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The Effects of Tropical Storms and Hurricanes on Phytoplankton and Nutrient Concentrations in Wetland-Estuary Transition Zones along the Gulf Coast

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THE EFFECTS OF TROPICAL STORMS AND HURRICANES ON PHYTOPLANKTON AND NUTRIENT CONCENTRATIONS IN WETLAND-ESTUARY TRANSITION ZONES ALONG THE GULF COAST

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I would like to dedicate this paper to my loving family, my mom, my dad, and my sister, without whose support I would not have been able to accomplish this. All the research trips that they accompanied me on, the field research that they assisted me with, I owe them so much. Last and definitely not least my, heavenly Father, who gave me the idea for this project. When I had no idea what I wanted to do, He showed me. His undying faith in me is unfathomable. Thank you.

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Abstract

Two consecutive storms made landfall along the Northern Gulf of Mexico in June and August 2012 (Tropical Storm Debby, 06/26/2012; Isaac, 08/28/2012, Category (Cat) 1 Saffir-Simpson Hurricane Scale). Each storm passed within 48 to 273 km of one of seven wetland-estuary transition zone sampling sites, and indirect storm effects associated with changes in freshwater discharge and an influx of inorganic nutrients were observed at five of the seven sites. To assess the impacts of the 2012 hurricanes on hydrology, nutrient concentrations, and phytoplankton concentrations at transition zones along the Gulf Coast, a within-sites analysis along with a seasonal analysis were conducted to differentiate between seasonality and any perturbations caused by storm effects at each site. Along with the within-sites analysis, a between-site analysis was also conducted to distinguish any consistent trends among sites after the passing of a storm. Finally, to better understand the status of nutrient limitation at each site, enrichment experiments were conducted, with an emphasis on phosphorous and nitrogen, to determine the limiting nutrient. The results of the before-and-after nutrient analysis were generally consistent, with nitrate, phosphate, silicate, and ammonium levels decreasing, and chlorophyll concentrations increasing, thus suggesting that the storm stimulated nutrient uptake and phytoplankton growth. However, at some sites low post-storm nutrient concentrations appeared to be part of a seasonal pattern of declining nutrient concentrations rather than the result of phytoplankton uptake stimulated by passage of the storms.

Chapter 1
Introduction and Literature Review

1.1. A Complex Relationship

Hurricanes and episodic storm events are common occurrences in wetland, estuarine, and coastal environments in the tropics and subtropics (Mallin et al. 1999; Paerl et al. 2001; Houston and Powell 2003; Mckinnon et al. 2003; Davis et al. 2004). Much infrastructural hurricane damage is associated with storm surge, and coastal wetlands are the first impediment to storm surge as hurricanes make landfall. The relationship between hurricane effects and wetlands is complex. The traditional rule of thumb is that each 14.5 km of wetlands reduces storm surge by 1 meter. This rule of thumb is based on a 1963 U.S. Army Corps of Engineers report, but the inland penetration of a storm surge is a very complex function of many variables (Corps of Engineers, 1963; Costanza et al., 2008) Wamsley et al. (2010) .

Because there is no barrier between coastal wetlands and the ocean, the potential impact of hurricanes on coastal wetlands is great. Prior research pertaining to the impacts of hurricanes on coastal wetlands has focused on storm-induced sedimentation (Reed et al., 2009; Turner et al., 2006; Turner et al., 2007), elevation change (Cahoon, 2006), or enhancement of wetland productivity (Conner et al., 1989). The impact of hurricanes on resource availability and the microbial communities in these ecotones is quite variable. The responses of wetlands to hurricanes are influenced by the environmental conditions preceding the storm, magnitude of the event (i.e., duration, wind strength, amount of precipitation, and proximity to the wetland), and post-storm climatic and environmental conditions (Tilmant et al. 1994; Mallin et al. 1999; Paerl et al. 2001; Davis et al. 2004;

Williams et al. 2008). There has been much research conducted on the ability of hurricanes to redistribute offshore sediments to coastal wetlands, the capacity of wetlands to act as a natural buffer against the impacts of storms on coastal communities, and indirect effects of episodic events on resource availability and microbial communities. On 29 August 2005, Hurricane Katrina made landfall as a category three storm, with sustained winds of 205 km/h, and produced 200–250 mm of rain along the Gulf Coast. Hurricane Rita followed on 24 September 2005. Turner et al (2006) conducted a study shortly after the flood waters accompanying Katrina and Rita receded. Their findings were a clear indication of the onshore movement of sediment by hurricanes in some areas. They observed an obvious layer of recently deposited mud, which was about 5 cm thick. (Turner et al., 2006) In 2007, a study was conducted that observed indirect storm effects associated with changes in freshwater discharge during an otherwise drought year. (Williams et al., 2007) Similar to this study, phytoplankton biomass increased significantly in the bay during storm-related freshwater discharge. However, at the same time a decrease was observed in the wetland mangrove ecotone from bloom conditions during the preceding drought. Another study conducted in 2012 revealed a decrease in Chl *a* in the water column, and no significant change in sediment Chl *a* following Hurricanes Gustav and Ike in September of 2008. (Galvin et al. 2012) The storm surge and strong winds that accompany a hurricane may disturb a wetland to the point that the phytoplankton communities within that system are exposed to variations in environmental conditions and the concentrations of inorganic nutrients that they utilize to carry out photosynthesis. These variations may be due to a post-disturbance changes in pH, salinity, or the amount of suspended sediments and nutrients in the water column.

This thesis describes a novel study in which the nutrient concentrations and some of the water quality characteristics within wetland waters were monitored prior to a hurricane and tropical storm as well as directly afterward. All of the sampling, analysis, and testing for this project were conducted along a timeline of 7 consecutive months. During the course of this project, several sample sites associated with four major bays along the Gulf Coast were visited monthly until a hurricane or tropical storm passed over the site or nearby. The preliminary observations were then recorded and statistically sorted within two weeks following the storm. Directly after the hurricane or storm, the sites closest to the path of the hurricane were revisited, and post-disturbance samples were taken, statistically analyzed, and the results compared to the pre-storm data from the same sites. To gain some insight into the degree of inorganic nutrient limitation of phytoplankton at each site, a series of nutrient enrichment experiments, with a main focus on phosphorous and nitrogen, was conducted. The nutrient analysis revealed distinct variations in the degree of phosphorous and nitrogen limitation at the sites.

1.2. The Storm Events

The 2012 Atlantic hurricane season was the third most active season on record. The hurricane seasons of 1887, 1995, 2010, and 2011 were equally active. In late June 2012, Tropical Storm Debby, the fourth storm of the season, brought extensive flooding to North Florida and the Florida Panhandle. Later, on August 21, Hurricane Isaac formed east of the Lesser Antilles. Although the storm remained relatively disorganized for much of its lifetime, Isaac still brought extensive flooding to the Gulf Coast. After becoming a Cat 1 hurricane on August 28, Isaac soon made landfall that same day in Louisiana, where it caused severe flooding associated with storm surge and rainfall.

1.2.1. Tropical Storm Debby (23 June 2012 to 27 June 2012)

Tropical Storm Debby developed from a trough of low pressure in the central Gulf of Mexico on 23 June 2012. Despite a projected track toward landfall in Louisiana or Texas, the storm headed in a different direction, moving slowly north-northeast and northeastward. On June 25, at approximately 5:00 am Central Daylight Time (CDT), Debby was located about 48 km south-southwest of Apalachicola, Florida, and had sustained winds of 72 km. The storm slowly strengthened, and at 1:00 pm CTD on June 25 attained its peak intensity, with maximum sustained winds of 100 km/h. At 4:00 pm CTD, the storm made landfall near Steinhatchee, Florida, approximately 154 km east of sites AB1 and AB2. (Figure 1.2.1a) Sustained tropical storm-force winds in association with Debby occurred over coastal portions of the Florida Panhandle through the Florida Big Bend on June 24–25. The highest 2-minute wind reported in this region was 72 km/h at Apalachicola, with gusts of 96 km/h. Debby produced two days of torrential rains across portions of the Florida peninsula, with central and north Florida receiving the bulk of the rainfall (Figure 1.2.1b). The highest storm total observed was near Curtis Mill in Wakulla County, where a local resident measured 731 mm. From Friday through Monday, Apalachicola recorded 322 mm of rainfall. On June 24, a record rainfall of 153 mm fell, breaking the old record of 80 mm set in 2002 (NOAA, 2012).

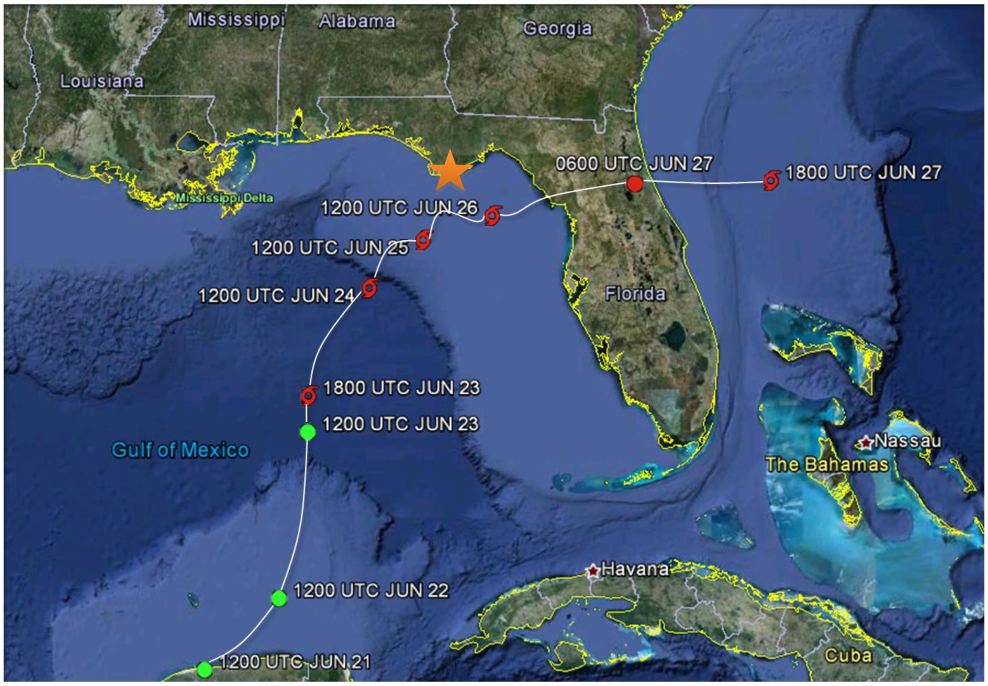

Figure 1.2.1a. Tropical Storm Debby Storm Track. The location of Apalachicola Bay sites AB1 and AB2 are indicated by the " ".

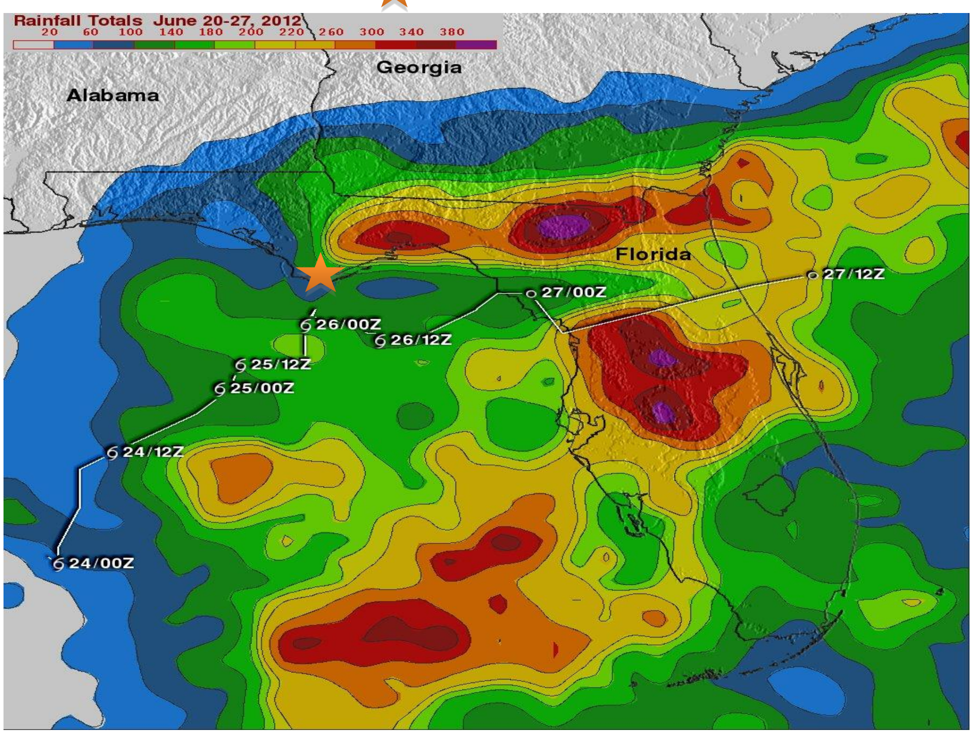

Figure: 1.2.1b. Tropical Storm Debby Rainfall. The location of Apalachicola Bay sites AB1 and AB2 are indicated by the " ".

1.2.2 Hurricane Isaac (21 August 2012 to 1 September 2012)

Hurricane Isaac (Cat 1) was a slowly moving storm that produced an immense amount of rain along the northern Gulf Coast in late August of 2012. The storm made its first U.S. landfall at 7:00 p.m. CDT on August 21, near the mouth of the Mississippi River, approximately 241 km east of Vermillion Bay (VB) and 274 km/h west of Mobile Bay sites MB1 and MB2 (Figure 1.2.2a). Because of its extraordinary wind speed of 80 mph, the hurricane produced a high storm surge along a long section of coastline (Figure 1.2.2d).

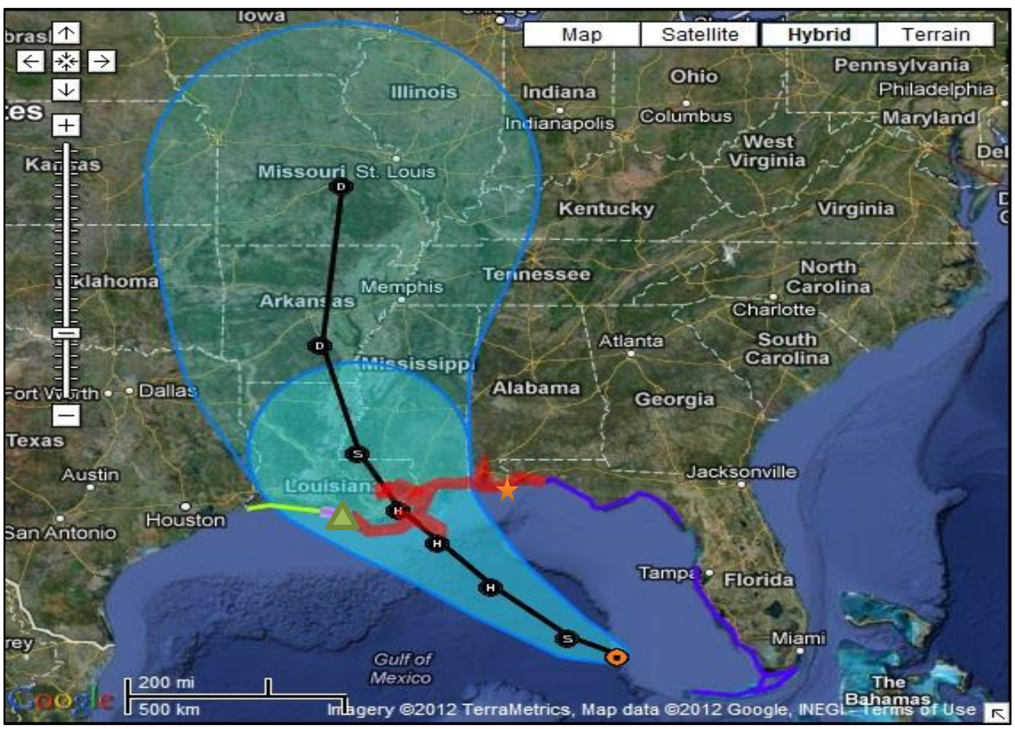

Figure 1.2.2a. Hurricane Isaac Storm Track. The locations of sites MB1, MB2, and VB are represented by " "," "," " respectively, relative to Hurricane's Isaac's track.

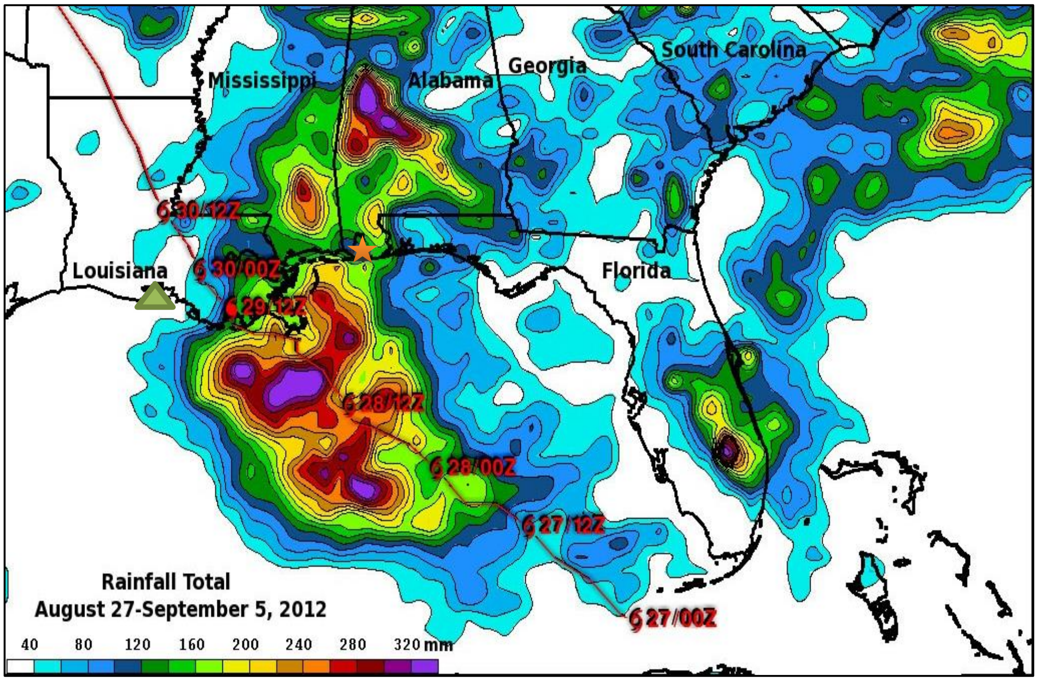

Figure 1.2.2b: Hurricane Isaac Rainfall. The locations of sites MB1, MB2, and VB are represented by " ", " " ," " , respectively.

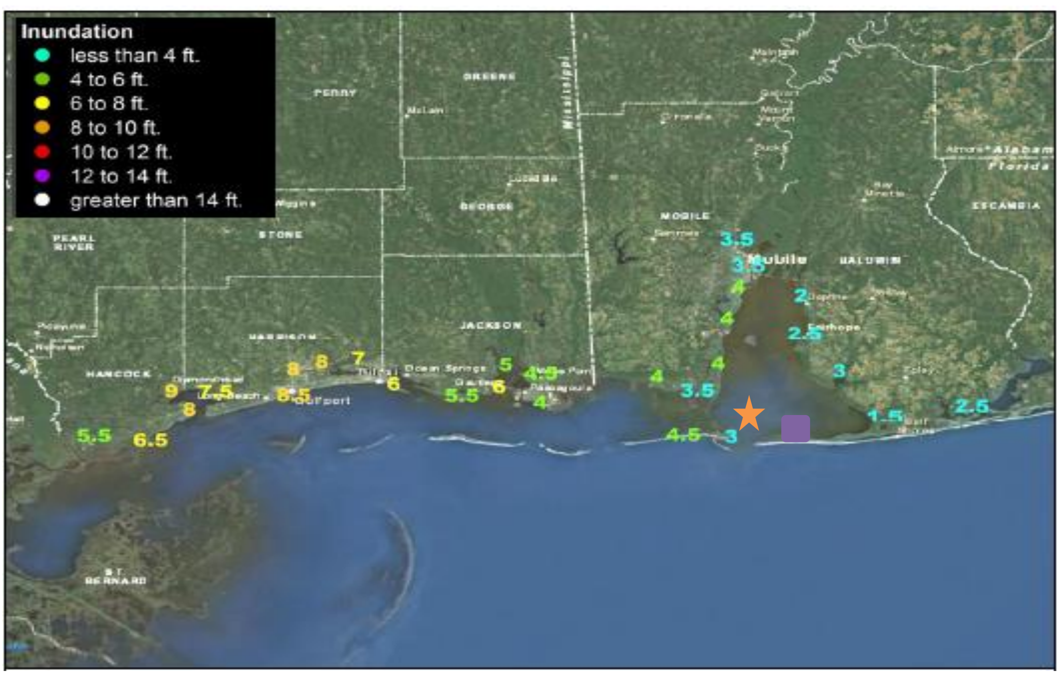

Figure 1.2.2c: Hurricane Isaac Inundation. The locations of sites MB1, and MB2 are represented by " ", " ", respectively.

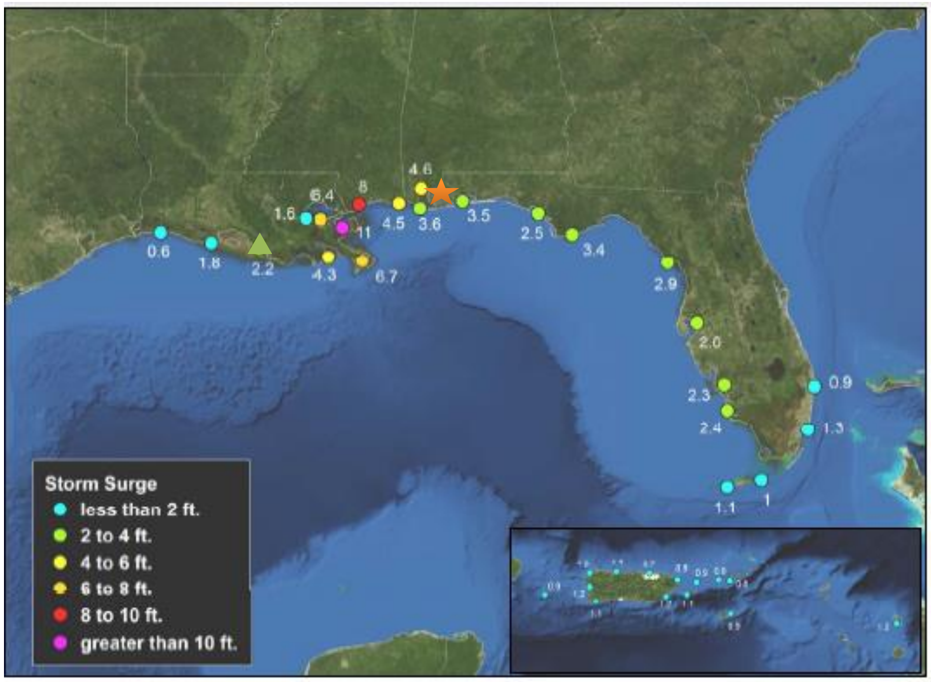

Figure 1.2.2d: Hurricane Isaac Storm Surge. The locations of sites MB1, MB2, and VB are represented by “ “,” “,” “respectively.

Chapter 2
Methods and Approaches

2.1 Sampling sites

Four main sampling sites and three sub-sites were chosen along the Gulf Coast, the main objective being to cover a large enough area to maximize the probability of intercepting the path of a hurricane or tropical storm. The first main site chosen was Galveston Bay (GB) in Texas, the site furthest to the west. The second main site further east was Vermillion Bay (VB) in Louisiana. Next was Mobile Bay (MB) in Alabama, and the final main site located furthest to the east was Apalachicola Bay (AB) in Florida. (Please see Figure 2.1.1.)

