ATTACHMENT B - Moorings Bay Water Quality and Biological Analysis (2016)

Moorings Bay Water Quality and Biological Data Analysis

October 2016

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Document Information

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Project Name	Moorings Bay Statistical Analysis
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1 Introduction

Moorings Bay, on the southwest coast of Florida, provides numerous recreational activities for the residents and guests of the City of Naples (City). Knowing the status of water quality and the biological community in Moorings Bay is of utmost importance to ensuring its health and maintaining its functionality and allure for those who live and recreate on this waterbody. The City implements a dedicated monitoring program in Moorings Bay, generating a consistent knowledge base from which to make informed management decisions that will protect the Bay for current residents and future generations. This document synthesizes the monitoring data collected from 2008–2015 and provides a comprehensive status update of water quality and biology in Moorings Bay. The purpose is to provide resource managers with the information necessary to make cost effective, informed management decisions.

Historically, the waterbody that would come to be known as Moorings Bay was a shallow sheltered bay area dominated by dense mangrove habitat with a single wave-dominated inlet, Doctors Pass, which migrated up and down the undeveloped coastline (FDEP 1997). In 1960, Doctors Pass was widened and dredged in its current location, and two boulder-mound jetties were constructed to prevent migration (FDEP 1997). At the same time in the late 1950s and early 1960s, a large residential development, The Moorings, began construction that would alter the size and shape of Moorings Bay (Reynolds 1982). Within 20 years, development had completely transformed the shape, depth, and size of the waterbody (Figure 1-1).

As a result of the long history of alteration and development, Moorings Bay is now considered a completely artificial waterbody (Collier County 1995). Today, Moorings Bay is armored with seawalls and riprap, surrounded by dense urban land use. Sources of water to Moorings Bay include wave and tidal exchange though Doctors Pass; urban stormwater runoff from the surrounding basin; and contributions from Clam Bay to the north. The Florida Department of Environmental Protection (FDEP) currently classifies Moorings Bay (WBID 3278Q2) as a Class II estuary, meaning the waterbody is designated for shellfish propagation or harvesting. Although no recent records of actual shellfish harvesting exist within Moorings Bay, this designation dictates applicable water quality criteria for the system.

Based on the history of Moorings Bay and its importance in the Naples landscape, the City Natural Resources Division embarked on a study to identify the current status of water quality and biological resources in Moorings Bay. A similar study was recently completed for Naples Bay (Cardno 2015). The City's Natural Resources Division maintains a robust long-term water quality and biological (fish) monitoring program in Moorings Bay that serves as the catalyst for this study. The purpose is to identify the current status of water quality with respect to applicable water quality criteria; identify any trends in water quality; characterize surface water inputs to Moorings Bay (to the extent possible); and characterize the existing biological community and any discernable interactions between the biology and water quality of Moorings Bay.

By characterizing the current status and trends in Moorings Bay, City resource managers can identify specific issues in need of management attention. The ultimate goal is to protect and preserve the water quality and biological communities of Moorings Bay for their inherent resource value as well as for the residents and guests of the City of Naples.

Figure 1-1. Historical Aerials of Moorings Bay

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GIS Analyst: Lauren.Federsel

2 Data Sources and Statistical Approach

The City Natural Resources Division implemented a water quality and biological monitoring program in Moorings Bay in 2008. The current program includes four water quality monitoring locations spread throughout the Bay as well as fish sampling monitoring design in four locations. The program was initiated to create a long term dataset from which to characterize the environmental condition of Moorings Bay. This effort is the first time the data have been compiled into a comprehensive analytical report of the status of Moorings Bay. The water quality analytical effort in this report is focused on constituents of concern to the City and those that are of regulatory concern to the FDEP with regard to the health of Moorings Bay. Particular attention was paid to nutrients and nutrient response variables, copper, and bacteria counts. These parameters have been identified in previous studies and discussions with the City as those of the most interest for this effort.

2.1 Data Sources

Water quality and biological data from Moorings Bay collected by the City of Naples were compiled and used as the basis for the analysis presented in this report. The data types are described in Table 2-1 and the data collection locations are shown on Figure 2-1.

Water quality samples in Moorings Bay were collected monthly throughout the period of record. During each sampling event, field measurements of salinity, temperature, dissolved oxygen (DO), pH, and specific conductance were collected from surface and bottom water at each site. A surface water sample was also collected for laboratory analysis.

Six stormwater lakes, along with the Moorings Country Club lake system, discharge into Moorings Bay. Four of the six stormwater lakes are sampled as part of the City's upland monitoring program. From 2010 to 2015 each lake was sampled approximately twice per year (three samples were collected in 2011 and 2015; and one in 2014): once during the dry season and once during the wet season. Beginning in late 2015, the monitoring design was revised to conduct more consistent quarterly monitoring. Chlorophyll-*a* was added to the monitoring program in December of 2014. Samples are collected from the discharge weir during each monitoring event.

Fish monitoring efforts were conducted four times per water year (WY) in WY 2010 and WY 2012–2015 (water years start in October, *e.g.* WY 2010 is from October 1, 2009 to September 30, 2010). Samples were collected using otter trawls along transects pulled for a fixed length and time. During the first year of monitoring, samples were collected at four fixed locations in the Bay, while later samples were collected from randomly selected grid boxes from each of four Bay zones. All fish caught in the trawls were identified to the lowest practical taxonomic level and counted, and up to 20 individuals of each species were measured.

Table 2-1. Water quality and biological data sources, Moorings Bay, City of Naples, 2008 - 2015.

Data Source	Location	Data type	Number of Stations	Date Range	Number of Records
City of Naples	Moorings Bay	Water Quality Grab Samples	4	2008–2015	336
	Stormwater Lakes	Water Quality Grab Samples	4	2010–Present	48
	Moorings Bay	Benthic Fish Trawls	4	2009–2015	80
NOAA	Naples Airport	Daily Rainfall	1	2008–2015	Daily Records

2.2 Statistical Approach

Data were summarized by calendar year or WY for certain analyses throughout the report and are noted as such where applicable. Some analyses were also conducted on seasonal data using the division of months into wet and dry seasons that is typical for south Florida: November through May designated as the dry season and June through October designated as the wet season.

In addition to a graphical and tabular interpretation of the current conditions of water quality in Moorings Bay, several types of statistical analyses were performed for each constituent of concern at long-term data stations throughout the Bay: paired t-tests to compare stations over the sampling events, student's t-test to compare wet and dry season means, autoregressive error time-series models or annual Kendall Tau analysis to examine trends over time, and parametric or nonparametric correlation analyses to show relationships between parameters.

In order to identify trends in the water quality data from Moorings Bay over time, we chose to use an Autoregressive Error Model (AEM). For many water quality variables, observations over time are temporally correlated. For example, the value of salinity at any given time (*t*) is correlated with the salinity value at an earlier time (*t-1*). Fitting a simple regression model through these data violates many of the statistical assumptions that are required for a proper trend detection. AEM is a simple model that reduces the chance of an incorrectly specified time series model that does not take temporal correlation into account. One potential covariate, natural log-transformed monthly total rainfall, was considered for each model. The best fit models for each parameter and station were chosen using total model r^2 and corrected AIC (Akaike Information Criterion). Water quality data used in the AEM models, with the exception of color, dissolved oxygen, and salinity, were natural log-transformed.

Six water quality parameters were not analyzed using the AEM model because the assumptions of the model could not be met, either because of changes in MDLs over time (copper, chlorophyll-*a*, *Enterococci*), the prevalence of undetected values (fecal coliform), rounded values (color), or other departures from expected normality (Secchi depth). For these six parameters, Kendall Tau nonparametric trend analysis was performed on the annual geometric means from 2009 to 2015. For each parameter with MDL changes, all of the data were censored to the highest MDL (*e.g*. the highest MDL for copper was 3.0 µg/L, so all reported values less than 3 µg/L were replaced with 3.0 µg/L before the annual geometric mean was calculated).

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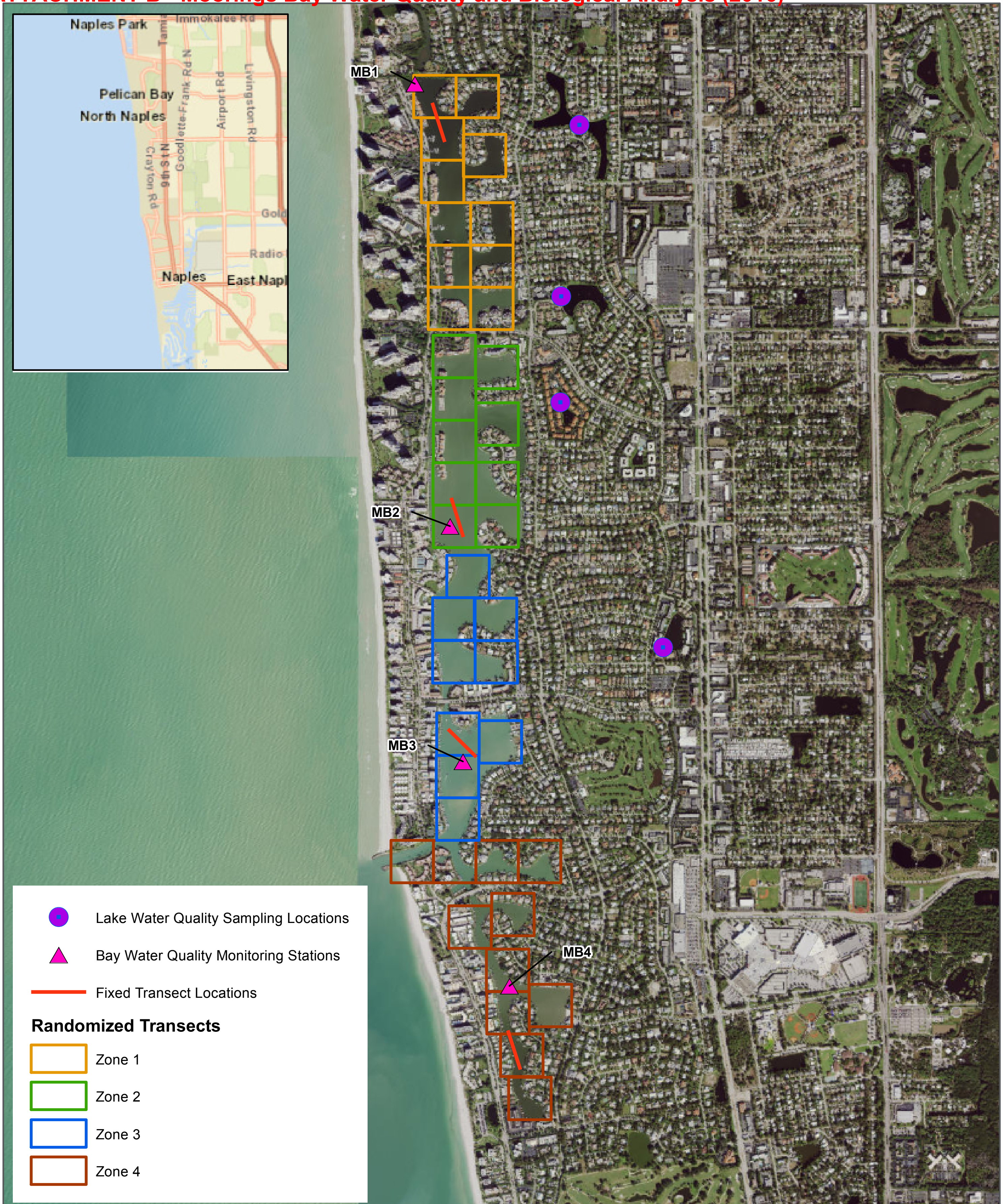

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Figure 2-1. Water Quality and Biological Monitoring Locations in Moorings Bay
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Collier County, Florida

0 — 2,000 — 4,000 Feet
0 — 610 — 1,220 Meters

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GIS Analyst: Lauren.Federsel

3 Sources to Moorings Bay

Given the dense residential land use surrounding Moorings Bay, it is no surprise that urban stormwater runoff is the main source of water delivered to Moorings Bay. The residential areas surrounding Moorings Bay have an extensive stormwater system with numerous direct discharge points into the Bay. There are also several wet-detention stormwater lakes that discharge to the Bay. At the time of this study, no data characterizing the quality or quantity of direct stormwater discharge were available. The main focus of this section is to characterize the stormwater influx using the available data from the City's upland stormwater monitoring program. This allows us to characterize a major source that has the ability to affect water quality and biology in Moorings Bay. The current water quality condition of the stormwater lakes that discharge to Moorings Bay as well as their estimated pollutant contribution to Moorings Bay are described in the following sections. Other major sources of water to Moorings Bay include tidal and wave exchange through Doctors Pass and tidal contributions from Clam Bay. These are also discussed, where data allow, as factors that can and do affect the condition of Moorings Bay.

3.1 Rainfall

Daily rainfall data for this study were obtained from the National Oceanic and Atmospheric Administration (NOAA) gauge located at the Naples Municipal Airport (USW00012897) for the study period (2008-2015) (Figure 3-1). This gauge was chosen for its proximity to the study area and completeness of data record during the study time period.

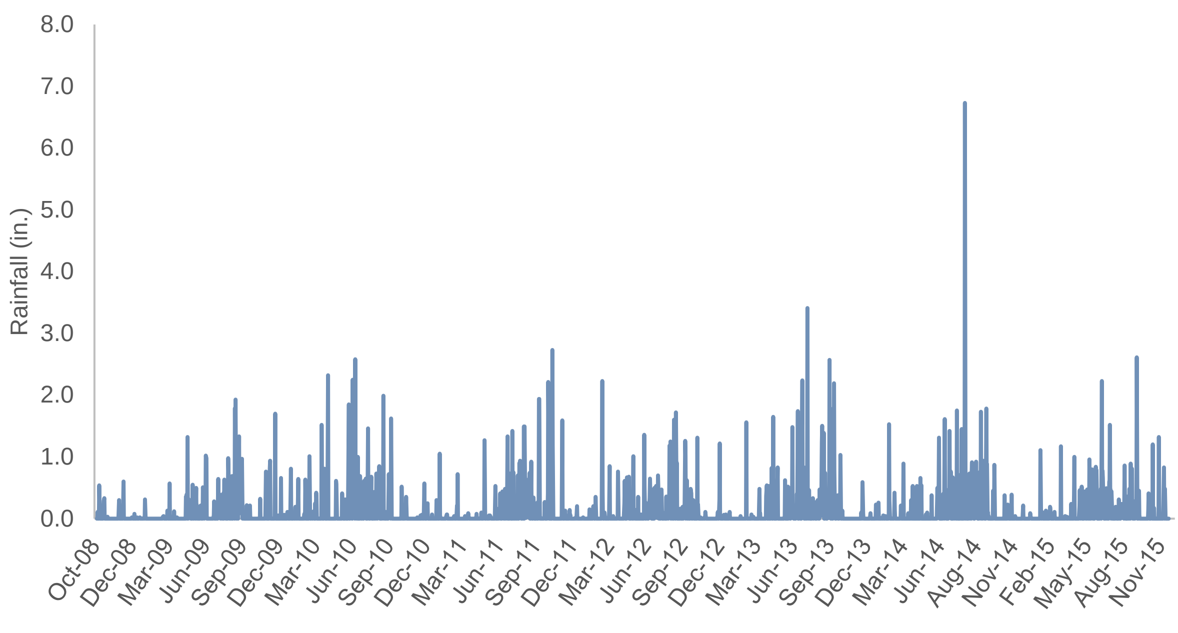

Figure 3-1. Daily rainfall near Moorings Bay (USW00012897, Naples Municipal Airport), October 2008–December 2015.

Monthly average rainfall in the study area showed typical seasonal patterns (Table 3-1). The wet season for this study was defined using the typical pattern for Florida (June–October); however, it is worth pointing out that during the 2008–2015 study period, October saw similar average rainfall amounts as April and May, which are included in the dry season (November–May). Annual precipitation totals for the

2008–2015 study period were below normal when compared to the long term average of 55.6 inches from 1981–2010 at NOAA rain gauge USC00086078 (FSU 2014), located approximately 6.4 miles to the east of the Naples Municipal Airport gauge.

Table 3-1. Monthly precipitation totals near Moorings Bay, Naples Municipal Airport (NOAA Gauge USW00012897), 2008–2015.

Month	Year								Average
	2008	2009	2010	2011	2012	2013	2014	2015	
January	0.7	0.2	1.7	1.5	0.2	0.2	2.4	0.1	**0.9**
February	1.5	0.3	1.1	0.2	3.2	1.7	0.8	1.5	**1.3**
March	0.7	0.2	2.8	1.1	1.0	0.6	1.9	1.5	**1.2**
April	5.9	0.7	4.7	0.2	2.5	4.4	1.8	1.8	**2.7**
May	0.3	3.9	1.6	1.7	2.5	3.5	2.0	3.2	**2.3**
June	9.5	2.4	9.7	2.4	4.5	8.8	8.2	6.3	**6.5**
July	9.8	3.2	7.8	6.1	4.3	9.1	7.0	10.2	**7.2**
August	10.0	6.2	7.1	8.0	10.9	7.9	13.9	2.8	**8.3**
September	4.3	11.4	6.1	7.0	3.8	11.0	10.1	6.8	**7.5**
October	4.6	0.5	0.5	8.0	3.2	1.2	1.4	1.1	**2.6**
November	0.3	1.1	0.6	1.7	0.1	0.8	1.1	3.0	**1.1**
December	0.6	4.0	1.0	0.4	1.8	0.3	0.3	1.6	**1.2**
Annual Total	**48.3**	**33.9**	**44.6**	**38.2**	**37.9**	**49.3**	**50.7**	**39.7**	**42.8**

3.2 Clam Bay

Clam Bay, situated to the north of Moorings Bay, exchanges water with Moorings Bay through three large culverts under Seagate Drive. The culverts were installed in 1976 to restore historical exchange between Clam and Moorings Bays (Atkins 2011), with the intent that flow would move primarily from Moorings Bay into Clam Bay. Water actually exchanged through the culverts in both directions so flap gates were installed in the late 1990's (PBS&J 2009) in an attempt to ensure northerly flow. However, the flap gates were later removed because they did not achieve this objective and water now exchanges in both directions through the culverts (Collier County 1997 and Atkins 2011). A 2009 study prepared for Collier County by PBS&J found that net flow was in the southerly direction; from Clam Bay to Moorings Bay during each tidal cycle (PBS&J 2009). The net contribution to Moorings Bay from Clam Bay is estimated to be 969,000 cubic feet during a typical tidal cycle (PBS&J 2009). A full characterization of the quality of the water entering Moorings Bay from Clam Bay and its potential effect on the water quality and biology of Moorings Bay is outside the scope of this report. However, previous comparisons of the water quality in Clam and Moorings Bays showed significant differences between the two bays in important water quality characteristics: salinity, temperature, Secchi depth, color, chlorophyll-*a*, total nitrogen (TN), total phosphorus (TP), and DO (Atkins 2011). As described in Sections 4 through 8 below, contributions from Clam Bay through the Seagate culverts may have a significant effect on water quality in the northern portion of Moorings Bay.

3.3 Urban Stormwater Lakes

All available water quality data for the four monitored stormwater lakes, Lake 1 – Devils Lake, Lake 2 – Swan Lake, Lake 3 – Colonnade Lake, and Lake 5 – Lake Suzanne (Figure 3-2), are shown in Figures 3-3 and 3-4. The current size of the dataset for the four lakes with current monitoring data (6 to 14 individual data points) precludes the use of formal time series analyses within each lake, so only descriptive summary statistics are provided here. The variance within each dataset from each lake is typically large with no apparent trends in either direction for most parameters. It is possible that TSS may be slightly decreasing in some of the stormwater lakes, but no trend can be detected using formal statistics at this time. While the variance among lakes tends to also be quite large, the lakes tend to show the most agreement in TN measurements.

As the main source of potential pollutants, it is important to attempt to quantify the stormwater loading to Moorings Bay. In 2012, AMEC, on behalf of the City of Naples, reported that the stormwater lakes that discharge to Moorings Bay contribute a total of approximately 4,600 kg/yr of TSS; 715 kg/yr of TN; 49 kg/yr of TP; and 6.7kg/yr of copper (AMEC 2012). Swan Lake (Lake 2) has the second largest contributing basin size of the lakes that discharge to Moorings Bay, but consistently shows the highest loading to Moorings Bay (AMEC 2012). Note that the loading estimates provided here are only for the stormwater lakes that discharge to Moorings Bay and do not include loadings from the remainder of the stormwater system with discharge to the Bay.

The City is implementing a 20 year restoration plan (City of Naples 2010) that includes Best Management Practices (BMP) for stormwater lakes. As a component of this plan, the City has installed floating islands in some of the stormwater lakes to provide treatment and improve the quality of the water discharged from the lake as well as improve the aesthetics and quality of the water in the lakes themselves. A more complete description of the floating island program is provided in the *Naples Bay Water Quality and Biological Analysis Project* report (Cardno 2015). To date, the City has installed floating islands in ten lakes and seven of those currently have islands installed. One of the lakes that discharges to Moorings Bay, Swan Lake (Lake 2), had a floating island installed in May 2013 and removed in November 2015.

A brief analysis was conducted for the available water quality data from Swan Lake to determine if the floating island resulted in any improvement in TN, TP, and copper discharges from the lake (Cardno 2015). The copper reductions were not expected to come from the floating island itself; rather the program was designed to educate and encourage homeowners to stop using copper sulfate to treat the lake if a floating island was installed. The 2015 analysis was based on the available data at the time (2010 to February 2015) and showed that no discernable changes in water quality were evident as a result of the floating island installation (Cardno 2015). In fact, the phosphorus concentrations generally appeared to increase throughout the dataset (Cardno 2015). However, the scarcity of available data may make any effect unnoticeable. Since that time, an additional four monitoring events have been conducted to add to the dataset. The additional available data were added to update the previous analysis and determine if any revisions to the conclusions should be made (Figure 3-5).

The Swan Lake dataset still lacks the statistical rigor to conduct any formal trend analyses, but a one-way ANOVA was conducted to determine if concentrations prior to the installation of the floating island were statistically different from concentrations while the island was in place and after the island was removed. Copper and TN were not significantly different among the three time periods (one-way ANOVA, $p > 0.05$). However, TP showed a statistically significant difference among time periods (one-way ANOVA, $F(2, 11) = 5.7$, $p = 0.02$) with lower measurements prior to the installation or removal of the island (Duncan's post-hoc test, $p < 0.05$). This is not meant to indicate that the island is actually causing TP to increase in Swan Lake; rather that the island does not appear to be providing any measureable treatment for TP in the lake.

While this brief analysis did not show any significant treatment of nutrients in Swan Lake as a result of the floating island, it is possible the available data are not sufficient to detect the real impact of the floating island. The City is in the beginning stages of developing a targeted program to evaluate the efficiency of the floating islands and their ability to improve not only the lakes themselves, but the quality of water discharged to receiving waters *(i.e.* Moorings Bay).

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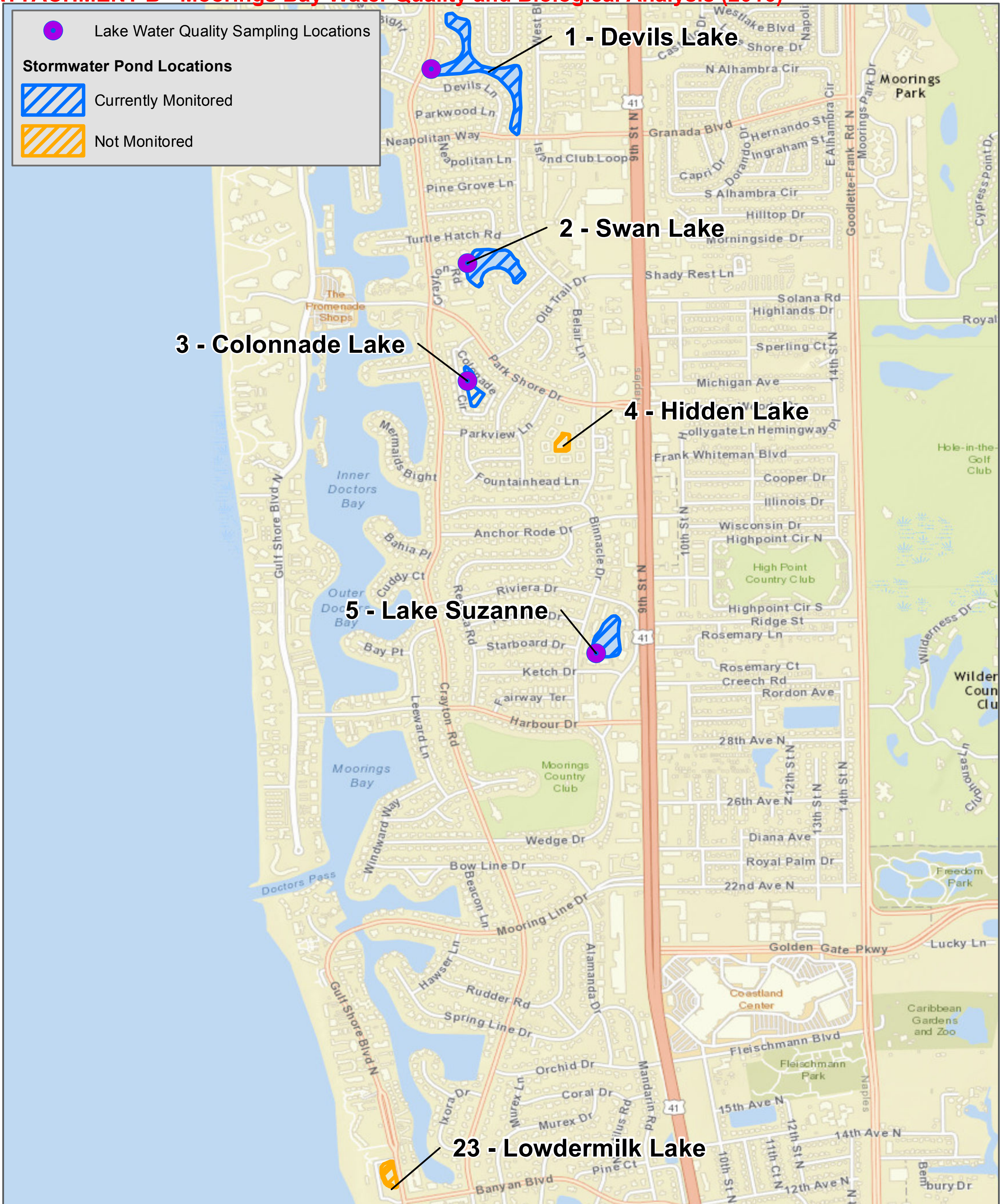

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Figure 3-2. Stormwater Lakes with Discharge to Moorings Bay

City of Naples
Collier County, Florida

0 1,500 3,000 Feet
0 500 1,000 Meters

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GIS Analyst: adam.bausch

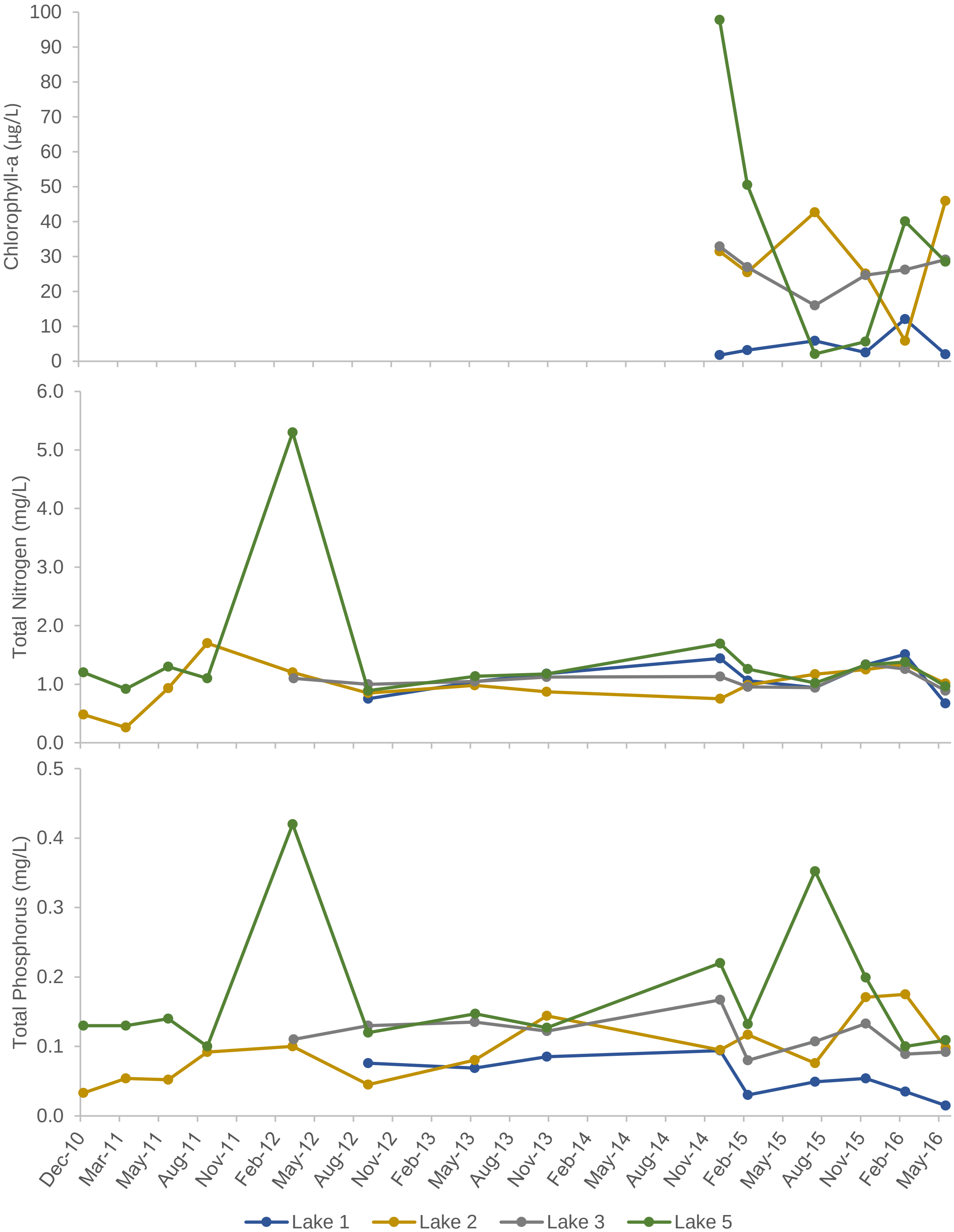


Figure 3-3. Chlorophyll-*a*, TN, and TP concentrations in stormwater lakes that discharge to Moorings Bay, December 2010–May 2016.

