WASTEWATER DISCHARGE, NUTRIENT LOADING, AND DISSOLVED OXYGEN DYNAMICS IN A SHALLOW TEXAS BAY

A Thesis

by

LEE SCHROER

Submitted to the Office of Graduate and Professional Studies of Texas A&M University
and the Graduate Faculty of The Texas A&M University – Corpus Christi
in partial fulfillment of the requirements for the joint degree of

MASTER OF SCIENCE

Chair of Committee,	Paul Montagna
Committee Members,	Michael Wetz
	Xinping Hu
Head of Department,	Joe Fox

August 2014

Major Subject: Marine Biology

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Approved to style and content by

Dr. Paul Montagna
(Chair of Committee)

Dr. Michael Wetz
(Member)

Dr. Xinping Hu
(Member)

Dr. Joe Fox
(Department Chair)

Dr. Frank Pezold
(Dean, College of Science and Engineering)

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Abstract

WASTEWATER DISCHARGE, NUTRIENT LOADING, AND DISSOLVED OXYGEN DYNAMICS IN A SHALLOW TEXAS BAY

Lee Schroer, Zoology, Texas A&M University-College Station

Chair of Advisory Committee: Dr. Paul Montagna

In Oso Bay, a wastewater treatment plant acts as a source of eutrophication and may have measureable impact on the health of the bay. The objectives of this study were to create a model for modeling dissolved oxygen concentrations over time and to determine if eutrophication caused by the wastewater treatment plant is harmful to the bay. Continuous monitoring of environmental variables was carried out at 6 stations in Oso Bay over a 9-month period beginning in February and ending in December of 2013. Variables measured were water temperature (oC), pH, salinity (ppt), conductivity (mS), depth (meters), turbidity (nephilometric turbidity units), dissolved oxygen in both % saturation and concentration (mg/L), and chlorophyll-α concentration (µg/L). Grab samples of chlorophyll concentration (µg/L), total suspended solids (mg/L), and nutrient concentrations (µM) were also taken throughout the sampling period. Nutrients of interest were phosphate (PO_4), silicates (SiO_4), ammonium (NH_4), and nitrate+/-nitrite (NO_x). Hypoxia was observed at each of the stations in the bay and fluctuated on a diel cycle. Temperature, salinity, and temporal variability were significant factors in explaining the variance in dissolved oxygen concentrations ($P < .0001$) and were used to model dissolved oxygen variance ($R^2 = .7810$). It is likely that the respiratory patterns of phytoplankton and bacteria also influence dissolved oxygen concentrations in Oso Bay, and that this is an indirect result of the discharge from the wastewater treatment plant.

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Acronyms and Abbreviations

DO: Dissolved oxygen

HRI: Harte Research Institute

POM: Particulate organic matter

DOM: Dissolved organic matter

OWTP: Oso Bay Wastewater Treatment Plant

NAS: Naval Air Station

ADCP: Acoustic Doppler Current Profiler

TSS: Total suspended solids

VOM: Volatile organic material

TCEQ: Texas Commission on Environmental Quality

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Introduction

Hypoxia has the potential to modify or harm estuarine habitats depending upon its spatial extent, duration, and frequency (Buzzelli et al., 2002). Saltwater containing less than 2 mg/ L of dissolved oxygen (DO) is considered hypoxic, and water containing no oxygen is defined as anoxic. The depletion of oxygen in the water column and seafloor can result from the degradation of particulate organic matter (POM) and dissolved organic matter (DOM) (Gray et al., 2002). POM & DOM originate from phytoplankton, zooplankton, and bacteria that can bloom in large quantities. These blooms are seasonal and short-lived, and when the initial bloom subsides as nutrients are exhausted, organic detritus rains down to the seafloor. Benthic organisms initially benefit from this, as it provides a readily available food source. However, if the size of the bloom outstrips the capacity of benthic organisms to graze it, the decomposition of the bloom quickly depletes the oxygen of the bottom waters (Baird et al., 2004). The carbon of POM & DOM is decomposed aerobically, consuming oxygen at a rate more rapid than the re-aeration of the bottom water and sediment (Rabalais et al., 2010). The resultant hypoxia drives away motile organisms and suffocates nonmotile ones (Ritter and Montagna, 1999; Montagna and Froeschke, 2009).

Although large algal blooms are responsible for creating some hypoxic areas, they are not the root cause. Nutrient loading of shallow, coastal areas has created some of the largest and most persistent hypoxic areas in the world, such as the "dead zone" in the northern Gulf of Mexico (Scavia et al., 2003). Anthropogenic activities over the last 200 years have created hypoxia in areas that were previously healthy and aggravated other habitats where oxygen was already at low levels (Diaz and Rosenberg, 2008). Point and non-point sources, rich in nitrogen and phosphorus, provides the necessary nutrients for large phytoplankton blooms (Rabalais et al., 2010). Photosynthetic phytoplankton are the primary food source for heterotrophic zooplankton, and correspondingly large zooplankton blooms can occur after the initial phytoplankton bloom (Dagg et al., 1982). In an ecosystem without anthropogenic nutrient input, the growth and consumption of phytoplankton and zooplankton would remain in equilibrium. But in a system where abnormally large blooms regularly take place, the growth of planktonic blooms outstrips the capacity of grazing organisms. The ungrazed production sinks to the seafloor as POM and DOM, and hypoxia sets in (Baird et al., 2004).

Hypoxia is caused by aerobic decomposition of organic matter, but physical and environmental factors can work synergistically to prolong the duration or increase the frequency of hypoxic episodes. Stratification of the water column continues to deplete DO at the sediment layer after hypoxia has set in (Breitburg, 1990). In bays on the Texas Gulf coast, stratification generally occurs due to differences in salinity between surface and subsurface water, and prevents the aeration of DO-deprived subsurface water (Ritter and Montagna, 1999). Highly saline waters from shallow estuaries can also be forced by wind into bays of lower salinity, further increasing the likelihood of stratification (Nelson, 2012).

Oso Bay, a tertiary bay south of Corpus Christi, Texas, has a documented history of high nutrient levels, due in part to the Oso Bay Wastewater Treatment Plant (Nicolau, 2001). The large amounts of nitrogen and phosphorus introduced into the bay could trigger large algal blooms, which could then cause hypoxia within the bay. The bay is a habitat for several fish species, and hypoxia will deny that habitat to these fish and render it useless to the fishermen who make use of the bay. The primary objective of the study was to identify the link between nutrient loading and DO levels in Oso Bay. The link will be established by measuring site-specific data such as DO and nutrient concentrations over time. By comparing the nutrient, chlorophyll-a, and DO concentrations of Oso Bay, we can determine the temporal and spatial extent of eutrophication and hypoxia, and what factors are likely contributing to these problems.

Materials and Methods

Site Description

Oso Bay is defined as the area between the Highway 358 bridge and the mouth where it enters Corpus Christi Bay (Figure 1). Its physical coordinates are 27^{o} 41' 30" N 97^{o} 18' 40" W. Corpus Christi Bay is its source of saltwater inflow, and Oso Creek to the south is its main freshwater source. The Barney Davis Power Station discharges cooling water drawn from the Laguna Madre into Oso Creek, which can lead to influxes of high-salinity water from the south (Nelson 2012). The outfall of the Oso Bay Wastewater Treatment Plant (OWTP) provides additional freshwater input at the western end of the bay. Oso Bay is shallow, with an average depth of 1.2-1.6 m. A portion of the western bay known as the Blind Oso is much shallower, with areas alternately wet or dry dependent on tidal fluctuations and an average water depth of 0.1 - 0.3 m. The bay bottom is composed of mud, clay, and silt.

Five stations were selected to monitor the above parameters. These sites were chosen due to their proximity to important features of Oso Bay and also because they serve as excellent indicators for large areas of the bay.