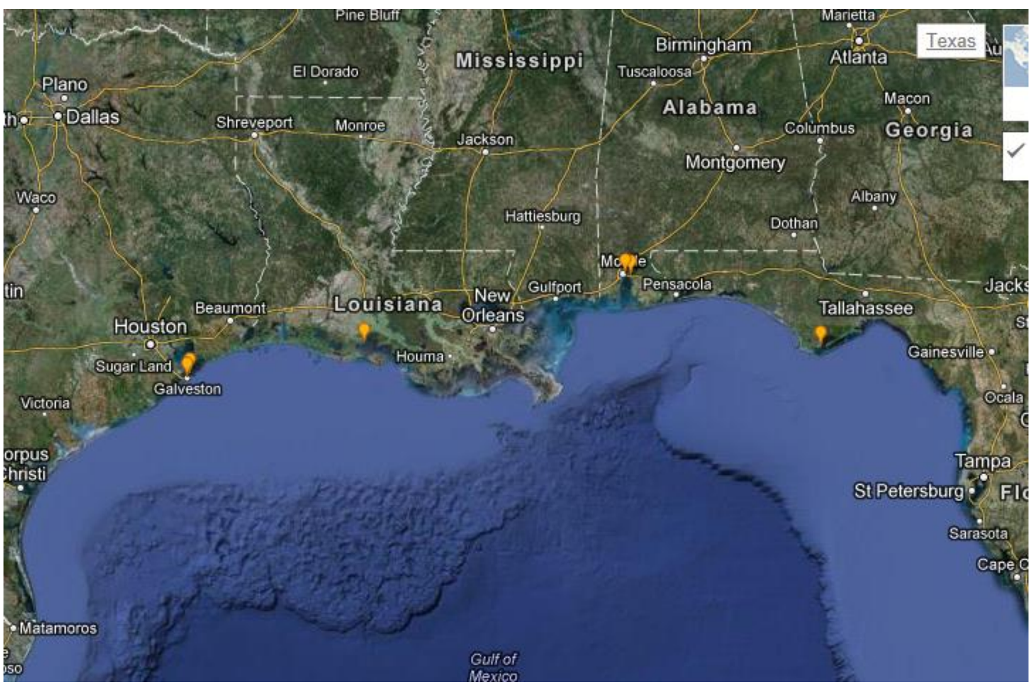

Figure 2.1.1.: Sampling Sites from left to right: GB1, GB2, VB, MB2, MB1, AB1, and AB2, These are now showing up as separate sites in the figure.

2.1.1 Galveston Bay (GB)

Galveston Bay is located near the major industrial complexes adjacent to Galveston Bay. Those complexes contribute substantially to pollution of the bay. Most of the pollution is the result of storm run-off from various commercial, agricultural, and residential sources. In recent decades, the enactment of conservation efforts has substantially improved water quality in the bay. Several different types of wetlands can be found in the Galveston Bay ecotone. As the bay bottom shoals near the shoreline, an emergent intertidal salt marsh borders the shore in high-salinity areas. The site chosen is associated with the Texas A&M at Galveston Wetland Center, which is located on the southwest edge of the bay.

2.1.2 Vermillion Bay (VB)

Vermillion Bay receives discharges from the Vermilion River and Bayou Teche. The upper portion of the watershed consists of alluvial ridges along Bayou Teche, prairies, and hills. The lower portion consists primarily of coastal marshes. Although the watershed is geologically stable and is expanding as a result of the emergence of the Atchafalaya River delta, the geomorphology and hydrology have been altered by the dredging of navigation channels and petroleum access canals and the construction of spoil banks and levees. The sampling site chosen in Vermillion Bay was an area along the Intracoastal Waterway where the Leland Bowman Lock is located. One of the primary purposes of the Leland Bowman Lock is to control the salinity of the water associated with that area and to prevent brackish water from the bay from contaminating rice paddies. The lock was damaged by a barge on September 30, 2011 and subsequently removed for repair. However, the inflow of saltwater into the Mermentau Basin as a

result of the removal of the lock threatened agricultural activities that were dependent on freshwater for irrigation. After a hurricane impacts the waterway, the US Army Corps of Engineers drains the waterway to combat saltwater intrusion. After Hurricane Gustav impacted Louisiana in early September 2008, the water was drained for a total of two months. Every morning the temperature and salinity of the water in the waterway are tested.

2.1.3 Mobile Bay (MB)

Mobile Bay is the sixth largest river basin in the United States and receives the runoff from approximately 75% of the state of Alabama, along with portions of Georgia, Tennessee, and Mississippi. Mobile Bay is an estuary where fresh water from streams and rivers meets and mixes with saltwater from the Gulf of Mexico. Estuaries like Mobile Bay play a critical role in protecting coastal communities from the forces unleashed by tropical storms. The coastal area of Mobile Bay has a long history of human misuse, ranging from garbage dumping during the civil war to current sewer overflows and dredging. The shallow depth of Mobile Bay, combined with the 37-km distance of the port from deep Gulf waters, has required major dredging projects since about 1830 to accommodate ocean-going vessels. Although these dredge channels greatly benefit water commerce, they may have serious environmental consequences. Channelization and spoil deposition from dredging projects may increase saltwater intrusion and turbidity, enhance flushing, alter tidal exchange and water circulation patterns, destroy submerged plants, and alter fish behavior and abundance. The increased frequency of natural disasters in recent years has affected the bay's ecosystem. The site chosen was along the I-10 Bridge that crosses the bay.

2.1.4 Apalachicola Bay

The Apalachicola–Chipola Basin encompasses approximately 7,941 km^2 and a complex hydrologic system. Ecosystems of the Apalachicola drainage basin include upland forests, swamps, marshes, and floodplain wetlands. The sections of the watersheds from the Florida panhandle to Mobile Bay support some of the richest biodiversity in all of North America. Increased demand for water by large upstream cities such as Atlanta have promoted engineering and water management projects that now divert freshwater resources from the Apalachicola-Flint-Chattahoochee river system. In addition, agriculture extracts well over 300 million gallons per day for irrigation.

2.2 Sample Dates

The sampling sites are hereafter denoted as follows: Galveston Bay, GB; Vermillion Bay, VB; Mobile Bay, MB; Apalachicola Bay, AB. Each site was visited monthly for 2–3 months prior to the hurricane and storm to provide adequate data for a pre-disturbance analysis. The first visit took place on April 29, 2012 at sites MB and AB. The second visit took place on May 14, 2012 and May 15, 2012, at sites GB and VB, respectively. The third visit took place on May 24, 2012 and May 25, 2012, at sites AB1 and MB1, respectively. During this third visit, two new sub-sites were chosen, both within 3 km of the original sites at both AB and MB. The reason that these sub-sites were chosen was to check the reproducibility of the data. These sub-sites will be denoted as AB2 and MB2 and the original sites as AB1 and MB1 hereafter. The fourth visit took place on June 17, 2012. On this date GB was revisited, along with a sub-site approximately 16 km from the original site. (See Table 2.2.1 below)

Table 2.2.1 Fair Weather Dates and Storm Dates in 2012

Fair Weather Dates and Storm Dates in 2012			
Sampling Dates	Site	North Laitude	West Longitude
April 29, 2012	AB1	29.74	87.99
April 29, 2012	MB1	30.67	87.92
May 14, 2012	GB1	29.31	94.80
May 15, 2012	VB	30.22	92.66
May 24, 2012	AB1	29.74	87.99
May 24, 2012	AB2	30.72	84.36
May 25, 2012	MB1	30.67	87.92
May 25, 2012	MB2	27.73	87.99
June 17, 2012	GB1	29.31	94.80
June 18, 2012	GB2	29.32	94.77
June 21, 2012	VB	30.22	92.66
Tropical Storm Debby June 26, 2012		26.67	83.39
June 29, 2012	AB1	29.74	87.99
June 29, 2012	AB2	30.72	84.36
July 1, 2012	MB1	30.67	87.92
July 1, 2012	MB2	27.73	87.99
August 26, 2012	VB	30.22	92.66
August 27, 2012	MB1	30.67	87.92
August 27, 2012	MB2	27.73	87.99
Hurricane Isaac August 29, 2012		29.11	90.19
September 3, 2012	VB	30.22	92.99
September 4, 2012	MB1	30.67	87.92
September 4, 2012	MB2	27.73	87.99

Site GB2 was located right along the beach. It consisted of a wetland separated by a sandbar. This sub-site was visited on June 18, 2012. The fifth trip was to site VB on June 21, 2012. VB was the only site for which a sub-site was not chosen due to the difficulty of access. The sixth trip was taken on June 29, 2012, just three days after Tropical Storm

Debby made landfall in Steinhatchee, FL. Steinhatchee is a coastal community in the southern part of Taylor County, FL located approximately 160 km east of Apalachicola. On June 29, 2012, sites AB1 and AB2 were visited and post-disturbance data were collected. There was an obvious difference in the water at both sites compared to the previous samples. The water level was at least 30 cm higher, and the water had a distinct greenish hue to it. On July 1, 2012 sites MB1 and MB2 were visited. In the wake of Hurricane Isaac, site VB was revisited a third time on August 26, 2012, and MB1 and MB2 on August 27, 2012, and again after the storm on September 3 and 4.

2.3 Preliminary Data Collection

2.3.1 Measurements of Nutrient Concentrations, Chl *a* and Parameters of Interest

Preliminary tests for all parameters of interest were run on the water samples immediately upon return to the lab. Nutrient concentration assays required water to be filtered in the field using a filter apparatus that consisted of a hand-operated vacuum pump, 36 cc, which was used to filter water into a 1000-ml Erlenmeyer flask. The filtrate was then immediately transferred to a 1-liter brown plastic bottle and kept on ice until assays could be performed. This method was used at each site during each visit. One to two liters were filtered, depending upon the rate at which the water could be filtered through the 47-mm glass microfiber filters with a porosity of 1.6 microns. Sample water taken to determine Chl *a* concentrations was filtered through Whatman 25-mm glass fiber filters with a porosity of 0.7 microns to detain phytoplankton. Those filters were then wrapped in foil and keep on ice until returning to the lab. Six to nine 1-liter bottles were filled with unfiltered sample water and kept on ice until returning to the lab. Upon returning to the lab, each parameter of interest was measured and recorded. The pH of

each sample was obtained with a Portable Refractometer, Model #RF20. A portable refractometer was used to measure salinity, which in turn was needed to measure the initial oxygen concentration in each sample. During the course of obtaining biochemical oxygen demand (BOD) measurements, each sample was put into a 300-ml BOD bottle, and a YSI Model 51B Oxygen Meter was used to obtain the initial measurement. The BOD bottles were then incubated in a covered water bath at 20°C for five days. The final concentration was then measured, and the BOD was determined by subtracting the final concentration from the initial concentration.

Soluble reactive phosphorous (SRP), reactive silicate, nitrate, and ammonia were determined by the method described by Strickland and Parsons (1965). The concentrations of inorganic nutrients were measured if they were above the limit of detection for each method. The limit of detection when referring to inorganic nutrients is the smallest concentration that can be measured with reasonable certainty, based on the method of analysis (Thomsen et al. 2003). Silicate analysis was carried out by allowing the water sample to react with molybdate under conditions that resulted in the formation of silicomolybdate, phosphomolybdate, and arsenomolybdate complexes. A reducing solution of metol and oxalic acid was added to reduce the silicomolybdate complex, yielding a reduction compound. The reducing solution also decomposed the phosphomolybdate and arsenomolybdate to prevent any phosphate or arsenate interference. The extinction was measured at 8100 Å using a Varian Cary 50 WinUV spectrophotometer. Phosphate analysis involved allowing the water sample to react with a composite reagent of molybdic acid, ascorbic acid, and trivalent antimony. The resulting complex heteropoly acid was reduced to create a blue solution whose extinction was

measured at 8850 Å. Nitrate analysis was carried out by reducing the nitrate in a water sample to nitrite by passing the water sample through a column of granulated copper-cadmium filings. This process allowed detection of nitrate plus nitrite (hereafter nitrate). The nitrite produced by this oxidation-reduction reaction was determined by diazotizing sulphanilamide and combining it with N-(1-napthyl)-ethylenediamine to form a pink solution whose extinction was measured at 5430 Å. Determination of ammonia-ammonium (hereafter ammonia) was conducted by treating the water sample in an alkaline citrate medium with sodium hypochlorite and phenol. Sodium nitroprusside acts as a catalyst to form a blue solution. The extinction was read at 6400 Å. Ammonia concentrations were measured at sites VB, MB1, and MB2. Tropical storm Debby had already affected sites AB1 and AB2 when the decision was made to include ammonia in the inorganic nutrient analysis. The 25 mm filters containing the chl *a* were removed from the foil and placed in a centrifuge tube with enough 90% acetone solution to submerge the whole filter to extract the pigments from the cells and were kept in a refrigerator until ready to process. The filters were then placed in test tubes, and ground up using a Teflon tissue grinder. This solution was then filtered back into centrifuge tubes using a GF/F filter to remove all of the filter paper from the sample. A spectrophotometer was used to detect light absorbance by the chlorophyll. The extinction was read at 750 nm (turbidity correction) and 665 nm.

2.4 Enrichment Experiments

The role of limiting nutrients, such as nitrogen (N) and phosphorus (P), in regulating the structure and function of aquatic and terrestrial ecosystems has long been the subject of biogeochemical and ecological study (Schlesinger 1997). To determine the limiting

nutrient at each site and to better understand the dynamics within each wetland, enrichment experiments were conducted on sample water that had been taken in June and July. Nutrient enrichment bioassay experiments involved assessment of phytoplankton growth responses to additions of N and P. For each experiment, 100 ml of sample water from each site was filtered through a 47-mm glass fiber filter (1.6-μm porosity) to remove zooplankton and then stored in four 16-ml test tubes. Each tube was then inoculated with an aliquot from the sample water. There were four treatments for each site: a control that received no added nutrients, a P-enriched treatment, an N-enriched treatment, and a treatment that received both N and P additions. The N and P were added at concentrations specified for f/2 medium (Guillard & Ryther 1962, Guillard 1975), 882 μM for nitrate and 36 μM for phosphate. The tubes were incubated at a temperature of approximately 20°C with illumination of approximately 200 μmol photons m^{-2} s^{-1} of 400–700 nm radiation provided from fluorescent lights. Each tube was then read on the spectrophotometer at a wavelength of 750 nm each day for 12 days at a recorded time, and the optimal density (OD) readings recorded. A wavelength of 750 nm was used because there is no absorption by photosynthetic pigments at this wavelength, so the attenuation of light is due entirely to scattering (Strickland and Parsons 1965). These OD readings were monitored until the concentrations began to level off. The asymptotic value of the OD readings was determined by fitting a logistic growth model to the data. The asymptote was taken to be a measure of the yield in each treatment.

Chapter 3
Results

3.1 Comparisons of all Affected Sites

An analysis of nutrient and chlorophyll concentrations was conducted at all of the sites together to determine whether there were patterns between pre-hurricane and post-hurricane concentrations across all sites. This analysis included data from Tropical Storm Debby and Hurricane Isaac. All pre-storm dates were grouped together and compared statistically to the post-storm dates by running a variety of statistical tests. Both parametric and non-parametric tests were used. The reason that both kinds of tests were used was to determine if all the tests would agree with one another and if not, to decipher why. The parametric tests that were used were an Analysis of Variance (ANOVA) and a paired *t*-test. These parametric tests were thought to be the stronger, in that if a significant difference truly did exist, they would be more likely to detect it. The non-parametric tests that were used were a Kruskal Wallis (KW) test and a paired signs test.

3.1.1 Phosphate Concentrations

A comparison of all pre-hurricane phosphate concentrations to post-hurricane concentrations revealed an obvious pattern. Post-hurricane concentrations were lower than pre-hurricane concentrations. Table 3.1.1 displays the results of all of the statistical test analysis of the pre-hurricane and post-hurricane concentrations. Figure 3.1.1 displays the resulting bar graph. The ANOVA and Paired t-test did not detect a significant difference while the KW and Signs test both resulted in the rejection of the null hypothesis. The conclusion is that post-hurricane phosphate concentrations were significantly lower than pre-hurricane concentrations.

Table 3.1.1 All statistical test results for the analyses of pre-hurricane and post-hurricane phosphate concentrations at all affected sites (AB-Debby, MB1-Isaac, MB2-Isaac, and VB-Isaac)

Test	Type	*p* value	Accept or Reject Ho
ANOVA	parametric	0.14	Accept
Paired t-test	parametric	0.2	Accept
Kruskal - Wallis	non-parametric	0.027	Reject
Sign	non-parametric	0.00024	Reject

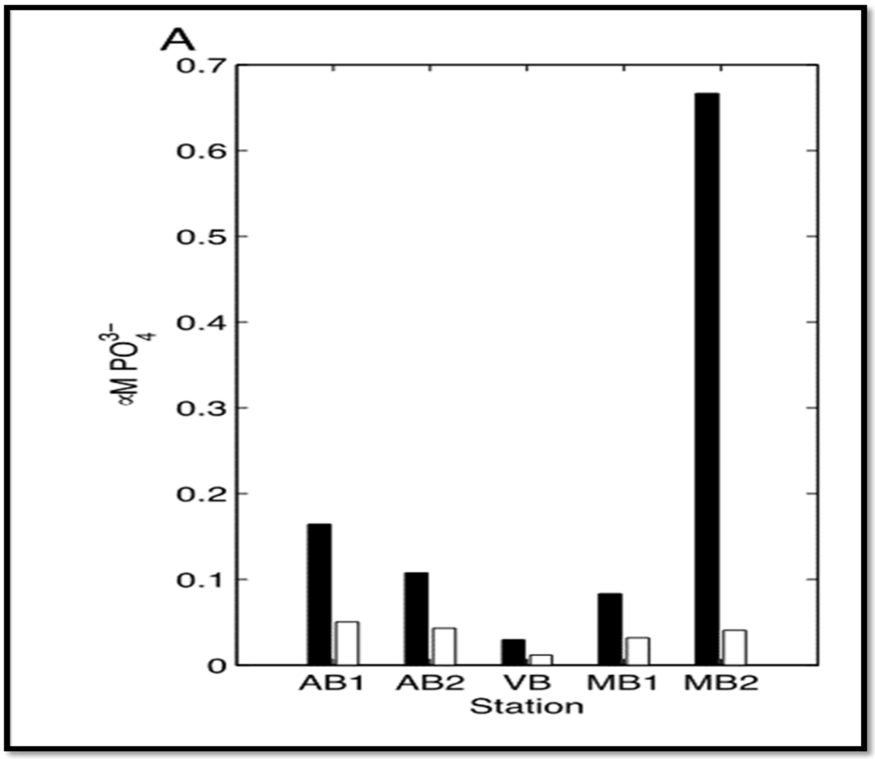

Figure 3.1.1. Bar graph of phosphate concentrations at sample sites. Solid and open bars are pre-hurricane and post-hurricane concentrations, respectively.

In this case, the non-parametric teste detected significant difference in phosphate co centration data. The ranks in the data are consistent. Some of the assumptions of the parametric test seem to be violated, for the example, the assumption of equal variances. The data from site MB2 is acting as an outlier.

3.1.2. Nitrate Concentrations

A comparison of all pre-hurricane nitrate concentrations to post-hurricane concentrations also revealed a pattern. Post-hurricane concentrations were lower than pre-hurricane concentrations. Table 3.1.2 shows the results of all of the statistical test analysis of the pre-hurricane and post-hurricane concentrations. The results for the parametric and non-parametric test were inconsistent. Figure 3.1.2 shows the resulting bar graph. The conclusion from the signs test and paired *t*-test is that post-hurricane nitrate concentrations were significantly lower than pre-hurricane concentrations.

Table 3.1.2 All statistical test results for the analyses of pre-hurricane and post-hurricane nitrate concentrations at all affected sites (AB-Debby, MB1-Isaac, MB2-Isaac, and VB-Isaac)

Test	Data	*p* value	Accept or Reject Ho
ANOVA	parametric	0.24	Accept
Paired t-test	parametric	0.02	Reject
Kruskal - Wallis	non-parametric	0.22	Accept
Sign	non-parametric	0.00024	Reject

In this case, there is no clear indication of which test (parametric or non-parametric) are stronger for detecting any significant difference. The ANOVA and Kruskal - Wallis test appear to be less capable of detecting significant differences in the case of pre vs post nitrate concentrations. There is a possibility the noise in the data disrupted the ANOVA and Kruskal – Wallis test. Ranks of pre storm concentrations are intermixed with ranks of post storm concentrations.

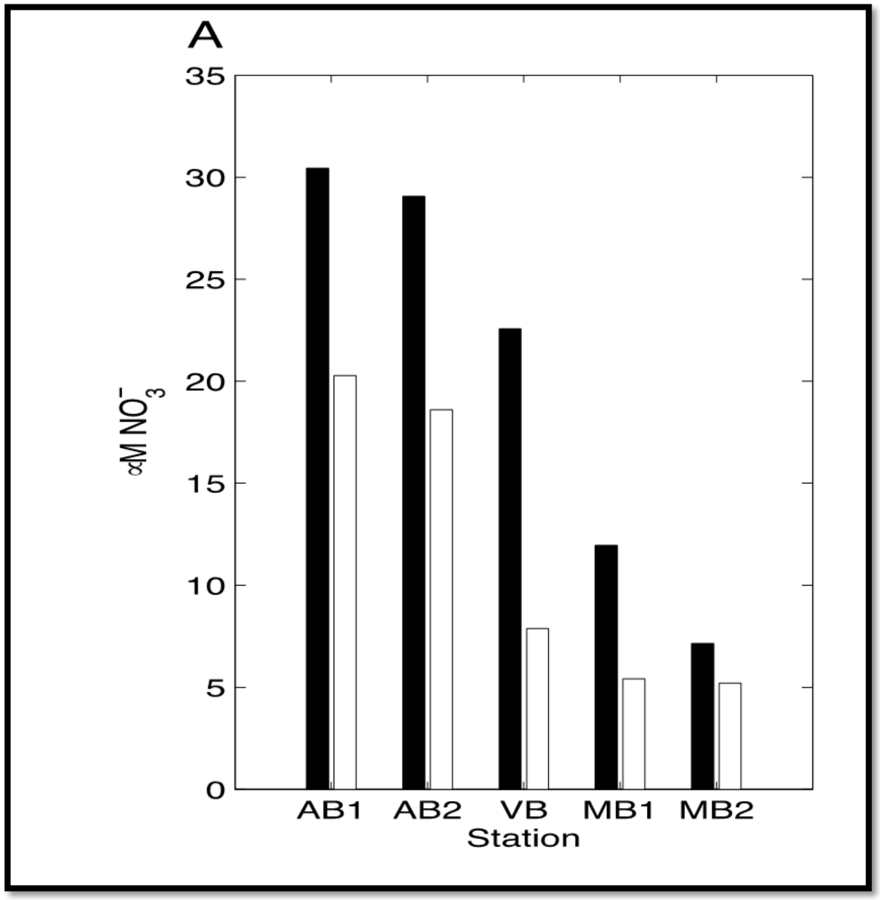

Figure 3.1.2. Bar Graph of nitrate concentrations at sample sites. Solid and open bars are pre-hurricane and post-hurricane concentrations.

3.1.3. Silicate Concentrations

A comparison of all pre-hurricane silicate concentrations to post-hurricane concentrations revealed no significant differences. Table 3.1.3 shows the results of all of the statistical test analyses of the pre-hurricane and post-hurricane concentrations. Figure 3.1.3 shows the resulting bar graph.

Table 3.1.3 All statistical test results for the analyses of pre-hurricane and post-hurricane silicate concentrations at all affected sites (AB-Debby, MB1-Isaac, MB2-Isaac, and VB-Isaac)

Test	Data	*p* value	Accept or Reject Ho
ANOVA	parametric	0.62	Accept
Paired t-test	parametric	0.70	Accept
Kruskal - Wallis	non-parametric	0.46	Accept
Sign	non-parametric	1	Accept

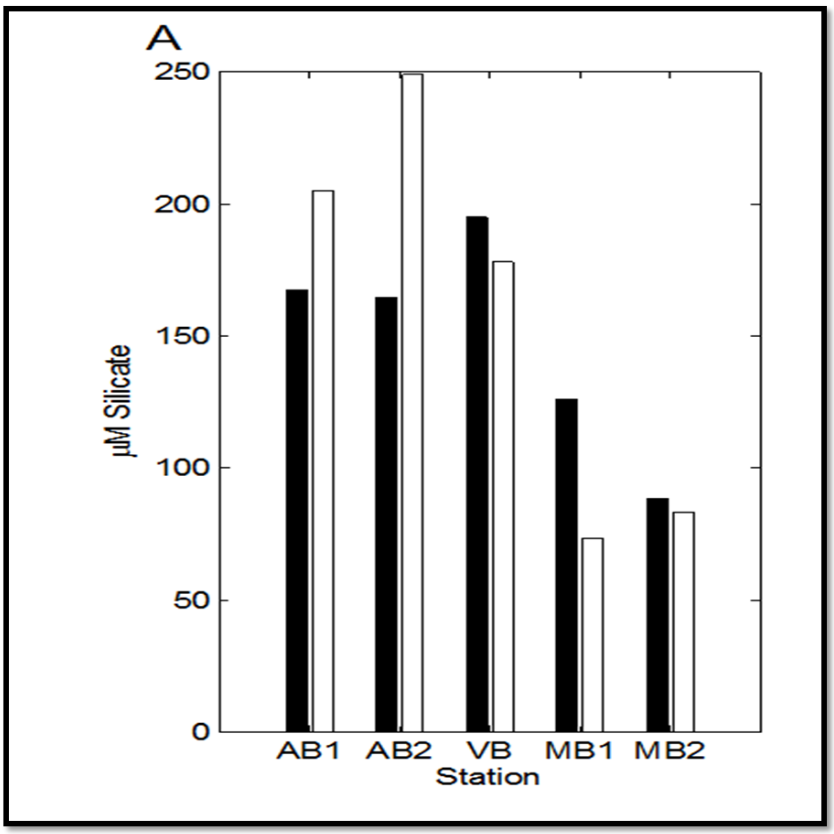

Figure 3.1.3. Bar Graph of silicate concentrations at sample sites. Solid and open bars are pre-hurricane and post-hurricane concentrations.