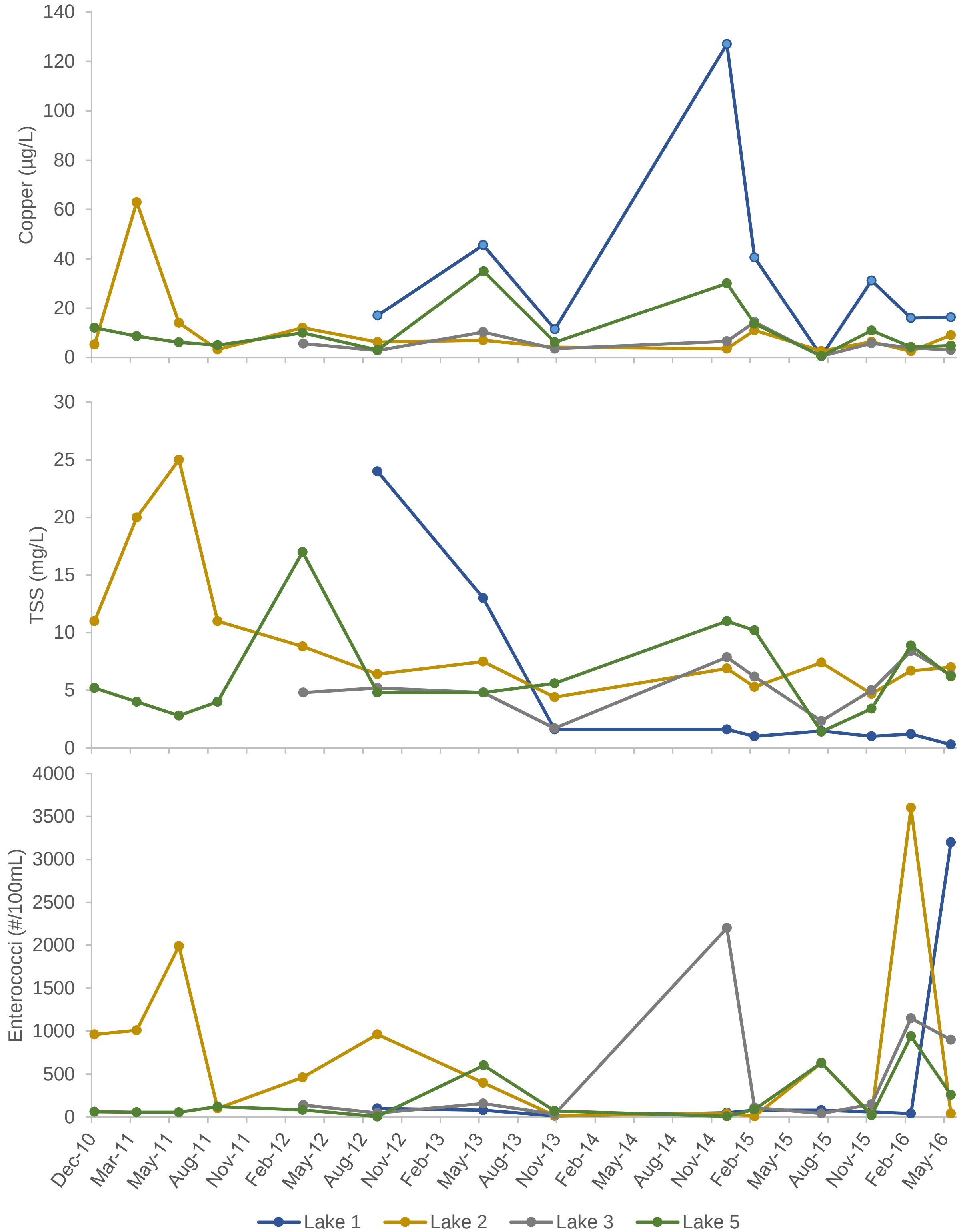


Figure 3-4. **Copper, TSS, and *Enterococci* concentrations in stormwater lakes that discharge to Moorings Bay, December 2010–May 2016.**

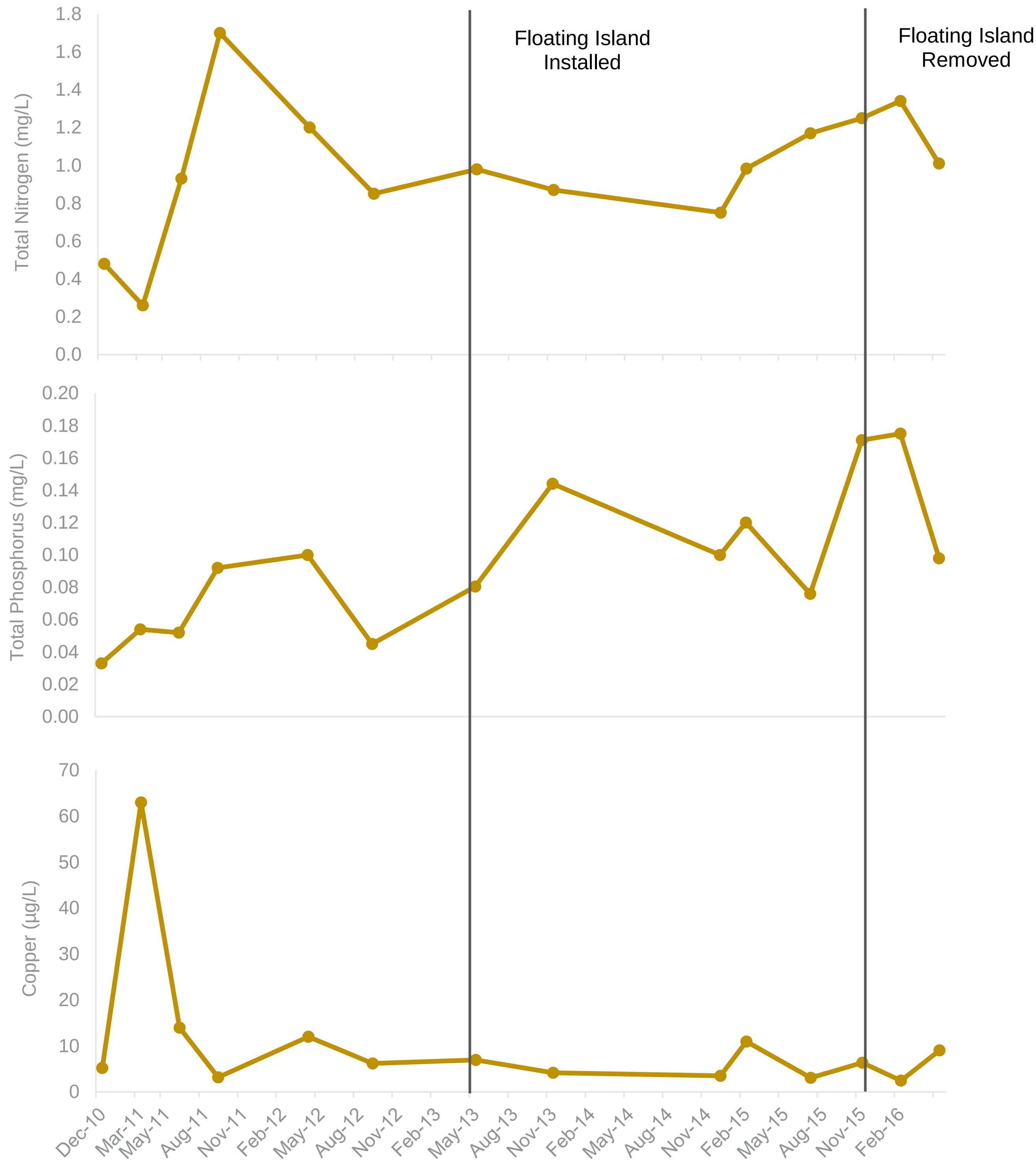


Figure 3-5. **Total nitrogen, total phosphorus, and copper concentrations in Swan Lake (Lake 2) before and after floating island installation and removal, December 2010–May 2016.**

4 Moorings Bay Water Quality

In this section, the available water quality data for the four locations in Moorings Bay are presented and analyzed for spatial and temporal patterns. Where applicable, the current status of Moorings Bay (WBID 3278Q2) with respect to applicable water quality standards is assessed. The goal is to provide a comprehensive understanding of Moorings Bay water quality and identify any patterns or concerns that demand management attention. Water quality data have been collected monthly at four locations in Moorings Bay since October 2008, and the analysis presented below is for data collected between 2008 and 2015. The four sampling locations, MB1 through MB4, are located from north to south within Moorings Bay (see Figure 2-1). MB1 is the northernmost station, closest to Seagate Drive and the culverts that connect Moorings Bay to Clam Bay. This location likely receives the least amount of exchange with the Gulf of Mexico. Station MB3 is located near Doctors Pass and has the most direct connection to Gulf waters.

4.1 Salinity

Moorings Bay does not have a continuous freshwater source because it is not the receiving waterbody for any river systems, although it does receive stormwater input from various sources. The salinity patterns in Moorings Bay are mostly impacted by rainfall (and associated surface runoff) and tidal exchange with the Gulf of Mexico and, to a lesser extent, Clam Bay. As such, the salinity regime in Moorings Bay is less variable seasonally and inter-annually than bays with riverine (or canal) inputs.

4.1.1 Spatial Patterns

Salinity was measured near the surface and near the bottom of the water column during each water quality sampling event. Surface and deep water readings were compared by station to look at patterns of water column stratification (Figure 4-1). Salinity patterns in bottom water are generally consistent across all stations, ranging from 31.7 to 38.2 ppt at depth. Surface salinity varies more overall, ranging from 21.6 to 38.1 ppt during the study period. There is also more variation in surface salinity among stations, with stations that are further from the tidal influence of Doctors Pass, especially station MB1, experiencing relatively lower surface salinities and greater differences between surface and bottom salinity (Figure 4-2). A t-test of dependent samples pairing the surface and bottom results for each station by sampling event, indicated that surface salinity is significantly lower than bottom salinity at each station (paired t-test, two-tailed, $p < 0.05$, Figure 4-2). The greatest stratification of the water column based on salinity generally occurs after large rainfall events and is most pronounced at the stations furthest from Doctors Pass.

When surface and bottom salinity were compared between stations, a set of t-tests of dependent samples pairing the results for each station by sampling event showed that station MB3 had significantly higher and MB1 had significantly lower surface and bottom salinity (paired t-test, two-tailed, $p < 0.05$, (Figure 4-2); for surface salinity, MB4 and MB2 has similar concentrations, but for bottom salinity, MB4 has higher salinity than MB2. This pattern is expected: MB3 and MB4 are the closest stations to Doctors Pass where saltier seawater enters Moorings Bay, and MB1 is the furthest from the Pass and is more influenced by lower salinity water from Clam Bay (Atkins 2011) and freshwater runoff.

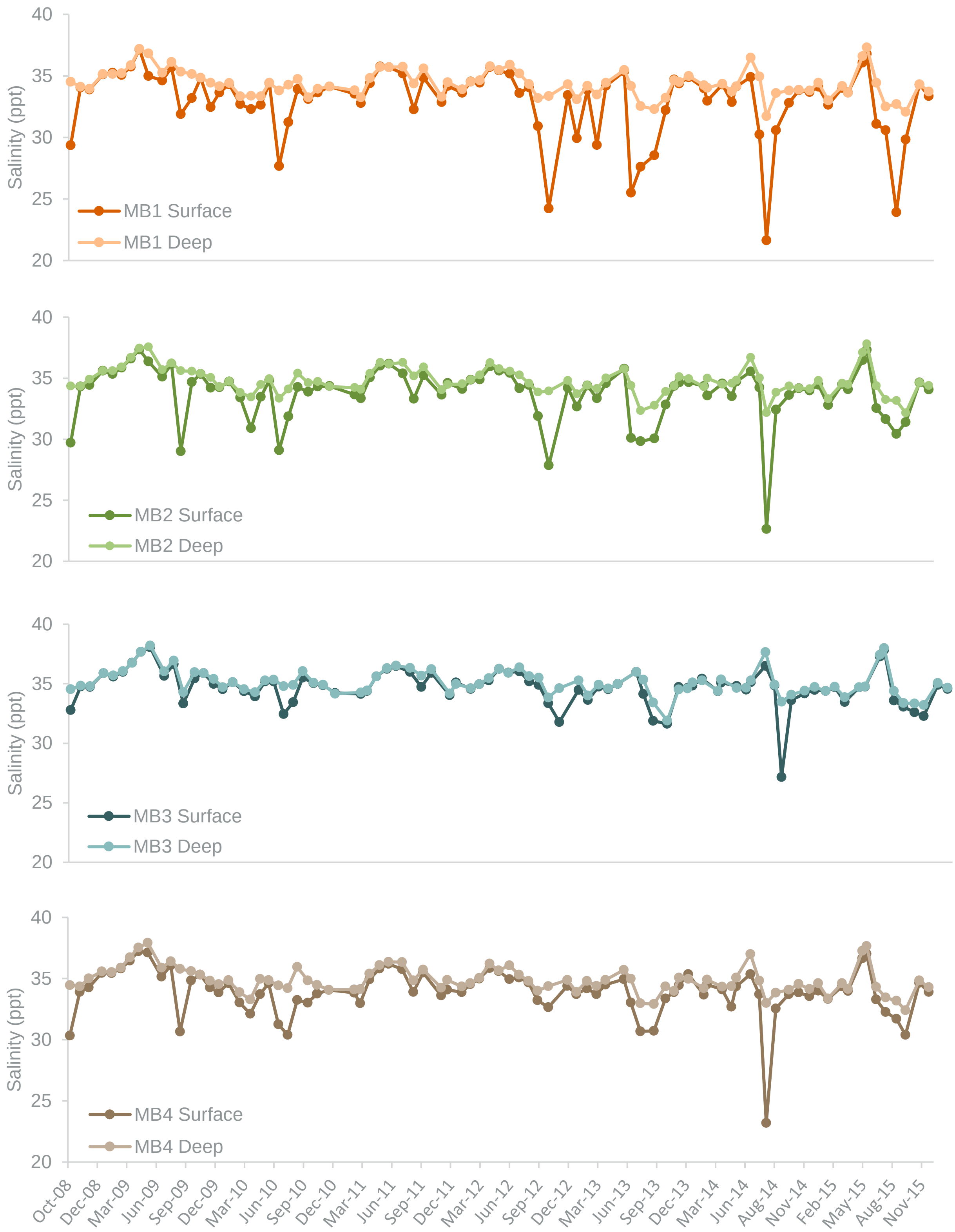


Figure 4-1. **Time series of surface and bottom salinity at Moorings Bay water quality monitoring stations, October 2008–December 2015.**

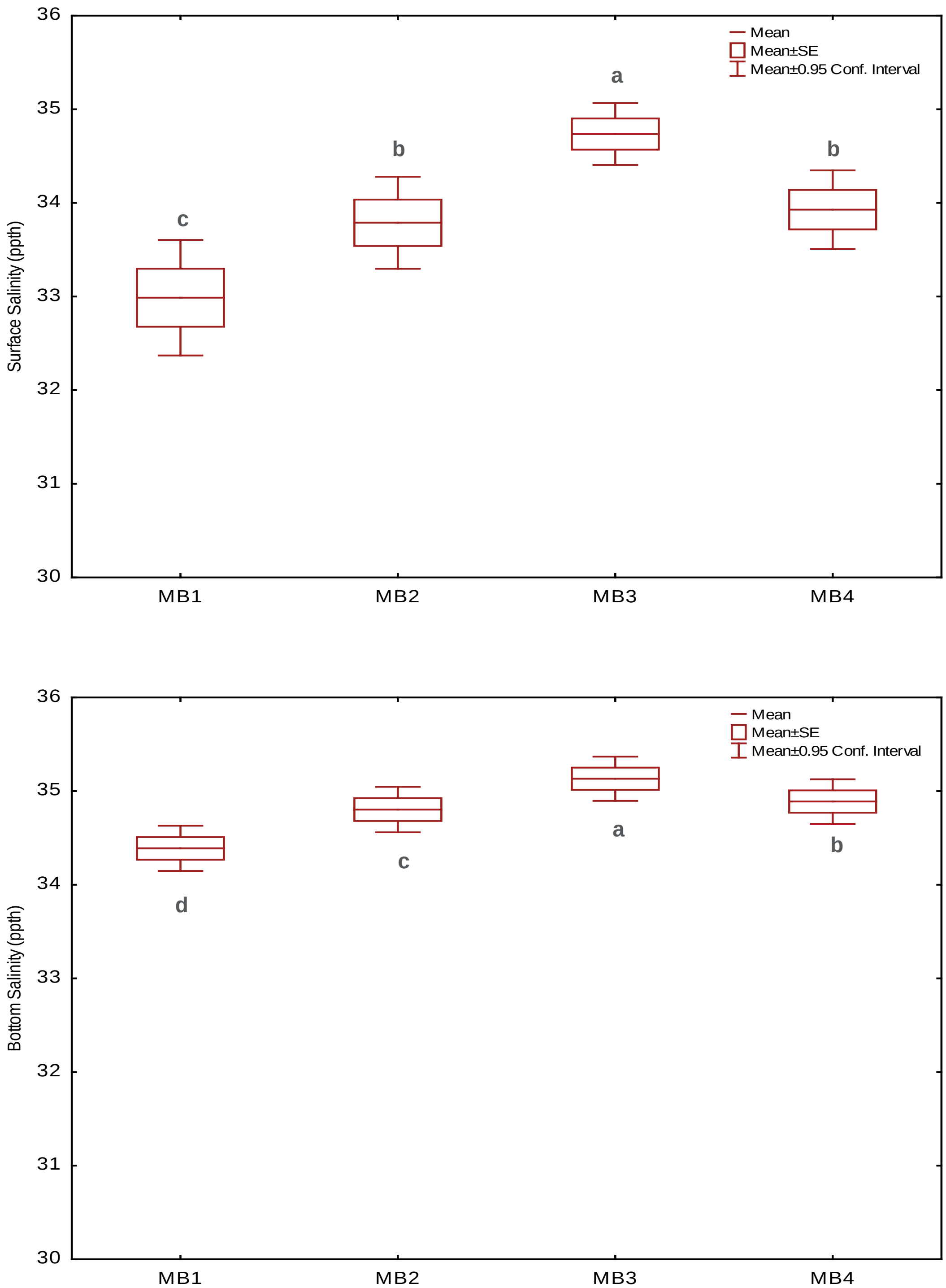


Figure 4-2. **Average surface and bottom salinity by station in Moorings Bay, October 2008–December 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, $p < 0.05$).**

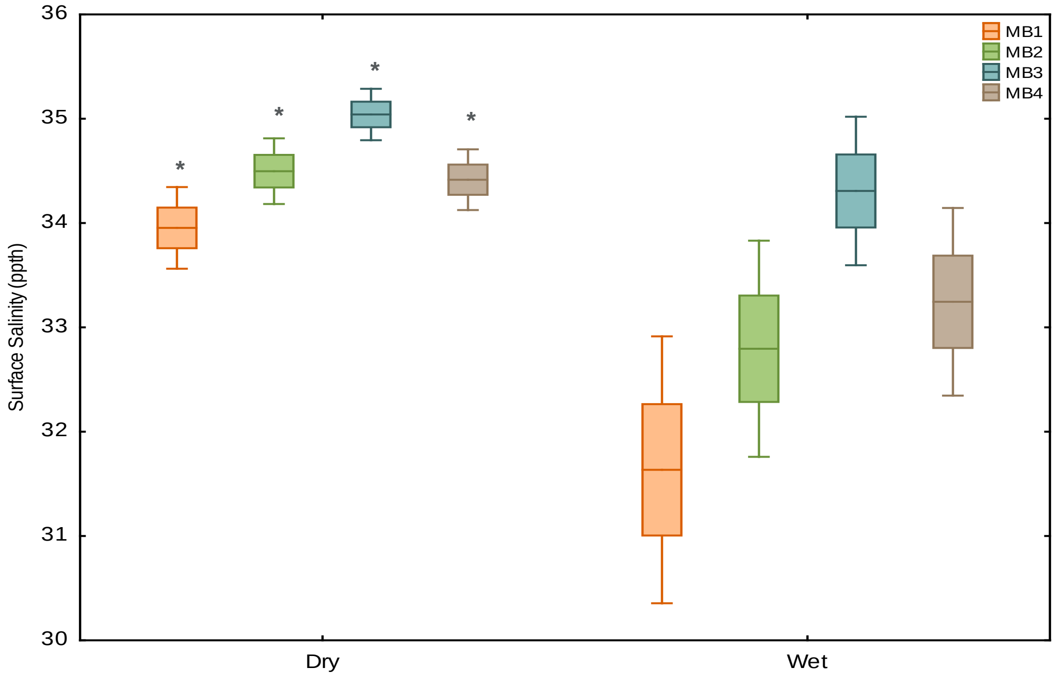
4.1.2 Temporal Trends

To examine differences in surface and bottom salinity between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Table 4.1). Surface salinity was significantly higher during in the dry season at each station and at all stations combined (t-test of seasons, two-tailed, $p < 0.05$, Figure 4-3). Bottom salinity was not significantly different between seasons (t-test of seasons, two-tailed, $p > 0.05$, Figure 4-3). Surface salinity is negatively correlated with rainfall in Moorings Bay at each station and all stations combined (Pearson correlation, $-0.34 > r > -0.47$, $p < 0.05$), but bottom salinity is not correlated with rainfall (Pearson correlation, $p > 0.05$). These results indicate that, as expected, surface salinity is more sensitive to changes in rainfall or runoff than bottom salinity in Moorings Bay.

Table 4.1. Seasonal salinity (ppt) range and average by station in Moorings Bay, October 2008–December 2015.

Sample Location &Station	Surface				Deep			
	MB1	MB2	MB3	MB4	MB1	MB2	MB3	MB4
Dry Season								
Min	29.38	30.89	33.46	32.11	33.02	33.30	33.86	33.29
Mean	33.95	34.50	35.04	34.42	34.39	34.87	35.15	34.88
Max	37.16	37.34	37.68	37.23	37.19	37.46	37.68	37.54
Wet Season								
Min	21.64	22.64	27.17	23.20	31.73	32.15	31.90	32.41
Mean	31.63	32.80	34.31	33.25	34.39	34.71	35.13	34.89
Max	36.78	37.31	38.06	37.12	37.32	37.80	38.20	37.92

Surface and bottom salinity data were examined for potential trends over time using the AEM model, with and without the autoregressive term and the log monthly rainfall covariate (Tables 4-2 and 4-3). For three of the four stations, the best fit model for surface salinity included the rainfall covariate, and some also included an autoregressive term of one-month, indicating temporal autocorrelation (*i.e*. salinity in one month affects the next months' salinity). However, surface salinity did not show statistically significant trends at the $p < 0.05$ level at any station, and only station MB3 (which did not include rainfall covariate) showed a statistically significant decreasing trends at the $p < 0.10$ level (Table 4-3 and Figure 4-4). Thus, one can conclude with some confidence that there may be a decreasing trend at station MB3 in surface salinity. For bottom salinity, rainfall was not a covariate in the best-fit models, but one to two month autoregression was (Table 4-3). Bottom salinity did show statistically significant decreasing trend at MB2 at the $p < 0.05$ level, and stations MB1 and MB4 showed statistically significant decreasing trends at the $p < 0.10$ level (Table 4-3 and Figure 4-5). Thus, one can conclude with some confidence that there may be a decreasing trend at three stations in bottom salinity, having more confidence in the trend at station MB2.



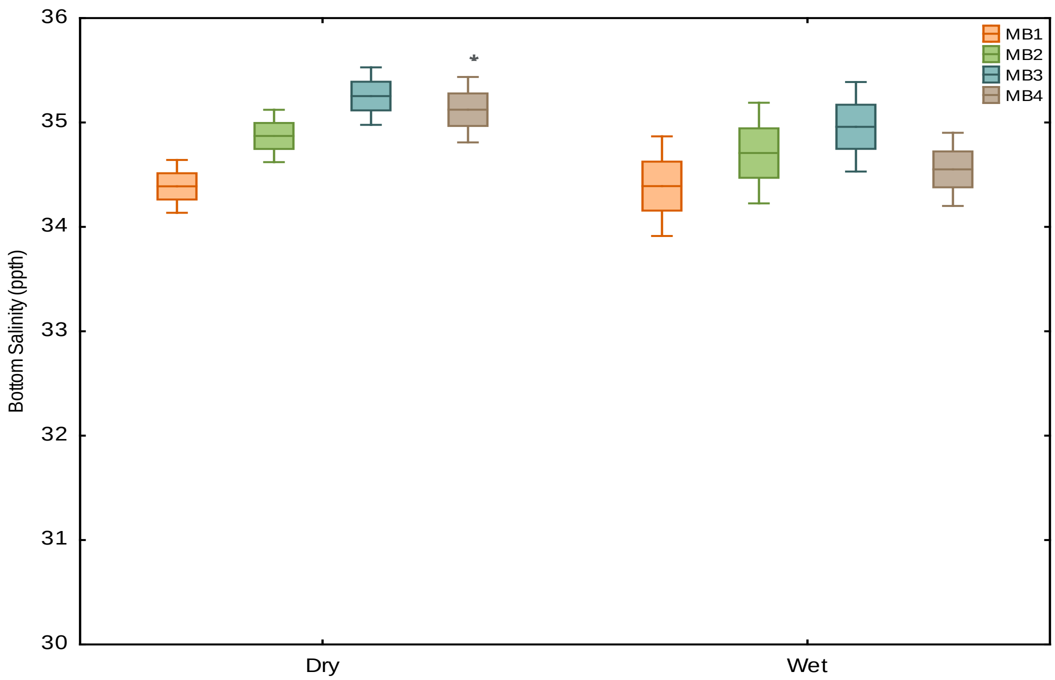


Figure 4-3. **Seasonal surface and bottom salinity by station in Moorings Bay, October 2008–December 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (two-tailed t-test).**

Table 4-2. Results of time-series models of monthly surface salinity in Moorings Bay, 2008–2015, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	
MB1	0.2	47.006	0.001	-0.0007	0.16	-0.46	0.08	1
MB2	0.12	41.19	0.0001	-0.0004	0.23	**-0.56**	**0.005**	
MB3	0.18	44.07	0.001	-0.0005	0.09			1
MB4	0.18	40.74	0.0001	-0.0003	0.33	-0.35	0.06	1

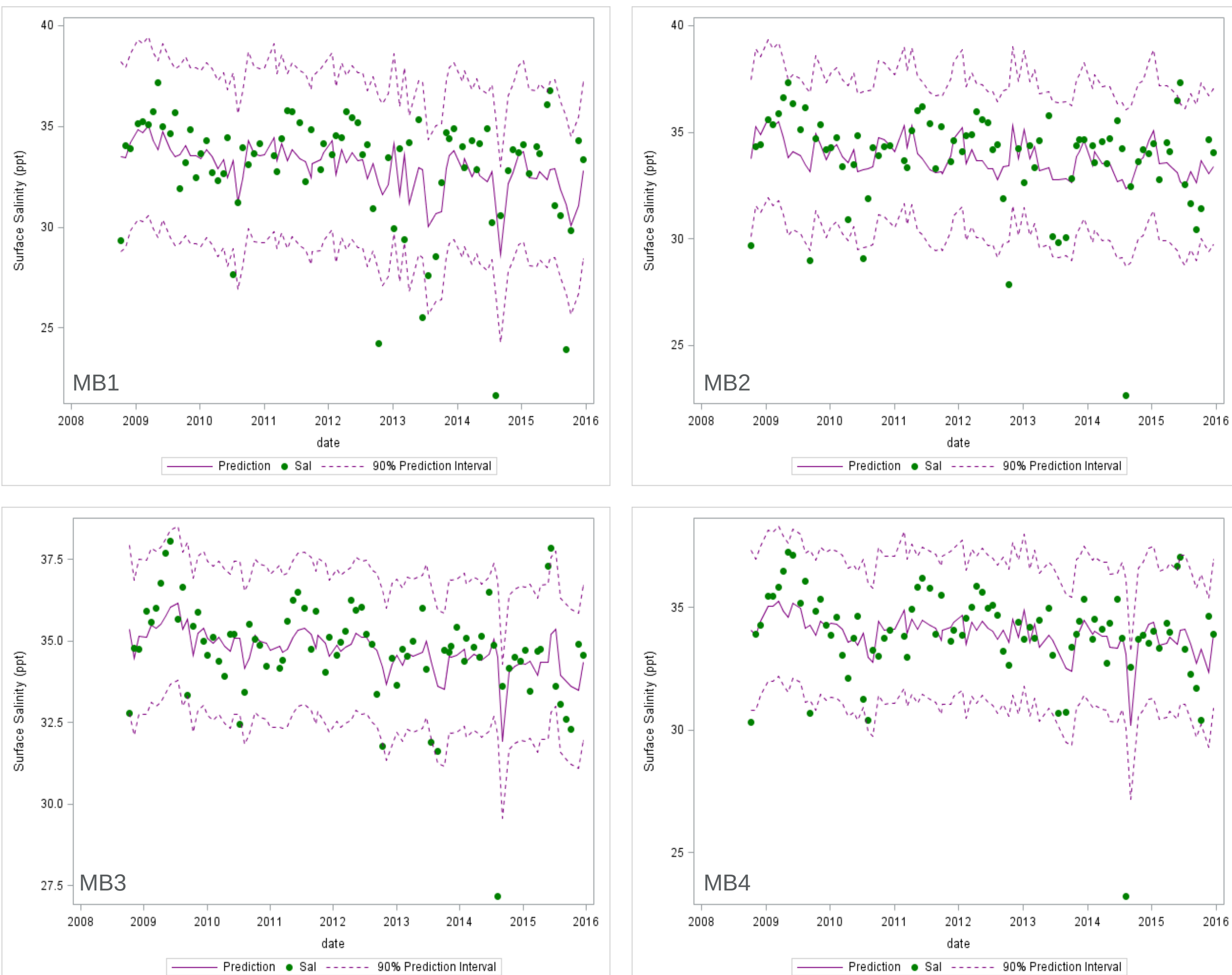


Figure 4-4. Results of AEM time series models of monthly surface salinity in Moorings Bay, 2008–2015, including observed, predicted, and 90 percent prediction intervals.

Table 4-3. Results of time-series models of monthly bottom salinity in Moorings Bay, 2008–2015, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	
MB1	0.3	42.22	0.0001	-0.0004	0.09			1
MB2	0.39	43.21	0.0001	**-0.0004**	**0.04**			1, 2
MB3	0.35	43.96	0.0001	-0.0004	0.16			1, 11
MB4	0.33	43.18	0.0001	-0.0004	0.07			1

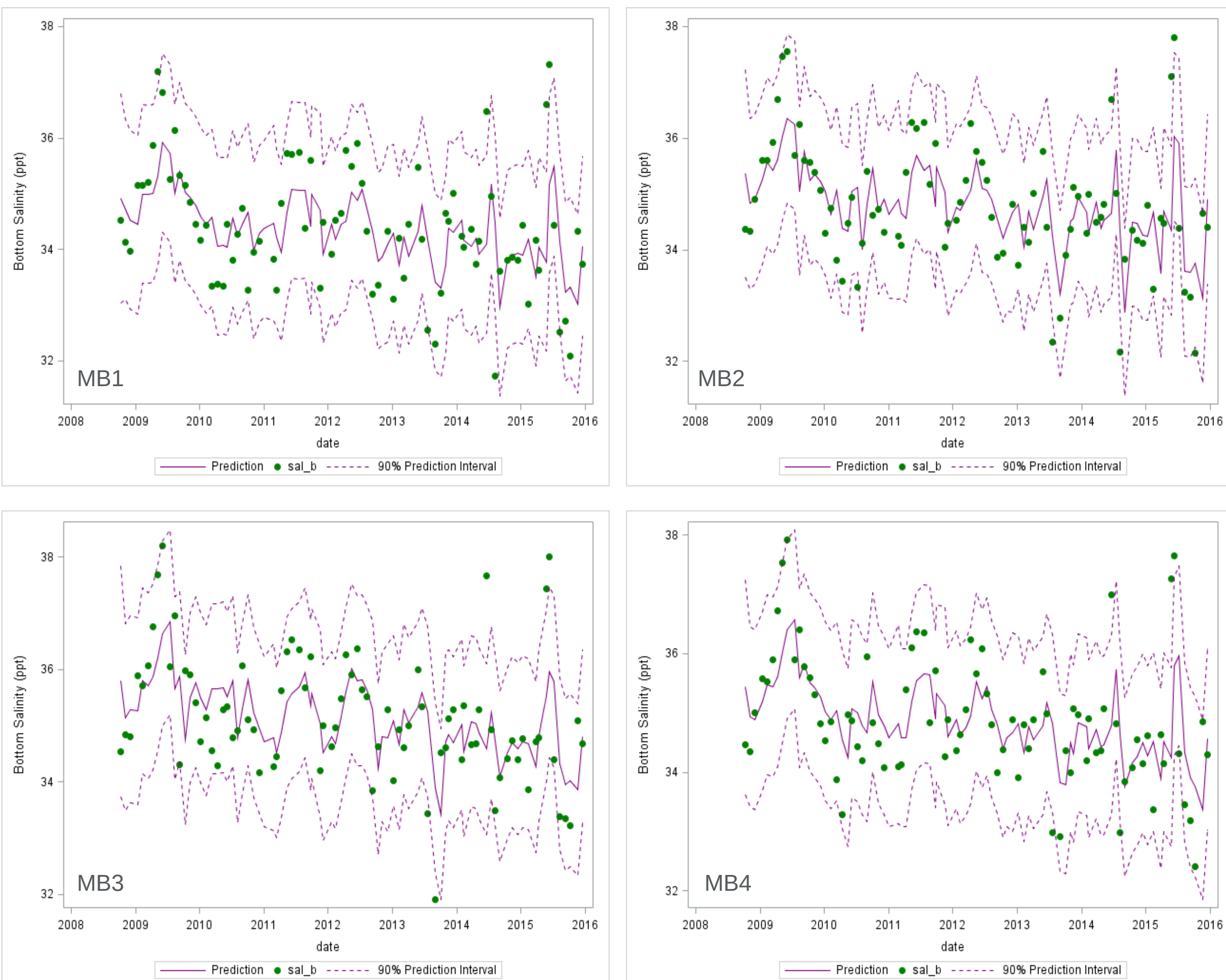


Figure 4-5. Results of AEM time series models of monthly bottom salinity in Moorings Bay, 2008–2015, including observed, predicted, and 90 percent prediction intervals.

4.2 Copper

Moorings Bay (WBID 3278Q2) is not currently listed as impaired for copper by FDEP. Copper is an essential trace element for many aquatic organisms, but can be toxic at levels slightly above those necessary for growth and reproduction (Hall *et al.* 1988). In estuaries, sources of copper include atmospheric deposition, industrial and municipal discharges, urban runoff, and antifouling marine paints (Hall *et al.* 1988). Copper sulfate is also very commonly used as an herbicide in lake management applications to control algae.

4.2.1 Water Quality Criteria

Copper concentrations in Moorings Bay were evaluated relative to the Class II water quality standard of 3.7 µg/L (Figure 4-6[1]). Before September 2012, copper concentrations in Moorings Bay rarely exceeded the threshold. Since that time, copper concentrations have exceeded the Class II Standard in approximately 17% of samples; most frequently at station MB1 (Figure 4-7). Impairment of a waterbody is determined by the percentage of individual samples above the applicable criterion (per 62-303, F.A.C.). Given that copper concentrations in Moorings Bay show more than a ten percent exceedance rate in the current data set and the frequency of exceedance has been increasing over time, it is highly likely that Moorings Bay will be listed as impaired for copper during the next assessment cycle (approximately 2019, according to FDEP's current assessment cycle). It is interesting to note that a similar pattern in copper exceedances was observed in Naples Bay over the same time period (Cardno 2015). This may indicate a regional source of copper affecting both waterbodies in a similar manner.

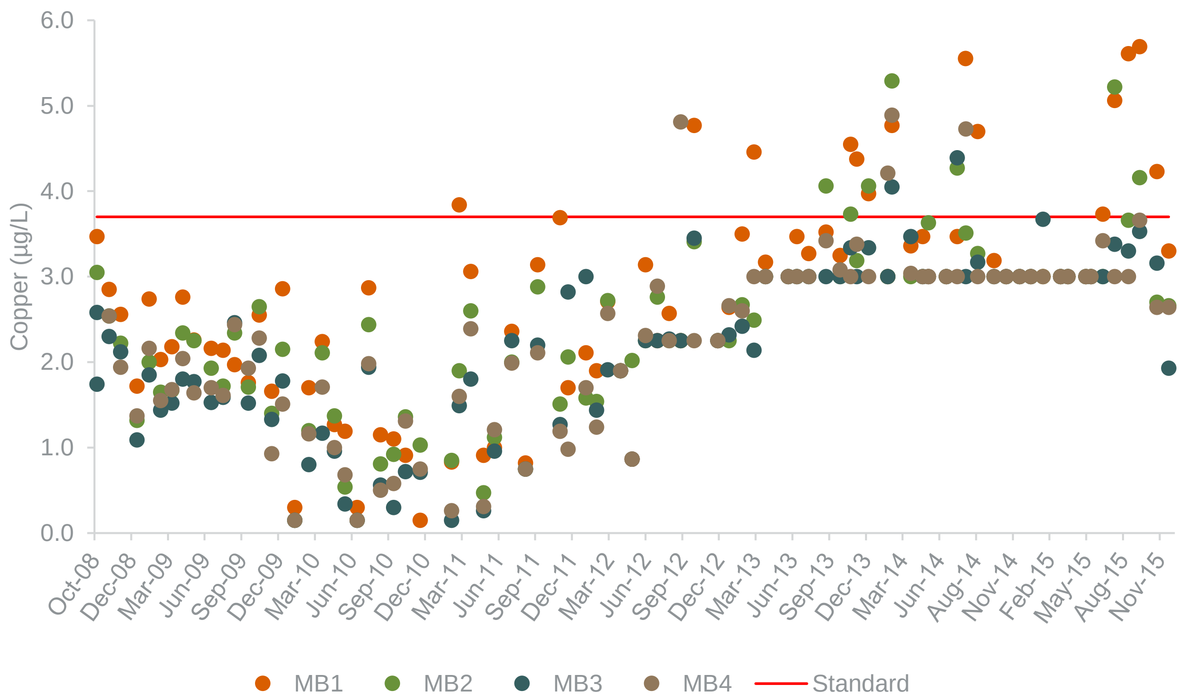


Figure 4-6. Copper concentrations in Moorings Bay (by sampling station) and Class II water quality criterion for copper, October 2008–December 2015.