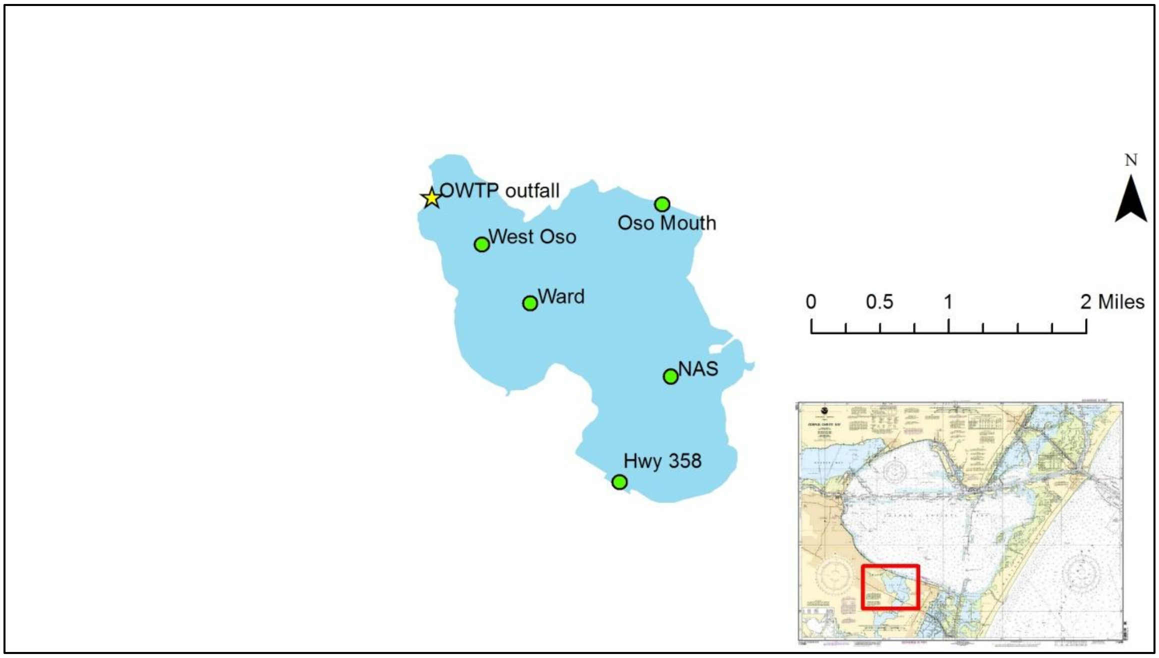


Figure 1. Map of Oso Bay and study sites, with map inset of Corpus Christi Bay. Yellow star denotes OWTP outfall location.

Highway 358

This station is located underneath State Highway 358 as it crosses Oso Bay. The shore is bare or covered in riprap to control erosion, having been cleared of vegetation during the construction of the highway (Nicolau, 2001). Average water depth ranges from 0.3 to 0.8 m, depending on tidal and wind action. Bottom sediment is a mixture of silt and mud, with pieces of shell fragments and chunks of concrete intermixed at the surface. This location was selected as a station to monitor inflow from the extreme southern reaches of Oso Bay and Oso Creek.

NAS

The NAS station is located in the eastern-central portion of Oso Bay. Average water depth ranges from 1.0 to 1.3 m. Bottom sediment is a mixture of clay and sand. This station was chosen to monitor physical variables in the eastern half of the central bay.

Ward

The Ward station is located in the western-central portion of Oso Bay, roughly 800 meters south of Ward Island. Average water depth varies from 0.8 to 1 m. Bottom sediment is composed of clay and sand. Dead oyster reefs are present in this area of the bay, but not at the station itself. This station was selected to monitor the western portion of the central bay, much the same as the NAS monitoring station to the east. Ward was also selected as a station to monitor the dispersion of water from the OWTP as it flows into the rest of Oso Bay.

West Oso

The West Oso station is located in the western extremity of Oso Bay, approximately 700 m east of the outfall of the OWTP. Average water depth ranges from 0.1 to 0.3 m, dependent on tidal and wind action. Bottom sediment is composed of clay and sand. This station was created to monitor water quality near the OWTP's outfall. Due to the large volume of nutrients introduced by the outfall, visible large plankton blooms occur frequently. Nutrients are sometimes introduced as runoff from the Oso Bay Municipal Golf Course to the north. The golf course waters its grounds using reclaimed wastewater, and this wastewater can make its way to the northern extremity of the bay.

Oso Mouth

The Oso Mouth station is located in a channel underneath the bridge between Ward Island and the Corpus Christi Naval Air Station. Average water depth ranges from 3.7 to 4.2 m. Bottom sediment is composed of mud and silt. The shore by the bridge is bare of vegetation. Oso Mouth has two monitoring stations mounted on one PVC pole to study the effects of depth on physical variables: one at a depth of ~ 1 m above the bottom and the other at a depth of ~8 centimeters above the bottom. The mouth of the Oso was chosen as a station to monitor water entering and exiting the bay via the confluence with Corpus Christi Bay.

Data Collection

Data collection began on February 15th, 2013 and ended on December 10th, 2013. A Hach Hydromet DS5X multiparameter sonde was deployed at each station. The sondes were mounted on frames constructed from PVC pipe and deployed at each site so that the sonde's sensors were ~7 cm above the bottom. The exception to this was at the Oso Mouth station. Two sondes were mounted on a vertical PVC pole at depths of ~1 m and ~0.08 m above the bottom sediment, respectively. These sondes were deployed and recovered using divers.

The sondes measured temperature, pH, conductivity, salinity, depth, turbidity, DO (both concentration and % saturation), and chlorophyll concentration. Calibrations were made using known standards for pH, conductivity, salinity, depth, turbidity, and DO concentration and % saturation. Chlorophyll calibrations used seawater whose chlorophyll content had been measured via filtration and fluorescence measurement.

Measurements were taken every 15 minutes. Sondes were recovered and replaced every 10 to 14 days to minimize fouling. Some sensors, primarily turbidity, were nonfunctional at the time of deployment on some of the sondes, and were not utilized.

The recovered sondes underwent post-deployment calibrations of the DO sensor prior to any cleaning upon their return from the field. The level of fouling on the sonde, as well as the fouling substance or organism was noted, and then the sonde was placed in a bucket of aerated water along with a bubbler. DO % saturation was recorded and evaluated based on certain thresholds. If saturation was within a 10% margin of error for 100% saturation, the data was recorded in its entirety. If the DO sensor fell below 90% saturation prior to cleaning, only the first three days' worth of recorded data were used in analysis. The sonde was then cleaned thoroughly with soap, water, and occasionally vinegar to remove difficult-to-reach barnacles. It was then returned to the aerated water and DO % saturation was tested again to make sure no organisms obstructed data collection.

Field measurements and samples were also conducted when deployed sondes were recovered from the field. Seawater was filtered through 25mm diameter filter paper with 1.6 µm pore size and both the filter and the seawater were frozen at -23 °C, to be analyzed usually within a two-week period. Analysis was initiated by the addition of 5 mL of methanol to the sample vial. The vial was left at -23 °C for a period of 12-18 hours, then slowly warmed up to room temperature over a period of 30 minutes. The samples were inverted to resuspend chlorophyll-α, and 2 mL of the methanol solution was analyzed on a fluorometer to obtain chlorophyll-α concentration.

The filtered seawater samples were frozen at -23 °C and analyzed for NO_x, silicate, ammonium, and orthophosphate content using an O.I. Analytical Flow Solution IV ® (FS IV®) autoanalyzer. Minimum detection limits (MDLs) are NO_x (0.007 µM/L; O.I. Analytical method 15040908, OIA 2008), silicate (0.071µM/L; O.I. Analytical method 15061001, OAI 2001a), ammonium (0.03 µM/L; O.I. Analytical method 15031107, OIA 2007), and orthophosphate (0.009 µM/L; O.I. Analytical method 11491200, OIA 2007). Typical lowest concentration minimum reportable levels (LCMRL) are: NO_x (0.25-10.0 µM; O.I. Analytical method 15040908, OIA 2008), silicate (10.0-300.0 µM; O.I. Analytical method 15061001, OAI 2001a), and ammonium (0.25-10.0 µM; O.I. Analytical method 15031107, OIA 2007). The orthophosphate method has a LCMRL of 0.10-10.0 μM (Perstorp Analytical method 000589, OIA 2001b), but is a modification of the Alpkem method (Alpkem, 1993).