3.1.4. Ammonia Concentrations

A comparison of all pre-hurricane ammonia concentrations to post-hurricane concentrations revealed an obvious pattern. Post-hurricane concentrations were lower than pre-hurricane concentrations. Table 3.1.4 displays the results of all of the statistical test analyses of the pre-hurricane and post-hurricane concentrations. Figure 3.1.4 displays the resulting bar graph. The results for the parametric tests were inconsistent, but both nonparametric tests recommended rejecting the null hypothesis. The conclusion is that post-hurricane ammonia concentrations were significantly lower than pre-hurricane concentrations.

Table 3.1.4. All statistical test results for the analyses of pre-hurricane and post-hurricane ammonia concentrations at all affected Sites (MB1-Isaac, MB2-Isaac, and VB-Isaac)

Test	Data	*p* value	Accept or Reject Ho
ANOVA	parametric	0.048	Reject
Paired t-test	parametric	0.160	Accept
Kruskal - Wallis	non-parametric	0.011	Reject
Sign	non-parametric	0.002	Reject

In the case of ammonia concentrations, only the paired t-test resulted in p value higher than 0.05. MB1 seems to be creating noise for the paired t test. The difference between pre vs post concentrations at MB1 is much larger than those of MB2 and VB.

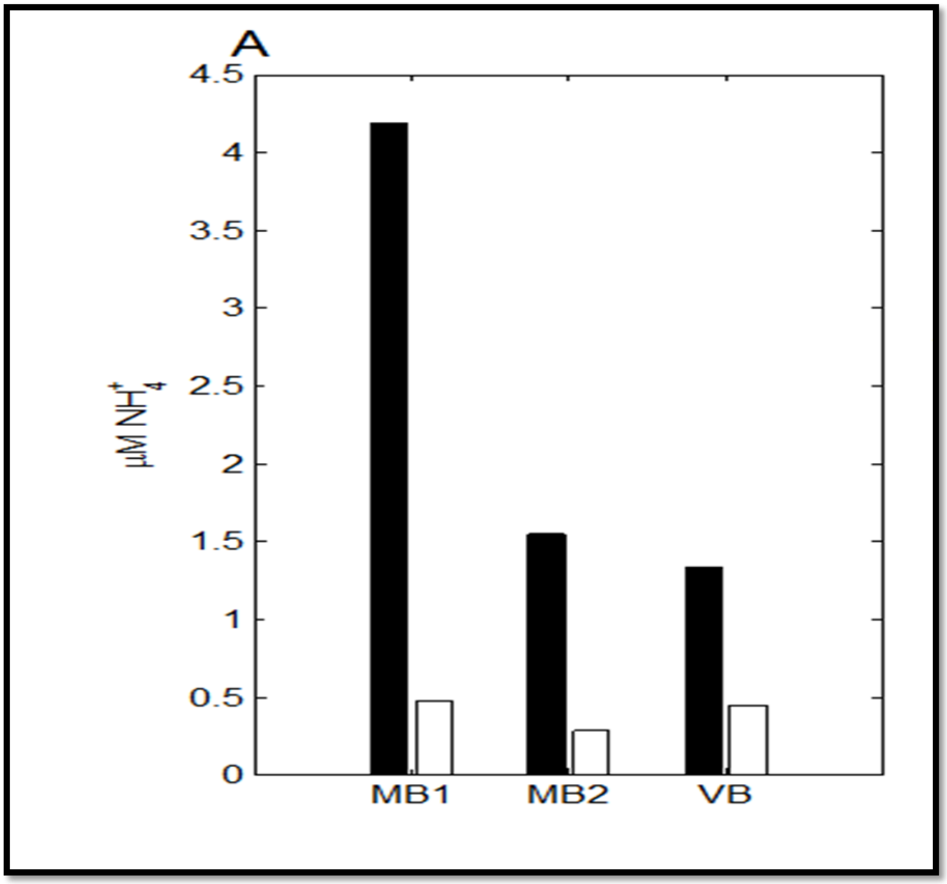

Figure 3.1.4. Bar graph of ammonia concentrations at sample sites. Solid and open bars are pre-hurricane and post-hurricane concentrations.

3.1.5 Chlorophyll Concentrations

A comparison of all pre-hurricane chlorophyll concentrations to post-hurricane concentrations revealed an obvious pattern. Post-hurricane concentrations were higher than pre-hurricane concentrations. Table 3.1.5 shows the results of all of the statistical test analyses of the pre-hurricane and post-hurricane concentrations. Figure 3.1.5 displays the resulting bar graph. Both non parametric tests revealed significant differences. The

conclusion is that post-hurricane chlorophyll concentrations were significantly higher than pre-hurricane concentrations.

Table 3.1.5. All statistical test results for the analyses of pre-hurricane and post-hurricane chlorophyll concentrations at all affected Sites (AB-Debby, MB1-Isaac, MB2-Isaac, and VB-Isaac)

Test	Data	*p* value	Accept or Reject Ho
ANOVA	parametric	0.24	Accept
Paired t-test	parametric	0.080	Accept
Kruskal - Wallis	non-parametric	0.040	Reject
Sign	non-parametric	0.00024	Reject

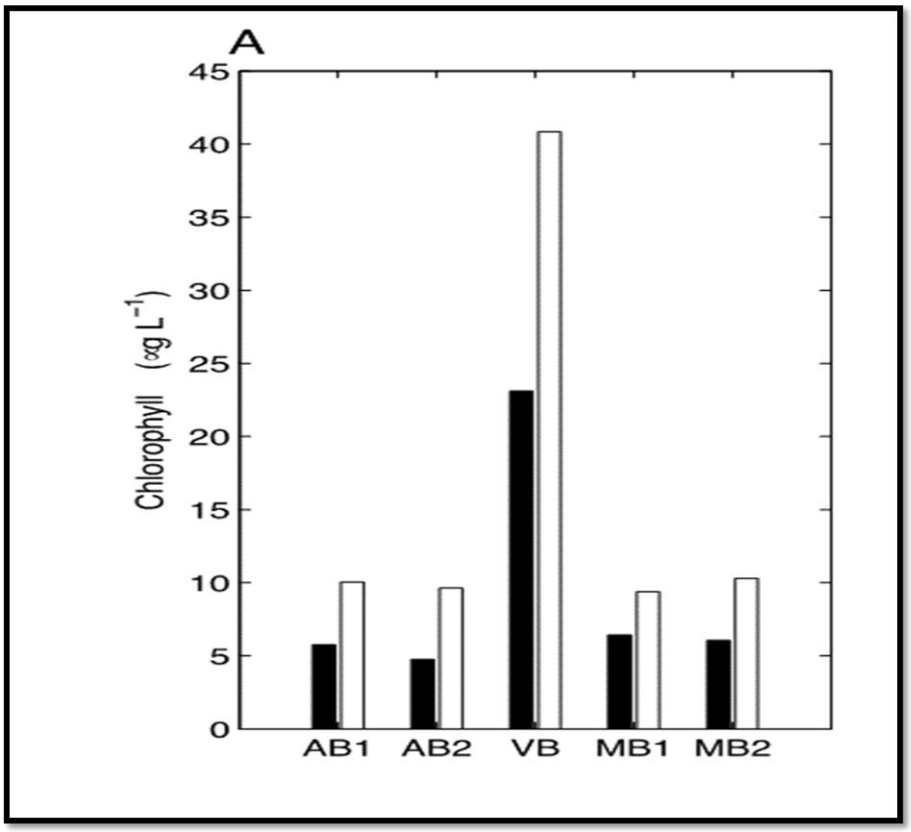

Figure 3.1.5. Bar graph of chlorophyll concentrations at sample sites. Solid and open bars are pre-hurricane and post-hurricane concentrations.

3.2 Seasonality of Inorganic Nutrient and Chlorophyll Concentrations at Each Site

Although the statistical tests indicated in some cases that there were significant differences between pre-storm and post-storm phosphate, nitrate, ammonia, and chlorophyll concentrations, it is possible that these differences were the result of nothing more than seasonality. In other words, it is possible that the effects were seasonal rather than episodic. This question could not be addressed at AB2 because there was only one pre-storm sample at AB2. However, at the other stations, it was possible to examine the time series of nutrient and chlorophyll data to determine whether the post-storm values were merely an extension of a trend in the pre-storm data. Figures 3.2.1–5 show the relevant graphs (see also Appendix D).

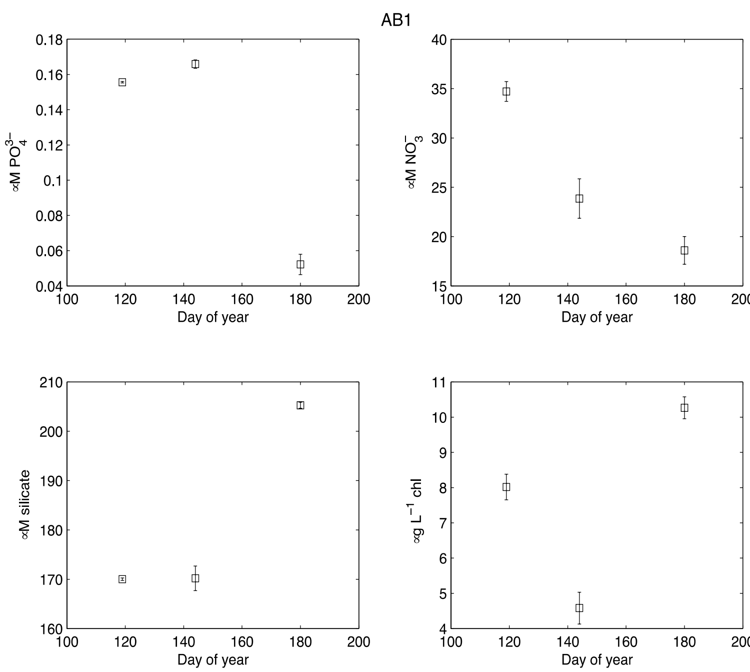

Figure 3.2.1. Concentrations of phosphate, nitrate, silicate, and chlorophyll at AB1 versus day of the year in 2012. Data points are median values, and the error bars are median absolute deviations. The last data point in the time series was taken on June 29 after Tropical Storm Debby.

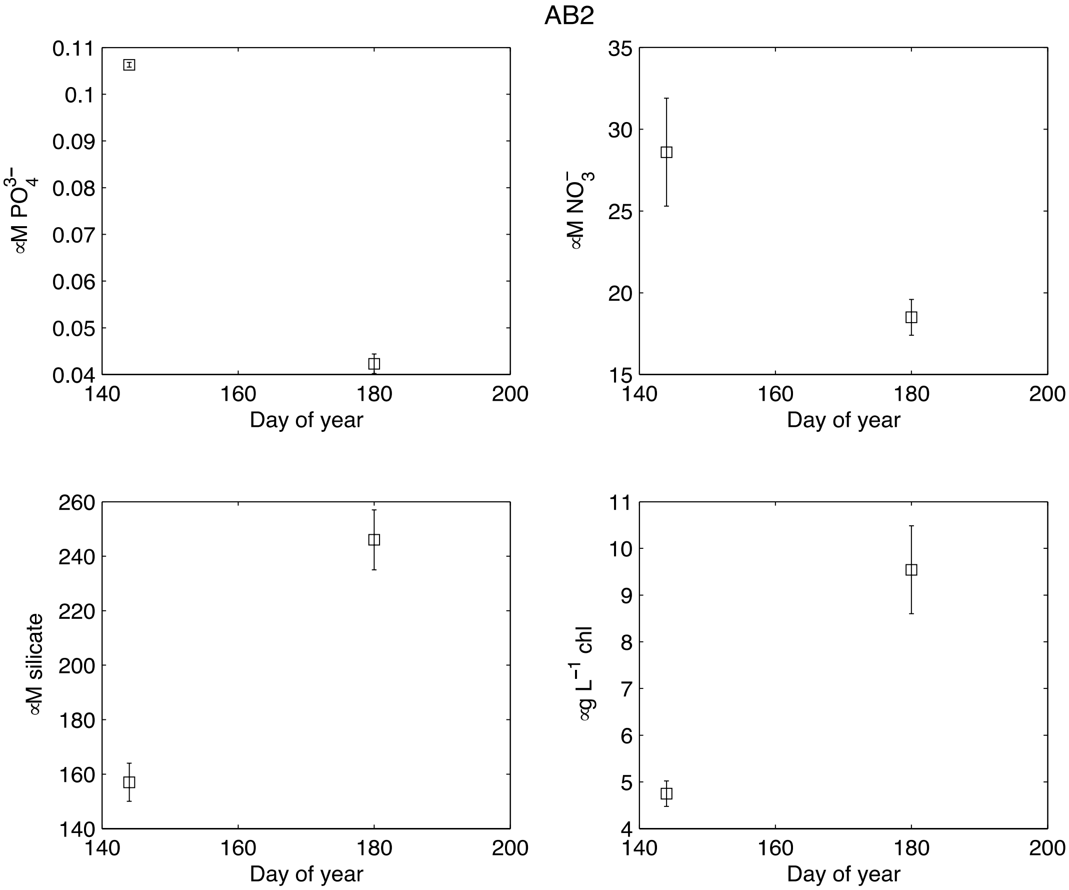

Figure 3.2.2. Concentrations of phosphate, nitrate, silicate, and chlorophyll at AB2 versus day of the year in 2012. Data points are median values, and the error bars are median absolute deviations. The last data point in the time series was taken on June 29 after Tropical Storm Debby.

When examining the time serious, obvious patterns can be seen in some cases which point to mere seasonality while others appear to be the result of an episodic event. AB2 was only visited twice so this site will be omitted from further observation of seasonality vs. episodic event.

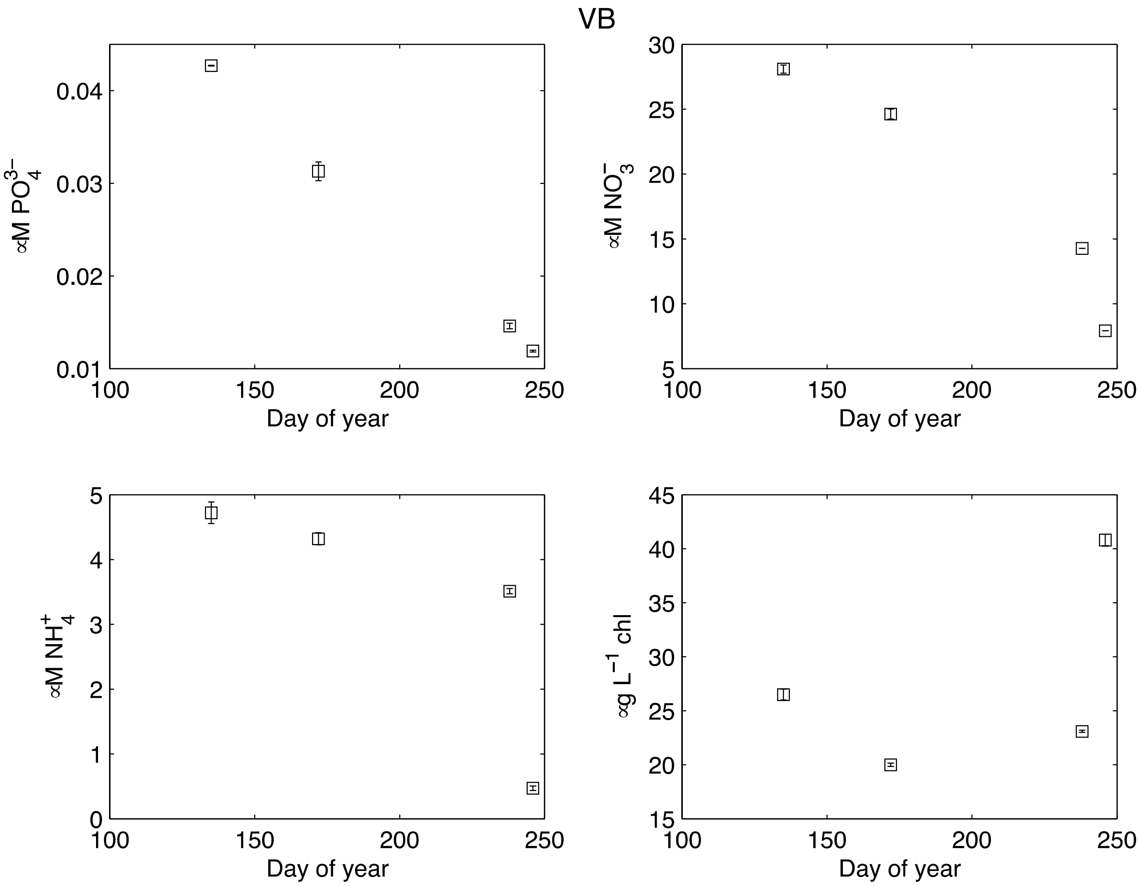

Figure 3.2.3. Concentrations of phosphate, nitrate, ammonium, and chlorophyll at VB versus day of the year in 2012. Data points are median values, and the error bars are median absolute deviations. The last data point in the time series was taken on August 29 after Hurricane Isaac.

In the case of VB, strong evidence of both scenarios can be seen. For example, when looking at phosphate (PO^{-3}_4) you can visual draw a linear line through the data and each point till be touching the line. In contrast, ammonia and chlorophyll show that the first three data points (pre storm dates) as replicates, and the fourth data point (post storm data), differed by a factor 40% - 50%.

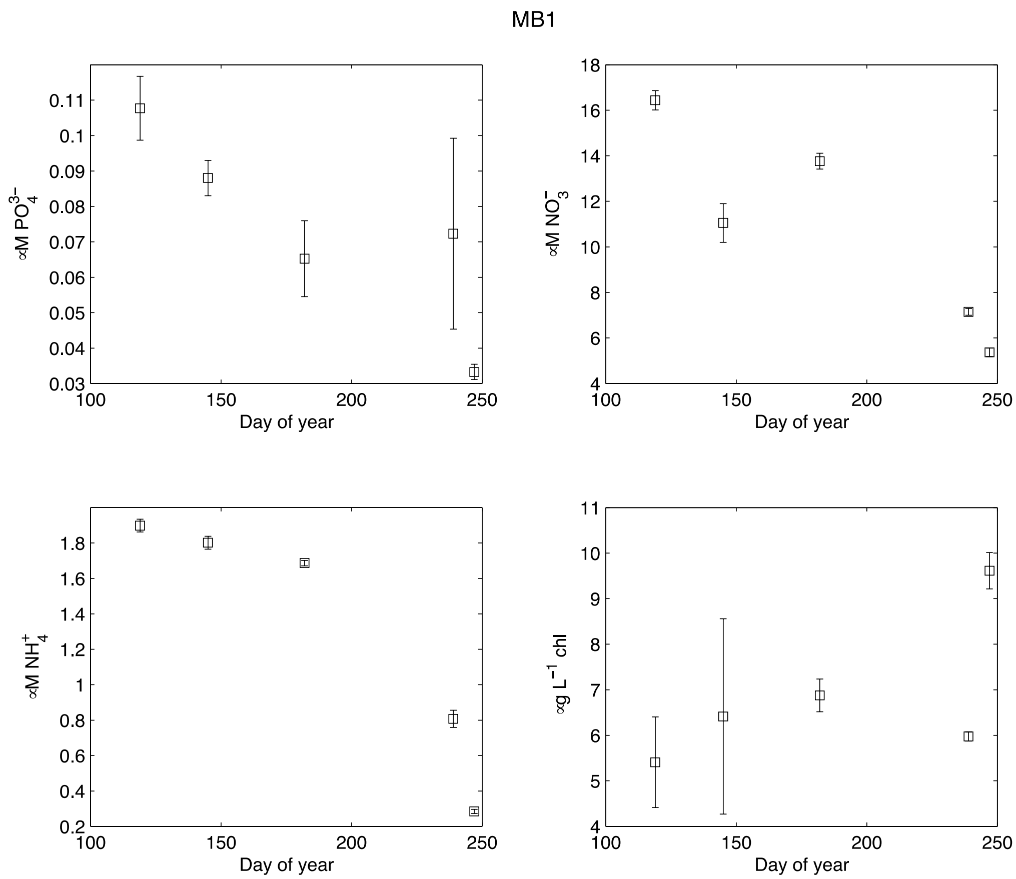

Figure 3.2.4. Concentrations of phosphate, nitrate, ammonium, and chlorophyll at MB1 versus day of the year in 2012. Data points are median values, and the error bars are median absolute deviations. The last data point in the time series was taken on August 29 after Hurricane Isaac.

In the case of MB1, there are some results that indicate that some of the concentrations were effected by an episodic event. For example, chlorophyll do not show any patterns that indicate seasonality.

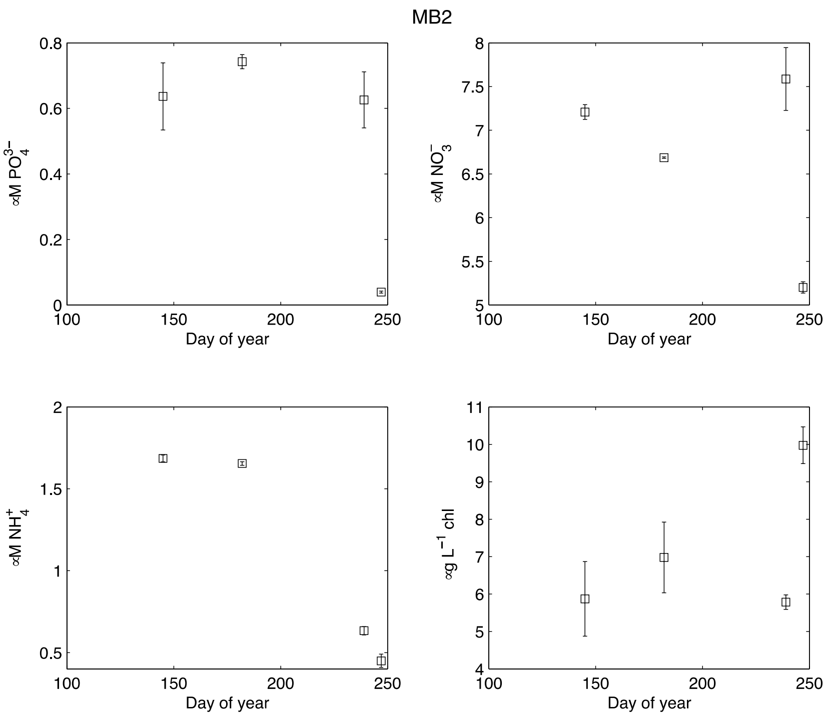

Figure 3.2.5. Concentrations of phosphate, nitrate, ammonium, and chlorophyll at MB2 versus day of the year in 2012. Data points are median values, and the error bars are median absolute deviations. The last data point in the time series was taken on August 29 after Hurricane Isaac.

ANOVA and KW tests were run on each dataset at each station to determine whether the differences between sampling dates (combined pre-storm and post-storm) were significant compared to the variability on each date. In almost all cases the differences between dates were significant at $p < 0.05$. The only exceptions were the phosphate and silicate concentrations at AB1 (Fig. 3.2.1), where the differences between dates were surprisingly judged to be significant at only $p = 0.05$ and 0.06, respectively, based on the KW test. The corresponding p values for the ANOVA were less than 3×10^{-6}. The relatively high type I error rate for the KW tests in this case reflects the small sample

size. The conclusion is that the differences between dates were significant compared to the variability within dates. In the Discussion I address the question of whether these differences were nothing more than seasonal trends or whether there is evidence of episodic effects due to Tropical Storm Debby and Hurricane Isaac.