[1] Figure 4-6 also illustrates that the MDL of copper has increased over time, beginning in 2012; this change causes the dataset to show a truncation of lower values and must be addressed in any statistical analysis.

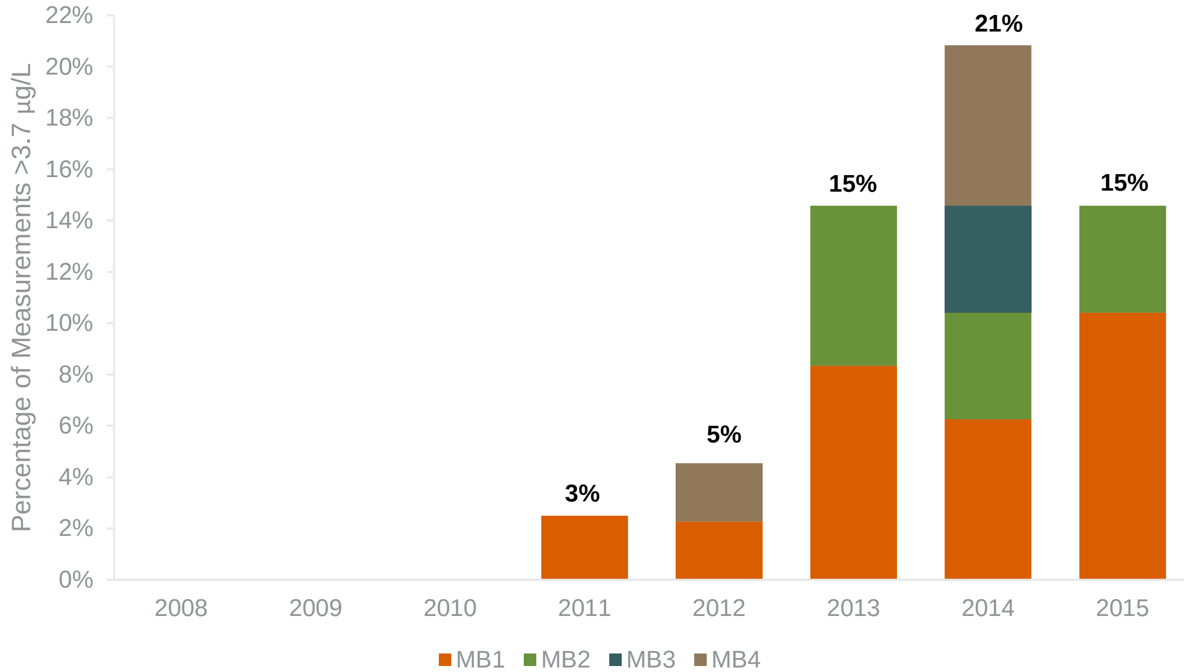


Figure 4-7. Annual percentage of copper concentrations greater than 3.7 µg/L by station in Moorings Bay, October 2008–December 2015.

4.2.2 Spatial Patterns

For any given sampling date, copper concentrations are usually (approximately 67 percent of the time) higher at station MB1 than any of the other three stations (Figures 4-6 and 4-8). When copper concentrations were compared between stations (Figure 4-8), a set of t-tests of dependent samples[2] pairing the results for each station by sampling event showed that station MB1 had significantly higher concentrations than the other three stations, and MB2 had significantly higher concentrations than MB3 and MB4 (paired t-test, two-tailed, $p < 0.05$); MB3 and MB4 had similar concentrations (paired t-test, two-tailed, $p > 0.05$). Thus, the stations farthest from Doctors Pass and closer to Clam Bay (which is currently on the verified impaired list for copper), and possibly more sensitive to freshwater input, showed the highest copper concentrations, indicating a non-Gulf source of copper.

[2] A paired t-test was performed for copper despite the changes in MDL because the MDL changes were consistent for each sampling event, so a comparison of the differences between stations was still valuable with minimal departure from statistical assumptions.

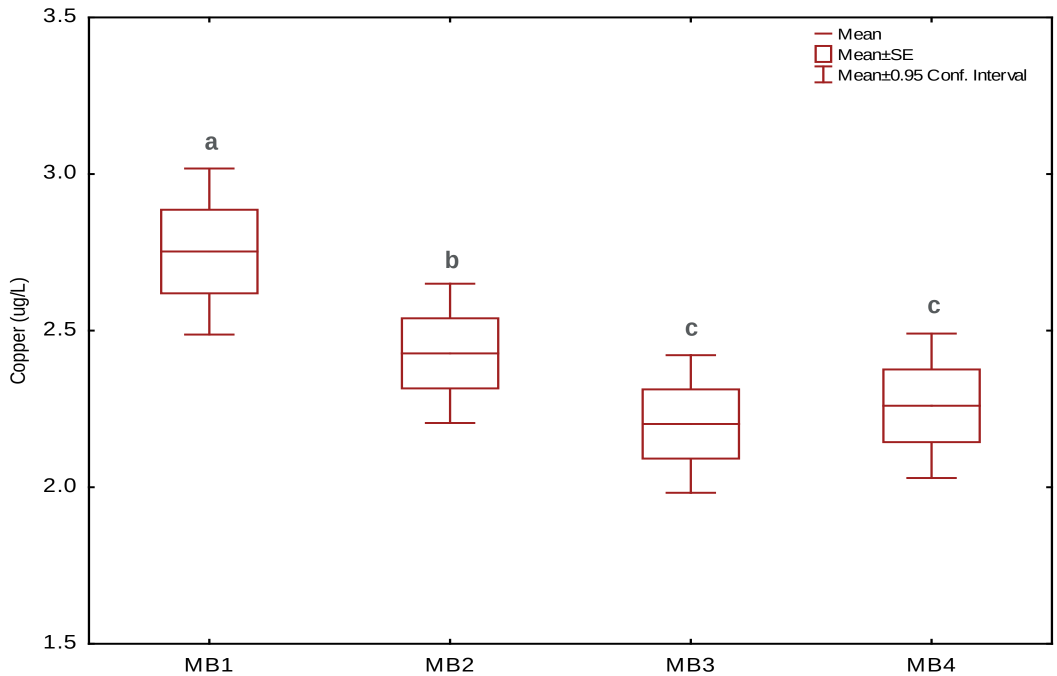


Figure 4-8. Copper concentrations by station in Moorings Bay, October 2008–December 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, $p < 0.05$).

4.2.3 Temporal Trends

To examine differences in copper concentrations between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Figure 4-9); this analysis was performed for separate time periods because of the changes in MDLs: 2008–2011 and 2013–2015. Copper concentrations were not different between seasons for the 2008–2011 time period at any station or at all stations combined (t-test of log copper by season, two-tailed, $p > 0.05$) (Figure 4-9). Copper concentrations were significantly higher during the wet season at stations MB1 and MB2 and at all stations combined for the 2013–2015 time period (t-test of log copper by season, two-tailed, $p < 0.05$) (Figure 4-9). Copper concentrations are not correlated with rainfall in Moorings Bay at any individual station or all stations combined for either the 2008–2011 or 2013–2015 time periods (Pearson correlation, $p > 0.05$). These results indicate that there may be a weak response of copper concentrations in northern Moorings Bay to wet season inputs of water, but that rainfall itself is not a direct causal factor.

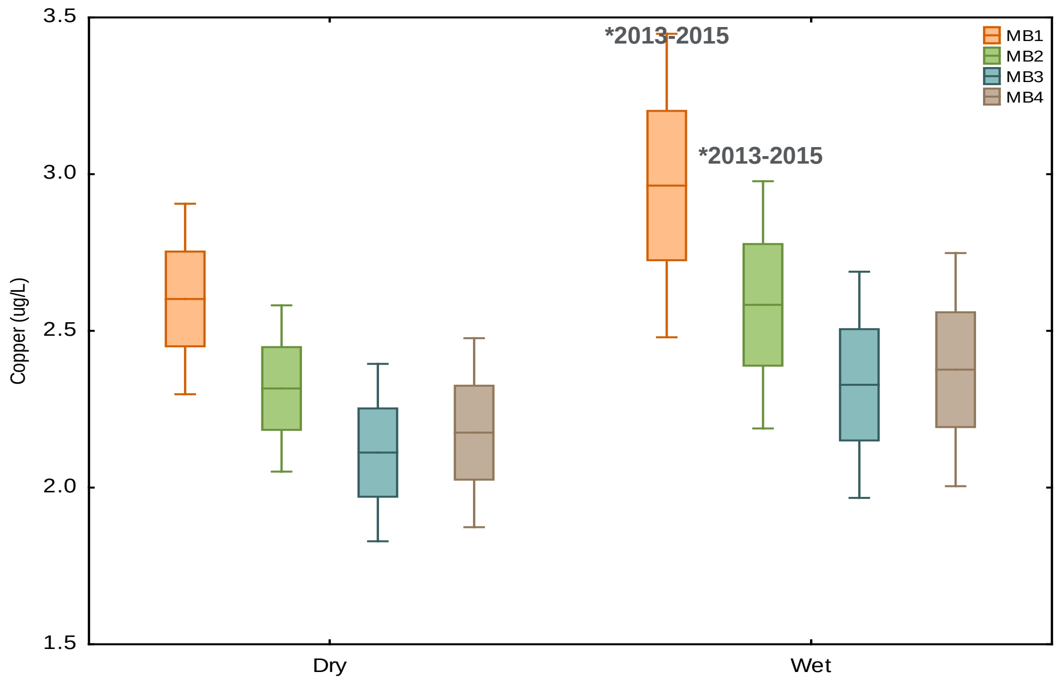


Figure 4-9. Seasonal copper concentrations by station in Moorings Bay, October 2008–December 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (two-tailed t-test).

Because of the changes in MDL over time, the AEM trend analysis was not suitable for copper. An alternate analysis, Kendall Tau nonparametric trend test, was used to examine the annual geometric mean copper concentrations over time for changes. Before the geometric means were calculated, all values below the highest MDL (3.0 µg/L) were replaced with that value as a censoring of the dataset. The Kendall Tau analysis indicated a statistically significant increasing trend in annual geometric means at all four stations (Kendall Tau, 0.62 > Tau > 0.82, $p < 0.05$), with the weakest trend at station MB4. This supports the results of the water quality criteria exceedance rate analysis from Figure 4-7, and increases the likelihood that Moorings Bay will be listed as impaired for copper during the next assessment cycle.

4.3 Nutrients: TN and TP

Nutrient levels in Florida waterbodies have increasingly gained the attention of resource managers with the difficult task of managing nutrients for their importance in the environment while preventing excess nutrients that can be undesirable and even harmful. The recent implementation of estuary-specific Numeric Nutrient Criteria (NNC) has provided managers with targets intended to represent the delicate balance between nutrient benefits and harms. Given its artificial nature and the intense urban land use surrounding it, Moorings Bay epitomizes the nutrient management saga. City resource managers can use the information here to develop long term, realistic management goals for Moorings Bay.

4.3.1 Water Quality Criteria

Moorings Bay has estuary-specific numeric interpretations of the NNC with thresholds for TN and TP that are not to be exceeded in more than 10 percent of samples (62-302.532, F.A.C.). Less than six percent of TN samples exceed the threshold of 0.85 mg/L, while over 17 percent of TP samples exceed the threshold of 0.040 mg/L (Table 4-4, Figure 4-10). These results indicate that Moorings Bay is likely to be listed as impaired for TP during the next assessment cycle (~2019).

Table 4-4. Exceedances of NNC thresholds for TN and TP in Moorings Bay and by station, October 2008–December 2015.

Parameter	TN	TP
Standard	**0.85 mg/L**	**0.04 mg/L**
Moorings Bay		
No. of Samples	366	336
No. of Exceedances	20	58
% Exceedance	5.95%	17.26%
% Exceedance By Station		
MB1	11%	43%
MB2	5%	11%
MB3	5%	4%
MB4	4%	12%

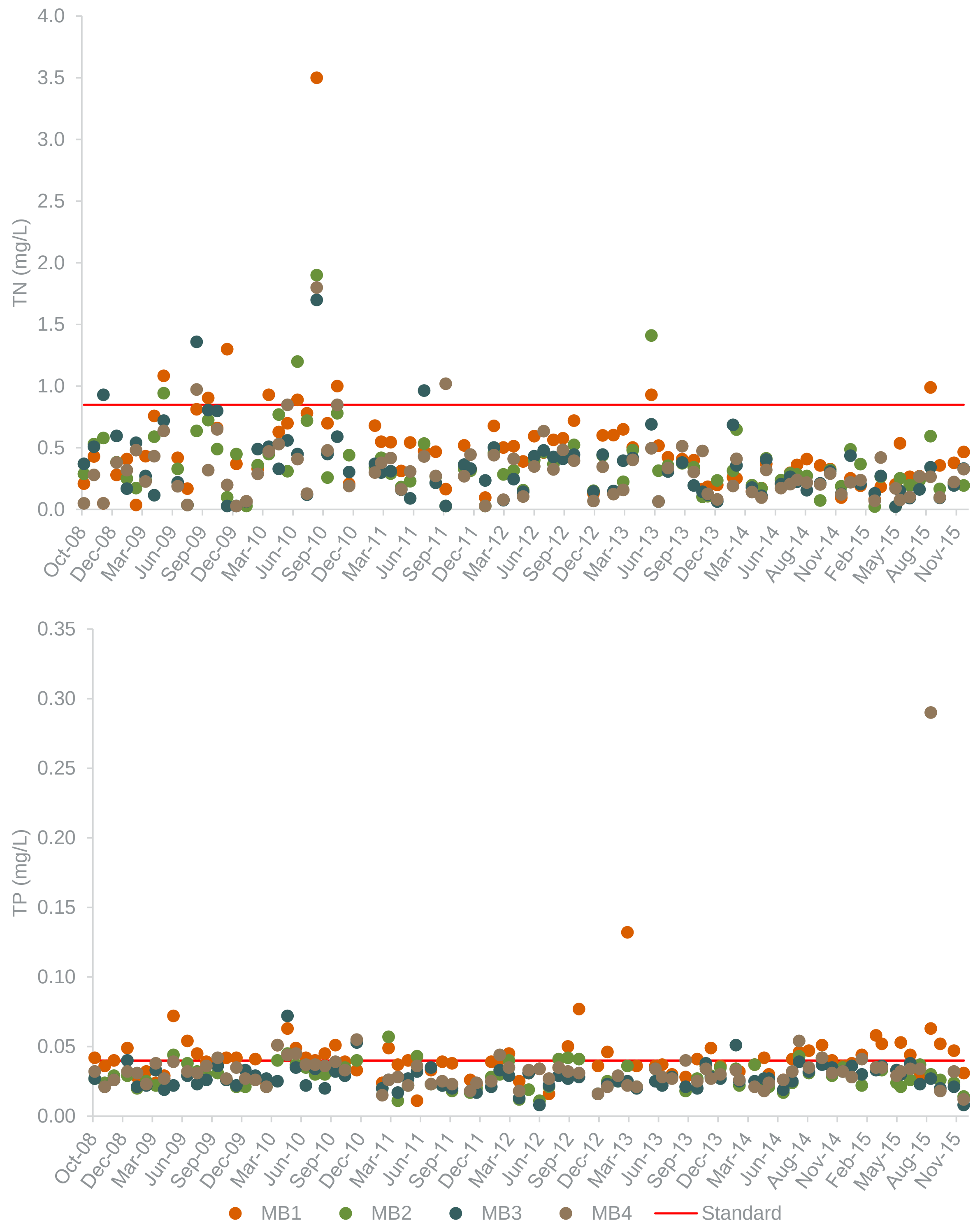
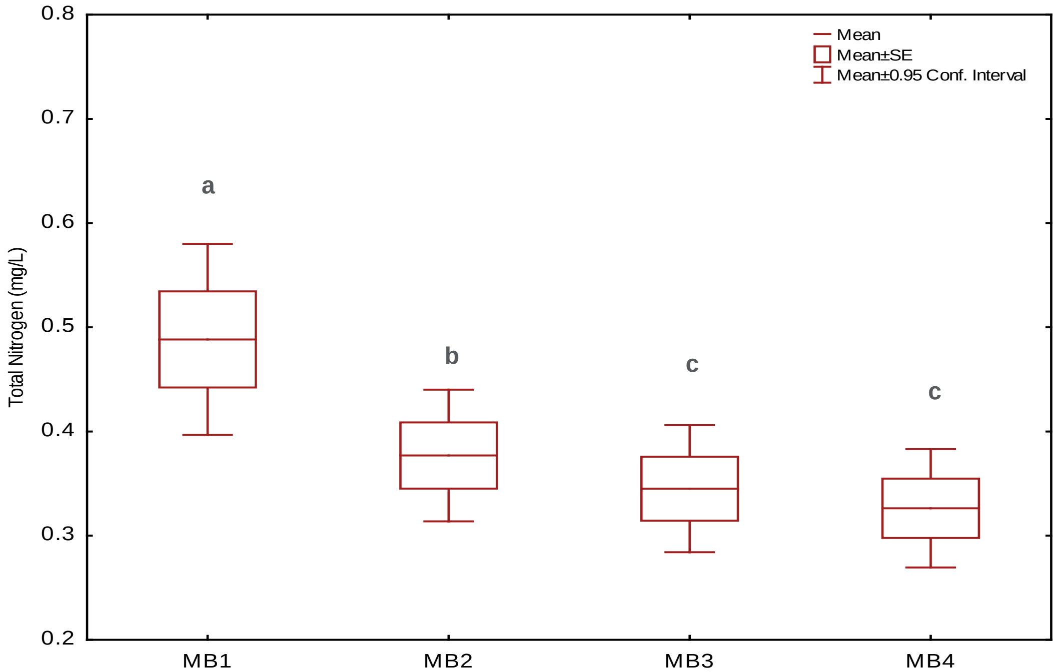


Figure 4-10. TN and TP concentrations in Moorings Bay (by sampling station) and NNC thresholds, October 2008–December 2015.

4.3.2 Spatial Patterns

For both TN and TP, samples from station MB1 exceed the water quality thresholds more frequently than any other station (Table 4-4, Figure 4-10). MB1, which is the least influenced by tidal flushing from Doctors Pass exceeds the TP threshold over 40 percent of the time, and at MB3, the station with the most tidal flushing, only four percent of samples exceed the threshold. Station MB1 has the greatest influence on Moorings Bay with respect to its potential impairment status.

When TN concentrations were compared between stations (Figure 4-11), a set of t-tests of dependent samples showed that station MB1 had significantly higher concentrations than the other three stations, and MB2 had significantly higher concentrations than MB3 and MB4 (paired t-test, two-tailed, $p < 0.05$); MB3 and MB4 had similar concentrations (paired t-test, two-tailed, $p > 0.05$). When TP concentrations were compared between stations (Figure 4-11), MB1 had significantly higher concentrations than the other three stations, and MB4 had significantly higher concentrations than MB2 and MB3 (paired t-test, two-tailed, $p < 0.05$); MB2 and MB3 had similar concentrations (paired t-test, two-tailed, $p > 0.05$). For both nutrients, the northern station (MB1) closest to Clam Bay and farthest from other marine inputs had much greater concentrations than the other stations. Previous comparisons of the water quality in Clam and Moorings Bays showed significant differences between the two bays in TN and TP, where Clam Bay was higher in both nutrients (Atkins 2011).



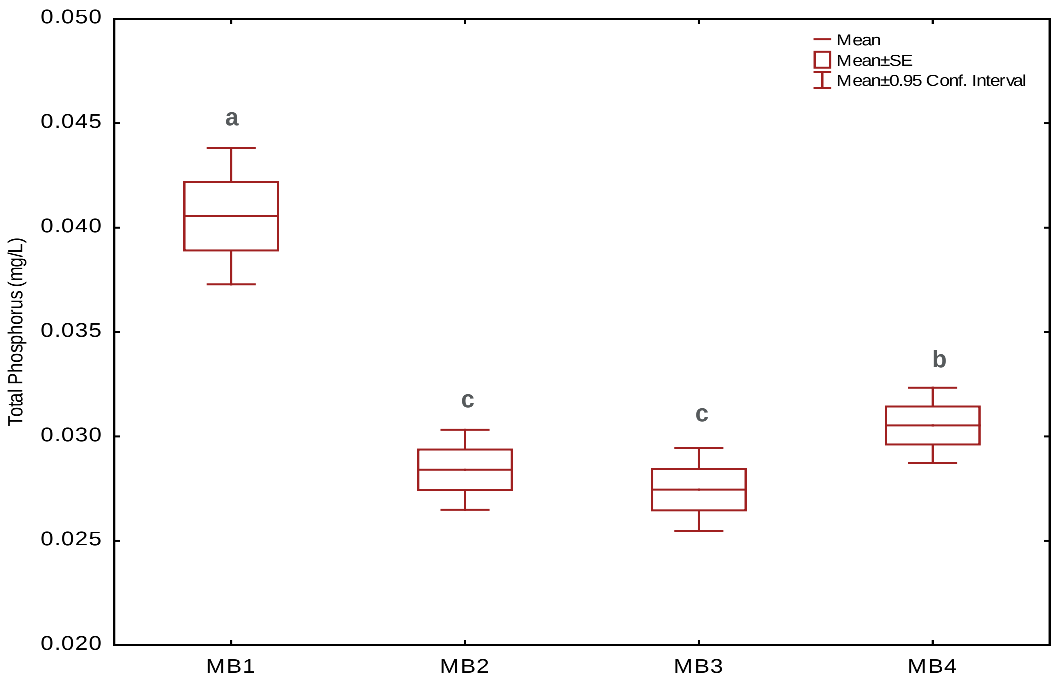


Figure 4-11. Total nitrogen and total phosphorus in Moorings Bay, October 2008–December 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, $p < 0.05$).

4.3.3 Temporal Trends

To examine differences in TN and TP between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Figure 4-12). TN was significantly higher in the wet season at station MB1 and at all stations combined (t-test of seasons, two-tailed, $p < 0.05$, Figure 4-12). TP was significantly higher in the wet season at station MB4 and at all stations combined (t-test of seasons, two-tailed, $p < 0.05$, Figure 4-12). Log transformed TN was positively correlated with rainfall at MB1 and at all stations combined (Pearson correlation, $0.12 < r < 0.25$, $p > 0.05$). Log transformed TP was positively correlated with rainfall at MB4 only (Pearson correlation, $r = 0.27$, $p > 0.05$). For both nutrients, rainfall and runoff during the wet season seem to contribute to concentrations in Moorings Bay at the northern station for TN and the southern station for TP.

TN and TP concentrations (log transformed) were examined for potential trends over time using the AEM model, with and without the autoregressive term and the log monthly rainfall covariate (Tables 4-5 and 4-6). For two of the four stations, the best fit model for TN included the rainfall covariate, and some also included autoregressive terms, indicating temporal autocorrelation and seasonal cycles. TN showed statistically significant decreasing trends over time at all stations at the $p < 0.05$ level (Table 4-5 and Figure 4-13) and overall exceedances of the TN threshold have become more infrequent over the evaluation period (Figure 4-12). For station MB4, the best fit model for TP included the rainfall covariate, and some also included autoregressive terms. TP did not show statistically significant trends over time at any stations at the $p < 0.05$ level (Table 4-6 and Figure 4-14).

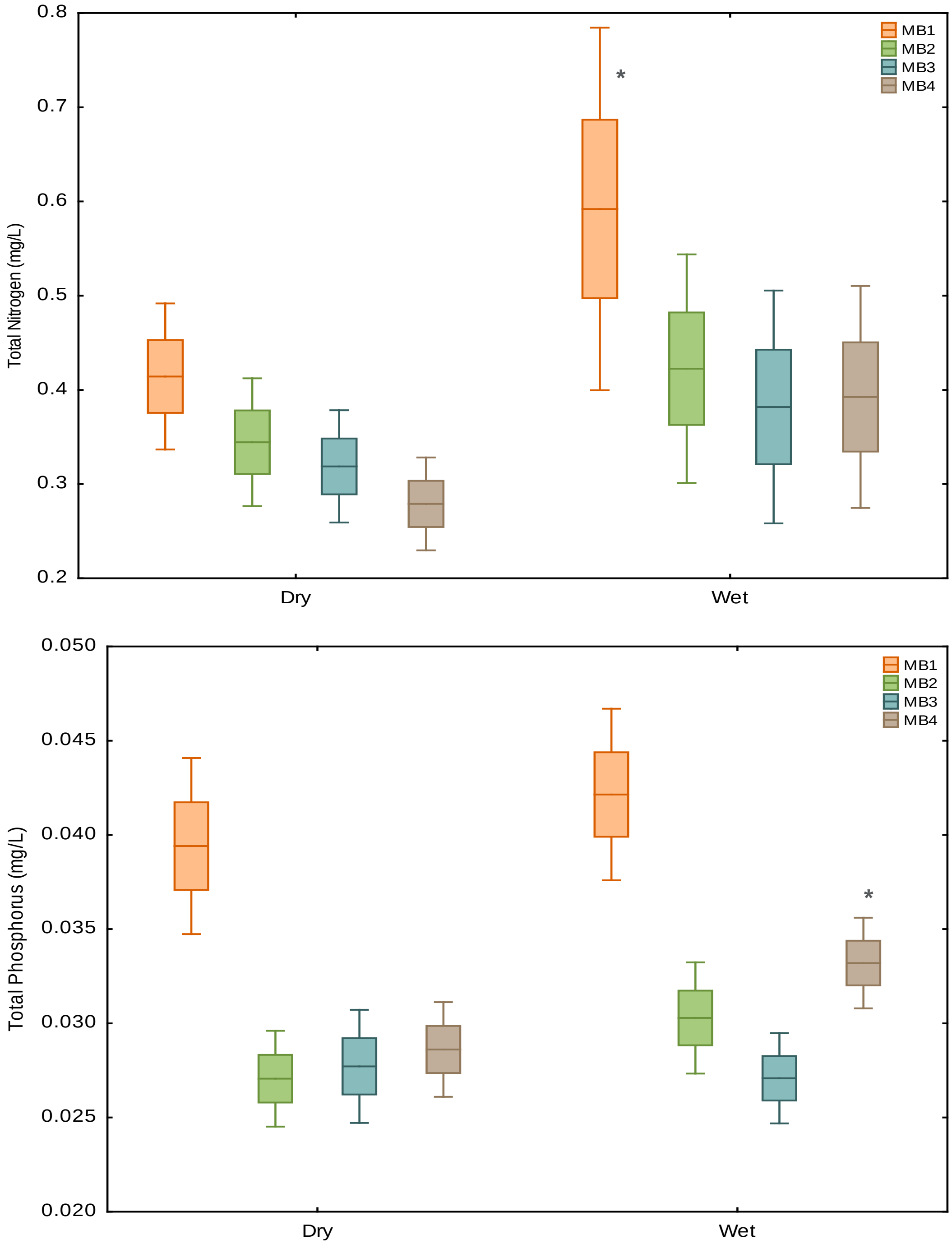


Figure 4-12. **Seasonal total nitrogen and total phosphorus by station in Moorings Bay, October 2008–December 2015 (mean, ± 1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (two-tailed t-test).**

Table 4-5. Results of time-series models of monthly total nitrogen in Moorings Bay, 2008–2015, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	
MB1	0.3	3.67	0.1	**-0.0002**	**0.03**	**0.2**	**0.001**	1, 11, 12
MB2	0.1	4.01	0.04	**-0.0003**	**0.01**	0.09	0.15	
MB3	0.08	4.09	0.05	**-0.0003**	**0.009**			
MB4	0.19	2.56	0.17	**-0.0002**	**0.04**			8, 12

Figure 4-13. Results of AEM time series models of monthly total nitrogen in Moorings Bay, 2008–2015, including observed, predicted, and 90 percent prediction intervals.

Table 4-6. Results of time-series models of monthly total phosphorus in Moorings Bay, 2008–2015, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	
MB1	0.008	-3.99	0.0001	0.00004	0.42			
MB2	0.06	-3.25	0.003	-0.00002	0.73			7
MB3	0.09	-3.26	0.005	-0.00002	0.73			7
MB4	0.17	-2.49	0.0001	-0.00006	0.08	**0.06**	**0.008**	10

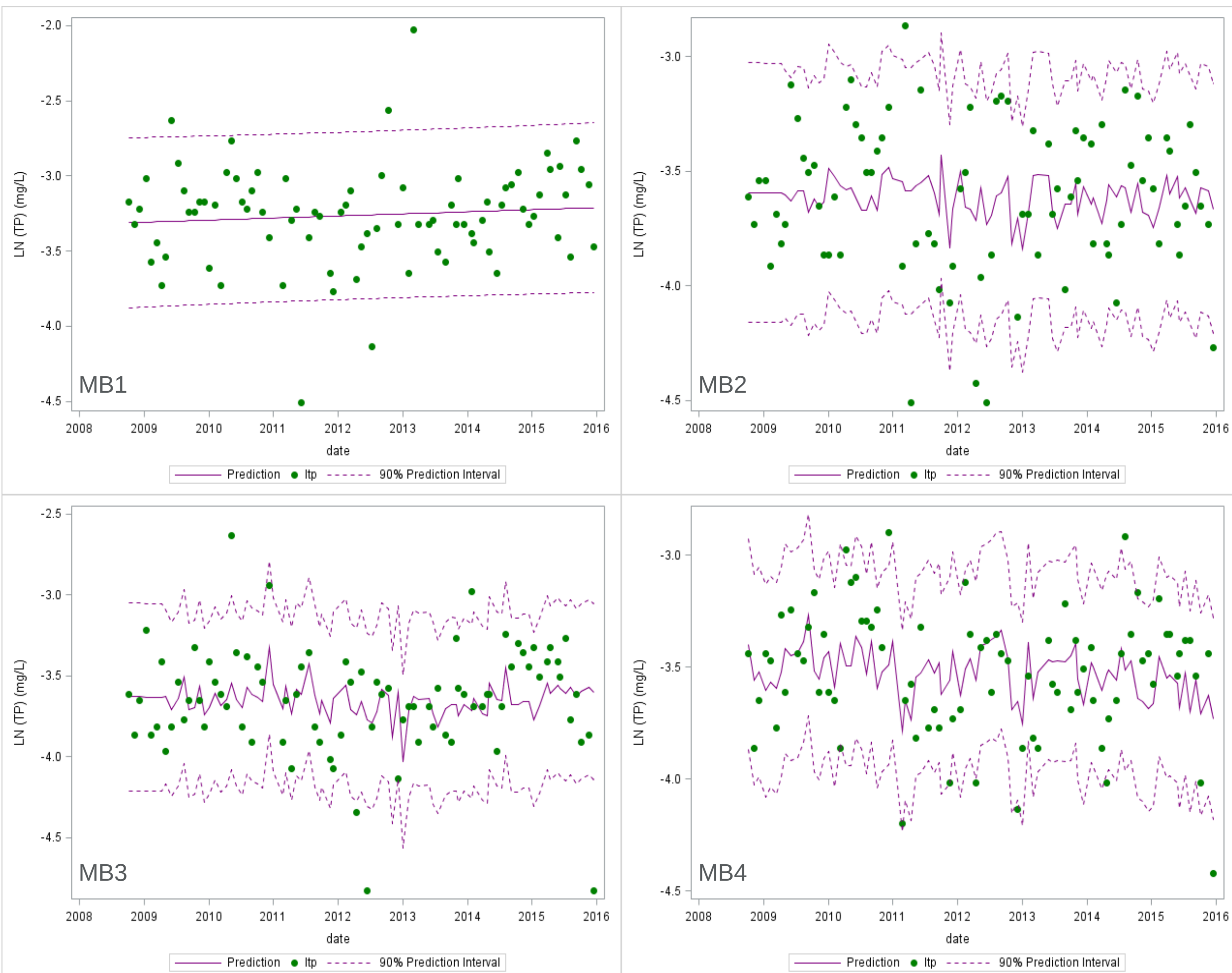


Figure 4-14. Results of AEM time series models of monthly total phosphorus in Moorings Bay, 2008–2015, including observed, predicted, and 90 percent prediction intervals.

4.4 Chlorophyll-*a*

Chlorophyll-*a* concentrations are commonly used as a surrogate for algal biomass in a waterbody. Evaluating current conditions and trends in chlorophyll-*a* in Moorings Bay can help to quantify the effect of nutrients and flushing over time. Chlorophyll-*a* concentrations tend to be a good representation of how the public views the overall quality of a waterbody.

4.4.1 Water Quality Criteria

The estuary specific chlorophyll-*a* limit for Moorings Bay is 8.1 µg/L as an annual geometric mean, not to be exceeded more than once in a three year period (62-302.532 FAC). When viewing the waterbody as a whole, annual geometric mean concentrations of chlorophyll-*a* in Moorings Bay do not exceed the NNC threshold at any time during the evaluation period (Figure 4-15). Since the criterion is based on a waterbody average, Moorings Bay does not currently violate the criterion, but the observed chlorophyll-a concentrations at station MB1 raise concern, and further evaluation of the data for this station is provided below.

