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Water Quality and Microbial Ecology of Upper Barataria Estuary in Southeast Louisiana, USA

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ABSTRACT

The waterways in the upper Barataria Estuary are important throughout the estuary because they receive large amounts of nutrients, such as nitrates and phosphates, through runoff from agriculture fields and natural swamp land. Although nutrients can stimulate increased microbial activity, large amounts of nutrients can be detrimental to the system. To develop effective managerial methods, it is becoming important to understand how factors within a system work together at the microbial level. Samples from five sites in the upper Barataria Estuary were collected bi-weekly to measure the bacterial load and to identify the bacterial communities. Dissolved nitrate, dissolved phosphate, organic carbon, and dissolved oxygen were measured bi-weekly. Sample collection started on 20 July 2007 and ended on 21 June 2008. Additional samples were taken 6 days after Hurricane Gustav on 7 September 2008. Statistical analysis was used to investigate seasonal and spatial variations among sample sites. Rainfall leading to floodplain inundation and runoff was suspected to be one of the main seasonal factors affecting the analyzed parameters. Among sampling sites, runoff from human dominated areas was suspected to be the primary factor affecting, pH, dissolved oxygen, dissolved nitrate, and dissolved phosphate. As expected, the high levels of organic carbon after Hurricane Gustav caused a significant decrease in the dissolved oxygen levels in the upper Barataria Estuary which led to a massive fill kill. The upper Barataria Estuary may be better managed by decreasing the amount of runoff into the upper Barataria Estuary.

Keywords: Upper Barataria Bay; fish kill; nutrient run-off; organic carbon; nitrogen; hypoxia; Hurricane Gustav

1. INTRODUCTION

The upper Barataria Estuary, located in south Louisiana, is a freshwater basin that no longer receives Mississippi River floodwaters due to the construction of flood protection structures. As a result of this construction, the predictable annual flood pulse of the Barataria Estuary has been eliminated. Today the system only floods due to heavy local rainfall (USACE, 2004).

The upper Barataria Estuary consists mostly of agricultural fields and forested wetlands (Braud et al., 2006). The waterways of the upper Barataria Estuary are important throughout the estuary because they receive large amounts of nutrients, such as nitrates and phosphates, through runoff from agriculture fields and natural swamp land (Day et al., 1976). Although nutrients can stimulate microbial activity, large amounts of nutrients can be detrimental to the system (Gulis and Suberkropp, 2003). An over abundance of nutrients can cause decreased dissolved oxygen (DO) levels which can lead to hypoxic conditions (DO $\leq$ 2.0 mg/L). Large amounts of nutrients can result in water quality problems and severely impact the system (Stow et al., 1985).

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The high amount of nitrate and phosphate from runoff in the upper Barataria Estuary has been documented (Hopkinson and Day, 1980; Stow et al., 1985). Microorganisms play an important role in energy flow of floodplain estuary ecosystems (Gulis and Suberkropp, 2003; Gulis et al., 2004; O' Connell et al., 2000; Uncles et al., 1998). However, the abundance and types of microorganisms that influence energy flow in an estuary are poorly understood (Gulis and Suberkropp, 2003; O' Connell et al., 2000).

Understanding how microbial activity influences nutrient cycling is critical for effective watershed management (Nienhuis, 2006; Stow et al., 1985). An increased understanding of what is occurring at the microbial level will help to develop effective management methods for water quality as urbanization and use of agriculture technology increase.

The purpose of this study was to measure the bacterial load, identify the bacterial communities, and perform water quality tests to quantify the concentrations of dissolved nitrate, dissolved phosphate, organic carbon, and dissolved oxygen from five sites in the upper Barataria Estuary as this is an important aquatic ecosystem in Louisiana and the water quality of this system was not studied in detail before. Bacterial load, bacterial communities, dissolved nitrate, dissolved phosphate, organic carbon, and dissolved oxygen were monitored to learn more about the bacterial interactions of the upper Barataria Estuary.

