10% of the samples should exceed total nitrogen (TN) concentrations of 0.85 mg/L.
  - No more than 10% of the samples should exceed total phosphorus (TP) concentrations of 0.04 mg/L.
  - The annual geometric mean of Chl-a should not exceed 8.1 ug/L more than once in a three-year period.
- Class II Criteria (Rule Ch. 62-302.530, F.A.C.):
  - Copper concentrations should not exceed 3.7 ug/L.

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or trip blank), H=value based on field kit and results may not be accurate, K=actual value is known to be less than reported value based on calibration curve or sample size and dilution, L=actual value is known to be greater than reported value based on linear range or calibration data, N=presumptive evidence only indicating potential presence of analyte, O=sample collected but analysis lost or not performed, T=value reported is less than detection limit and included for information purposes only and should not be used in statistical analysis (differs from U data in which parameter not detected and reported value is equal to method detection limit), V=parameter detected in sample and method blank, Y=improperly preserved sample, and ?=data rejected and should not be used because quality control data outside criteria.

- Enterococci counts should not exceed a monthly geometric mean of 35 and no more than 10% of the samples should exceed 130 during any 30-day period. Because of data frequency requirements, the Moorings Bay data were compared to the 30-day criteria (130 counts).
- Dissolved Oxygen saturation (%): The daily average DO saturation should not be below 42 percent saturation in more than 10% of the values. Additional DO criteria include a seven-day average and a 30-day average, but the Moorings Bay data did not meet data frequency requirements for these criteria.

For the analysis of long-term trends, the POR was set to 2008 through 2020. Consistent with FDEP methodology when analyzing data for non-impairment assessment purposes, "U" qualified data were set one-half of the MDL and "I" qualified data were not adjusted. Significant trends in the long-term data were tested using Mann-Kendall (MK) tests and Thiel Sen (Sen's slope). The MK test is commonly used for assessing changes in water quality. Non-parametric methods are preferred for water quality data because they make no assumptions about the underlying distribution of the data, are robust to outliers, and detect nonlinear upward or downward trends while accommodating serial correlation (also known as autocorrelation) and seasonality. For this procedure, these data were first tested for serial correlation. If serial correlation was detected, the "zyp" package (Bronaugh and Werner, 2019) in R was used to adjust these data based on autocorrelation, and then the MK trend test routine was executed. If there was no evidence of autocorrelation, then the "rkt" package (Marchetto, 2021) in R was used, and the seasonal MK test was used, blocking seasons on median quarterly values. The slope was estimated with Sen's slope. Like the MK test, Sen's slope is a non-parametric procedure that is robust to outliers (Gilbert, 1987).

An examination of copper and Enterococci concentrations was included to provide context for trends in these parameters relative to changes in MDLs.

2.3.2 Moorings Bay Water Quality Stations

For analysis of water quality at the individual Moorings Bay water quality stations (MB1, MB2, MB3, and MB4), the POR spanned the available data and ranged from 2008 through 2020. Qualified data was treated consistent with FDEP methodology for non-impairment assessment purposes: "U" qualified data were set to one-half the MDL, and "I" qualified data were not adjusted. The "S" qualifier is applicable to Secchi disk measurements, which are a field measurement of water clarity in which a Secchi disk (a weighted black and white disk) is lowered into the water column and the depth at which it is no longer visible is recorded. The "S" qualifier indicates Secchi reading on bottom and these values were removed from the dataset. Summary statistics by station are included in **Appendix A**. Note that DO saturation was examined separately for the top and bottom values.

For TN, TKN, NOx, TP, Chl-a, copper, Enterococci, DO saturation, Secchi depth, turbidity, TSS, color, and salinity, comparisons among the four Moorings Bay stations were conducted with statistical significance testing using the non-parametric Kruskal-Wallis (KW) tests. If KW tests were significant (suggesting differences among stations), a Wilcoxon test, with Bonferroni correction, was then conducted to test for pairwise differences between the stations. The data were also visualized in box plots for TN, TP, Chl-a, copper, Enterococci, and DO saturation.

Long-term trends (slope and p-value) of TN, TKN, NOx, TP, Chl-a, copper, Enterococci, DO saturation, Secchi depth, turbidity, TSS, color, and salinity were estimated using the non-parametric MK test and Sen's slope, as described above for analysis of the Bay-wide trends. The non-parametric MK trend test was used to

detect whether or not a significant increasing or decreasing trend was present and Sen's slope was estimated. For DO saturation, the top and bottom values were also graphed separately. For TN, TP, Chl-a, copper, Enterococci, and DO saturation, the long-term trends were also graphed with comparison to the regulatory criteria applicable to the Bay-wide water quality.

Seasonal data was incorporated and the statistical differences by season for each station were analyzed using the following seasonal categories: wet season (June through November) and dry season (December through May). For each station, the Mann-Whitney U test was used to assess whether the median concentration over the POR of TN, TP, Chl-a, copper, Enterococci, DO saturation, and salinity were significantly different in the wet season versus the dry season.

Correlations among water quality variables (Chl-a, copper, DO concentration, Enterococci, fecal coliform, ammonia-N, NOx, orthophosphate, pH, salinity, specific conductance, Secchi depth, temperature, TKN, TN, TOC, TP, total suspended solids, and turbidity) and the total 30-day rainfall prior to sampling were assessed using non-parametric Spearman tests. Additional parameters were included in the correlation (for example, nutrients: ammonia-N, NOx, orthophosphate) to allow for correlations showing which parameters might be driving correlations or similarly changing. Correlations are used to assess the strength of relationships between parameters. A strong correlation does not imply that an increase (or decrease) in one parameter *causes* an increase (or decrease) in another parameter; it does, however, suggest that the values are changing similarly. Significance of correlations were declared at $p < 0.05$. With this many parameters, the most efficient method to present the correlation results is using a correlation matrix plot. The "rstatix" package from R was used to create this plot.

The Moorings Bay station water quality data were also analyzed using a multivariate approach with PRIMER v7 and PERMANOVA. First, the mean annual values were calculated; this reduced variability, enabling a clearer picture of the water quality conditions among the locations. Then, correlations between water quality parameters were examined using draftsman plots. When correlated ($r > 0.7$) parameters were identified, one of the parameters was removed. Then, the distribution of the remaining variables was examined using histogram plots. Parameters exhibiting non-normal distributions were transformed as necessary. A $\log_{10}(x+1)$ transformation was used since most water quality data were right-skewed. Finally, because these parameters are measured on different scales, these data were normalized to a mean of zero and a standard deviation of one. Using these transformed and normalized data, a resemblance matrix was then created based on Euclidean distances. An ANOSIM test was then conducted to test for overall differences among stations. If an overall difference was detected ($p < 0.05$), an ANOSIM pairwise test was conducted to test for differences between stations. These data from the Euclidean matrix based on annual averages for each station was displayed using a Principal Components Analysis (PCA) to simultaneously compare water quality among the four locations in multivariate space. To examine annual changes in water quality, an additional PCA plot was created using data pooled by years among all stations. PCA is a commonly used multivariate method in water quality investigations, as it provides an exploratory method to reduce the dimensionality of a dataset and can help indicate and visualize parameters that most strongly affect the study area of interest. Variables that were correlated ($r > 0.4$) with the PCA were displayed as vectors on the PCA plot.

3.0 MOORINGS BAY BIOLOGY METHODS

Biological data (otter trawls for fish and aquatic invertebrates) were provided by the City of Naples. Analyses included with both univariate and multivariate methods:

- Taxa richness, species abundance, and diversity indices were calculated for the four Moorings Bay trawl zones.
- Calculation of β-diversity, which measures the extent of change in community composition.
- Comparisons were made across Zones, over time, and according to season.

These analyses are described in detail below.

3.1 Data Collection

Biological samples were collected in partnership with Rookery Bay National Estuarine Research Reserve using a 6.1 m otter trawl with a 1/8" mesh towed for 0.1NM (approximately five minutes at 1200-1400 rpm). During the first year of monitoring, samples were collected at four fixed locations in the Bay. Samples collected after the first year were collected from randomly selected grid boxes from each of the four-bay zones (**Figure 13**). All fish caught in the trawls were identified to the lowest practical taxonomic level, 20 individuals are measured for some fish species, and then counted. For invertebrates, commercially important species including pink shrimp, blue crabs, and stone crabs were measured and counted; other invertebrate species were noted for presence. Though not included in the present analyses, data on SAV and drift algae are also collected from the trawls. Additionally, water quality data (dissolved oxygen, salinity, and temperature) were collected at each trawl location using a hand-held water quality meter.

The final dataset was provided by the City of Naples/Rookery Bay and included trawl data (species, lengths, and abundances) for a total of 40 trawls conducted between 2009-2020. The final dataset also included the water quality data collected with the trawls. The number of trawls per calendar year ranged from one to five per zone (**Table 2**). The number of trawls per water year ranged from three to five per zone (**Table 3**). The water year (October through September) is a hydrologic term and the water year is defined by the United States Geological Survey (USGS) to capture precipitation trends within a 12-month period. Note that no data were collected in the water year 2011, as only one sample was collected in November 2011. Trawls were categorized into Dry (December through May) and Wet (June-November). Of the 40 trawls conducted between 2009-2020, no trawl samples were collected in April, May or December. The trawl data were further divided into Dry-Early (January and February), Dry-Late (March), Wet-Early (June, July and August) and Wet-Late(Late (September, October, and November).

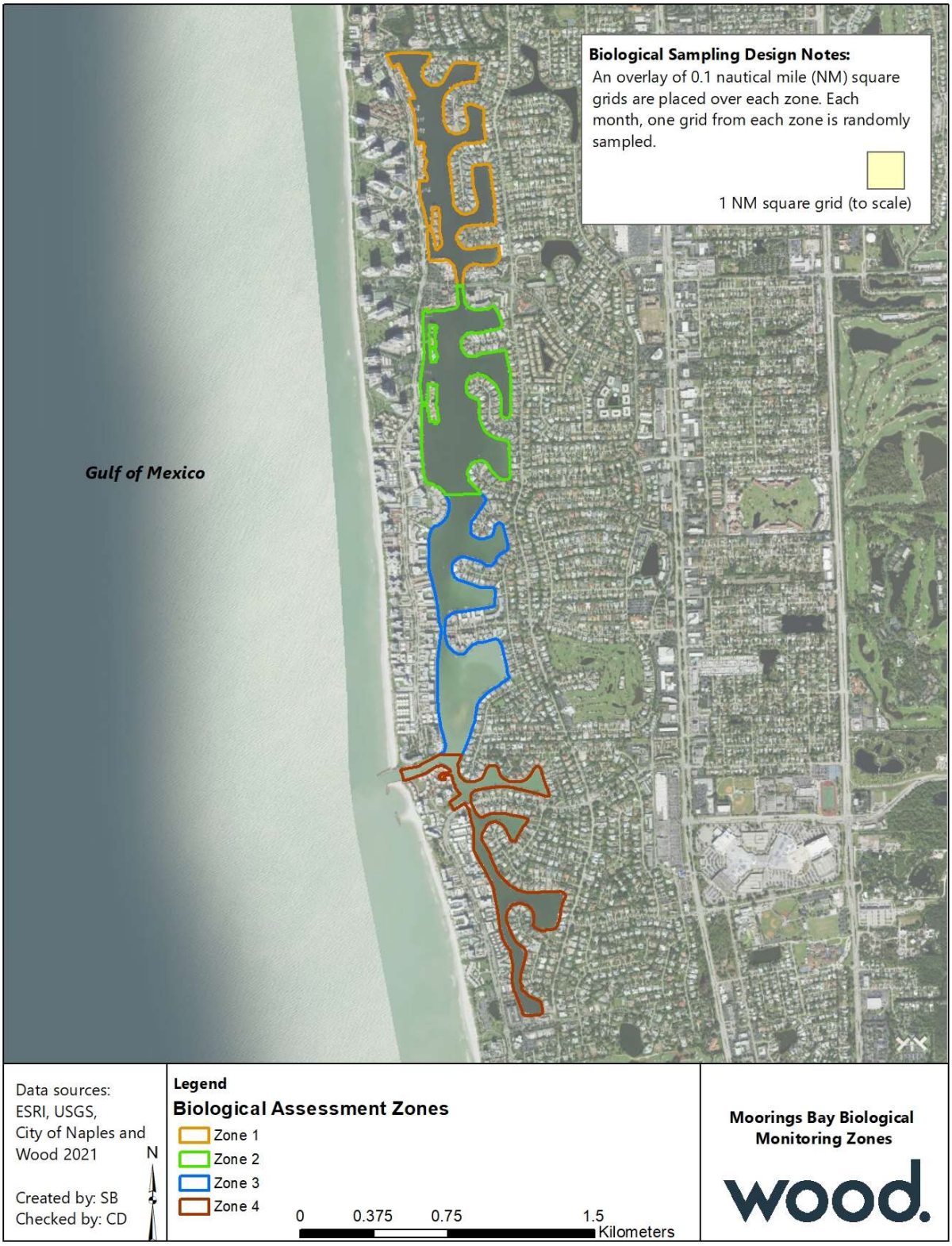

Figure 13. Biological monitoring locations in Moorings Bay.

Table 2. Number of trawl samples per calendar year for each zone

Year	Zone 1	Zone 2	Zone 3	Zone 4
2009	1	1	1	1
2010	3	3	3	3
2011	1	1	1	1
2012	4	4	4	4
2013	4	4	4	4
2014	4	4	4	4
2015	3	3	3	3
2016	4	4	4	4
2017	5	5	5	5
2018	3	3	3	3
2019	4	4	3	3
2020	4	4	4	4

Table 3. Number of trawl samples per water year (October through September) for each zone

Year	Zone 1	Zone 2	Zone 3	Zone 4
2010	3	4	4	4
2012	4	4	4	4
2013	4	4	4	4
2014	4	4	4	4
2015	4	4	4	4
2016	4	4	4	4
2017	3	3	3	3
2018	4	5	5	5
2019	4	4	3	3
2020	4	4	4	4

Note: No data were collected in the water year 2011.

3.2 Data Processing

Initially, a quality assurance check was performed on the taxonomic data and then these data were converted to the proper formats for importing into various statistical routines. The taxa codes that the City of Naples used for identifying the fish and invertebrates were converted to currently accepted scientific nomenclature using reliable, online databases (Froese and Pauly, 2021; WoRMS Editorial Board, 2021). Several duplicates of the same taxon were identified in the dataset, so these were combined into one taxon (**Appendix B**). For ambiguous taxa (i.e., sometimes listed as genus, but more frequently identified to a genus and species) a merge "parents with children" approach was used (Cuffney et al., 2007). The merge parent with child method has been found to provide the best information for examining responses to environmental changes (Cuffney et al., 2007). Additionally, Portunidae spp., *Callinectes sapidus*, and

Callinectes similis were all collapsed into *Callinectes* spp. given the difficulty of identifying portunid crabs to species level[7].

3.3 Data Analysis

Biological data were analyzed with both univariate and multivariate methods. Univariate analyses included the following metrics: total abundance, taxa richness and Shannon's Diversity Index (H'($\log_e$)). The Shannon Index is a commonly used metric of biodiversity, that incorporates both abundances and evenness of the organisms. This index can range from 0 to 5, with higher values indicating higher diversity. The second index was Pielou's Evenness. This index is calculated by dividing the Shannon Index by the species richness and can range from 0 (completely uneven) to 1 (completely even). This provides an indication of the variability of the biodiversity among or within samples. These metrics were calculated for each trawl sample using PRIMER v7. Metrics were compared among zones using box plots. Total abundances, taxa richness, and their respective annual means were also plotted across time for each zone to visualize changes over time.

Analyses of biological data using multivariate methods is a powerful method to characterize biological communities over space and time and can provide additional information that may not be evident with just univariate methods. This is because biological data, by definition, are multivariate in structure. Wood used a variety of multivariate methods in these analyses.

Trawls were categorized into Dry (December through May) and Wet (June-November). Differences in the biological community among seasons were also tested using multivariate methods with seasons and zones as main effects. Two seasonal analyses were conducted. The first was using the four seasons: Dry-Early (December, January, and February), Dry-Late (March, April, and May), Wet-Early (June, July, and August), and Wet-Late (September, October, and November). These seasons were defined in the City's biological data.

Multivariate analyses were conducted in PRIMER v7 with the PERMANOVA+ add-on (PRIMER-e ltd, Quest Research Limited; Anderson et al., 2008; Clarke et al., 2014; Clarke and Gorley, 2015). This software was used because it is robust, flexible, and allows the analysis of multivariate data for complex sampling designs. PRIMER is ideal for ecological data consisting of species abundances that rarely satisfy the assumptions for parametric statistical analyses (Anderson et al., 2008).

Raw invertebrate and fish abundances were variously transformed (square root, fourth root, dispersion-weighting, and $\log_{10}$) to meet the assumptions required for each statistical test and compared to determine the transformation that resulted in the best dimensionality. Because a few species were extremely abundant (orders of magnitude greater), a strong transformation ($\log_{10}(x+1)$) was warranted to reduce the influence of these few species on the overall patterns in the biological assemblage. Bray-Curtis similarities were calculated between samples to produce a resemblance matrix (Bray and Curtis, 1957; Clarke et al., 2006).

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[7] *Callinectes* spp., *Callinectes sapidus*, *Callinectes similes*, and Portunidae sp. data were collapsed into one taxon, *Callinectes* spp., due to the difficulty in identifying these species in the field, especially for juvenile organisms. The Abele & Kim (1986) and Williams (1984) keys are for adults only. Additionally, different color morphs may result in an incorrect identification. Furthermore, these four taxa likely occupy the same ecological niche. There were so few *Callinectes* spp. compared to other more common organisms that collapsing the taxon into *Callinectes* spp. is unlikely to change the results of the analyses.

Non-metric multidimensional scaling (nMDS) ordination plots were created using the Bray-Curtis similarity values to visualize potential spatiotemporal trends in the biological assemblages.

The nMDS ordination plots had relatively high stress[8] values (stress = 0.21) resulting in poor visual discrimination of the zones. Therefore, counts were then averaged over a calendar year, and Bray-Curtis similarities were calculated for these average annual values. This somewhat improved the multivariate representation (stress = 0.19). To further improve the ordination fit, the assemblage data were then aggregated by averaging the zone data for each water year and by wet and dry seasons. Water years were used because this increased the number of samples per year (**Table 3**), and reduced the influence of the first year with only one sample. This greatly improved the fit (stress = 0.07). A clustering technique (CLUSTER with the SIMPROF option) was then used to test for significant differences in the biological assemblages among the water years. Clustering was based on the Bray-Curtis resemblance matrix of the log-transformed data, followed by a SIMPROF test based on a significance level of $p < 0.05$. This resulted in a new factor (SFG1) which grouped water years that were significantly different from each other into groups. This new factor was then utilized in other multivariate analyses or in plots to help visualize trends over time .

The high-stress values and limited separation of groups or years in the nMDS plots suggested that there could be significant interactions between the main factors of water years, zones, and seasons. Therefore, PERMANOVA was used to evaluate differences in the biological composition between these factors, and the interaction of these factors. PERMANOVA partitions the variation in multivariate dissimilarity space to allow for testing of complex study designs (Anderson et al., 2008). PERMANOVA is similar to the classic ANOVA approach, in that the overall main effects can be tested for statistical significance, as well as the interactions, and finally, pairwise comparisons can be made. The typical approach after finding a significant main effect is to run a canonical analysis of principal coordinates (CAP, Anderson et al., 2008). The CAP method can be effective in discriminating factors, that are known, *a priori*. The Similarity Percentages (SIMPER) routine was used to identify the species accounting for differences among the significant pairwise comparisons. The cut-off contribution was set at 70% (the 70% cut-off is the recommended cut-off for the SIMPER routine and helps avoid long tables by not listing species that have limited contribution to average dissimilarity between the two groups (Clarke and Gorley, 2015)). Seasons were classified by the group sampling the biological data into two categories: the first grouping consisted of: Dry-Early (January and February), Dry-Late (March), Wet-Early (June, July and August) and Wet-Late (September, October, and November). The second seasonal grouping consisted of: Dry (December-May) and Wet (June through November) seasons. As described earlier, of the 40 trawls conducted between 2009-2020, no trawl samples were collected in April, May or December.

A final multivariate method was used to test for differences in β-diversity among the zones. β-diversity is an important measure of biological diversity, and it can be defined as the extent of change in community composition (Whittaker, 1960). To test for changes in β-diversity the PERMDISP routine was used. The PERMDISP routine in the PERMANOVA+ package tests for homogeneity of multivariate dispersions. This compares the within-group spread among groups using the average value of the distances from individual observations to their group centroids (Anderson, 2006). This multivariate dispersion is a measure of β-diversity which, in turn, is defined as the variability in species composition along with a sampling unit (time or space, Anderson et al., 2006). PERMDISP enables a test of differences in composition among these sampling units. Differences in β-diversity among zones and over the sampling POR were tested by pooling

[8] Stress is a measure of how well the multivariate data can be placed into two-dimensional space. A stress of <0.2 gives a potentially useful 2-dimensional picture, except one should be concerned about the values on the upper end of this plot (Clarke et al., 2014). When this occurs, averaging replicates is recommended to improve the fit (Clarke et al., 2014).

individual trawl sample data within water years. This was done for the overall test of changes over time throughout the Bay (pooling the samples by Zone), as well as separately by zone over time.

4.0 WATER QUALITY AND BIOLOGICAL INTERACTION METHODS

Where possible, the relationships between water quality and rainfall (sum of rain 30 days prior to sampling) and the biological data were examined. As noted previously (Cardno, 2016), water quality samples (MB1, MB2, MB3, and MB4) were not collected in the same locations as the biological sampling. Therefore, only water quality parameters that were collected during the actual trawling were used. These data include (measured at bottom): dissolved oxygen, salinity, and temperature.

First, the relationships between the biological metrics and water quality and precipitation were explored using Spearman rank correlations. Significance was set at $p < 0.05$. Second, the relationship between the entire biological community and the water quality data were examined using the BEST (BIO-ENV) routine in Primer. Prior to conducting this routine, correlations among these parameters and their individual distributions were assessed using draftsman plots and histogram plots. Correlations between the environmental variables (DO, salinity, temperature, and sum of rainfall in the previous 30 days) were low (rho < 0.7), and other than rainfall, these data appeared normally distributed. Thus, these data were not removed. Rainfall data were log-transformed. Environmental data were then normalized to place them on the same scale prior to BEST. BEST searches for high matrix correlations (rank-based) between a species assemblage matrix and a data matrix (environmental). This routine searches and tests for the best correlation using combinations of environmental factors.

5.0 MOORINGS BAY WATER QUALITY RESULTS

The results of the Bay-wide and water quality station analysis are described below.

5.1 Bay-wide Exceedance Analysis

The exceedance analysis for Bay-wide water quality over the FDEP's verified period (January 1, 2013- June 30, 2020) followed FDEP procedures of reducing "I" qualified data to the MDL and "U" qualified data to ½ the MDL. The analysis revealed concentrations of nutrients in the Bay in exceedance of FDEP criteria and indicating an impaired status with Chl-a, DO, copper, and Enterococci within regulatory limits:

- TN concentrations exceeded the NNC in 13.5% of samples, indicating an impaired status (**Figure 14, Table 4**).
- TP concentrations exceeded the NNC in 32.2% of samples, indicating an impaired status (**Figure 15, Table 4**).
- There were zero exceedances for the Chl-a AGM NNC (**Figure 16, Table 4**).
- The DO saturation was below the Class II criteria of 42% in 2.6% of samples, indicating that the Bay is not impaired for DO (**Figure 17, Table 4**).
- Copper exceeded the Class II criteria in 3.2% of samples, indicating that the Bay is not impaired for copper (**Table 4**). Enterococci counts exceeded the Class II criteria in 5.7% of samples, indicating that the Bay is not impaired for Enterococci (**Table 4**). Because of changes in MDLs, these data were not graphed. Additional discussion on the copper and Enterococci data, with reference to exceedance criteria, is included in **Section 5.2**.

The Bay is currently on FDEP's verified impaired list for TP and based on the exceedance analysis results above and in **Table 4**, the Bay will remain impaired for TP and will also be impaired for TN. This is consistent with the FDEP's draft verified impaired list status for Moorings Bay.

Table 4. Bay-wide exceedance analysis for total nitrogen, total phosphorus, chlorophyll-a, copper, Enterococci, and dissolved oxygen saturation (FDEP's verified period (January 1, 2013- June 30, 2020)).

Parameter	Regulatory Criteria	No. of Exceedances	No. of Samples	% Exceedance	Status
Total Nitrogen	0.85 mg/L in 10% of Samples	47	348	13.5	Exceeding criteria (impaired)
Total Phosphorus	0.04 mg/L in 10% of Samples	103	320	32.2	Exceeding criteria (impaired)
Chlorophyll-a	20 µg/L, Annual Geometric Mean (AGM), More than 1 in 3 years	0	7	0	Not exceeding criteria
Copper	3.7 µg/L in 10% of Samples	9	278	3.2	Not exceeding criteria
Enterococci	130 Counts/100 mL in 10% of Samples	20	348	5.7	Not exceeding criteria
Dissolved Oxygen	42% in 10% of Samples	9	351	2.6	Not exceeding criteria

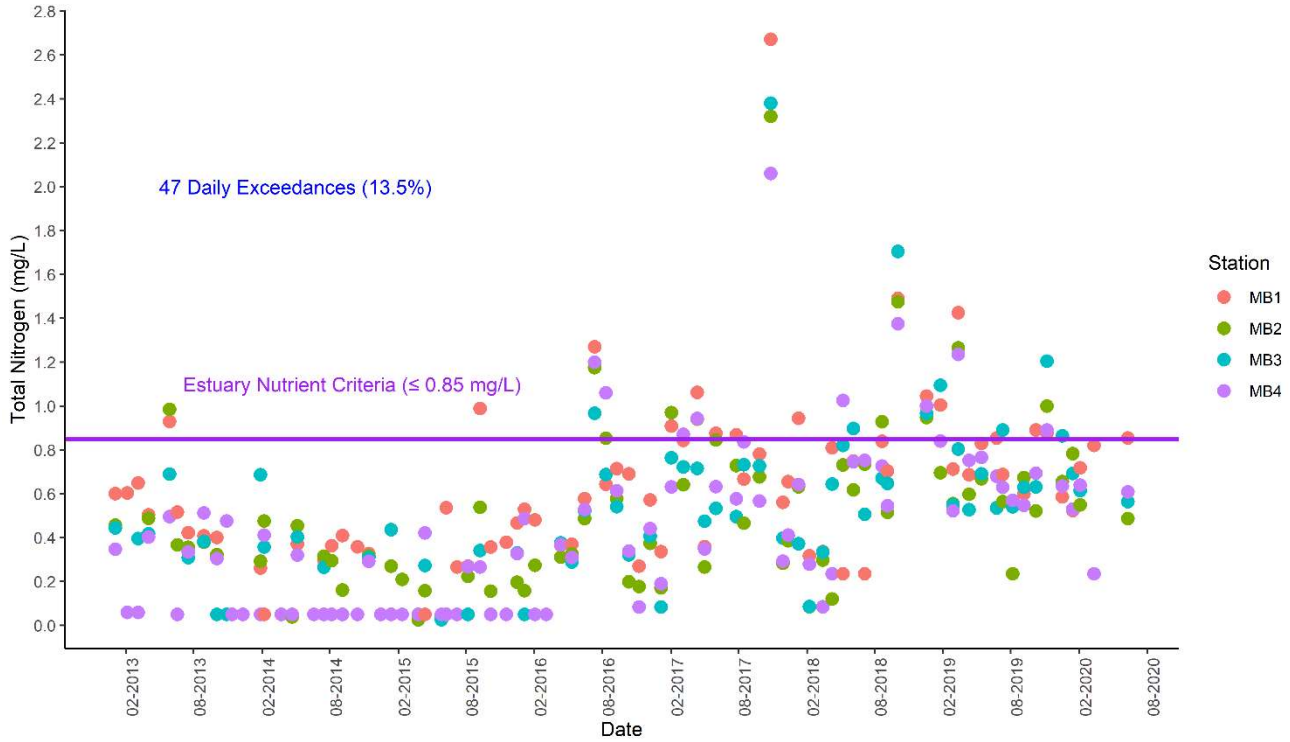

Figure 14. Total nitrogen concentrations in Moorings Bay during the FDEP Verified Period (January 1, 2013- June 30, 2020) with exceedance percentage. Purple line represents regulatory criteria.