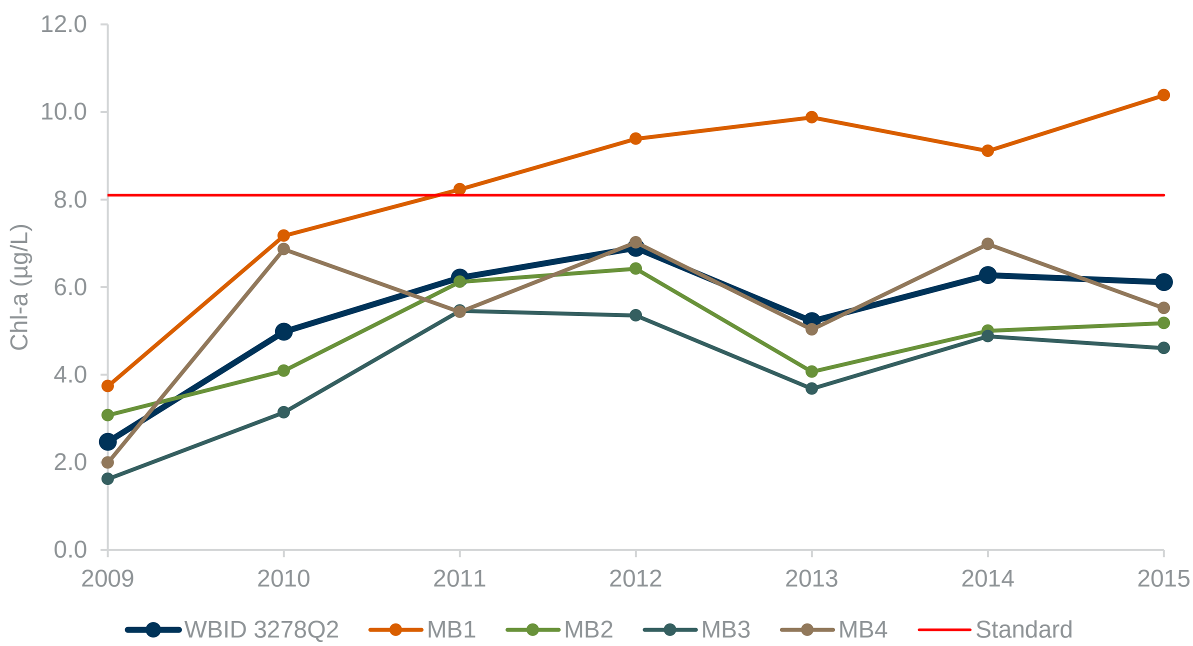


Figure 4-15. Chlorophyll-*a* concentrations in Moorings Bay and by sampling station with the NNC threshold, October 2008–December 2015.

4.4.2 Spatial Patterns

For any given sampling date, chlorophyll-*a* concentrations are usually (approximately 64 percent of the time) higher at station MB1 than any of the other three stations (Figure 4-16). Annual geometric mean chlorophyll-*a* concentrations are always higher at station MB1 than at the other three sampling stations and are generally lowest at station MB3 (Figure 4-15). Even though Moorings Bay as a whole does not violate the water quality criterion, station MB1 has exceeded the NNC threshold of 8.1 µg/L every year since 2011. When chlorophyll-*a* concentrations were compared between stations, a set of t-tests of dependent samples showed that station MB1 had significantly higher concentrations than the other three stations, and MB3 had significantly lower concentrations than MB2 and MB4 (paired t-test, two-tailed, $p < 0.05$, Figure 4-17); MB2 and MB4 had similar concentrations (paired t-test, two-tailed, $p > 0.05$, Figure 4-

17). Thus the northern station closest to Clam Bay has much higher chlorophyll-*a* concentrations, while stations closer to Doctors Pass have lower concentrations.

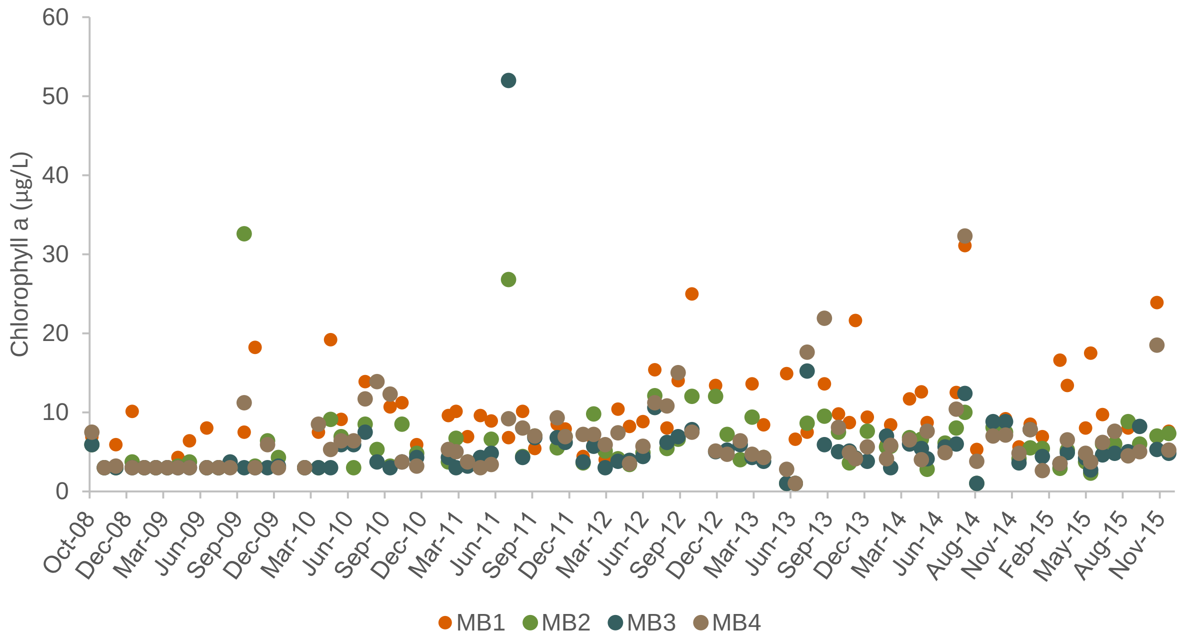


Figure 4-16. Chlorophyll-*a* concentrations in Moorings Bay (by sampling station), October 2008–December 2015.

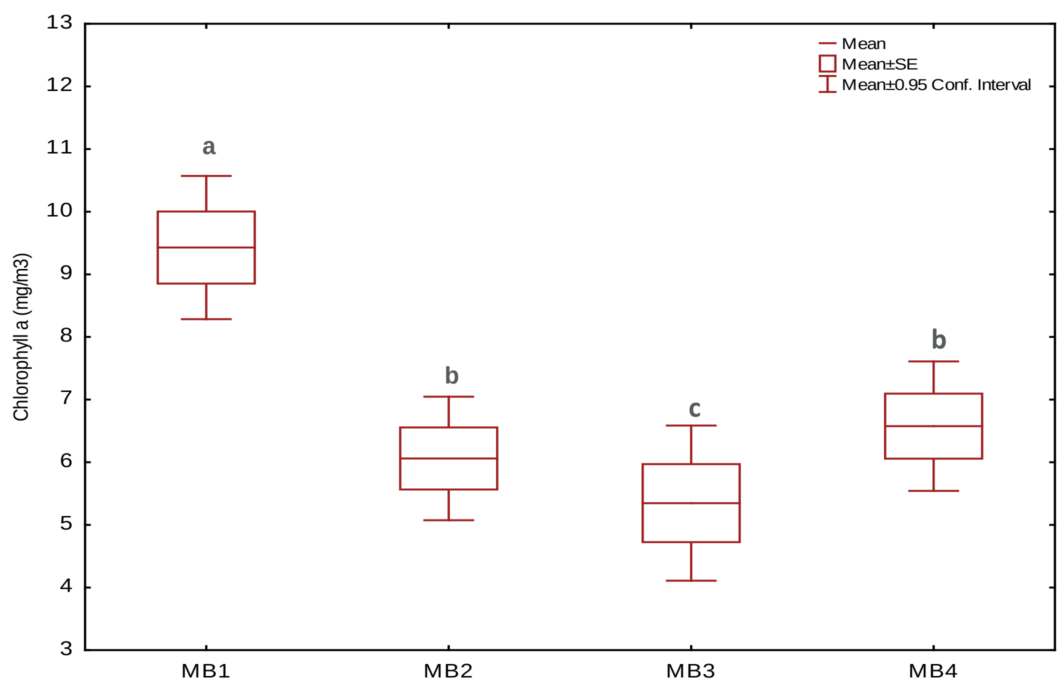


Figure 4-17. Chlorophyll-*a* concentrations by station in Moorings Bay, October 2008–December 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, $p < 0.05$).

4.4.3 Temporal Trends

To examine differences in chlorophyll-*a* concentrations between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Figure 4-18). Chlorophyll-*a* concentrations were significantly higher in the wet season at station MB3 and MB4 and at all stations combined (t-test of seasons, two-tailed, $p < 0.05$). Log transformed chlorophyll-*a* was positively correlated with rainfall at MB4 and at all stations combined (Pearson correlation, $0.13 < r < 0.31$, $p > 0.05$). Rainfall and/or seasonal changes in temperature seem to have more influence over chlorophyll-*a* at the stations closer to Doctors Pass.

Because of the changes in MDL of chlorophyll-*a* over time, the AEM trend analysis was not suitable. An alternate analysis, Kendall Tau nonparametric trend test, was used to examine the annual geometric mean chlorophyll-*a* concentrations over time for changes. Before the geometric means were calculated, all values below the highest MDL (3.0 µg/L) were replaced with that value as a censoring of the dataset. The Kendall Tau analysis indicated a statistically significant increasing trend in annual geometric means at station MB1 (Kendall Tau, Tau = 0.81, $p < 0.05$), but not at other stations. This trend, combined with the overall higher chlorophyll-*a* concentrations at this station, indicates that the factors influencing algal growth are different at this station compared to the rest of Moorings Bay.

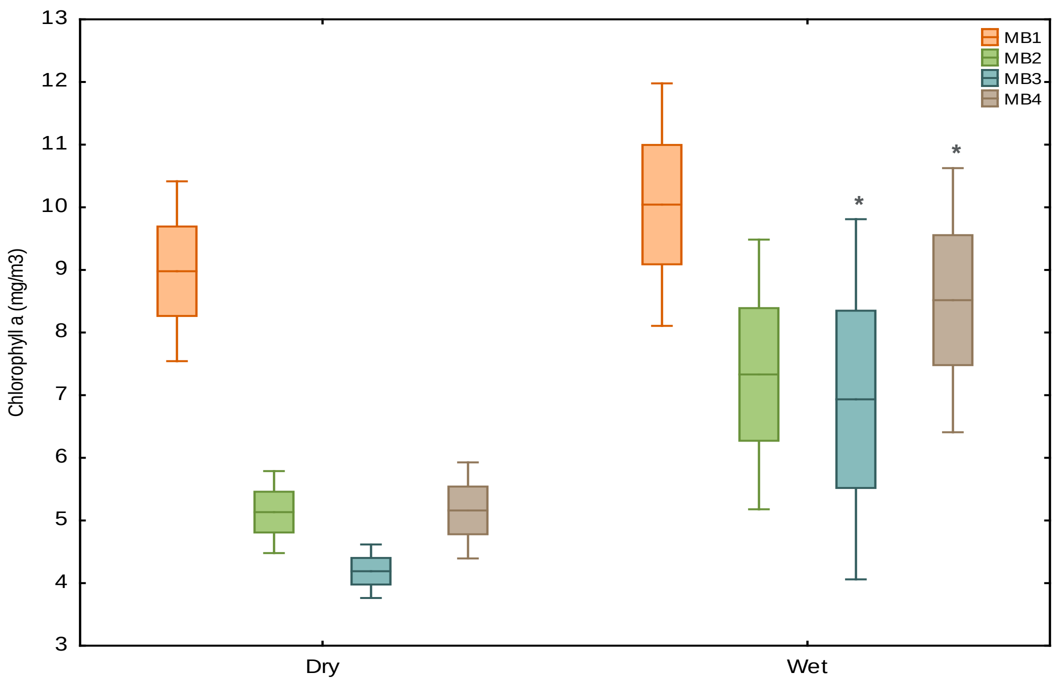


Figure 4-18. Seasonal chlorophyll-*a* concentrations by station in Moorings Bay, October 2008–December 2015 (mean, ± 1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (two-tailed t-test).

4.5 Dissolved Oxygen

Dissolved oxygen (DO) is viewed as a general indicator of waterbody health because it is essential to aquatic life. DO changes over the course of the day, driven by the production of oxygen during plant and algal photosynthesis and respiration at night when photosynthesis stops. DO also fluctuates on seasonal cycles which are impacted by a variety of environmental factors such as hours of daylight, temperature, salinity, and wind or flow driven aeration. Given that Moorings Bay is sea-walled and located in a dense urban area with a single pass connection the Gulf, in-depth evaluation of the DO regime and its potential connection to the observed biology of Moorings Bay is warranted.

4.5.1 Water Quality Criteria

The marine DO criteria is based on percent saturation (rather than concentration) and requires that a daily average of at least 42 percent saturation is maintained (62-302.533, F.A.C.) in 90 percent of the measurements. In addition to the daily average, a seven day average percent saturation of 51 and a 30 day average percent saturation of 56 shall also be maintained. For comparisons to the marine water quality standard, DO is assessed at the WBID scale. The monthly grab sample data available for Moorings Bay are insufficient to assess the seven day and 30 day average components of the criteria, but the daily average component is included here.

The sampling program in Moorings Bay includes both surface and bottom DO measurements at each sampling station. In order to assess DO in Moorings Bay with respect to the daily average criteria, these data were averaged (as described in 62-303.320(6), F. A. C.) so that one value could be obtained for each sampling station on each sample date. Overall, 7.14 percent of DO measurements fell below the 42 percent threshold (all of which are from station MB1), and therefore, Moorings Bay is not in violation of the DO criterion (Figure 4-19).

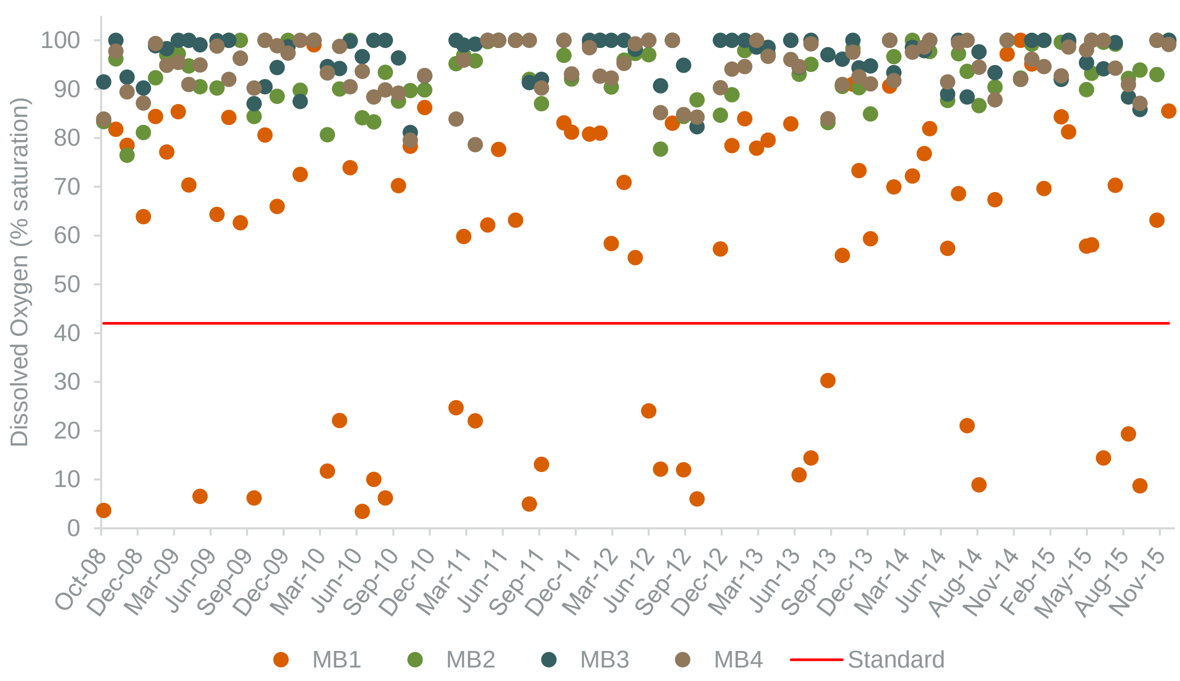


Figure 4-19. Dissolved oxygen percent saturation in Moorings Bay (by sampling station) and the Class II water quality criterion, October 2008–December 2015.

4.5.2 Spatial Patterns

Dissolved oxygen was measured near the surface and near the bottom of the water column during each water quality sampling event. Surface and deep water readings were compared by station to look for patterns of water column stratification in DO concentration (Figure 4-20). A t-test of dependent samples pairing the surface and bottom results for each station by sampling event, indicated that surface DO is significantly higher than bottom DO at MB1, MB2, and MB4 (paired t-test, two-tailed, $p < 0.05$, Figure 4-20), but not MB3. Of the four stations, MB1 has the lowest average DO concentrations and the greatest water column stratification in DO. DO concentrations in near-bottom water at MB1 frequently drops below hypoxic levels (2 mg/L). DO stratification is less pronounced at MB2 and MB4, and rarely occurs at MB3.

When surface DO was compared between stations, a set of t-tests of dependent samples showed that all stations were significantly different from each other, with the highest DO at station MB4 and lowest at MB1 (paired t-test, two-tailed, $p < 0.05$, Figure 4-21). Bottom DO was significantly different at each station, higher at station MB3 and lower at MB1 (paired t-test, two-tailed, $p < 0.05$, Figure 4-21). Based on this analysis, DO at the station closest to Clam Bay is highly stratified and much lower than other stations, while DO nearer Doctors Pass is higher and less likely to be stratified.

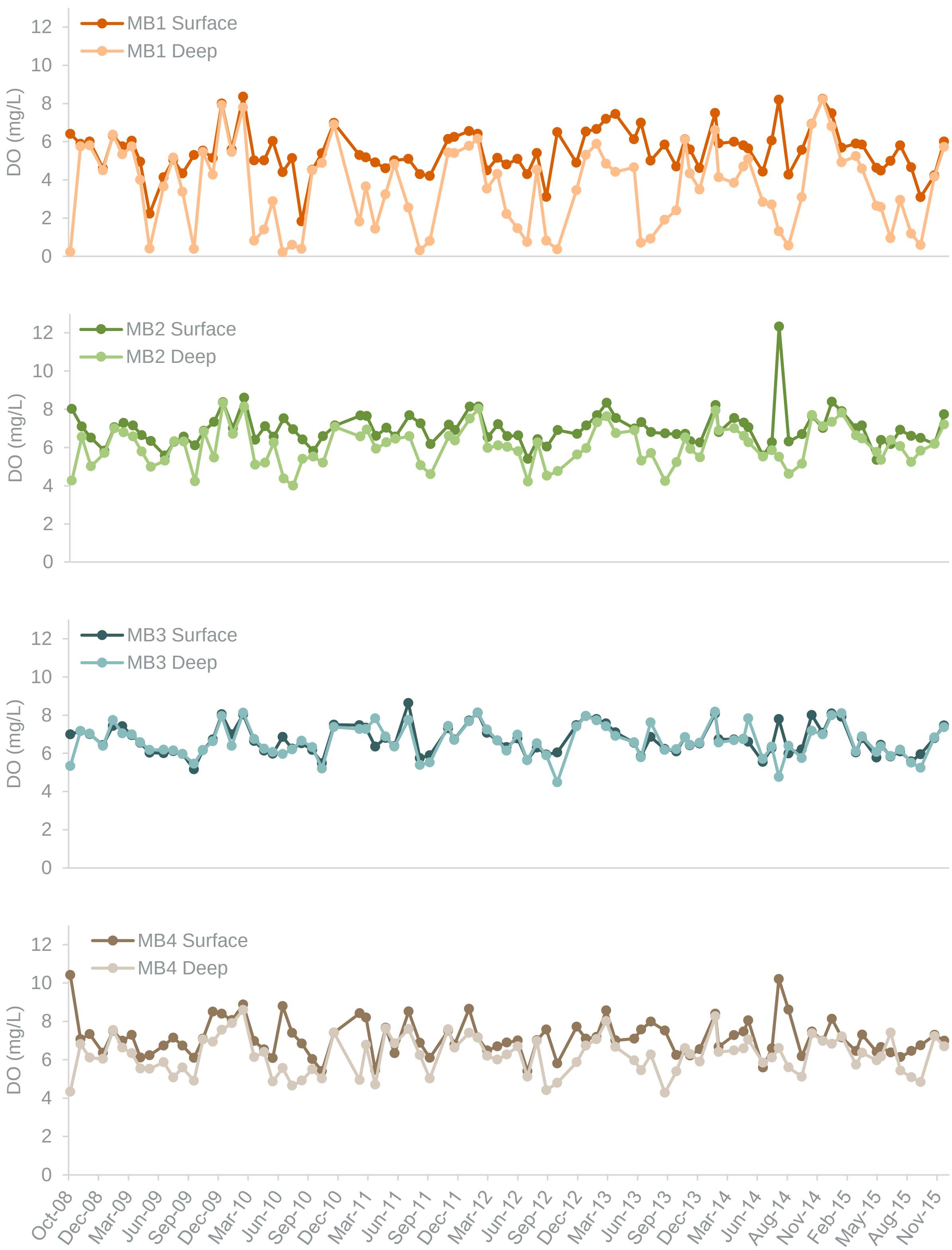
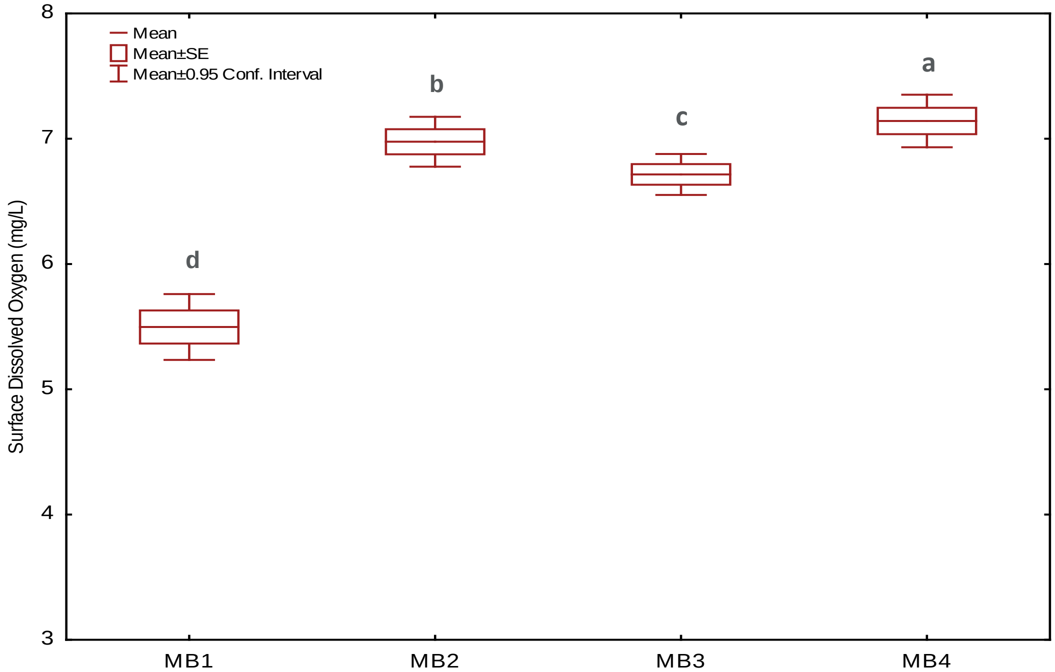


Figure 4-20. Surface and bottom dissolved oxygen at Moorings Bay water quality monitoring stations, October 2008–December 2015.



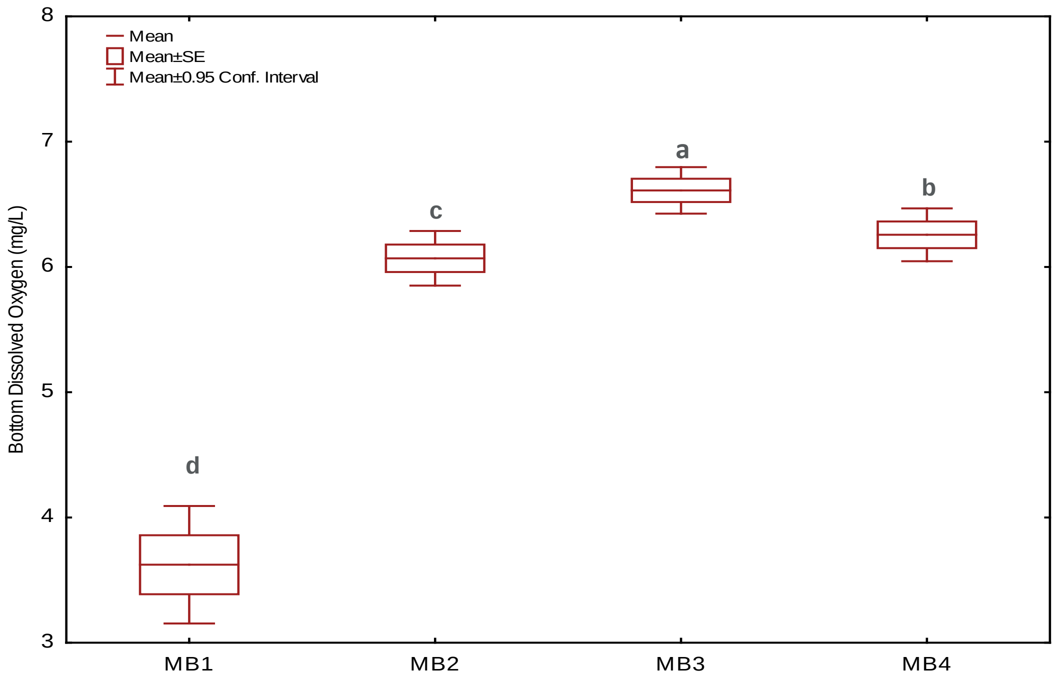


Figure 4-21. **Surface and bottom dissolved oxygen in Moorings Bay, October 2008–December 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, $p < 0.05$).**

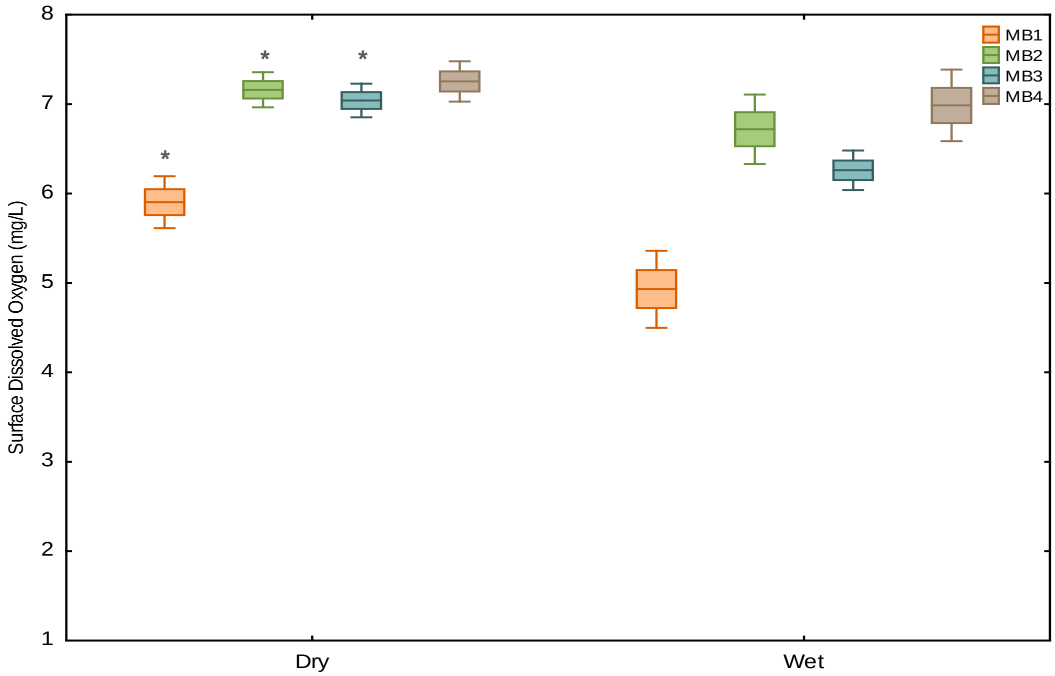
4.5.3 Temporal Trends

To examine differences in surface and bottom dissolved oxygen between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Table 4-7). Surface dissolved oxygen was significantly higher during in the dry season at each station except MB4 and at all stations combined (t-test of seasons, two-tailed, $p < 0.05$, Figure 4-22). Bottom dissolved oxygen was significantly higher during the dry season at each station and at all stations combined (t-test of seasons, two-tailed, $p < 0.05$, Figure 4-22). Bottom dissolved oxygen is negatively correlated with rainfall in Moorings Bay at stations MB1, MB2, MB3, and all stations combined (Pearson correlation, $-0.32 > r > -0.53$, $p < 0.05$), but surface dissolved oxygen is only negatively correlated at station MB3 (Pearson correlation, $r = -0.32$, $p < 0.05$). Dissolved oxygen concentrations have a stronger seasonal cycle, as expected given the influence of water temperature on dissolved oxygen; the relative influence of temperature and rainfall on the seasonal differences in DO is not apportioned as part of this analysis.

Surface and bottom dissolved oxygen data was examined for potential trends over time using the AEM model, with and without the autoregressive term and the log monthly rainfall covariate (Tables 4-8 and 4-9). For two of the four stations, the best fit model for surface dissolved oxygen did not include the rainfall covariate, but some included autoregressive terms. Surface dissolved oxygen did not show statistically significant trends at the $p < 0.05$ level at any station (Table 4-8, Figure 4-23). For bottom dissolved oxygen, rainfall was not a covariate in the best-fit models, but there were some autoregressive terms (Table 4-9). Bottom dissolved oxygen did show statistically significant increasing trend at MB2 at the $p = 0.05$ level (Table 4-10 and Figure 4-24). When considered over all of Moorings Bay, DO shows little evidence of changes over time.

Table 4-7. Seasonal DO (mg/L) range and average by station in Moorings Bay, October 2008–December 2015.

Sample Location &Station	Surface				Deep			
	MB1	MB2	MB3	MB4	MB1	MB2	MB3	MB4
Dry Season								
Min	4.23	5.34	5.48	5.41	0.81	5.01	5.21	4.70
Mean	5.90	7.16	7.04	7.25	4.80	6.57	7.06	6.67
Max	8.35	8.60	8.13	8.87	8.21	8.32	8.18	8.60
Wet Season								
Min	1.82	5.40	5.17	5.40	0.21	4.00	4.48	4.28
Mean	4.93	6.72	6.26	6.99	1.97	5.36	6.05	5.62
Max	8.19	12.33	8.64	10.42	6.11	6.59	7.76	7.60



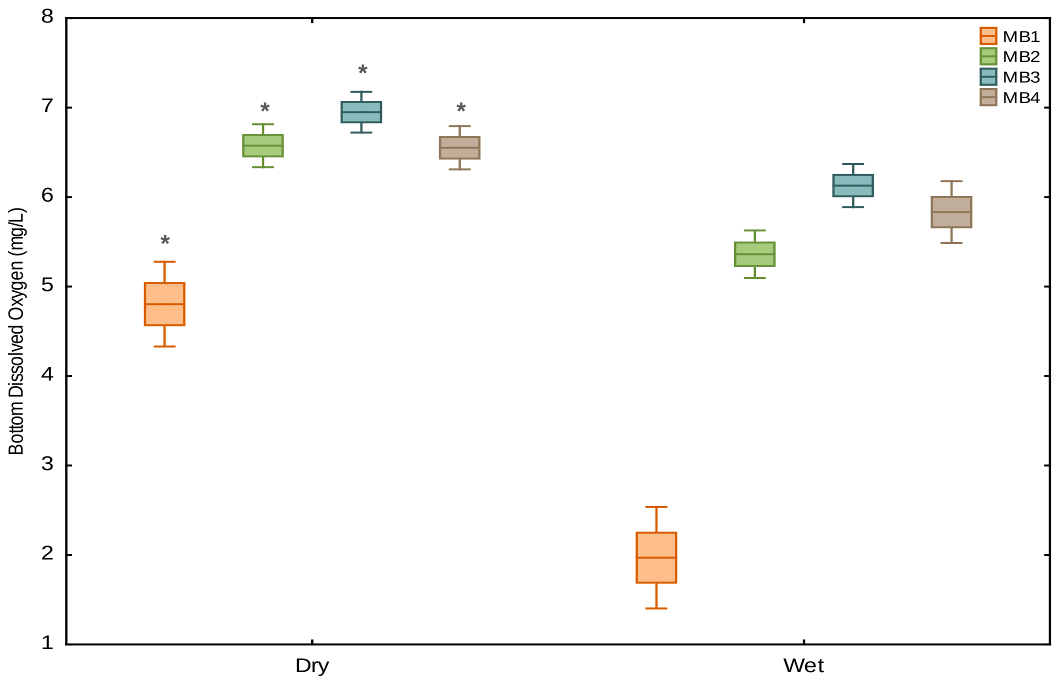


Figure 4-22. Surface and bottom dissolved oxygen by station in Moorings Bay, October 2008–December 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (paired t-test).