2. MATERIALS AND METHODS

2.1 Description of the sampling sites

Five sampling areas in the upper Barataria Estuary were selected (Figure 1). The main area investigated in the upper Barataria Estuary was Bayou Chevreuil. Lac Des Allemands, designated as area 1, is a lake that receives water from lower Bayou Chevreuil and other water bodies. Due to the open area of the lake, it receives more wind and solar energy than the other selected areas in the upper Barataria Estuary. The sampling site in Lac Des Allemands was 0.30 km from the entry of lower Bayou Chevreuil. The site distance from lower Bayou Chevreuil was chosen to allow appropriate mixture of Lac Des Allemands and lower Bayou Chevreuil waters, and to ensure that other water bodies emptying into Lac Des Allemands were not nearby. Areas 2, 3, and 5 were designated as lower Bayou Chevreuil, middle Bayou Chevreuil, and upper Bayou Chevreuil, respectively. Lower Bayou Chevreuil may receive water from Lac Des Allemands during windy periods; otherwise water usually flows downstream from middle Bayou Chevreuil. Middle Bayou Chevreuil receives water from the St. James Canal and upper Bayou Chevreuil. The sampling site in middle Bayou Chevreuil was selected near a public boat launch at the Highway 20 bridge. The site was 2.25 km from the merge of upper Bayou Chevreuil and St. James Canal. There are other small waterways that empty into Bayou Chevreuil between the sampling site and the merge of upper Bayou Chevreuil and St. James Canal. The St. James Canal sampling site (Sample site 4) was located 2.69 km from the point where St. James Canal empties into Bayou Chevreuil. The land area around St. James Canal is mostly comprised of agricultural fields. The sampling site was selected downstream from sugarcane fields and residential areas with cow and horse pastures. Upper Bayou Chevreuil is mostly comprised of private camps and natural swamp lands. The upper Bayou Chevreuil sampling site was located near a private hunting camp and downstream from other private hunting camps and natural swamp land. Further upstream, upper Bayou Chevreuil is comprised of urban areas and agricultural fields.

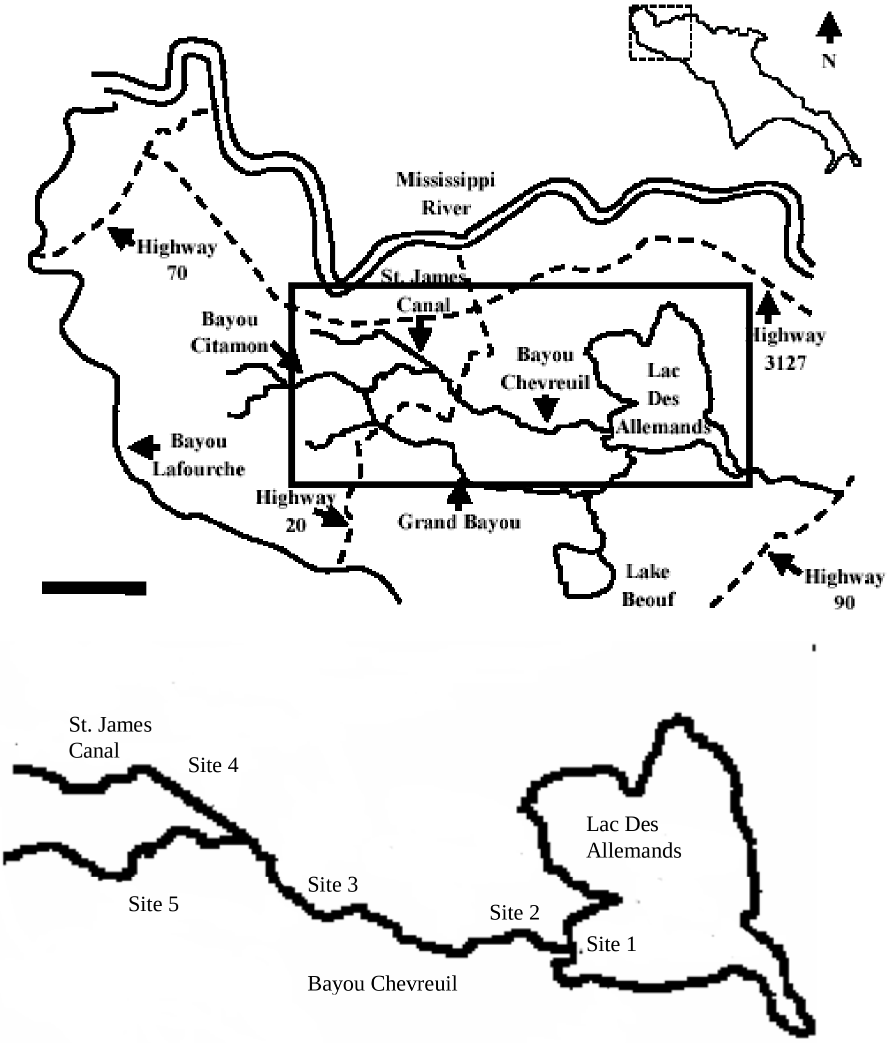

Figure 1 Location of upper Barataria Estuary within the Barataria-Terrebonne Estuarine System (Top). Major highways and waterways are outlined (Top). Locations of the 5 study sites (Bottom) within the upper Barataria Estuary. GPS coordinates for each site are Site 1: 29°53′31″N, -90°36′49.0″W; Site 2: 29°53′26″N, -90°36′49″W; Site 3: 29°54′39″N, -90°43′44″W; Site 4: 29°56′42″N, -90°46′13″W; Site 5: 29°55′52″N, 90°46′47.1″W