3.3 Enrichment Experiments

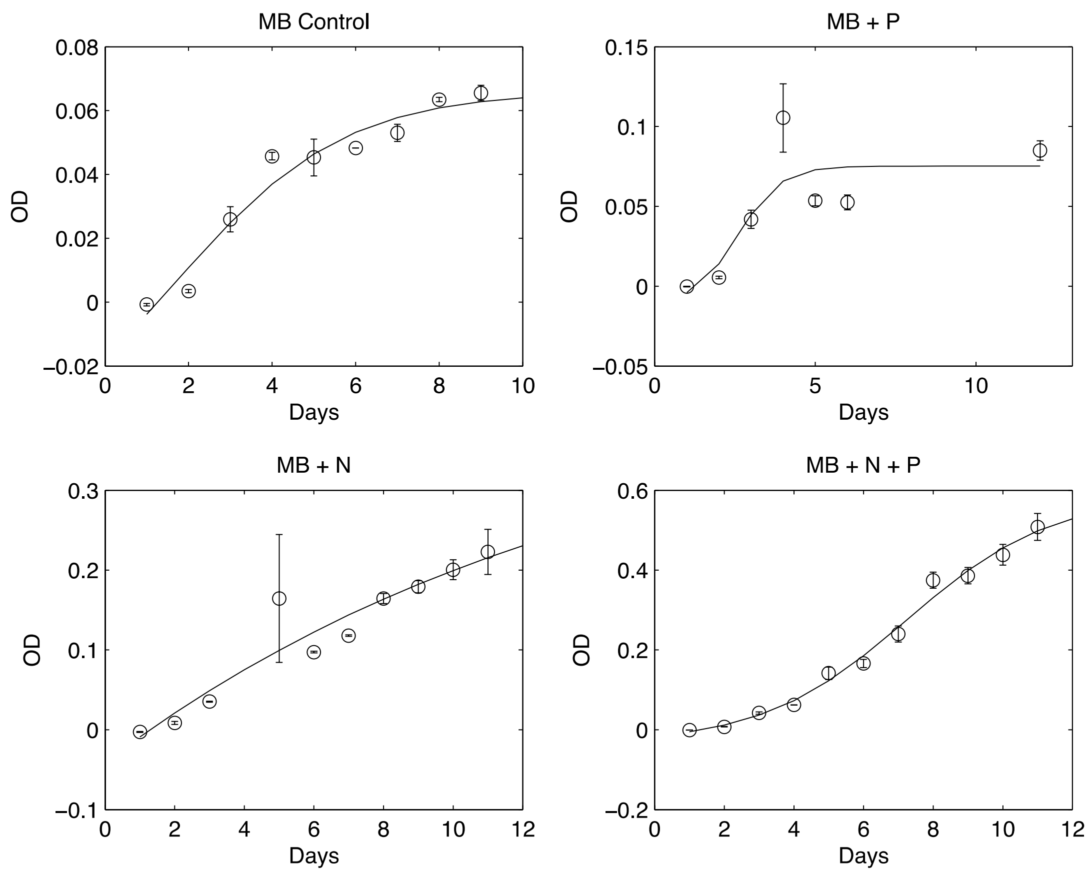

Figure 3.3.1. Time series of optical density (OD) readings in the control flask and in the flasks enriched with phosphate (MB + P), nitrate (MB + N), and both phosphate and nitrate (MB + N + P) at site MB1. The smooth curve in each panel is a logistic growth model fit to the data.

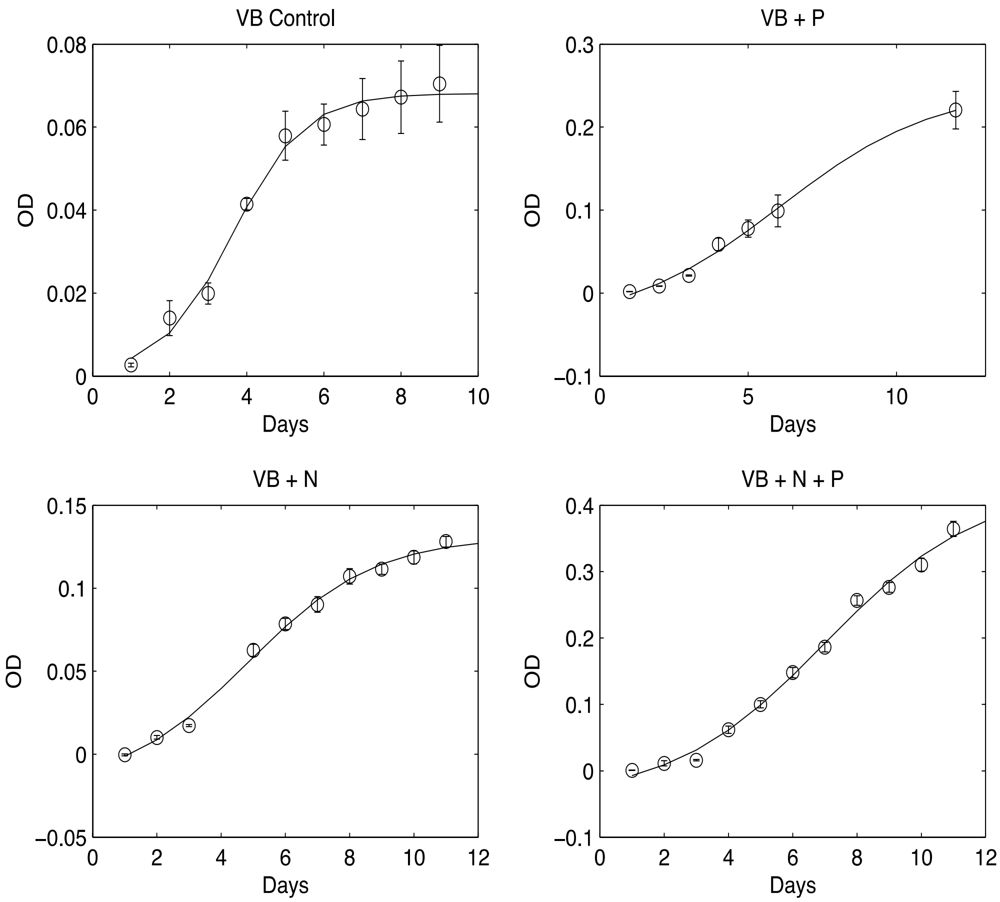

Figure 3.3.2. Time series of OD readings in the control flask and in the flasks enriched with phosphate (VB + P), nitrate (VB + N), and both phosphate and nitrate (VB + N + P) at site VB. The smooth curve in each panel is a logistic growth model fit to the data.

In the figures in this section, the y-axis shows the optimal density readings (OD), and the x-axis shows the days that readings were taken. Readings were taken on a spectrophotometer daily for a total of 12 days until the growth curve leveled out.

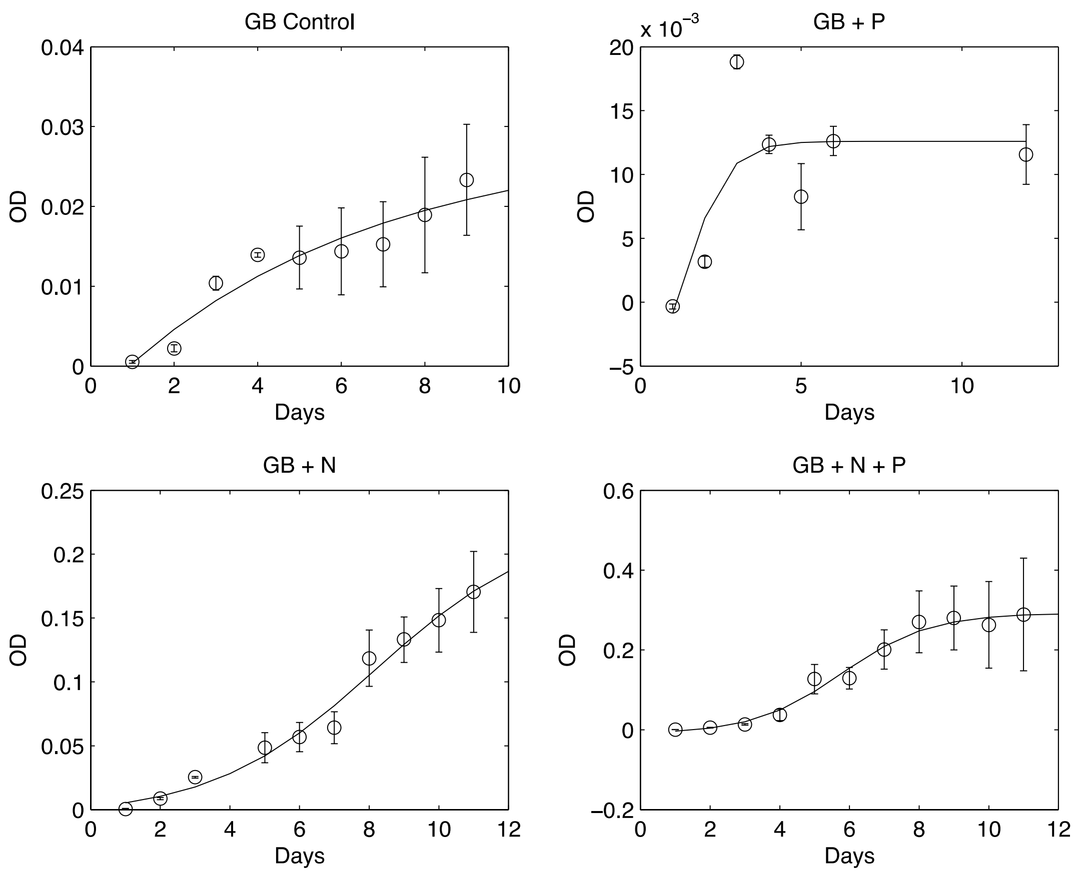

Figure 3.3.3. Time series of OD readings in the control flask and in the flasks enriched with phosphate (GB + P), nitrate (GB + N), and both phosphate and nitrate (GB + N + P) at site GB. The smooth curve in each panel is a logistic growth model fit to the data.

The limiting nutrient of each site were determined by observing the final OD values, and concluding which of these nutrient or nutrients yielded the most growth during the course of the experiments. The asymptotic values of the OD readings are summarized in Table 3.3.1.

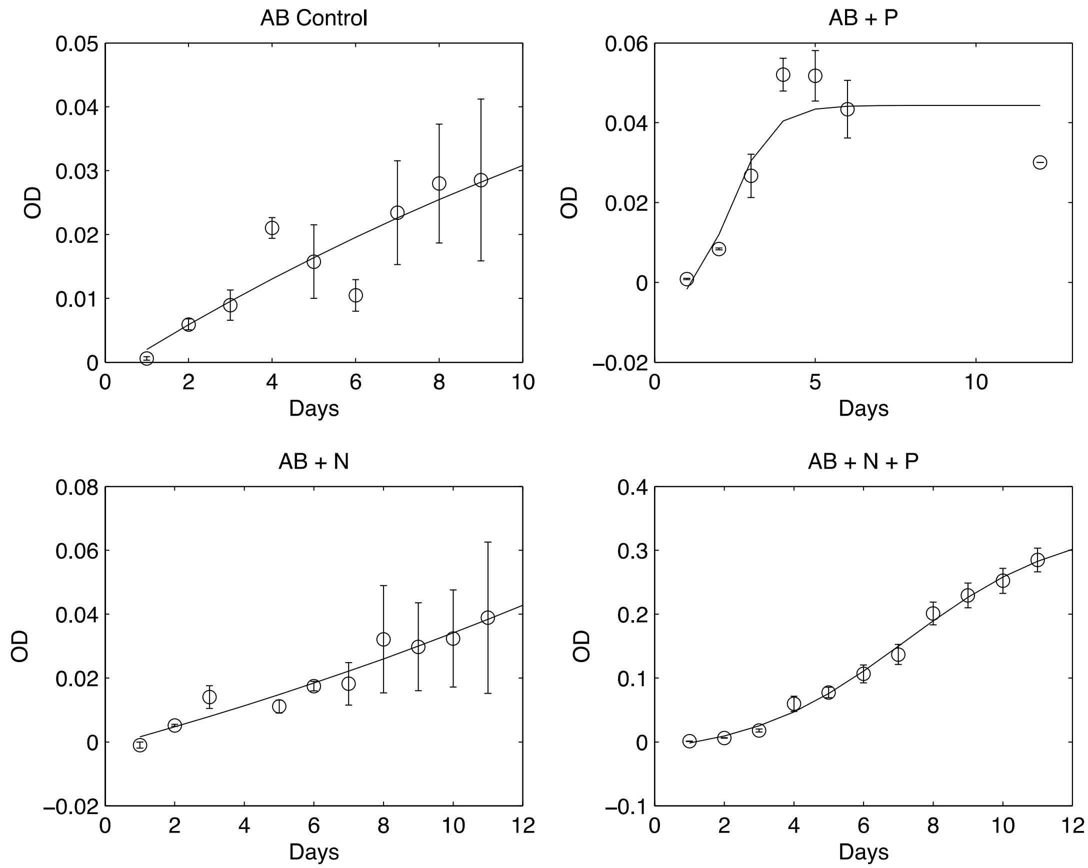

Figure 3.3.4. Time series of OD readings in the control flask and in the flasks enriched with phosphate (AB + P), nitrate (AB + N), and both phosphate and nitrate (AB + N + P) at site AB. The smooth curve in each panel is a logistic growth model fit to the data.

Table 3.3.1. Asymptotic OD readings

Site	Control	+ P	+ N	+ P + N
MB	0.0782	0.0850	0.3099	0.6611
VB	0.1231	0.2204	0.1005	0.5358
GB	0.0144	0.0116	0.2976	0.2383
AB	0.0136	0.0300	0.0329	0.1902

3.4 Other Parameters

VB is primarily a shallow freshwater basin, and this increase in salinity suggests that there was an intrusion of saltwater due to the storm surge and mixing of surrounding bodies of water caused by the high winds associated with this storm. There was no change in salinity at MB1, but a twofold increase at MB2, suggesting that the same phenomena took place as this sight and VB. It is uncertain why two sites, so close in proximity to each other, exhibited such different results. MB2 was a high traffic area, subject to recreational and sport disruption. Following Tropical Storm Debby a decrease in temperature of 2.2°C was observed at AB1. Following Hurricane Isaac, VB experienced a temperature increase of 2°C. Sites MB1 and MB2 showed a slight increase of 0.2°C. There was no significant change in pH at any of the affected sites following a storm. Following Tropical Storm Debby, the BOD increased at site AB1 by 0.53 mg/L. Contrastingly, site AB2 witnessed a decrease of 0.6 mg/L in BOD. After Hurricane Isaac, site MB1 experienced a decrease in BOD of 1.6 mg/L, while MB2 had an increase of 0.2 mg/L. At site VB, a decrease in BOD of 1.44 mg/L was observed. See Appendix C.

Chapter 4
Discussion

4.1 Inorganic Nutrients and Variability (Pre-event vs. Post-event)

Some years, hurricane season brings about high winds, heavy rain, and forceful storm surge that dramatically impact wetlands all along the Gulf coast. These massive storms can cause a fluctuation in the amount of nutrients available to the phytoplankton within these multifaceted ecosystems, and these fluctuations can in turn affect phytoplankton concentrations. Nutrient availability is what determines the rate and degree to which phytoplankton grow, and inputs of excess nutrients can result in serious eutrophication problems (Obenour et al. 2013; Turner and Rabalais 2013; Turner et al. 2012). Other factors can also affect the rates at which phytoplankton grow. Those factors include pH, temperature, and salinity, all of which may be affected by the massive amounts of freshwater introduced into a coastal ecosystem during a storm event. Hurricanes and tropical storms can cause a shift in water chemistry that can be documented directly after an episodic event. However, before it can be firmly concluded that storms cause changes in nutrient and chlorophyll concentrations, it is important to consider the possibility that the low nutrient and high chlorophyll concentrations are merely seasonal phenomena. For example, the high concentration of bacteria (vibrios) in the floodwaters of New Orleans, LA following Hurricane Katrina (Sinigalliano et al. 2007) was a seasonal phenomenon associated with the high water temperatures at the time of the hurricane. Thus, it is important to discern how various environmental parameters impact the responses of wetlands to storm events.

4.2 Seasonal Versus Episodic Effects

To address the question of whether the post-storm low nutrient and high chlorophyll concentrations were merely seasonal phenomena, the time series of data from stations AB1, VB, MB1, and MB2 were examined (Figs. 3.2.1–5). I ignored the results from AB2 because there was only one pre-storm sample at that site. In the other cases, I looked at the trends in the data from the pre-storm samples to see if the post-storm sample appeared to be merely an extension of that trend. In the case of the VB, MB1, and MB2 results, I focused in particular on the differences in the concentrations measured 2–3 days prior to Hurricane Isaac and the post-storm samples, which were measured 5–6 days after the storm. The following table summarizes this subjective analysis.

Table 4.2.1. Evidence that the post-storm concentrations were merely seasonal phenomena

Site	PO_4^{3-}	NO_3^-	NH_3	Chl *a*
AB1	no	yes	—	no
VB	yes	no	no	no
MB1	yes	yes	no	no
MB2	no	no	yes	no

In the 15 cases where I could test the hypothesis that the post-storm concentrations were merely seasonal phenomena, I saw five cases where I might be inclined to accept this hypothesis: phosphate at VB and MB1, nitrate at AB1 and MB1, and ammonia at MB2. In no case did the post-storm chl *a* concentrations seem to be seasonal phenomena. The four phosphate concentrations at VB fell on almost a perfect straight line (r = –0.999), and the correlation between phosphate concentration and time was significant at p= 0.0009. Thus there is no reason to attribute the low post-storm phosphate concentration at

VB to Hurricane Isaac. The five phosphate concentrations at MB1 were also negatively correlated with time ($r = -0.87$, $p = 0.052$). The fact that the correlation was not quite significant at $p = 0.05$ was due entirely to the August 27 sample, which had a large range of uncertainty (Fig. 3.2.4). Thus it appears that the low phosphate concentration measured at MB1 following Hurricane Isaac may have been merely part of a seasonal pattern. Although the post-storm ammonia concentration at MB2 was considerably lower than the concentrations measured in May and July, it was in fact little different from the concentration measured on August 27, two days before Hurricane Isaac. Hence there was no reason to attribute the low post-storm ammonia concentration at MB2 to Hurricane Isaac. The nitrate concentrations at AB1 and MB1 were both negatively correlated with the day of the year, and at MB1 the concentration measured 6 days after Hurricane Isaac was little different from the concentration measured 2 days before the hurricane. Thus I did not feel that there was a good reason to attribute the low post-storm nitrate concentrations at AB1 and MB1 to storm effects.

In the other cases I hypothesized that there was good reason to believe that the low nutrient and high chl *a* concentrations were episodic rather than seasonal phenomena. This was true in the case of all the high post-storm chl *a* concentrations, and I felt that a particularly strong case could be made that the storms were responsible for the low post-storm phosphate and nitrate concentrations at MB2, the low post-storm ammonia concentration at VB, and the low post-storm phosphate concentration at AB1. The following is a detailed assessment of temporal patterns at each of the four sampling sites where I collected more than one pre-storm sample.

4.2.1. Sample Site AB1

I visited AB1 a total of three times, April 29, May 24, and June 29 (Table 2.2.1). ANOVA revealed significant differences in phosphate concentrations, regardless of whether the analysis was based on a nested ANOVA (ANOVAN) of pre-storm versus post-storm concentrations or a one-way ANOVA analysis of the three sampling dates (ANOVA1). Both tests indicated that there were significant differences in the phosphate concentrations. An *a-posteriori* (*post-hoc*) Tukey-Kramer test identified the concentration on June 29 as being significantly different from the other concentrations. However, the KW test of the three sampling dates was significant at only $p = 0.05$. In general, a KW test is less likely to detect differences than an ANOVA, but the KW test does not require that the data be normally distributed with equal variances. The nitrate concentrations at AB1 differed significantly between the three sampling dates (ANOVA1, $p<0.05$), but there was no difference between pre-storm and post-storm nitrate concentrations (ANOVAN, $p=0.37$). The latter conclusion is consistent with the supposition that the nitrate time series reflected a seasonal trend (Table 4.2.1). The silicate concentrations at AB1 differed significantly between the three sampling dates (ANOVA1, $p<0.05$), and the post-storm concentrations were judged to be significantly different from the pre-storm concentrations (ANOVAN, $p<0.05$). A Tukey-Kramer test revealed that the post-storm concentrations were significantly higher than the pre-storm concentrations. In fact the silicate concentrations after Tropical Storm Debby were about 35 μM higher than the two pre-storm concentrations (Fig. 3.2.1). A KW test of the silicate concentrations on the three sampling dates was not quite significant ($p=0.06$), again a reflection of the greater power of ANOVA to detect differences between groups.

The chlorophyll concentrations at AB1 differed significantly between the three sampling dates (ANOVA1 and KW, $p<0.05$), but there was no significant difference between the post-storm and pre-storm concentrations (ANOVAN, $p=0.34$). The post-storm chlorophyll concentration was the highest of the three concentrations, but the difference between the two pre-storm concentrations was comparable to the difference between the post-storm and mean pre-storm concentrations. A Tukey-Kramer test revealed that the chlorophyll concentrations on May 24 and June 29 were different from each other ($p<0.05$), but the chlorophyll concentration on April 29 was not different from either of the other concentrations ($p>0.05$).

4.2.2 Sample Site MB1

MB1 was visited five times during the summer, April 29, May 25, July 1, August 27, and September 4. The phosphate concentrations were judged to be significantly different between the five sampling times (ANOVA1, KW, $p<0.05$). However, there was no significant difference between the post-storm and pre-storm phosphate concentrations (ANOVAN, $p=0.09$). This latter conclusion is consistent with the supposition that the post-storm concentration was merely part of a seasonal trend (Table 4.2.1). The results for nitrate, silicate, and ammonia were similar to the phosphate results: there was a significant difference between the five sampling dates (ANOVA1, KW, $p<0.05$), but there was no difference between pre-storm and post-storm nitrate concentrations (ANOVAN, $p=0.23$, 0.39, and 0.11 for nitrate, silicate, and ammonia, respectively). Thus one could argue that the post-storm nitrate, silicate, and ammonia concentrations were also merely part of seasonal trends. This conclusion is consistent with Table 4.2.1 in the case of nitrate. It seems unlikely that the roughly threefold decrease in ammonia

concentrations between August 27 and September 9 (Figure 3.2.4) should be attributed entirely to seasonality, and the Tukey-Kramer test revealed that the September 4 ammonia concentration was significantly different ($p<0.05$) from all four of the concentrations measured prior to Hurricane Isaac. The chlorophyll concentrations were judged to be significantly different between the five sampling dates (ANOVA1, KW, $p<0.05$) as well as between the pre-storm and post-storm samples (ANOVAN, $p=0.018$). A Tukey-Kramer test revealed that the chlorophyll concentration on September 4 was significantly different ($p<0.05$) from all four of the concentrations measured prior to Hurricane Isaac.

4.2.3 Sample Site MB2

Site MB2 was visited four times during the course of this experiment, May 25, July 1, August 27, and September 4. The statistical results for phosphate, nitrate, ammonia, and silicate all indicated that there were significant differences between the four sampling dates. However, the tests for differences between pre-storm and post-storm concentrations (ANOVAN) were significant at p = 0.015, 0.058, 0.33, and 0.85 for phosphate, nitrate, ammonia, and silicate, respectively. The low ammonia concentrations after Hurricane Isaac thus appeared to reflect nothing more than seasonality (Table 4.2.1). The fact that the difference between the pre-storm and post-storm nitrate concentrations was significant at only p = 0.058 reflects a combination of the level of noise in the pre-storm samples (Fig. 3.2.5) and the fact that there were only three pre-storm samples. A Tukey-Kramer test revealed that there was a significant difference ($p<0.05$) between the nitrate concentration on September 4 and all three of the concentrations measured before Hurricane Isaac. The chlorophyll concentrations were judged to be significantly different

both between the four sampling dates (ANOVA1, KW, $p<0.05$) and between the pre-storm and post-storm samples (ANOVAN, $p= 0.02$). A Tukey-Kramer test revealed that there was no significant difference between the three pre-storm chlorophyll concentrations, but there was a significant difference between the chlorophyll concentration on September 4 and all three of the chlorophyll concentrations measured prior to Hurricane Isaac.