Total suspended solids (TSS) samples were collected in 500 mL brown Nalgene bottles at each site, and returned to the lab for analysis. The bottles were vigorously shaken to resuspend sediment, and then filtered through 47mm filter paper. The filters were dried at 60 ^{o}C for 24 hours, and then weighed. To determine the total amount of suspended solids, the weight of the filter prior to use was subtracted from the weight of the dried filter and the difference was divided by the amount of sample water filtered. The quotient was then multiplied by one thousand to give the amount in milligrams. The filters were then combusted at 451 ^{o}C for 3 hours to burn off any organic material and then weighed. To determine the amount of volatile organic material in the sample, the mass of the combusted filter was subtracted from the mass of the dried filter and the difference provides the total amount of volatile organic compounds present.

Aquadopp current profilers were also deployed on the bottom at the Oso Mouth and Ward sites. The Oso Mouth site was selected to measure the current velocity and direction at the interface of Oso Bay and Corpus Christi Bay. Ward was selected because it was the site closest to the OWTP with a suitable water depth. By tracking current speed and flow direction from the OWTP, a model for the dispersion of treated wastewater and any resultant hypoxia can be determined. Both ADCPs were programmed to record current velocity and amplitude every 15 minutes. The sensor head was given a coat of marine antifouling paint to prevent barnacle and algae growth. The paint did not interfere with data collection. ADCPs were retrieved and replaced in June and October.

Results

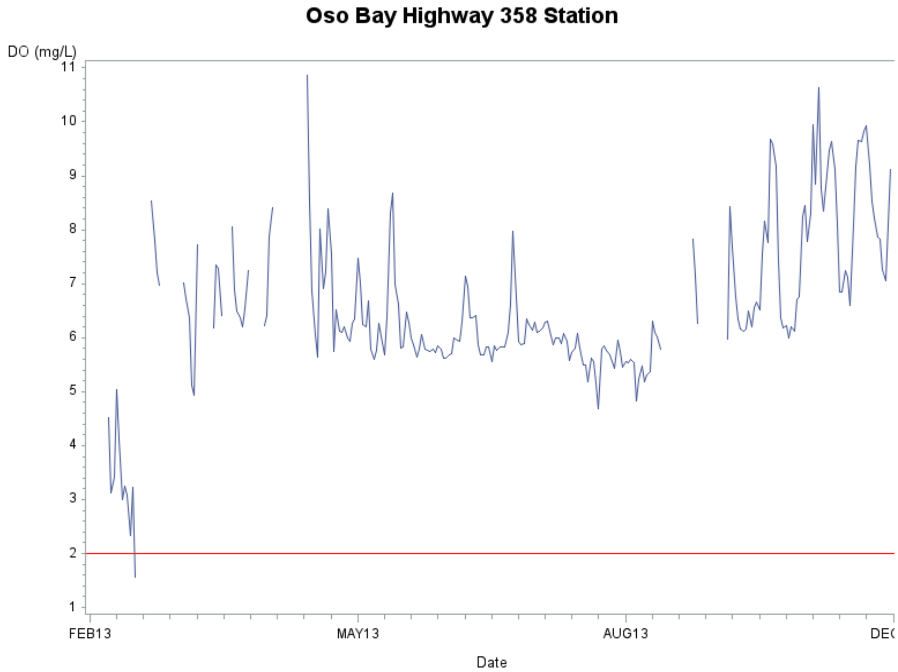
Algae growth and barnacle settling occur very quickly in Oso Bay. As such, sondes become fouled quickly and need frequent replacement to continue to provide accurate data. This was an occasional problem at all of the stations, but sondes deployed at the West Oso station in particular failed post-calibration checks regularly and some of the data recorded during the latter halves of deployments had to be omitted from analysis. Despite these difficulties, much useable data was recorded for each station. Table 1 gives averages for physical and chemical variables in the bay by station.

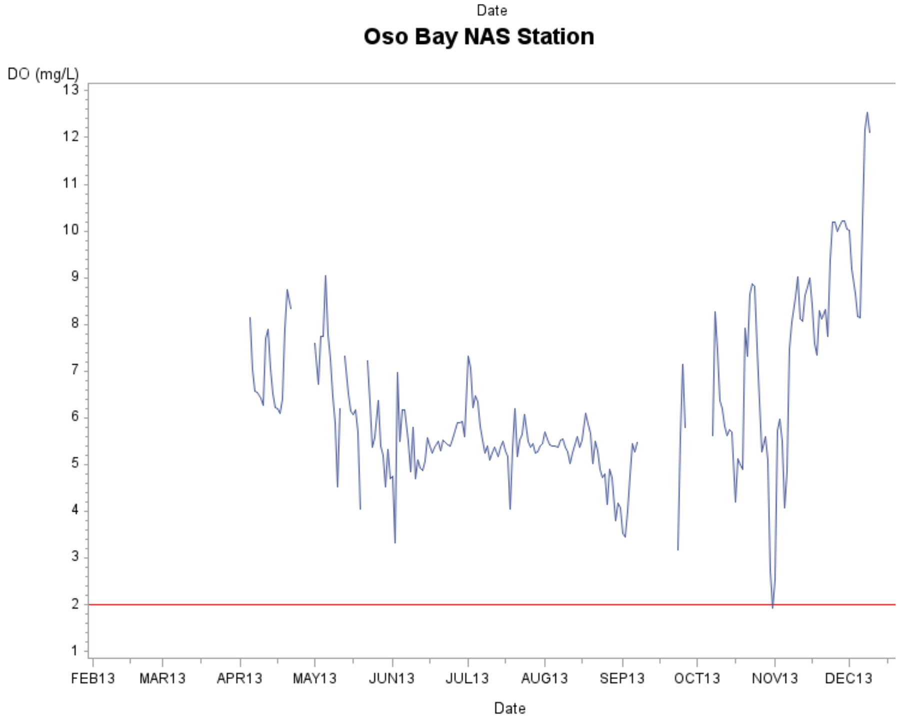
Table 1: Average temperature, salinity, DO (% saturation and concentration), chlorophyll, total suspended solids (TSS), volatile organic materials (VOM), orthophosphate, silicates, ammonium, and nitrate/nitrite for each station.

Station	**Temperature (°C)**	**Salinity (ppt)**	**DO % saturation**	**DO conc. (mg/L)**	**Chlorophyll (µg/L)**	**TSS (mg/L)**	**VOM (mg/L)**	**PO_4 (µM)**	**SiO_4(µM)**	**NH_4(µM)**	**NO_x(µM)**
Hwy 358	25.55	40.39	96.65	6.31	12.25	135.65	6.72	1.83	53.67	1.35	2.28
NAS	25.62	39.57	91.79	6.07	8.70	104.71	6.04	1.49	44.71	1.12	1.07
Oso Mouth Shallow(~2.5m)	25.14	37.47	93.77	6.41	7.11	62.70	4.98	0.69	33.77	1.33	1.5
Oso Mouth Deep(~3.6m)	25.44	39.63	94.23	6.26	9.06	74.67	5.08	1.2	44.71	1.12	1.07
Ward	25.7	35.78	90.84	5.94	17.88	75.98	5.41	3.48	54.45	5.71	9.72
West Oso	23.32	28.24	111.09	8.09	23.54	105.38	5.51	10.37	63.83	23.74	32.47

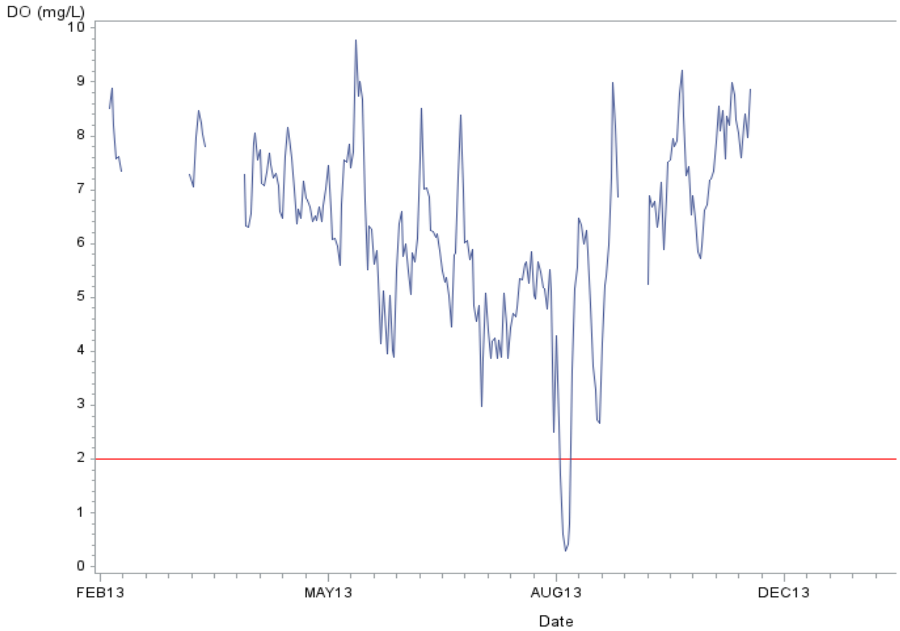
Notice that salinity increases as Oso Bay is traversed from west to east. This is due to the freshwater released from the OWTP outfall. In addition to freshwater, the OWTP outfall is also responsible for the large concentrations of nitrogen and phosphorus seen at the West Oso and Ward stations.