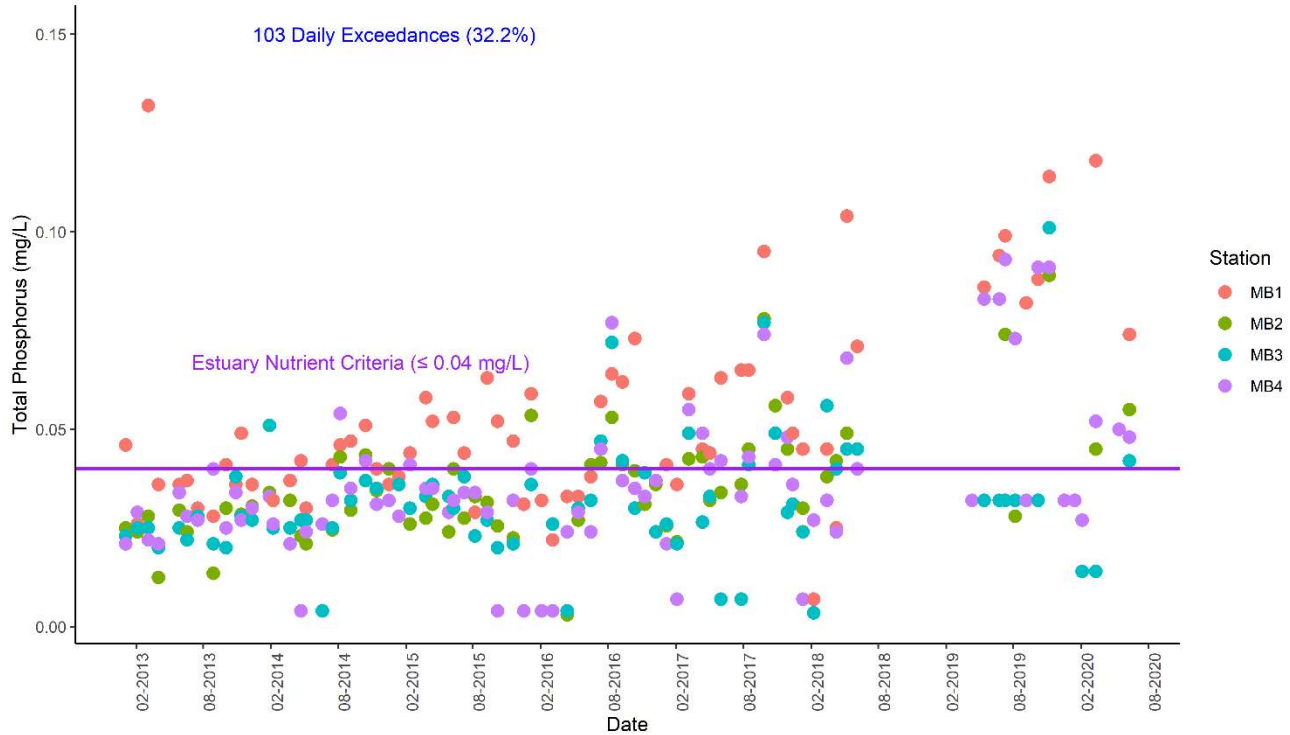

Figure 15. Total phosphorus concentrations in Moorings Bay during the FDEP Verified Period (January 1, 2013- June 30, 2020) with exceedance percentage. Purple line represents regulatory criteria.

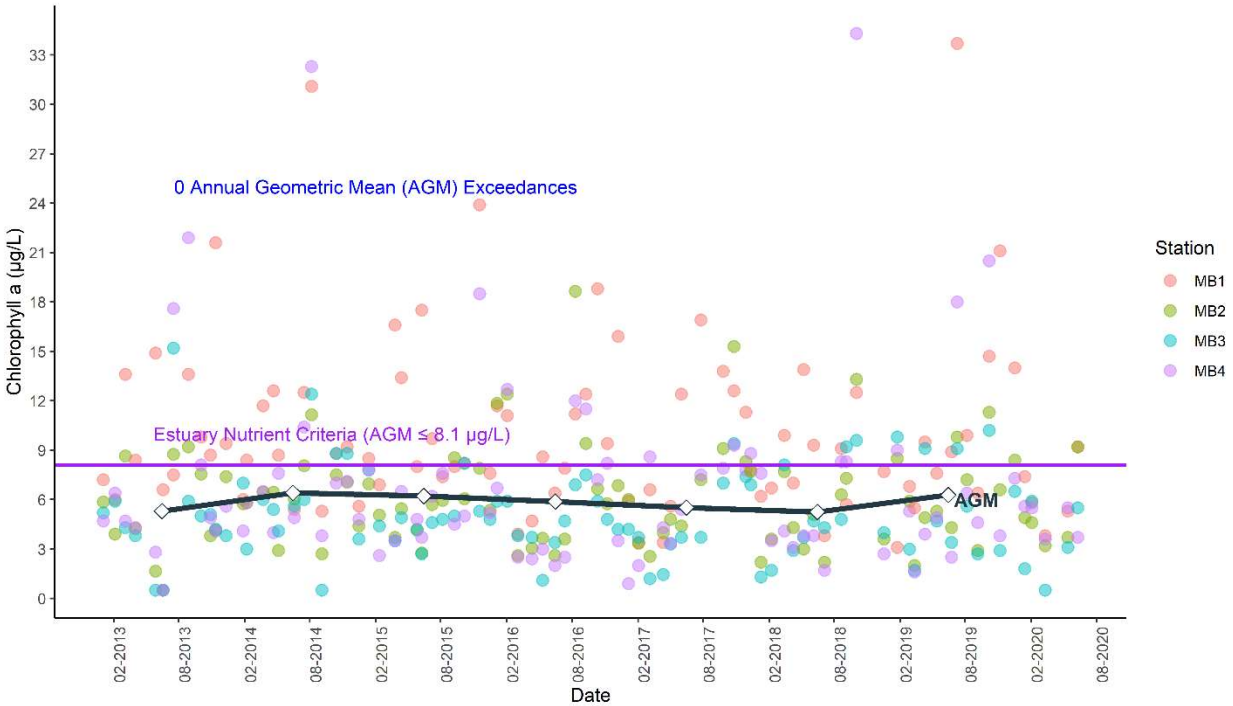

Figure 16. Chlorophyll-a concentrations in Moorings Bay during the FDEP Verified Period (January 1, 2013- June 30, 2020) with exceedance percentage. Black line is Bay-wide AGM, purple line represents regulatory criteria. Individual data points in lighter hue because impairment status based on AGM.

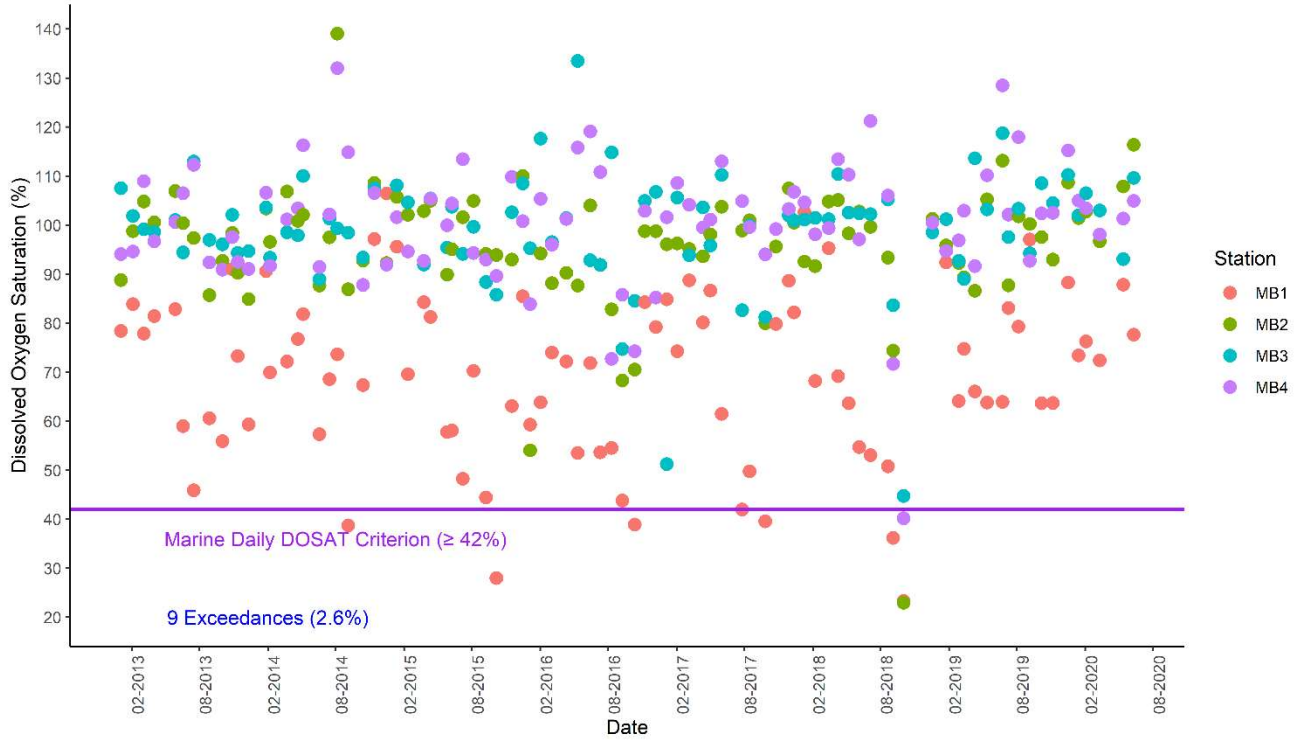

Figure 17. Dissolved oxygen saturation in Moorings Bay during the FDEP Verified Period (January 1, 2013- June 30, 2020) with exceedance percentage. Purple line represents regulatory criteria.

5.2 Bay-wide Long-term Trends

The long-term water quality trends analysis in Moorings Bay (2008-2020) kept "I" qualified data as is and converted "U" qualified data to ½ the MDL. The results of the analyses are summarized below and included in **Table 5:**

- TN concentrations are significantly increasing (Sen's Slope = 0.025, $p < 0.001$, **Figure 18**).
- TP concentrations are significantly increasing (Sen's Slope = 0.002, $p < 0.001$, **Figure 19**).
- Chl-a concentrations are significantly increasing (Sen's Slope = 0.207, $p < 0.001$, **Figure 20**).
- No significant trend in DO saturation was found when comparing surface and bottom separately nor when analyzing combined daily averages (**Figure 21**).
- Copper concentrations appear to be significantly decreasing (Sen's Slope = -0.025, $p < 0.01$) however, this trend may be artificial because the MDLs have decreased over time. See below for additional analysis of Moorings Bay copper concentrations. Enterococci counts appear to be significantly increasing (Sen's Slope = 0.5, $p < 0.05$), however, this trend may also be artificial and related to MDLs and additional analysis is included below.

From 2008 through 2020, the concentrations of nutrients in the Bay increased significantly, and as described earlier, these concentrations (TN and TP) are exceeding regulatory criteria. While not currently at concentrations indicating an impairment, Chl-a concentrations in the Bay are also increasing significantly.

Table 5. Long-term (2008 – 2020) Bay-wide trends of total nitrogen, total phosphorus, chlorophyll-a, copper, Enterococci, and dissolved oxygen saturation.

Parameter	Significant Trend	Slope (unit per year)	p-value
Total Nitrogen	Increasing	0.025	<0.001
Total Phosphorus	Increasing	0.002	<0.001
Chlorophyll-a	Increasing	0.207	<0.001
Copper	Decreasing*	-0.025	<0.01
Enterococci	Increasing*	0.50	<0.05
Dissolved Oxygen	No significant trend	0.398	0.055
* - Trend determination may be affected by changes in method detection limits over time.			

The copper MDL has decreased during the 2008 through 2020 long-term dataset and "U" qualified data, which are interpreted as one-half of the MDL subsequently decreased over time. In the trend analysis, this lowered MDL may be partly responsible for the observed decrease in copper concentrations from 2008 through 2020. As an alternative method, the copper data were compared to the Class II Criteria (**Figure 22**) to visualize the changes in the percent exceedances over time. The Class II Criteria for copper is 3.7 ug/L, which is higher than the range of copper MDLs in the long-term dataset. In **Figure 22**, the percentage of samples exceeding the copper criteria peaked in 2014 and have generally decreased in subsequent years. For the Enterococci data, the MDL has increased over time. Therefore, the "U" qualified data subsequently increased over time, potentially artificially increasing the observed concentrations. The criteria exceedances (compared to the FDEP Class II Criteria of 130 counts) are included in **Figure 23** and exceedances have generally decreased since 2014.

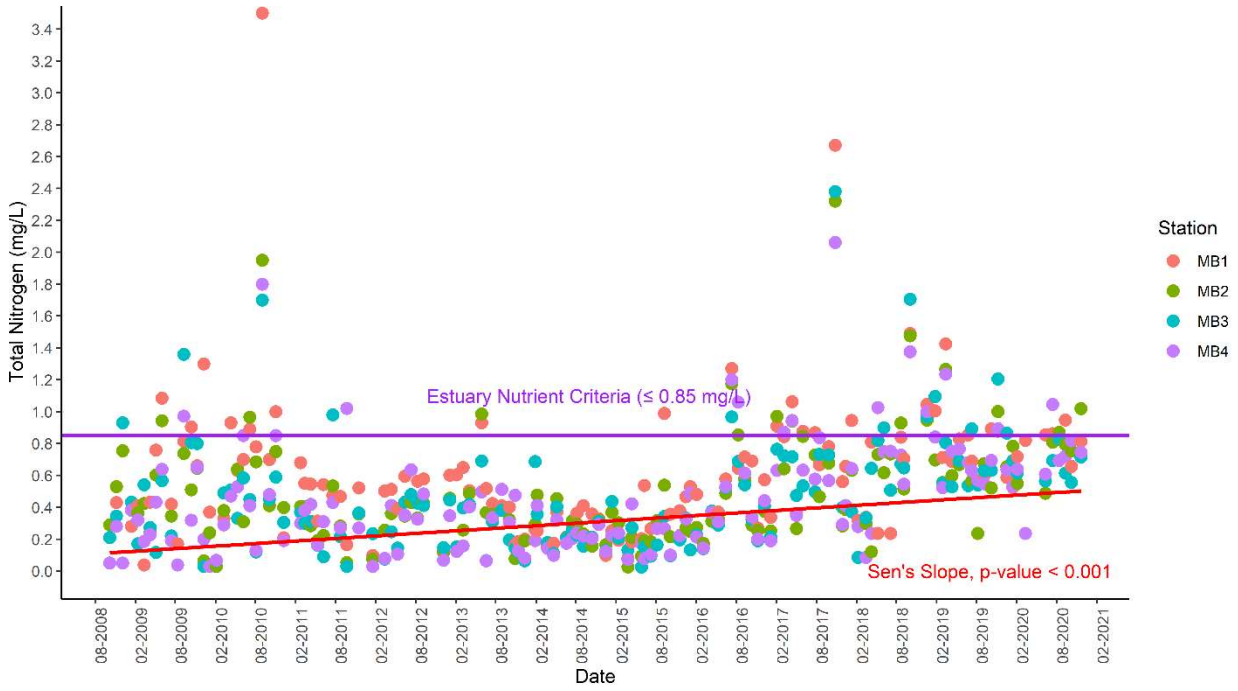

Figure 18. Long-term (2008 – 2020) total nitrogen concentrations in Moorings Bay; red Bay-wide trendline is significantly increasing (Sen's Slope = 0.025, p < 0.001). Purple line represents regulatory criteria.

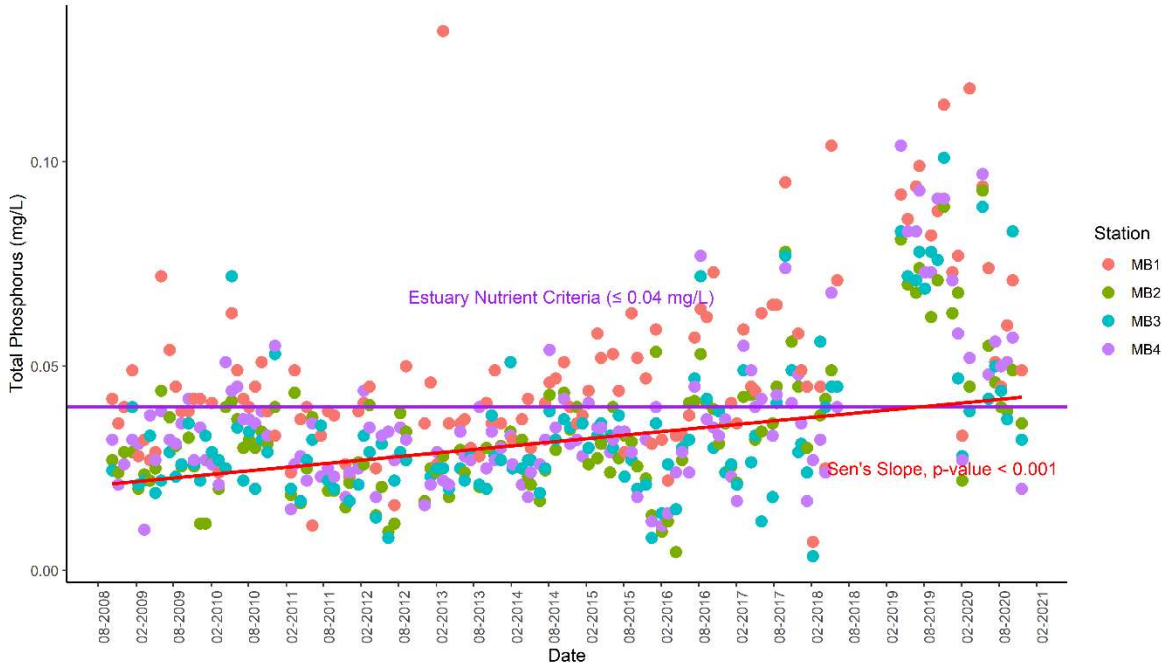

Figure 19. Long-term (2008 – 2020) total phosphorus concentrations in Moorings Bay; red Bay-wide trendline is significantly increasing (Sen's Slope = 0.002, p < 0.001). Purple line represents regulatory criteria.

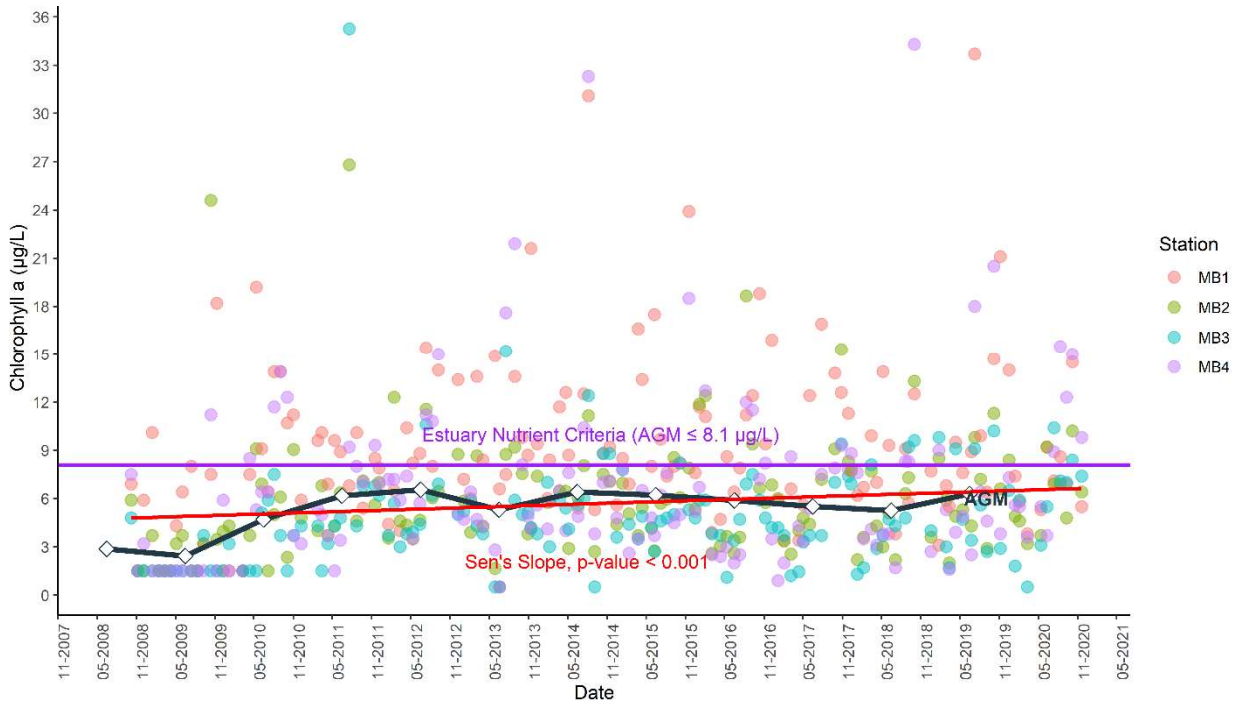

Figure 20. Long-term (2008 – 2020) chlorophyll-a concentrations in Moorings Bay; red Bay-wide trendline is significantly increasing (Sen's Slope = 0.207, p < 0.001). Black line represents the AGM, purple line

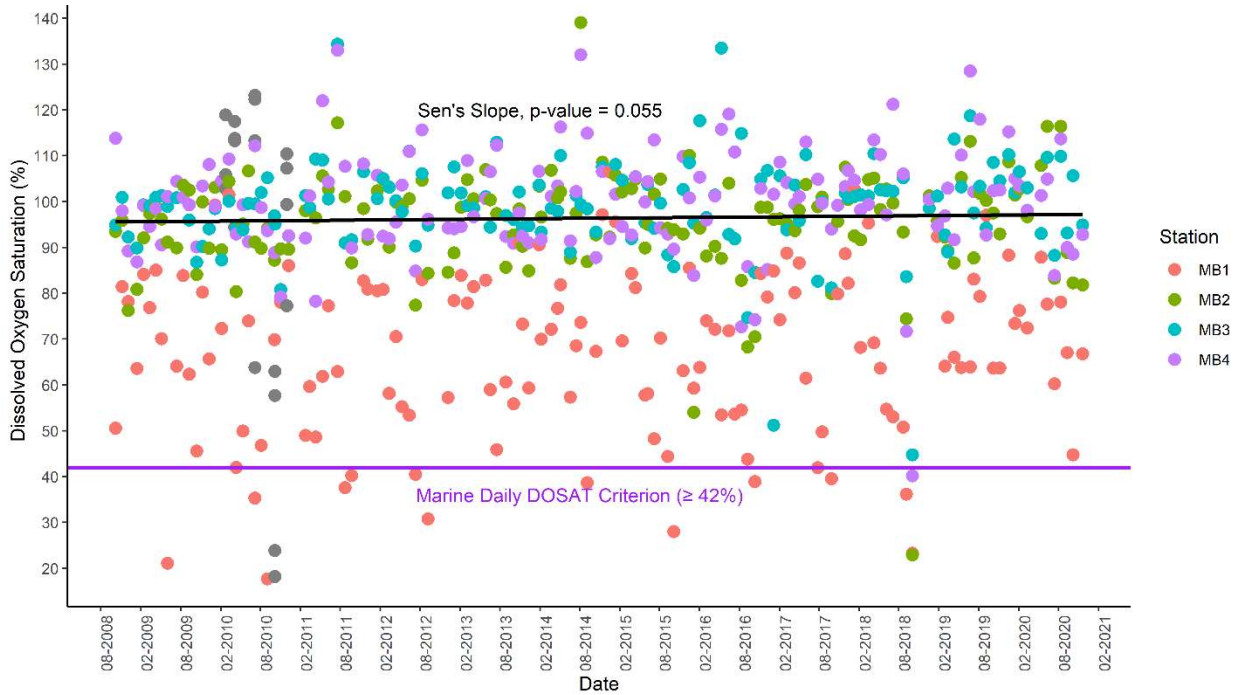

Figure 21. Long-term (2008 – 2020) DO saturation in Moorings Bay; black Bay-wide trendline is not significantly increasing or decreasing. Purple line represents regulatory criteria.

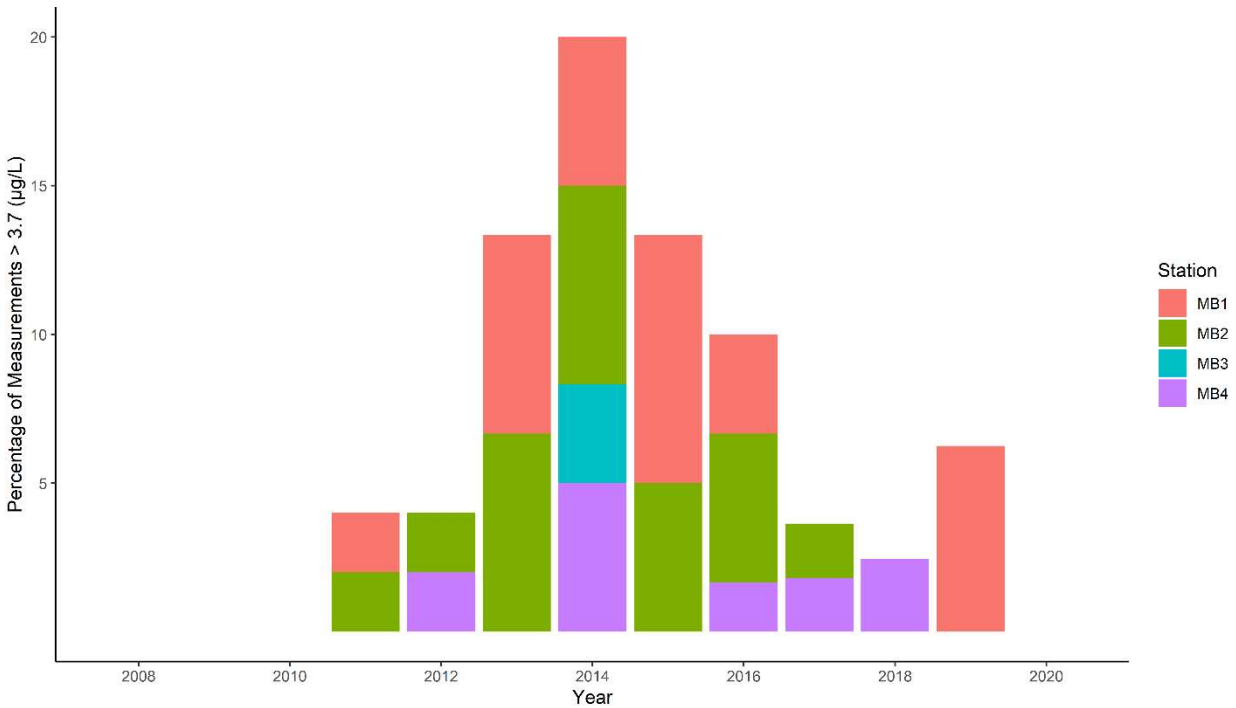

Figure 22. Percentage of copper concentrations exceeding the Class-II criteria of 3.7 ug/L for the four Moorings Bay water quality monitoring locations from 2008 – 2020. There were no exceedances in 2008-2010 or 2020.

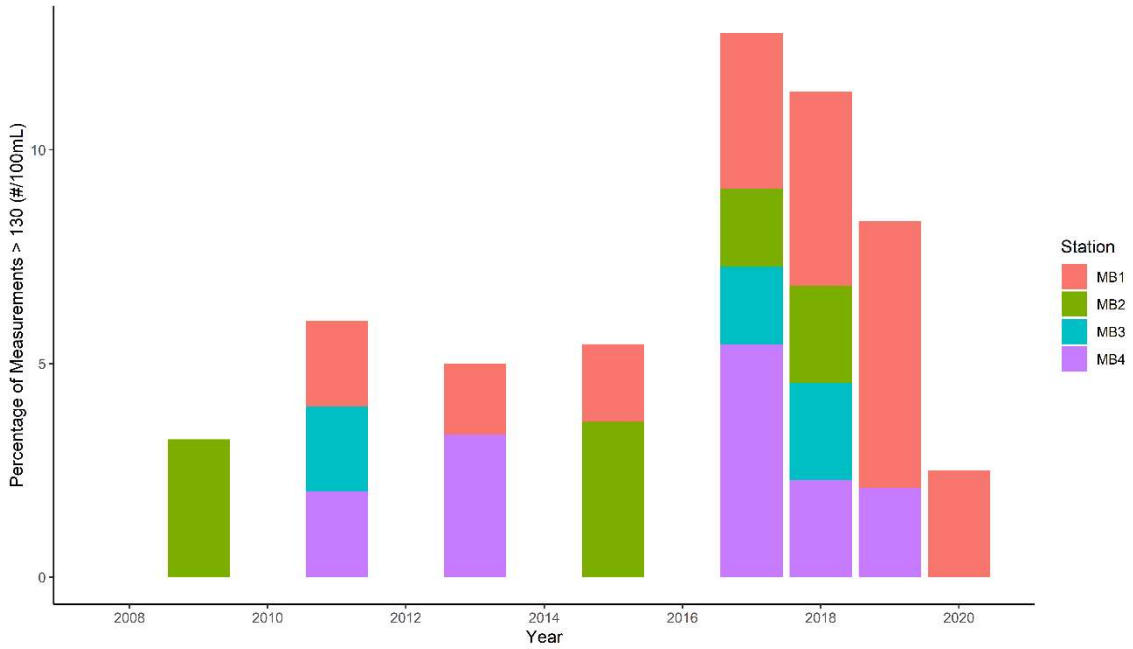

Figure 23. Percentage of *Enterococci* concentrations exceeding the Class-II criteria of 130 #/100mL for the four Moorings Bay water quality monitoring locations from 2008 – 2020. Lack of bars indicates that there were no exceedances for that year.

5.3 Water Quality Among Moorings Bay Water Quality Stations

Over the 2008 through 2020 study period, water quality of Moorings Bay was variable among the monitoring stations for TN, TP, Chl-a, copper, and DO saturation with MB1 exhibiting higher concentrations of nutrients, Chl-a, and copper and lower DO:

- Concentrations of TN (**Figure 24**) and TP (**Figure 25**) were significantly ($p < 0.05$) higher at MB1 compared to the other three stations (MB2, MB3, and MB4).
- Concentrations of Chl-a were significantly ($p < 0.05$) higher at MB1 compared to the other three stations (**Figure 26**).
- Copper was significantly ($p < 0.05$) higher at MB1 (**Figure 27**).
- Enterococci counts were not significantly ($p > 0.05$) different among the stations (**Figure 28**).
- Both surface and bottom DO were significantly ($p < 0.05$) lower at station MB1 (**Figure 29**).