4.2.4 Sample Site VB

VB was visited four times during the course of the summer, May 15, June 21, August 26, and September 3. Analysis of the data indicated that phosphate, nitrate, silicate, ammonia, and chlorophyll all varied significantly between the four dates (ANOVA1, KW, $p<0.05$). However, only the ammonia and chlorophyll concentrations were judged to be significantly different between pre-storm and post-storm sampling (ANOVAN, $p=0.003$ and 0.038 for ammonia and chlorophyll, respectively). A Tukey-Kramer test revealed that the ammonia and chlorophyll concentrations measured on September 3 were significantly different from all three of the concentrations measured prior to Hurricane Isaac. The differences between pre-storm and post-storm phosphate, nitrate, and silicate concentrations were significant (ANOVAN) at $p = 0.39$, 0.21, and 0.63, respectively. The lack of a significant storm effect in the case of phosphate can certainly be attributed to seasonality (Fig. 3.2.3). Although there was clearly a decreasing trend in the nitrate concentrations prior to Hurricane Isaac (Fig. 3.2.3), the decrease of 7 μM between August 26 and September 3 is much greater than the decrease of 1 μM predicted by a regression line fit to the pre-storm data. It therefore seems reasonable to conclude that most of the decrease of the nitrate concentration between August 26 and September 3

was due to Hurricane Isaac. A Tukey-Kramer test revealed that the nitrate concentration on September 3 was in fact different from all three of the nitrate concentrations measured prior to Hurricane Isaac.

4.2.5 Summary of Seasonal and Episodic Effects

AB was revisited 3 days after Tropical Storm Debby. VB, MB1, and MB2 were revisited 5 and 6 days, respectively, after Hurricane Isaac. Had each site been revisited one day after a storm, the results might have been significantly different. The results described in this paper supply substantial supporting evidence of the significant impact of storms on the nutrient concentrations in coastal wetlands. A common trend was observed among all of the sample sites. This trend is clearly seen when all the affected sites were pooled together. There was a decrease in phosphate levels following each storm event, as well as a significant depletion in nitrate levels. Resulting silicate and ammonia concentrations tended to vary among sites. Phytoplankton consistently increased significantly, suggesting that the influx of nutrients brought by the storm was assimilated immediately, resulting in favorable conditions for eutrophication. All of the high chlorophyll concentrations appeared to be a result of the storms. However, about half the low phosphate, ammonia, and nitrate concentrations appear to reflect seasonality.

Based on these results, the question of why these nutrients were not being taken up before the storms arises. This could be due to the fact that there was another unknown nutrient that was limiting. The storms arrived, disturbing the water table and suspending sediments that could have released a reservoir of this unknown nutrient, allowing the phytoplankton to flourish. Another scenario is that before the storm, the phytoplankton

populations were controlled by predation, and when the storms did come through and suspended sediments, hydrogen sulfide was released into the water column. Hydrogen sulfide is a very toxic gas and may have allowed the phytoplankton to grow unchecked by killing some of the predators. It is also possible that the turbulence caused by the storms resuspended phytoplankton cells that had sunk to the bottom.

4.3 Enrichment Experiments

When nutrients are added one at a time, there will be no response from the phytoplankton if something other than the added nutrient is limiting the phytoplankton biomass. Alternatively, if the added nutrient is limiting and if there is a surplus of all other essential nutrients, there will be an increase of phytoplankton biomass until something else becomes limiting. For example, adding both N and P will produce no response if something other than N and P is limiting, but there will be an increase in biomass if either N or P or both is limiting and there is a surplus of all other essential nutrients. A caveat in all cases is that some changes in plankton biomass may occur as a result of shifts in the elemental composition of the phytoplankton, which is certainly not the only possibility. As a rule of thumb, more than twice the original biomass (versus the control) should be considered as a positive response, and anything less than that should be considered to be no response (Laws, Aquatic Pollution, vol 3, 2000).

The following is a summary and interpretation of the results of the nutrient-enrichment experiments (Table 3.3.1). Adding P produced essentially no response at MB and GB, the implication being that something other than P was limiting at these sites. When N was added at these two sites, the yield (asymptotic value of the OD reading) increased

dramatically, by a factor of 4 at MB and by a factor of 21 at GB. Adding both N and P at MB increased the yield by an additional factor of 2.1, the implication being that P was eventually exhausted in the +N treatment. At GB there was no additional yield associated with addition of both N and P, the implication being that there really was a surplus of P at this site. Thus N appeared to be the limiting nutrient at both MB and GB.

At VB adding N produced no response, and addition of P increased the yield by only about 80%. However, adding both N and P produced a yield that was 4.3 times the yield in the control treatment. The implication is that N and P were simultaneously limiting at VB.

At AB, addition of either P or N individually roughly doubled the yield, but addition of both N and P produced a yield that was about 14 times the yield in the control. The implication is that N and P were simultaneously limiting at AB.

Chapter 5
Conclusions

Several conclusions can be reached from this research. First, the relatively low nitrate, ammonium, and phosphate concentrations measured during the post-storm sampling were in some cases attributable to the effects of the storms but in other cases appeared to be simply part of a seasonal cycle. In the former case, the likely explanation for the low post-storm concentrations is uptake by phytoplankton. In the latter case, the likely explanation is that runoff of fertilizer applied to annual crops in the spring elevated the nutrient concentrations during the first few months of the study.

Most crops grown in the states bordering the Gulf of Mexico are annuals. Examples include corn, cotton, rice, and soybeans. Fertilizer is applied when these crops are first planted, and during the time that the plants are nothing more than seeds in the ground, the potential for runoff of fertilizer from the fields is high. Later in the growing season, several months after the last application of fertilizer and when the aboveground portion of the plant has become established, the potential for runoff is much lower. The seasonality of fertilizer runoff from farmland may therefore largely account for the pattern of decreasing nutrient concentrations over time that I observed at several of my sites.

In several cases, however, the low post-storm nutrient concentrations did not appear to be part of a seasonal pattern but instead appeared to be the result of an episodic event, i.e., the passage of a tropical storm or hurricane. Because these storms were associated with considerable rainfall and strong winds, my expectation was that nutrient concentrations would increase as a result of land runoff and the stirring up of sediments. Had I sampled immediately after the storms, I might have found that inorganic nutrient concentrations

had in fact increased. However, in stirring up the sediments in these shallow systems, the storms would have resuspended phytoplankton cells that had sunk to the bottom of the water column. The high temperatures and abundant sunlight in the upper water column would have created ideal conditions for rapid phytoplankton growth. At a temperature of 32°C, some phytoplankton are capable of growing at rates of roughly 6 doublings per day (Eppley 1972). It is therefore possible that the episodic decrease of nutrient concentrations reflected the resuspension of phytoplankton cells from the sediments and the subsequent very rapid nutrient uptake by those phytoplankton under conditions of abundant light and high temperatures.

In all cases I observed an episodic increase of chlorophyll *a* concentrations after passage of the storms. This increase was likely the result of a combination of factors: resuspension of phytoplankton cells that had sunk to the bottom of the water column and the rapid uptake of nutrients introduced via a combination of land runoff and the interstitial water of resuspended sediment.

The results of my study lead to two important conclusions regarding the use of statistics. First, it is important to look at experimental results (i.e., make a graph) in addition to just running standard tests such as an analysis of variance or a *t*-test. Had I not plotted the data versus time, for example, it is very unlikely that I would have noticed the possibility that some of my results were probably due to seasonal effects rather than episodic events. Second, the four different statistical tests that I used to determine whether there were differences in pre-storm versus post-storm concentrations in most cases led to different conclusions regarding the statistical significance of the differences. Although parametric tests are generally thought to be more powerful (i.e., more likely to detect significant

differences) than nonparametric tests, in my study a simple nonparametric sign test in many cases detected significant differences in pre-storm versus post-storm concentrations when other tests, including the parametric anova and paired *t*-tests, failed to detect significant differences. The failure of the anova and paired *t*-tests to detect significant differences in cases where the nonparametric Kruskal-Wallis and sign test detect differences was apparent from examination of the data. It therefore seems advisable to use multiple statistical tests when more than one test is appropriate. In that way one can avoid jumping to possibly unwarranted conclusions.

Finally, it is noteworthy that the phytoplankton community did not seem to be adversely affected by the passage of the storms. In fact, the phytoplankton communities seemed to benefit, probably from a combination of resuspension of sediments, land runoff, and perhaps suppression of predators due to the introduction of compounds such as H_2S associated with the resuspended sediments. Tropical storms and hurricanes can do serious damage to the salt marsh macrophytes such as species of Spartina and Juncus, and because these plants grow slowly compared to phytoplankton, their recovery from storm/hurricane damage may take years. Because phytoplankton and typical salt marsh macrophytes appear to contribute roughly equally to the organic carbon utilized by primary consumers in salt marshes (Peterson et al. 1986), the resilience of the phytoplankton community vis-à-vis the macrophyte community to perturbations associated with the passage of tropical storms and hurricanes may therefore have important implications for the resilience of the overall salt marsh biotic community.

References

Army Corp. of Engineers. 2004. The Lakes District East Baton Rouge Parish, Louisiana: Preliminary Restoration Report. U.S. Army Corp. of Engineers, New Orleans District.

Admiraal, W. Van Der Vlugt J. 1990. Impact of eutrophication on the silicate cycle of man-made basins in the Rhine Delta. *Hydrobiologia*, Vol. 24.

Boesch, D.F., Shabman, L., Antle, L.G., Day, J.W. Jr., Dean, R.G., Galloway, G.E., Groat, C.G., Laska, S.B., et al. 2006. A New Framework for Planning the Future of Coastal Louisiana after the Hurricanes of 2005. University of Maryland Center for Environmental Science, Cambridge, MD, 24 pp. 6.

Corps of Engineers, US Army Engineer District, New Orleans, Interim Survey Report, Morgan City, Louisiana and Vicinity, serial no. 63, US Army Engineer District, New Orleans, LA (November 1963).

Costanza, R., Mitsch, W.J. and Day, J.W. Jr. 2006. The Value of Coastal Wetlands for Hurricane Protection. Ambio Vol. 37, No. 4, J

Eppley, R. W. 1972. Temperature and phytoplankton growth in sea. Fishery Bulletin 70 (4), 1063–1085.

Galvan, Kari et al., 2012. The Effects of Two Consecutive Hurricanes on Basal Food Resources in a Shallow Coastal Lagoon in Louisiana. *Journal of Coastal Research,* 28(2), 407-420. West Palm Beach (Florida), ISSN 0749-0208.

J. D. H. Strickland and T. R. Parsons: A Practical Handbook of Seawater Analysis. Ottawa: Fisheries Research Board of Canada, Bulletin 167, 1968. 293

Kimberlain, Todd B. (January 7, 2013) (PDF). Tropical Cyclone Report: Tropical Storm Debby (Report). Miami, Florida: National Hurricane Center. Retrieved January 7, 2013.

Peterson, B. J., R. W. Howarth, and R. H. Garritt. 1986. Sulfur and carbon isotopes as tracers of salt-marsh organic-matter flow. Ecology 67 (4), 865–874.

R. W. Eppley 1972. Temperature and phytoplankton growth in the sea. Fishery Bulletin 70(4): 1063–1085.

“Record Event Report for Apalachicola". National Weather Service Office in Tallahassee, Florida (National Oceanic and Atmospheric Administration). June 25, 2012. Retrieved June 26, 2012

Reed, J. Denise, F. 2009. Marsh Elevation Response to Hurricanes Katrina and Rita and the Effects of Altered Nutrient Regimes (July 2001- June 2002). *Journal of Coastal Research*, Special Issue. 54, pp. 65-76.

Resio, T. Donald, Westerink, J. Joannes. 2008. Modeling the physics of Storm Surge. *Physics Today*, editor, American Institute of Physics, pp. 33-34.

Roth, David M. (2012). "Hurricane Isaac – August 25 – September 3, 2012". Hydrometeorological Prediction Center. National Oceanic and Atmospheric Administration. Retrieved October 8, 2012.

Simpson, R.H. and Riehl, H. 1981. The Hurricane and Its Impact. Louisiana State University Press, Baton Rouge, LA, 398 pp. Rouge/Parish of East Baton Rouge Department of Public Works. Baton Rouge, Louisiana, 298 pp.

Turner et al., 2006. Wetland Sedimentation from Hurricanes Katrina and Rita, Science 20 October 2006: 449-452.Published online 21 September 2006

Obenour, D.R., D. Scavia, N.N. Rabalais, R.E. Turner, and A.M. Michalak. 2013. Retrospective Analysis of Midsummer Hypoxic Area and Volume in the Northern Gulf of Mexico, 1985-2011. *Environmental Science & Technology* 47: 9808-9815.

Sinigalliano, C.D., M.L. Gidley, T. Shibata, D. Whitman, T.H. Dixon, E.A. Laws, A. Hou, D. Bachoon, L. Brand, L. Amaral-Zettler, R.J. Gast, G.F. Steward, O.D. Nigro, R.S. Fujioka, W.Q. Betancourt, G. Vithanage, J. Mathews, L.E. Fleming, and H. Solo-Gabriele. 2007. Impacts of hurricanes Katrina and Rita on the microbial landscape of the New Orleans area. *Proceedings of the National Academy of Sciences, USA* 104: 9029-9034.

Turner, R.E., and N.N. Rabalais. 2013. Nitrogen and phosphorus phytoplankton growth limitation in the northern Gulf of Mexico. *Aquatic Microbial Ecology* 68: 159-169.

Turner, R.E., N.N. Rabalais, and D. Justic. 2012. Predicting summer hypoxia in the northern Gulf of Mexico: Redux. *Marine Pollution Bulletin* 64: 319-324.

Williams, C.J., Boyer, J.N., and Jochem, F.J. 2007. Indirect Hurricane Effects on Resource Availability and Microbial Communities in a Subtropical Wetland-Estuary Transition Zone, *Estuaries and Coasts*: J CERF (2008) 31:204-214.

Appendix A: Nutrient Concentration Data

Table A.1: AB1 Summary of Concentrations of Phosphate Pre and Post storm

AB1 Phosphate Concentrations (µMol/L)		
Pre storm (April 29)	Pre storm (May 24)	Post storm (June 29)
0.1556	0.1792	0.0522
0.1674	0.1635	0.0580
0.1552	0.1659	0.0412

Table A.2: AB1 Summary of Concentrations of Nitrate Pre and Post storm

AB1 Nitrate Concentrations (µMol/L)		
Pre storm (April 29)	Pre storm (May 24)	Post storm (June 29)
36.3663	36.0153	19.9485
32.6986	21.4552	17.1870
33.6849	25.3528	17.1104
34.6972	22.2998	18.6467
35.4832	28.5460	18.3298

Table A.3: AB1 Summary of Concentrations of Silicate Pre and Post storm

AB1 Silicate Concentrations (µMol/L)		
Pre storm (April 29)	Pre storm (May 24)	Post storm (June 29)
160.1619	161.6185	203.6156
170.2668	172.6680	205.8889
170.0178	170.1780	205.2654

Table A.4: AB1 Summary of Concentrations of Chlorophyll Pre and Post storm

AB1 Chlorophyll Concentrations (αgL¯¹)		
Pre storm (April 29)	Pre storm (May 24)	Post storm (June 29)
6.6641	5.0337	10.8691
2.3298	3.2473	9.8743
8.0172	4.5819	8.4592
8.3813	4.8938	9.9511
8.3746	4.9773	10.2636
8.9400	3.8927	10.4561
7.7445	3.5689	10.4838

Table A.5: AB2 Summary of Concentrations of Phosphate Pre and Post storm

AB2 Phosphate Concentrations (µMol/L)	
Pre storm (May 24)	Post storm (June 29)
0.1058	0.0464
0.1063	0.0402
0.1108	0.0423

Table A.6: AB2 Summary of Concentrations of Nitrates Pre and Post storm

AB2 Nitrate Concentrations (µMol/L)	
Pre storm (May 24)	Post storm (June 29)
33.2854	19.8520
25.2952	18.5253
28.5736	17.3677

Table A.7: AB2 Summary of Concentrations of Silicate Pre and Post storm

AB2 Silicate Concentrations (µMol/L)	
Pre storm (May 24)	Post storm (June 29)
153.8733	287.8724
173.9783	256.8764
156.8724	214.1302
149.9843	239.4672
187.7362	245.7282

Table A.8: AB2 Summary of Concentrations of Chlorophyll Pre and Post storm

AB2 Chlorophyll Concentrations (αgL^{-1})	
Pre storm (May 24)	Post storm (June 29)
3.8738	8.8722
4.7482	8.0782
5.7832	9.5421
4.8712	8.3787
4.3872	10.3414
4.6738	11.7582
5.0231	10.4838

Table A.9: VB Summary of Concentrations of Phosphate Pre and Post storm

VB Phosphate Concentrations (µMol/L)			
Pre storm (May 15)	Pre storm (June 21)	Pre storm (Aug 26)	Post storm (Sept 3)
0.0428	0.0313	0.0134	0.0115
0.0427	0.0305	0.0143	0.0119
0.0427	0.0301	0.0125	0.0119
0.0422	0.0313	0.0146	0.0120
0.0427	0.3050	0.0148	0.0119
0.0427	0.0301	0.0146	0.0096
0.0425	0.0320	0.0150	0.0122
0.0425	0.0342	0.0149	0.0120

Table A.10: VB Summary of Concentrations of Nitrate Pre and Post storm

VB Nitrate Concentrations (µMol/L)			
Pre storm (May 15)	Pre storm (June 21)	Pre storm (Aug 26)	Post storm (Sept 3)
28.4088	24.6256	14.2724	7.9154
29.0856	24.6273	14.2723	7.9153
27.7728	25.9721	14.2722	7.9152
27.7728	23.8501	15.8721	7.7543

Table A.11: VB Summary of Concentrations of Silicate Pre and Post storm

VB Silicates Concentrations (µMol/L)			
Pre storm (May 15)	Pre storm (June 21)	Pre storm (Aug 26)	Post storm (Sept 3)
219.5078	216.5898	163.7623	185.6201
220.8812	171.9794	172.2284	178.9320
219.8969	186.9390	173.3606	165.2135
220.2393	198.7548	167.9654	179.6754
219.9825	206.7544	165.3576	180.6479

Table A.12: VB Summary of Concentrations of Ammonia Pre and Post storm

VB Ammonia Concentrations (µMol/L)			
Pre storm (May 15)	Pre storm (June 21)	Pre storm (Aug 26)	Post storm (Sept 3)
4.3854	4.3642	3.4338	0.5565
4.9753	4.6313	3.5188	0.4832
4.7976	4.2753	3.5039	0.4162
4.6425	4.1789	3.5862	0.4622

Table A.13: VB Summary of Concentrations of Chlorophyll Pre and Post storm

VB Chlorophyll Concentrations (αgL^{-1})			
Pre storm (May 15)	Pre storm (June 21)	Pre storm (Aug 26)	Post storm (Sept 3)
26.9684	20.1204	23.1893	41.8963
26.9831	20.3489	23.1729	41.0157
25.9321	19.8612	22.9683	40.6013
24.8921	19.7613	22.8639	39.8314

Table A.14: MB1 Summary of Concentrations of Phosphate Pre and Post storm

MB1 Phosphate Concentrations (µMol/L)				
Pre storm (April 29)	Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
0.1257	0.0865	0.0536	0.0435	0.0236
0.1065	0.0732	0.0649	0.0388	0.0309
0.0953	0.0895	0.0643	0.0418	0.0283
0.0942	0.9540	0.0488	0.0472	0.0327
0.0983	0.0853	0.0765	0.0980	0.0356
0.1089	0.0986	0.0656	0.0974	0.0352
0.1163	0.0834	0.0864	0.0980	0.0338
0.1127	0.0934	0.0754	0.1005	0.0348

Table A.15: MB1 Summary of Concentrations of Nitrate Pre and Post storm

MB1 Nitrate Concentrations (µMol/L)				
Pre storm (April 29)	Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
1.6861	1.1904	1.2128	0.6967	0.5185
1.5954	0.9761	1.4110	0.7146	0.5684
1.6438	1.1051	1.3765	0.7293	0.5372

Table A.16: MB1 Summary of Concentrations of Silicate Pre and Post storm

MB1 Silicates Concentrations (µMol/L)				
Pre storm (April 29)	Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
165.8088	160.9143	113.4325	59.9008	71.8374
163.2254	160.9571	111.7790	69.8415	71.7518
164.8643	163.3927	110.9775	69.3240	77.0353

Table A.17: MB1 Summary of Concentrations of Ammonia Pre and Post storm

MB1 Ammonia Concentrations (µMol/L)				
Pre storm (April 29)	Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
1.8527	1.7539	1.7698	1.0669	0.2322
1.9621	1.7484	1.7547	0.8019	0.3086
1.8652	1.8473	1.7543	0.7560	0.2837
1.9075	1.8737	1.5754	0.7076	0.3016
1.9013	1.7842	1.5784	0.7045	0.2965

Table A.18: MB1 Summary of Concentrations of Chlorophyll Pre and Post storm

MB1 Chlorophyll Concentrations ($\alpha g L^{-1}$)				
Pre storm (April 29)	Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
7.1715	6.4146	5.8653	6.1963	8.6321
5.3846	9.4593	7.9567	6.2136	9.6134
5.4080	6.3798	7.2342	5.8923	10.0134
4.4147	8.5605	6.8235	5.8743	8.9682
7.0234	3.6495	6.8765	5.9754	9.7654

Table A.19: MB2 Summary of Concentrations of Phosphate Pre and Post storm

MB2 Phosphate Concentrations (µMol/L)			
Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
0.6367	0.7853	0.8025	0.0293
0.5321	0.7643	0.3820	0.0370
0.8753	0.6865	0.5403	0.0374
0.7543	0.7638	0.3406	0.0327
0.4768	0.8372	0.6779	0.0424
0.5343	0.7215	0.8556	0.0471
0.6434	0.6428	0.6261	0.0414
0.6179	0.7426	0.6947	0.0394
0.7248	0.7421	0.5983	0.0598

Table A.20: MB2 Summary of Concentrations of Nitrate Pre and Post storm

MB2 Nitrate Concentrations (µMol/L)			
Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
7.1231	6.6868	7.0389	5.2014
7.4063	6.6782	7.5870	5.2653
7.2079	6.6983	7.9468	5.1298

Table A.21: MB2 Summary of Concentrations of Silicate Pre and Post storm

MB2 Silicate Concentrations (µMol/L)			
Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
100.6941	103.0017	62.1068	82.0154
102.3512	97.5469	66.6239	83.0775
99.8943	98.4184	63.9549	84.6999

Table A.22: MB2 Summary of Concentrations of Ammonia Pre and Post storm

MB2 Ammonia Concentrations (µMol/L)			
Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
1.6854	1.6987	0.6547	0.3811
1.6986	1.7532	0.6336	0.4497
1.6643	1.6532	0.6079	0.4271
1.6323	1.6432	0.5791	0.4902
1.7421	1.6544	0.7232	0.4941

Table A.23: MB2 Summary of Concentrations of Chlorophyll Pre and Post Storm

MB2 Chlorophyll Concentrations (µMol/L)			
Pre storm (May 25)	Pre storm (July 1)	Pre storm (Aug 27)	Post storm (Sept 4)
7.7724	6.9784	5.7872	9.7865
4.8787	7.9230	5.9789	10.7327
5.8738	6.9783	5.2345	11.5726
6.9748	5.8782	5.7863	9.4843
4.9873	5.1249	4.7932	9.9742

Appendix B: Analysis of Inorganic Nutrients Variation Pre vs. Post Disturbance

Table B.1: Statistical Results for Variation of Phosphate Concentrations at sit AB1 (Tropical Storm Debby)

Sample Dates: 4/29/2012 & 5/24/2012 & 6/29/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	4.89E-02	Accept
Nested	Fsgroups	0.17261	Accept

Table B.2: Statistical Results for Variation of Nitrates Concentrations at site AB1 (Tropical Storm Debby)

Sample Dates: 4/29/2012 & 5/24/2012 & 6/29/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	3.66E-01	Accept
Nested	Fsgroups	0.020885	Reject

Table B.3: Statistical Results for Variation of Silicates Concentrations at site AB1 (Tropical Storm Debby)

Sample Dates: 4/29/2012 & 5/24/2012 & 6/29/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	1.97E-02	Reject
Nested	Fsgroups	0.74254	Accept

Table B.4: Statistical Results for Variation of Chlorophyll Concentrations at site AB1 (Tropical Storm Debby)

Sample Dates: 4/29/2012 & 5/24/2012 & 6/29/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	3.37E-01	Accept
Nested	Fsgroups	0.0014884	Reject