Average daily DO concentrations for each station were also graphed over time and plotted (Figure 2). Periods of increase and decrease are visible, but there are few instances where hypoxic conditions persist more than a few days. Fouling and sensor failure are responsible for missing data.

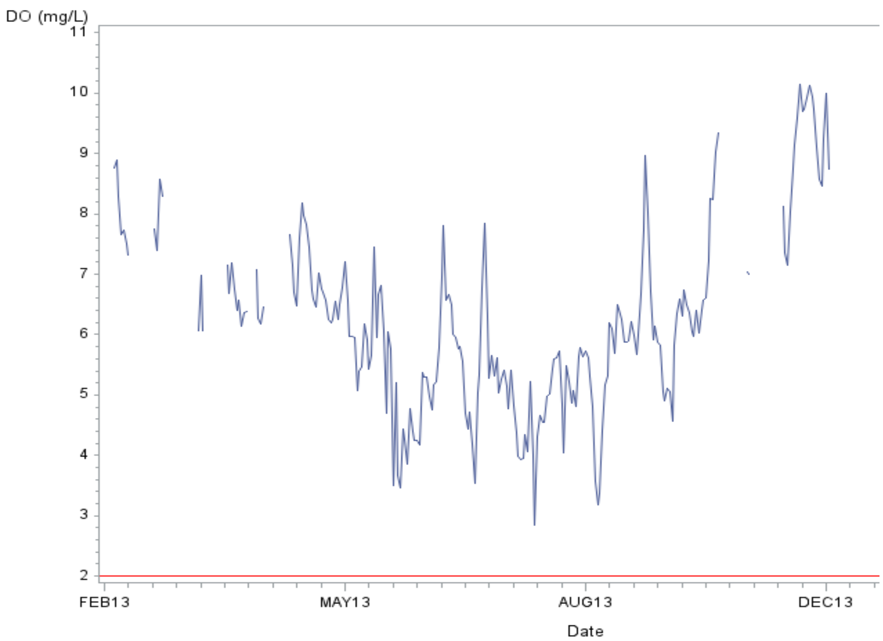




Oso Bay Oso Mouth Shallow Station



Oso Bay Oso Mouth Deep Station



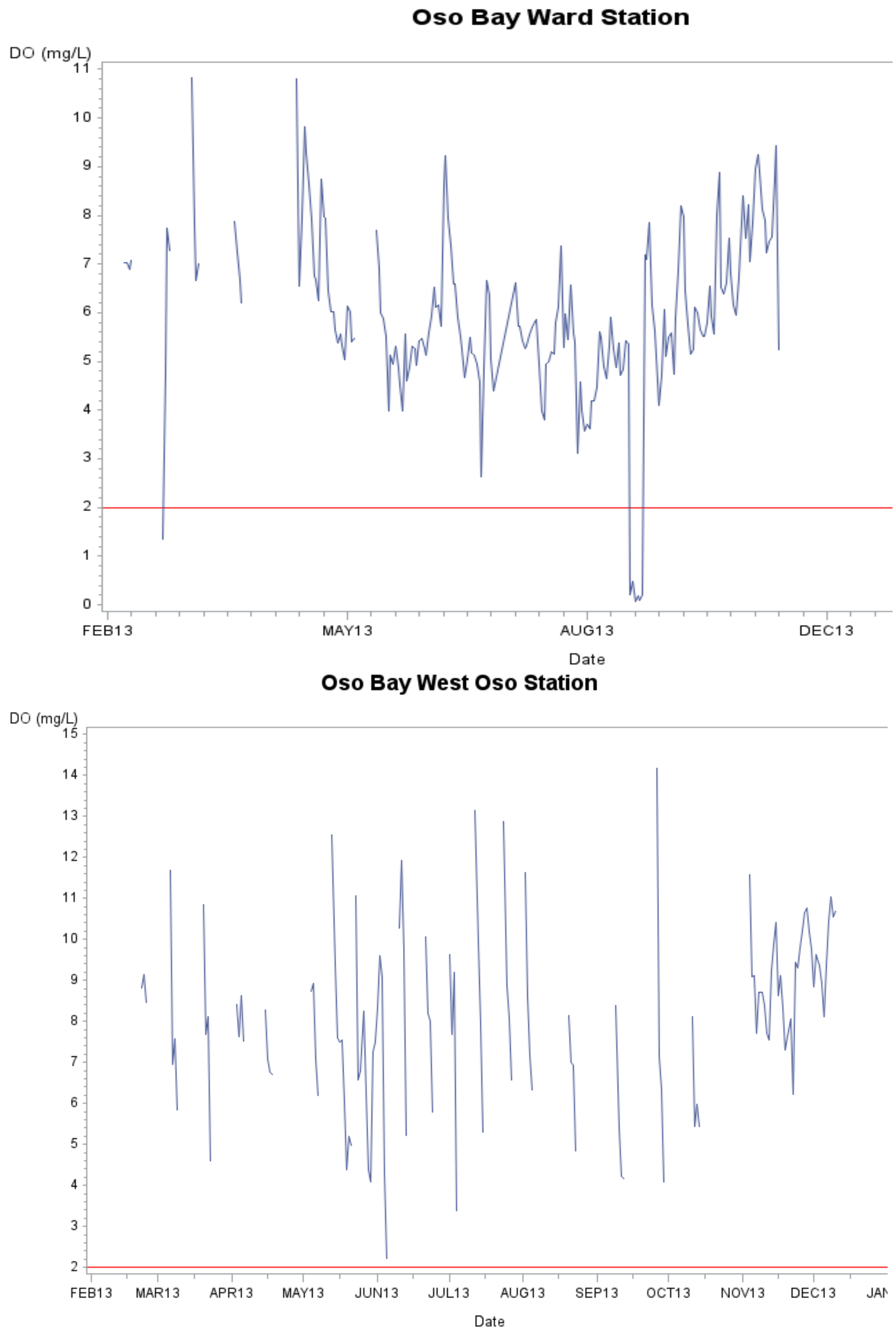


Figure 2: Averaged daily values for DO concentrations at each station. Starting at the upper left and moving from left to right, stations are Hwy 358, NAS, Oso Mouth Shallow, Oso Mouth Deep, Ward, and West Oso. Red line indicates oxygen minimum threshold of 2 mg/L.

Fluctuations in oxygen concentrations can be seen at each station in Figure 2, but their exact frequencies cannot be determined at a glance. Spectral analysis was used to determine what temporal changes were occurring. For each of the stations, a daily cycle of increase and decrease was seen in DO concentrations.

To explain the variance in DO concentration over time, a linear regression model was used. SAS 9.3 was used for all statistical analysis. The Durbin-Watson test was used to check for the presence of autocorrelation, which is common in time-series data. Each station had significant autocorrelation, with $p < 0.0001$ for all stations. To correct for autocorrelation, an autoregressive linear model was instead used to model fluctuations in DO. Daily averages were taken from the data and used in a stepwise autoregressive model using the maximum likelihood method. A diel cycle was identified in spectral analysis, and prior studies of Oso Bay and Corpus Christi Bay suggest additional fortnightly and lunar cycles in DO concentration (Nelson, 2012; Nicolau, 2001). To correct for cyclical variance within the model, a lag period of 15 days was used.