These data indicate poorer water quality conditions at MB1. For the data analysis in this section, "U" qualified data were set to one-half the MDL, and "I" qualified data were not adjusted. As noted above, the copper and Enterococci MDLs have changed over time, however methodology was consistent across stations and the effect on analysis is likely less significant when comparing spatially across station (rather than over time).

The among-station difference for the remaining parameters (TKN, NOx, Secchi disk depth, turbidity, TSS, color, and salinity) are summarized in **Table 6**:

- TKN concentrations were significantly higher at MB1 compared to the other stations and the concentration at MB2 was significantly higher than MB3 and MB4 ($p < 0.05$). TKN includes nitrogen from organic sources. Thus, it appears that the water quality in this area is potentially influenced by inputs from organic matter, potentially mangroves, or other wetlands in the sub-watershed. Stormwater lakes may also be contributing.
- There were no significant differences in NOx concentrations among the stations ($p > 0.05$). The presence of nitrate can suggest that there are human sources of nitrogen (i.e., septic tanks, or fertilizers), however, source tracking should be conducted to provide additional evidence as to the source of nitrate.
- Secchi disk depth was significantly higher at MB1 and MB2 compared to MB3 and MB4 ($p < 0.05$). Turbidity was significantly higher at MB3 ($p < 0.05$), TSS was highest at MB3 but was only significantly higher than MB1 ($p < 0.05$). These parameters indicate water clarity, and the station differences are potentially related to the unique flow regimes and inputs across the Bay.
- Apparent color was significantly ($p < 0.05$) higher at MB1 than all other stations, although median values for MB1 and MB2 were the same. Higher levels of color are usually associated with vegetative debris inputs, especially leaf litter. This provides additional evidence that this area is influenced by inputs from the mangrove areas that are hydrologically connected to this area.
- Salinity was significantly highest at MB3 and lowest at MB1 ($p < 0.05$). Station MB3 is closest to Doctors Pass, thus has a higher degree of hydrologic connectivity to the open ocean.

In general, these data provide additional evidence for conditions at MB1 being different from the other stations (with some exceptions). These differences may be related to the northern location of MB1 where it receives less flushing via Doctors Pass.

Table 6. Individual parameter comparisons among locations (2008 through 2020). Median values are presented for each parameter at each station. The p-value is from the Kruskal-Wallis rank sum test for the overall dataset and letters in parenthesis indicate significant differences ($p < 0.05$) based on Wilcoxon rank-sum test with Bonferonni correction. P-values < 0.05 are bolded.

Parameter	p-value	MB1	MB2	MB3	MB4
Total Kjeldahl Nitrogen (mg/L)	**<0.001**	0.51 (A)	0.32 (B)	0.38 (B)	0.34 (B)
Nitrate+Nitrite (mg/L)	0.71	0.014 (A)	0.013 (A)	0.013 (A)	0.013 (A)
Secchi Depth (m)	**<0.001**	1.4 (A)	1.3 (A)	1.1 (B)	1.2 (B)
Turbidity (NTU)	**<0.001**	2.4 (A)	2.3 (A)	3.9 (B)	2.7 (A)
Total Suspended Solids (mg/L)	**0.001**	9 (A)	11.1 (B)	12.85 (B)	10 (AB)
Apparent Color (PCU)*	**<0.001**	15 (A)	15 (B)	10 (C)	13 (BC)
Salinity (ppt)	**<0.001**	33.8 (A)	34.2 (B)	34.6 (C)	34.1 (B)
*-POR is October 2009 through June 2017					

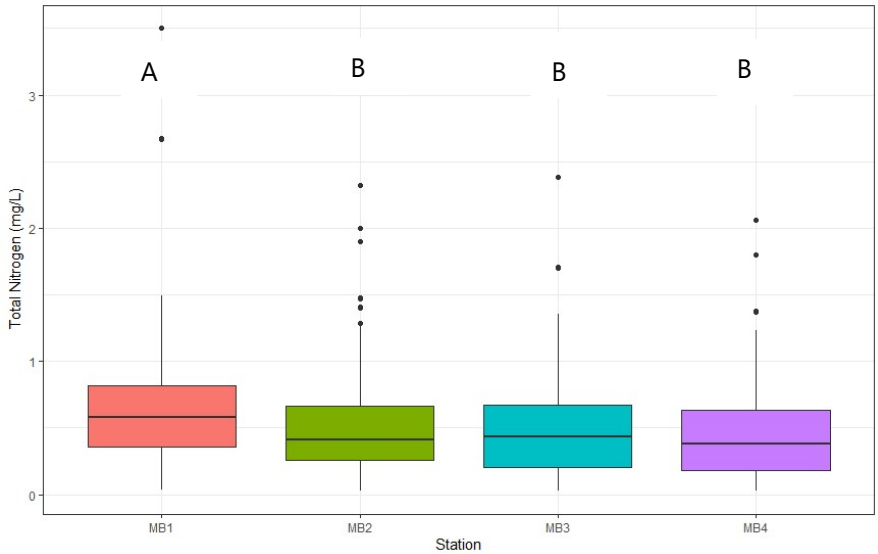

Figure 24. Box plots of total nitrogen concentrations among locations for data collected from 2008 through 2020. Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges. Boxplots with different letters indicate significant differences among stations based on a significant Kruskal-Wallis test ($p < 0.05$), followed by the Wilcoxon rank-sum test with Bonferonni correction ($p < 0.05$).

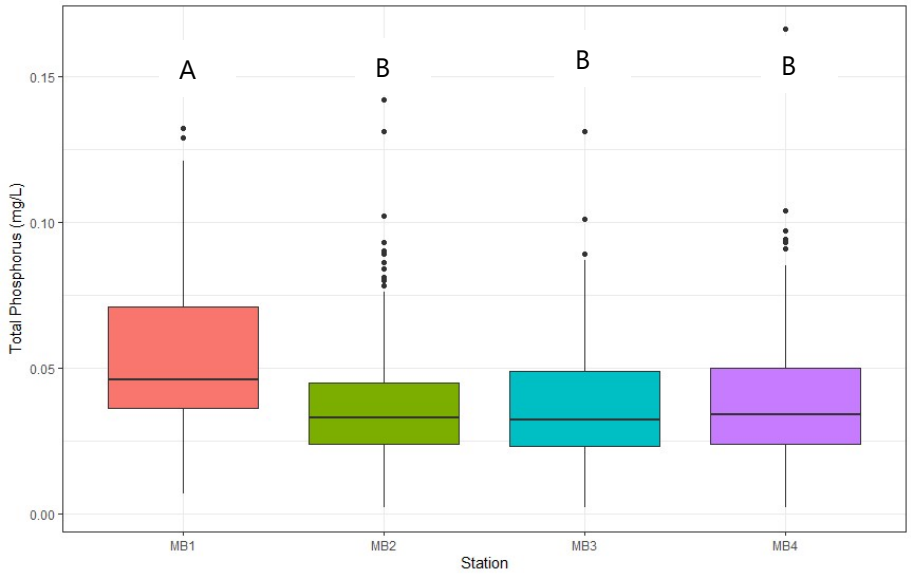

Figure 25. Box plots of total phosphorus concentrations among locations for data collected from 2008 through 2020. Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges. Boxplots with different letters indicate significant differences among stations based on a significant Kruskal-Wallis test ($p < 0.05$), followed by the Wilcoxon rank-sum test with Bonferonni correction ($p < 0.05$).

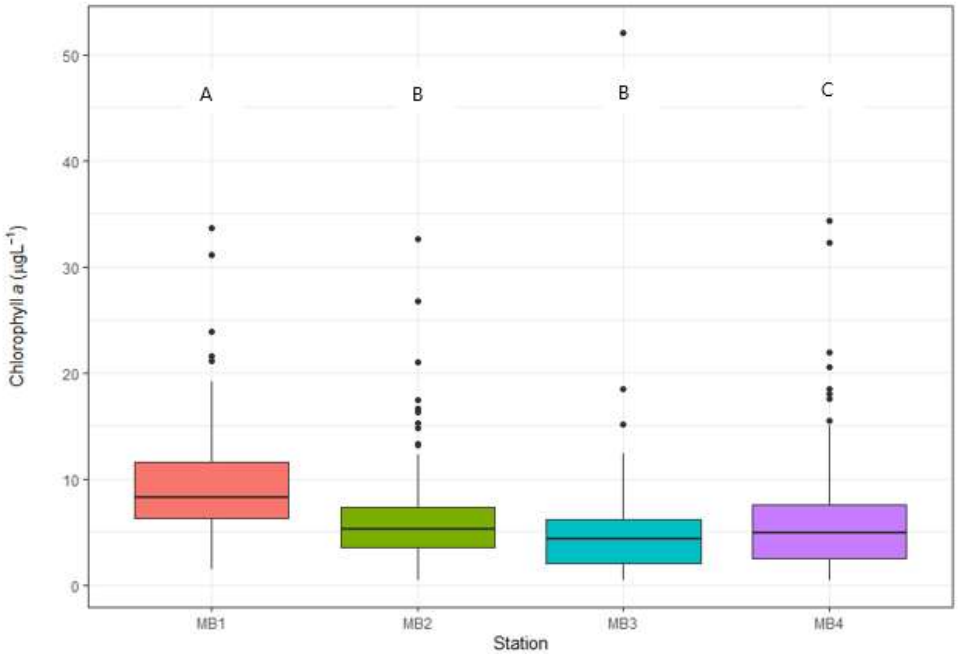

Figure 26. Box plots of chlorophyll-a concentrations among locations for data collected from 2008 through 2020. Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges. Boxplots with different letters indicate significant differences among stations based on a significant Kruskal-Wallis test ($p < 0.05$), followed by Wilcoxon rank-sum test with Bonferonni correction ($p < 0.05$).

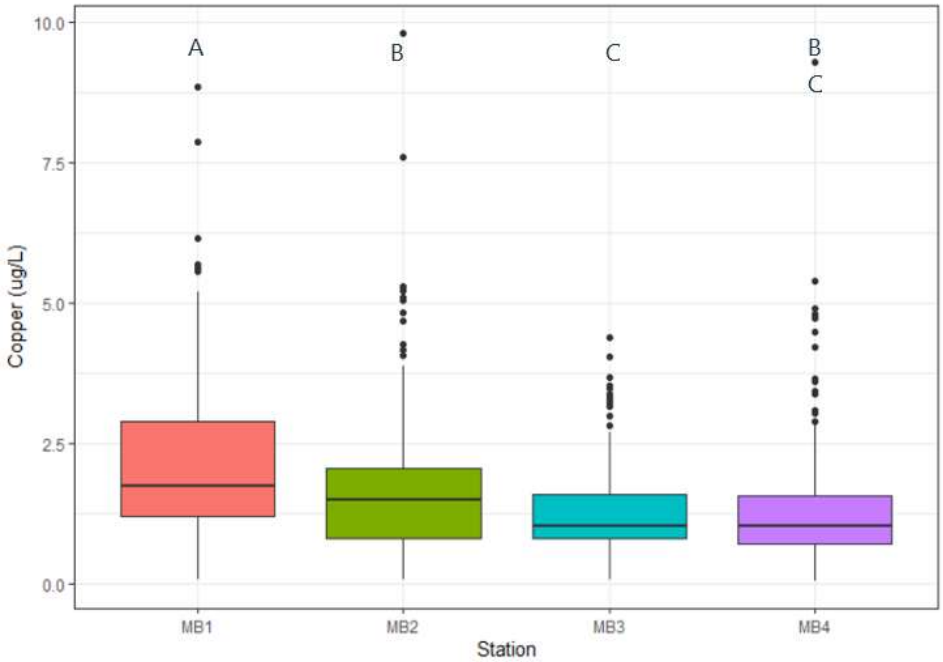

Figure 27. Box plots of copper concentrations among locations for data collected from 2008 through 2020. Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges. Boxplots with different letters indicate significant differences among stations based on a significant Kruskal-Wallis test ($p < 0.05$), followed by Wilcoxon rank-sum test with Bonferonni correction ($p < 0.05$).

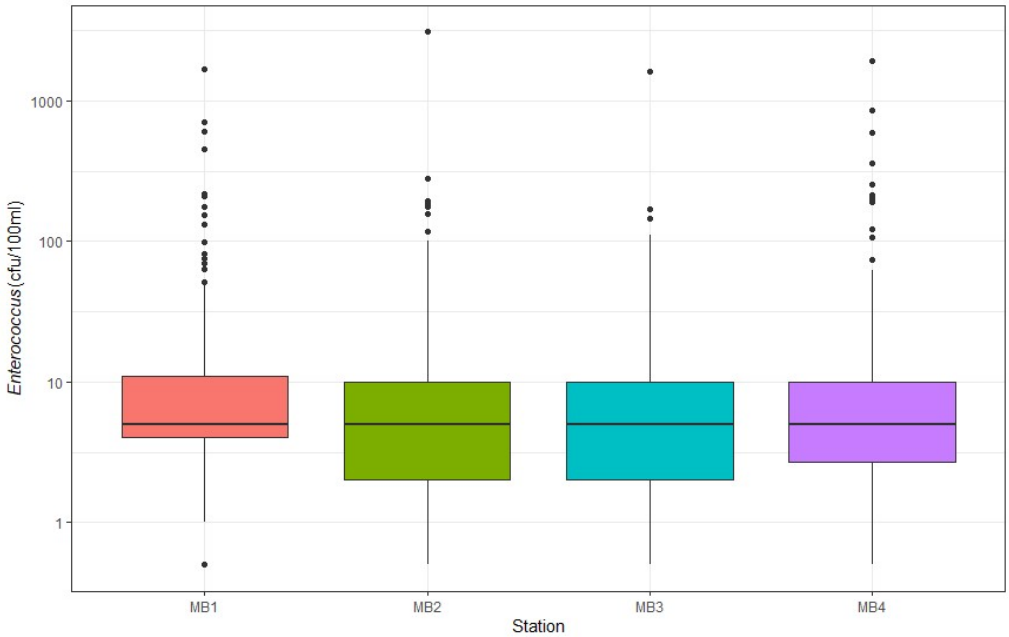

Figure 28. Box plots of Enterococci counts among locations for data collected from 2008 through 2020. Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges. No significant differences were found among stations (Kruskal-Wallis test, $p = 0.34$), followed by the Wilcoxon rank-sum test with Bonferonni correction ($p < 0.05$).

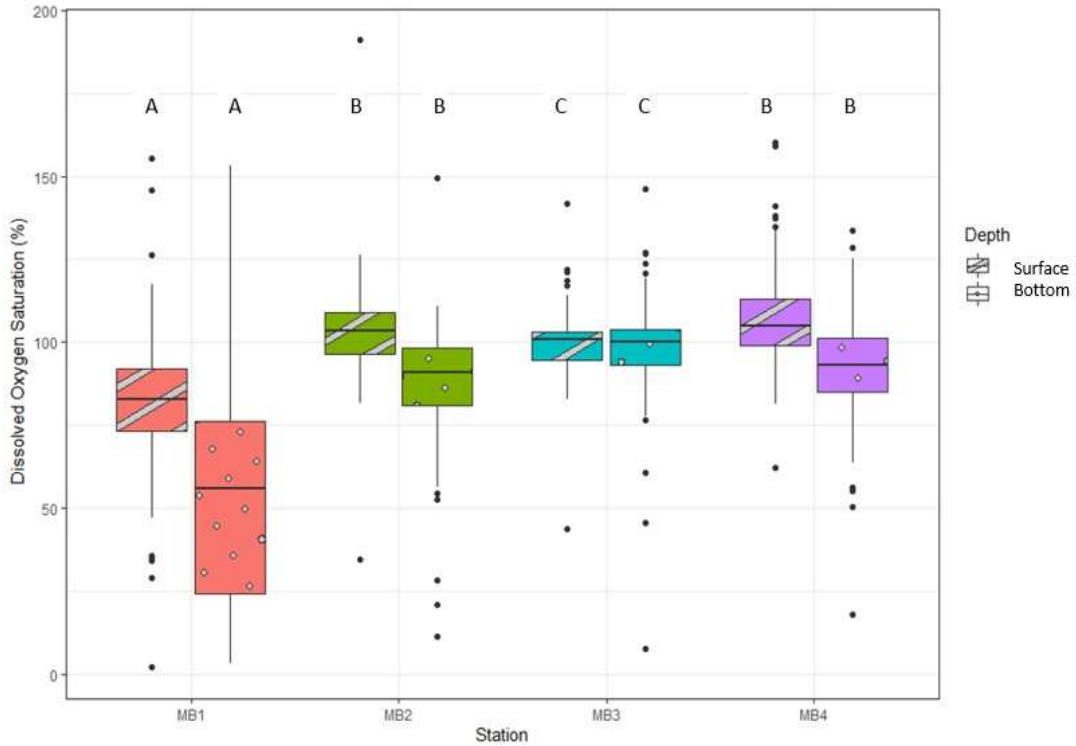

Figure 29. Box plots of dissolved oxygen saturation among locations for data collected from 2008 through 2020. Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5 x interquartile ranges. Boxplots with different letters indicate significant differences among stations based on a significant Kruskal-Wallis test ($p < 0.05$, followed by the Wilcoxon rank-sum test with Bonferonni correction ($p < 0.05$). "Surface" (≤0.3 m) and "Bottom" (>0.3 m) results are plotted and analysed separately.

5.4 Water Quality Over Time at Moorings Bay Water Quality Stations

The changes over time (2008 – 2020) of TN, TP, Chl-a, and DO at the four Moorings Bay water quality stations are included in **Figure 30** through **Figure 34**. Some figures include the regulatory criteria, however, note that these regulatory criteria (NNC and Class II Criteria) are applicable to the Bay-wide conditions over the FDEP Verified Period (January 1, 2013- June 30, 2020) and the comparisons are provided for informational purposes only:

- Concentrations of TN (**Figure 30**) and TP (**Figure 31**) increased significantly over time at all four stations ($p < 0.05$), individual samples were higher than the NNC at all four stations.
- Chl-a concentrations significantly increased at stations MB2 and MB3 ($p < 0.05$) while significant trends over time for Chl-a were not observed at MB1 and MB4 (**Figure 32**); the AGM for Chl-a is included in **Figure 33** with the Chl-a NNC and only AGMs at MB1 were higher than the NNC.
- The top and bottom DO saturations by station are included in **Figure 34**, showing nearly equal saturations in the top and bottom DO at MB3. The largest difference between top and bottom DO saturations are seen at MB1.

For the results present in this section, "U" qualified data were set to one-half the MDL, and "I" qualified data were not adjusted. Trends for copper and Enterococci over time are not included because of the potential issues with MDLs artificially effecting trends.

Similar to the Bay-wide trends, these results show increasing concentration of nutrients (TN and TP) throughout the Bay, further indicating nutrient concentrations contributing to poorer water quality within the Bay.

Temporal trends (slopes and p-values) for TKN, NOx, Secchi disk depth, turbidity, TSS, color, and salinity are also included in **Table 7** through **Table 10**. Trends of note (from 2008 through 2020) include:

- As described above, TN increased at all stations. TKN was also observed to increase significantly ($p < 0.05$) at all stations while nitrate concentrations decreased significantly ($p < 0.05$) at all stations.
- At the four stations, Secchi depth did not increase or decrease significantly ($p > 0.05$) over time.
- Turbidity concentrations increased significantly at all stations ($p < 0.05$) while TSS decreased significantly ($p < 0.05$) at all stations. This apparent discrepancy is because turbidity and TSS measure different water quality parameters: turbidity measures the amount of light scattering, and can be affected by dissolved solutes (i.e., dissolved organic matter) as well as physical particles. TSS measures the physical particles retained by a 0.7 µm filter.
- Apparent Color (using data from October 2009 through June 2017) decreased significantly ($p < 0.05$) at MB2, MB3 and MB4.
- Salinity decreased significantly ($p < 0.05$) at all stations.

These temporal differences at each station are potentially related to the unique flow regimes and inputs across the Bay. The decreasing salinity at all stations indicate a potential increase of freshwater inputs from, for example, rainfall runoff.

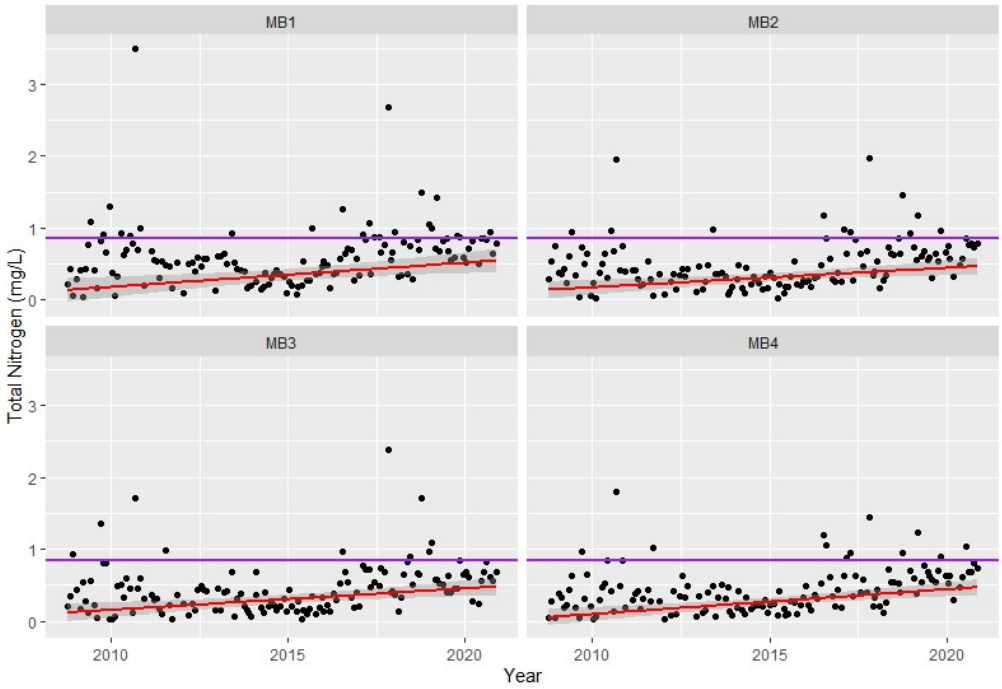

Figure 30. Long-term (2008 – 2020) total nitrogen concentrations at the four Moorings Bay water quality stations; red trendline indicates significant increasing trend ($p < 0.05$). Purple line represents regulatory criteria applicable to Bay-wide conditions over FDEP Verified Period (January 1, 2013- June 30, 2020).

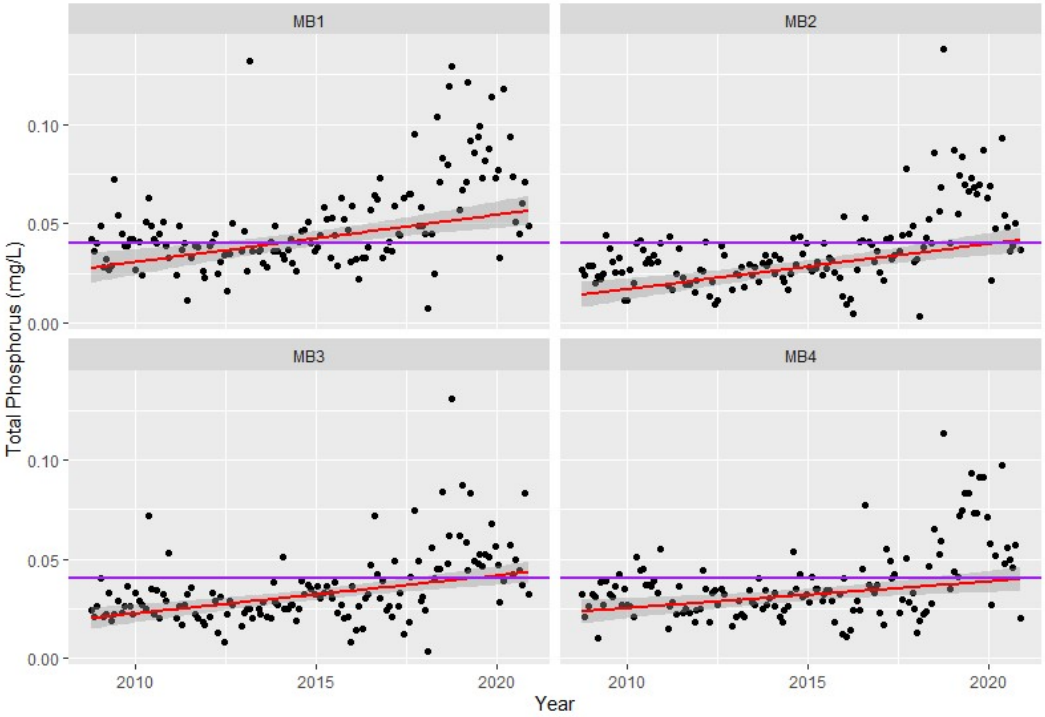

Figure 31. Long-term (2008 – 2020) total phosphorus concentrations at the four Moorings Bay water quality stations; red trendline indicates significant increasing trend ($p < 0.05$). Purple line represents regulatory criteria applicable to Bay-wide conditions over FDEP Verified Period (January 1, 2013- June 30, 2020).

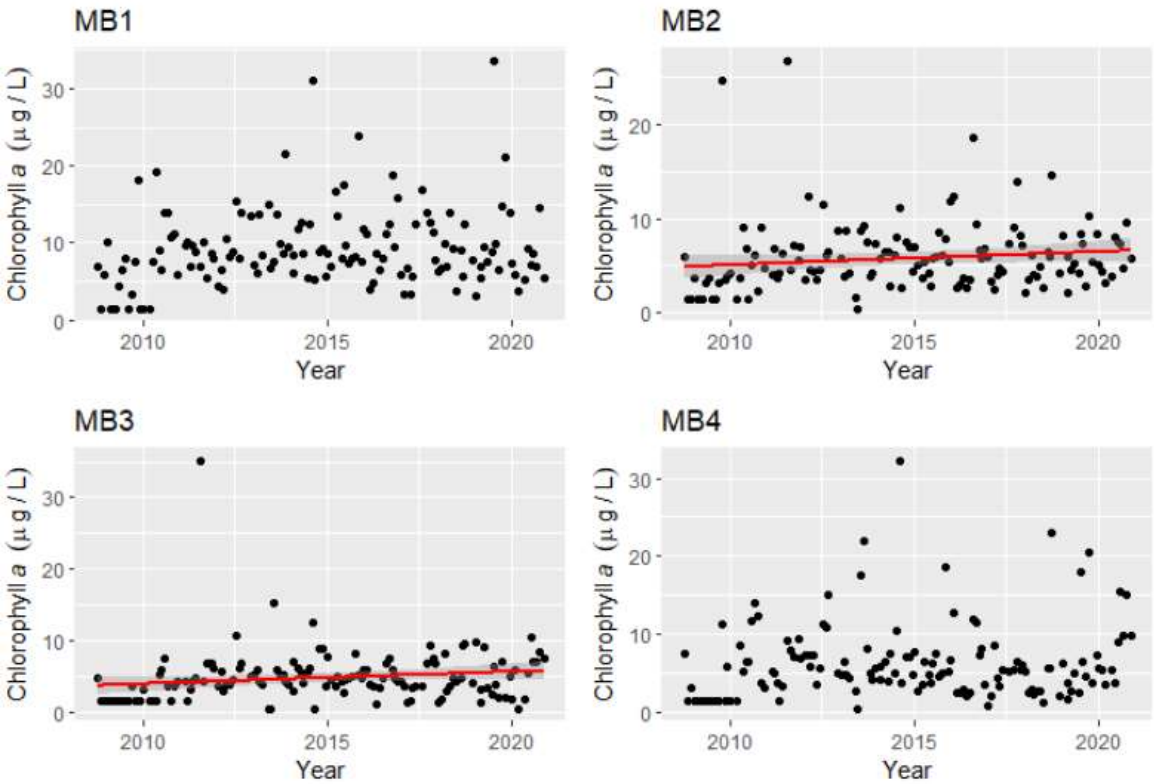

Figure 32. Long-term (2008 – 2020) chlorophyll-a concentrations at the four Moorings Bay water quality stations; red trendline indicates significant increasing trend ($p < 0.05$).

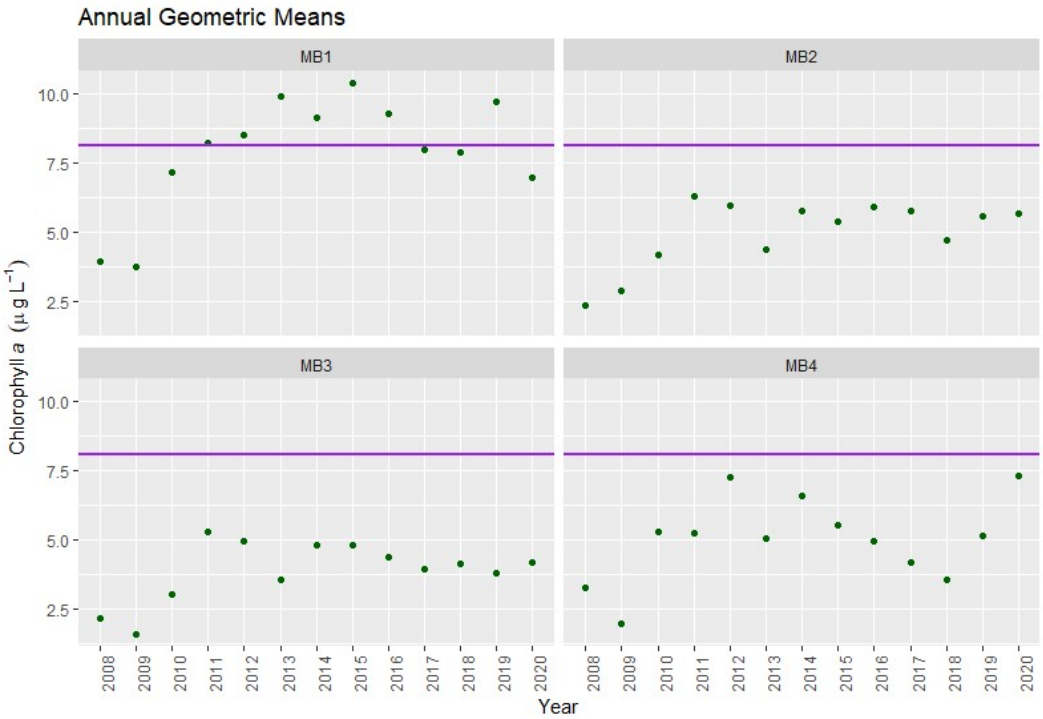

Figure 33. Long-term (2008 – 2020) annual geometric mean chlorophyll-a concentrations at the four Moorings Bay water quality stations. Purple line represents regulatory criteria applicable to Bay-wide conditions over FDEP Verified Period (January 1, 2013- June 30, 2020).