Table B.5: Statistical Results for Variation of Phosphate Concentrations at site AB2 (Tropical Storm Debby)

Sample Dates: 5/24/2012 & 6/29/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
ANOVA	Normal	1.16E-05	Reject
Kruskal Wallis	Non-normal	0.0495	Reject

Table B.6: Statistical Results for Variation of Nitrate Concentrations at site AB2 (Tropical Storm Debby)

Sample Dates: 5/24/2012 & 6/29/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
ANOVA	Normal	0.0126	Reject
Kruskal Wallis	Non-normal	0.0495	Reject

Table B.7: Statistical Results for Variation of Silicate Concentrations at site AB2 (Tropical Storm Debby)

Sample Dates: 5/24/2012 & 6/29/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
ANOVA	Normal	0.0003	Reject
Kruskal Wallis	Non-normal	0.009	Reject

Table B.8: Statistical Results for Variation of Chlorophyll Concentrations at site AB2 (Tropical Storm Debby)

Sample Dates: 5/24/2012 & 6/29/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
ANOVA	Normal	1.14E-06	Reject
Kruskal Wallis	Non-normal	0.0017	Reject

Table B.9: Statistical Results for Variation of Phosphate Concentrations at site VB (Hurricane Isaac)

Sample Dates: 5/15/2012 & 6/21/2012 & 8/26/2012 & 9/3/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	3.40E-01	Accept
Nested	Fsgroups	3.18E-12	Reject

Table B.10: Statistical Results for Variation of Nitrate Concentrations at site VB (Hurricane Isaac)

Sample Dates: 5/15/2012 & 6/21/2012 & 8/26/2012 & 9/3/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	2.13E-01	Accept
Nested	Fsgroups	6.05E-12	Reject

Table B.11: Statistical Results for Variation of Silicate Concentrations at site VB (Hurricane Isaac)

Sample Dates: 5/15/2012 & 6/21/2012 & 8/26/2012 & 9/3/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	6.27E-01	Accept
Nested	Fsgroups	1.36E-06	Reject

Table B.12: Statistical Results for Variation of Ammonia Concentrations at site VB (Hurricane Isaac)

Sample Dates: 5/15/2012 & 6/21/2012 & 8/26/2012 & 9/3/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	3.45E-02	Reject
Nested	Fsgroups	8.36E-07	Reject

Table B.13: Statistical Results for Variation of Chlorophyll Concentrations at site VB (Hurricane Isaac)

Sample Dates: 5/15/2012 & 6/21/2012 & 8/26/2012 & 9/3/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	3.80E-02	Reject
Nested	Fsgroups	9.26E-08	Reject

Table B.14: Statistical Results for Variation of Phosphate Concentrations at site MB1 (Hurricane Isaac)

Sample Dates: 4/29/2012 & 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	8.87E-02	Accept
Nested	Fsgroups	3.16E-05	Reject

Table B.15: Statistical Results for Variation of Nitrates Concentrations at site MB1 (Hurricane Isaac)

Sample Dates: 4/29/2012 & 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	2.33E-01	Accept
Nested	Fsgroups	1.60E-07	Reject

Table B.16: Statistical Results for Variation of Silicates Concentrations at site MB1

Sample Dates: 4/29/2012 & 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	3.87E-01	Accept
Nested	Fsgroups	5.91E-14	Reject

Table B.17: Statistical Results for Variation of Ammonia Concentrations at site MB1

Sample Dates: 4/29/2012 & 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	4.89E-02	Accept
Nested	Fsgroups	3.25E-14	Reject

Table B.18: Statistical Results for Variation of Chlorophyll Concentrations at site MB1

Sample Dates: 4/29/2012 & 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	1.81E-02	Reject
Nested	Fsgroups	0.38692	Accept

Table B.19: Statistical Results for Variation of Phosphate Concentrations at site MB2

Sample Dates: 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	1.53E-02	Reject
Nested	Fsgroups	0.04607	Accept

Table B.20: Statistical Results for Variation of Nitrate Concentrations at site MB2 (Hurricane Isaac)

Sample Dates: 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	5.79E-02	Accept
Nested	Fsgroups	0.0082544	Reject

Table B.21: Statistical Results for Variation of Silicate Concentrations at site MB2

Sample Dates: 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	8.54E-01	Accept
Nested	Fsgroups	2.84E-08	Reject

Table B.22: Statistical Results for Variation of Ammonia Concentrations at site MB2

Sample Dates: 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	3.30E-01	Accept
Nested	Fsgroups	1.11E-16	Reject

Table B.23: Statistical Results for Variation of Chlorophyll Concentrations at site MB2

Sample Dates: 5/25/2012 & 7/1/2012 & 8/27/2012 & 9/4/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
Nested	Fgroups	2.00E-02	Reject
Nested	Fsgroups	0.249	Accept

Appendix C: Parameters of Interest

Table C.1: Parameter Results at site AB1 (Seasonal)

AB1				
Dates	Temp(°C)	pH	Salinity(ppt)	BOD(ppm)
29-Apr-12	24.4	7.7	5	1.15
24-May-12	30.6	5.8	6	1.60
29-Jun-12	28	6.5	4	2.13

Table C.2: Statistical Results

AB1	Temp	pH	Salinity	BOD
Mean	27.1	6.7	5	1.63
Standard Deviation	2.54	0.76	0.82	0.04

Table C.3: Parameter Results at site AB2 (Seasonal)

AB2				
Dates	Temp(°C)	pH	Salinity(ppt)	BOD(ppm)
24-May-12	30	6.7	8	2.00
29-Jun-12	28.2	6.9	4	1.4

Table C.4: Statistical Results

AB2	Temp	pH	Salinity	BOD
Mean	29.1	6.8	5	1.63
Standard Deviation	2.54	0.14	0.82	0.04

Table C.5: Parameter Results at site MB1 (Seasonal)

MB1				
Dates	Temp(°C)	pH	Salinity(ppt)	BOD(ppm)
29-Apr-12	27.1	8.6	3	3.43
25-May-12	31.6	8.9	3	4.66
1-Jul-12	31.9	8.9	7	2.13
27-Aug-12	30.8	7.4	3	2.60
4-Sep-12	31	7.4	5	2.44

Table C.6: Statistical Results

MB1	Temp	pH	Salinity	BOD
Mean	30.5	8.24	4.2	3.05
Standard Deviation	1.74	0.69	1.6	0.91

Table C.7: Parameter Results at site MB2 (Seasonal)

MB2				
Dates	Temp(°C)	pH	Salinity(ppt)	BOD(ppm)
25-May-12	30.2	7.9	5	1.92
1-Jul-12	33	8.1	10	2.23
27-Aug-12	29.8	7.7	6	1.70
4-Sep-12	30	7.7	6	1.9

Table C.8: Statistical Results

MB2	Temp	pH	Salinity	BOD
Mean	30.75	7.85	6.75	1.94
Standard Deviation	1.31	0.69	1.6	0.91

Table C.9: Parameter Results at site GB1 (Seasonal)

GB1				
Dates	Temp(°C)	pH	Salinity(ppt)	BOD(ppm)
14-May-12	31.4	8.6	10	3.85
17-Jun-12	33.8	8.3	10	4.47

Table C.10: Statistical Results

GB1	Temp	pH	Salinity	BOD
Mean	30.75	7.85	6.75	1.94
Standard Deviation	1.31	0.69	1.6	0.91

Table C.11: Parameter Results at site VB (Seasonal)

VB				
Dates	Temp(°C)	pH	Salinity(ppt)	BOD(ppm)
15-May-12	27.7	7.4	1	1.30
21-Jun-12	28.2	7.1	5	2.08
26-Aug-12	31.2	6.9	0	1.60
3-Sep-12	32.4	6.9	1	0.16

Table C.12: Statistical Results

VB	Temp	pH	Salinity	BOD
Mean	29.9	7.1	2.3	1.3
Standard Deviation	2	0.1	2	0.7

Appendix D: Seasonal Comparisons (Date Consideration)