Principal components analysis was used to determine which variables had strong influences on DO concentration. pH, turbidity, depth, and continuous chlorophyll sampling did not strongly affect DO and were not used in the model. Conductivity and DO % saturation were correlated to salinity and DO concentration respectively, and were not used in the model. Date, temperature, and salinity were significant factors ($p \leq 0.01$), with exceptions when the model was ran for each station individually. Table 3 provides statistical information on the autoregressive model for Oso Bay and for each individual station. The regressive R^2 value is a measure of how well the model fits the data. The total R^2 is a measure of how well the model is able to predict the next value in the series.

Table 3: Autoregressive models for Oso Bay and each individual station.

	DF	Estimate	Standard Erro	t Value	Pr > |t|
Oso Bay, regressive R^2=0.6347, total R^2=0.9825					
Date	1	0.0241	0.0057	4.21	<0.0001
Temperature	1	0.8477	0.0143	59.23	<0.0001
Salinity	1	0.0344	0.0122	2.81	0.0049
Hwy 358, regressive R2=0.4743, total R2=0.9821					
Date	1	0.022	0.0138	1.6	0.1103
Temperature	1	0.6862	0.0394	17.43	<0.0001
Salinity	1	0.0635	0.0343	1.85	0.0642
NAS, regressive R2=0.4211, total R2=0.9853					
Date	1	0.0749	0.0397	1.89	0.0595
Temperature	1	0.7261	0.0304	23.87	<0.0001
Salinity	1	-0.012	0.0213	-0.56	0.5735
Oso Mouth Shallow, regressive R2=0.4863, total R2=0.9866					
Date	1	0.0791	0.0208	3.81	0.0001
Temperature	1	0.6805	0.0297	22.94	<0.0001
Salinity	1	0.0364	0.0231	1.58	0.1148
Oso Mouth Deep, regressive R2=0.4637, total R2=0.9806					
Date	1	0.0345	0.0272	1.27	0.2045
Temperature	1	0.6946	0.0402	17.27	<0.0001
Salinity	1	0.0598	0.0345	1.74	0.0827
Ward, regressive R2=0.7280, total R2=0.9895					
Date	1	-0.0123	0.0258	-0.48	0.6335
Temperature	1	0.9239	0.0324	28.48	<0.0001
Salinity	1	0.0772	0.0275	2.81	0.0051
West Oso, regressive R2=0.9046, total R2=0.9840					
Date	1	0.0323	0.0138	2.34	0.0198
Temperature	1	0.9004	0.028	32.13	<0.0001
Salinity	1	0.1212	0.0256	4.73	<0.0001

ADCP data was collected and compiled for ease of statistical analysis. During the third deployment at the Oso Mouth station, the ADCP shifted on its mounting during its installation and as a result, accurate current data was only collected for the bottom 1.5 m of the station for the last two months of data collection. Current data for the top and bottom 0.5 m at the Oso Mouth station and the top and bottom 0.25 m at Ward was compiled into a current rose. The current roses (Figures 3 & 4) give velocities, direction of current flow, and the percent of deployment time each speed and direction took out of the whole.

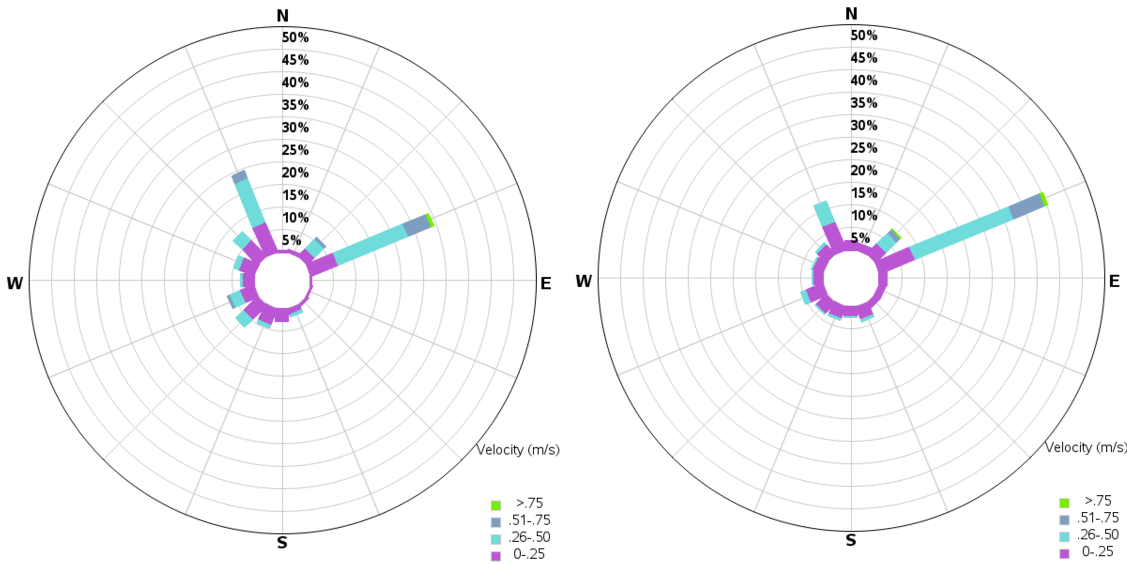


Figure 3: Current speed and direction for bottom (on left) and top (on right) 0.5 m at Oso Mouth station.

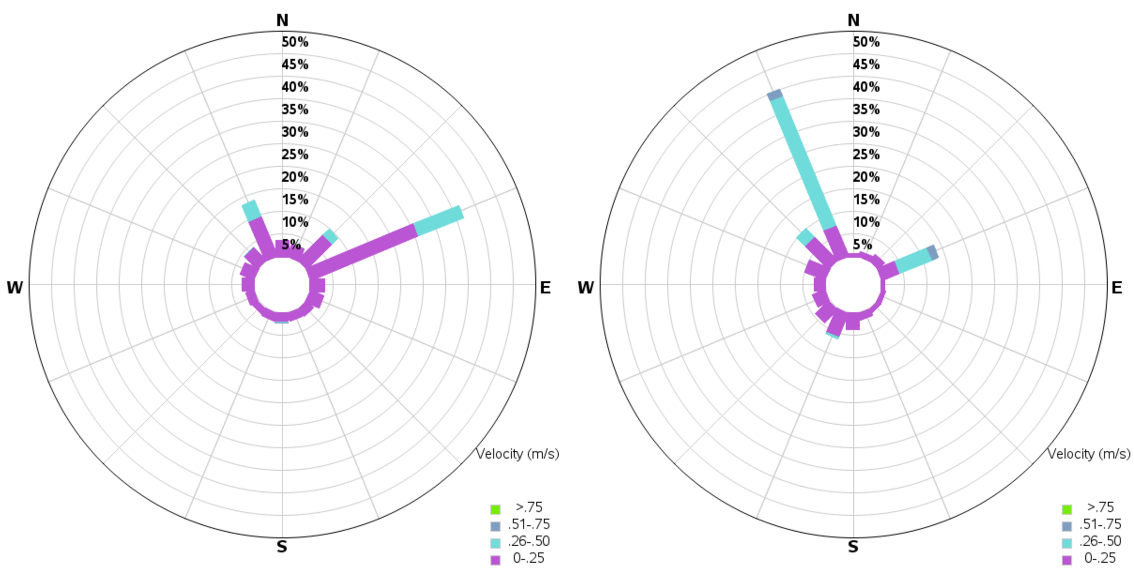


Figure 4: Current speed and direction for bottom (on left) and top (on right) 0.25 m at Ward station.

It is interesting to note that while the Oso Mouth current roses are mostly similar to each other at the top and bottom 0.5 m, the top 0.25 m differs from the bottom 0.25 m at Ward. There is a great deal more water flowing NNW at the surface than at the bottom, and at greater velocity too. This is likely due to the wind and the increased amount of fetch the Ward station faces when the wind blows from SSE.

A two-way ANOVA was used to analyze variance for chlorophyll, total suspend solids (TSS), volatile organic material (VOM), and nutrient grab samples. We were unable to collect grab samples for all of the stations on the same day, so the various dates were binned into deployments. Deployment and station then served as the two factors for analysis in the ANOVA. The results for chlorophyll, total suspended solids, volatile organic material, and nutrient concentration are shown in Table 4.