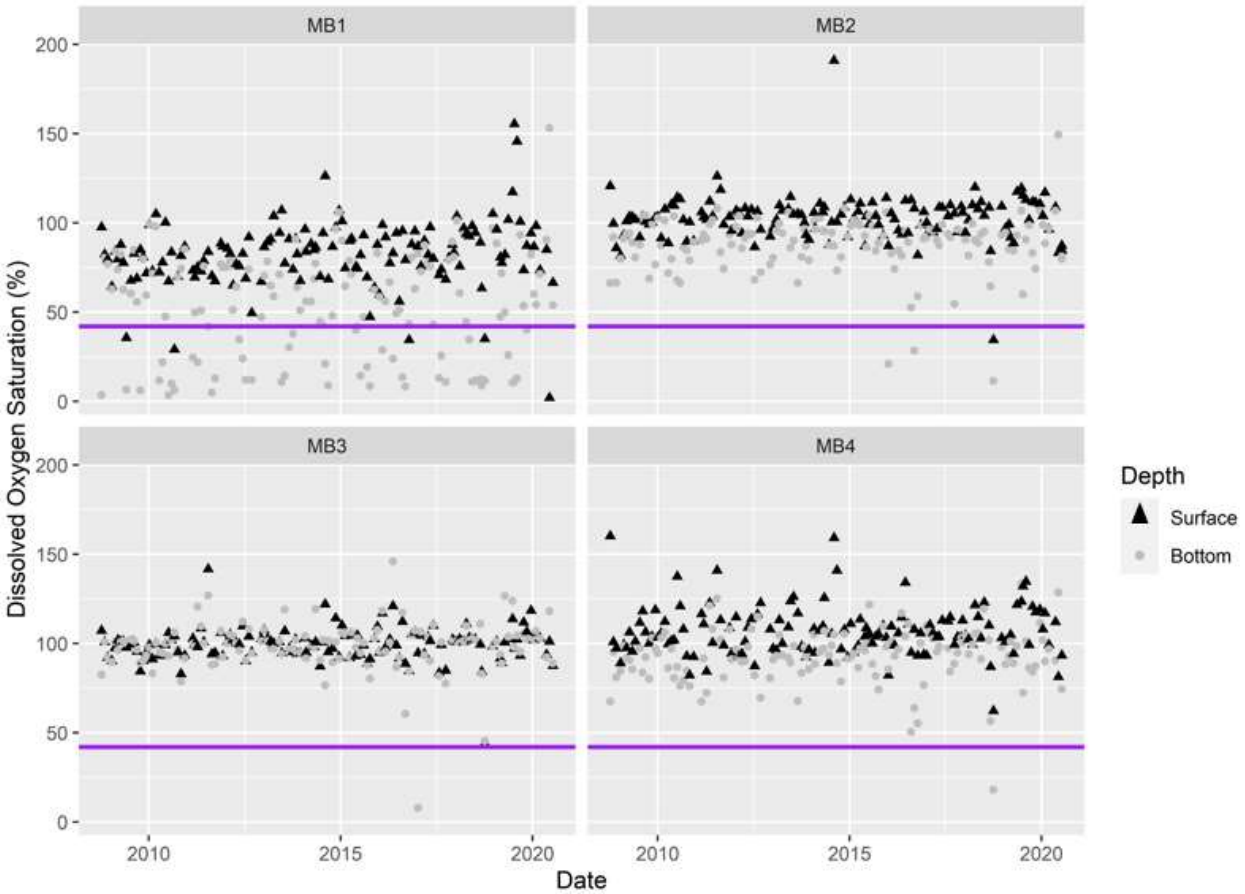

Figure 34. Long-term (2008 – 2020) dissolved oxygen saturation at the four Moorings Bay water quality stations; a significant trend over time was not observed at the stations. Purple line represents regulatory criteria applicable to Bay-wide conditions over FDEP Verified Period (January 1, 2013- June 30, 2020). "Surface" (≤0.3 m) and "Bottom" (>0.3 m) results are plotted with unique shapes and colors and were analyzed for trends separately.

Table 7. Mann-Kendall Trend tests for station MB1 (October 2008 through November 2020).

Parameter	Tau	Slope (Annual Rate of Change)	p-value	Trend
Total Kjeldahl Nitrogen (mg/L)	0.15	0.028	0.007	Significant Increase
Nitrate + Nitrite (NOx) (mg/L)	-0.39	-0.002	<0.001	Significant Decrease
Secchi Disk Depth (m)	0.04	0.000	0.54	No Significant Trend
Turbidity (NTU)	0.28	0.008	<0.01	Significant Increase
Total Suspended Solids (mg/L)	-0.25	-0.983	<0.001	Significant Decrease
Apparent Color (PCU)*	-0.08	-0.161	0.030	No Significant Trend
Salinity (ppt)	-0.15	-0.141	<0.01	Significant Decrease
*- POR is October 2009 through June 2017				

Table 8. Mann-Kendall trend tests for station MB2 (October 2008 through November 2020).

Parameter	Tau	Slope (Annual Rate of Change)	p-value	Trend
Total Kjeldahl Nitrogen (mg/L)	0.16	0.023	0.005	Significant Increase
Nitrate + Nitrite (NOx) (mg/L)	-0.54	-0.003	<0.001	Significant Decrease
Secchi Disk Depth (m)	0.02	0.003	0.75	No Significant Trend
Turbidity (NTU)	0.24	0.008	<0.001	Significant Increase
Total Suspended Solids (mg/L)	-0.17	-1.283	<0.001	Significant Decrease
Apparent Color (PCU)*	-0.26	-0.829	<0.001	Significant Decrease
Salinity (ppt)	-0.16	-0.136	<0.01	Significant Decrease
*- POR is October 2009 through June 2017				

Table 9. Mann-Kendall trend tests for station MB3 (October 2008 through November 2020).

Parameter	Tau	Slope (Annual Rate of Change	p-value	Trend
Total Kjeldahl Nitrogen (mg/L)	0.25	0.036	<0.001	Significant Increase
Nitrate + Nitrite (NOx) (mg/L)	-0.47	-0.002	<0.001	Significant Decrease
Secchi Disk Depth (m)	0.03	0.000	0.60	No Significant Trend
Turbidity (NTU)	0.20	0.248	<0.001	Significant Increase
Total Suspended Solids (mg/L)	-0.26	-1.583	<0.001	Significant Decrease
Apparent Color (PCU)*	-0.32	-0.996	<0.001	Significant Decrease
Salinity (ppt)	-0.18	-0.139	<0.01	Significant Decrease
*- POR is October 2009 through June 2017				

Table 10. Mann-Kendall trend tests for station MB4 (October 2008 through November 2020).

Parameter	Tau	Slope (Annual Rate of Change)	p-value	Trend
Total Kjeldahl Nitrogen (mg/L)	0.27	0.036	<0.001	Significant Increase
Nitrate + Nitrite (NOx) (mg/L)	-0.45	-0.002	<0.001	Significant Decrease
Secchi Disk Depth (m)	0.03	0.000	0.60	No Significant Trend
Turbidity (NTU)	0.25	0.139	<0.001	Significant Increase
Total Suspended Solids (mg/L)	-0.40	-0.009	<0.001	Significant Decrease
Apparent Color (PCU)*	-0.17	-0.663	<0.05	Significant Decrease
Salinity (ppt)	-0.19	-0.158	<0.01	Significant Decrease
*- POR is October 2009 through June 2017				

5.5 Water Quality by Season at Moorings Bay Water Quality Stations

The seasonal comparison for wet versus dry median concentrations over the 2008 – 2020 period for TN, TP, Chl-a, copper, Enterococci, and DO saturation are included in **Table 11** and summarized below:

- TN and TP were significantly higher in the wet season at MB1, MB2, and MB4; a seasonal difference was not observed at MB3.
- The concentrations of Chl-a were higher in the wet season at all four stations.
- Seasonal significant difference in copper concentrations were not observed at any station.
- DO saturation was lower in the wet season at MB1. Significant seasonal differences were not observed at other stations.
- Seasonal significant difference in Enterococci counts were not observed at any station.
- Salinity was significantly lower in the wet season at all stations.

For the results present in this section, "U" qualified data were set to one-half the MDL, and "I" qualified data were not adjusted. The higher nutrient concentrations in the wet season indicate the influence of precipitation and resulting runoff on nutrient concentrations, with nutrients potentially delivered to the Bay by rainfall runoff.

Table 11. Seasonal (wet vs. dry) comparison of median values of selected water quality parameters. p-values from Mann-Whitney-Wilcoxon Test for independent samples. Wet season include samples collected: June through November, and Dry season includes December through May. Bolded values are significantly different between seasons.

Parameter	Station	Dry Season Median	Wet Season Median	p-value	Significant Difference
Total Nitrogen (mg/L)	MB1	0.0395	0.049	**0.004**	**TN higher in wet season**
	MB2	0.0295	0.0345	**0.04**	**TN higher in wet season**
	MB3	0.027	0.032	0.17	No significant difference
	MB4	0.0295	0.036	**0.004**	**TN higher in wet season**
Total Phosphorus (mg/L)	MB1	0.474	0.59775	**0.008**	**TP higher in wet season**
	MB2	0.316	0.4655	**0.014**	**TP higher in wet season**
	MB3	0.3325	0.488	0.051	No significant difference
	MB4	0.3205	0.498	**0.005**	**TP higher in wet season**
Chlorophyll a (ug/L)	MB1	7.4	9.1	**<0.001**	**Chl-a higher in wet season**
	MB2	4.6	6.6	**<0.001**	**Chl-a higher in wet season**
	MB3	3.8	5.3	**<0.001**	**Chl-a higher in wet season**
	MB4	4.7	7.5	**<0.001**	**Chl-a higher in wet season**
Copper (ug/L)	MB1	1.8	1.82	0.71	No significant difference
	MB2	1.5	1.5	0.94	No significant difference
	MB3	1.375	1.27	0.77	No significant difference
	MB4	1.305	1.5	0.29	No significant difference
Dissolved Oxygen (% Saturation) (surface and bottom averaged)	MB1	76.65	63.85	**<0.001**	**DO lower in wet season**
	MB2	95.7	98.55	0.97	No significant difference
	MB3	100.75	99.1	0.39	No significant difference
	MB4	99.15	100.75	0.46	No significant difference
Enterococci (cfu/100 ml)	MB1	5	6	0.11	No significant difference
	MB2	5	5	0.8	No significant difference
	MB3	5	5	0.87	No significant difference
	MB4	5	5	0.92	No significant difference
Salinity (ppt)	MB1	34.0	33.6	**0.008**	**Salinity lower in wet season**
	MB2	34.5	33.9	**<0.001**	**Salinity lower in wet season**
	MB3	34.8	34.3	**0.002**	**Salinity lower in wet season**
	MB4	34.4	34.0	**0.01**	**Salinity lower in wet season**

5.6 Water Quality and Rainfall Correlations

The rainfall data obtained for the correlation analysis is included in **Figure 35**.

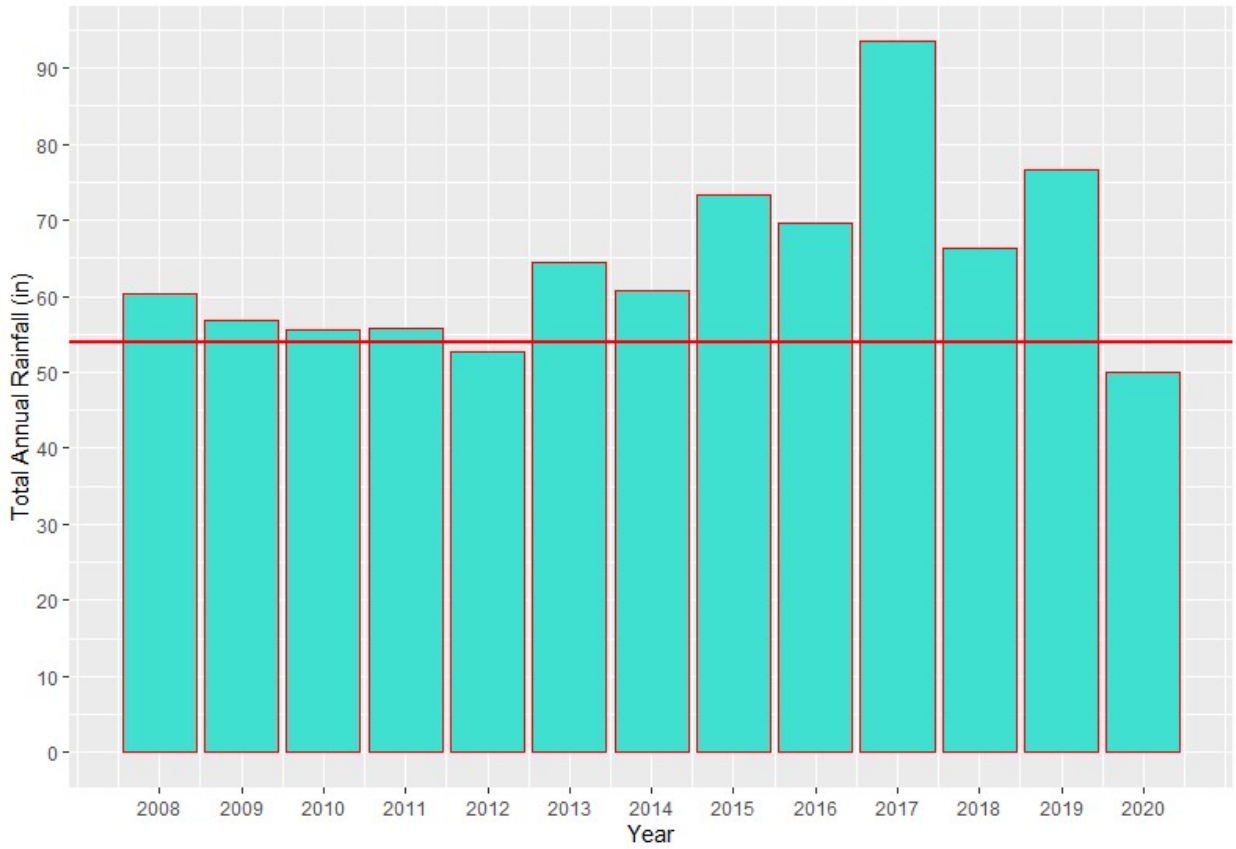

Figure 35. Total annual rainfall (bars) and long-term average (1942 through 2020) rainfall from station USW000012897 (Lat: 26.155°, Long: -81.7752°), located approximately 2.3 miles southeast of the southern end of Moorings Bay.

Correlations among water quality variables were generally low with some exceptions (**Figure 36**). The strongest positive correlations were between salinity and specific conductance. This should not be unexpected, as salinity positively increases specific conductance. Fecal coliform and Enterococcus (a fecal indicator bacteria) were also unsurprisingly correlated. Again unsurprisingly, dissolved concentrations and dissolved oxygen saturation were strongly correlated, since this saturation is directly related to concentration.

Ch-a was negatively correlated with salinity and specific conductance, suggesting that Chl-a is associated with freshwater inputs to the system. Chl-a was positively correlated with both total nitrogen and total phosphorus, suggesting that algae in this system is influenced by both nitrogen and phosphorus. Nitrogen and phosphorus were also correlated with rainfall, suggesting that inputs of these nutrients is driven, in part, by rainfall. Turbidity and Secchi disk depth were negatively correlated, indicating that turbidity has a strong influence on water clarity.

There was a weak (but significant) positive correlation between the precipitation (**Figure 35**) and TN, TP, Chl-a, while precipitation was not correlated with nitrate, ammonia, or orthophosphate (the dissolved fractions) (**Figure 36**). This indicates that the particulate fraction of the nutrients are potentially being delivered to the Bay by rainfall runoff.

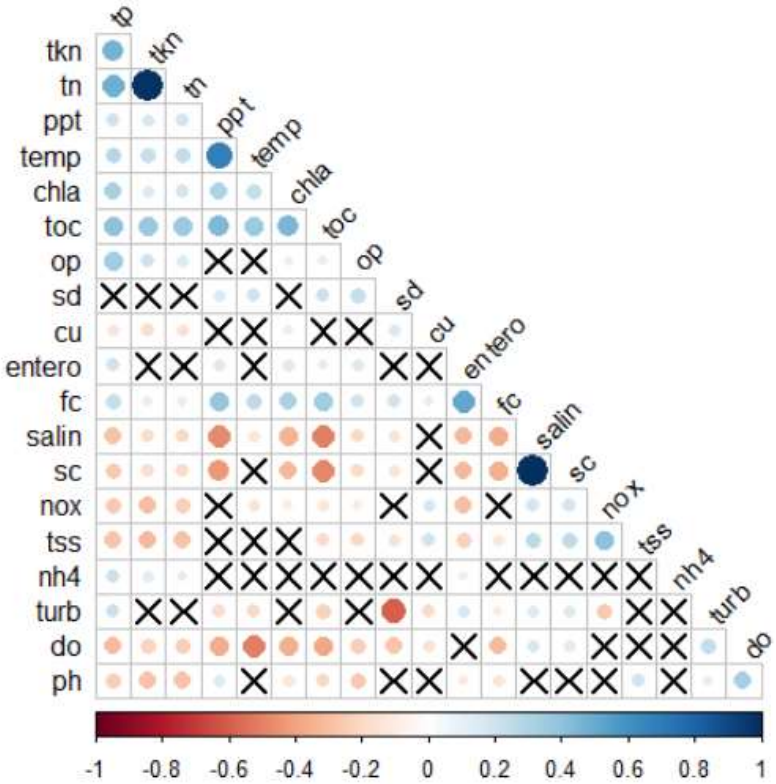

Figure 36. Spearman correlation matrix for water quality variables. Note: Significant ($p < 0.05$) correlations shown with colored circles. An "X" represents nonsignificant correlations ($p > 0.05$). Colors indicate rank correlation coefficients. Labels are as follows: tss = total suspended solids; salin = salinity; sc = specific conductance; turb = turbidity; do = dissolved oxygen; do_sat = dissolved oxygen (% saturation); chla = chlorophyll a; ppt = 30-day total precipitation, prior to sampling; temp = temperature; tn = total nitrogen; tp = total phosphorus; sd = secchi disk depth; col = color; op = orthophosphate; cu = copper; entero = enterococci; fc = fecal coliform.

5.7 Principal Components Analysis

The multivariate analyses of the water quality data provides a clear representation of water quality throughout Moorings Bay, as well as over time (**Figure 37**). The PCA analyses was started with 14 water quality variables, and these were reduced to 10 variables based on variables meeting analytical requirements and collinearity. These final parameters included: Chl-a, dissolved oxygen (mg/L), Enterococcus, salinity, Secchi disk depth, temperature, total nitrogen, total phosphorus, total suspended solids, and turbidity.

The ANOSIM test is a test for differences among stations indicated that there was an overall difference in water quality among the stations (ANOSIM R: 0.362, $p = 0.001$) The pairwise tests suggested that station MB1 was statistically significantly different than MB2, MB3, and MB4 ($p = 0.001$). Station MB2 was also different than MB3 ($p = 0.013$). However, station MB4 was not different than stations MB2 and MB3 ($p > 0.05$).

These results can clearly be observed in the PCA plot (**Figure 37**). The first two axes of the PCA plot, based on the annual average water quality values, explained 55.3% of the variability (31.7% for PC1 and 23.6% for PC2). Stations MB1 and MB3 appeared furthest apart on the plot, suggesting greatest differences in water quality. The vector plot on the right side of **Figure 37**, show the water quality variables separating the stations, and the years. Stations MB1 and MB3 appear to separated by Chl-a and nutrients on the right, suggesting MB1 has higher concentrations of these parameters, as well as higher water clarity (Secchi disk depth). The stations MB2 and MB4 were closer to MB3, suggesting they were more similar to MB3.

Finally, the temporal trajectories in water quality can also be observed in **Figure 37**. For example, all stations appear to be moving to the top right of the figure, driven by higher turbidity, Enterococcus, total phosphorus and total nitrogen.

The second PCA shows differences among years, with these data averaged across all stations (**Figure 38**). Using this approach improved the model fit, with PC1 and PC2 explaining 42.5% and 20.2% of the variability in these data. The water quality variables driving the differences were similar to the first PCA. This analysis shows that the first year (2008) of sampling was different than the following 12 years. This was a result of lower temperature and salinity, with mean values 5.1% lower in 2008 than in 2009. This, in turn, may be due to there only being three samples collected in the fall/winter (October, November, and December) of 2008, which could be biasing based on the seasons that samples were collected. In addition, after 2016, the water quality conditions appear to have changed, driven by higher TN, turbidity, and temperature.

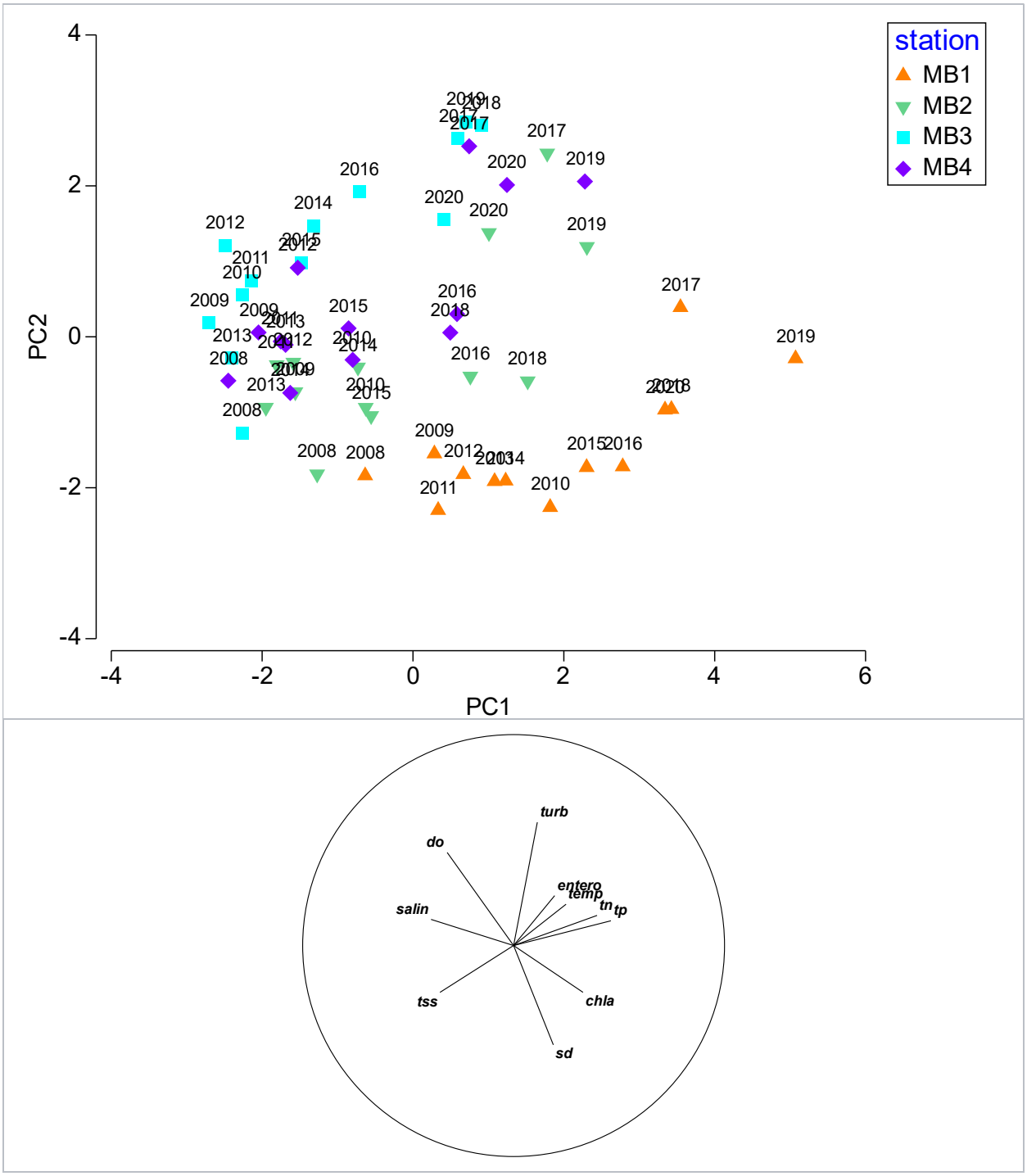

Figure 37. Top: Principal component analyses (PCA) based on average annual water quality data for each station from 2008 through 2020. Note: Points closer in space indicate more similar water quality. **Bottom**: vector plot shows the water quality variables correlated (r > 0.3) with the PCA axes. The length of the vector indicates the strength of the correlations. Note: Symbols are as follows: tss = total suspended solids; salin = salinity; do = dissolved oxygen (mg/L); turb = turbidity; entero = Enterococcus, temp = temperature, tn = total nitrogen; tp = total phosphorus; chla = chlorophyll-a; and, sd = Secchi disk depth.

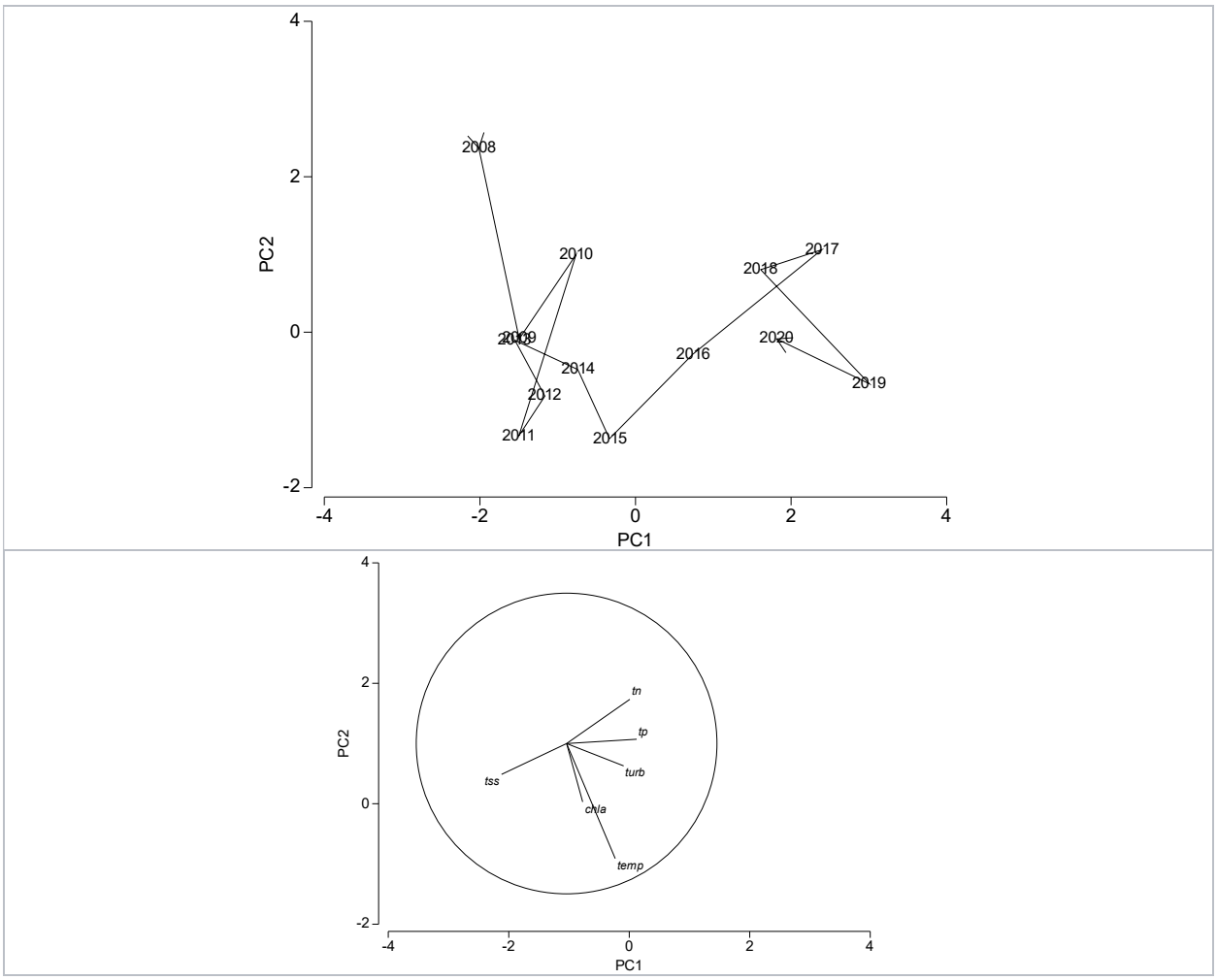

Figure 38. **Top**: Principal component analyses (PCA) ordination plot based on data pooled among sample stations. Years are connected with lines to aid in visualization of temporal changes. Points closer in space indicate more similar water quality. **Bottom**: Correlation vector plot of water quality variables correlated (r > 0.4) with the principal components overlaid as vectors. Note: Symbols are as follows: tss = total suspended solids, turb = turbidity, temp = temperature, tn = total nitrogen; tp = total phosphorus; and chla = chlorophyll-a. The length of the vector indicates the strength of the correlation.