ATTACHMENT B - Moorings Bay Water Quality and Biological Analysis (2016)

Table 4-8. Results of time-series models of monthly surface dissolved oxygen in Moorings Bay, 2008–2015, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	
MB1	0.16	1.02	0.74	0.0002	0.15			1, 6
MB2	0.09	5.12	0.01	0.0001	0.35			9
MB3	0.33	6.4	0.0001	0.00002	0.8			5, 8, 11
MB4	0.14	8.72	0.0001	-0.00008	0.43			9

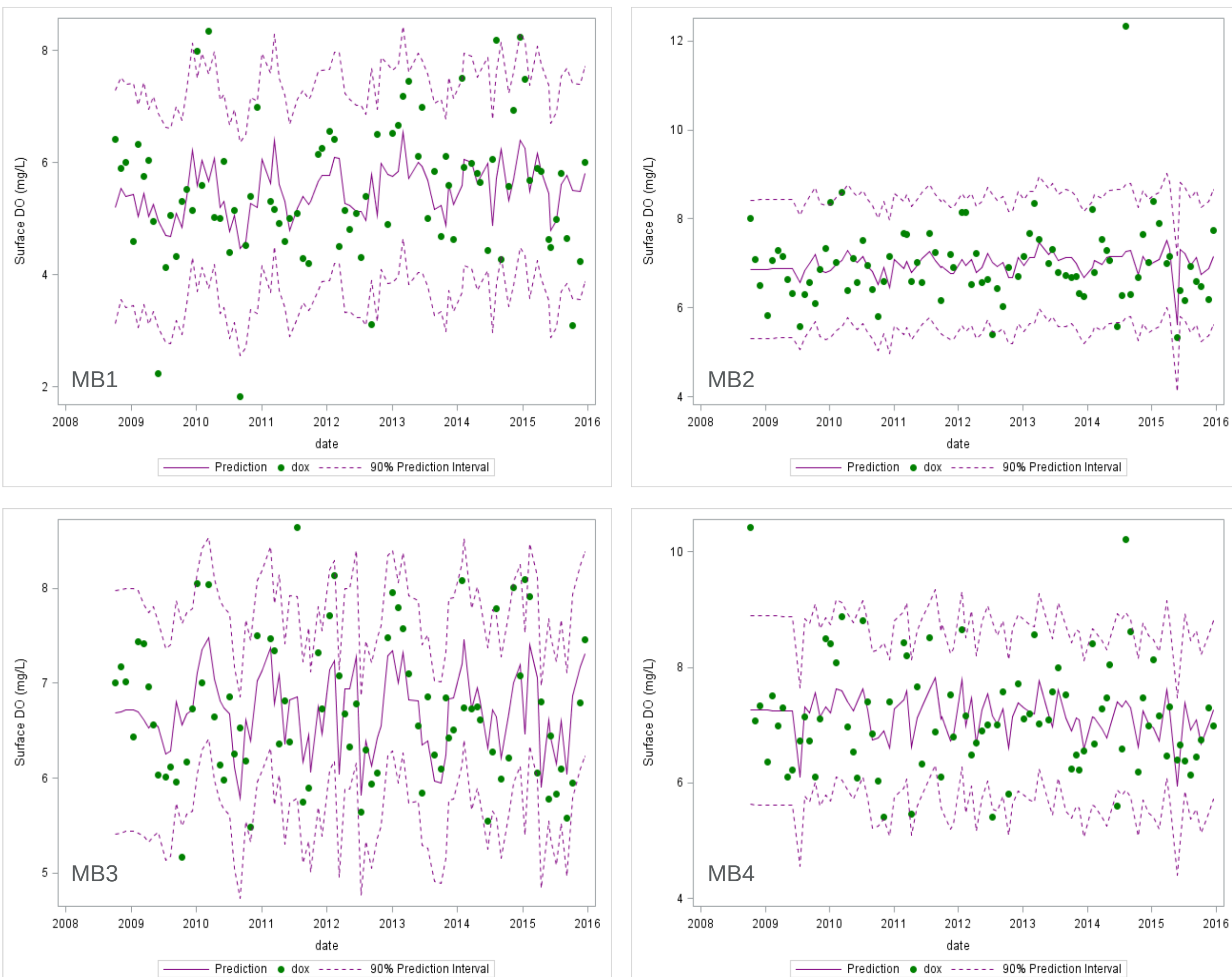


Figure 4-23. Results of AEM time series models of monthly surface dissolved oxygen in Moorings Bay, 2008–2015, including observed, predicted, and 90 percent prediction intervals.

Table 4-9. Results of time-series models of monthly bottom dissolved oxygen in Moorings Bay, 2008–2015, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	
MB1	0.32	4.4	0.51	-0.00004	0.91			1, 5, 12
MB2	0.38	2.76	0.04	**0.0002**	**0.01**			5, 7, 8
MB3	0.34	6.55	0.0001	0.000004	0.95			5, 8, 11
MB4	0.22	4.47	0.002	0.00009	0.21			4, 5, 9

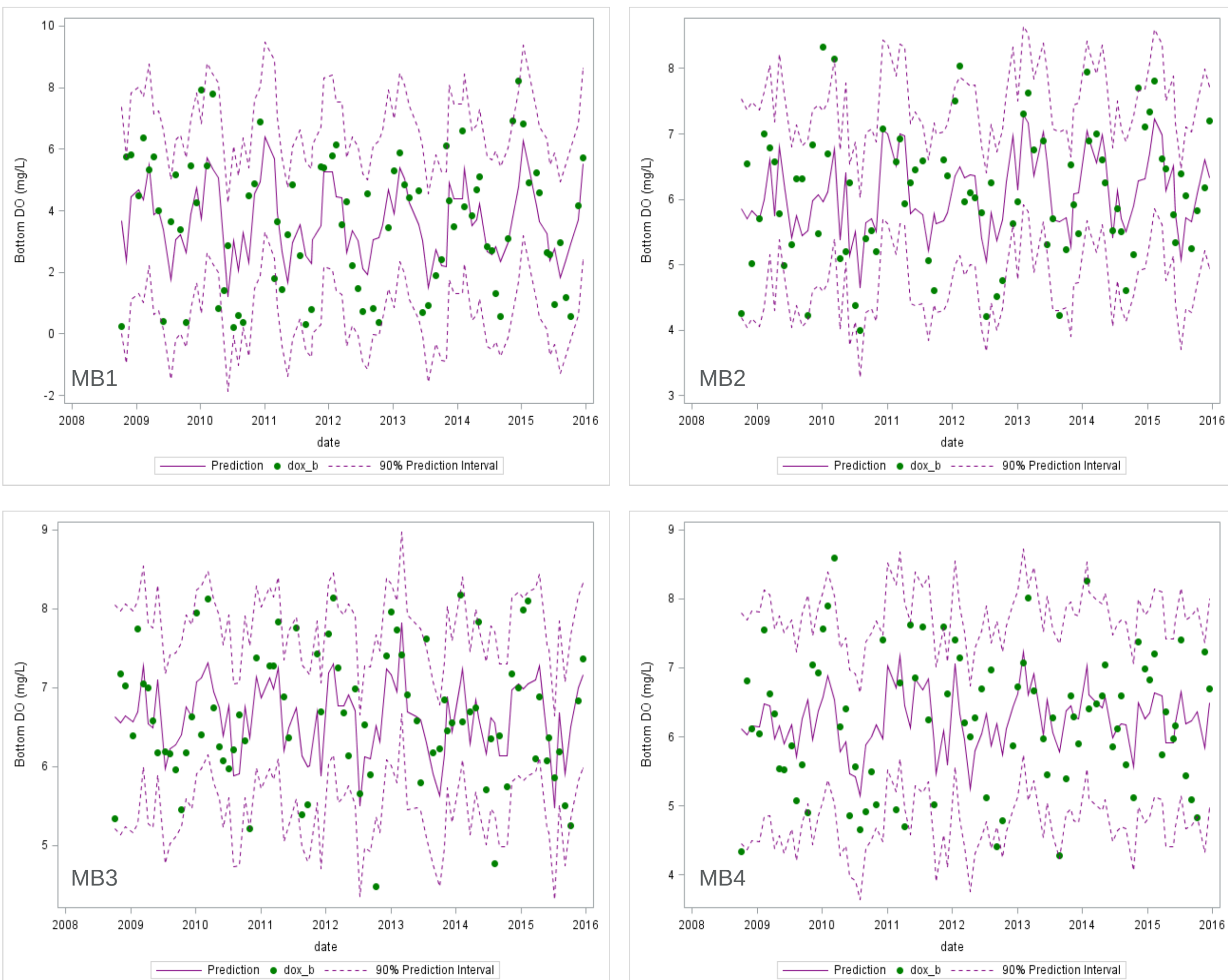


Figure 4-24. Results of AEM time series models of monthly bottom dissolved oxygen in Moorings Bay, 2008–2015, including observed, predicted, and 90 percent prediction intervals.

4.6 Bacteria (Fecal Coliform and *Enterococci*)

Recently, FDEP revised the bacteriological water quality criteria to base them on EPA's recommendations for potential human health impacts and to attempt to make them more indicative of potential anthropogenic inputs. For most classes of waters, the revisions meant the elimination of fecal coliform bacteria from the criteria, and a reliance on either *E. coli* or *Enterococci*. However, as a conservative measure for Class II waters (potential shellfish harvesting areas), in which Moorings Bay is included, the new bacteriological criteria include limits for fecal coliform as well as *Enterococc*i bacteria.

4.6.1 Water Quality Criteria

The fecal coliform bacteria criteria states that counts shall not exceed a median value of 14 MPN with not more than 10 percent of the samples exceeding 43 MPN, nor exceed 800 MPN on any given day (62-302.530(6)(a), F.A.C.). The *Enterococci* standard states that counts shall not exceed a monthly geometric mean of 35 MPN nor exceed 130 MPN in 10 percent or more of samples during any 30 day period (62-302.530(6)(c), F.A.C.). According to the water quality standard, monthly geometric means are to be calculated from a minimum of ten samples. The Moorings Bay monitoring program samples each station monthly, therefore insufficient data exist to establish a monthly geometric mean. For the purposes of this assessment, monthly geometric means were calculated from four samples (one measurement per station) for each month. This evaluation is for informational purposes only to give a general condition for Moorings Bay and is not sufficient for direct comparison to the water quality criteria.

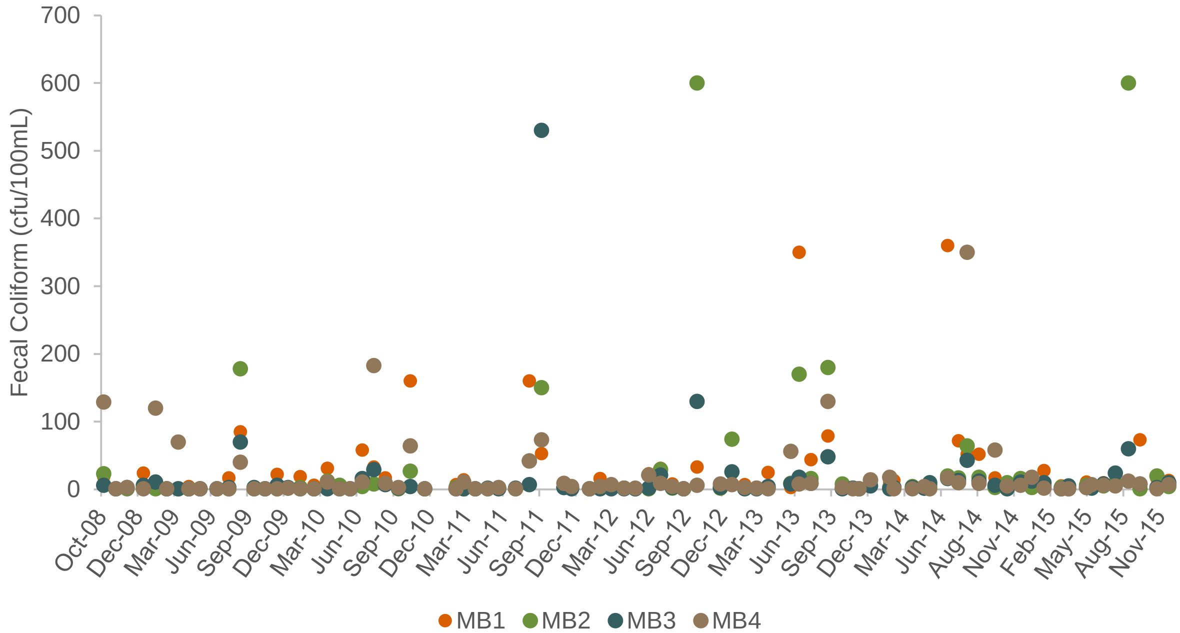
Note the water quality criteria are expressed in units of MPN (Most Probable Number), and the results from the Moorings Bay monitoring program are in cfu/100 ml (colony forming units). These are analogous expressions of the results from the analytical laboratory and are used interchangeably.

Although the Moorings Bay dataset does not meet the data sufficiency requirements for evaluation against the bacteriological water quality criteria, the available monitoring data were compared to the criteria to provide a benchmark from which to interpret the bacteria measurements. In Moorings Bay, the median fecal coliform measurement for Moorings Bay (2008-2015) is 3 cfu/100 ml with approximately 11 percent of values above 43 MPN and no values above 800 MPN.

When individual monthly geometric means were calculated for *Enterococci*, six months were found have mean measurements (from four samples) greater than 35 MPN. Additionally, at least one individual sample during six different months had counts higher than 130 MPN. While the available data are insufficient to make any direct regulatory evaluation of Moorings Bay bacteria levels, periodic elevated levels of *Enterococci* bacteria may indicate a management concern for Moorings Bay.

4.6.2 Spatial Patterns

Raw data plots for fecal coliform and *Enterococci* bacteria measurements are shown in Figure 4-25. When fecal coliform and *Enterococci* concentrations were compared between stations, a set of t-tests of dependent samples showed that for fecal coliform, station MB1 had significantly higher concentrations than the other three stations (fecal coliform), and for *Enterococci,* MB1 had significantly higher concentrations than MB2 and MB3 (paired t-test, two-tailed, $p < 0.05$, Figure 4-26). Similar to other water quality parameters, the station closest to Clam Bay and farthest from Doctors Pass, MB1, had the highest bacteria concentrations.



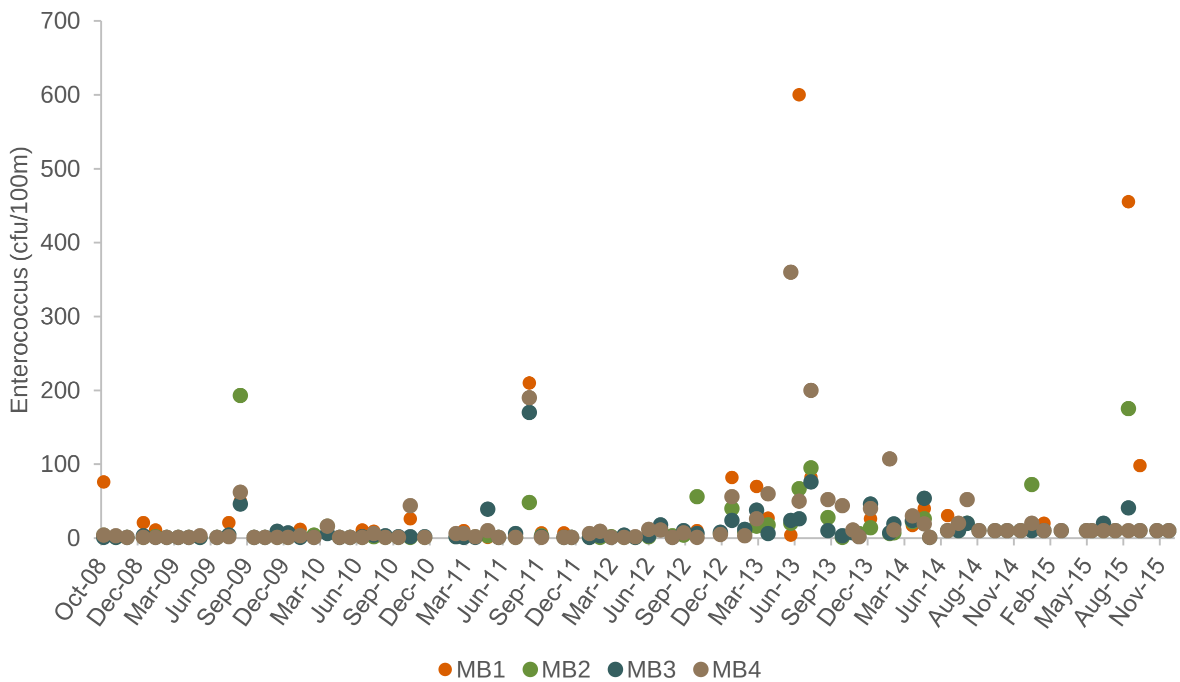
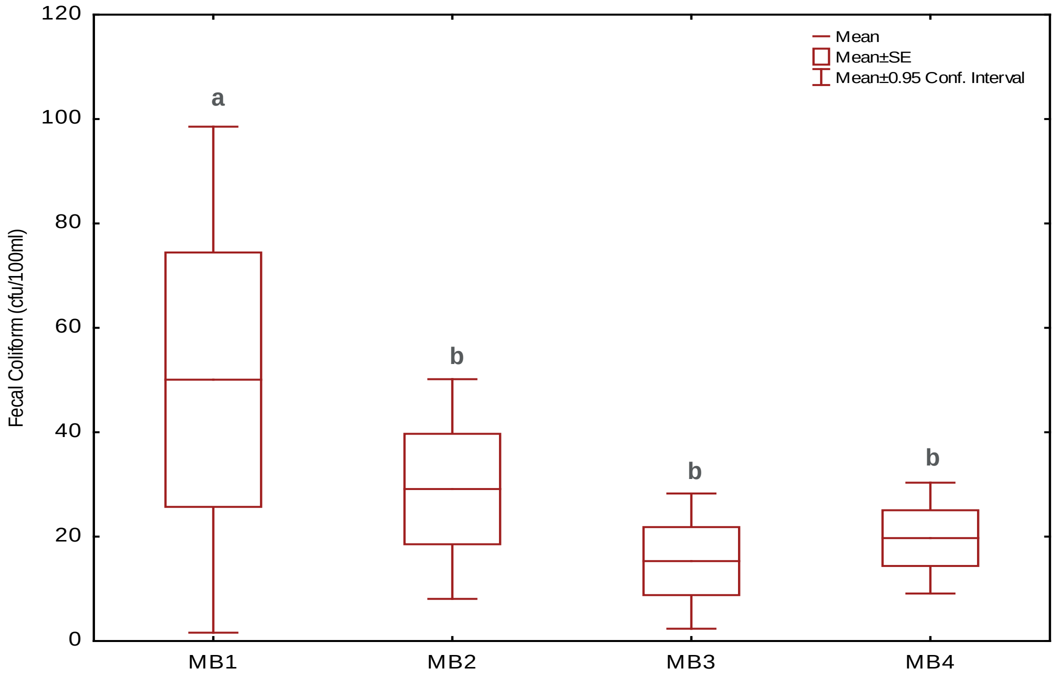


Figure 4-25. Fecal coliform and *Enterococci* concentrations in Moorings Bay (by sampling station), October 2008–December 2015.



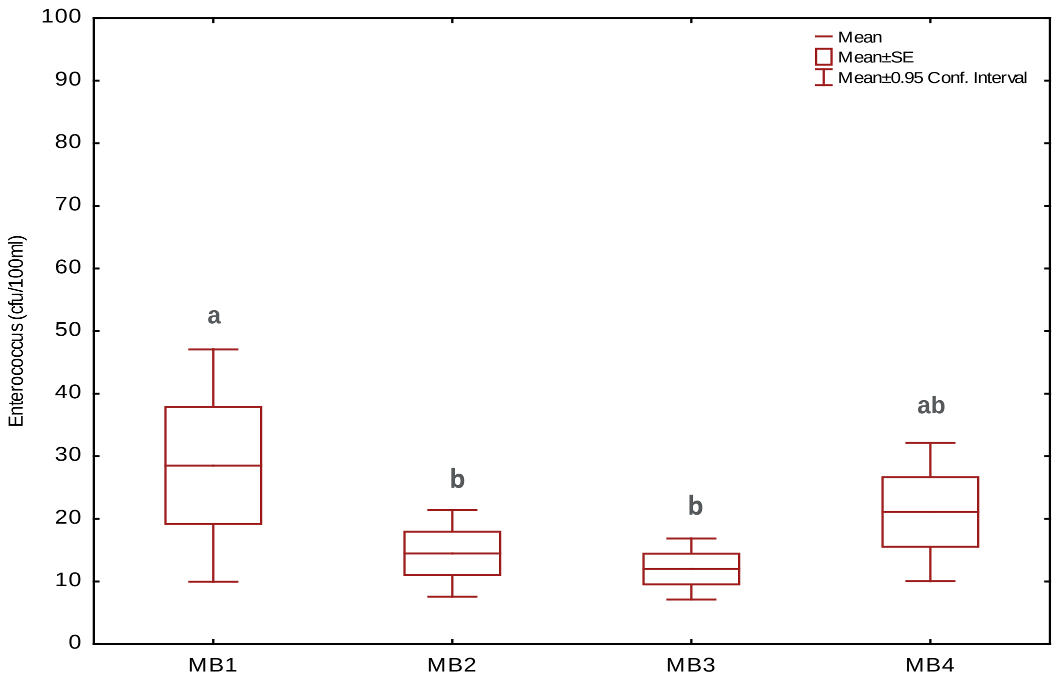


Figure 4-26. **Fecal coliform and *Enterococci* concentrations in Moorings Bay, October 2008–December 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, $p < 0.05$).**

4.6.3 Temporal Trends

To examine differences in fecal coliform and *Enterococci* concentrations between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Figure 4-27). Bacteria concentrations were significantly higher in the wet season at each station and at all stations combined for fecal coliform and at station MB1 and at all stations combined for *Enterococci* (t-test of seasons, two-tailed, $p < 0.05$, Figure 4-27). Log transformed fecal coliform and *Enterococci* concentrations were positively correlated with rainfall at each station and at all stations combined (Pearson correlation, $0.28 < r < 0.51$, $p < 0.05$). Rainfall and associated runoff during the wet season may be an influencing factor in bacteria concentrations in Moorings Bay.

Because of the changes in MDL of *Enterococci* over time and the prevalence of non-detects for both parameters, the AEM trend analysis was not suitable. An alternate analysis, Kendall Tau nonparametric trend test, was used to examine the annual geometric mean fecal coliform and *Enterococci* concentrations over time for changes. Before the geometric means were calculated, all values below the highest MDL were replaced with that value as a censoring of the dataset. The Kendall Tau analysis indicated a statistically significant increasing trend in annual geometric means at stations MB1, MB2, and MB3 for fecal coliform (Kendall Tau, $0.62 < \text{Tau} < 0.71$, $p < 0.05$). *Enterococci* did not show significant trends over time, but the increasing MDL over time and subsequent censoring of the dataset for this analysis may limit the likelihood of detecting trends. Over most of Moorings Bay, bacteria concentrations are increasing, which poses a potential human health concern.

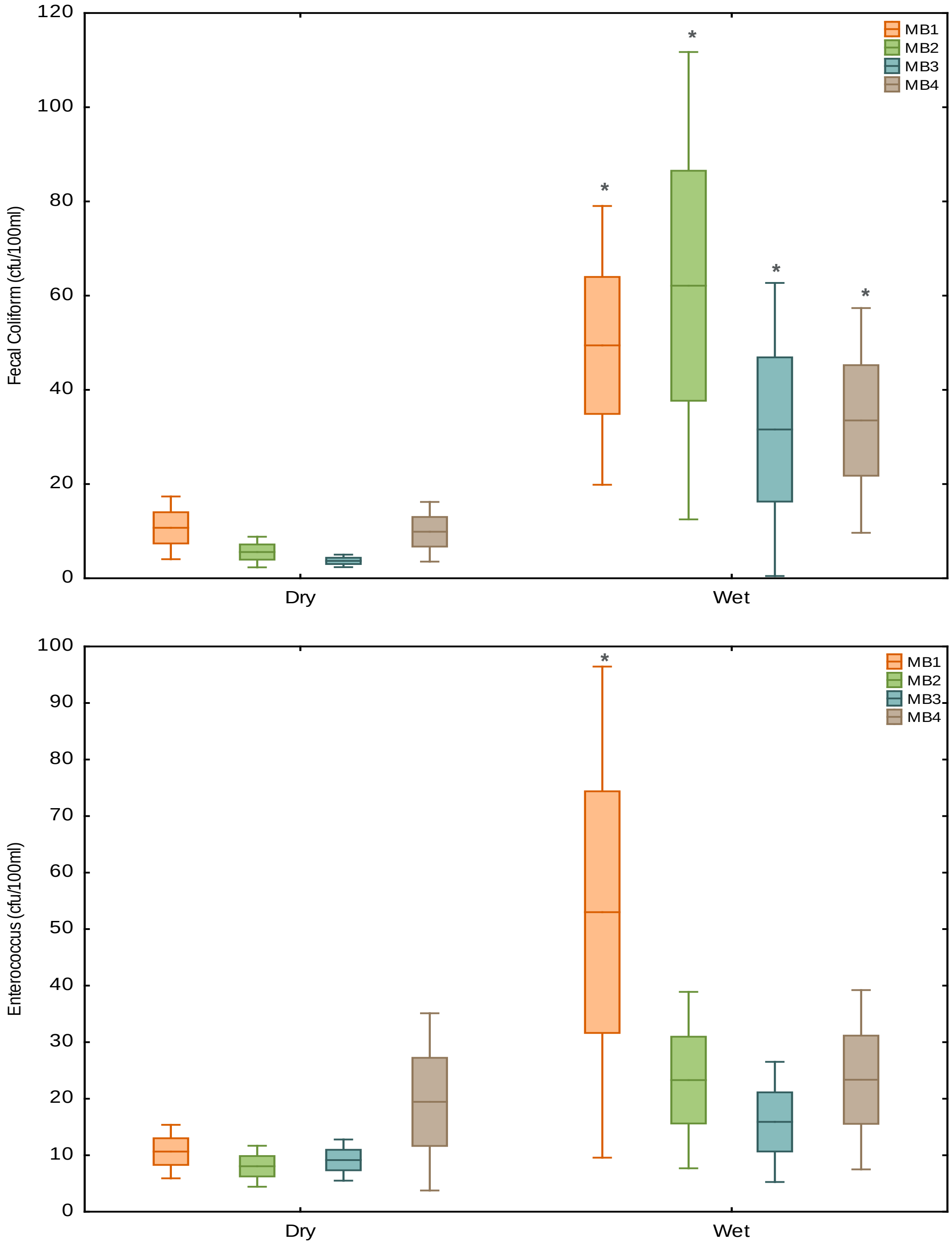


Figure 4-27. Fecal coliform and *Enterococci* concentrations by station in Moorings Bay, October 2008–December 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (paired t-test).

5 Moorings Bay Water Clarity

This section is dedicated to investigating spatial and temporal trends in parameters related to water clarity in Moorings Bay. Where applicable, the current status of Moorings Bay (WBID 3278Q2) with respect to applicable water quality standards is assessed. The goal is to provide a comprehensive understanding of Moorings Bay water clarity and identify any patterns or concerns that demand management attention.

5.1 Turbidity

Turbidity is an important measure of water clarity in estuarine systems. It measures to what extent the amount of suspended material in the water column decreases the passage of light through the water. Turbidity is measured in nephelometric turbidity units (NTU), where the higher the NTU value, the more suspended materials are hindering light passage in the water. Turbidity is affected by particulate matter in the water column, algal biomass, and color. Elevated turbidity levels are an indicator of reduced light penetration and may be linked to reduced aquatic productivity and poor aesthetic quality.

5.1.1 <u>Water Quality Criteria</u>

There is a marine quality standard for turbidity, but it is based on comparisons relative to natural background conditions which are not defined for Moorings Bay. Turbidity values in Moorings Bay are low relative to the exceedance values defined in the standard (Figure 5-1) and would not violate water quality criteria. As such, patterns and trends in turbidity were examined at the station level rather than the WBID level.

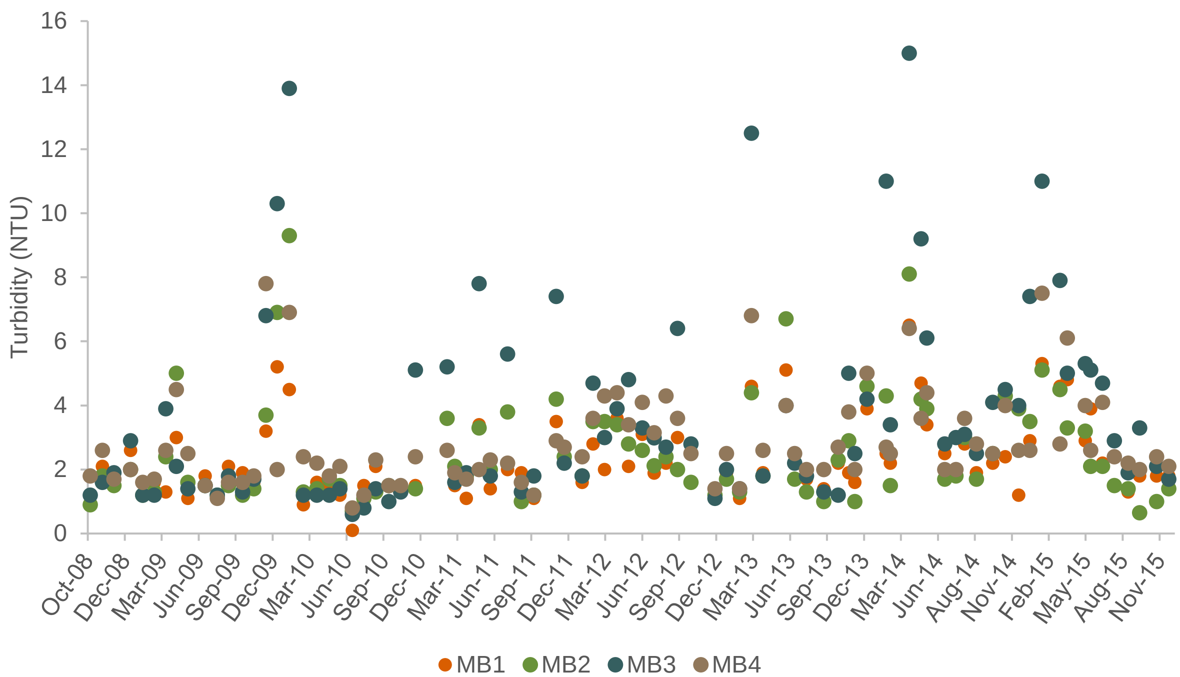


Figure 5-1. Turbidity in Moorings Bay (by sampling station), October 2008–December 2015.

5.1.2 Spatial Patterns

When turbidity was compared between stations, a set of t-tests of dependent samples showed that stations MB3 and MB4 had significantly higher concentrations than MB1 and MB2 (paired t-test, two-tailed, $p < 0.05$, Figure 5-2). The stations closer to the tidal influence of Doctors Pass had the greatest turbidity. This is likely indicative of sediment and sand resuspension from tidal and wave activity closer to Doctors Pass.

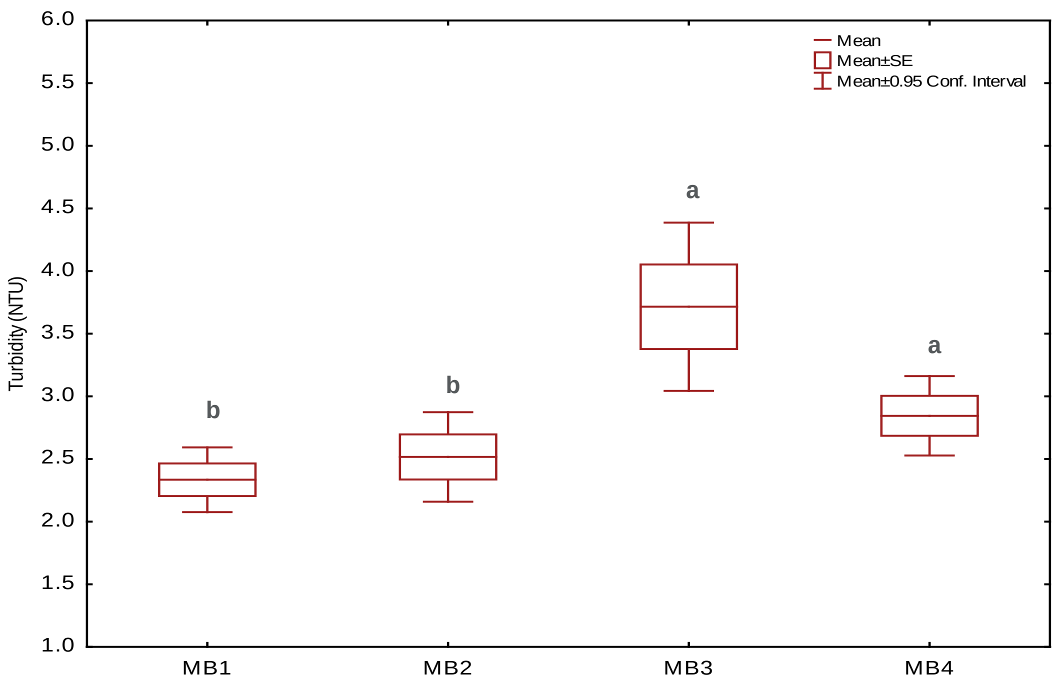


Figure 5-2. Turbidity concentrations by station in Moorings Bay, October 2008–December 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, p < 0.05).

5.1.3 Temporal Trends

To examine differences in turbidity between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Figure 5-3). Turbidity was significantly higher in the dry season at each station and at all stations combined (t-test of seasons, two-tailed, $p < 0.05$, Figure 5-3). Log transformed turbidity was negatively correlated with rainfall at stations MB2 and MB3 and at all stations combined (Pearson correlation, $-0.19 > r > -0.25$, $p > 0.05$). A similar pattern was observed in Naples Bay (Cardno 2015).

Turbidity (log transformed) was examined for potential trends over time using the AEM model, with and without the autoregressive term and the log monthly rainfall covariate (Tables 5-1). For station MB1, the best fit model included the rainfall covariate, and the other stations' models included autoregressive terms. Turbidity showed statistically significant increasing trends over time at all stations at the $p < 0.05$ level (Table 5-1 and Figure 5-4).