Table 4: ANOVAs for chlorophyll concentration, TSS, VOM, and nutrient concentrations

		ANOVAs for discrete samples				
	Factors	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Chlorophyll	Deployment	21	11283.22	537.3	11.31	< 0.0001
	Station	5	8986.32	1797.26	37.84	< 0.0001
	Deployment*Station	103	16391.37	159.14	3.35	< 0.0001
TSS	Deployment	20	698330.43	34916.52	31.54	< 0.0001
	Station	5	124469.96	24893.99	22.49	< 0.0001
	Deployment*Station	96	975958.63	10166.24	9.18	< 0.0001
VOM	Deployment	20	617.51	30.88	12.98	< 0.0001
	Station	5	67.27	13.45	5.66	< 0.0001
	Deployment*Station	96	778.33	8.12	3.41	< 0.0001
Nutrients	Deployment	19	32636.73	1717.72	472.17	< 0.0001
	Station	4	1027.15	256.79	70.59	< 0.0001

Analysis of variance revealed that there were significant spatial and temporal differences between group means for each of the grab samples collected. Variances between stations in chlorophyll and nutrient concentrations are unsurprising, due to the different physical and chemical factors each station undergoes, as are the variances brought on by time.

Discussion

During the course of this project, environmental data were sampled for a duration previously unseen in Oso Bay. Earlier studies (Nicolau, 2001) performed 24-hour monitoring of DO concentrations at locations near the Hwy 358 and Oso Mouth sites, but the addition of sampling stations in closer proximity to the wastewater treatment plant (OWTP) provides direct measures of its impact on the bay. The use of current profilers also provides important data about dispersion and flushing of water from the OWTP. Together, these data can help inform decision-making about the health of Oso Bay.

Temperature, salinity, and nutrient and chlorophyll concentrations are important factors to consider when interpreting DO concentrations in Oso Bay. The relationship between water temperature and oxygen concentration is well documented (Officer et al., 1984; Breitburg 1990; Paerl et al. 1998; Applebaum et al., 2005). As temperature increases, retention of DO in water decreases. The effects of increased water temperature on biomass are also known, with higher temperatures causing increased respiration by fish and benthic organisms alike (Randall et al., 1967; Robarts and Zohary, 1987; Ritter and Montagna, 1999;). Insolation, the transfer of heat energy from the sun to the water's surface, has also been shown to be an important factor influencing hypoxia, particularly diel cycles in shallow estuaries (Tyler et al., 2009). Increased insolation can decrease the concentration of DO in the water column, but it can also stimulate increased photosynthesis and respiration by phytoplankton as well (D'Avanzo and Kremer, 1994).

Salinity is important as well, but it doesn’t stratify in Oso Bay as would be seen in other bays, such as Corpus Christi Bay to the north (Nelson, 2012; Ritter and Montagna, 1999). Strong haloclines can prevent the mixing of the water column, dividing it into two distinct layers and trapping deoxygenated water on the bottom in shallow estuaries. (Buzzelli et al., 2002). There is one major source of saline input to the bay: periodic inputs of highly saline water from the Laguna Madre pulsed by the Barney Davis Power Plant (average salinity = ~36 ppt; http://www.gulfbase.org/bay/view.php?bid=laguna). However, the saline pulses from the power plant have their effects mitigated by the freshwater from Oso Creek. Oso Creek has a maximum permitted discharge flow of 2158.71 million L^3 per day into Oso Bay (Arismendez, 2010). In contrast, the average monthly discharge of hypersaline water from Barney Davis Power Plant from 1988 to 1992 was 1161.75 million L^3 per day, and this volume has decreased in recent years due to decreased electrical demand (Powell et al., 1997; Nelson, 2012). Mean salinity for the Highway 358 station (Table 1) is within 1-2 ppt of all the stations not in close proximity to the OWTP outfall. It can be hypothesized that the daily inflow of freshwater from Oso Creek is enough to offset any stratifying effects of the saline pulses from Barney Davis Power Plant.

Nutrient loads sharply decrease in concentration as water from the Blind Oso and the OWTP outfall disperses across the rest of the bay. Traveling from West Oso to the next closest station (Ward), PO_4, NH_4, and NO_x concentrations all drop by 66% or more (Table 1). Little to none of the original nitrogen and phosphorus input is transported to the interface of Corpus Christi Bay, which has average nitrogen and phosphorus concentrations of ~0.56 mg/L and 1.5 mg/L, respectively (Nelson, 2012). It is likely that the large quantities of nutrients in Oso Bay are being metabolized by plankton or sinking into the sediment.

The large phytoplankton populations seen in Oso Bay play an important role in the ecology of the bay. Chlorophyll-α concentrations are highest at West Oso and Ward, likely due to those stations' close proximity to the OWTP outfall, but average values at the other stations also exceed or come close to criteria of 11.6 µg/L set by TCEQ (Texas Surface Water Quality

Standards, section 307.10, Appendix F), as seen in Table 1. Wastewater treatment plant outfalls are rich in nitrogen and phosphorus, two limiting elements in the growth of phytoplankton and other primary producers, facilitating large blooms that can persist for long periods of time (Dunstan and Menzel, 1971). In turn, diel-cycling hypoxia has been linked to respiration of phytoplankton and bacteria, occurring between the hours of 2 A.M. to 10 A.M (Tyler et al., 2009). In Oso Bay, analysis of variance for hypoxia at specific hours of the day revealed no significant differences between each hour in terms of hypoxic episodes. However, even when lacking a specific timeframe for hypoxia to occur in, similar patterns are observed in both Oso Bay and the estuary studied in Tyler et al. (2009). Inability to pinpoint peak hypoxic hours in this study could be a result of data gaps resulting from fouling.

Bacterial decomposition of large phytoplankton populations are known to deplete bottom-water DO concentrations (Baird et al., 2004). But the same large blooms that facilitate hypoxia may also be responsible for the re-aeration of the water column. Studies of diel-cycling hypoxia in shallow-water estuaries have experimentally demonstrated that the oxygen concentrations produced by phytoplankton photosynthesis and respiration are high enough to re-aerate bottom waters in shallow estuaries. Kemp and Boynton's measurements of DO transport in waters of 0-4m in depth showed phytoplankton capable of generating 2 to 3 mg/L of DO while actively photosynthesizing (Kemp and Boynton, 1980). In the Childs River and Waquoit Bay, phytoplankton generated 10-15 mg/L of DO during photosynthesis and respiration (D'Avanzo and Kremer, 1994).

There are areas of Oso Bay where hypoxic episodes persist for greater lengths of time than a diel-cycle would allow. Graywater runoff from the Oso Bay Municipal Golf Course, located in the Blind Oso to the north, and the confluence of the OWTP outfall and Oso Bay have both demonstrated DO concentrations of < 2 mg/L for long periods of time (M. Wetz, personal correspondence, 2014). The factors influencing the change in DO cycling and respiration at these locations are not fully understood yet, and require further study.

Oso Bay is a challenging environment for continuous data collection. Large quantities of organic detritus in the water column provide a ready food source for barnacles willing to settle on practically anything solid, and algae will accumulate wherever the barnacles disdained to. Naturally, this fouling casts doubt on the accuracy of any data logged by optical sensors, and respiration of fouling organisms on DO sensors can skew oxygen concentrations towards lower values. We took steps to limit these sorts of inaccuracies when data were being collected by replacing deployed sondes with calibrated, cleaned sondes every 10-14 days. Even this brief span in the field was not enough to wholly solve the problem of fouling and bioaccumulation, but shortening deployment time in the field even further was prohibitive in terms of both time cost and labor.

For data processing, we chose to be as conservative as possible to forgo any erroneous conclusions. Sondes that did not pass a postcalibration check within a 10% margin of error only had the first three days of their deployment data used in analysis. These gaps can be seen in data from every station, and at the West Oso station in particular. Much of the raw data collected at the West Oso station don't greatly deviate from the cycles seen at the other stations, but since its accuracy cannot be verified it cannot be used in analysis.

The OWTP is a dominant factor in driving the hydrology and nutrient loading of Oso Bay. The nutrients it discharges facilitate large phytoplankton blooms, which in turn influence DO concentrations through daily respiratory cycles. This study has taken the first steps in understanding the environment and ecology of Oso Bay, but work remains to be done. The impact of daily hypoxic episodes on the benthos and macrofauna of Oso Bay has not been researched, and may provide future avenues for study. Finally, Oso Bay should be carefully monitored to ensure anthropogenic inputs do not further damage a stressed environment.