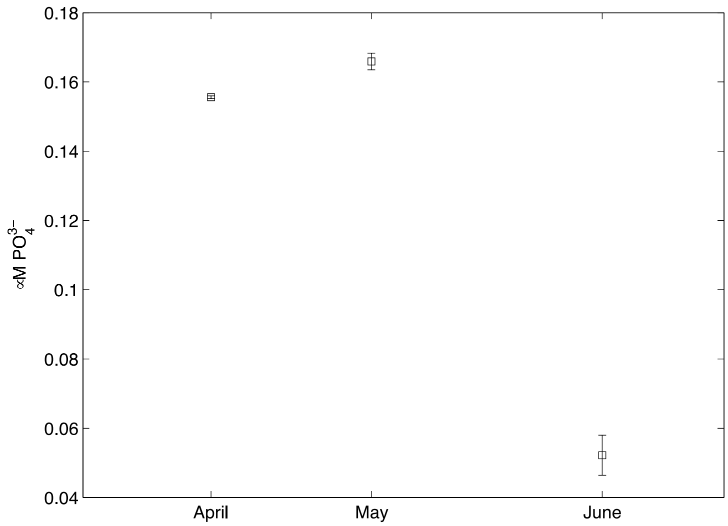

Figure D.1: AB1 Phosphate Analysis

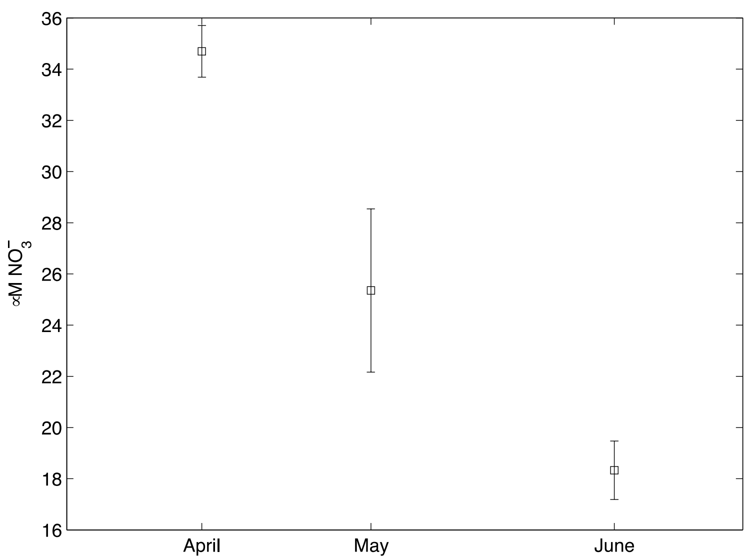

Figure D.2: AB1 Nitrate Analysis

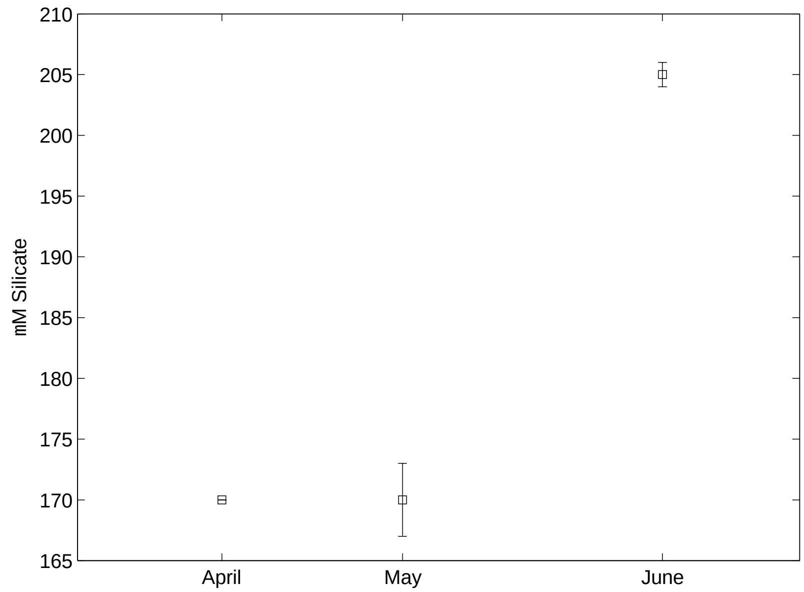

Figure D.3: AB1 Silicate Analysis

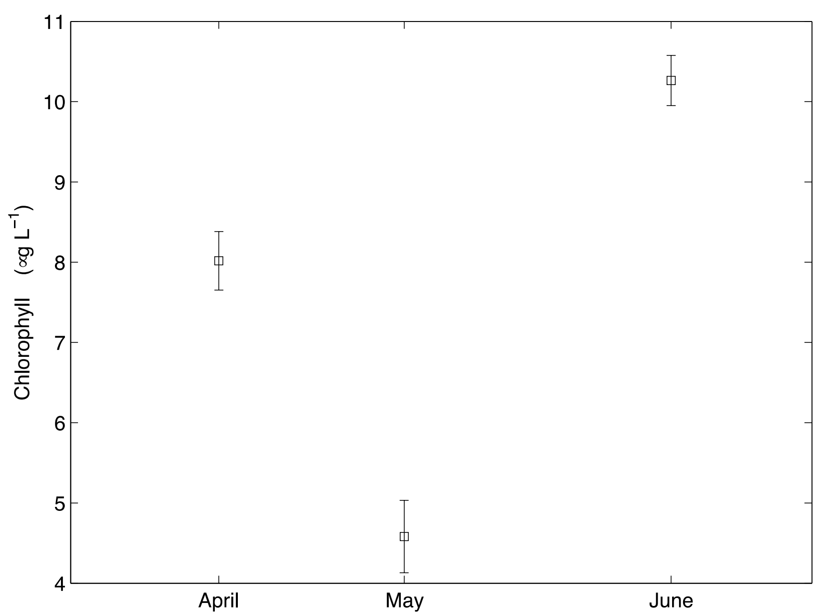

Figure D.4: AB1 Chlorophyll Analysis

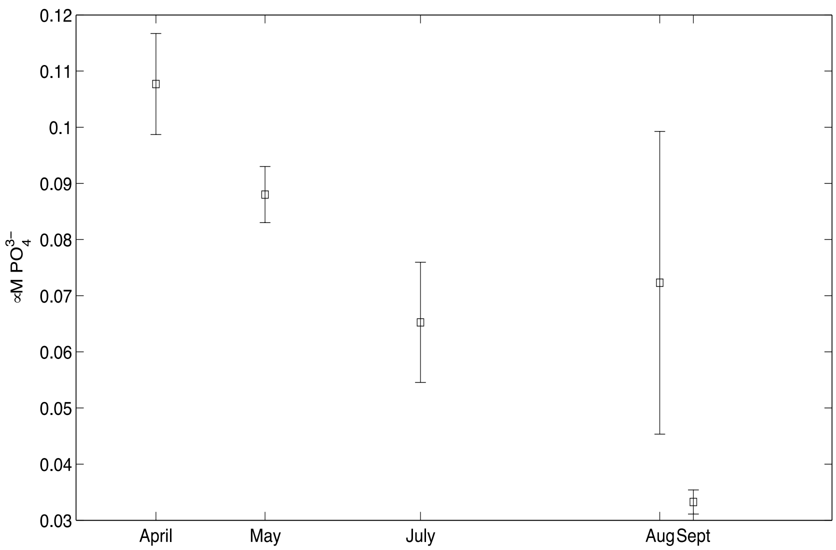

Figure D.5: MB1 Phosphate Analysis

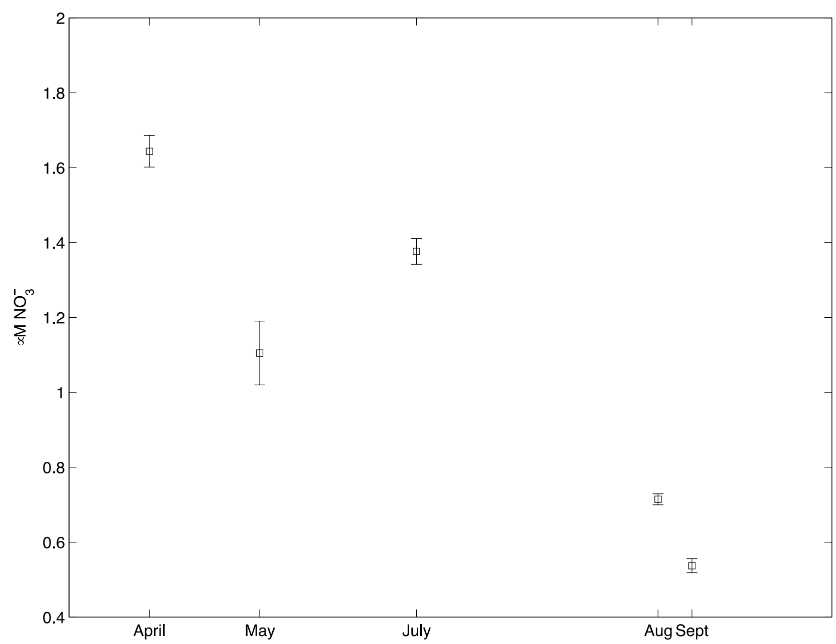

Figure D.6: MB1 Nitrate Analysis

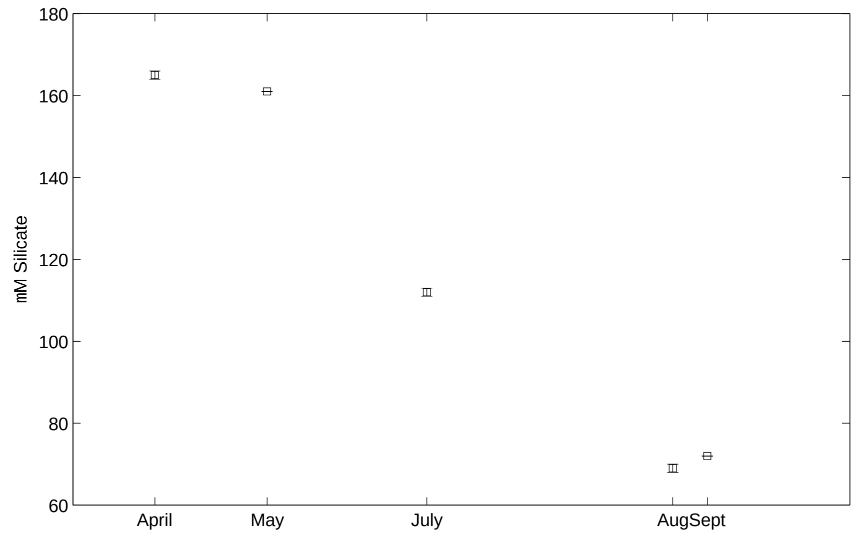

Figure D.7: MB1 Silicate Analysis

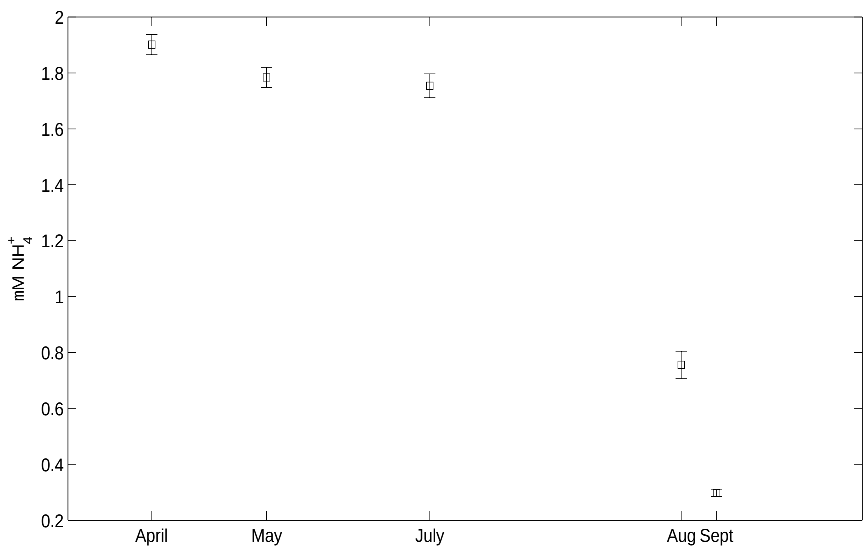

Figure D.8: MB1 Ammonia Analysis

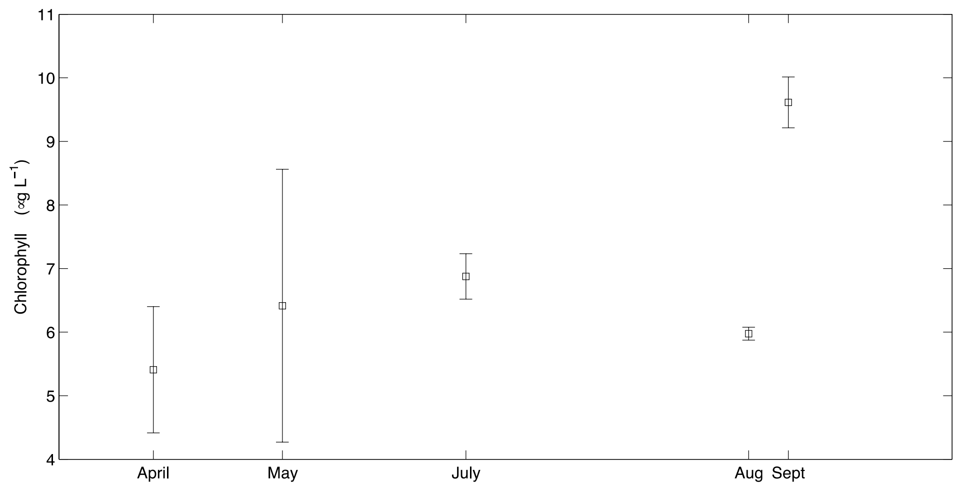

Figure D.9: MB1 Chlorophyll Analysis

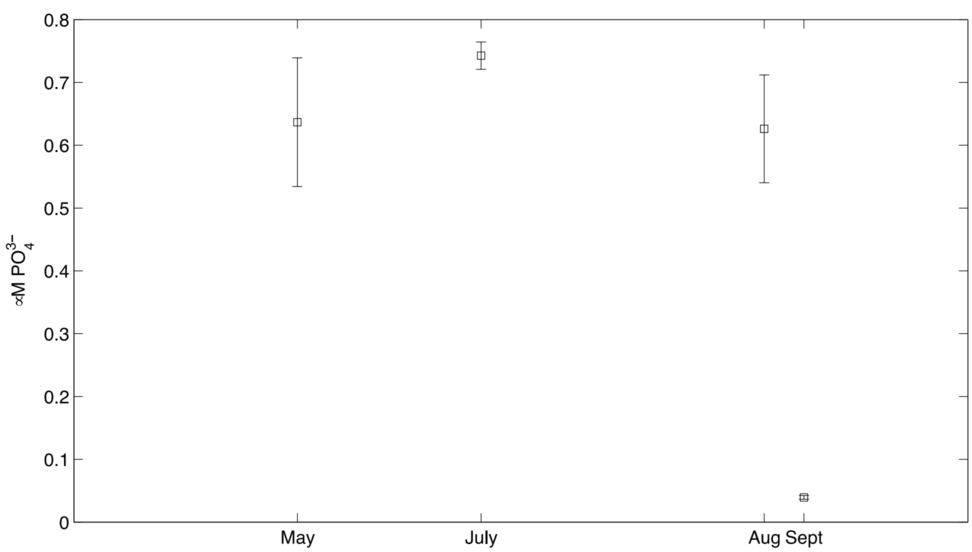

Figure D.10: MB2 Phosphate Analysis

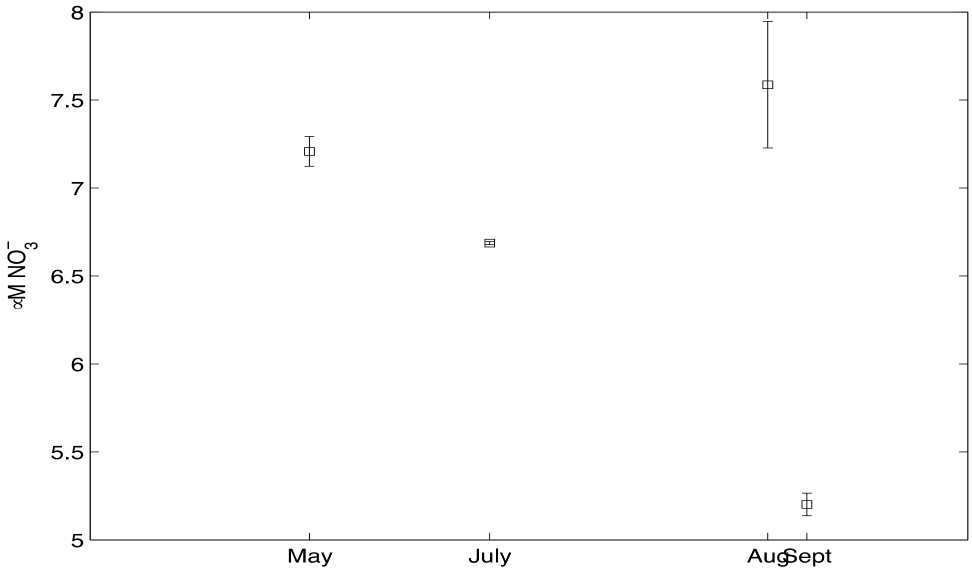

Figure D.11: MB2 Nitrate Analysis

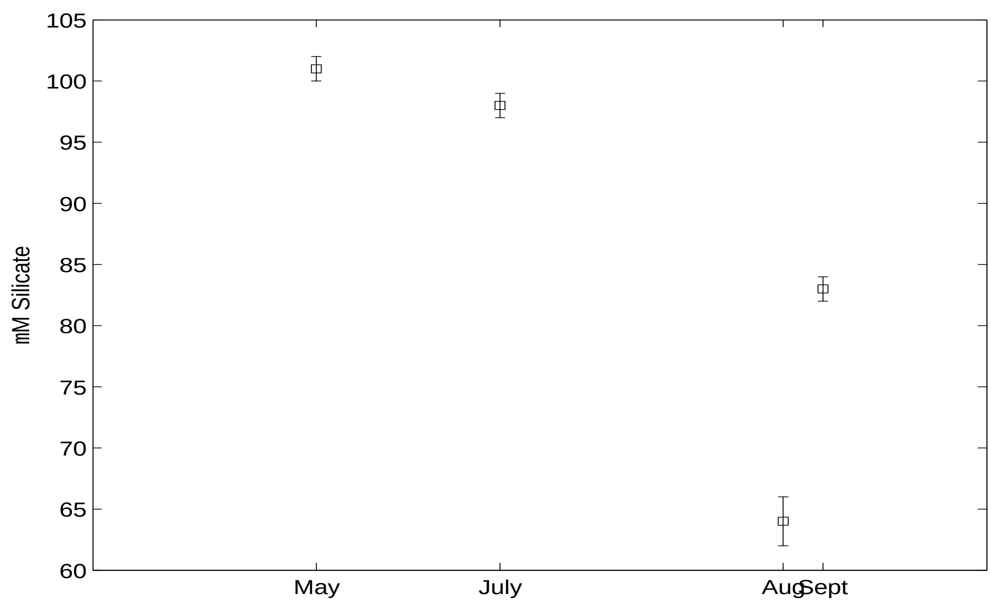

Figure D.12: MB2 Silicate Analysis

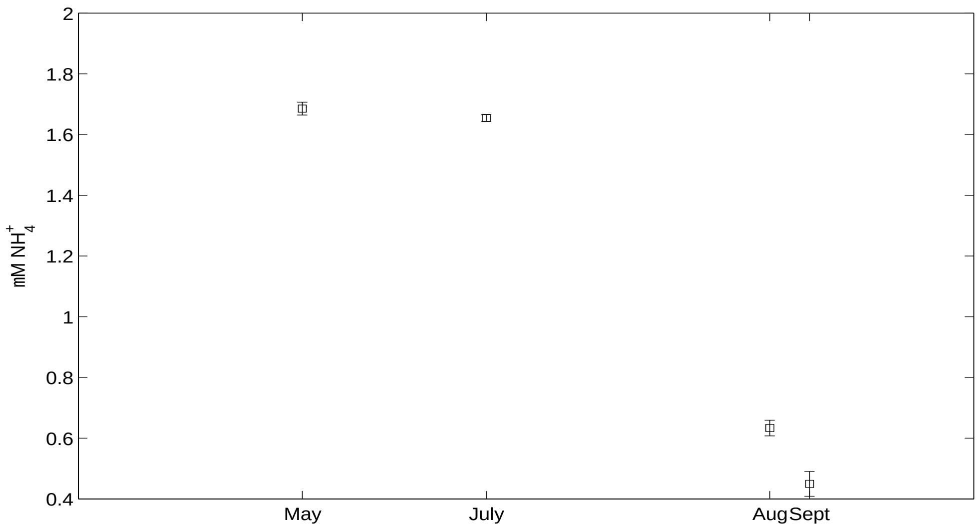

Figure D.13: MB2 Ammonia Analysis

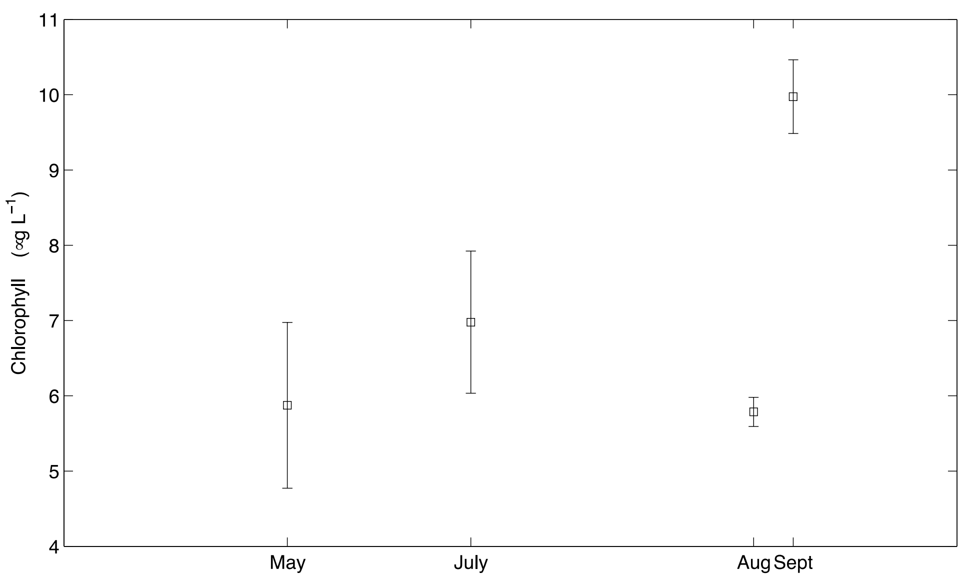

Figure D.14: MB2 Chlorophyll Analysis

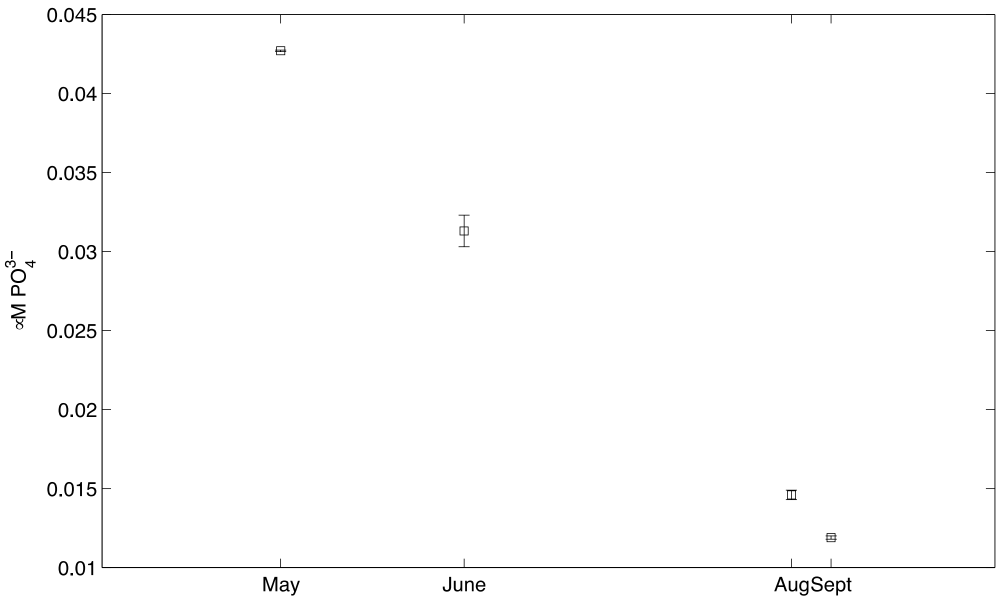

Figure D.15: VB Phosphate Analysis

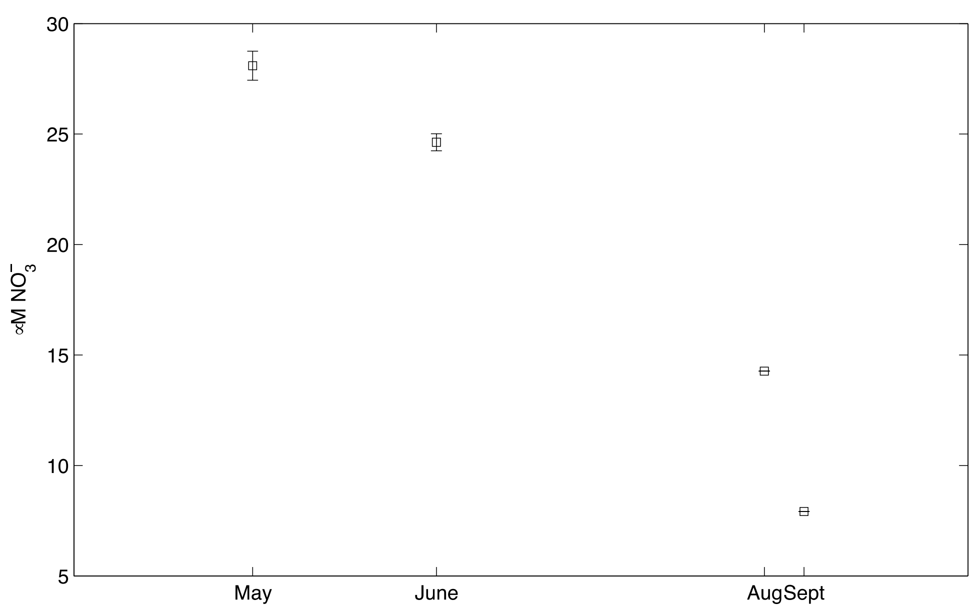

Figure D.16: VB Nitrate Analysis

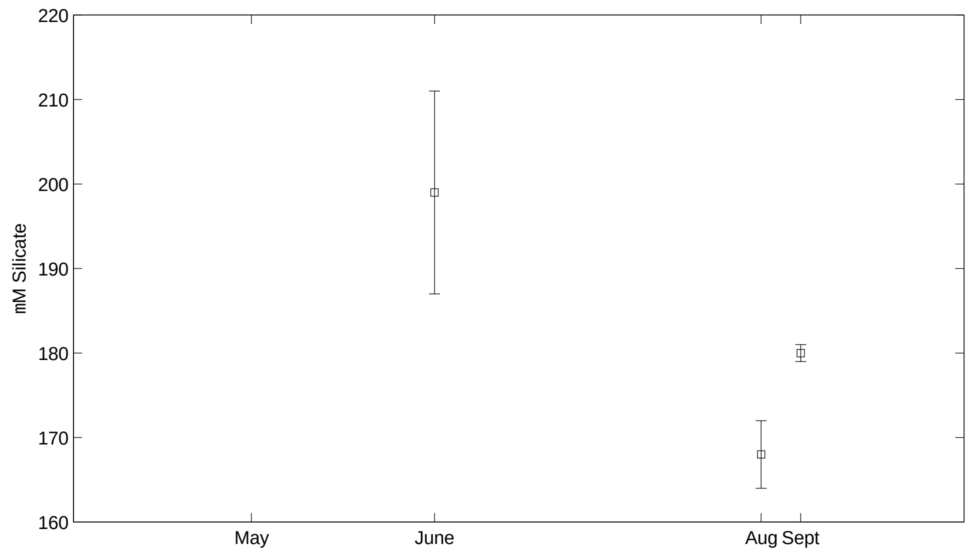

Figure D.17: VB Silicate Analys

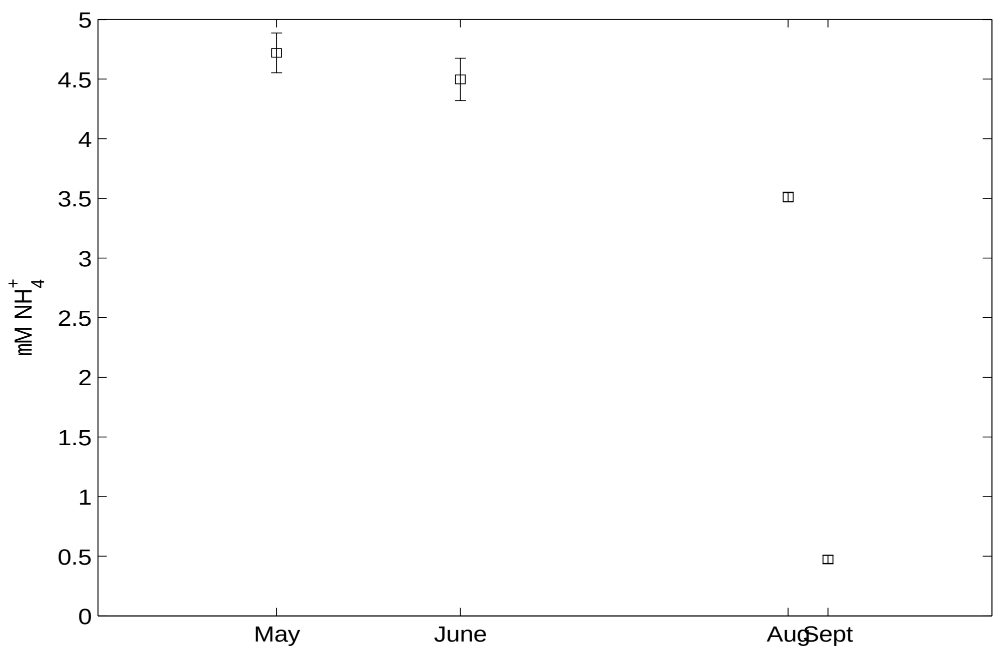

Figure D.18: VB Ammonia Analysis

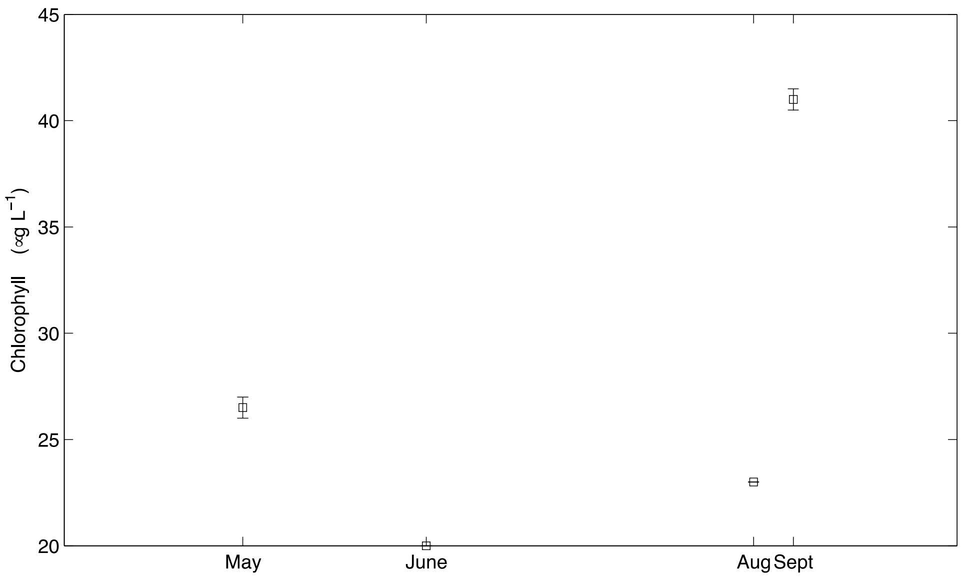

Figure D.19: VB Chlorophyll Analysis

Appendix E: Seasonal Mean Comparisons

Table E.1: VB Phosphate Seasonal Mean Comparison

ANOVA Between Group Analysis		
Group#	Dates	
1	(15-May)	All groups have means significantly different from group #1
2	(21-June)	Groups #1 and #4 have means significantly different from group #2
3	(26-Aug)	Groups #1 and #4 have means significantly different from group #3
4	(3-Sept)	All groups have means significantly different from group #4

Table E.2: VB Phosphate Seasonal Mean Comparison

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(15-May)	Group #4 has a mean significantly different from group #1
2	(6-June)	Group #4 has a mean significantly different from group #2
3	(26-Aug)	No groups have means significantly different from group #3.
4	(3-Sept)	Groups #1 & 2 have means significantly different from group #4

Table E.3: VB Nitrate Seasonal Mean Comparison

ANOVA Between Group Analysis		
Group#	Dates	
1	(15-May)	The means of group #1 and #4 are significantly different
2	(21-June)	No groups have means significantly different from group #2
3	(26-Aug)	No groups have means significantly different from group #3
4	(3-Sept)	The means of group #1 and #4 are significantly different

Table E.4: VB Nitrate Seasonal Mean Comparison

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(15-May)	Group #4 has a mean significantly different from group #1
2	21-June)	No groups have means significantly different from group #2
3	(26-Aug)	No groups have means significantly different from group #3
4	(3-Sept)	Group #1 has a mean significantly different from group #4

Table E.5: VB Silicate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(15-May)	Groups #3 and #4 have means significantly different from group #1
2	(21-June)	No groups have means significantly different from group #2
3	(26-Aug)	The means of group #1 and #3 are significantly different
4	(9-Sept)	The means of group #1 and #4 are significantly different

Table E.6: VB Silicate Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(15-May)	Groups #3 and #4 have means significantly different from group #1
2	(21-June)	No groups have means significantly different from group #2
3	(26-Aug)	The means of groups #1 and #3 are significantly different
4	(3-Sept)	The means of groups #1 and #4 are significantly different

Table E.7: VB Chlorophyll Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(15-May)	All groups have means significantly different from group #1
2	21-June)	No groups have means significantly different from group #2
3	(26-Aug)	No groups have means significantly different from group #3
4	(3-Sept)	All groups have means significantly different from group #4

Table E.8: VB Chlorophyll Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(15-May)	Group #4 has a mean significantly different from group #1
2	(21-June)	Groups #1 and #4 have means significantly different from group #2
3	(26-Aug)	Groups #1 and #4 have means significantly different from group #3
4	(3-Sept)	Group #1 has a mean significantly different from group #4

Table E.9: MB1 Phosphate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(29-April)	Groups #2, #3 & #5 have means significantly different from group #1
2	(25-May)	Group #1 has a mean significantly different from group #2
3	(1-July)	Group #1 has a mean significantly different from group #3
4	(27-Aug)	Group #5 has a mean significantly different from group #4
5	(4-Sept)	Groups #1 & #4 have means significantly different from group #5

Table E.10: MB1 Phosphate Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(29-April)	Group #5 has a mean significantly different from group #1
2	(25-May)	No groups have means significantly different from group #2
3	(1-July)	No groups have means significantly different from group #3
4	(27-Aug)	No groups have means significantly different from group #4
5	(4-Sept)	Group #1 has a mean significantly different from group #5

Table E.11: MB1 Nitrate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(29-April)	Groups #2, #3 & #5 have means significantly different from group #1
2	(25-May)	Group #1 has a mean significantly different from group #2
3	(1-July)	Group #1 has a mean significantly different from group #3
4	(27-Aug)	Group #5 has a mean significantly different from group #4
5	(4-Sept)	Groups #1 & #4 have means significantly different from group #5

Table E.12: MB1 Nitrate Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(29-April)	Group #5 has a mean significantly different from group #1
2	(25-May)	No groups have means significantly different from group #2
3	(1-July)	No groups have means significantly different from group #3
4	(27-Aug)	No groups have means significantly different from group #4
5	(4-Sept)	Group #1 has a mean significantly different from group #5

Table E.13: MB1 Silicate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(29-April)	Groups #3, #4 & #5 have means significantly different from group #1
2	(25-May)	Groups #3, #4 & #5 have means significantly different from group #2
3	(1-July)	All groups have means significantly different from group #3
4	(27-Aug)	Groups #1, #2 & #3 have means significantly different from group #4
5	(4-Sept)	Groups #1, #2 & #3 have means significantly different from group #5

Table E.14: MB1 Silicate Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(29-April)	Group #4 has a mean significantly different from group #1
2	(25-May)	No groups have means significantly different from group #2
3	(1-July)	No groups have means significantly different from group #3
4	(27-Aug)	Group #1 has a mean significantly different from group #4
5	(4-Sept)	No groups have means significantly different from group #5

Table E.15: MB1 Ammonia Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(29-April)	Groups #4 & #5 have means significantly different from group #1
2	(25-May)	No groups have means significantly different from group #2
3	(1-July)	No groups have means significantly different from group #3
4	(27-Aug)	Group #1 has a mean significantly different from group #4
5	(4-Sept)	Groups #1 have means significantly different from group #5

Table E.16: MB1 Ammonia Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(29-April)	Groups #4 & #5 have means significantly different from group #1
2	(25-May)	No groups have means significantly different from group #2
3	(1-July)	No groups have means significantly different from group #3
4	(27-Aug)	Group #1 has a mean significantly different from group #4
5	(4-Sept)	Groups #1 have means significantly different from group #5

Table E.17: MB1 Ammonia Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(29-April)	All groups have means significantly different from group #1
2	(25-May)	Groups #1 & #5 have means significantly different from group #2
3	(1-July)	Groups #1 & #5 have means significantly different from group #3
4	(27-Aug)	Groups #1 & #5 have means significantly different from group #4
5	(4-Sept)	All groups have means significantly different from group #5

Table E.18: MB1 Ammonia Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(29-April)	Group #5 has a mean significantly different from group #1
2	(25-May)	No groups have means significantly different from group #2
3	(1-July)	No groups have means significantly different from group #3
4	(27-Aug)	No groups have means significantly different from group #4
5	(4-Sept)	Groups #1 have means significantly different from group #5

Table E.19: MB2 Phosphate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(25-May)	Group #4 has a mean significantly different from group #1
2	(1-July)	Groups #1 and #4 have means significantly different from group #2
3	(27-Aug)	Group #4 has a mean significantly different from group #3
4	(4-Sept)	Group #3 has a mean significantly different from group #4

Table E.20: MB2 Phosphate Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(25-May)	The means of group #1 and #4 are significantly different
2	(1-July)	No groups have means significantly different from group #2
3	(27-Aug)	No groups have means significantly different from group #3
4	(4-Sept)	The means of group #1 and #4 are significantly different

Table E.21: MB2 Nitrate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(25-May)	All groups have means significantly different from group #1
2	(1-July)	All groups have means significantly different from group #2
3	(27-Aug)	All groups have means significantly different from group #3
4	(4-Sept)	All groups have means significantly different from group #4

Table E.22: MB2 Nitrate Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(25-May)	The means of group #1 and #4 are significantly different
2	(1-July)	No groups have means significantly different from group #2
3	(27-Aug)	No groups have means significantly different from group #3
4	(4-Sept)	The means of group #1 and #4 are significantly different

Table E.23: MB2 Silicate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(25-May)	Groups #3 & #4 have means significantly different from group #1
2	(1-July)	Groups #3 & #4 have means significantly different from group #2
3	(27-Aug)	All groups have means significantly different from group #3
4	(4-Sept)	All groups have means significantly different from group #4

Table E.24: MB2 Silicate Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(25-May)	The means of group #1 and #3 are significantly different
2	(1-July)	No groups have means significantly different from group #2
3	(27-Aug)	The means of group #1 and #3 are significantly different
4	(4-Sept)	No groups have means significantly different from group #4

Table E.25: AB1 Phosphate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(29-April)	No groups have means significantly different from group #1
2	(24-May)	Group #2 has a mean significantly different from group #3
3	(29-June)	Group #3 has a mean significantly different from group #2

Table E.26: AB1 Phosphate Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(29-April)	No groups have means significantly different from group #1
2	(24-May)	No groups have means significantly different from group #2
3	(29-June)	No groups have means significantly different from group #3

Table E.27: AB1 Nitrate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(29-April)	All groups have means significantly different from group #1
2	(24-May)	All groups have means significantly different from group #2
3	(29-June)	All groups have means significantly different from group #3

Table E.28: AB1 Nitrate Seasonal Mean Comparison (Kruskal Wallis)

ANOVA Between Group Analysis		
Group#	Dates	
1	(29-April)	All groups have means significantly different from group #1
2	(24-May)	All groups have means significantly different from group #2
3	(29-June)	All groups have means significantly different from group #3