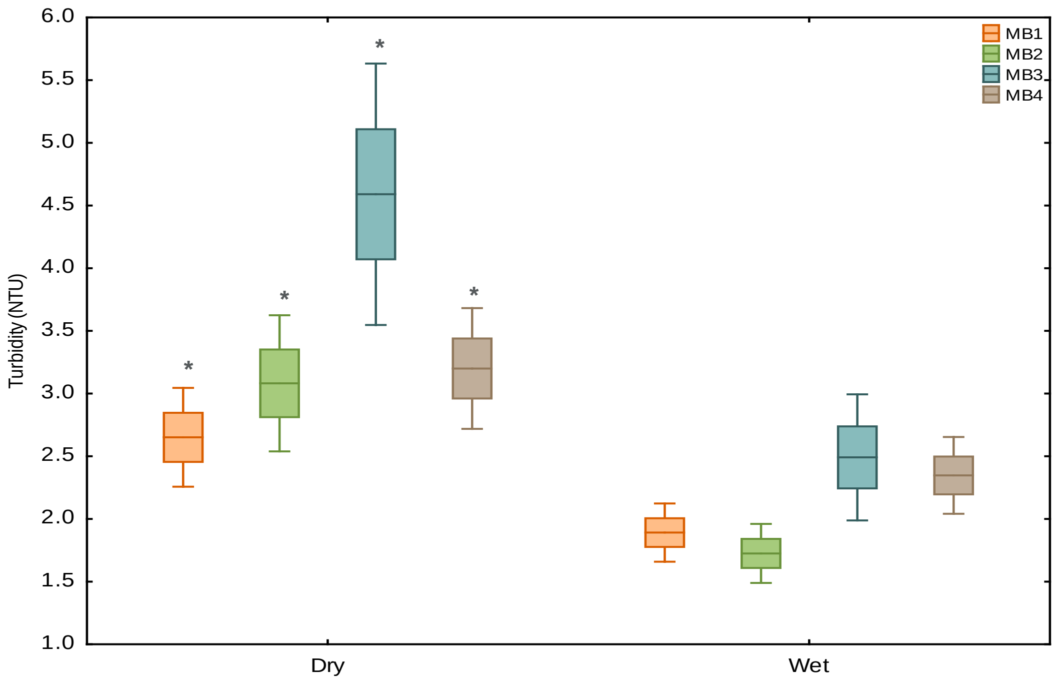


Figure 5-3. **Seasonal turbidity concentrations by station in Moorings Bay, October 2008–December 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (two-tailed t-test).**

Table 5-1. **Results of time-series models of monthly turbidity in Moorings Bay, 2008–2015, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.**

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	
MB1	0.1	-3.38	0.02	**0.0002**	**0.005**	-0.05	0.26	
MB2	0.23	-2.22	0.14	**0.0002**	**0.05**			1, 6
MB3	0.29	-6.26	0.001	**0.0004**	**0.0002**			1, 6
MB4	0.23	-3.05	0.01	**0.0002**	**0.001**			2, 4

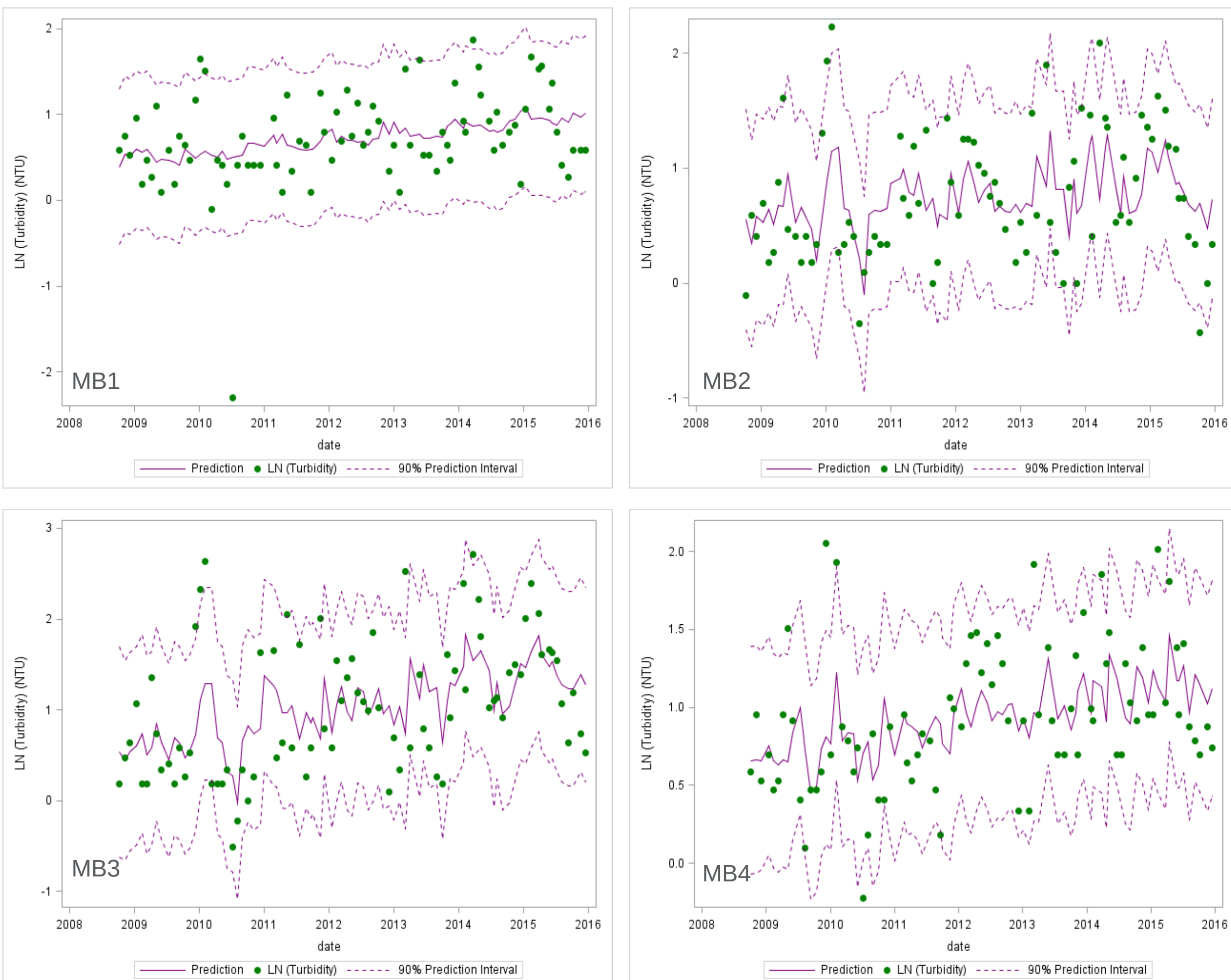


Figure 5-4. **Results of AEM time series models of monthly turbidity in Moorings Bay, 2008–2015, including observed, predicted, and 90 percent prediction intervals.**

5.2 TSS

TSS is a measure of the amount of solid particles suspended in the water column. These may be inorganic or organic and include sands, silts, phytoplankton, organic debris, and/or industrial wastes. Particulate matter in the water column, including particles contributing to TSS and finer particles not measured as TSS, can affect the physical and biological environment of an estuarine system like Moorings Bay in many ways. It absorbs light, which makes the water warmer and restricts light passage through the water column. Warmer water has less ability to hold oxygen, which can adversely affect fish and invertebrate communities. Light restriction in the water column can adversely affect photosynthetic activity of plants including seagrass. In addition, particulate matter in the water column can serve as attachment vehicles for other pollutants such as metals and bacteria (USGS 2015).

5.2.1 Spatial Patterns

TSS was generally in a similar range for all stations (Figure 5-5), although when TSS was compared between stations, a set of t-tests of dependent samples showed that stations MB3 had significantly higher concentrations than the other three stations (paired t-test, two-tailed, $p < 0.05$, Figure 5-6).

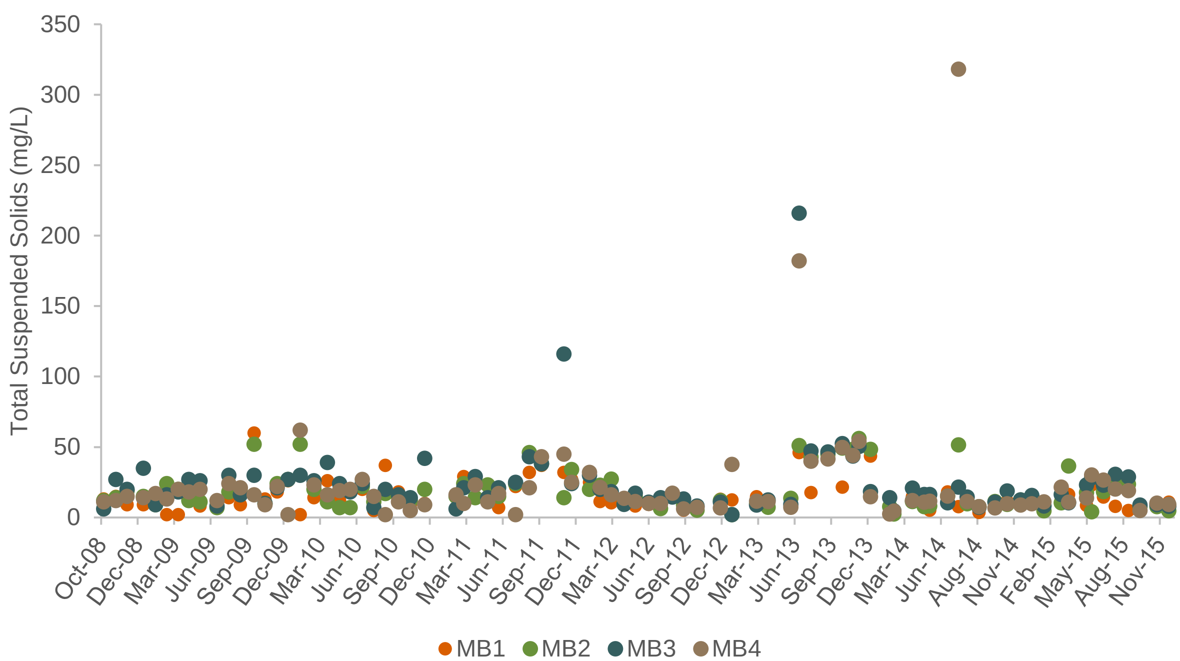


Figure 5-5. TSS in Moorings Bay by sampling station, October 2008–December 2015.

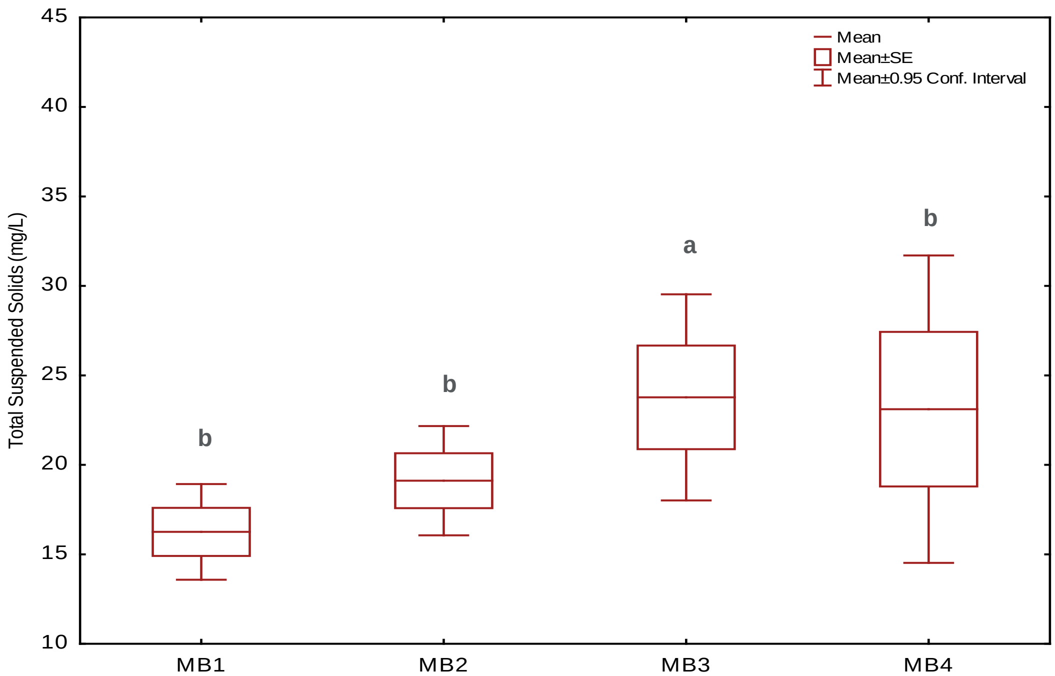


Figure 5-6. Total suspended solids concentrations by station in Moorings Bay, October 2008–December 2015. Letters next to the boxes designate significantly different groups (paired t-test, two-tailed, $p < 0.05$).

5.2.2 Temporal Trends

To examine differences in TSS between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Figure 5-7). TSS was significantly higher in the wet season only for all stations combined (t-test of seasons, two-tailed, $p < 0.05$, Figure 5-7). Log transformed TSS was positively correlated with rainfall only at all stations combined (Pearson correlation, $r = 0.16$, $p < 0.05$). Because only the analysis with the greatest statistical power (all stations combined) found significant seasonal relationships with TSS, it is likely that the seasonal differences are present, but weak.

TSS (log transformed) was examined for potential trends over time using the AEM model, with and without the autoregressive term and the log monthly rainfall covariate (Tables 5-2). For station MB4, the best fit model included the rainfall covariate, and the other stations' models included autoregressive terms. TSS showed a statistically significant decreasing trend over time at station MB4 at the $p < 0.05$ level (Table 5-2 and Figure 5-8).

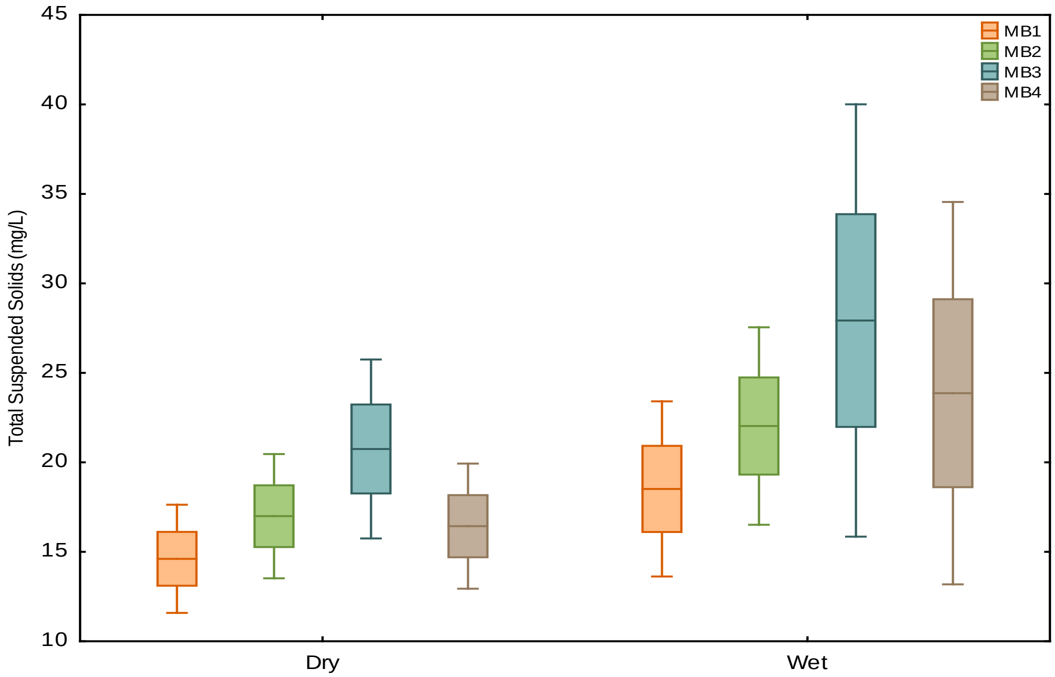


Figure 5-7. Seasonal total suspended solids concentrations by station in Moorings Bay, October 2008–December 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (two-tailed t-test).

Table 5-2. Results of time-series models of monthly total suspended solids in Moorings Bay, 2008–2015, including total model fit (r^2); intercept, time, and covariate parameter estimates and p values; and statistically significant autoregression frequency.

Station	Total Model r^2	Intercept		Time (Date)		LN Rain		Auto-regression (Months)
		B_0	p	B_1	p	X_1	p	
MB1	0.06	3.31	0.18	0.00004	0.76			1
MB2	0.19	5.54	0.07	-0.0006	0.34			1
MB3	0.18	3.75	0.03	-0.00006	0.51			2, 7, 12
MB4	0.27	5.71	0.0001	**-0.0002**	**0.02**	**0.18**	**0.0003**	10, 12

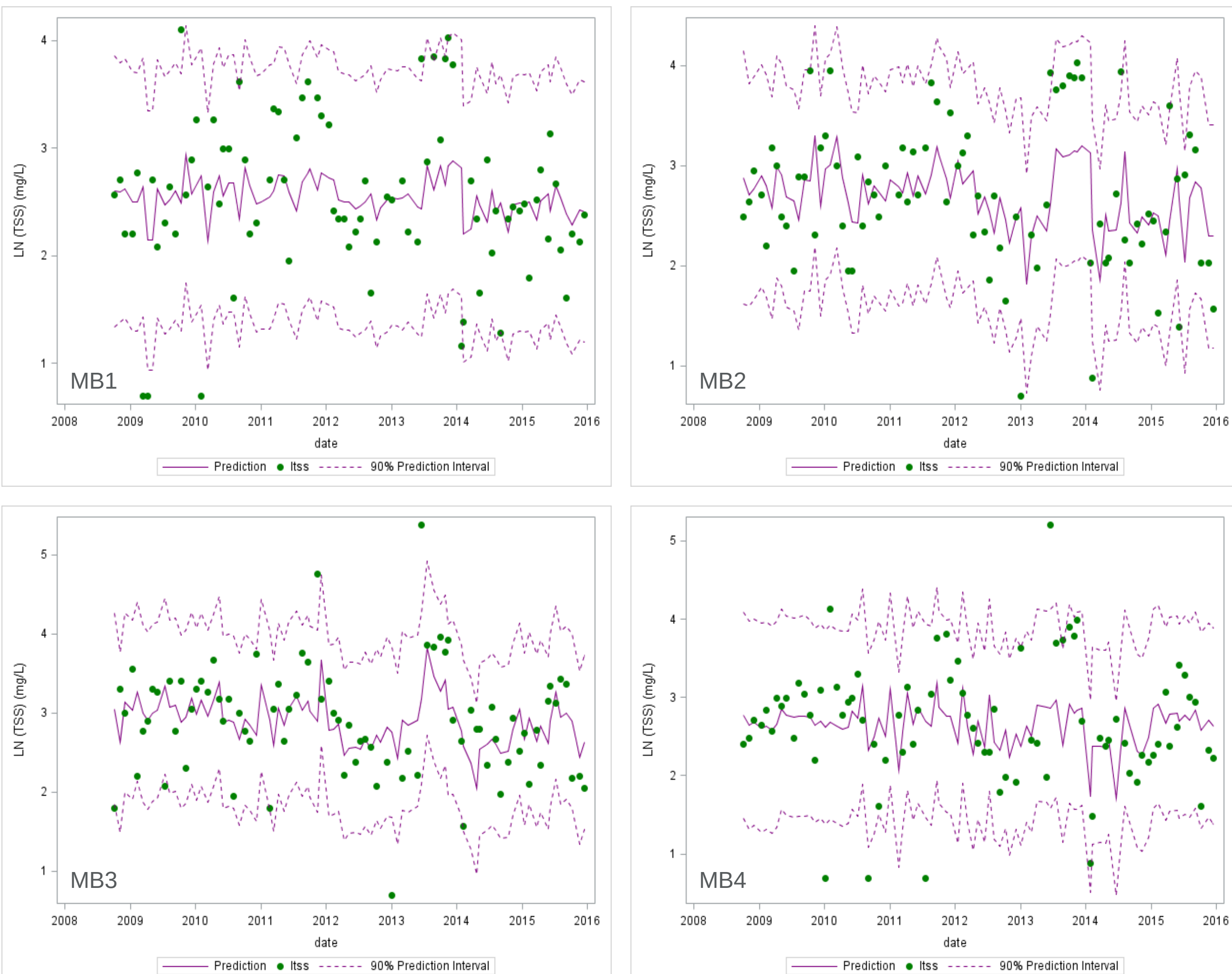


Figure 5-8. Results of AEM time series models of monthly total suspended solids in Moorings Bay, 2008–2015, including observed, predicted, and 90 percent prediction intervals.

5.3 Secchi Depth

Secchi depth is a very common tool for observational measurements of water clarity. Secchi depth is measured as the depth a colored disc (usually black and white) is no longer visible or distinguishable from the surrounding water. Typically, the measurement is the average of the depth recorded when lowering the disc into the water and the depth observed when raising the disc up from the bottom. Secchi depth is a very useful tool for measuring overall water clarity, but it cannot distinguish between the sources that affect water clarity.

5.3.1 Spatial Patterns

Secchi depth in Moorings Bay generally ranged from 0.5 m to 2.0 m (Figure 5-9). When Secchi depth was compared between stations, a set of t-tests of dependent samples showed that stations MB1 and MB2 had significantly greater depths than MB3 and MB4 (paired t-test, two-tailed, $p < 0.05$, Figure 5-10). When Secchi depth was converted to percent of total depth (e.g. Secchi depth/(bottom sampling depth + 0.3 m), “ON BOTTOM” is 100%), the percent of total depth was significantly higher at MB3 and lower at MB1 than the other stations (paired t-test, two-tailed, $p < 0.05$); however, some values were missing for MB4 with no indication of an “ON BOTTOM” measurement, which may have affected the comparisons with that station. This indicates that Secchi depth is lowest at MB1 relative to its overall station depth and is not surprising given the water quality conditions (*i.e.* chlorophyll-*a*) at this location. Secchi depth data were not corrected relative to tidal stage during sampling, so differences in Secchi depth among stations may not necessarily be related to water quality parameters.

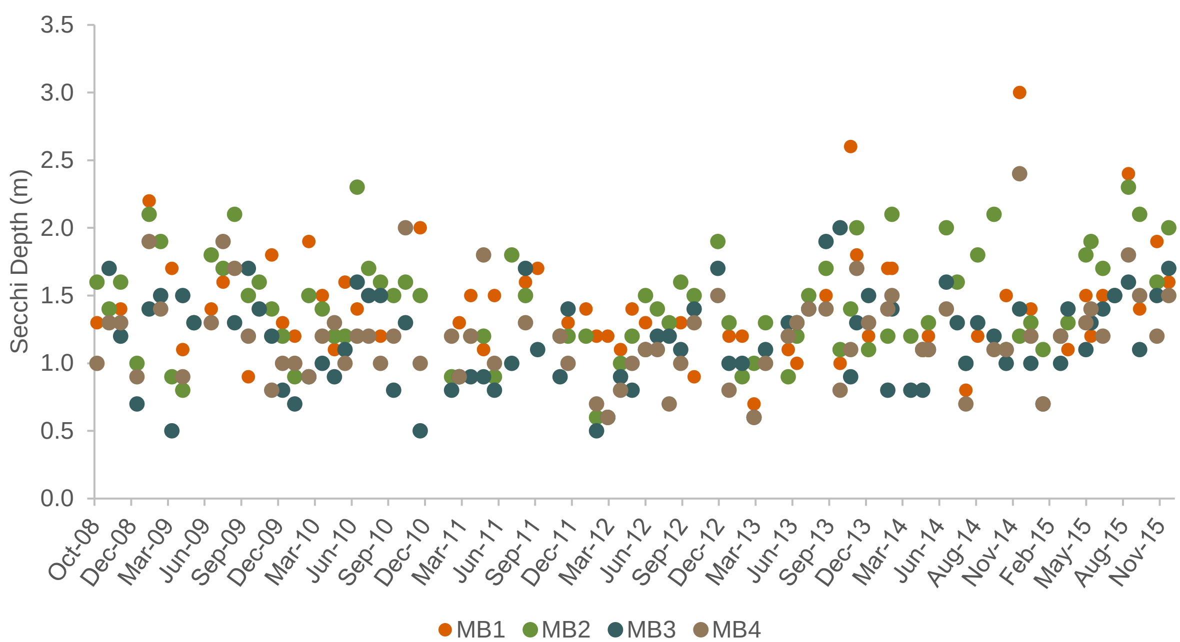


Figure 5-9. Secchi depth in Moorings Bay (by sampling station), October 2008–December 2015.

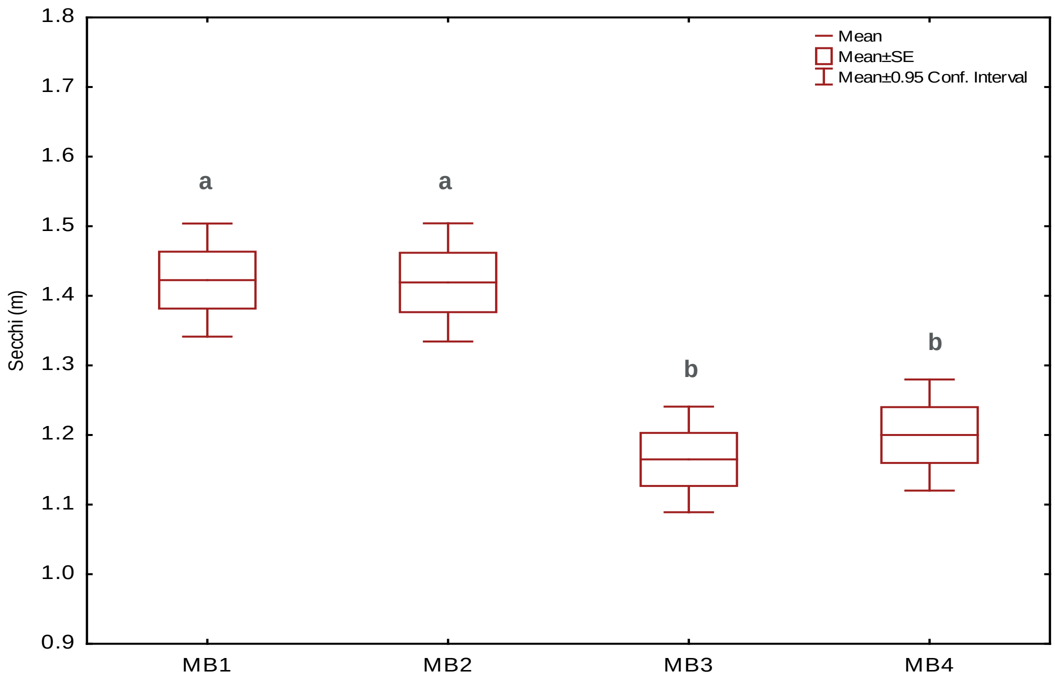


Figure 5-10. Secchi depths by station in Moorings Bay, October 2008–December 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, $p < 0.05$).

5.3.2 Temporal Trends

To examine differences in Secchi depth between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Figure 5-11). Secchi depth was significantly greater in the wet season at stations MB2 and MB3 and at all stations combined (t-test of seasons, two-tailed, $p < 0.05$, Figure 5-11). Secchi depth was positively correlated with rainfall at stations MB2 and MB3 (Pearson correlation, $0.22 > r < 0.35$, $p > 0.05$). From this analysis, it appears that Secchi depth is more influenced by rainfall or other seasonal factors at MB2 and MB3 than other stations.

Because Secchi depth is limited by total depth at the time of sampling, the AEM trend analysis was not suitable. An alternate analysis, Kendall Tau nonparametric trend test, was used to examine the annual geometric mean Secchi depth over time for changes, but the analysis showed no significant trends at any station (Kendall Tau, $p > 0.05$).

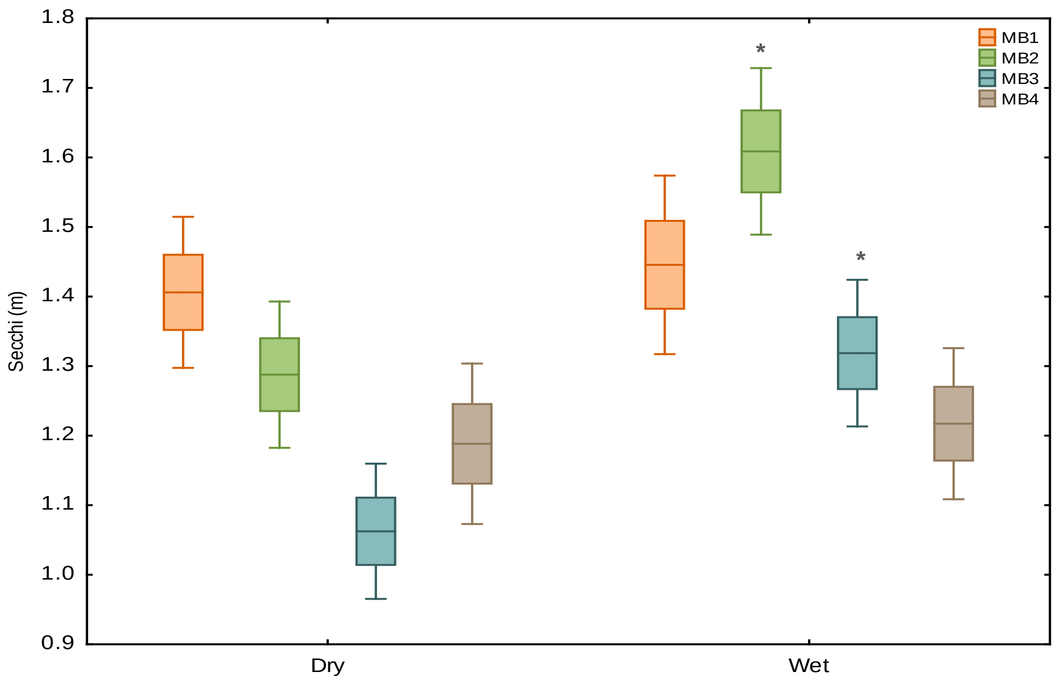


Figure 5-11. Seasonal Secchi depths by station in Moorings Bay, October 2008–December 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (two-tailed t-test).

5.4 Color

Color can be linked to water clarity; light penetration is reduced in water with higher color which may decrease water clarity. Typically, color in an estuary is an indicator of freshwater riverine inflow to the system; Naples Bay is an example. Moorings Bay does not have these inflows, therefore changes in color may be more representative of stormwater runoff.

5.4.1 Spatial Patterns

Color values in Moorings Bay are generally between 10 PCU and 20 PCU (Figure 5-12). When color was compared between stations, a set of t-tests of dependent samples showed that station MB1 had significantly greater color than other stations and MB3 had lower color than other stations (paired t-test, two-tailed, $p < 0.05$, Figure 5-13).

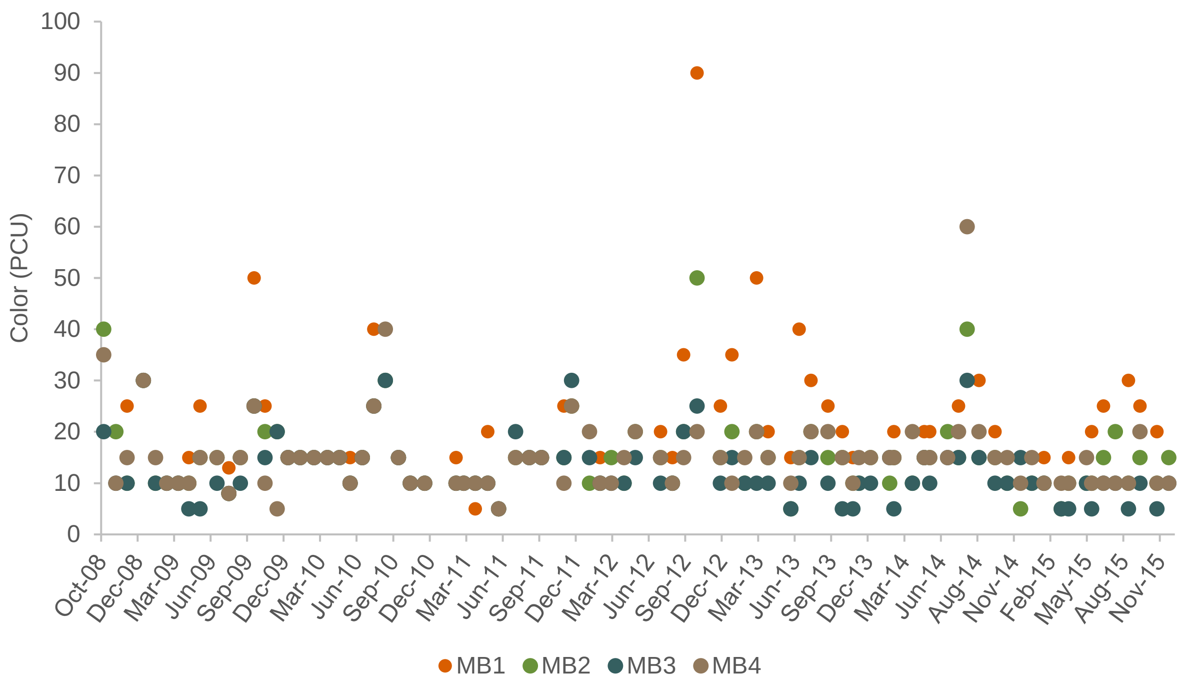


Figure 5-12. Color in Moorings Bay (by sampling station), October 2008–December 2015.