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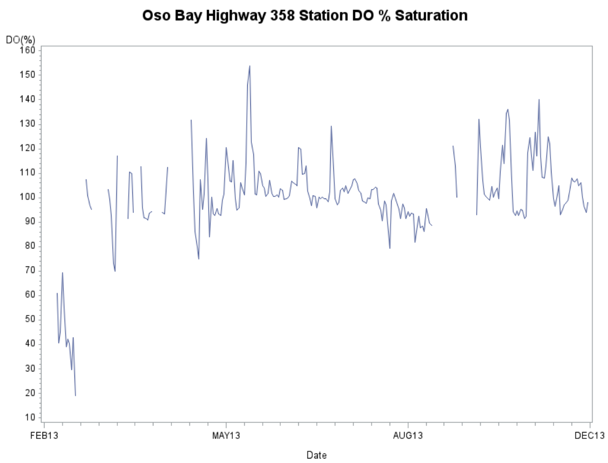
Appendix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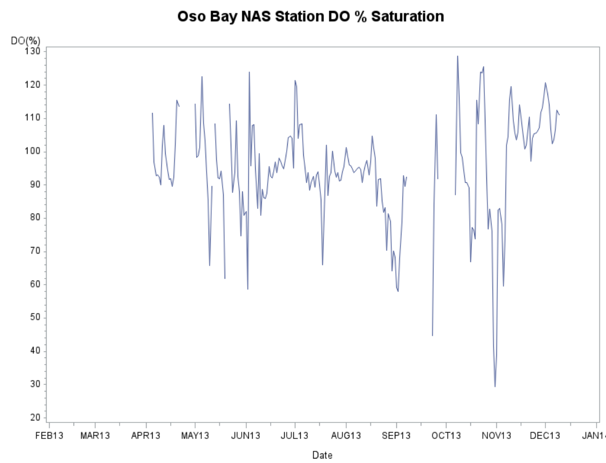
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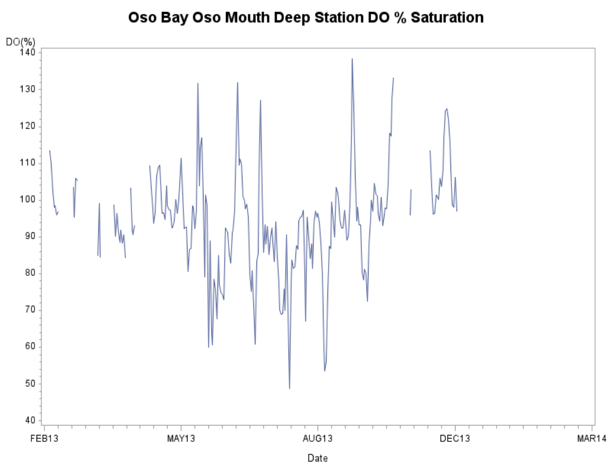
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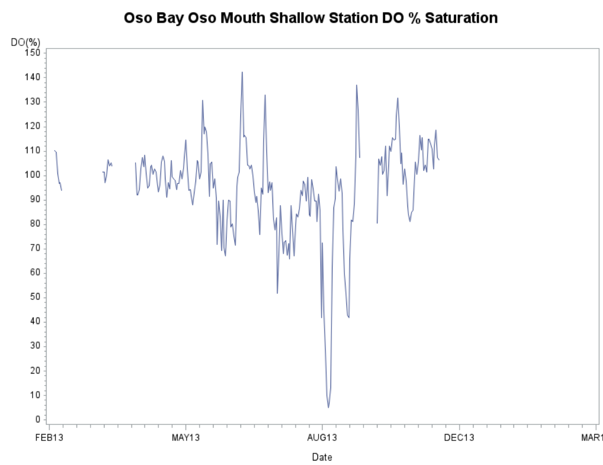
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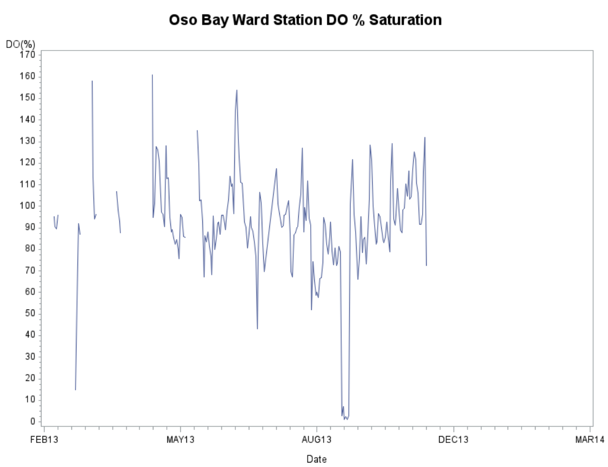
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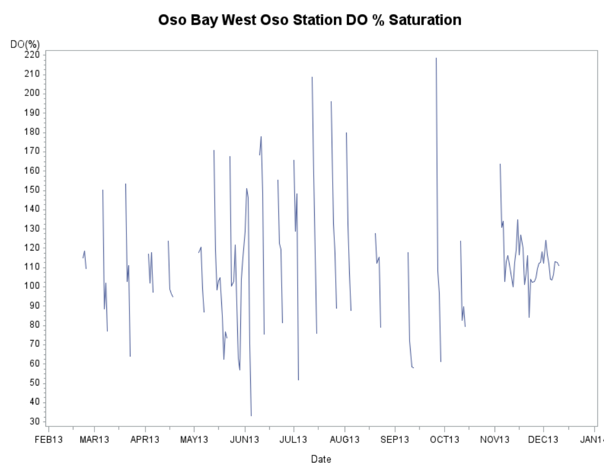
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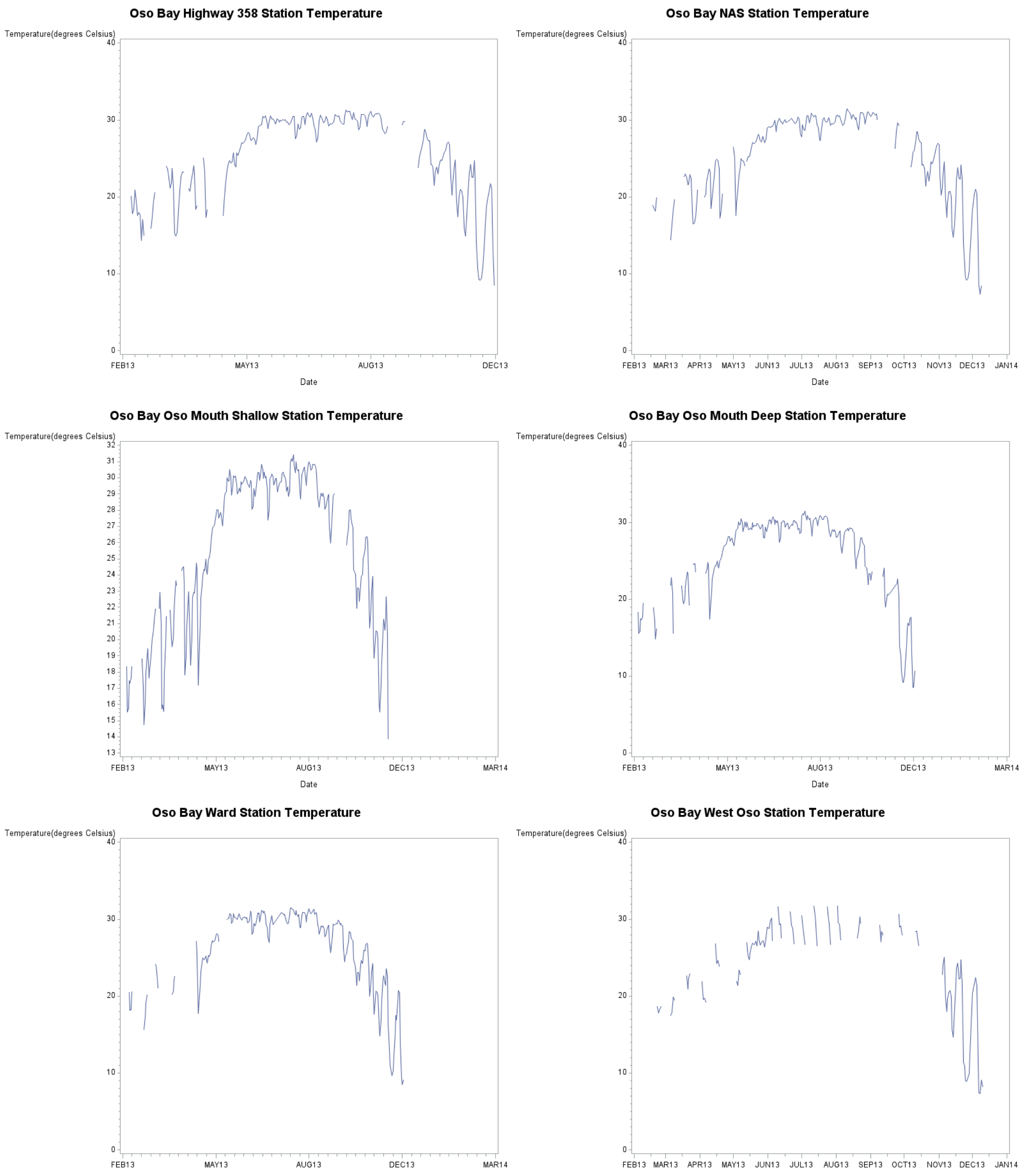
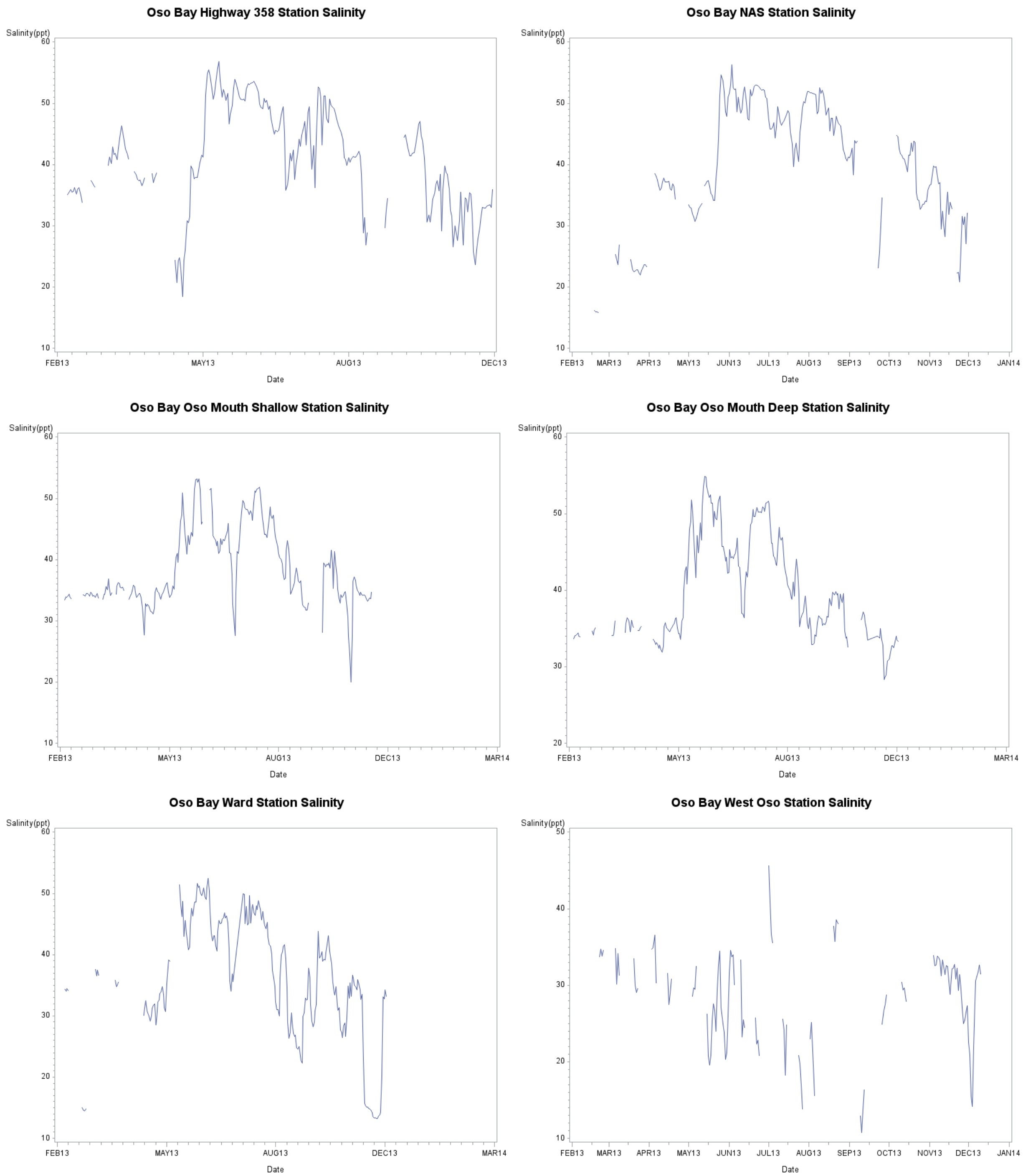
FEB13 MAR13 APR13 MAY13 JUN13 JUL13 AUG13 SEP13 OCT13 NOV13 DEC13 JAN14
Date