Table E.29: AB1 Silicate Seasonal Mean Comparison (ANOVA)

ANOVA Between Group Analysis		
Group#	Dates	
1	(29-April)	All groups have means significantly different from group #1
2	(24-May)	Group #3 has a mean significantly different from group #2
3	(29-June)	Group #2 has a mean significantly different from group #3

Table E.30: AB1 Silicate Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(29-April)	No groups have means significantly different from group #1
2	(24-May)	No groups have means significantly different from group #2
3	(29-June)	No groups have means significantly different from group #3

Table E.31: AB1 Chlorophyll Seasonal Mean Comparison (Kruskal Wallis)

Kruskal Wallis Between Group Analysis		
Group#	Dates	
1	(29-April)	No groups have means significantly different from group #1
2	(24-May)	Group #3 has a mean significantly different from group #2
3	(29-June)	Group #2 has a mean significantly different from group #3

Appendix F: GB Monthly Nutrient Analysis

Table F.1: Statistical Results for Variation of Phosphate Concentrations at site GB1

Sample Dates: 5/14/2012 & 6/17/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
ANOVA	Normal	0.0008	Reject
Kruskal Wallis	Non-normal	0.0495	Reject

Table F.2: Statistical Results for Variation of Nitrates Concentrations at site GB1

Sample Dates: 5/14/2012 & 6/17/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
ANOVA	Normal	0.0828	Accept
Kruskal Wallis	Non-normal	0.0495	Reject

Table F.3: Statistical Results for Variation of Silicates Concentrations at site GB1

Sample Dates: 5/14/2012 & 6/17/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
ANOVA	Normal	0.1927	Accept
Kruskal Wallis	Non-normal	0.0495	Reject

Table F.4: Statistical Results for Variation of Chlorophyll Concentrations at site GB1

Sample Dates: 5/14/2012 & 6/17/2012			
Statistical Analysis			
Test Performed	Data Distribution	Resulting *p* Value	Accept or Reject *Ho*
ANOVA	Normal	0.6967	Accept
Kruskal Wallis	Non-normal	0.8273	Accept

Appendix G: OD vs Time

Table G.1: Day 1 through Day 3

Site/Nutrient	Date:9/22/13 Time: 11:40a			Date:9/23/13 Time:5:57			Date:9/24/13 Time:4:15p		
MB C	-0.0001	-0.0011	-0.0005	0.0032	0.0023	0.0047	0.0194	0.0222	0.0335
	-0.0006	-0.0017	-0.0005	0.0032	0.0027	0.0043	0.0218	0.0232	0.0338
	-0.0004	-0.0018	-0.0003	0.0031	0.0033	0.0044	0.0222	0.0232	0.0340
MB P	-0.0002	-0.0001	0.0004	0.0049	0.0063	0.0046	0.0307	0.0467	0.0509
	-0.0005	-0.0001	0.0000	0.0047	0.0070	0.0046	0.0303	0.0469	0.0463
	-0.0012	-0.0001	-0.0006	0.0046	0.0076	0.0046	0.0305	0.0475	0.0471
MB N	-0.0035	-0.0026	-0.0019	0.0058	0.0121	0.0078	0.0346	0.0355	0.0358
	-0.0040	-0.0026	-0.0017	0.0058	0.0119	0.0077	0.0342	0.0361	0.0357
	-0.0036	-0.0024	-0.0014	0.0058	0.0120	0.0080	0.0334	0.0358	0.0364
MB N+P	-0.0002	-0.0014	-0.0009	0.0070	0.0066	0.0082	0.0381	0.0397	0.0473
	-0.0006	-0.0013	-0.0008	0.0067	0.0064	0.0091	0.0374	0.0400	0.0471
	-0.0002	-0.0012	-0.0008	0.0070	0.0066	0.0100	0.0373	0.0420	0.0474
VB C	0.0022	0.0027	0.0037	0.0109	0.0092	0.0072	0.0178	0.0173	0.0255
	0.0019	0.0021	0.0037	0.0099	0.0095	0.0060	0.0170	0.0177	0.0243
	0.0019	0.0026	0.0031	0.0094	0.0097	0.0540	0.0167	0.0176	0.0253
VB P	0.0016	0.0021	0.0019	0.0077	0.0086	0.0089	0.0218	0.0214	0.0203
	0.0017	0.0020	0.0015	0.0088	0.0092	0.0078	0.0227	0.0216	0.0193
	0.0017	0.0021	0.0014	0.0082	0.0096	0.0073	0.0225	0.0199	0.0201
VB N	0.0009	-0.0007	-0.0009	0.0087	0.0120	0.0091	0.0183	0.0179	0.0165
	0.0010	-0.0012	-0.0010	0.0088	0.0105	0.0095	0.0179	0.0175	0.0158
	0.0006	-0.0013	-0.0010	0.0090	0.0144	0.0090	0.0175	0.0185	0.0155
VB N+P	0.0009	0.0012	0.0010	0.0087	0.0065	0.0194	0.0174	0.0142	0.0151
	0.0004	0.0009	0.0008	0.0077	0.0066	0.0192	0.0170	0.0141	0.0168
	0.0009	0.0007	0.0005	0.0081	0.0066	0.0187	0.0168	0.0140	0.0187
GB C	0.0019	0.0007	0.0006	0.0027	0.0027	0.0012	0.0074	0.0115	0.0104
	0.0002	0.0002	0.0004	0.0030	0.0026	0.0014	0.0084	0.0113	0.0114
	0.0005	0.0002	0.0000	0.0025	0.0025	0.0014	0.0102	0.0117	0.0112
GB P	-0.0009	-0.0006	-0.0001	0.0025	0.0032	0.0039	0.0194	0.0174	0.0192
	-0.0005	-0.0007	0.0000	0.0025	0.0037	0.0036	0.0192	0.0179	0.0194
	-0.0004	-0.0001	0.0002	0.0019	0.0036	0.0036	0.0192	0.0179	0.0197
GB N	0.0011	0.0003	0.0007	0.0090	0.0102	0.0073	0.0245	0.0259	0.0254
	0.0013	0.0003	-0.0002	0.0092	0.0097	0.0070	0.0235	0.0257	0.0263
	0.0013	0.0004	-0.0002	0.0092	0.0097	0.0068	0.0241	0.0271	0.0253
GB N+P	0.0009	0.0005	0.0006	0.0067	0.0051	0.0031	0.0155	0.0104	0.0168
	0.0005	0.0004	0.0011	0.0068	0.0061	0.0033	0.0120	0.0099	0.0169
	0.0003	0.0006	0.0010	0.0067	0.0058	0.0039	0.0133	0.0104	0.0157
AB C	0.0009	0.0003	0.0001	0.0057	0.0075	0.0042	0.0133	0.0060	0.0062
	0.0011	0.0004	0.0001	0.0060	0.0068	0.0043	0.0137	0.0068	0.0074
	0.0013	0.0008	0.0002	0.0068	0.0075	0.0045	0.0139	0.0058	0.0072
AB P	0.0009	0.0011	0.0006	0.0080	0.0084	0.0083	0.0220	0.0206	0.0377
	0.0014	0.0007	0.0005	0.0089	0.0090	0.0078	0.0216	0.0202	0.0381
	0.0012	0.0004	0.0008	0.0090	0.0084	0.0076	0.0218	0.0214	0.0368
AB N	-0.0020	-0.0021	0.0009	0.0045	0.0059	0.0059	0.0195	0.0132	0.0080
	-0.0018	-0.0016	0.0009	0.0053	0.0055	0.0038	0.0209	0.0160	0.0080
	-0.0019	-0.0023	0.0010	0.0057	0.0058	0.0042	0.0204	0.0125	0.0080
AB N+P	0.0008	0.0010	0.0011	0.0071	0.0060	0.0050	0.0249	0.0146	0.0169
	0.0007	0.0007	0.0010	0.0067	0.0060	0.0055	0.0221	0.0145	0.0168
	0.0012	0.0012	0.0008	0.0071	0.0061	0.0055	0.0213	0.0150	0.0154

Table G.2: Day 4 through Day 6

Date:9/25/13 Time:4:15p			Date:9/26/13 Time:4:46p			Date:9/27/13 Time:1:00p		
0.0427	0.0470	0.0466	0.0497	0.0308	0.0516	0.0482	0.0482	0.0482
0.0431	0.0473	0.0466	0.0495	0.0354	0.0525	0.0488	0.0488	0.0488
0.0443	0.0473	0.0467	0.0498	0.0354	0.0531	0.0478	0.0478	0.0478
0.0934	0.1476	0.1072	0.0473	0.0553	0.0577	0.0438	0.0594	0.0549
0.0929	0.1473	0.0109	0.047	0.0552	0.0574	0.0435	0.0587	0.0554
0.0927	0.1464	0.1102	0.0479	0.0558	0.058	0.0435	0.0595	0.0535
0.0437	0.0467	0.0488	0.0832	0.0869	0.808	0.0961	0.0988	0.0984
0.0433	0.0470	0.0489	0.0826	0.0866	0.0828	0.0946	0.0981	0.0979
0.0429	0.0472	0.0476	0.0833	0.0835	0.0825	0.0953	0.0984	0.0980
0.0631	0.0627	0.0617	0.1169	0.1384	0.1711	0.2248	0.1846	0.1528
0.0621	0.0625	0.0612	0.1163	0.1381	0.1701	0.0226	0.1866	0.1518
0.0624	0.0619	0.0609	0.1164	0.1371	0.1700	0.2307	0.1862	0.1538
0.0442	0.0385	0.0409	0.0574	0.0683	0.0479	0.0518	0.0551	0.0711
0.0438	0.0391	0.0414	0.0583	0.0679	0.0477	0.0612	0.0580	0.0703
0.0436	0.0396	0.0416	0.0583	0.0682	0.0473	0.0528	0.0551	0.0701
0.0725	0.0457	0.0590	0.0950	0.0601	0.0795	0.1311	0.1028	0.0660
0.0722	0.0457	0.0586	0.0953	0.0592	0.0783	0.1326	0.0980	0.0664
0.0714	0.0455	0.0581	0.0955	0.0590	0.0782	0.1328	0.0965	0.0658
0.0731	0.0440	0.0590	0.0554	0.0680	0.0651	0.0798	0.0832	0.0716
0.0727	0.0447	0.0586	0.0557	0.0665	0.0646	0.0798	0.0839	0.0724
0.0724	0.0440	0.0581	0.0551	0.0670	0.0660	0.0786	0.0845	0.0724
0.0707	0.0562	0.0559	0.1093	0.0954	0.0933	0.1622	0.1430	0.1385
0.0737	0.0582	0.0549	0.1107	0.0971	0.0940	0.1637	0.1419	0.1374
0.0743	0.0593	0.0537	0.1116	0.0956	0.0940	0.1634	0.1433	0.1381
0.0143	0.0135	0.0139	0.0120	0.0213	0.0085	0.0132	0.0246	0.0054
0.0140	0.0145	0.0126	0.0118	0.0213	0.0075	0.0129	0.0245	0.0062
0.0143	0.0147	0.0135	0.0119	0.0207	0.0073	0.0116	0.0246	0.0063
0.0128	0.0134	0.0125	0.0057	0.0137	0.0051	0.0142	0.0100	0.0142
0.0108	0.0144	0.0116	0.0064	0.0134	0.0054	0.0135	0.0116	0.0135
0.0107	0.0135	0.0114	0.0050	0.0132	0.0064	0.0136	0.0094	0.0136
0.0412	0.0468	0.0443	0.0686	0.0475	0.0281	0.0565	0.0367	0.0787
0.0417	0.0472	0.0474	0.0697	0.0478	0.0289	0.0562	0.0370	0.0775
0.0417	0.0462	0.0475	0.0701	0.0471	0.0287	0.0559	0.0380	0.0744
0.0265	0.0201	0.0659	0.0959	0.0848	0.1969	0.0254	0.1260	0.1197
0.0264	0.0204	0.0649	0.0948	0.0863	0.1990	0.2541	0.1260	0.0121
0.0260	0.0211	0.0652	0.0946	0.0851	0.2043	0.2529	0.1254	0.1202
0.0239	0.0184	0.0195	0.0267	0.0075	0.0121	0.0122	0.0062	0.0146
0.0241	0.0189	0.0205	0.0264	0.0080	0.0136	0.0113	0.0056	0.0135
0.0245	0.0187	0.0206	0.0276	0.0073	0.0126	0.0120	0.0052	0.0135
0.0441	0.0561	0.0563	0.0406	0.0612	0.0542	0.0298	0.0475	0.0540
0.0440	0.0553	0.0564	0.0397	0.0619	0.0532	0.0296	0.0470	0.0533
0.0434	0.0554	0.0574	0.0397	0.0620	0.0532	0.0289	0.0465	0.0539
0.0200	0.0153	0.0158	0.0140	0.0100	0.0086	0.0159	0.0157	0.0199
0.0188	0.0143	0.0154	0.0144	0.0091	0.0083	0.0149	0.0169	0.0195
0.0191	0.0146	0.0145	0.0169	0.0099	0.0085	0.0151	0.0178	0.0215
0.0587	0.0399	0.0807	0.0934	0.0642	0.0742	0.0963	0.0882	0.1352
0.0568	0.0394	0.0805	0.0930	0.0652	0.0742	0.0977	0.0879	0.1338
0.0578	0.0401	0.0816	0.0934	0.0657	0.0735	0.0979	0.0885	0.1337

Table G.3: Day 7 through Day 9

Date:9/28/13 Time:11:00a			Date:9/30/13 Time:4:45p			Date:10/01/13 Time:4:15p		
0.0518	0.0574	0.0492	0.0614	0.0651	0.0621	0.0609	0.0690	0.0659
0.0516	0.0585	0.0499	0.0641	0.0655	0.0631	0.0608	0.0694	0.0666
0.0513	0.0588	0.0486	0.0637	0.0638	0.0622	0.0613	0.0693	0.0666
0.0497	0.0585	0.0624	0.0651	0.0666	0.0557	0.0697	0.0724	0.0618
0.0494	0.0593	0.0654	0.0646	0.0671	0.0551	0.0680	0.0744	0.0600
0.0489	0.0581	0.0645	0.0674	0.0568	0.0551	0.0709	0.0721	0.0601
0.1182	0.1156	0.1187	0.1771	0.1569	0.1590	0.1951	0.1681	0.1745
0.1181	0.1179	0.1197	0.1762	0.1586	0.1586	0.1942	0.1693	0.1738
0.1184	0.1153	0.1196	0.1781	0.1570	0.1585	0.1932	0.1687	0.1752
0.2783	0.2311	0.2211	0.4144	0.3450	0.3620	0.4239	0.3559	0.3774
0.2788	0.2312	0.2041	0.4122	0.3459	0.3656	0.4247	0.3560	0.3772
0.2785	0.2321	0.2051	0.4138	0.3453	0.3679	0.4260	0.3570	0.3775
0.0779	0.0544	0.0617	0.0544	0.0648	0.0842	0.0535	0.0683	0.0875
0.0790	0.0533	0.0605	0.0537	0.0639	0.0828	0.0541	0.0682	0.0874
0.0785	0.0534	0.0605	0.0526	0.0650	0.0834	0.0586	0.0692	0.0871
0.1425	0.2176	0.7000	0.1481	0.1331	0.2498	0.0778	0.1154	0.1192
0.1428	0.2170	0.0721	0.1496	0.1329	0.2489	0.0796	0.1146	0.1233
0.1428	0.2175	0.0721	0.1489	0.1331	0.2483	0.0787	0.1162	0.1217
0.0808	0.0930	0.0971	0.0995	0.1058	0.1148	0.1175	0.1116	0.1066
0.0809	0.0932	0.0968	0.0980	0.1058	0.1152	0.1162	0.1102	0.1065
0.0813	0.0921	0.0965	0.1009	0.1077	0.1163	0.1174	0.1116	0.1061
0.1971	0.1876	0.1746	0.2640	0.2639	0.2420	0.2860	0.2819	0.2629
0.1986	0.1820	0.1746	0.2651	0.2625	0.2418	0.2856	0.2816	0.2617
0.2016	0.1840	0.1748	0.2654	0.2621	0.2420	0.2853	0.2804	0.2613
0.0135	0.0248	0.0058	0.0159	0.0326	0.0088	0.0179	0.0337	0.0219
0.0126	0.0254	0.0073	0.0165	0.0330	0.0089	0.0168	0.0339	0.0125
0.0133	0.0259	0.0087	0.0153	0.0325	0.0069	0.0166	0.0440	0.0126
0.0095	0.0153	0.0076	0.0081	0.0103	0.0170	0.0108	0.0134	0.0204
0.0092	0.0146	0.0071	0.0080	0.0109	0.0171	0.0108	0.0128	0.0196
0.0098	0.0142	0.0069	0.0072	0.0118	0.0166	0.0106	0.0134	0.0206
0.0857	0.0427	0.0661	0.1614	0.0923	0.1003	0.1683	0.1119	0.1174
0.0856	0.0412	0.0650	0.1625	0.0955	0.0997	0.1681	0.1139	0.1192
0.0855	0.0425	0.0625	0.1632	0.0924	0.0993	0.1694	0.1121	0.1174
0.1460	0.1568	0.2984	0.1768	0.2081	0.4230	0.2213	0.1800	0.4382
0.1481	0.1574	0.2997	0.1772	0.2096	0.4252	0.2231	0.1825	0.4388
0.1485	0.1551	0.2990	0.1816	0.2070	0.4251	0.2168	0.1816	0.4386
0.0397	0.0114	0.0180	0.0270	0.0132	0.0470	0.0525	0.0115	0.0207
0.0387	0.0120	0.0186	0.0263	0.0124	0.0425	0.0535	0.0109	0.0214
0.0392	0.0129	0.0202	0.0261	0.0123	0.0449	0.0537	0.0113	0.0213
0.0511	0.0690	0.0581	0.0578	0.0792	0.0799	0.0683	0.0810	0.0601
0.0512	0.0697	0.0598	0.0581	0.0791	0.0797	0.0693	0.0808	0.0599
0.0512	0.0691	0.0598	0.0586	0.0794	0.0799	0.0687	0.0809	0.0593
0.0324	0.0139	0.0097	0.0150	0.0164	0.0652	0.0127	0.0207	0.0575
0.0312	0.0131	0.0101	0.0139	0.0162	0.0665	0.0132	0.0190	0.0564
0.0302	0.0132	0.0097	0.0144	0.0161	0.0656	0.0135	0.0177	0.0573
0.1665	0.1307	0.1146	0.2368	0.1854	0.1792	0.2066	0.2131	0.2677
0.1680	0.1264	0.1152	0.2363	0.1946	0.1789	0.2061	0.2147	0.2679
0.1676	0.1284	0.1143	0.2360	0.1862	0.1783	0.2057	0.2134	0.2684

Table G.4: Day 10 through Day 12

Date:10/02/13 Time:7:23			Date:10/04/2013 Time:4:00p			Date:10/09/2013 Time:4:10p		
0.0694	0.0679	0.0653	0.0693	0.0833	0.0706	0.0701	0.0932	0.0701
0.0694	0.0751	0.0649	0.0696	0.0818	0.0698	0.0709	0.0932	0.0709
0.0689	0.0747	0.0648	0.0690	0.0820	0.0705	0.0709	0.0932	0.0709
0.0742	0.0734	0.0625	0.0764	0.0831	0.0658	0.0827	0.0965	0.0756
0.0739	0.0730	0.0623	0.0778	0.0815	0.0655	0.0831	0.0965	0.0756
0.0722	0.0724	0.0612	0.0762	0.0810	0.0670	0.0826	0.0965	0.0756
0.2229	0.1833	0.1932	0.2780	0.1805	0.2098	0.3577	0.2167	0.3577
0.2247	0.1825	0.1941	0.2751	0.1801	0.2118	0.3564	0.2167	0.3564
0.2250	0.1826	0.1953	0.2759	0.1817	0.2115	0.3555	0.2167	0.3555
0.4873	0.4028	0.4240	0.4864	0.5659	0.4630	0.6291	0.7432	0.6087
0.4874	0.4012	0.4258	0.4868	0.5889	0.4633	0.6325	0.7432	0.6087
0.4895	0.4033	0.4252	0.4873	0.5681	0.4638	0.6324	0.7432	0.6087
0.0890	0.0709	0.0551	0.0497	0.0740	0.0670	0.0987	0.1432	0.1265
0.0902	0.0720	0.0539	0.0508	0.0735	0.0696	0.1011	0.1432	0.1265
0.0886	0.0714	0.0546	0.0504	0.0726	0.0730	0.0994	0.1432	0.1265
0.1617	0.1331	0.0829	0.0866	0.1399	0.1646	0.1725	0.2432	0.2432
0.1610	0.1334	0.0825	0.0861	0.1405	0.1647	0.1767	0.2432	0.2432
0.1608	0.1338	0.0853	0.0853	0.1397	0.1677	0.1756	0.2432	0.2432
0.1124	0.1170	0.1256	0.1352	0.1179	0.1296	0.1001	0.1001	0.1001
0.1135	0.1163	0.1263	0.1307	0.1186	0.1293	0.1005	0.1005	0.1005
0.1122	0.1177	0.1260	0.1325	0.1293	0.1290	0.1009	0.1009	0.1009
0.3212	0.3161	0.2917	0.3406	0.3757	0.3744	0.5341	0.5341	0.5341
0.3260	0.3163	0.2915	0.3422	0.3774	0.3740	0.5338	0.5338	0.5338
0.3238	0.3159	0.2908	0.3428	0.3763	0.3758	0.5394	0.5394	0.5394
0.0148	0.0382	0.0211	0.0451	0.0141	0.0266	0.0233	0.0088	0.0132
0.0153	0.0396	0.0213	0.0439	0.0136	0.0262	0.0222	0.0076	0.0143
0.0162	0.0397	0.0206	0.0441	0.0134	0.0263	0.0205	0.0074	0.0123
0.0232	0.0139	0.0136	0.0282	0.0176	0.0172	0.0162	0.0098	0.0098
0.0228	0.0138	0.0128	0.0278	0.0184	0.0170	0.0162	0.0087	0.0087
0.0230	0.0132	0.0126	0.0275	0.0184	0.0170	0.0163	0.0092	0.0092
0.1957	0.1265	0.1212	0.1258	0.1535	0.2327	0.2494	0.2494	0.3865
0.1978	0.1270	0.1197	0.1253	0.1551	0.2318	0.2525	0.2525	0.3965
0.1998	0.1259	0.1208	0.1252	0.1552	0.2297	0.2531	0.2531	0.3854
0.1786	0.1314	0.4790	0.5697	0.1233	0.1786	0.4264	0.1428	0.1428
0.1779	0.1320	0.4784	0.5697	0.1207	0.1710	0.4286	0.1433	0.1433
0.1789	0.1316	0.4779	0.5692	0.1237	0.1739	0.4325	0.1423	0.1423
0.0535	0.0127	0.0232	0.0215	0.0575	0.0126	0.0087	0.0243	0.0087
0.0530	0.0138	0.0232	0.0210	0.0568	0.0133	0.0093	0.0243	0.0093
0.0528	0.0128	0.0236	0.0213	0.0574	0.0134	0.0085	0.0212	0.0085
0.0613	0.0845	0.0682	0.0630	0.0668	0.0692	0.0302	0.0302	0.0302
0.0530	0.0841	0.0691	0.0681	0.0669	0.0699	0.0301	0.0301	0.0301
0.0528	0.0840	0.0679	0.0668	0.0704	0.0686	0.0298	0.0298	0.0298
0.0633	0.0183	0.0165	0.0868	0.0160	0.0159	0.0756	0.0128	0.0128
0.0622	0.0173	0.0169	0.0858	0.0150	0.0158	0.0745	0.0118	0.0118
0.0630	0.0170	0.0171	0.0863	0.0147	0.0138	0.0764	0.0104	0.0104
0.2918	0.2401	0.2262	0.2578	0.2726	0.3216	0.1602	0.1678	0.2543
0.2897	0.2397	0.2260	0.2583	0.2727	0.3216	0.1642	0.1721	0.2145
0.2904	0.2413	0.2251	0.2672	0.2720	0.3213	0.1612	0.1713	0.2466

VITA

Tiffany Chantelle Johnson was born in Lafayette, Louisiana. After completing her school work at Booker T Washington High school in Pensacola in 2005, Tiffany entered Florida State University in Tallahassee, Florida. She received a Bachelor of Arts with a major in Environmental Science from Florida State University in 2009. In August 2010, she entered the Graduate School of Louisiana State University.