6.0 MOORINGS BAY BIOLOGY RESULTS

From 2009 through 2020, a total of 46,335 animals, representing 84 taxa (67 fishes, one lancelet, seven crustaceans, four mollusks, three echinoderms, one polychaete worm, and one jellyfish) were caught and identified in the trawls (**Appendix B**). Two fish species, Mojarra (*Eucinostomus* spp.) and Bay anchovy (*Anchoa mitchilli*), accounted for over 90% of the abundances. Except for Zone 2, *Eucinostomus* spp. were the most abundant animals (**Figure 33**). Both mojarra and bay anchovies are schooling species, which explains the high relative abundances. Shrimp (*Penaeus* spp.), spot *(Leiostomus xanthurus*), and pinfish (*Lagadon rhomboides*) accounted for the next 3.7% (**Table 12**).

Table 12. Total counts, relative abundances, and Phylum of the ten most abundant taxa caught in trawl samples over the entire period of record.

Common Name	Taxa	Total Caught	Relative Abundance (%)	Phylum
Mojarra	*Eucinostomus* spp.	36,355	78.46	Chordata
Bay Anchovy	*Anchoa mitchilli*	5,539	11.95	Chordata
Shrimp	*Penaeus* spp.	643	1.39	Arthropoda
Spot	*Leiostomus xanthurus*	587	1.27	Chordata
Pinfish	*Lagadon rhomboides*	486	1.05	Chordata
Atlantic Bumper	*Chloroscombrus chrysurus*	268	0.58	Chordata
Blue Crab	*Callinectes* spp.	220	0.47	Arthropoda
Hardhead Catfish	*Arius felis*	194	0.42	Chordata
Sand Seatrout	*Cynoscion arenarius*	182	0.39	Chordata
American Silver Perch	*Bairdiella chrysoura*	174	0.38	Chordata

6.1 Fish and Invertebrates Among Moorings Bay Zones

The variations in the biological community are described below:

- Taxa richness was similar to trawl samples from Rookery Bay, where 72 taxa were identified in Rookery Bay trawl samples collected in the 1970s, 1990s, and 2010s (Schmid and O'Donnell, 2015).
- The relative abundances of the top ten most abundant taxa were variable among zones (**Figure 39**).
- There was no evidence that the abundances per trawl were different among zones (**Figure 40**).
- The mean taxa richness per trawl was highest (9.5) at Zone 3 and lowest (5.1) at Zone 1.
- There was evidence that the taxa richness at Zone 1 was significantly lower than the other zones, and that taxa richness was not different among Zones 2 through 4 (**Figure 41, Table 13**).
- Mojarras were found at all four zones but were most abundant (relative abundance) at Zone 1. Anchovies were also caught at all zones but were more abundant at Zone 2.
- Mean Shannon Index values were lowest at Zone 1 and highest at Zone 2 (**Table 13**). The Shannon Index is a measure of biodiversity, based on species and abundances.

- Mean Pieolou Evenness Index values were relatively low and similar among zones (0.36 to 0.47). This suggests that the species caught in each trawl was dissimilar among sample events (**Table 13**).
- The multivariate analyses of the biological community indicated that the interaction between zone and year was not significant (PERMANOVA test interaction term (zone x year), $p = 0.782$) (**Table 14**). Therefore, this allowed us to pool data across zones and years.
    - After pooling of data, there was evidence to suggest that there were significant differences in the biological assemblages among the zones and years ($p = 0.001$ for both factors) (**Table 15**).
    - The PERMANOVA pairwise comparisons suggested that similarity was relatively low between the zones (30.5 to 38.8% similarity: **Table 15**).
    - There was evidence that the biological assemblages in Zone 1 were different than Zones 3 and 4 ($p < 0.05$). In addition, assemblages in Zone 2 were different than Zone 3 ($p < 0.05$). Finally, the biotic community within Zones 3 and 4 were statistically different ($p < 0.05$) (**Tables 16** through **18**).
    - The CAP plot provides a visual representation of the similarities among the biological communities for each zone (**Figure 42**). Points closer together on the plot have a more similar biological community.
        - While there is some overlap among zones, Zone 1 clusters to the left of the majority of the other zones, especially Zone 3. This suggests that Zone 1 is most dissimilar to the other zones, especially Zone 3.
    - Taxa driving these differences (based on SIMPER tests) were lower abundances of mojarra, bay anchovies, and shrimp at Zone 1, as compared to the other zones (**Tables 16** and **17**).
    - Fish and invertebrates accounting for differences between Zones 2 and 3 were mojarra, shrimp, and bay anchovies. Finally, the biological assemblages at Zone 3 were also significantly different from Zone 4 due to lower abundances of mojarra and bay anchovies in Zone 3 (**Table 18**).
- The PERMDISP is a test of β-diversity, which, in turn is defined as the variability in the biological community composition among sampling units for a given area. If the PERMDISP test is not significant ($p > 0.05$), this suggests that the biological communities among the zones are similar in terms of their composition. The results for the Bay suggest that there are differences in the biological communities among the four zones ($p = 0.019$) (**Table 19**).
    - The variation in biological community structure was lowest at Zone 1, and highest at Zone 4, meaning lowest variability in the species composition at Zone 1, and conversely, the highest at Zone 4. This can be seen by the size of the mean centroids, with Zone 4 being the smallest, suggesting lowest variability in β-diversity over time at this zone.(**Table 20**).
    - In addition, the size of these multivariate dispersions were significantly different between Zones 1 and 4 ($p = 0.012$), again, providing more evidence that these areas differed in terms of species composition.

These results suggest that the biological assemblages in the northern portion of the Bay (Zone 1) are significantly different than the other Zones.

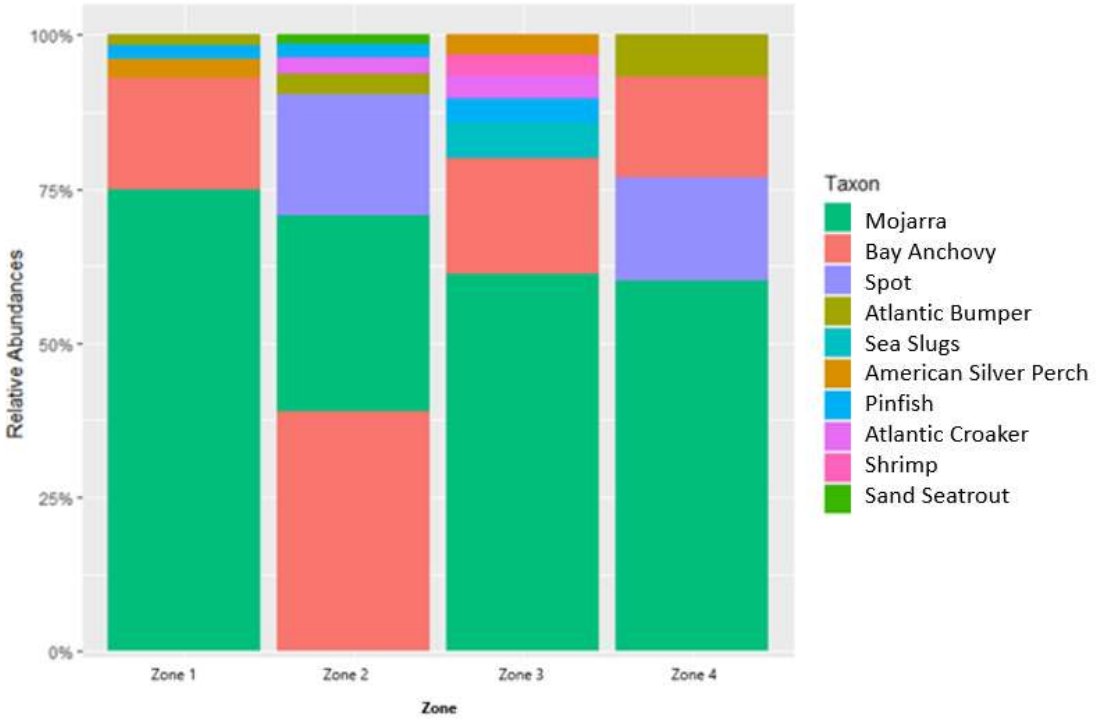

Figure 39. Relative abundances of the ten most abundant taxa by zone. Species in taxon legend listed from highest to lowest abundance.

Table 13. Biological metrics for each zone.

Zone	Total Taxa Richness	Total Abundance	Shannon's Diversity ($H'(\log_e)$) (Mean for Trawls)	Pielou's Evenness ($1-\lambda'$) (Mean for Trawls)
1	48	12,951	0.51	0.44
2	62	10,545	1.26	0.42
3	71	10,107	0.94	0.47
4	57	12,733	0.97	0.36

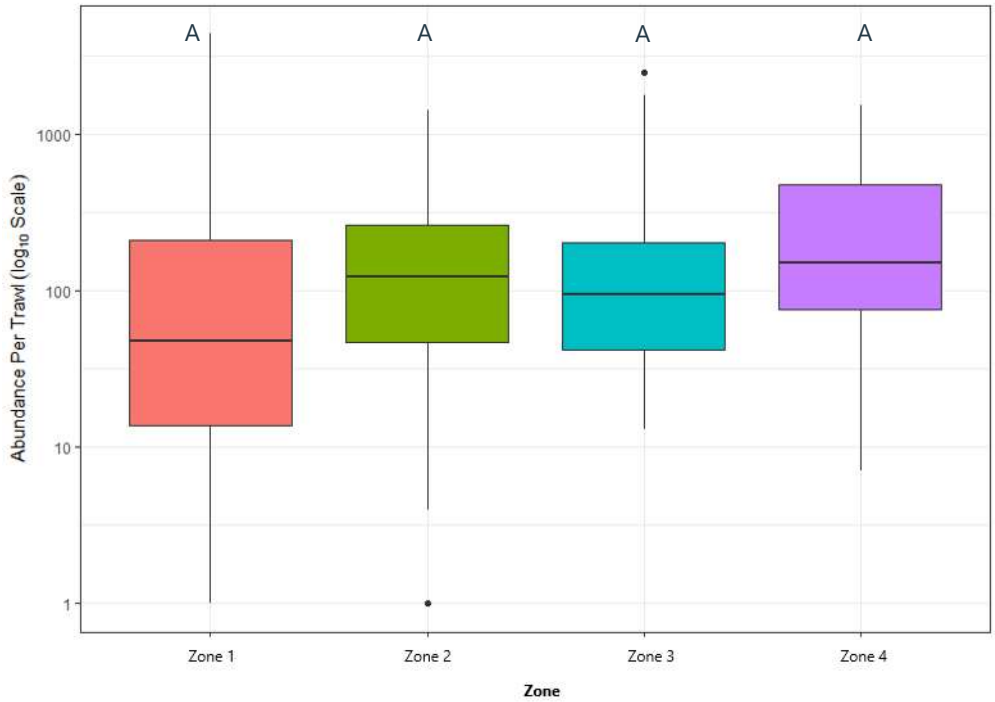

Figure 40. Box plots of total abundances per trawl for each zone. Note: Plotted on a log scale. The middle line represents the median, upper and lower lines represent the 25th and 75th percentile, and whiskers represent 1.5x interquartile ranges. Boxes with the same letter indicate non-significant ($p > 0.05$) differences in the ranked values among Zones. Pairwise tests conducted after conducting a Kruskal-Wallis rank sum test to test for overall differences.

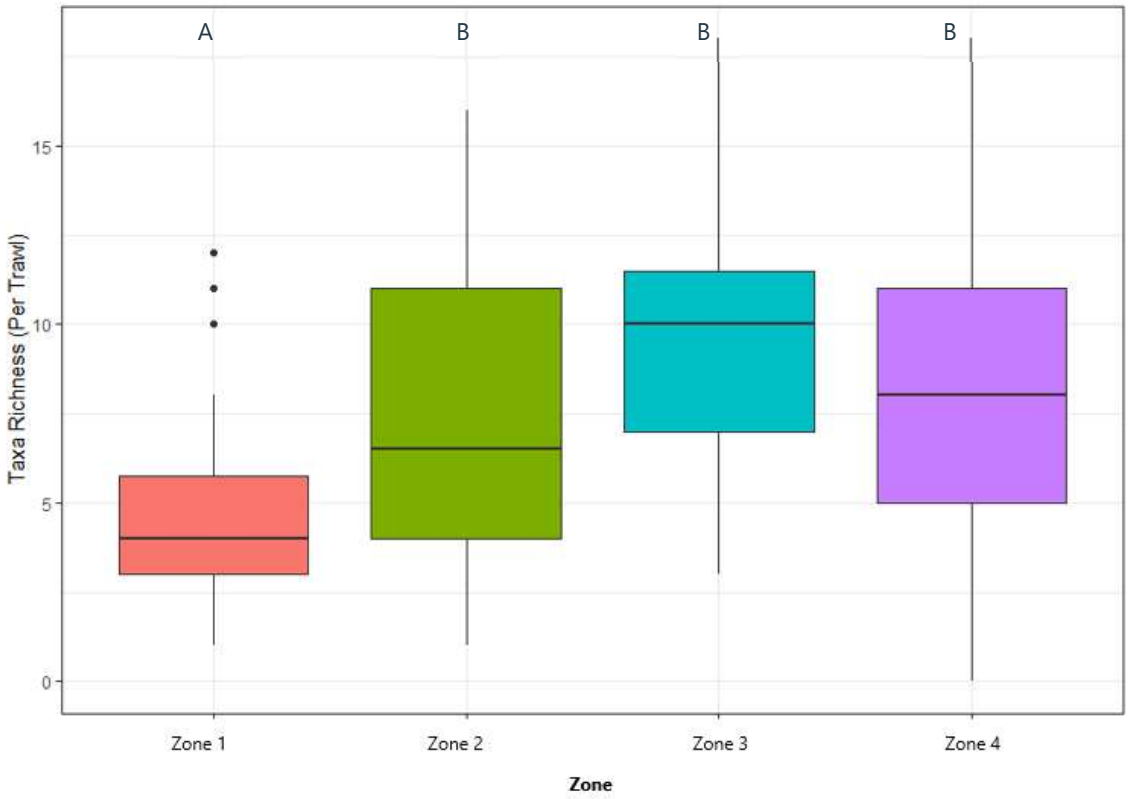

Figure 41. Boxplots of taxa richness per trawl for each zone. Note: Middle line represents median, upper and lower lines represent 25th and 75th percentile, and whiskers represent 1.5x interquartile ranges.

Table 14. Results from main effects PERMANOVA test using log(x+1) transformed biological assemblage data with zone and water years as factors. Significant terms indicated in bold ($p < 0.05$).

Source	df	SS	MS	Pseudo-F	P(perm)	Unique Permutations
Zone	3	19087	6362.2	3.3173	**0.001**	998
Water Year (WY)	9	37299	4144.3	2.0253	**0.001**	995
Zone x WY	27	51734	1916.1	0.9364	0.782	998
Residual	116	2.37E+05	2046.2			
Total	155	3.46E+05				

Note: df = degrees of freedom; SS = sum of squares; MS = Mean squares; Psuedo-F: F-statistic, based on permutation; P(perm) = p-value based on permutations; Unique Permutations: number of permutations in model.

Table 15. Results from PERMANOVA pairwise comparisons among zones, pooled by years. Similarities based on Bray-Curtis Dissimilarity, $\log_{10}(x+1)$ transformed biological data. Significant pairwise comparisons are indicated in bold ($p < 0.05$).

Groups	Average Similarity Between Groups (%)	p-value for PERMANOVA pairwise comparison
Zone 1 and Zone 2	32.5	0.062
Zone 1 and Zone 3	30.5	**0.001**
Zone 1 and Zone 4	33.3	**0.006**
Zone 2 and Zone 3	34.8	**0.008**
Zone 2 and Zone 4	38.2	0.089
Zone 3 and Zone 4	38.8	**0.017**

Table 16. SIMPER results for taxa accounting for differences between Zone 1 and Zone 3.

Species	Zone 1 Av. Abund	Zone 3 Av.Abund	Av.Diss	Contrib(%)	Cumulative(%)
Eucinostomus spp.	3.34	4.15	11.49	16.53	16.53
Penaeus spp.	0.69	1.05	4.51	6.48	23.01
Lagadon rhomboides	0.56	0.54	3.63	5.21	28.22
Lutjanus synagris	0.04	0.75	3.5	5.03	33.25
Anchoa mitchilli	0.41	0.57	3.34	4.81	38.06
Arius felis	0.4	0.59	2.84	4.09	42.15
Luidia spp.	0.04	0.55	2.67	3.84	45.99
Synodus foetens	0.14	0.56	2.67	3.84	49.83
Callinectes spp.	0.45	0.53	2.66	3.82	53.65
Decapodiformes spp.	0.37	0.24	2.14	3.08	56.73
Majoidea spp.	0.21	0.38	2.04	2.93	59.66
Etropus crossotus	0	0.45	2	2.87	62.53
Cynoscion arenarius	0.31	0.19	1.8	2.59	65.12
Ogcocephalus cubifrons	0.02	0.36	1.58	2.27	67.39
Bairdiella chrysoura	0.15	0.34	1.51	2.17	69.56
Orthopristis chrysoptera	0.11	0.34	1.45	2.08	71.64

Note: Av. Diss = average dissimilarity between zones; Contrib (%) = percent contribution of the taxa to this difference; Cumulative (%) = total cumulative percent.

Table 17. SIMPER results for taxa accounting for differences between Zone 1 and Zone 4.

Species	Zone 1 Av.Abund	Zone 4 Av.Abund	Av.Diss	Contrib%	Cum.%
Eucinostomus spp.	3.34	4.63	13.46	20.18	20.18
Anchoa mitchilli	0.41	1.03	5.16	7.74	27.92
Penaeus spp.	0.69	1.12	4.44	6.66	34.59
Synodus foetens	0.14	0.87	3.71	5.57	40.16
Lagadon rhomboides	0.56	0.34	3.27	4.9	45.06
Arius felis	0.4	0.66	3.18	4.77	49.83
Callinectes spp.	0.45	0.51	2.88	4.33	54.15
Cynoscion arenarius	0.31	0.41	2.44	3.66	57.81
Lutjanus synagris	0.04	0.54	2.4	3.6	61.41
Decapodiformes spp.	0.37	0.12	1.91	2.87	64.28
Majoidea spp.	0.21	0.21	1.65	2.47	66.75
Chloroscombrus chrysurus	0.13	0.22	1.37	2.06	68.8
Etropus crossotus	0	0.25	1.18	1.78	70.58

Note: Av. Diss = average dissimilarity between zones; Contrib (%) = percent contribution of the taxa to this difference; Cumulative (%) = total cumulative percent.

Table 18. SIMPER results for taxa accounting for differences between Zone 3 and Zone 4.

Species	Zone 3 Av.Abund	Zone 4 Av.Abund	Av.Diss	Contrib%	Cum.%
Eucinostomus spp.	4.15	4.63	7.18	11.74	11.74
Anchoa mitchilli	0.57	1.03	4.48	7.32	19.05
Penaeus spp.	1.05	1.12	4.12	6.73	25.78
Lutjanus synagris	0.75	0.54	3.09	5.05	30.83
Synodus foetens	0.56	0.87	2.72	4.45	35.28
Arius felis	0.59	0.66	2.56	4.18	39.47
Callinectes spp.	0.53	0.51	2.38	3.89	43.35
Luidia spp.	0.55	0.19	2.31	3.78	47.13
Lagadon rhomboides	0.54	0.34	2.24	3.65	50.79
Etropus crossotus	0.45	0.25	1.92	3.14	53.93
Cynoscion arenarius	0.19	0.41	1.67	2.74	56.67
Majoidea spp.	0.38	0.21	1.54	2.51	59.18
Ogcocephalus cubifrons	0.36	0.14	1.53	2.5	61.68
Orthopristis chrysoptera	0.34	0.23	1.46	2.39	64.07
Bairdiella chrysoura	0.34	0.2	1.34	2.19	66.26
Menticirrhus americanus	0.21	0.13	1.17	1.91	68.17
Chloroscombrus chrysurus	0.09	0.22	1.03	1.68	69.85
Decapodiformes spp.	0.24	0.12	1.02	1.67	71.52

Note: Av. Diss = average dissimilarity between zones; Contrib (%) = percent contribution of the taxa to this difference; Cumulative (%) = total cumulative percent.

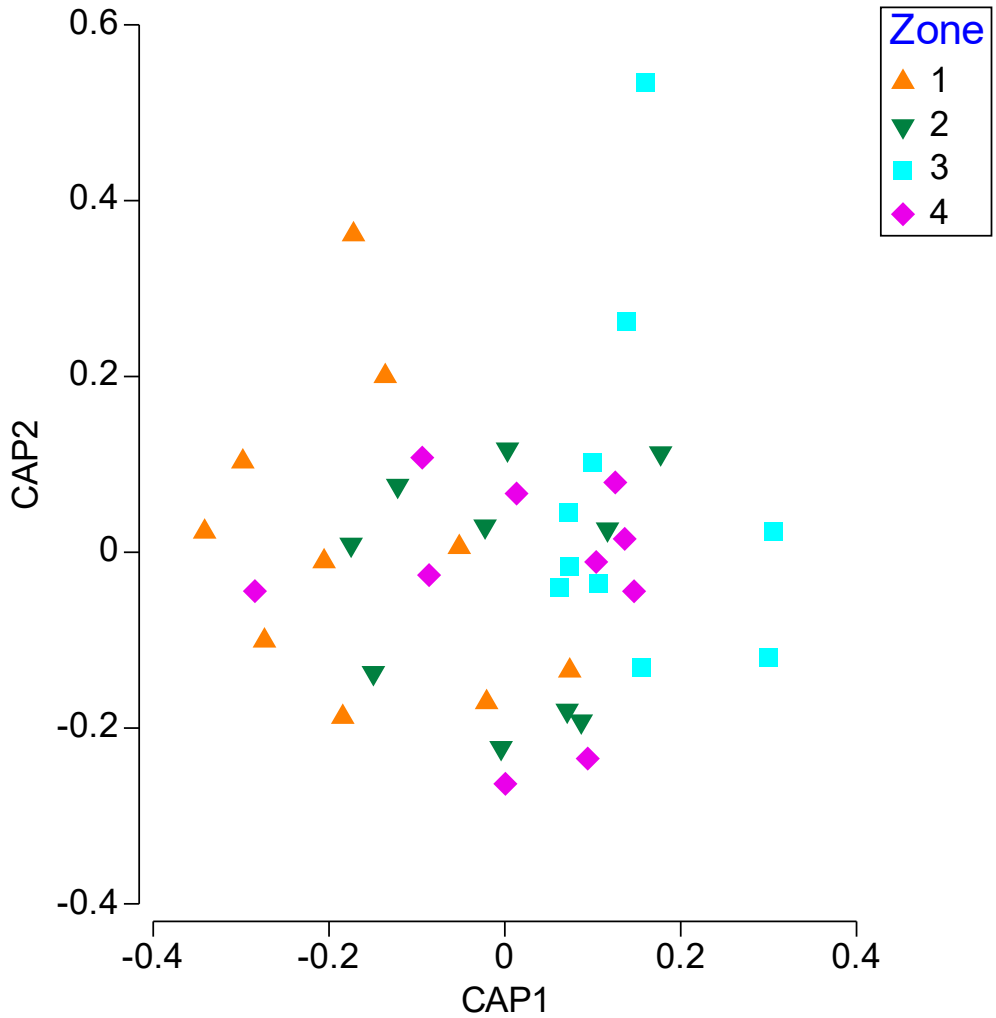

Figure 42. Canonical analysis of principal coordinates (CAP) ordination plot that best discriminate the biological assemblages among the four zones. Each point represents the average (based on the Bray-Curtis resemblance values) biological community for each water year for each zone. Points closer together are more similar, in terms of the biological community. There appears to be overlap among the zones, suggesting similar biological communities. The greatest differences were between Zones 1 and 3 that were furthest apart.

Table 19. Results from PERMDISP for means and standard errors of centroids zones for biological assemblage data pooled over the entire period of record.

Period	Size of Mean Centroid	Standard Error
Zone 1	48.9	2.2
Zone 2	44.9	1.6
Zone 3	43.6	1.1
Zone 4	40.2	1.8

Table 20. Results from PERMDISP pairwise comparison of β-diversity among sampling zones for biological assemblage data pooled over the entire period of record. Significant pairwise comparisons are indicated in bold ($p < 0.05$).

Zones	t-Value	p-value
Zone 1 vs Zone 2	1.46	0.190
Zone 1 vs Zone 3	2.13	0.068
Zone 1 vs Zone 4	**3.06**	**0.012**
Zone 2 vs Zone 3	0.64	0.540
Zone 3 vs Zone 4	1.94	0.092
Zone 3 vs Zone 4	1.61	0.131

Note: t-value is the test statistic for the PERMDISP test.

6.2 Temporal Changes in Fish and Invertebrates for Zones within Moorings Bay

The temporal changes in the biological community within Moorings Bay are summarized below:

- With the exception of some outliers, total abundances were relatively similar over the study period, and typically below 500 animals per trawl (**Figure 43**).
- Taxa richness ranged from 0 to 20, within each zone, with high variability within and among years (**Figures 44, 45**).
- The Mean annual Shannon Index values were most variable at Zone 1, and most stable at Zone 4 (**Figure 46**).
- The mean annual Pielou's evenness values were most variable at Zone 1, and less variable at Zone 4 (**Figure 47**).
- These results suggest that the biological community at Zone 1 was more variable over time, lowest in biodiversity and was relatively uneven.
- The CAP plot illustrating the biological community, suggested that some years (e.g., 2018 and 2019) were different (**Figure 48**). Thus, to improve the ability to discriminate among the years, data were averaged across all zones for each water year.
- The similarity of the biological assemblages, averaged across the water years, was first tested using a clustering technique, then plotted on a nMDS plot (**Figure 49**). These results suggested that for the entire Bay, the biotic community in years 2017, 2018, and 2019 were significantly different than the other years ($p < 0.05$).
    - Differences in years 2017, 2018, and 2019 were driven primarily by lower abundances of bay anchovies, and higher numbers of pinfish and American silver perch. These three species accounted for almost 30% of the differences in the similarity between 2017, 2018, and 2019 versus the other years (**Table 21**). These differences could be related to different

life history and environmental requirements of these species or varying responses to the disruption from Hurricane Irma.

- There was no evidence ($p > 0.05$) of changes in biological compositions (multivariate dispersion) over time (water years) at any of the four zones ($p > 0.05$) (**Figure 50**). Average centroid size appears to have increased in water year 2017 in both Zones 2 and 4, suggesting higher diversity in the trawl samples. β-diversity appears to have declined in the last one to three water years, suggesting the trawl catches are becoming more homogenous. The homogenization is also shown in **Figure 43** where these last three years are clustering closer together than the previous years, with greater distances between points.

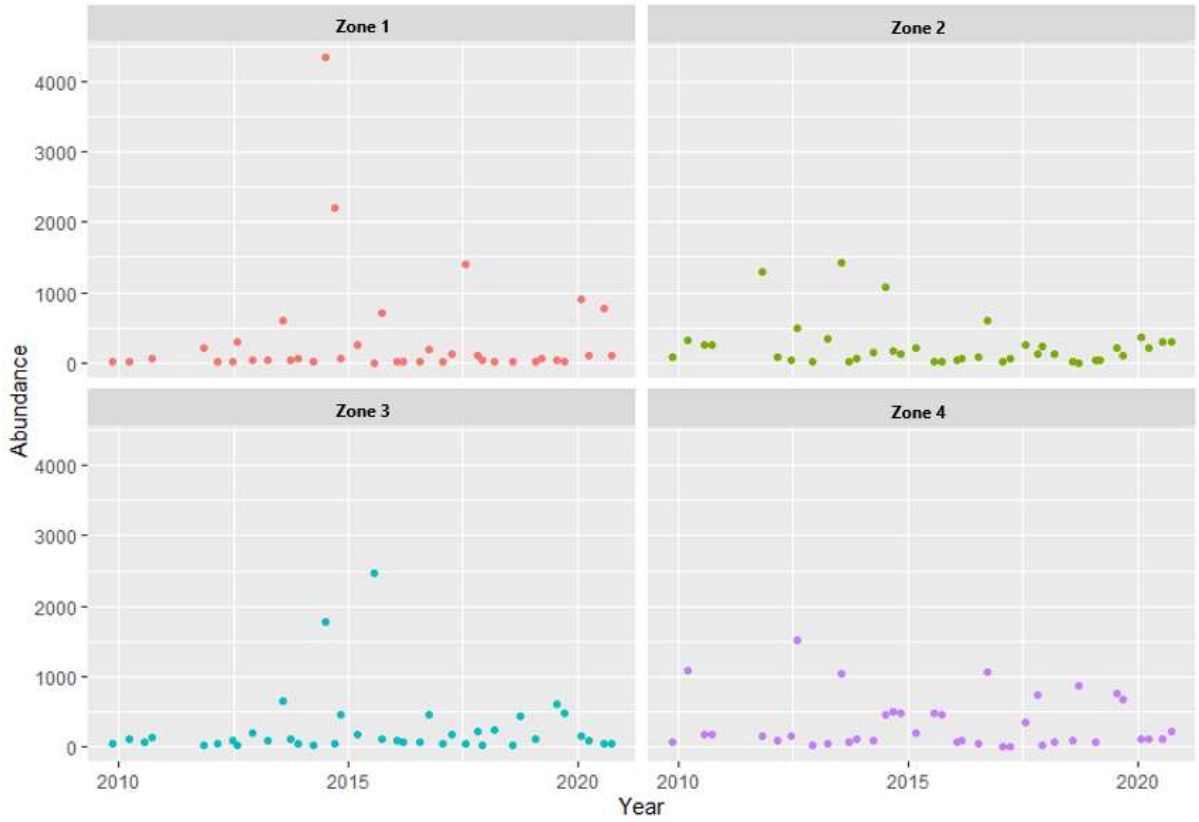

Figure 43. Total abundances per trawl for each zone over the entire period of record.