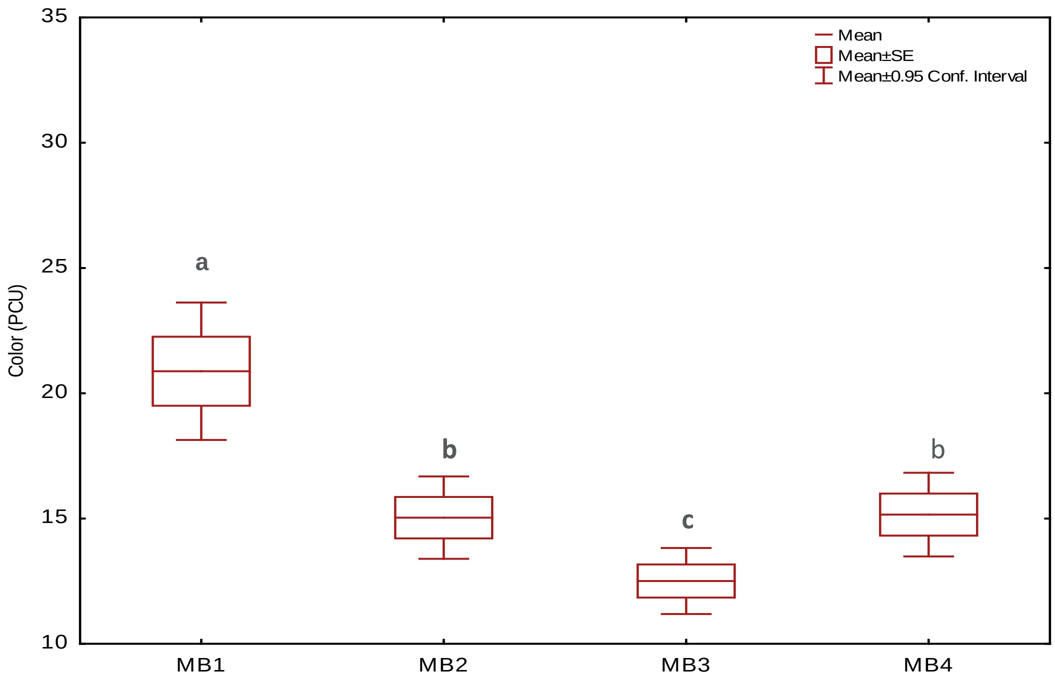


Figure 5-13. Color concentrations by station in Moorings Bay, October 2008–December 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, $p < 0.05$).

5.4.2 Temporal Trends

To examine differences in color between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Figure 5-14). Color was significantly greater in the wet season at stations MB1, MB2, MB4 and at all stations combined (t-test of seasons, two-tailed, $p < 0.05$, Figure 5-14). Color was positively correlated with rainfall at stations MB1 and MB4 and at all stations combined (Pearson correlation, $0.20 > r < 0.29$, $p > 0.05$). Increased color inputs to Moorings Bay during the wet season could include tannins and other material from runoff.

Because the precision of color is limited (rounded to nearest five, see Figure 5-12), the AEM trend analysis was not suitable. An alternate analysis, Kendall Tau nonparametric trend test, was used to examine the annual geometric mean color over time for changes, but the analysis showed no significant trends at any station (Kendall Tau, $p > 0.05$).

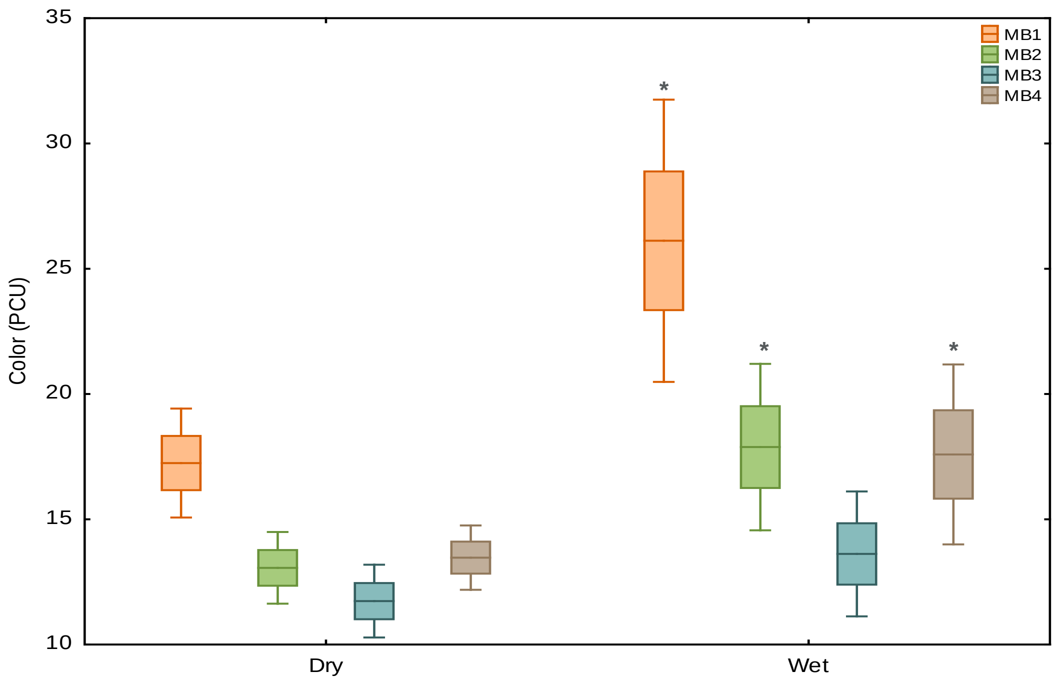


Figure 5-14. Seasonal color concentrations by station in Moorings Bay, October 2008–December 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (two-tailed t-test).

6 Moorings Bay Fish Community

This section is devoted to the identification of trends in fish community data in Moorings Bay. The City has been monitoring fish since 2009 using bottom trawls. Samples were collected one to four times per calendar year with trawls in each of four zones in the bay (Figure 2-1) during each sampling event. In 2009 and 2010, sampling was conducted at fixed transect sites. Starting in November 2011, sampling was conducted in one randomly selected grid within each zone at each sampling event. Fish species were identified, counted, and measured. Results of statistical analysis of fish community structure, diversity, richness, and abundance are presented in this section.

6.1 Abundance and Species Composition

From November 2009 to September 2015, 80 bottom trawl samples were collected in Moorings Bay: 20 samples from each of the four zones. A total of 29,139 individuals from 59 fish taxa and five invertebrate taxa were collected during the study (see Appendix A, Table A-1 and Table A-2 for a full list of taxa). Catch per trawl ranged from zero to 4,358 individuals. The number of different taxa per trawl ranged from zero to 17.

Eucinostomus spp. (mojarras) were by far the most numerous taxon collected: they accounted for 80.6 percent of the total catch from 2009–2015 (Table 6-1). The next most abundant taxon was *Anchoa* spp. (anchovies), which made up about 12.5 percent of the total catch. The remaining 62 taxa caught in Moorings bay accounted for just 7 percent of the total catch over the survey period. Mojarras were also the most frequently caught taxon: they were caught in nearly every trawl sample in varying abundances ranging from one individual per trawl to several thousand individuals per trawl (Table 6-2). In general, the other most frequently encountered species were also the most abundant overall: e.g. anchovies, pink shrimp, hardhead catfish, seatrout, snappers, and squid (Table 6-1 and 6-2). Twenty one taxa, one-third of the total taxa found in Moorings Bay, were caught in only one or two trawls, with usually only one individual caught in each trawl (Table 6-2).

Table 6-1. The most abundant taxa (grouped to Genus level) in Moorings Bay bottom trawls, October 2009–September 2015.

Taxa	Common Name	Rank	Number of Individuals	% of Total
Eucinostomus sp.	Mojarra	1	23,489	80.6
Anchoa sp. *A. hepsetus* *A. mitchilli*	Anchovies	2	3,636	12.5
Leiostomus xanthurus	Spot	3	585	2.0
Chloroscombrus chrysurus	Atlantic Bumper	4	264	0.91
Farfantepenaeus duorarum	Pink Shrimp	5	174	0.60
Cynoscion arenarius *C. nebulosus*	Seatrout	6	131	0.45
Order Teuthida	Squid	7	107	0.37
Ariopsis felis	Hardhead Catfish	8	92	0.32
Lagodon rhomboides	Pinfish	9	87	0.30
Lutjanus synagris *L. griseus*	Snappers	10	83	0.28

Table 6-2. The most frequently caught (grouped to Genus level) in Moorings Bay bottom trawls, October 2009–September 2015.

Taxa	Common Name	Rank	Number of Trawls	% of Total
Eucinostomus sp.	Mojarra	1	77	96%
Farfantepenaeus duorarum	Pink Shrimp	2	40	50%
Ariopsis felis	Hardhead Catfish	3	37	46%
Anchoa sp. *A. hepsetus* *A. mitchilli*	Anchovies	4	34	43%
Synodus foetens	Inshore Lizardfish	4	34	43%
Cynoscion arenarius *C. nebulosus*	Seatrout	5	25	31%
Lutjanus synagris *L. griseus*	Snappers	5	25	31%
Order Teuthida	Squid	6	24	30%
Callinectes sapidus *C. similis*	Blue Crabs	6	24	30%
Etropus crossotus	Fringed Flounder	7	23	29%
Chloroscombrus chrysurus	Atlantic Bumper	8	15	19%
Microgobius gulosus *M. thalassinus*	Gobies	8	15	19%
Ogcocephalus cubifrons	Polka Dot Batfish	9	14	18%
Bairdiella chrysoura	Silver Perch	10	13	16%

Table 6-3. The least frequently caught and least abundant taxa (grouped to Genus level) in Moorings Bay bottom trawls, October 2009–September 2015.

Least Common and Least Abundant			
Taxon	**Common Name**	**Number of Occurrences**	**Number of Individuals**
Micropogonias undulatus	Atlantic Croaker	2	16
Sciaenops ocellata	Red Drum	2	4
Achirus lineatus	Lined Sole	2	2
Chilomycterus schoepfii	Striped Burrfish	2	2
Gymnura micrura	Smooth Butterfly Ray	2	2
Hemicaranx amblyrhynchus	Bluntnose Jack	2	2
Eugerres plumieri	Striped Mojarra	1	6
Urophycis floridana	Southern Hake	1	3
Albula vulpes	Bonefish	1	1
Brevoortia sp.	Menhaden	1	1
Caranx sp.	Jack	1	1
Citharichthys spilopterus	Bay Whiff	1	1
Dasyatis americanus	Southern Stingray	1	1
Diplectrum formosum	Sand Perch	1	1
Gobiosoma robustum	Code Goby	1	1
Haemulon plumierii	White Grunt	1	1
Lutjanus griseus	Mangrove Snapper	1	1
Stephanolepis hispidus	Planehead Filefish	1	1
Scorpaena brasiliensis	Barbfish	1	1
Sphoeroides spengleri	Bandtail Puffer	1	1
Trichiurus lepturus	Atlantic Cutlassfish	1	1

6.1.1 Spatial Patterns

When taxa are grouped to the Genus level (or higher), there are some notable differences in the distribution among the sampling zones. First, when we consider taxa that are unique to or more commonly associated with one zone over the others, Zones 2 and 4 have the most taxa that fit this description (Table 6-4). Zone 1, however, does not contain any unique taxa and does not have any taxa that are more commonly associated with it than the other zones. Second, when we look at taxa that are uncommon to or missing from a particular zone, Zone 1 has the longest list of missing or less common species (Tables 6-5). It is possible that habitat or life history variables contribute to these patterns, but those variables are not explored in this report.

Table 6-4. Taxa that are unique to or more common in one sampling zone in bottom trawl catches, October 2009–September 2015.

Zone	Genus	Species Common Name	Number in Zone	Total Number
1	NONE			
2	*Anchoa*	Anchovies	2138	3636
	Cynoscion	Seatrout	66	131
	Order Teuthida	Squids	57	107
	Prionotus	Searobin	19	32
	Micropogonias	Atlantic Croaker	13	16
	Harengula	Scaled sardine	11	16
	Eugerres	Striped mojarra	6	6
3	*Lutjanus*	Snapper	53	83
	Etropus	Fringed flounder	24	46
	Ogcocephalus	Polka dot batfish	18	29
4	*Leiostomus*	Spot	388	585
	Chloroscombrus	Atlantic bumper	154	264
	Lagodon	Pinfish	45	87
	Synodus	Inshore lizardfish	38	79
	Archosargus	Sheepshead	14	16
	Orthopristis	Pigfish	12	17
	Opisthonema	Atlantic thread herring	12	17

Table 6-5. Taxa that are missing from or less common in one sampling zone in bottom trawl catches, October 2009–September 2015.

Zone	Genus	Species Common Name	Number in Zone	Total Number
1	*Prionotus*	Searobin	2	32
	Lutjanus	Snapper	2	83
	Anchoa	Anchovies	32	3636
	Leiostomus	Spot	0	585
	Ogcocephalus	Polka dot batfish	0	29
	Symphurus	Blackcheek tonguefish	0	19
	Archosargus	Sheepshead	0	16
	Micropogonias	Atlantic Croaker	0	16
2	*Archosargus*	Sheepshead	0	16
3	*Chloroscombrus*	Atlantic bumper	3	264
	Leiostomus	Spot	1	585
	Opisthonema	Atlantic thread herring	0	17
	Micropogonias	Atlantic Croaker	0	16
	Chaetodipterus	Atlantic spadefish	0	6
4	Order Teuthida	Squids	5	107
	Prionotus	Searobin	1	32
	Harengula	Scaled sardine	0	16
	Chaetodipterus	Atlantic spadefish	0	6

In general, Moorings Bay hosts the same fish community as nearby Naples Bay. *Eucinostomus* sp. (mojarras) and *Anchoa* sp. (anchovies) are the dominant genera, and make up more than 80 percent of the catch (numerically) in both bays. However, while the two taxa occur in roughly equal number in Naples Bay (Cardno 2015), mojarras dominate the community in Moorings Bay. With few exceptions, the remaining taxa found in Moorings Bay also occur in Naples Bay, though typically in lower abundance, and the Moorings Bay hosts nearly all the same species found in Naples Bay. Only five taxa found in Naples Bay were absent from Moorings Bay, and all five were taxa that are only rarely encountered in Naples Bay (Table 6-6). Likewise, six taxa were found in Moorings Bay that were not caught in Naples Bay, but all were rarely encountered in Moorings Bay.

Table 6-6. Species that do not co-occur in both Moorings Bay and Naples Bay, October 2009–September 2015.

Taxa	Common Name	Number in Naples Bay	Number in Moorings Bay
Trinectes maculatus	Hogchoker	3	0
Nicholsina usta	Emerald Parrotfish	2	0
Gobiesox strumosus	Skilletfish	2	0
Hypsoblennius hentz	Feather Blenny	1	0
Ophichthus gomesii	Shrimp Eel	1	0
Diplectrum formosum	Sand Perch	0	1
Eugerres plumieri	Striped Mojarra	0	6
Citharichthys spilopterus	Bay Whiff	0	1
Hemicaranx amblyrhynchus	Bluntnose Jack	0	2
Lophogobius cyprinoides	Crested Goby	0	1
Trichiurus lepturus	Atlantic Cutlassfish	0	1

6.1.2 Temporal Patterns

When the taxa are grouped to the Family level, there are seasonal differences in the occurrence of some taxa groups (Table 6-7). Species in the Carangidae and Gerreidae families are more than five times more likely to be encountered in the wet season (June– October) than in the dry season (November–May). Conversely, species in the Sparidae and Sciaenidae families are more than five times more likely to be caught in the dry season than in the wet season. (Notably, one genus in the Sciaenidae family, *Cynoscion*, shows a different pattern from the rest of the family and is more abundant in wet season trawl samples.) While these patterns are certainly interesting and worth further exploration for potential links with life history or habitat variables, it should be noted that tests for significant differences in abundance of individual species between seasons were not conducted due to limited sample size and replication. In addition, in some cases patterns seem evident but are based on a small number of individuals relative to the total number of individuals caught over the whole monitoring period.

There are also some notable inter-annual patterns in the occurrence of the most common taxa, when data are grouped by WY (Figure 6-1). For two species, *Leiostomus xanthurus* (spot) and *Lagodon rhomboides* (pinfish), most of the individuals (99 and 85 percent, respectively) were caught at the beginning of the monitoring period in WY 2010 and then were rarely caught in any other year. Even for the two most common taxa, *Eucinostomus* spp. (mojarras) and *Anchoa* spp. (anchovies), the distribution of individuals over years was not equal, with 45 percent of mojarras caught in WY 2014 and 43 percent of anchovies caught in WY 2012. As with the seasonal patterns mentioned above, these patterns were not explored for statistical significance but are worth further exploration for potential links to life history or environmental variables.

Table 6-7. Abundance of selected taxonomic groups by season in Moorings Bay bottom trawls, October 2009–September 2015.

	Family	Dominant Genera*	Total Number of Individuals		Wet:Dry
			Wet	Dry	
More Common in Wet Season	Carangidae	*Chloroscombrus*	262	9	29.11
	Gerreidae	*Eucinostomus*	20,185	3,310	6.10
	Order Teuthida	Squid	78	29	2.69
More Equally Distributed Between Seasons	Gobiidae	*Microgobius*	29	15	1.93
	Penaeidae	*Farfantepenaeus*	97	77	1.26
	Ariidae	*Ariopsis*	48	51	0.94
	Synodontidae	*Synodus*	37	42	0.88
	Engraulidae	*Anchoa*	1,398	2, 238	0.62
	Lutjanidae	*Lutjanus*	30	53	0.57
More Common in Dry Season	Paralichthyidae	*Etropus* *Paralichthys*	18	42	0.43
	Ogcocephalidae	*Ogcocephalus*	8	21	0.38
	Family Portunidae	Unidentified swimming crabs	11	30	0.37
	Sciaenidae	*Cynoscion** *Bairdiella* *Leiostomus* *Micropogonias*	100	662	0.15
	Sparidae	*Archosargus* *Lagodon*	6	97	0.06

**Cynoscion* has a different seasonal pattern that the other species listed in the same Family.

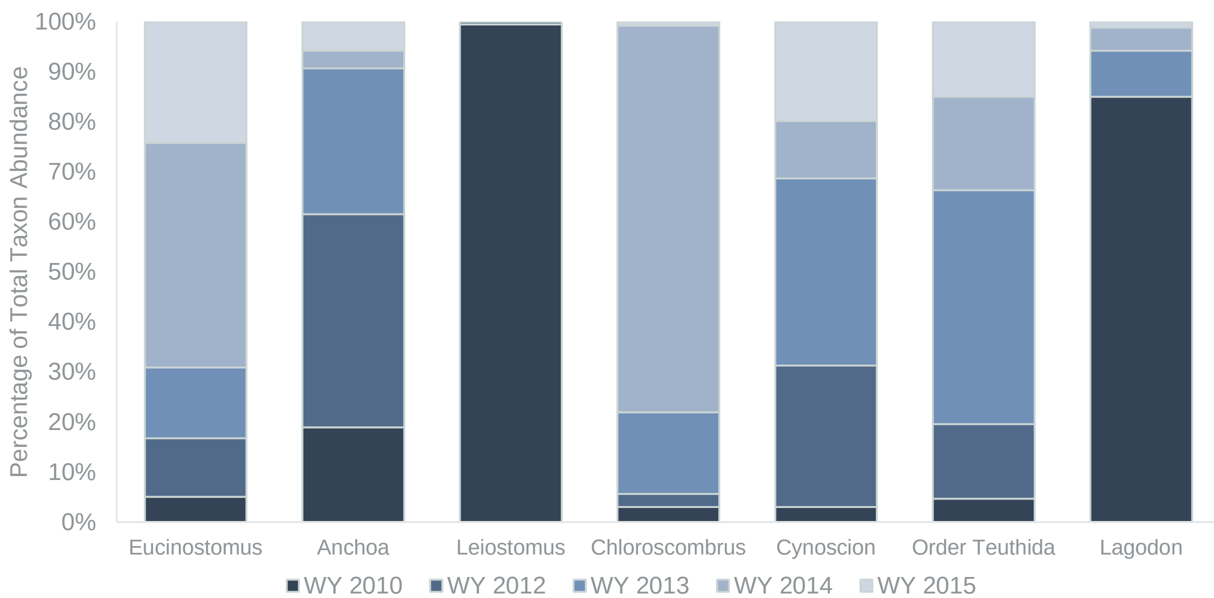


Figure 6-1. Percentage of the total abundance caught in each water year for common taxa, October 2009–September 2015.

6.2 Diversity Indices

6.2.1 Spatial Patterns

Several univariate measures of diversity were calculated for each trawl sample: total abundance, richness (number of taxa), diversity (Shannon), and evenness (Pielou's). Results were compared among zones (Figures 6-2 and 6-3). Zone 1, which covers the northernmost section of the Bay, has significantly lower abundance (log transformed), species richness, and diversity than Zone 4, which covers the southernmost section of the Bay including the area adjacent to Doctors Pass (paired t-test, two-tailed, $p < 0.05$). There are no significant differences in evenness among zones (paired t-test, two-tailed, $p > 0.05$).

6.2.2 Temporal Patterns

Tests for differences in diversity metrics among years or over time were not conducted for this analysis. The sampling effort was not frequent enough for AEM analysis and not spaced equally enough for Kendall Tau analysis. Investigation of temporal patterns was instead focused on seasonal differences overall and within stations.

To examine differences in diversity metrics between wet and dry seasons, the difference between seasonal means was compared using a two-tailed t-test, by station and for all stations combined (Figures 6-4 and 6-5). Log transformed abundance was not significantly different between seasons when all zones were combined, but is significantly higher in the wet season in Zone 4 (t-test of seasons, two-tailed, $p < 0.05$, Figure 6-4). No significant differences in species richness were found between seasons, either by zone or when all zones were combined (t-test of seasons, two-tailed, $p > 0.05$, Figure 6-4). Evenness and was higher in the dry season when all zones were combined and in Zone 1 alone (t-test of seasons, two-tailed, $p < 0.05$, Figure 6-5). Shannon diversity was also higher in the dry season for all zones combined, and also in the dry season for Zone 1 and Zone 4 individually (t-test of seasons, two-tailed, $p < 0.05$, Figure 6-5).

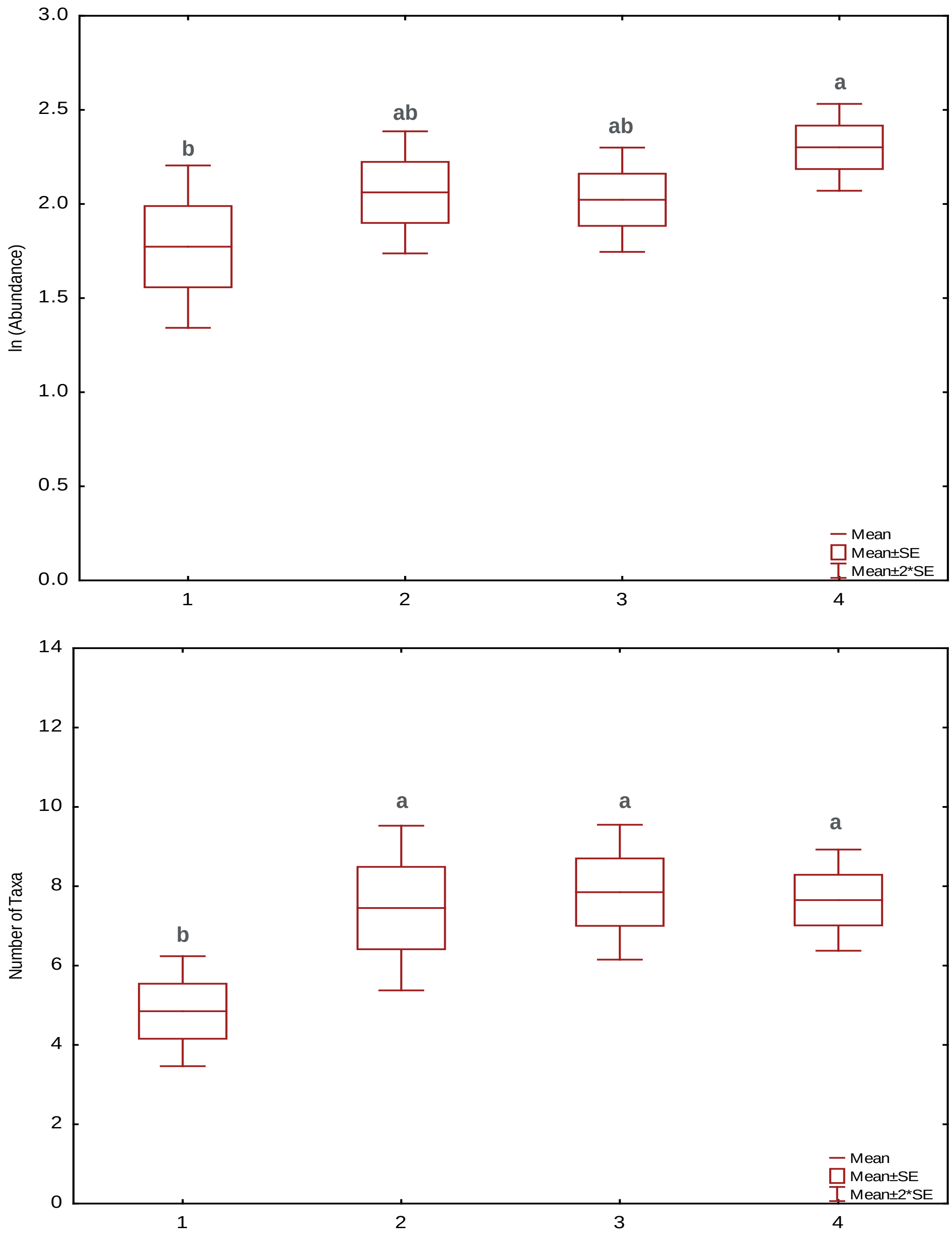


Figure 6-2. **Total abundance and species richness (number of taxa) in bottom trawls by zone in Moorings Bay, November 2009–September 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, p < 0.05).**

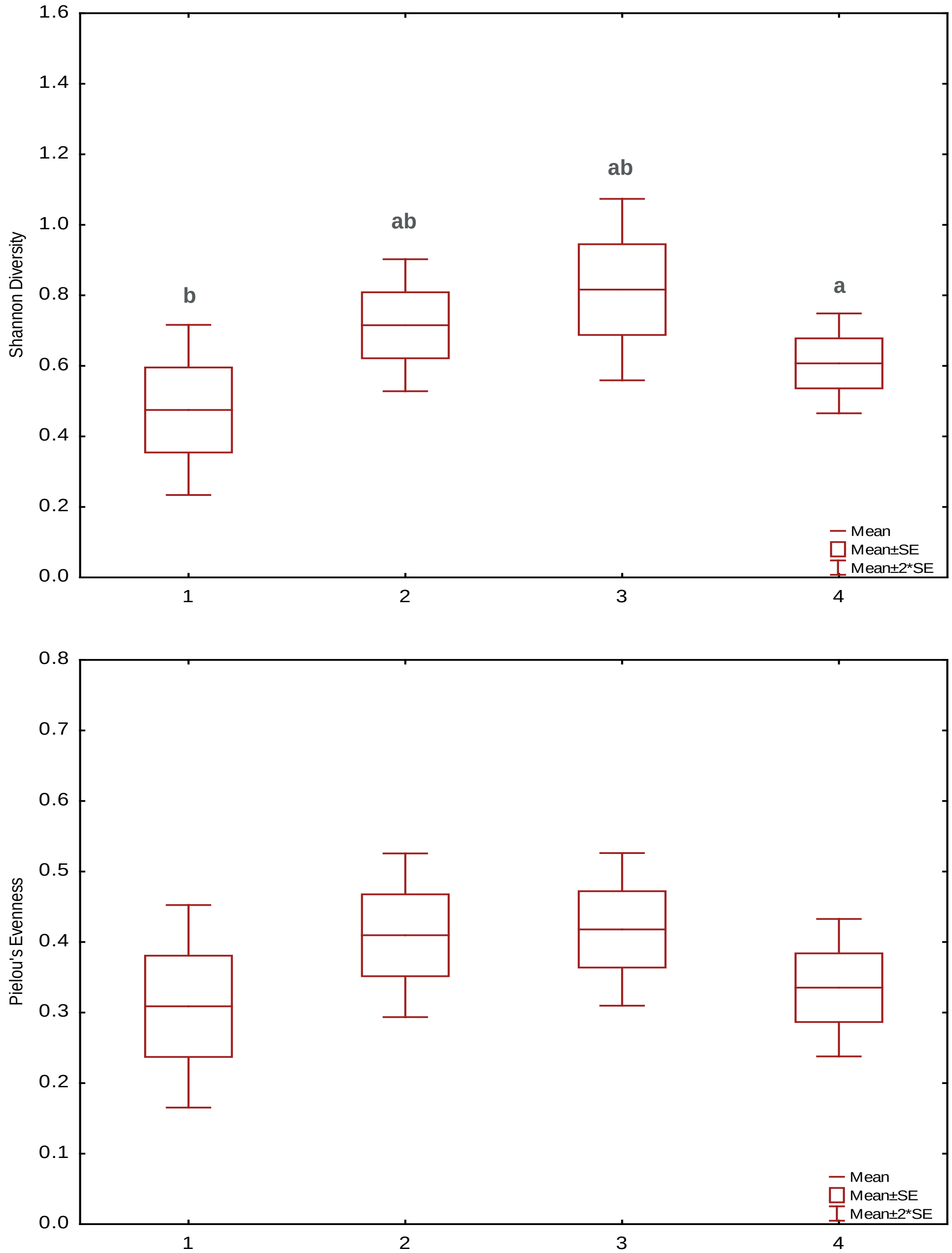


Figure 6-3. **Diversity and evenness in bottom trawls by zone in Moorings Bay, November 2009–September 2015. Within each plot, letters next to the boxes designate statistically significant different groups (paired t-test, two-tailed, $p < 0.05$).**

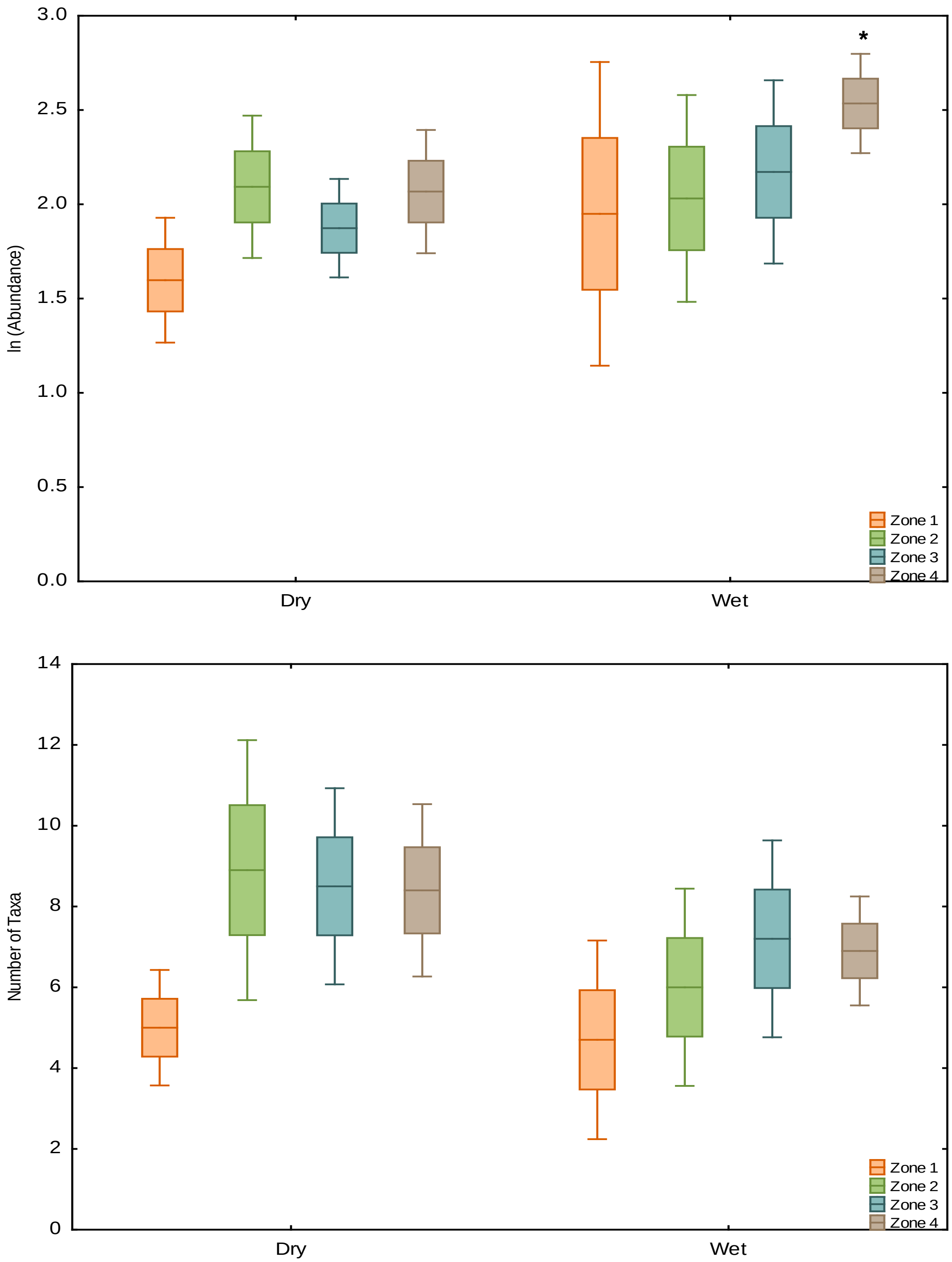


Figure 6-4. **Total abundance and species richness (number of taxa) in bottom trawls by zone and by season in Moorings Bay, November 2009–September 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (paired t-test).**

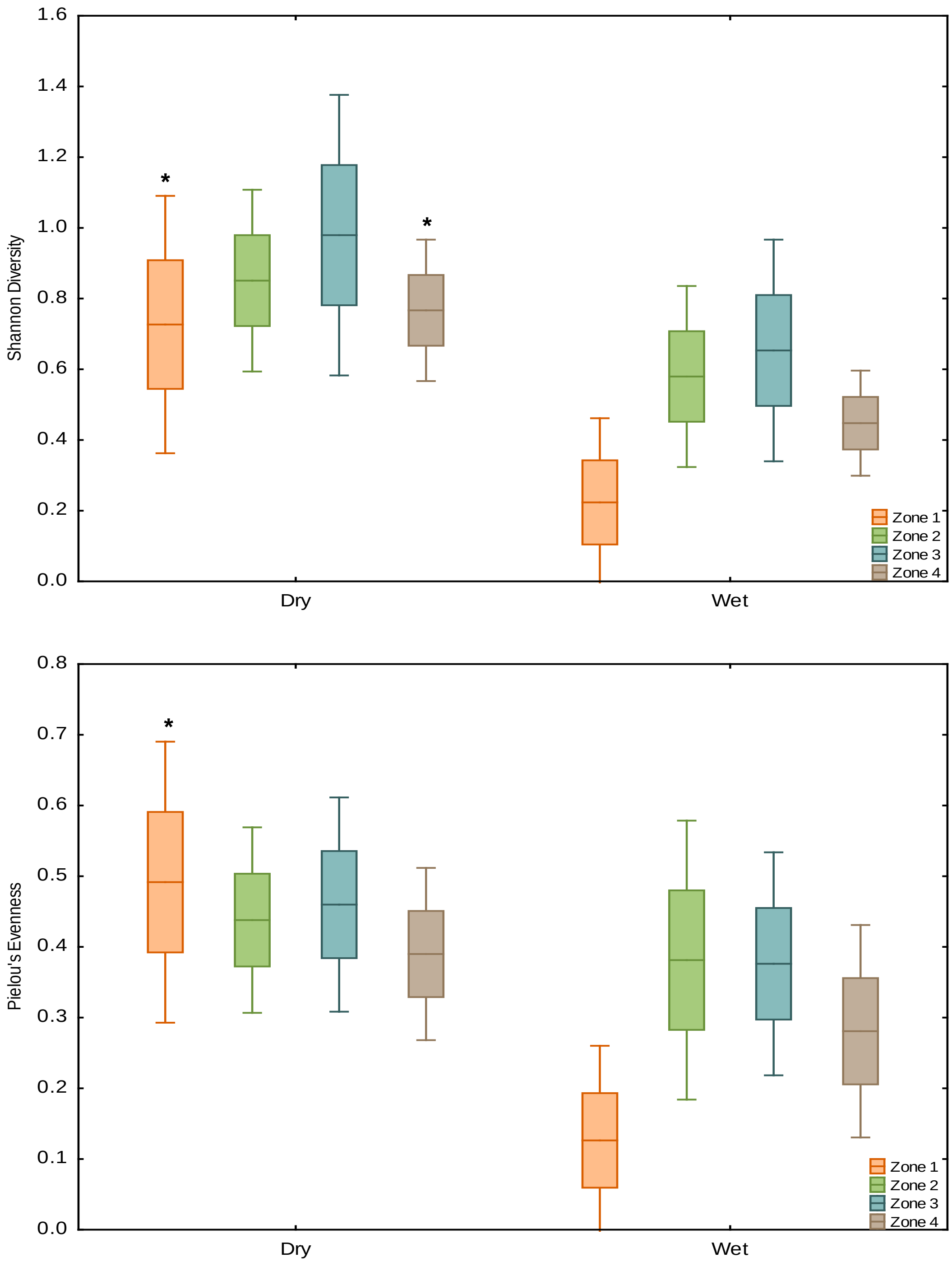


Figure 6-5. Diversity and evenness in bottom trawls by zone and by season in Moorings Bay, November 2009–September 2015 (mean, ±.1SE, and ± 0.95 confidence interval). Within each plot, asterisks indicate stations with a significant difference between seasons (paired t-test).