2.2 Sampling frequency

Five fixed sites in the upper Barataria Estuary as explained above were sampled bi-weekly between 20 July 2007 and 21 June 2008. Samples were also collected at the same sampling sites on 7 September 2008, six days after Hurricane Gustav. Nautical distances (km) from sites 1, 2, 3, 4, and 5 to the Louisiana Highway 20 bridge were measured using Google Earth™ (Google Earth, 2007). Sterilized milk dilution bottles were used for collection from the surface of the water. Water samples at the four bayou sites were collected from the middle of the channel and collection at the lake site occurred outside the mouth of lower Bayou Chevreuil. For the duration of the collection trip, samples were placed on ice. Temperature (°C), dissolved oxygen (mg/L), and specific conductance (μS) at each site were measured using a handheld YSI dissolved oxygen and salinity probe (Model 85-10FT, Yellow Springs, Ohio). Turbidity was measured using Secchi disk depth (cm) at each site.

2.3 Water quality analysis

After a collection trip, samples were stored in the laboratory at 4°C. Within the first week after sampling, dissolved nitrate (mg/L), dissolved phosphate (mg/L), and pH were measured using the Hach method (Hach, 2000). Organic carbon was measured in the form of total chemical oxygen demand (COD; mg/L) using the Hach method (Hach, 2000). Bacterial load was also measured during this time using standard microbiological methods (Benson, 2002). Bacterial communities were identified using the Biolog method (Biolog, 2002).

2.4 Statistical analysis

Analysis of variance (ANOVA; alpha = 0.05) was used to compare mean dissolved nitrate (mg/L), dissolved phosphate (mg/L), organic carbon (mg/L), dissolved oxygen (mg/L), and bacterial loading (CFU) among sites and seasons. The following months represented each season: December through February represented Winter, March through May represented Spring, June through August represented Summer, and October through November represented Fall. Also, correlation analysis was used to assess the relationships among dissolved nitrate (mg/L), dissolved phosphate (mg/L), organic carbon (mg/L), dissolved oxygen (mg/L), bacterial loading (CFU) and sites.

3. RESULTS

3.1 Water quality

The system-wide mean (±SD) water temperature was 22.1 ± 6.7°C (Figure 2). The highest and lowest observed water temperatures were 32.5°C at site 2 on 19 August 2007 and 7.2°C at site 4 on 20 January 2008 respectively. There was no difference in mean (±SD) water temperature among sites. The system-wide mean (±SD) pH for the sampling period was 6.4 ± 0.3 (data not shown). The lowest and highest pH observed were 5.56 at site 5 on 2 February 2008 and 7.26 at site 1 on 24 May 2008 respectively.

The system-wide mean (±SD) dissolved oxygen (mg/L) was 4.4 ± 2.5 mg/L (Figure 3). The lowest observed dissolved oxygen was 0.15 mg/L on 23 December 2007 at site 5 and the highest was 9.95 mg/L on 19 December 2007 at site 1. The highest and lowest mean dissolved oxygen respectively were 8.0 ± 0.9 mg/L on 20 January 2007 and 0.9 ± 0.8 mg/L on 23 December 2007. Among seasons, there was no difference in dissolved oxygen among Winter and Spring or Summer and Fall, but Summer and Fall were different from Winter and Spring. The mean (±SD) dissolved oxygen was lowest in the Fall, 3.48 ± 2.03 mg/L, and highest in the Spring, 5.51 ± 2.33 mg/L, across sampling sites. Mean (±SD) dissolved oxygen for Winter and Summer were 5.18 ± 2.75 mg/L and 3.55 ± 2.36 mg/L, respectively.