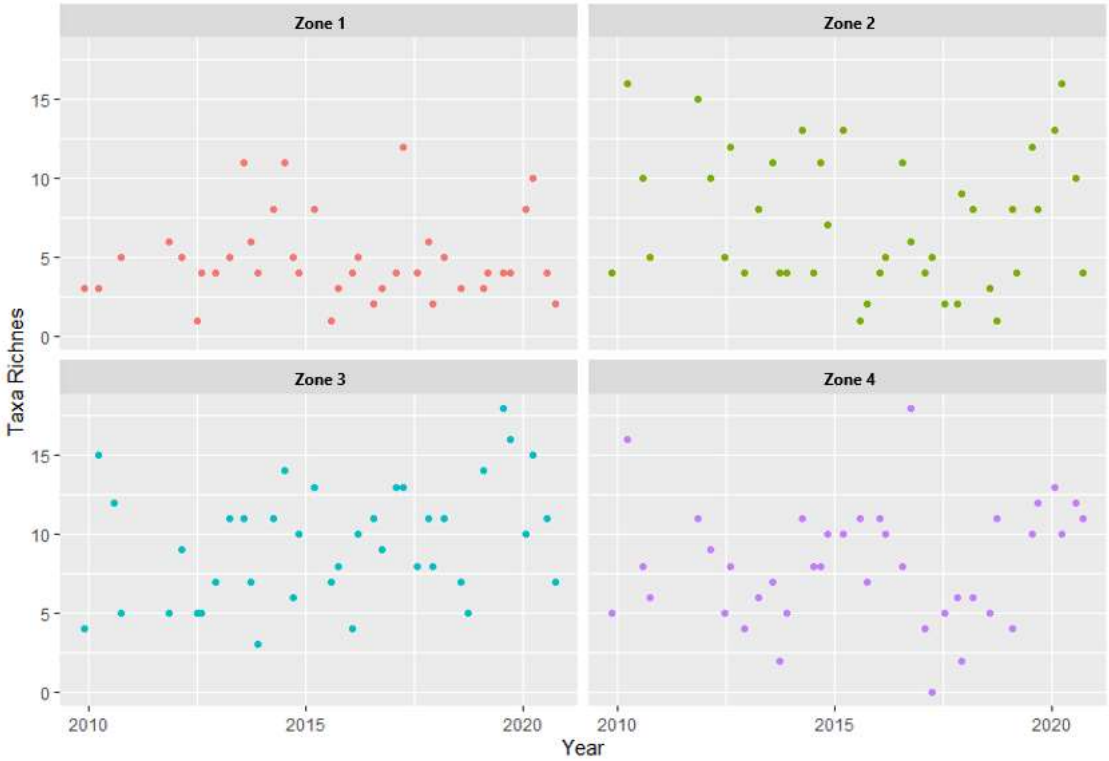

Figure 44. Taxa richness per trawl for each zone over the entire period of record.

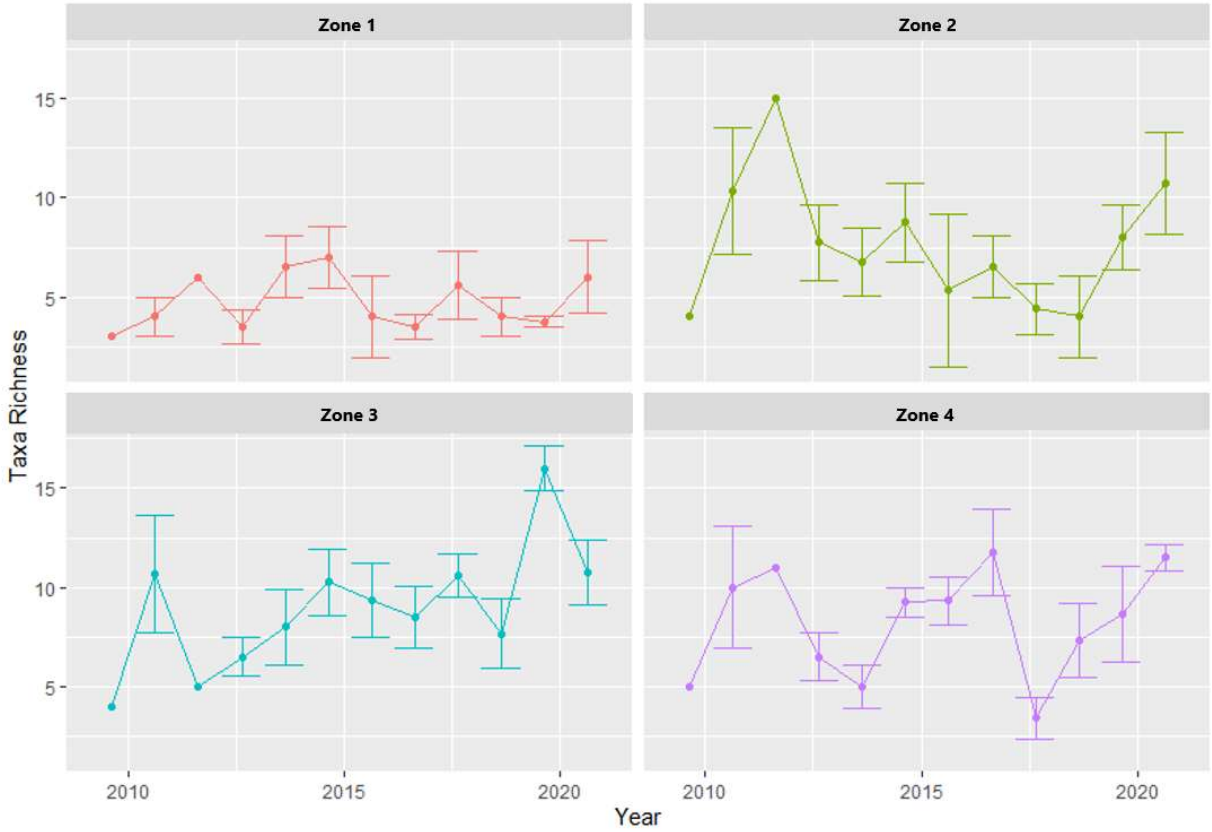

Figure 45. Annual mean (+/- 1 SE) of taxa richness per trawl sample for each zone.

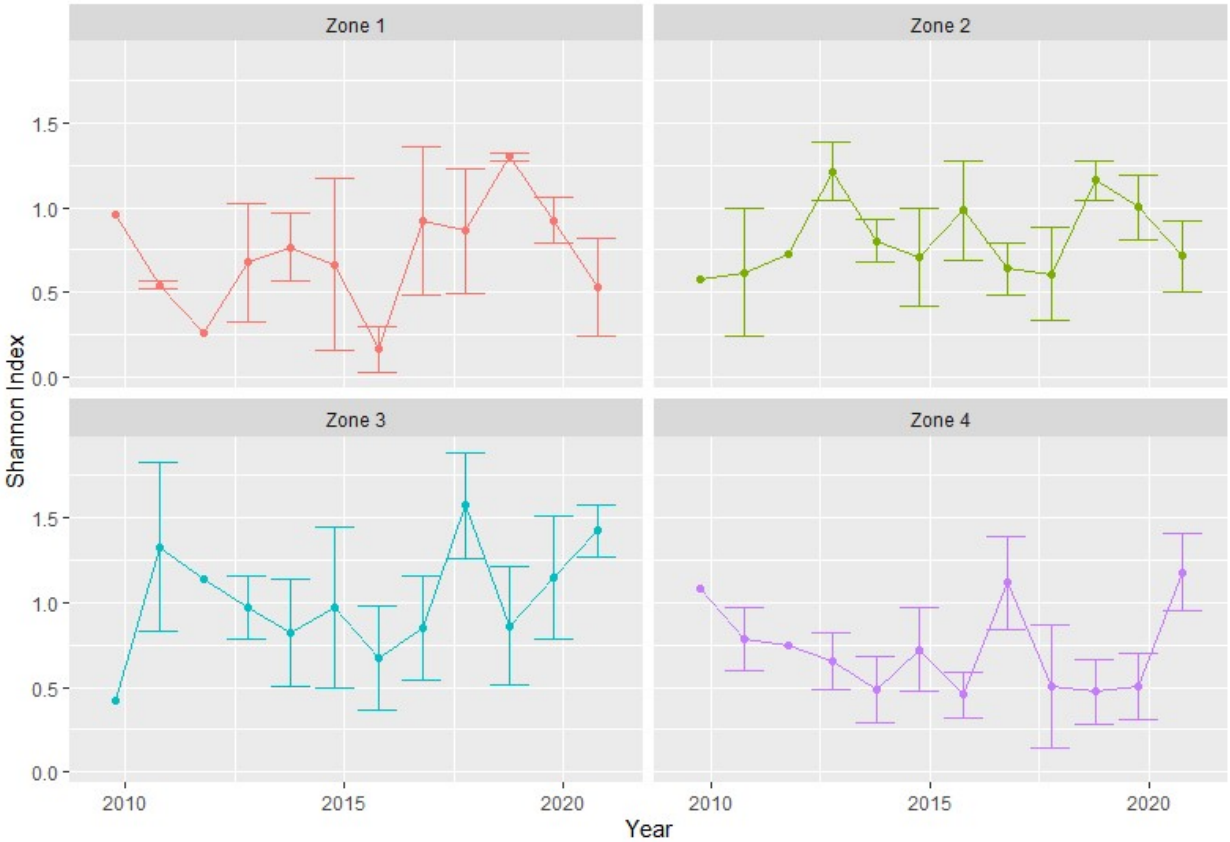

Figure 46. Annual mean (+/- 1 SE) Shannon's Diversity Index values for each zone.

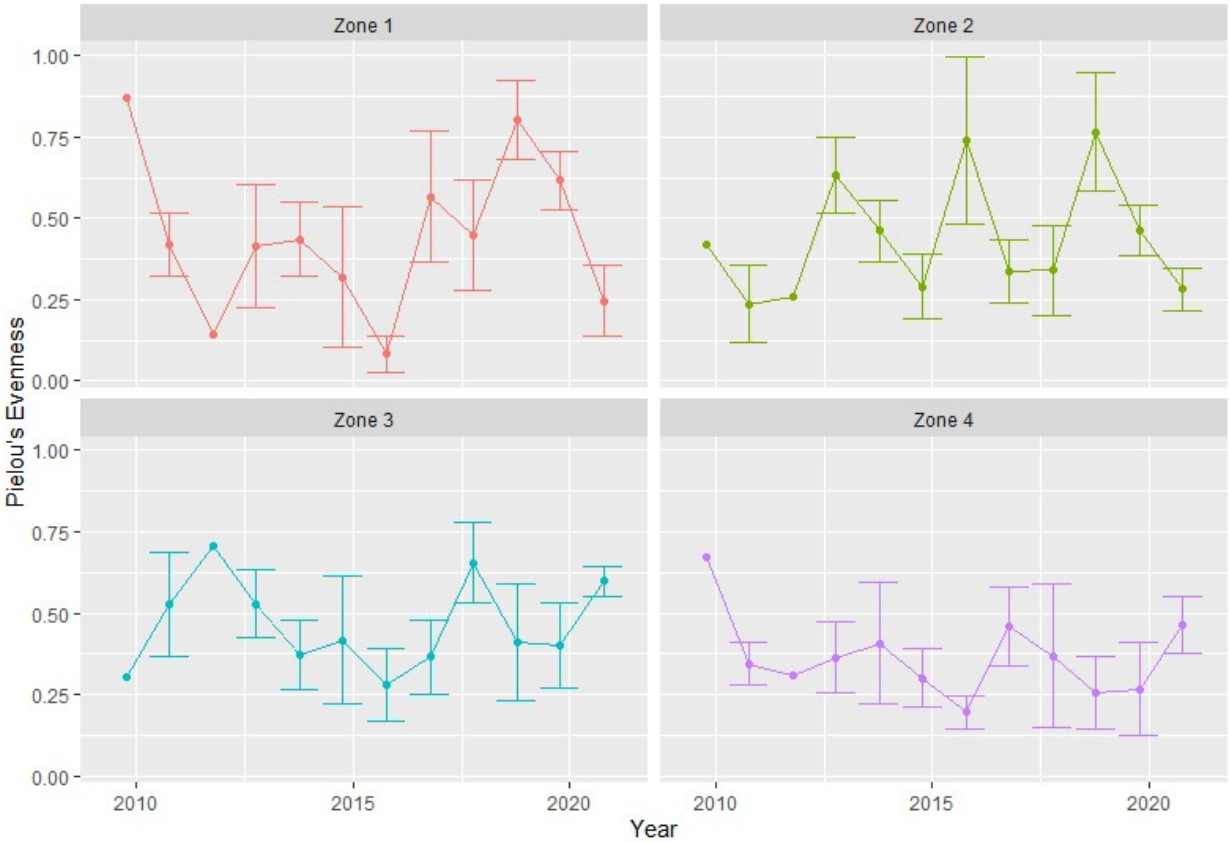

Figure 47. Annual mean (+/- 1 SE) Pielou's Evenness Index values for each zone.

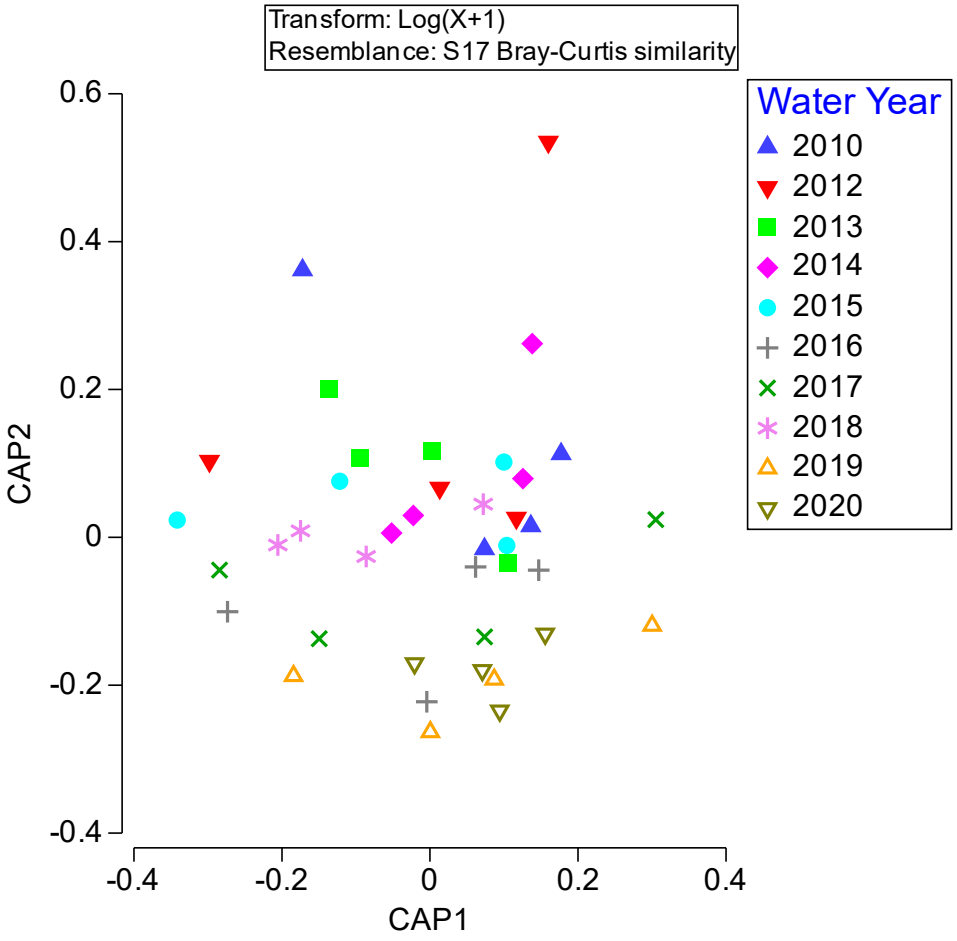

Figure 48. Canonical analysis of principal coordinates (CAP) ordination plot of biological assemblages by water year, by separate zone. Symbols represent annual mean biotic assemblages collected in each calendar year for the four zones. Symbols closer together had more similar biological communities.

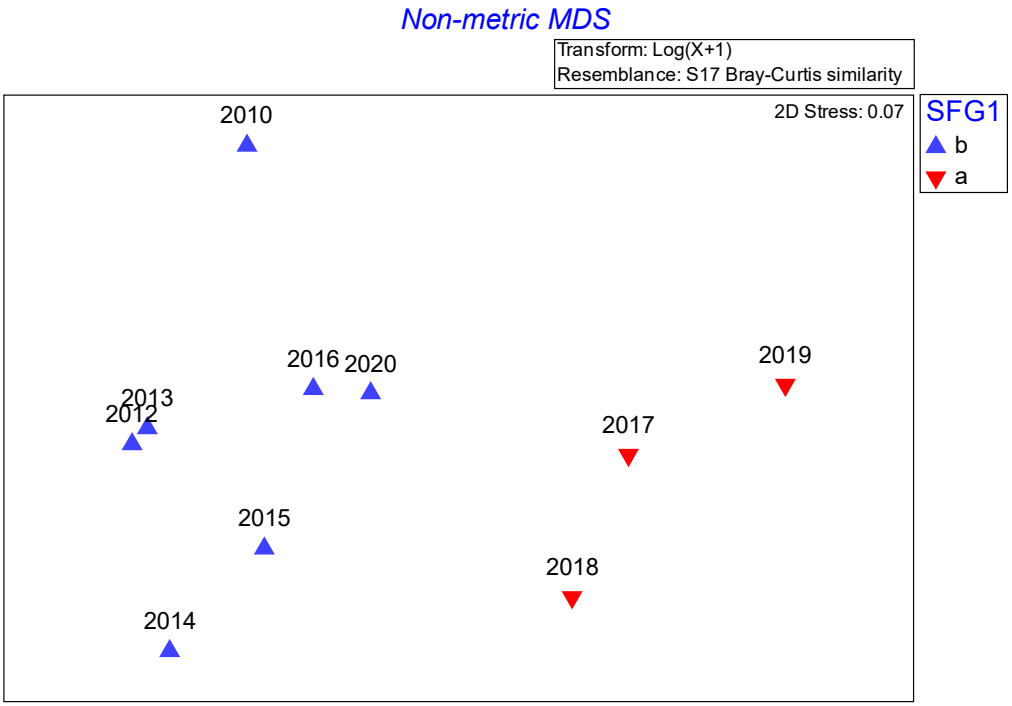

Figure 49. Water year nMDS plot of Bray-Curtis similarity values, based on log10(x+1) transformed biological data. Data were averaged for all zones within each water year. Groupings are signified by "SFG1", based on cluster analyses followed by a SIMPROF test based on the significance of $p < 0.05$. The biotic community of years closer together are considered more similar. Note: Group b Includes years: 2010, 2012, 2013, 2014, 2015, 2016, and 2020. Group a includes years: 2017, 2018, 2019.

Table 21. SIMPER results for taxa accounting for differences between Group a and Group b.

Species	Av.Abund Group b	Av.Abund Group a	Av.Diss	Diss/SD	Contrib%	Cum.%
Anchoa mitchilli	3.65	0.77	6.55	2.47	15.42	15.42
Lagadon rhomboides	0.64	2.16	3.46	2.12	8.13	23.54
Bairdiella chrysoura	0.27	1.27	2.28	1.53	5.36	28.91
Callinectes spp.	0.5	1.46	2.15	3.11	5.06	33.96
Penaeus spp.	1.4	1.57	1.81	1.44	4.25	38.22
Chloroscombrus chrysurus	0.69	0.06	1.52	0.76	3.58	41.79
Cynoscion arenarius	0.85	0.34	1.26	1.71	2.96	44.75
Leiostomus xanthurus	0.55	0.04	1.25	0.44	2.93	47.68
Orthopristis chrysoptera	0.26	0.68	1.18	1.47	2.77	50.45
Majoidea spp.	0.33	0.71	1.08	1.11	2.55	53

Note: Group b Includes years: 2010, 2012, 2013, 2014, 2015, 2016, and 2020. Group a includes years: 2017, 2018, 2019. Av.Abund = average abundance; Av. Diss = average dissimilarity between zones; SD = standard deviation; Contrib% = percent contribution of the taxa to this difference; Cum.% = total cumulative percent.

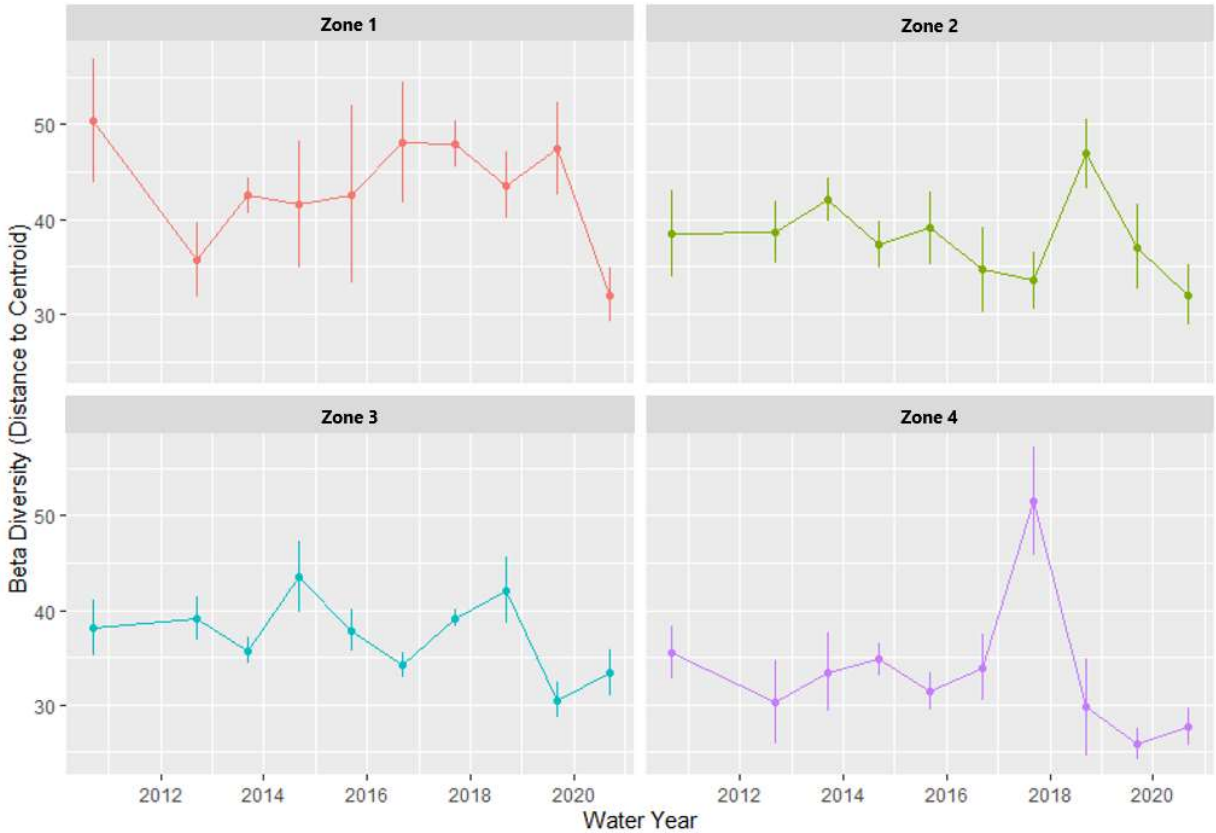

Figure 50. Annual mean (+/- 1SE) distances to multivariate centroids (β-diversity) for trawl samples pooled by water year for each zone.

6.3 Fish and Invertebrates by Seasons in Moorings Bay

Two seasonal analyses were conducted, the first using the finer seasonal divisions (Dry-Early, Dry-Late, Wet-Early, and Wet-Late) and the second using the overall Wet and Dry seasons:

Early-Dry, Late Dry, Early-Wet, Late-Wet

- Differences in biological communities among seasons were tested using PERMANOVA with seasons and zones as main effects.
- Results suggested that the interaction between zones and seasons was not significantly different, and when pooled across zones, the seasons were significantly different ($p < 0.05$) (**Table 22**).
- Pairwise comparisons of biological assemblages captured in the wet-early and wet-late seasons were different ($p < 0.05$) (**Table 23**).
- Higher abundances of mojarra (*Eucinostomus* spp.) were caught in the wet seasons (both early and late), as compared to the dry seasons (**Tables 24** through **28**).

Wet vs Dry Season

- Dry (December-May) versus Wet (June through November) seasons resulted in significant ($p < 0.05$) differences between zones, years, and the interaction of zones and years (**Table 29**).
- Since the interaction term was significant ($p = 0.019$), the seasons were considered separately among the zones. These results suggested that mojarra (*Eucinostomus* spp.) accounted for the greatest difference between wet and dry seasons for all zones, with higher abundances of this fish species in the wet season (similar to above [**Tables 30** through **33**]).
- Pinfish (*Lagadon rhomboides*), anchovies (*Anchoa mitchilli*), and crabs (*Callinectes* spp.) were more abundant in the dry season. These differences could be related to different life history and environmental requirements of these species.

Table 22. Main Effects PERMANOVA for Zones and Seasons (Dry-Early, Dry-Late, Wet-Early, Wet-Late). Significant terms are indicated in bold ($p < 0.05$).

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Season	3	34834	11611	5.958	**0.001**	998
Zone	3	18549	6183.1	3.1727	**0.001**	999
Season x Zone	9	18935	2103.9	1.0795	0.262	998
Residual	140	2.73E+05	1948.9			
Total	155	3.46E+05				

Note: df = degrees of freedom; SS = sum of squares; MS = Mean squares; Psuedo-F: F-statistic, based on permutation; P(perm) = p-value based on permutations; Unique Permutations: number of permutations in model.

Table 23. PERMANOVA pairwise comparisons among seasons. Significant pairwise comparisons are indicated in bold ($p < 0.05$).

Groups	t	P(perm)	perms
WET LATE, DRY LATE	3.4045	**0.001**	999
WET LATE, WET EARLY	1.5961	**0.013**	998
WET LATE, DRY EARLY	2.8833	**0.001**	999
DRY LATE, WET EARLY	2.474	**0.001**	998
DRY LATE, DRY EARLY	1.1697	0.146	995
WET EARLY, DRY EARLY	2.2017	**0.001**	999

Table 24. SIMPER results for taxa contributing to differences between Wet-Late, Dry-Late seasons.

Taxa	Wet-Late Av.Abund	Dry-Late Av.Abund	Av.Diss	Contrib%	Cum.%
Eucinostomus spp.	4.41	3.2	9.75	13.98	13.98
Lagadon rhomboides	0.07	1.59	6.45	9.24	23.22
Anchoa mitchilli	0.43	1.4	5.86	8.4	31.62
Penaeus spp.	0.65	1.2	4.37	6.27	37.89
Callinectes spp.	0.29	1.01	3.77	5.4	43.29
Arius felis	0.39	0.86	3.12	4.47	47.76
Synodus foetens	0.59	0.44	2.53	3.62	51.38
Lutjanus synagris	0.49	0.37	2.49	3.58	54.96
Cynoscion arenarius	0.48	0.06	1.81	2.59	57.55
Decapodiformes spp.	0.36	0.12	1.75	2.51	60.07

Note: Av.Abund = average abundance; Av. Diss = average dissimilarity between zones; Contrib% = percent contribution of the taxa to this difference; Cum.% = total cumulative percent.

Table 25. SIMPER results for taxa contributing to differences between Wet-Late and Wet-Early seasons.

Taxa	Wet-Late Av.Abund	Wet-Early Av.Abund	Av.Diss	Contrib%	Cum.%
Eucinostomus spp.	4.41	4.69	11.37	18.43	18.43
Penaeus spp.	0.65	1.19	4.79	7.77	26.2
Anchoa mitchilli	0.43	1.03	4.54	7.37	33.57
Cynoscion arenarius	0.48	0.52	2.97	4.81	38.38
Arius felis	0.39	0.59	2.89	4.68	43.07
Synodus foetens	0.59	0.41	2.87	4.66	47.72
Decapodiformes spp.	0.36	0.46	2.76	4.48	52.2
Lutjanus synagris	0.49	0.18	2.4	3.89	56.09
Callinectes spp.	0.29	0.34	1.87	3.03	59.12
Chloroscombrus chrysurus	0.31	0.19	1.72	2.79	61.91

Note: Av.Abund = average abundance; Av. Diss = average dissimilarity between zones; Contrib% = percent contribution of the taxa to this difference; Cum.% = total cumulative percent.