6.3 Community Structure

Nonparametric multivariate analyses were used to assess similarity in species composition and abundance (‘community structure’). Analyses were conducted using PRIMER vC6 statistical software (Clarke and Gorley, 2006). Similarity was calculated using taxa abundance data for each sample (unless otherwise noted as pooled). Non-metric multidimensional scaling (MDS) was used for a visual depiction of the community structure relationship among samples. Statistical differences in community structure among or between groups of samples were identified using Analysis of Similarity (ANOSIM), and Similarity Percentage analysis (SIMPER) was used to identify which taxa were representative of dissimilarities among groups. The focus within Moorings Bay was on differences among sampling zones, between seasons, and over time (among years).

6.3.1 Spatial Patterns

Species presence/absence data from the entire survey period (2009–2015) were pooled together by zone to give broad-level picture of similarity in the species assemblages across zones. Overall, the similarity (Bray-Curtis) between zones ranged from 62 percent to 79 percent. Zone 1 had the lowest similarity to the other zones (Table 6-8) which indicates that it shares the fewest taxa with the other zones. In addition, in general, adjacent zones have more taxa in common (*i.e.* higher similarity) than zones that are not adjacent.

Table 6-8. Similarity of species assemblage between zones within Moorings Bay, November 2009–September 2015. (Bray-Curtis similarity, presence/absence, pooled by zone).

Zone	1	2	3	4
1				
2	72.97			
3	62.16	79.07		
4	63.49	74.67	77.33	

The one-way ANOSIM test for differences among samples (unpooled data, aggregated to Genus level, 4th root transformed, Bray-Curtis Similarity) from different zones shows that there are significant but very weak differences (ANOSIM Global R = 0.062, p = 0.003)) among zones: The community structure in Zone 1 is significantly different from Zone 3 (ANOSIM R = 0.138, p = 0.001) and Zone 4 (ANOSIM R = 0.094, p = 0.002). Zones 3 and 4 are also significantly different from one another (ANOSIM R = 0.07, p = 0.045). An MDS plot of these data does not show good separation among the zones (Figure 6-6).

SIMPER analysis was used to quantify the average similarity among samples within zone, the average dissimilarity between zones, and which taxa contribute most to the similarity/dissimilarity. The SIMPER results show that, for the most part, there is very low similarity among samples from the same zone and very high dissimilarity among samples from different zones (Table 6-9). When both species occurrence and abundance are considered together, samples from the same zone are about as different from one another as they are from samples from other zones. Although the fish community in Moorings Bay is dominated by just one taxon, *Eucinostomus* spp. (which was caught in almost every sample), the number of individuals caught varied greatly among trawls, adding to dissimilarity among samples. At the same time, while most of the other taxa found in Moorings Bay are ubiquitous rather than limited to a specific zone, they occur relatively infrequently (in total abundance and in number of occurrences) and the average total number of taxa caught in each trawl is low (median = 6) relative to the size of the species pool in Moorings Bay. Thus, even if samples have roughly equal numbers of *Eucinostomus* spp., they rarely share many (if any) other species in common, decreasing the similarity between the samples.

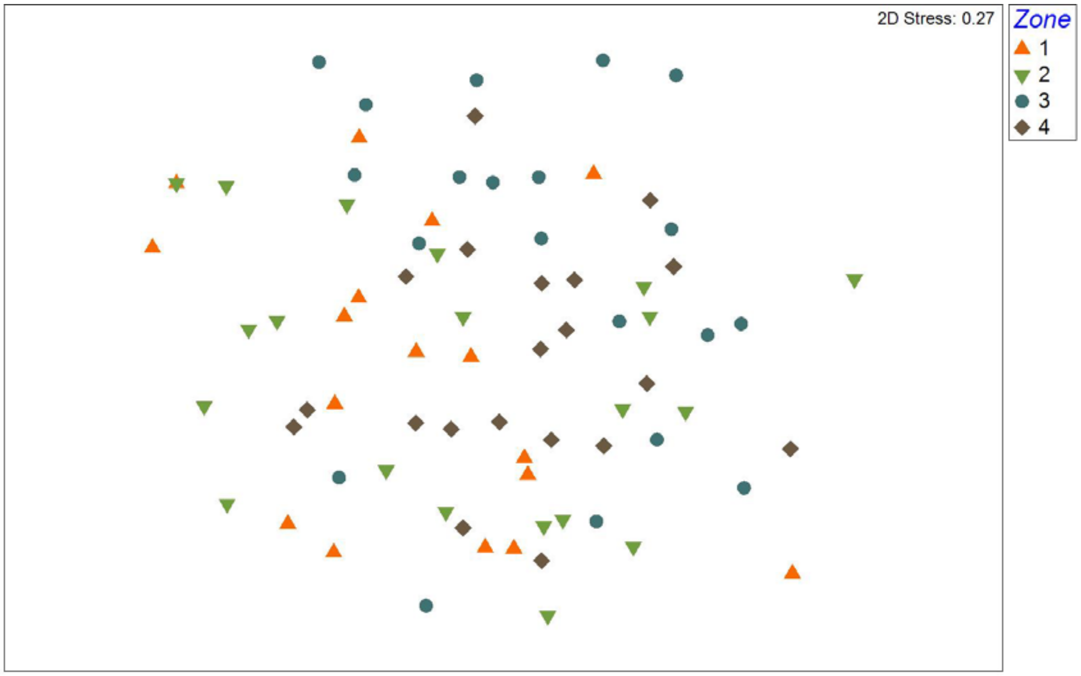


Figure 6-6. **MDS of the fish community in Moorings Bay (Bray-Curtis similarity, 4th root transformed data.) by zone, November 2009–September 2015. Each point represents an individual trawl sample.**

Table 6-9. **Average within group similarity (bold, italics) and between group dissimilarity for season and zones within Moorings Bay, November 2009–September 2015. (Bray-Curtis similarity, Genus-level, 4th root transformed data)**

Zone	1	2	3	4
1	***14.55***			
2	82.23	***18.44***		
3	86.16	80.69	***23.05***	
4	81.17	77.72	76.10	***28.27***

6.3.2 Temporal Patterns

An ANOSIM test found no significant differences among water years (ANOSIM R = 0.021, p = 0.19). Considering season and zone together in a two-way ANOSIM test shows that there is a weak but significant difference between seasons (Global R = 0.174, p = 0.001), driven by significant differences between the wet late season and all other seasons (p = 0.001). However, when the points on the MDS plot are coded by season, there is little difference between wet and dry seasons, but appears to be some separation between samples from the early part of the dry season and the late part of the dry season (Figure 6-7).The differences among the zones are a little weaker when season is taken into account (Global R = 0.059, p = 0.08), and Zones 1 and 4 are no longer significantly different from each other.

Much like comparisons among and within zones, SIMPER analysis by season or year shows that there is very low similarity among samples from the same zone and very high dissimilarity among samples from different zones (Table 6-10).

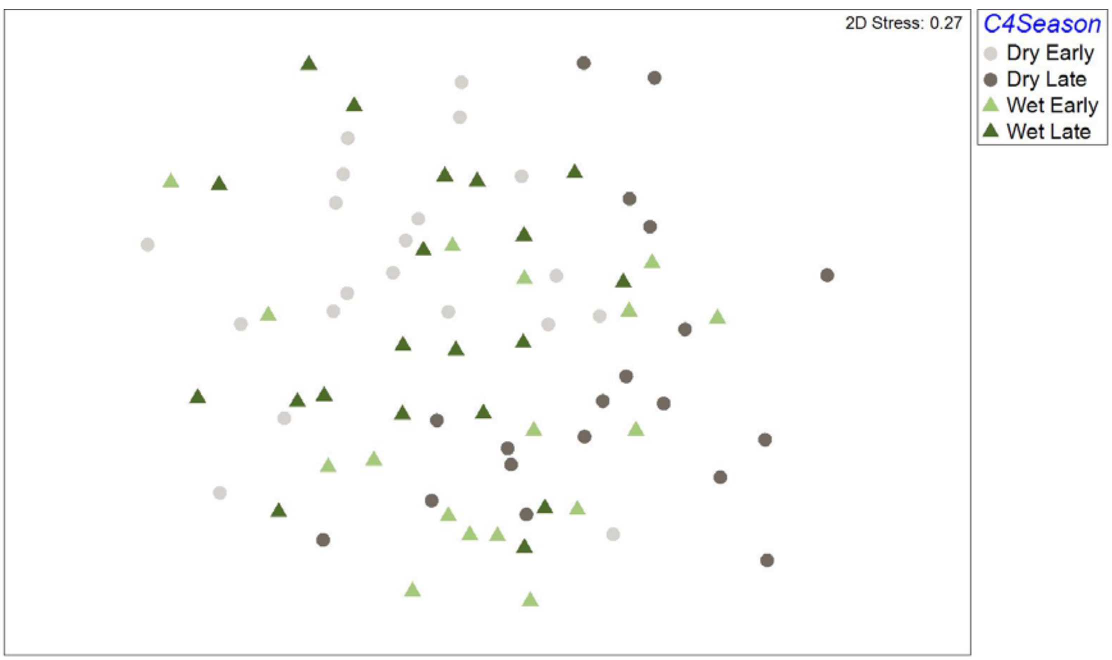


Figure 6-7 MDS of the fish community in Moorings Bay (Bray-Curtis similarity, 4th root transformed data.) by season, November 2009–September 2015. Each point represents an individual trawl sample.

Table 6-10. Average within group similarity (bold, italics) and between group dissimilarity for seasons and years within Moorings Bay, November 2009–September 2015. (Bray-Curtis similarity, Genus-level, 4th root transformed data)

By Season					
	Early Dry	Late Dry	Early Wet	Late Wet	
Early Dry	***18.35***				
Late Dry	82.92	***30.72***			
Early Wet	83.35	78.73	***18.72***		
Late Wet	79.91	80.82	80.65	***19.37***	
By Water Year					
	2010	2012	2013	2014	2015
2010	***15.58***				
2012	81.11	***20.21***			
2013	82.26	79.56	***23.31***		
2014	81.91	80.85	78.38	***22.49***	
2015	82.35	79.16	80.15	79.89	***20.36***

7 Water Quality and Biological Interactions

In order to make use of the water quality and biological results for resource management, it is important to attempt to determine if the observed water quality patterns are contributing to the observed biological condition of Moorings Bay. In this section we explore the relationships (correlations) between factors that can reasonably be expected to contribute to a biological condition. Chlorophyll-*a* concentrations are commonly used as a surrogate for algal biomass and can help explain a relationship between nutrients and primary productivity in Moorings Bay. Similarly, correlations between DO and chlorophyll-*a* may help to explain the effect of primary productivity on oxygen levels in certain portions of the Bay and therefore other biological communities, such as fish. This information can help the City resource managers make informed decisions on management actions that may be necessary to ensure protection of Moorings Bay resources.

In this study, chlorophyll-*a* showed a weak positive correlation with TP at the MB1 station (Pearson's correlation on log transformed values, $r = 0.31$, $p < 0.05$) and a weak positive correlation with TN only at the MB4 location (Pearson's correlation on log transformed values, $r = 0.24$, $p < 0.05$). Chlorophyll-*a* measurements are notoriously variable and may explain the weak correlations observed. The increasing trend in chlorophyll-*a* at the MB1 location and the fact that chlorophyll-*a*, TN, and TP are all highest at the MB1 location appear to indicate a potential source of nutrients in this portion of the Bay. It is also possible a lack of adequate flushing in the northern portion of the Bay may attribute to the nutrient and chlorophyll-*a* condition observed. Given that the culverts under Seagate Drive allow for a net contribution of water from Clam Bay into Moorings Bay, it is possible Clam Bay serves as a source of nutrients and algal biomass to the northern end of Moorings Bay.

DO is an important indicator of waterbody health and can be an important link between pollutants and their effect on the biology of a waterbody. Chlorophyll-*a* concentrations were negatively correlated with DO concentrations and saturation percentage in both the surface and bottom measurements at station MB1 (Pearson's correlation on log transformed chlorophyll-*a*, $-0.30 > r > -0.52$, $p < 0.05$), meaning that when observations of chlorophyll-*a* were higher, the observed DO tended to be lower. This typically indicates that respiration of the algal community is dominating and consuming more oxygen than it is producing. Given the reduced flushing at the MB1 location and the nearby connection to the slow moving waters of lower Clam Bay, this is not surprising. As described in section 4.5.2, the bottom DO concentrations at this location typically drop below 2.0 mg/L and can be harmful to aquatic life.

A relatively simple method of determining if the DO regime is heavily influenced by the effects of photosynthesis is to evaluate any links between DO and pH within the waterbody. Similar to DO, pH also increases during the day as a result of photosynthesis, and decreases at night with respiration of the algal community. A positive correlation between DO and pH within Moorings Bay would indicate the algal community influences the overall DO regime of the system. This is useful information for managers tasked with protecting and preserving the biological character of the Bay and provides a direction to pursue management options. Surface DO concentrations and percent saturation were positively correlated with pH measurements at all locations, with the exception of MB4 (Pearson's correlation, $0.23 < r < 0.48$, $p < 0.05$). Bottom DO concentrations are positively correlated with pH measurements at MB1 ($r = 0.35$, $p < 0.05$), and bottom DO percent saturation is positively correlated with pH at MB1, MB2, and MB4 (Pearson's correlation, $0.30 < r < 0.38$, $p < 0.05$). Given these results, it is apparent that photosynthesis and respiration of the algal community is a large driver (and stressor) of DO in Moorings Bay.

Within the Moorings Bay system, the four water quality monitoring stations are fixed sites and are not necessarily representative of water quality throughout an entire trawling zone. As a result of this consideration as well as the shape of Moorings Bay, it was determined that it would not be useful to construct a water quality dataset to use for Principle Components Analysis (PCA) or BIO ENV and RELATE procedures (in Primer) on the data, because water quality at the monitoring stations could not be assumed to represent the whole trawling zone. For example, a portion of trawling Zone 4 is isolated from the rest of the zone and water quality station MB4 by a bridge that may act as a barrier. Thus, investigating potential links between fish community structure and water quality using this approach would have limited utility. An attempt to reassign each trawl sample to a dummy zone variable based on proximity to water quality monitoring stations resulted in not enough replication within the dummy zones to find meaningful relationships. In addition, community-level analyses would be further complicated by the predominance of one taxon in the fish samples, making links to water quality parameters difficult to identify.

To look for links between water quality and the fish community, analyses were conducted using water quality measurements collected during trawling sampling events: bottom salinity, bottom temperature, and bottom DO. Univariate diversity metrics such as number of taxa, species richness, abundance, and Shannon diversity were plotted against each of the three water quality parameters to see if patterns between the variables existed (Figure 7-1).

When all data are pooled together, water temperature was significantly negatively correlated to evenness (Pearson correlation $r = -0.34$, $p < 0.05$) and diversity (Pearson correlation $r = -0.41$, $p < 0.05$) and positively correlated to log transformed abundance (Pearson correlation $r = 0.22$, $p < 0.05$). These patterns are related to seasonal differences in water temperature as described in Section 6. Bottom DO was positively correlated to species richness (Pearson correlation $r = 0.38$, $p < 0.05$), evenness (Pearson correlation $r = 0.38$, $p < 0.05$), and diversity (Pearson correlation $r = 0.51$, $p < 0.05$). As mentioned above, DO is important for biological function and it appears that low DO areas and events are impacting the distribution of fish in Moorings Bay.

Even though this is a very limited investigation into links between water quality and the fish community in Moorings Bay, it highlights some potentially important patterns. Zone 1 stands out as having the most differences from the other stations: in species distribution, in diversity metrics, and in community structure (see Section 6). Zone 1 is the farthest from the influence of Doctors Pass (and presumably the source populations of fish in the Gulf of Mexico) and the closest to inputs from Clam Bay. Therefore, biological patterns in Moorings Bay might be spatially driven, water quality driven, or both. Better coupling of biological and water quality data, along with greater replication in fish sampling could help clarify which variables drive the community structure.

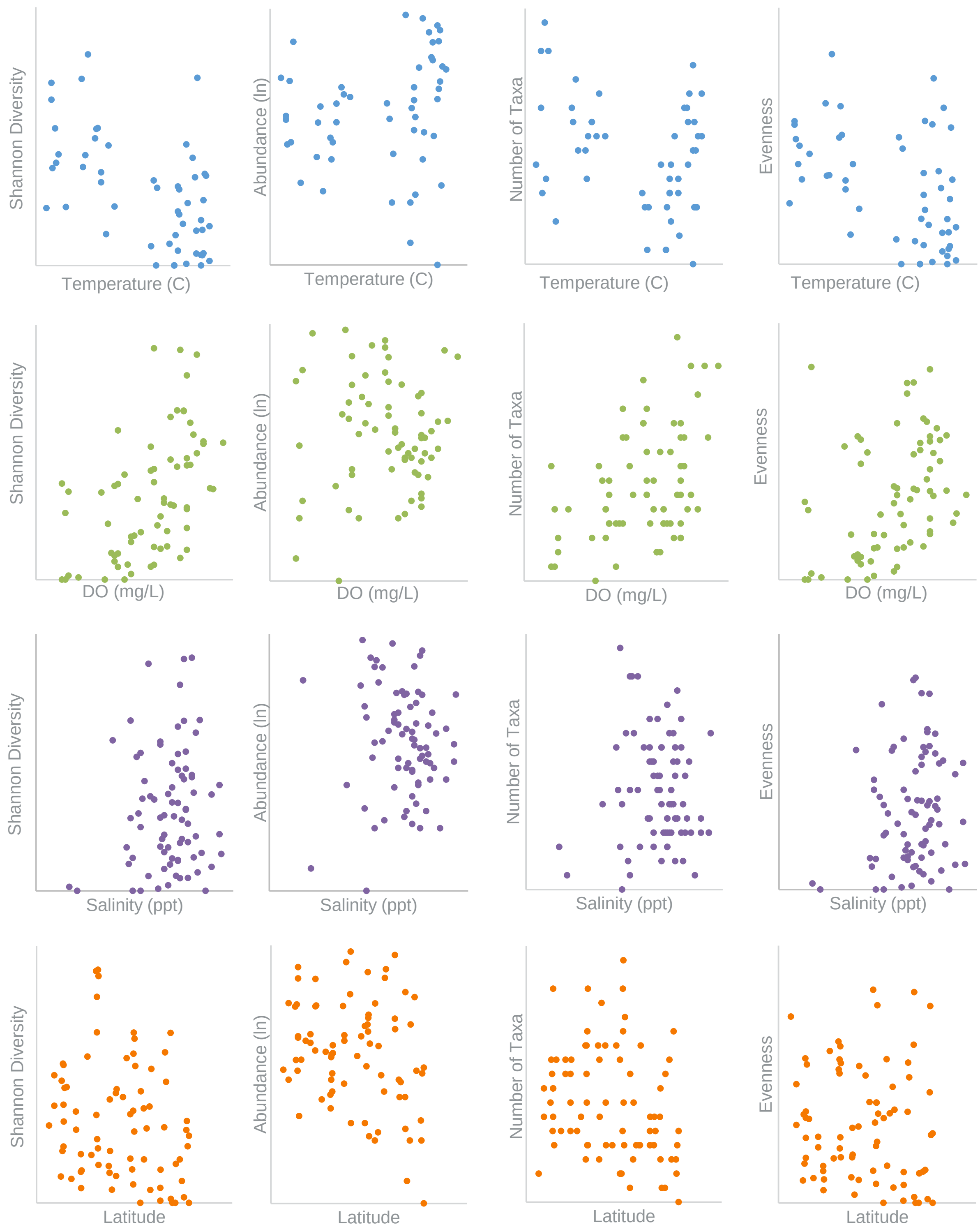


Figure 7-1. Scatterplots of environmental factors versus diversity metrics for Moorings Bay trawl data, November 2009–September 2015.

8 Conclusions

The City of Naples Natural Resources Division commissioned a study to develop a comprehensive understanding of the current status and trends in water quality and biology in Moorings Bay. The purpose was to gain an understanding of the system in order to develop and prioritize management options to protect and preserve the water quality and biology of the Moorings Bay system. This study should be viewed as the first step to achieving this goal. A summary of the major conclusions are provided below.

Moorings Bay Water Quality

> Copper, turbidity, fecal coliform bacteria, and chlorophyll-*a* concentrations all showed statistically significant increasing trends for at least one station in Moorings Bay over the study period. These same parameters showed increasing trends in Naples Bay as well (Cardno 2015) indicating a similar source or regional trend may be affecting both waterbodies in a similar manner.

> Total nitrogen concentrations exhibit a statistically significant decreasing trend at all four Moorings Bay locations, also similar to Naples Bay.

> Although Moorings Bay is not currently listed as impaired for any constituent by the FDEP, this study concludes that copper, TP, and potentially bacteria measurements (*Enterococci*) may trigger an impairment listing during the next assessment cycle (anticipated approximately 2019).

> Monitoring location MB1 in northern Naples Bay consistently exhibits different water quality than the other locations. With the highest concentrations of nutrients, chlorophyll-*a*, and copper, and the lowest DO, northern Moorings Bay exhibits poorer water quality than the rest of Moorings Bay.

> Reduced flushing combined with significant contributions from outer Clam Bay likely contribute to the observed poor water quality in northern Moorings Bay. A quantification of the water quality inputs from Clam Bay is warranted to prioritize management options for Moorings Bay.

Moorings Bay Biological Community

> The Moorings Bay fish community is dominated by *Eucinostomus* spp. (mojarras) (80 percent of total catch) and *Anchoa* spp. (anchovies) (~ 12 percent of total catch). A similar pattern was observed in Naples Bay (Cardno 2015).

> Northern Moorings Bay (Zone 1) exhibits the lowest abundance, richness, and diversity. Analysis of community structure indicates northern Moorings Bay (Zone 1) exhibits the lowest similarity to the other zones.

Water Quality and Biological Interactions

> Dissolved oxygen, an important indicator of waterbody health and essential for biological communities, is driven by photosynthesis and respiration of the algal community in Moorings Bay.

> Low DO may contribute the reduction in abundance, richness, and diversity observed in northern Moorings Bay compared to other portions of the system.

> Contributions from Clam Bay should be quantified to determine the extent of potential impact to Moorings Bay.

> Management prioritization for Moorings Bay should include Clam Bay in order to create cost effective management for both systems.

This study serves as the first comprehensive analytical and statistical characterization of Moorings Bay. The conclusions of this effort lay the groundwork for understanding this complex system and developing cost effective, feasible management goals. The City's robust monitoring of Moorings Bay should continue in order to quantify and track the effects of future management activities. Proper resource management is essential for successful City initiatives as well as to the residents who live, work, play, and depend on Moorings Bay.

9 Literature Cited

AMEC Environment & Infrastructure. 2012. City of Naples Stormwater Quality Analysis, Pollutant Loading and Removal Efficiencies. Prepared for the City of Naples Department of Streets and Stormwater. January 2012. 95 pp.

Atkins. 2011. Collier County: Numeric Nutrient Criteria. Clam Bay-Development of Site Specific Alternative Water Quality Criteria. July 2011 (Draft). 25 pp.

Cardno. 2015. Naples Bay Water Quality and Biological Analysis Project. Prepared for the City of Naples Streets and Stormwater Department, Natural Resources Division. August 2015. 151 pp.

City of Naples. 2010. A Twenty Year Plan (and Visionary Guide) for the Restoration of Naples Bay. Naples, Florida. 28 pp.

Clarke, K.R. and R.N. Gorley. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth. 192 pp.

Collier County. 1995. Collier County Manatee Protection Plan. Collier County Environmental Services Division. May 1995. Publication Series NRD-SP93-01. 136 pp.

Collier County. 1997. Clam Bay Natural Resource Protection, Annual Report. October 1997. 17 pp.

Florida Department of Environmental Protection. 1997. Doctors Pass Inlet Management Study Implementation Plan Certificate of Adoption. June 1997. 8 pp.

Florida State University. 2014. Florida Climate Center. Center for Ocean-Atmospheric Prediction Studies https://climatecenter.fsu.edu/products-services/data/1981-2010-normals/naples. Accessed September 2016.

Hall, W.S., S.J. Bushong, L.W. Hall, Jr., M.J. Lenkevich, and A.E. Pinkney. 1988. Monitoring Dissolved Copper Concentrations in Chesapeake Bay, U.S.A. Environmental Monitoring and Assessment vol 11, pgs 33–42.

PBS&J. 2009. Clam Bay System Data Collection & Analysis. Prepared for Collier County Coastal Zone Management Department. October 2009. 89 pp.

Reynolds, D. 1982. The Man Who Made the Moorings. Naples Now, April 1982:15-19.

United States Geological Survey Water Science School. 2015. http://water.usgs.gov/edu/turbidity.html.

Moorings Bay Water Quality and
Biological Data Analysis

APPENDIX

A

BIOLOGICAL TAXA TABLES

ATTACHMENT B - Moorings Bay Water Quality and Biological Analysis (2016)

Appendix A
Biological Taxa Tables

Table A-1. Fish taxa caught in Moorings Bay bottom trawls, October 2009–September 2015.

Scientific Name	Common Name	Species Code
Acanthostracion quadricornis	Scrawled Cowfish	LACT QUAD
Achirus lineatus	Lined Sole	ACHI LINE
Albula vulpes	Bonefish	ALBU VULP
Anchoa hepsetus	Striped Anchovy	ANCH HEPS
Anchoa mitchilli	Bay Anchovy	ANCH MITC
Ancylopsetta ommata	Ocellated Flounder	ANCL QUAD
Archosargus probatocephalus	Sheepshead	ARCH PROB
Ariopsis felis	Hardhead Catfish	ARIU FELI
Bagre marinus	Gaftopsail Catfish	BAGR MARI
Bairdiella chrysoura	Silver Perch	BAIR CHRY
Brevoortia spp.	Menhaden	BREV SPP
Chaetodipterus faber	Atlantic Spadefish	CHAE FABE
Chilomycterus schoepfii	Striped Burrfish	CHIL SCHO
Chloroscombrus chrysurus	Atlantic Bumper	CHLO CHRY
Citharichthys spilopterus	Bay Whiff	CITH SPIL
Ctenogobius smaragdus	Emerald Goby	GOBI SMAR
Cynoscion arenarius	Sand Seatrout	CYNO AREN
Cynoscion nebulosus	Spotted Seatrout	CYNO NEBU
Dasyatis americanus	Southern Stingray	DASY AMER
Dasyatis sabina	Atlantic Stingray	DASY SABI
Diplectrum formosum	Sand Perch	DIPL FORM
Etropus crossotus	Fringed Flounder	ETRO CROS
Eucinostomus spp.	Mojarra	EUCI SPP
Eugerres plumieri	Striped Mojarra	EUGE PLUM
Gobionellus oceanicus	Highfin Goby	GOBI OCEA
Gobiosoma robustum	Code Goby	GOBI ROBU
Gymnura micrura	Smooth Butterfly Ray	GYMN MICR
Haemulon plumierii	White Grunt	HAEM PLUM
Harengula jaguana	Scaled Sardine	HARE JAGU
Hemicaranx amblyrhynchus	Bluntnose Jace	HEMI AMBL???
Hippocampus erectus	Lined Seahorse	HIPP EREC
Lagodon rhomboides	Pinfish	LAGA RHOM
Leiostomus xanthurus	Spot	LEIO XANT

Table A-1. Fish taxa caught in Moorings Bay bottom trawls, October 2009–September 2015.

Scientific Name	Common Name	Species Code
Lophogobius cyprinoides	Crested Goby	LOPH CYPR
Lutjanus griseus	Mangrove Snapper	LUTJ GRIS
Lutjanus synagris	Lane Snapper	LUTJ SYNA
Menticirrhus americanus	Southern Kingfish	MENT AMER
Menticirrhus spp.	Kingfish	MENT SPP
Microgobius gulosus	Clown Goby	MICR GULO
Microgobius thalassinus	Green Goby	MICR THAL
Micropogonias undulatus	Atlantic Croaker	MICROPOGONIUS UNDULATUS
Ogcocephalus cubifrons	Polka-Dot Batfish	OGCO CUBI
Opisthonema oglinum	Atlantic Thread Herring	OPIS OGLI
Opsanus beta	Gulf Toadfish	OPSA BETA
Orthopristis chrysoptera	Pigfish	ORTH CHRY
Paralichthys albigutta	Gulf Flounder	PARA ALBI
Prionotus scitulus	Leopard Searobin	PRIO SCIT
Prionotus tribulus	Bighead Searobin	PRIO TRIB
Sciaenops ocellata	Red Drum	SCIA OCEL
Scorpaena brasiliensis	Barbfish	SCOR BRAS
Selene vomer	Lookdown	SELE VOME
Sphoeroides nephelus	Southern Puffer	SPHR NEPH
Sphoeroides spengleri	Bandtail Puffer	SPHR SPEN
Stephanolepis hispidus	Planehead Filefish	MONA HISP
Symphurus plagiusa	Blackcheek Tonguefish	SYMP PLAG
Syngnathus louisianae	Chain Pipefish	SYNG LOUI
Synodus foetens	Inshore Lizardfish	SYNO FOET
Trichiurus lepturus	Atlantic Cutlassfish	TRICHIURUS LEPTURUS
Urophycis floridana	Southern Hake	UROP FLOR

*Leptocephalus larvae were not included in analysis presented in this report.

Table A-2. Invertebrate taxa caught in Moorings Bay bottom trawls, October 2009–September 2015.

Scientific Name	Common Name	Species Code
Included in Analysis		
Callinectes sapidus	Blue Crab	CALI SAP
Callinectes similis	Lesser Blue Crab	CALI SIM, CALI SIMILUS, SALI SIM
Farfantepenaeus duorarum	Pink Shrimp	PENA SPP
Family Portunidae	Swimming Crabs	SWIM CRABS, SWIM CRAB
Order Teuthida	Squids	SQUID
Excluded from Analysis		
Menippe mercenaria	Stone Crab	MENI MERC
Aplysia sp.	Seahares	APLYSIA SEAHARE
Libinia sp. (?)	Spider Crabs	SPIDER CRAB
Order Stomatopoda	Mantis Shrimp	MANTIS SHRIMP
Family Xanthidae	Mud Crabs	MUD CRAB, MUD CRABS
Superfamily Majoidea	Decorator Crab	DECORATOR CRAB
Melongena corona	Crown Conch	CROWN CONCH
Family Inachidae	Arrow Crabs	ARROW CRAB
Hepatus epheliticus	Calico Box Crab	CALICO CRAB
Superfamily Paguroidea	Hermit Crabs	HERMIT CRAB
Luidia sp.	Nine-Armed Sea Star	9 ARM SEA STAR, 9ARM SS, 9ARM
Class Asteroidea	Five-Armed Sea Star	5 ARM SEA STAR
Class Ophiuroidea	Brittle Stars	BRITTLE STAR
Limulus polyphemus	Atlantic Horseshoe Crab	HORSESHOE CRAB
Order Neogastropoda	Whelk Egg Case	WHELK EGG CASE
Order Decapoda	Purple Crab	PURPLE CRAB
Order Anaspidea	Seahares	SEA HARES
Bursatella leachii	Ragged Seahare	RAGGED SEA HARES
Aplysia fasciata	Mottled Seahare	SEA HARE MOT, SH M