The system-wide mean (±SD) specific conductance was 189.6 ± 61.5 μS (data not shown). There was no difference in the mean (±SD) specific conductance among sampling sites. The mean (±SD) specific conductance among sampling sites were 204.73 ± 62.70 μS for site 1, 190.60 ± 59.41 μS for site 2, 183.49 ± 63.21 μS for site 3, 199.65 ± 56.00 μS for site 4, and 170.000 ± 65.02 μS for site 5. There was no difference in mean (±SD) specific conductance for Summer and Fall or Winter and Summer. The system-wide mean (±SD) turbidity measured as absorbance was 0.11 ± 0.14 (data not shown). The lowest absorbance measured was 0.012 at site 1 on 1 September 2007, and the highest was 0.697 at site 4 on 24 May 2008. There was no difference among sampling sites for mean (±SD) absorbance.

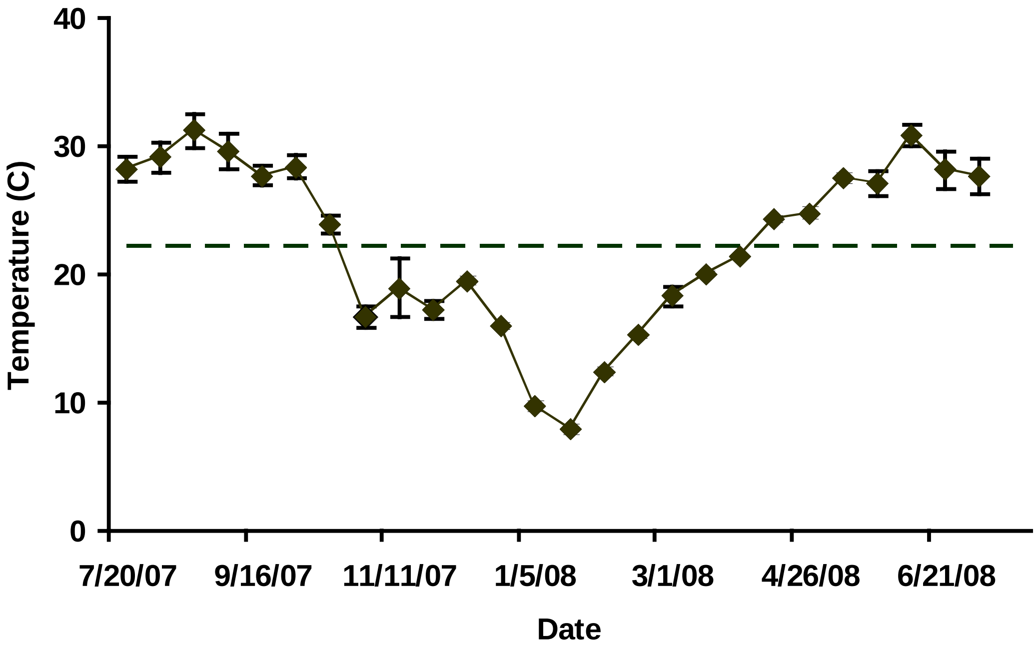

Figure 2 Mean temperature of all sampling sites combined in the upper Barataria Estuary for each sampling date from 20 July 2007 to 21 June 2008 and 7 September 2008 (N = 26). Dashed line represents the overall mean temperature for the sampling period