Table 26. SIMPER results for taxa contributing to differences between Dry-Late and Wet-Early seasons.

Taxa	Dry-Late Av.Abund	Wet-Early Av.Abund	Av.Diss	Contrib%	Cum.%
Eucinostomus spp.	3.2	4.69	10.51	15.27	15.27
Anchoa mitchilli	1.4	1.03	6.41	9.32	24.59
Lagadon rhomboides	1.59	0.19	5.98	8.7	33.29
Penaeus spp.	1.2	1.19	4.3	6.25	39.54
Callinectes spp.	1.01	0.34	3.4	4.94	44.47
Arius felis	0.86	0.59	2.9	4.22	48.7
Synodus foetens	0.44	0.41	2.1	3.05	51.75
Cynoscion arenarius	0.06	0.52	1.74	2.53	54.28
Decapodiformes spp.	0.12	0.46	1.65	2.39	56.67
Lutjanus synagris	0.37	0.18	1.59	2.31	58.98
Luidia spp.	0.22	0.24	1.44	2.09	61.08

Note: Av.Abund = average abundance; Av. Diss = average dissimilarity between zones; Contrib% = percent contribution of the taxa to this difference; Cum.% = total cumulative percent.

Table 27. SIMPER results for taxa contributing to differences between Wet-Late and Dry-Early seasons.

Species	Wet-Late Av.Abund	Dry-Early Av.Abund	Av.Diss	Contrib%	Cum.%
Eucinostomus spp.	4.41	3.04	10.26	15.21	15.21
Penaeus spp.	0.65	1.05	4.41	6.53	21.74
Anchoa mitchilli	0.43	1	4.4	6.52	28.26
Callinectes spp.	0.29	0.9	3.93	5.82	34.08
Lagadon rhomboides	0.07	0.8	3.46	5.13	39.21
Arius felis	0.39	0.64	2.94	4.36	43.57
Majoidea spp.	0.19	0.56	2.84	4.21	47.78
Lutjanus synagris	0.49	0.38	2.79	4.14	51.92
Synodus foetens	0.59	0.46	2.71	4.01	55.93
Etropus crossotus	0.17	0.36	1.93	2.86	58.79
Decapodiformes spp.	0.36	0.13	1.92	2.85	61.64

Note: Av.Abund = average abundance; Av. Diss = average dissimilarity between zones; Contrib% = percent contribution of the taxa to this difference; Cum.% = total cumulative percent.

Table 28. SIMPER results for taxa contributing to differences between Wet-Early and Dry-Early seasons.

Species	Wet-Early Av.Abund	Dry-Early Av.Abund	Av.Diss	Contrib%	Cum.%
Eucinostomus spp.	4.69	3.04	11.15	16.55	16.55
Anchoa mitchilli	1.03	1	5.41	8.03	24.57
Penaeus spp.	1.19	1.05	4.41	6.55	31.12
Callinectes spp.	0.34	0.9	3.46	5.14	36.26
Lagadon rhomboides	0.19	0.8	3.32	4.92	41.18
Arius felis	0.59	0.64	2.86	4.25	45.43
Majoidea spp.	0.15	0.56	2.62	3.9	49.33
Synodus foetens	0.41	0.46	2.32	3.44	52.77
Etropus crossotus	0.24	0.36	1.96	2.91	55.68
Lutjanus synagris	0.18	0.38	1.83	2.72	58.4
Cynoscion arenarius	0.52	0.03	1.81	2.68	61.08

Note: Av.Abund = average abundance; Av. Diss = average dissimilarity between zones; Contrib% = percent contribution of the taxa to this difference; Cum.% = total cumulative percent.

Table 29. Main Effects PERMANOVA for Zones and Seasons (Wet vs Dry). Significant terms are indicated in bold ($p < 0.05$).

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Season	3	18541	6180.3	3.148	**0.001**	997
Zone	1	27223	27223	13.868	**0.001**	999
Season x Zone	3	8844.5	2948.2	1.5018	**0.019**	998
Residual	148	2.9053E+05	1963			
Total	155	3.4561E+05				

Note: df = degrees of freedom; SS = sum of squares; MS = Mean squares; Psuedo-F: F-statistic, based on permutation; P(perm) = p-value based on permutations; Unique Permutations: number of permutations in model.

Table 30. SIMPER output for taxa in Zone 1 accounting for differences between wet and dry seasons. Average dissimilarity = 77.81.

Taxa	Wet Season Avg. Abundance	Dry Season Average Abundance	Av.Diss	Contrib%	Cum %
Eucinostomus spp.	4.16	1.93	18.86	24.24	24.24
Lagadon rhomboides	0.08	1.37	8.88	11.41	35.65
Penaeus spp.	0.51	1.00	5.17	6.64	42.29
Anchoa mitchilli	0.06	1.00	4.88	6.27	48.56
Callinectes spp.	0.14	0.97	4.74	6.09	54.65
Arius felis	0.31	0.57	3.69	4.74	59.38
Majoidea spp.	0.06	0.46	3.41	4.38	63.76
Decapodiformes spp.	0.55	0.05	3.16	4.06	67.82
Cynoscion arenarius	0.45	0.08	2.56	3.28	71.11

Note: Av. Diss = average dissimilarity between zones; Contrib% = percent contribution of the taxa to this difference; Cum % = total cumulative percent.

Table 31. SIMPER output for taxa in Zone 2 accounting for differences between wet and dry seasons. Average dissimilarity = 66.70

Taxa	Wet Season Avg. Abundance	Dry Season Average Abundance	Av.Diss	Contrib%	Cum %
Eucinostomus spp.	4.29	3.56	7.98	11.96	11.96
Anchoa mitchilli	1.15	1.99	7.89	11.83	23.79
Lagadon rhomboides	0.13	1.48	6.00	8.99	32.78
Penaeus spp.	0.87	1.22	4.38	6.56	39.34
Callinectes spp.	0.38	1.15	4.37	6.56	45.90
Arius felis	0.53	0.79	2.80	4.20	50.10
Decapodiformes spp.	0.69	0.13	2.47	3.71	53.81
Synodus foetens	0.31	0.55	2.11	3.16	56.98
Majoidea spp.	0.05	0.49	2.05	3.07	60.05
Cynoscion arenarius	0.64	0.10	2.01	3.01	63.06
Stomatopoda spp.	0.24	0.46	1.88	2.82	65.88
Prionotus tribulus	0.08	0.47	1.56	2.35	68.22
Harengula jaguana	0.08	0.34	1.38	2.07	70.29

Note: Av. Diss = average dissimilarity between zones; Contrib% = percent contribution of the taxa to this difference; Cum % = total cumulative percent.

Table 32. SIMPER for taxa in Zone 3 accounting for differences between wet and dry seasons. Average dissimilarity = 63.62

Taxa	Wet Season Avg. Abundance	Dry Season Average Abundance	Av.Diss	Contrib%	Cum %
Eucinostomus spp.	4.36	3.74	5.23	8.22	8.22
Lagadon rhomboides	0.11	1.38	4.17	6.56	14.77
Penaeus spp.	1.05	1.04	3.91	6.14	20.92
Callinectes spp.	0.26	1.07	3.17	4.98	25.90
Anchoa mitchilli	0.52	0.67	3.14	4.93	30.83
Lutjanus synagris	0.75	0.75	2.92	4.59	35.43
Luidia spp.	0.55	0.56	2.55	4.02	39.44
Arius felis	0.51	0.74	2.44	3.84	43.28
Ogcocephalus cubifrons	0.19	0.68	2.42	3.80	47.08
Etropus crossotus	0.38	0.60	2.14	3.36	50.44
Synodus foetens	0.66	0.35	2.03	3.18	53.63
Orthopristis chrysoptera	0.22	0.58	1.95	3.06	56.69
Bairdiella chrysoura	0.29	0.44	1.72	2.70	59.39
Majoidea spp.	0.40	0.33	1.69	2.66	62.05
Menticirrhus americanus	0.17	0.31	1.41	2.21	64.26
Prionotus scitulus	0.24	0.27	1.23	1.94	66.20
Decapodiformes spp.	0.24	0.22	1.18	1.86	68.06
Stomatopoda spp.	0.04	0.30	1.02	1.60	69.66
Bursatella leachii	0.16	0.11	0.90	1.42	71.08

Note: Av. Diss = average dissimilarity between zones; Contrib% = percent contribution of the taxa to this difference; Cum % = total cumulative percent.

Table 33. SIMPER output for taxa in Zone 4 accounting for differences between wet and dry seasons. Average dissimilarity = 61.17

Taxa	Wet Season Avg. Abundance	Dry Season Average Abundance	Av.Diss	Contrib%	Cum %
Eucinostomus spp.	5.28	3.34	9.83	16.06	16.06
Anchoa mitchilli	0.95	1.19	5.58	9.12	25.18
Penaeus spp.	1.04	1.28	3.95	6.47	31.64
Synodus foetens	0.89	0.84	2.97	4.86	36.50
Lutjanus synagris	0.46	0.70	2.82	4.62	41.12
Callinectes spp.	0.45	0.63	2.82	4.61	45.72
Arius felis	0.52	0.95	2.76	4.51	50.24
Lagadon rhomboides	0.16	0.69	2.18	3.56	53.80
Cynoscion arenarius	0.61	0.00	2.04	3.33	57.13
Etropus crossotus	0.24	0.28	1.68	2.74	59.87
Menticirrhus americanus	0.08	0.23	1.46	2.38	62.25
Leiostomus xanthurus	0.12	0.46	1.36	2.22	64.47
Majoidea spp.	0.17	0.30	1.26	2.06	66.53
Chloroscombrus chrysurus	0.33	0.00	1.17	1.91	68.44
Orthopristis chrysoptera	0.27	0.16	1.17	1.91	70.35

Note: Av. Diss = average dissimilarity between zones; Contrib% = percent contribution of the taxa to this difference; Cum % = total cumulative percent.

7.0 WATER QUALITY AND BIOLOGICAL INTERACTION RESULTS

Environmental data collected during the trawling events were compared to biological data from the trawls. These data included the following measured during trawling: bottom salinity, bottom temperature, and bottom dissolved oxygen (**Table 34**). Total rainfall data during the previous 30 days were also used in this analysis. The correlation matrix is shown in **Figure 51**.

- The correlation between environmental factors and the biotic metrics, indicated that:
  - Salinity was not correlated with any biotic metrics ($p > 0.05$).
  - Water temperature was positively correlated with abundance in the trawl samples, and negatively correlated with Evenness and Shannon Indices ($p < 0.05$).
  - Higher dissolved oxygen (concentration) was negatively correlated with total abundance (i.e., counts) and positively correlated with Evenness and Shannon indices ($p < 0.05$).
  - Rainfall was similar to temperature, with positive correlations with abundance in the trawl samples, and negatively correlated with Evenness and Shannon Indices ($p < 0.05$).
  - Taxa richness was not correlated with any of the measured environmental factors ($p > 0.05$).
- Correlations between the multivariate structure of the biological community and the environmental factors were analyzed with the BEST routine and indicated that:
  - The highest correlation was between the biological community (based on multivariate structure) and dissolved oxygen ($r = 0.14$). The addition of other environmental factors did not improve the correlation.

Table 34. Water quality parameters measured during trawl sampling and used in the analyses of water quality and biological data.

Environmental Parameter	# of Samples with Usable Data	# of Samples Missing Data	# of Samples that have Depth with "+" Sign	Total # of Samples	Was Parameter Used In Analyses?
Bottom Salinity	153	5	N/A	158	Yes
Bottom Temperature	153	5	N/A	158	Yes
Bottom DO	137	21	N/A	158	Yes
Surface Salinity	24	134	N/A	158	No
Surface Temperature	27	131	N/A	158	No
Surface DO	24	134	N/A	158	No
Depth	85	39	34*	158	No

Note: Depth measurements with a "+" sign following the number could not be used in the multivariate analyses because this number did not represent a true depth for these samples.

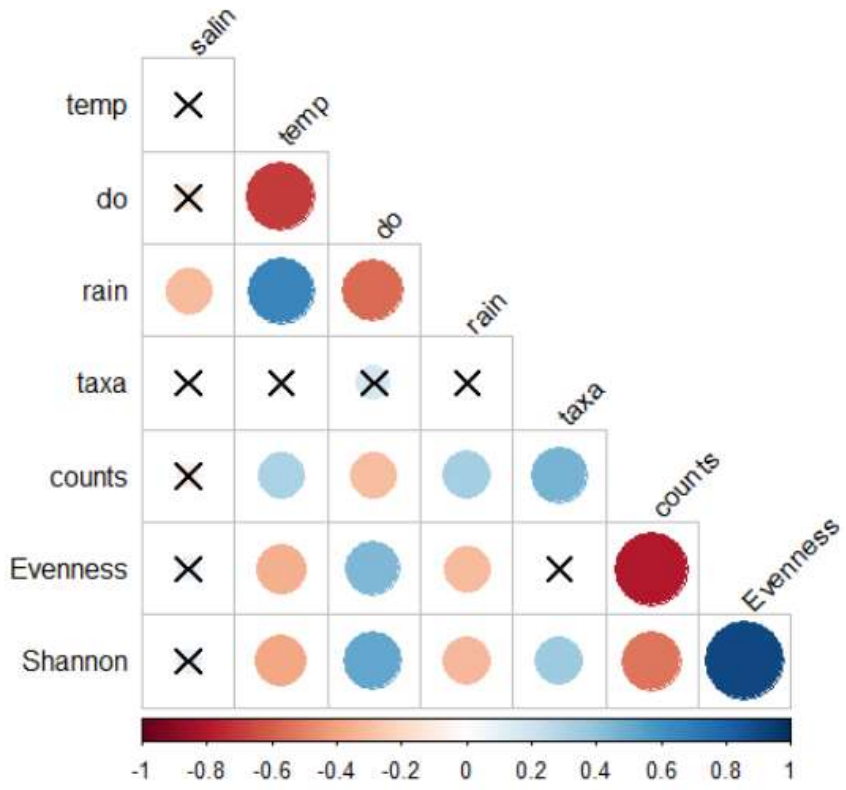

Figure 51. Correlation matrix of environmental factors and biological metrics. Note: salin = salinity (ppt), temp = temperature(C), do = dissolved oxygen (mg/L), rain = sum of rainfall 30 days prior to sampling, taxa = taxa richness, counts = abundances, Evenness = Pielou's Evenness Index, Shannon = Shannon Diversity Index.

8.0 SUMMARY

The goal of this project was to examine the water quality and biological assemblages of Moorings Bay. This project builds upon the 2016 Moorings Bay Water Quality and Biological Analysis Report (Cardno, 2016) and includes analyses of trends in water quality and the biological assemblages, as well as linkages between the two.

Concentrations of TN, TP, and Chl-a are increasing significantly in Moorings Bay **(Table 35)**. The Bay is currently on FDEP's verified impaired list for TP and based on Wood's exceedance analysis, the Bay will remain impaired for TP and will also be impaired for TN. This is consistent with the FDEP's draft verified impaired list status for Moorings Bay. Based on the results of the data analysis, rainfall runoff is likely contributing nutrients to Moorings Bay, with higher concentrations of TN and TP in the wet season and a significant positive correlation between precipitation and TN, TP, and Chl-a. One of the potentially major pathways that runoff enters the Bay is via the stormwater lakes that discharge to the Bay (in addition to other outfalls). Based on the analysis of the stormwater lake data (**Section 1.2**), samples exceeding the downstream Moorings Bay regulatory criteria (which do not apply to the sampled stormwater lakes) for TN, TP, and Chl-a were frequently observed in Devils Lake, Swan Lake, Colonnade Lake, and Lake Suzanne. Clam Bay also generally had higher concentrations of nutrients compared to Moorings Bay.

Overall, water at station MB1 was of lower quality, as compared to water quality at the other Moorings Bay stations. Significantly higher concentrations of TN, TP, and Chl-a were measured at MB1 compared to other stations. A multivariate analysis, examining multiple water quality variables simultaneously, provided additional evidence that station MB1 was different than the other stations (**Figure 41**). MB1 is the closest station to Clam Bay, which (as described in **Section 1.2**) had generally higher concentrations of TN, TP, and Chl-a compared to Moorings Bay. DO stratification was also more pronounced at MB1, which can affect biology and nutrient cycles. Low dissolved oxygen is detrimental to aquatic life and can also accelerate nutrient release from sediments. This is likely related to the location of MB1, at the north end of the Bay, furthest from Doctors Pass, where it is expected to receive less flushing compared to the other stations. The concentrations of TN, TP, and Chl-a were significantly higher at MB1 in the wet season compared to the dry season, indicating that stormwater inputs may also be contributing to these higher concentrations.

Copper temporal trends are not included in the summary table (**Table 35**) below because, as described earlier, the analysis of copper concentrations is potentially affected by the changes in analytical methods over the years. As analytical methods improve, the MDL decreases, and concentrations can be detected at lower levels. These analytical improvements can sometimes translate to an apparent decrease in concentrations over time that is not reflective of actual trends. However, similar to the nutrient concentrations across the stations, station MB1 had higher copper concentrations than the other stations, with significantly higher concentrations in the wet season. Also, an analysis of the number of Class II criteria exceedances over time revealed less exceedances in recent years, again though, the majority of exceedances were found at MB1. Sources of copper in Moorings Bay could include copper-containing antifouling paints used on boats and buoys and from copper-treated timbers in pilings and decks[9]. Copper is also an ingredient in herbicides and algicides to control nuisance algae and aquatic plants in stormwater ponds. As described earlier in **Section 1.2**, the average copper concentrations were higher in the stormwater lakes, with lower concentrations in Moorings Bay (based on data from 2017 through 2020). Devils Lake, at the

[9] Aquatic Life Criteria – Copper, available at: https://www.epa.gov/wqc/aquatic-life-criteria-copper, accessed 2021-10-22.

north end of Moorings Bay showed the highest copper concentrations with the majority of samples exceeding the Moorings Bay Class II Criteria (**Section 1.2**). Similar to the high nutrient concentrations at MB1, copper concentrations at MB1 may be related to stormwater inputs in that area of the Bay and reduced flushing.

Enterococci trends are also not included in the **Table 35** because of potential issues with the MDL. The Enterococci MDL increased over time, potentially artificially increasing the observed concentrations. An analysis of the number of Class II criteria exceedances over time revealed less exceedances in recent years, again though, the majority of exceedances were found at MB1. Enterococci indicates contamination from fecal waste (from humans, pets, and birds) and potential sources include stormwater runoff, sewage discharged from boats. Enterococci can also be found in higher concentrations in sediments compared to the water column (Rothenheber and Jones, 2018), providing a water column source for the bacteria. Like copper, the higher concentrations at MB1 may be related to stormwater inputs and reduced flushing.

Additional parameters were analyzed only at the individual stations (TKN, NOx, Secchi disk depth, turbidity, TSS, color, and salinity) and can provide additional context for the water quality conditions in the Bay:

- The TN trends (increasing both Bay-wide as well as the individual stations) appear to be driven by TKN, rather than NOx. TKN includes the organic sources of nitrogen, potentially indicating that organic sources of nitrogen are increasing; sources of organic nitrogen in the Bay include mangrove areas, or other areas containing high amounts of organic material, such as leaves, grass clippings, debris or soil.
- Indicators of water clarity, including Secchi disk depth, TSS and color exhibited interesting trends: there was no significant trend over time at any station for Secchi disk depth, turbidity increased over time at all stations, and TSS decreased over time at all stations. The Secchi disk depth is a more rudimentary measurement of clarity and is affected by environmental conditions (i.e., color) . Turbidity and TSS are more precise measurements, and though both are indicators of water clarity, they measure different components, have different units, and are not directly comparable. Turbidity measures the passage of light and TSS quantifies the amount of solids. Both methods will detect algae, sediment, and silt (for example), while only TSS will detect settleable solids and only turbidity will detect dyes and organic matter.
- As expected, salinity was significantly higher at MB3, the station closest to Doctors Pass, and significantly lower at MB1, lending support to the idea presented above that there is decreased flushing at MB1.

The fish and invertebrate community of Moorings Bay appears to be similar to other estuaries in Florida. For example, the most abundant species collected in trawl samples from Moorings Bay were mojarra and bay anchovies. High abundances of these fish were collected in trawl samples from Sarasota Bay (Wessel et al., 2013), and Rookery Bay (Schmid and O'Donnell, 2015; Wilkie, 2018). Similar numbers of taxa were also found in Rookery Bay, with 72 taxa identified in samples from the 1970's, 1990's, and 2010's, as compared to 84 taxa identified in Moorings Bay (Schmid and O'Donnell, 2015). Similar, but slightly higher diversity indices were found in the northern Indian River Lagoon in the early 1990s (Tremain and Adams, 1995), where a study found Shannon Indices ranging from 0.9 to 1.4 (in Moorings Bay, Shannon Indices ranged from 0.5 to 1.26).

The composition of the biological community, based on the trawl samples, varied throughout Moorings Bay. It appears that the north zone sample area was different, with fewer taxa, lower diversity indices, and

different multivariate structure (based on both the abundances and taxa). Specifically, fewer numbers of the more abundant taxa, such as bay anchovies, mojarras, and spot were caught in the trawl samples.

While there were some differences over time in the biological community, there was also high variability in the community. Thus, there did not appear to be strong temporal changes in metrics as well as the biological multivariate structure. Differences in the biological community were observed in the years 2017, 2018, and 2019. This may have been due to Hurricane Irma passing over this area in September 2017 and resulting in disruption to the biological assemblages within the Bay. Interestingly, the fish and invertebrate assemblages in 2020 were more similar to the assemblages before 2017, possibly suggesting a recovery from this storm. Over the past three years, the community appears to be becoming more homogenous. A similar trend was observed in long-term Rookery Bay fish community composition data, suggesting the community has become more similar over time. Rookery Bay researchers suggested that this is potentially a result of an observed loss of SAV in Rookery Bay. Therefore, the continuation of the City's Moorings Bay monitoring program is critical, as rapid changes in biological communities are now common throughout the world (Eriksson and Hillebrand, 2019).

Through separate analyses, the poorer water quality and biological data were observed at station MB1 and Zone 1, in the northern part of Moorings Bay. This suggests that the poorer water quality is influencing the aquatic species. The correlation analyses between biological metrics and multivariate data provides further evidence that dissolved oxygen appears to be a significant ($p < 0.05$) factor influencing the biological community. This result was also reported by Cardno (2016).

Table 35. Summary of Bay-wide and station water quality in Moorings Bay

Parameters with Temporal Trend Analysis								
Parameter	**Current Moorings Bay Status**	**Draft Moorings Bay Status (2013-2020)**	**Significant Long-term Trends (2008-2020) ▲=Increasing, ▼=decreasing, ●=no trend**					**Station Concentration Comparison**
			Bay-wide	**MB1**	**MB2**	**MB3**	**MB4**	
Total Nitrogen	Not impaired	Impaired	▲	▲	▲	▲	▲	Significantly higher concentrations at MB1; at MB1, wet season concentrations higher than dry season.
Total Phosphorus	Impaired	Impaired	▲	▲	▲	▲	▲	Significantly higher concentrations at MB1; at MB1, wet season concentrations higher than dry season.
Chlorophyll-a	Not impaired	Not impaired	▲	●	▲	▲	●	Significantly higher concentrations at MB1; at MB1, wet season concentrations higher than dry season.
Dissolved Oxygen Saturation	Not impaired	Not impaired	●	T ●	T ●	T ●	T ●	Significantly lower DO at MB1 (surface and bottom), wet season DO significantly lower. No trend in DO, including top (T) and bottom (B).
				B ●	B ●	B ●	B ●	

Parameters Without Temporal Trend Analysis				
Parameter	**Current Moorings Bay Status**	**Draft Moorings Bay Status (2013-2020)**	**Notes on Class II Criteria Exceedance Analysis**	**Station Concentration Comparison**
Copper	Not impaired	Not impaired	Less Class II criteria exceedances in recent years with majority of exceedances found at MB1.	Significantly higher concentrations at MB1; no seasonal difference observed.
Enterococci	Not impaired	Not impaired	Less Class II criteria exceedances in recent years with majority of exceedances found at MB1.	No significant differences among stations or seasons.

9.0 RECOMMENDATIONS

Moorings Bay is a complex system, receiving stormwater runoff from numerous outfalls and six stormwater lakes, as well as inputs from Clam Bay. Moorings Bay is currently impaired for TP, with concentrations of TP, TN, Chl-a, and Enterococci increasing over time at water quality stations throughout the Bay (TP, TN, and Enterococci concentrations are increasing at all four stations and Chl-a is increasing at MB2 and MB3). Through continued monitoring and study efforts of the Moorings Bay system and ongoing efforts to address stormwater runoff, the City of Naples has demonstrated a commitment to improving water quality. The following recommendations were prepared to assist the City with meeting the goals and objectives of improving water quality and habitat within the Bay. The recommendations are divided into two categories: (1) additional study to add to the body of knowledge of Moorings Bay and (2) a discussion of habitat and water quality improvement projects.

9.1 Moorings Bay Monitoring Recommendations

The current Moorings Bay water quality and biological data collection and analysis program provides valuable data on an important resource and should be continued. Our monitoring recommendations range from suggested alterations to the current Bay monitoring programs to allow for enhanced statistical analysis to additional supplementary data collection to novel, large scale studies, as described below:

- Characterization of benthic habitat including qualitative measurements of sediments, and presence of seagrass: Continue collecting temperature, salinity, and DO and add other parameters such as nutrients and water clarity indicators (turbidity, TSS, and color) at a minimum. Light penetration through the water column is critical for survival of submerged aquatic plants. Furthermore, Lunt and Smee (2020) found elevated turbidity to be associated with decreased fish species richness and diversity and proposed that the elevated turbidity effected community composition and potentially interfered with the fish population foraging ability.
- Assess if the current water quality monitoring stations adequately represent the zones: This could be accomplished by conducting transect sampling across the zones to assess if water quality conditions are relatively homogeneous across the zones. This, in turn, could improve the biological-environmental analyses.
- Improved characterization of the Bay: To help identify potential contaminant hotspots, it is recommended to conduct sediment sampling for nutrients (TN, TP, etc.), metals (Zn, Cu, Ni, Ba), sediment size distribution (percent fines such as silts and clays), and percent organic matter.
- Benthic organisms: A study of the benthic organisms and bottom type would provide additional valuable information about the aquatic organisms found in the Bay and the habitat available. Such data would be useful in the initial stages of planning habitat restoration focused projects.
- Moorings Bay Watershed Management Plan: The current monitoring program provides valuable information on status and trends of the Bay but does not provide enough information to propose site-specific improvement projects. A comprehensive watershed management plan (WMP) can include a hydrologic and hydraulic (H&H) modeling (to assess potential flooding and hydrologic conditions in the watershed), or if resources are limited, then the H&H modeling could be deferred, and a focused surface water resource assessment (the water quality assessment component of a WMP) could be prioritized if flooding is not an issue. The WMP can be used as a tool in the planning, regulation, and management of the Bay's watershed for

future development and as a method for determining and prioritizing capital improvements projects. WMPs can yield results and recommendations for water quality, flood control, and natural system improvement projects. Further, the WMPs can consider sea level rise (SLR), where appropriate, as part of the County's resiliency planning efforts. Special assessments conducted under WMPs that are especially applicable to Moorings Bay include:

  - Pollutant Load Modeling at the Moorings Bay and at sub-basin (i.e., each stormwater lake and/or outfall) levels can be developed to estimate the stormwater and groundwater loads within each basin scale. This assessment is a desktop analysis, assuming drainage basin delineations are sufficiently detailed and permit coverages for existing stormwater treatment systems are available.
  - Additional sampling at lake inflow and lake outflow to quantify in-lake processes (i.e., potential contributions from groundwater seepage and/or sediment flux driven internal loading), and monitoring flows out of lake. However, with the large numbers of stormwater lakes within the City of Naples, specific lakes should be identified for this additional sampling. Sampling frequencies for groundwater seepage typically range from a monthly to bimonthly frequency. Sediment characterization and flux studies are conducted as a standalone study that is not required to be repeated more than once every five years or so unless high sediment accumulations are expected.
  - The contribution of outfalls not associated with the stormwater lake program that are directly discharging to Moorings Bay present a data gap. The City could consider implementing a larger Moorings Bay basin scale pollutant source tracking study to identify nutrient sources and to measure loads. The study would also evaluate not only stormwater, but also wastewater discharges to surface or groundwater (via reclaimed application), and other potential sources such as erosive based sediment transport to the Bay via untreated flow paths.
  - WMPs can be used to guide development of BMP alternatives and conceptual plans for BMPs that can provide the pollutant removal benefits (for example, pounds of TN removed per year) and cost per pound removed.

- Advanced statistical modeling can provide additional insight: For example, with sufficient monitoring data, machine learning techniques such as random forests could help identify and rank the variables that most strongly predict downstream/receiving waterbody conditions (e.g., nutrient concentrations or algae abundance). Random forests analysis has been used as a tool to identify important subbasin level contributions by using decision tree-based analyses. Then, linear mixed effects models could quantify the detected associations and test for statistical significance. The machinery enabling these analyses has already been developed over the course of previous projects by Wood (implemented in the R programming language).

- Lake sediment evaluation: The City should also consider a sediment quality evaluation of all lakes that are discharging to Moorings Bay to inform potential projects. Based on the trends and correlations seen in the results from this study, it is likely that sediment quality may be driving some of the elevated values of nutrients in Moorings Bay.