Appendix Figure 1: DO saturation average daily value plots for each station. Starting at top left and moving left to right, stations are Hwy 358, NAS, Oso Mouth Shallow, Oso Mouth Deep, Ward, and West Oso in lower right.

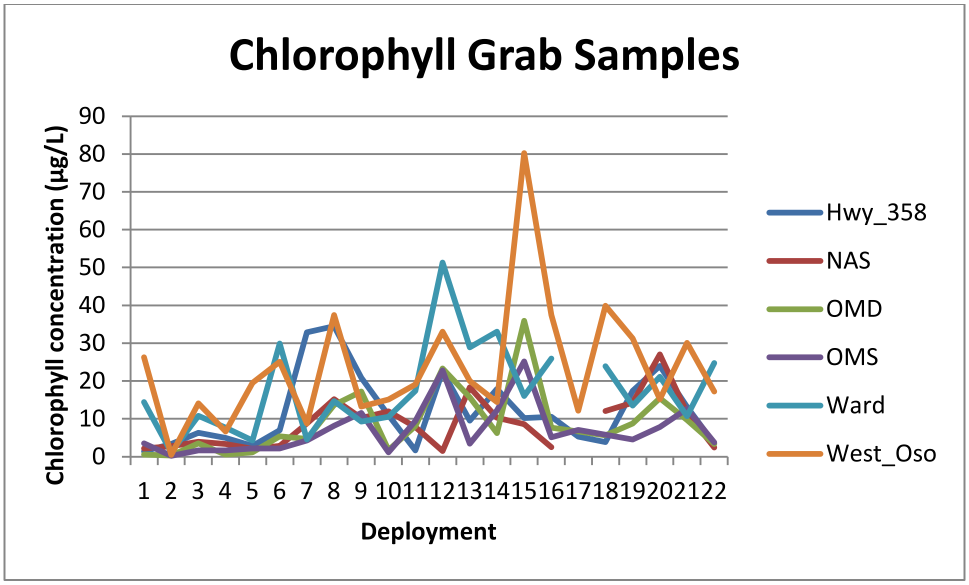


Appendix Figure 2: Temperature average daily value plots for each station. Starting at top left and moving left to right, stations are Hwy 358, NAS, Oso Mouth Shallow, Oso Mouth Deep, Ward, and West Oso in lower right.

Appendix Figure 3: pH average daily value plots for each station. Starting at top left and moving left to right, stations are Hwy 358, NAS, Oso Mouth Shallow, Oso Mouth Deep, Ward, and West Oso in lower right.



Appendix Figure 4: Salinity average daily value plots for each station. Starting at top left and moving left to right, stations are Hwy 358, NAS, Oso Mouth Shallow, Oso Mouth Deep, Ward, and West Oso in lower right.



Appendix Figure 5: Averaged values of chlorophyll grab samples for each binned deployment.