In addition to the studies described above, Wood also recommends the continuation of the City's current rigorous stormwater lakes monitoring program. Recently (October 2020), the City increased the monitoring efforts to include all six lakes discharging to Moorings Bay. We recommend continuing the stormwater sampling program and ensuring that if programmatic changes are required (e.g., sampling fewer lakes, prioritizing selected lakes), sampling is retained at the six lakes discharging to Moorings Bay. As described earlier, the six lakes discharging to Moorings Bay discharge different runoff volumes to the Bay. While the

actual runoff volumes are unknown, an earlier study (Amec, 2012) described the size of the lakesheds as an indicator of potential lake discharges (where larger lakesheds potentially produce larger lake discharges). According to Amec (2012), Swan Lake (Lake 2) has the highest annual lakeshed volume (171 acre-feet) followed by Devils Lake (a combined 88 acre-feet), Lake Suzanne (85 acre-feet), Hidden Lake (27 acre-feet), Colonnade Lake (26 acre-feet), and Lowdermilk Lake (6 acre-feet). If the City intends to conduct focused studies, Wood recommends additional analysis of the lake volume discharging to Moorings Bay and selecting from the lakes with higher potential discharge and higher concentrations of parameters of concern. For example, based on the lakeshed volume (listed above), Swan Lake or Devil's Lake are potentially larger contributors of stormwater to the Bay and should be prioritized for additional study and for development of water quality improvement projects.

The recommendations above provide data for a broader understanding of the Moorings Bay system. Depending on the habitat and water quality improvement projects that the City of Naples pursues, additional site-specific studies and monitoring programs may also be required.

9.2 Habitat and Water Quality Improvement Projects

Habitat restoration and water quality improvement projects are a primary tool for municipalities to combat the detrimental environmental effects of development and high impervious surfaces in urban watersheds. Beck et al. (2019) conducted a meta-analysis of the cumulative effects of restoration activities on Tampa Bay water quality to identify project types producing the greatest water quality improvements. Beck et al. (2019) reported that water infrastructure projects targeting point and non-point source controls were consistently associated with improved water quality and habitat restoration projects were associated with a lesser magnitude of water quality improvement (where improvement was measured as reductions in Chl-a). However, there are additional benefits from habitat restoration projects (e.g., wildlife habitat improvement, biodiversity) and combining habitat protection and source control could potentially provide the measurable water quality benefits for a similar level of effort. Therefore, a variety of habitat and water quality improvement projects are proposed below, including projects currently being implemented in the Moorings Bay watershed.

Nutrient runoff from nonpoint sources contributes to algae blooms, anoxia, and reduced biodiversity in aquatic environments (Yang and Toor, 2016), and Jani et. al (2020) reported that stormwater runoff is a leading source of nitrogen to waterbodies. Based on the water quality analysis which demonstrated concentrations of TN, TP, Chl-a, and Enterococci increasing over time within Moorings Bay, water quality improvement projects targeting nutrients in stormwater are recommended. For example, additional water quality improvement gains could possibly be made in respect to the potential sediment internal cycling load from contributing lakes. If additional investigation into the potential sediment related loads from lakes finds that loads are extensive, it is recommended that the City move forward with sediment inactivation projects using innovative and highly effective sediment capping products such as Phoslock or Virophos. Unlike some of the more traditional nutrient treatment products, like Alum, Virophos and Phoslock do not require dredging. Wood has tested these products on the bench and mesocosm scales and have found between 80-95% reduction of phosphorus loading from the sediment when the product is applied to the top of the sediment as a chemical cap. The products have both been tested by the manufacturers, distributors and academia and have found the products to be non-toxic and safe for organisms in the benthos and with the waterbody. Additional toxicity information is available from each of the manufacturers (SePRO for Phoslock and Enviremed for Virophos). Phoslock has been approved and permitted by the FDEP to be applied to a couple of lakes in Florida (Pine Lake and Prima Vista Lake). Virophos has not yet been applied at a whole lake scale and only applied during a mesocosm study (Crystal Lake in City of Lakeland).

Additional toxicity information will be available upon completion of the mesocosm study. The City should consider a sediment quality evaluation of all lakes that are discharging to Moorings Bay to rule out if sediment inactivation projects should be prioritized to improve water quality discharging from the lakes into the Bay.

Among other water quality improvement projects, the City encourages the construction of rain gardens and other low impact development projects that also treat the stormwater prior to infiltration into the groundwater. AECOM (2018) identified specific projects in Basins 1 and 2 (which contribute to Moorings Bay), including additional rain gardens and reclaiming swales that have been filled in or landscaped over. Rain gardens (areas designed for water collection and landscaped with plants) and swale reclamation can improve water quality by providing more pervious surfaces that can filter out runoff pollutants[10] that would otherwise be discharged directly to stormwater pipes and lakes. While the City is moving forward with the swale improvement initiative, rain gardens can also be installed in small spaces and homeowners can install rain gardens on their properties to provide both water quality improvement and aesthetic benefits. The LID techniques such as rain gardens, tree boxes and/or enhanced swales can be loaded with biosorptive activated media (BAM) to enhance the potential for nutrient removal prior to infiltration. Homeowners can also utilize Florida-friendly landscaping principles and incorporate low-maintenance plants that don't require as much fertilizer, if any. Residents living on waterways can also plant a vegetative, low-maintenance buffer between seawalls and sodded areas to help capture and slow runoff coming from lawns.

The study and monitoring recommendations (**Section 9.1**) would also provide the opportunity for more targeted projects. For example, the outfall study could identify locations that would benefit from source control projects. Smaller source control projects could include the installation of baffle boxes and/or upflow filters enhanced with BAM at outfalls. BAM can also be incorporated into swales and the outfall study may reveal locations that would benefit from enhanced bioswales. Enhanced bioswales provide both water storage and nutrient removal and can be planted with native vegetation, adding aesthetic and habitat value.

In addition to projects focused on structural controls, the City could consider non-structural control projects such as targeting nutrient pollution through fertilizer regulation and community outreach. The application of fertilizer to residential lawns and sports fields (i.e. ball fields and golf courses) has been recognized as an important source of nitrogen and phosphorus pollution in urban areas (Souto et al., 2019; Yang and Toor, 2016; Yang and Toor, 2017; Krimsky et al., 2021), via stormwater runoff and groundwater infiltration that eventually reaches the surface water system. Most of the several golf courses in the Moorings Bay watershed are likely receiving nutrients from both reclaimed water and additional applied fertilizer. The City should consider engaging with the golf course industry/community to develop a plan to reduce the amount of nutrients that are applied from both reclaimed water and fertilizer. Online tools exist that can assist these entities to calculate the amount of nutrients that are applied via reclaimed water, and thus could reduce the amount of fertilizer that is applied to reduce nutrients in stormwater runoff from the greens.

Municipal and county governments throughout Florida have enacted restrictions on residential fertilizer use as part of water quality restoration efforts (Krimsky et al. 2021). Quantifying the success of these programs at improving water quality is difficult because of the numerous sources of nutrients (e.g., atmospheric deposition, pet waste, yard clippings, septic and wastewater) in addition to fertilizers (Yang and Toor, 2016; Yang and Toor, 2017; Krimsky et al., 2021) and landscape differences (Krimsky et al. 2021). However, Krimsky et al. (2021) reported that the source and concentration of these nutrients are influenced by homeowner

[10] USEPA Rain Gardens, available at: https://www.epa.gov/soakuptherain/soak-rain-rain-gardens, accessed 10/1/2021.

fertilizer behavior and recommended that nutrient management should include outreach and education. The City of Naples has already implemented a fertilizer ordinance[11] and developed web-based outreach materials including a fertilizer calculator that can assist residents along with brochures emphasizing how everyone can do their part to minimize fertilizer impacts to surrounding waterways. Landscape companies are also required to complete the Green Industries Best Management Practices certification provided through the State—an initiative that was started within the City of Naples' and grew statewide based on these efforts. The addition of an environmental public outreach position within the City would allow for the expansion of outreach efforts to landscape companies and Homeowners Associations for example. Other initiatives to supplement ongoing efforts could contribute to a targeted outreach or education campaign.

Moorings Bay may also benefit from habitat restoration focused projects. The City is already taking a habitat restoration approach in Naples Bay with oyster reef restoration[12]. The project aims to provide numerous benefits to Naples Bay, including shoreline resiliency by buffering wave action, water quality improvement via the filter-feeding mechanism of oysters, and benefits to the fish and invertebrate populations. Although oyster reef projects utilizing this same design may not be suitable for Moorings Bay, there are still opportunities to increase community awareness of ecosystem services and the benefits to taking pro-active approaches to increase habitat and gain community support. For example, the shoreline of Moorings Bay is mostly dominated by seawalls, which are vertical structures that provide very little beneficial habitat. Educating homeowners regarding the benefits of using riprap (sloping stone structures) in lieu of seawalls to secure their shoreline can go a long way in providing oyster, fish, and mangrove habitat. An alternative could be placing riprap in front of an existing seawall which will not only extend the life of the seawall but will also provide a sloping structure with nooks and crannies where oysters can attach, mangroves can grow, and fish habitat is created. These types of living shoreline projects could provide valuable habitat, improve water quality, and help abate wave energy from boats and storms.[13]

Lastly, during the biological data analysis, we observed a recent change in the biological community. The years 2017, 2018, and 2019 had significantly lower fish abundance compared to prior years. Hurricane Irma passed over the area in 2017 and the Moorings Bay fish abundance returned to pre-2017 levels in 2020. Although we are unable to attribute the change in fish abundance over time to a severe weather event, Hurricane Irma serves as a good reminder of the loss of resiliency in highly developed watersheds. Urban areas, with high impervious surface coverage and armored shorelines, experience more severe effects (e.g., flooding) from storm events than undeveloped areas. Natural features, like mangroves and salt marshes, that function to mitigate flood risks are missing in urban landscapes. These natural features also provide immense water quality and habitat benefits. Although climate change is threatening these ecosystems, a study currently being conducted at the Rookery Bay National Estuarine Research Reserve aims to evaluate the effectiveness of natural and nature-based features in restoration scenarios[14]. The project has an estimated completion date of August 2022 and may provide valuable insight into estuarine restoration options.

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[11] Fertilizer Use and Maintenance of Landscapes, City of Naples, available at: https://www.naplesgov.com/fertilizer, accessed 2021-07-23.

[12] Restoring Oyster Reefs in Naples Bay, City of Naples, available at: https://www.naplesgov.com/naturalresources/page/restoring-oyster-reefs-naples-bay, accessed 2021-07-23.

[13] Living Shorelines, NOAA, available at: https://www.habitatblueprint.noaa.gov/living-shorelines/, accessed 2021-07-23.

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Appendix A – Water Quality Summary Statistics

Appendix 1. Summary statistics for water quality of Moorings Bay.

Station	Parameter	Units	n	Avg	Median	Min	Max	StDev
MB1	Chlorophyll a-corrected	µg/L	138	9.2	8.3	1.5	33.7	5.18
MB1	Color	PCU	35	7.7	4	1	48	9.24
MB1	Copper	µg/L	139	2.3	1.82	0.075	8.83	1.47
MB1	Dissolved Oxygen	mg/L	140	4.6	4.955	0.13	10.58	2.08
MB1	Dissolved Oxygen (%)	Percent	140	63.9	70.55	2.1	126.3	28.46
MB1	Enterococci	#/100 ml	132	45	5	0.5	1674	171.31
MB1	Fecal Coliform	#/100 ml	117	61.2	10	0.5	4000	372.72
MB1	Salinity	ppt	140	33.5	33.83	21.64	37.57	2.46
MB1	Secchi Depth	meters	140	1.4	1.4	0.7	3	0.35
MB1	Specific Conductance	µmhos/cm	140	51043	51615	34350	57374	3304
MB1	Temperature	deg C	140	26.2	27.035	15.89	32.92	4.65
MB1	Total Nitrogen	mg/L	138	0.6	0.54	0.038	3.5	0.43
MB1	Total Phosphorus	mg/L	140	0.1	0.044	0.007	0.132	0.02
MB1	Total Suspended Solids (TSS)	mg/L	132	12.5	9.1	1	60	11.08
MB1	Turbidity	NTU	140	2.7	2.3	0.05	7.8	1.33
MB2	Chlorophyll a-corrected	µg/L	138	6	5.25	0.5	32.6	4.25
MB2	Color	PCU	35	3.4	1.5	1	16	3.4
MB2	Copper	µg/L	140	1.8	1.5	0.075	9.8	1.36
MB2	Dissolved Oxygen	mg/L	140	6.5	6.595	2.15	12.33	1.22
MB2	Dissolved Oxygen (%)	Percent	140	96.1	96.4	11.4	190.9	16.57
MB2	Enterococci	#/100 ml	132	39.6	5	0.5	3076	268.71
MB2	Fecal Coliform	#/100 ml	118	52.6	3	0.5	4000	370.22
MB2	Salinity	ppt	140	33.9	34.3	21.5	37.56	2.19
MB2	Secchi Depth	meters	138	1.4	1.4	0.6	2.6	0.38
MB2	Specific Conductance	µmhos/cm	140	51705	52073	34376	56944	2975
MB2	Temperature	deg C	140	26	26.955	15.54	33.26	4.65
MB2	Total Nitrogen	mg/L	138	0.5	0.3935	0.0255	2.321	0.35
MB2	Total Phosphorus	mg/L	140	0	0.032	0.002	0.142	0.02
MB2	Total Suspended Solids (TSS)	mg/L	132	14	10.3	1	56	12.01
MB2	Turbidity	NTU	140	3.2	2.3	0.65	18	2.46
MB3	Chlorophyll a-corrected	µg/L	138	4.8	4.3	0.5	18.5	2.9
MB3	Color	PCU	35	2.9	1.5	1	13	2.95

Station	Parameter	Units	n	Avg	Median	Min	Max	StDev
MB3	Copper	µg/L	139	1.4	1.33	0.075	4.39	0.93
MB3	Dissolved Oxygen	mg/L	140	6.7	6.685	2.76	9.7	0.87
MB3	Dissolved Oxygen (%)	Percent	140	98.1	99.95	7.84	127	12.19
MB3	Enterococci	#/100 ml	132	24.7	5	0.5	1616	141.57
MB3	Fecal Coliform	#/100 ml	118	49.3	3	0.5	4000	370.88
MB3	Salinity	ppt	140	34.6	34.7	28.8	38.2	1.38
MB3	Secchi Depth	meters	132	1.2	1.1	0.4	2.1	0.35
MB3	Specific Conductance	µmhos/cm	140	52580	52668	42541	57530	2146
MB3	Temperature	deg C	140	25.7	26.79	15.24	33.14	4.62
MB3	Total Nitrogen	mg/L	138	0.5	0.401	0.0255	2.381	0.36
MB3	Total Phosphorus	mg/L	140	0	0.0295	0.0035	0.131	0.02
MB3	Total Suspended Solids (TSS)	mg/L	130	15.8	12.85	1	52.4	11.04
MB3	Turbidity	NTU	140	4.8	3.85	0.05	26	3.87
MB4	Chlorophyll a-corrected	µg/L	138	6.6	5.35	0.5	34.3	5.25
MB4	Color	PCU	35	3.4	1.5	1	11	3.1
MB4	Copper	µg/L	139	1.6	1.45	0.05	9.29	1.25
MB4	Dissolved Oxygen	mg/L	140	6.7	6.825	3.15	10.21	1.11
MB4	Dissolved Oxygen (%)	Percent	140	100	99.9	55.3	159.1	15.07
MB4	Enterococci	#/100 ml	132	39.1	5	0.5	1904	178.15
MB4	Fecal Coliform	#/100 ml	118	55.7	3.5	0.5	4000	372.54
MB4	Salinity	ppt	140	33.8	34.23	23.2	37.54	2.27
MB4	Secchi Depth	meters	124	1.2	1.2	0.6	2.4	0.32
MB4	Specific Conductance	µmhos/cm	140	51682	52159	36927	57050	3025
MB4	Temperature	deg C	140	26.2	27.23	15.97	33.27	4.63
MB4	Total Nitrogen	mg/L	138	0.5	0.374	0.0295	2.061	0.34
MB4	Total Phosphorus	mg/L	140	0	0.034	0.005	0.166	0.02
MB4	Total Suspended Solids (TSS)	mg/L	131	15.3	10	1	318	28.98
MB4	Turbidity	NTU	140	3.4	2.75	0.05	11	1.92

Appendix B – Phylogenetic Taxonomic List and Abundances

Phylum	Subphylum	Class	Subclass	Order	Family	Taxon	City of Naples Code(s)	Total Abundance	Relative Abundance	Notes
Cnidaria		Scyphozoa	Discomedusae	Rhizostomeae	Cassiopeidae	*Cassiopea* spp.	CASEOPIA CASSEOPEIA JF	11	0.024%	Combined due to duplicate names.
Annelida		Polychaeta	Sedentaria		Chaetopteridae	*Chaetopterus pergamentaceus*	PARCHMENT WORM	2	0.004%	
Mollusca		Cephalopoda	Coleoidea			Decapodiformes spp.	SQUID	136	0.294%	
Mollusca		Gastropoda	Heterobranchia	Aplysiida	Aplysiidae	*Aplysia* spp.	MOTTLED SEA HARE SEA HARE MOT SH M	4	0.009%	Combined due to duplicate names.
Mollusca		Gastropoda	Heterobranchia	Aplysiida	Aplysiidae	*Bursatella leachii*	RAGGED SEA HARES SH R	79	0.170%	Combined due to duplicate names.
Mollusca		Gastropoda	Heterobranchia			Heterobranchia spp.	SEA SLUG ID???	20	0.043%	
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Decapoda	Menippidae	*Menippe mercenaria*	MENI MERC	2	0.004%	
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Decapoda	Penaeidae	*Penaeus* spp.	PENA SPP	643	1.388%	
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Decapoda	Portunidae	*Callinectes* spp.	CALI CALI SAP CALI SIMILUS SWIM CRAB	220	0.475%	Collapsed all to Callinectes spp. because of difficulty identifying portunid crabs.
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Decapoda		Alphaeoidea spp.	PISTOL SHRIMP	10	0.022%	
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Decapoda		Majoidea spp.	ARROW CRAB DECORATOR CRAB SPIDER CRAB	106	0.229%	Collapsed all under Superfamily Majoidea spp. because of difficulty identifying these crabs.
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Decapoda		Stomatopoda spp.	MANTIS SHRIMP	62	0.134%	
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Decapoda		Xanthoidea spp.	MUD CRAB	3	0.006%	
Echinodermata	Asterozoa	Asteroidea		Paxillosida	Luidiidae	*Luidia* spp.	9 ARM SEA STAR 9ARM SS	96	0.207%	Combined due to duplicate names.
Echinodermata	Asterozoa	Ophiuroidea				Ophiuroidea spp.	BRITTLE STAR	18	0.039%	
Echinodermata	Echinozoa	Echinoidea				Echinoidea spp.	URCHIN URCHINS	6	0.013%	Combined due to duplicate names.
Chordata	Cephalochordata	Leptocardii			Branchiostomatidae	*Branchiostoma* spp.	AMPHIOXIS	1	0.002%	
Chordata	Vertebrata	Actinopteri	Teleostei	Acanthuriformes	Ephippidae	*Chaetodipterus faber*	CHAE FABE	16	0.035%	
Chordata	Vertebrata	Actinopteri	Teleostei	Albuliformes	Albulidae	*Albula vulpes*	ALBU VULP LEPTO-VULP	2	0.004%	Combined due to duplicate names.
Chordata	Vertebrata	Actinopteri	Teleostei	Anguilliformes	Congridae	Leptocephalus larvae	LEPTO LEPTO CEPH	16	0.035%	Combined due to duplicate names.
Chordata	Vertebrata	Actinopteri	Teleostei	Aulopiformes	Synodontidae	*Synodus foetens*	SYNO FOET	165	0.356%	
Chordata	Vertebrata	Actinopteri	Teleostei	Batrachoidiformes	Batrachoididae	*Opsanus beta*	OPSA BETA	18	0.039%	
Chordata	Vertebrata	Actinopteri	Teleostei	Carangiformes	Carangidae	*Hemicaranx amblyrhynchus*	HEMI AMBL???	3	0.006%	
Chordata	Vertebrata	Actinopteri	Teleostei	Carangiformes	Carangidae	*Caranx hippos*	CARA HIPP CARA SPP	2	0.004%	Collapsed *Caranx* spp. into *Caranx hippos*.
Chordata	Vertebrata	Actinopteri	Teleostei	Carangiformes	Carangidae	*Chloroscombrus chrysurus*	CHLO CHRY	268	0.578%	
Chordata	Vertebrata	Actinopteri	Teleostei	Carangiformes	Carangidae	*Selene vomer*	SELE VOME	4	0.009%	
Chordata	Vertebrata	Actinopteri	Teleostei	Carangiformes	Carangidae	*Trachinotus carolinus*	TRAC CARO	1	0.002%	
Chordata	Vertebrata	Actinopteri	Teleostei	Clupeiformes	Clupeidae	*Brevoortia* spp.	BREV SPP	2	0.004%	
Chordata	Vertebrata	Actinopteri	Teleostei	Clupeiformes	Clupeidae	*Harengula jaguana*	HARE JAGU	27	0.058%	
Chordata	Vertebrata	Actinopteri	Teleostei	Clupeiformes	Clupeidae	*Opisthonema oglinum*	OPIS OGLI	18	0.039%	
Chordata	Vertebrata	Actinopteri	Teleostei	Clupeiformes	Engraulidae	*Anchoa hepsetus*	ANCH HEPS	19	0.041%	
Chordata	Vertebrata	Actinopteri	Teleostei	Clupeiformes	Engraulidae	*Anchoa mitchilli*	ANCH MITC ANCH SPP	5538	11.952%	Collapsed *Anchoa* spp. into *Anchoa mitchilli* based on zone and date collected.
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Gerreidae	*Eucinostomus* spp.	EUCI SPP	36355	78.461%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Gerreidae	*Eugeres plumieri*	EUGE PLUM	6	0.013%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Haemulidae	*Haemulon plumieri*	HAEM PLUM	10	0.022%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Haemulidae	*Orthopristis chrysoptera*	ORTH CHRY	85	0.183%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Lutjanidae	*Lutjanus analis*	LUTJ ANAL	1	0.002%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Lutjanidae	*Lutjanus griseus*	LUTJ GRIS	24	0.052%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Lutjanidae	*Lutjanus synagris*	LUTJ SYNA	156	0.337%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Scaridae	*Nicholsina usta*	NICH USTA	2	0.004%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sciaenidae	*Bairdiella chrysoura*	BAIR CHRY	174	0.376%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sciaenidae	*Cynoscion arenarius*	CYNO AREN CYNO ????????????	182	0.393%	Collapsed *Cynoscion* spp. into *Cynoscion arenarius*, based on zone and date collected.
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sciaenidae	*Cynoscion nebulosus*	CYNO N	20	0.043%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sciaenidae	*Leiostomus xanthurus*	LEIO XANT	587	1.267%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sciaenidae	*Menticirrhus americanus*	MENT AMER MENT SPP	38	0.082%	Collapsed *Menticirrhus* spp. into *Menticirrhus americanus*.
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sciaenidae	*Micropogonias undulatus*	MICR UNDU MICROPOGONIUS UNDULATUS	29	0.063%	Combined due to duplicate names.
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sciaenidae	*Scianops ocellata*	SCIA OCEL	8	0.017%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sparidae	*Archosargus probatocephalus*	ARCH PROB	22	0.047%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sparidae	*Calamus arctifrons*	CALA ARCT	2	0.004%	
Chordata	Vertebrata	Actinopteri	Teleostei	Eupercaria incertae sedis	Sparidae	*Lagodon rhomboides*	LAGA RHOM	486	1.049%	
Chordata	Vertebrata	Actinopteri	Teleostei	Gadiformes	Phycidae	*Urophysis floridana*	UROP FLOR	3	0.006%	
Chordata	Vertebrata	Actinopteri	Teleostei	Gobiiformes	Gobiidae	*Ctenogobius smaragdus(Gobionellus)*	GOBI BOLE	19	0.041%	
Chordata	Vertebrata	Actinopteri	Teleostei	Gobiiformes	Gobiidae	*Gobionellus oceanicus*	GOBI OCEA	7	0.015%	
Chordata	Vertebrata	Actinopteri	Teleostei	Gobiiformes	Gobiidae	*Gobiosoma robustum*	GOBI ROBU	8	0.017%	
Chordata	Vertebrata	Actinopteri	Teleostei	Gobiiformes	Gobiidae	*Lophogobius cyprinoides*	LOPH CYPR	3	0.006%	
Chordata	Vertebrata	Actinopteri	Teleostei	Gobiiformes	Gobiidae	*Microgobius gulosus*	MICR GULO	15	0.032%	
Chordata	Vertebrata	Actinopteri	Teleostei	Gobiiformes	Gobiidae	*Microgobius microlepis*	MICR MICR	2	0.004%	
Chordata	Vertebrata	Actinopteri	Teleostei	Gobiiformes	Gobiidae	*Microgobius thallisinus*	MICR THAL	39	0.084%	
Chordata	Vertebrata	Actinopteri	Teleostei	Lophiiformes	Ogcocephalidae	*Ogcocephalus cubifrons*	OGCO CUBI	48	0.104%	
Chordata	Vertebrata	Actinopteri	Teleostei	Perciformes	Scorpaenidae	*Scorpaena brasiliensis*	SCOR BRAS	2	0.004%	
Chordata	Vertebrata	Actinopteri	Teleostei	Perciformes	Serranidae	*Diplectrum formosum*	DIPL FORM	5	0.011%	
Chordata	Vertebrata	Actinopteri	Teleostei	Perciformes	Triglidae	*Prionotus scitulus*	PRIO SCIT	25	0.054%	
Chordata	Vertebrata	Actinopteri	Teleostei	Perciformes	Triglidae	*Prionotus tribulus*	PRIO TRIB	40	0.086%	
Chordata	Vertebrata	Actinopteri	Teleostei	Pleuronectiformes	Achiridae	*Achirus lineatus*	ACHI LINE	4	0.009%	
Chordata	Vertebrata	Actinopteri	Teleostei	Pleuronectiformes	Cynoglossidae	*Symphurus plagiusa*	SYMP PLAG	29	0.063%	
Chordata	Vertebrata	Actinopteri	Teleostei	Pleuronectiformes	Paralichthyidae	*Ancyclopsetta quadrocellata*	ANCL QUAD	8	0.017%	
Chordata	Vertebrata	Actinopteri	Teleostei	Pleuronectiformes	Paralichthyidae	*Citharichthys macrops*	CITH MACR?	1	0.002%	
Chordata	Vertebrata	Actinopteri	Teleostei	Pleuronectiformes	Paralichthyidae	*Citharichthys spilopterus*	CITH SPIL	1	0.002%	
Chordata	Vertebrata	Actinopteri	Teleostei	Pleuronectiformes	Paralichthyidae	*Etropus crossotus*	ETRO ETRO CROS	65	0.140%	Collapsed *Etropus* spp. into *Etropus crossotus*.
Chordata	Vertebrata	Actinopteri	Teleostei	Pleuronectiformes	Paralichthyidae	*Paralichthys albigutta*	PARA ALBI	9	0.019%	
Chordata	Vertebrata	Actinopteri	Teleostei	Scombriformes	Trichiuridae	*Trichiurus lepturus*	TRIC LEPT	1	0.002%	
Chordata	Vertebrata	Actinopteri	Teleostei	Siluriformes	Ariidae	*Arius felis*	ARIU FELI	194	0.419%	
Chordata	Vertebrata	Actinopteri	Teleostei	Siluriformes	Ariidae	*Bagre marinus*	BAGR MARI	8	0.017%	
Chordata	Vertebrata	Actinopteri	Teleostei	Syngnathiformes	Syngnathidae	*Hippocampus erectus*	HIPP EREC	8	0.017%	
Chordata	Vertebrata	Actinopteri	Teleostei	Syngnathiformes	Syngnathidae	*Syngnathus louisianae*	SYNG LOUI	18	0.039%	
Chordata	Vertebrata	Actinopteri	Teleostei	Syngnathiformes	Syngnathidae	*Syngnathus scovelli*	SYNG SCOV	1	0.002%	
Chordata	Vertebrata	Actinopteri	Teleostei	Tetraodontiformes	Diodontidae	*Chilomycterus schoepfi*	CHIL SCHO	7	0.015%	
Chordata	Vertebrata	Actinopteri	Teleostei	Tetraodontiformes	Monacanthidae	*Monacanthus hispidus*	MONA HISP	19	0.041%	
Chordata	Vertebrata	Actinopteri	Teleostei	Tetraodontiformes	Ostraciidae	*Lactophrys quadricornis*	LACT QUAD	8	0.017%	
Chordata	Vertebrata	Actinopteri	Teleostei	Tetraodontiformes	Tetraodontidae	*Sphroides nephelus*	SPHR NEPH	19	0.041%	
Chordata	Vertebrata	Actinopteri	Teleostei	Tetraodontiformes	Tetraodontidae	*Sphroides spengleri*	SPHR SPEN	1	0.002%	
Chordata	Vertebrata	Elasmobranchii	Neoselachii	Myliobatiformes	Dasyatidae	*Dasyatis americanus*	DASY AMER	1	0.002%	
Chordata	Vertebrata	Elasmobranchii	Neoselachii	Myliobatiformes	Dasyatidae	*Dasyatis sabina*	DASY SABI	6	0.013%	
Chordata	Vertebrata	Elasmobranchii	Neoselachii	Myliobatiformes	Gymnuridae	*Gymnura micrura*	GYMN MICR	6	0.013%	