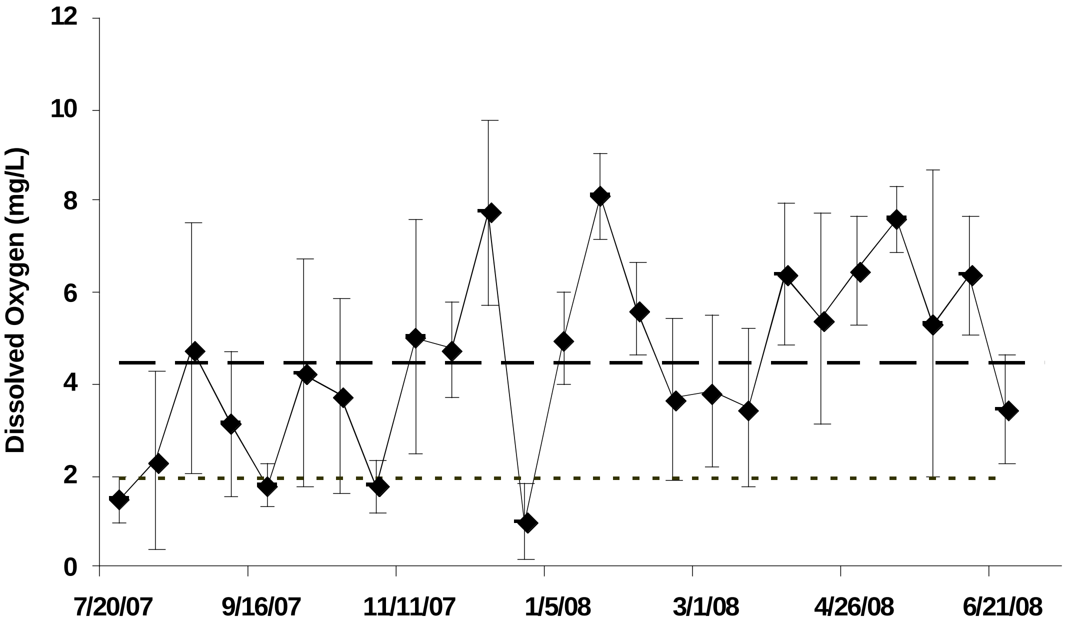

Figure 3 Mean (±SD) dissolved oxygen concentration (mg/L) for all sampling sites combined in the upper Barataria Estuary for each sampling date from 20 July 2007 to 21 June 2008 and 7 September 2008 (N = 26). Dashed line represents the overall mean dissolved oxygen concentration for the sampling period. Dotted line represents the hypoxic level of 2.00 mg/L

3.2 Water chemistry

The system-wide mean (±SD) dissolved nitrate was 3.1 ± 0.9 mg/L. The highest and lowest mean (±SD) dissolved nitrate across sampling dates were 7.04 ± 5.03 mg/L and 1.85 ± 0.57 mg/L, respectively. Among seasons, there was no difference in dissolved nitrate. Mean (±SD) dissolved nitrate for Winter was 3.2 ± 0.8 mg/L, Spring was 3.4 ± 1.3 mg/L, Summer was 3.2 ± 1.2 mg/L, and Fall was 3.0 ± 2.4 mg/L. Among sampling sites, there was a difference in mean (±SD) dissolved nitrate at sites 1 and 4. The mean (±SD) dissolved nitrate was 2.2 ± 0.7 mg/L at site 1 and 3.8 ± 2.3 mg/L at site 4. The mean (±SD) dissolved nitrate at site 2, 3, and 5 were 2.7 ± 1.0 mg/L, 3.6 ± 2.5 mg/L, and 3.2 ± 1.6 mg/L, respectively (Figure 4). All means (±SD) reported are representative of the routine bi-weekly sampling period, 20 July 2007 through 21 June 2008.

The system-wide mean (±SD) dissolved phosphate was 0.5 ± 0.1 mg/L. The highest and lowest mean (±SD) dissolved phosphate among sampling dates were 0.81 ± 0.18 mg/L and 0.18 ± 0.04 mg/L, respectively. Among seasons, there was a difference in dissolved phosphate (mg/L) between Summer and Fall. The mean (±SD) dissolved phosphate was 0.56 ± 0.27 mg/L in the Fall, 0.56 ± 0.32 mg/L in the Summer, 0.54 ± 0.26 mg/L in the Winter, and 0.56 ± 0.25 mg/L in the Spring (Figure 5). Mean (±SD) dissolved phosphate for site 4 was significantly different than sites 1 and 2. Mean (±SD) dissolved phosphate was lowest at sites 1 and 2 and highest at site 4. Mean (±SD) dissolved phosphate was 0.43 ± 0.27 mg/L and 0.38 ± 0.18 mg/L at sites 1 and 2, respectively and 0.66 ± 0.31 mg/L at site 4. Mean (±SD) dissolved phosphate were 0.53 ± 0.22 mg/L and 0.51 ± 0.32 mg/L at sites 3 and 5, respectively.

Mean (±SD) total chemical oxygen demand (organic carbon) was 46.8 ± 15.5 mg/L. The lowest and highest total chemical oxygen demands observed were 0.00 at site 1 on 2 February 2008, and 87.10 at site 4 on 26 April 2008, respectively (Figure 6). There was no difference in mean (±SD) total chemical oxygen demand among sampling sites or seasons. Mean (±SD) total chemical oxygen demand was 47 ± 15 mg/L for Winter, 49 ± 19 mg/L for Spring, 44 ± 15 mg/L for Summer, and 45 ± 11 mg/L for Fall. Mean (±SD) total chemical oxygen was 44 ± 16 mg/L for site 1, 46 ± 12 mg/L for site 2, 45 ± 14 mg/L for site 3, 48 ± 19 mg/L for site 4 mg/L, and 47 ± 14 mg/L for site 5. All means (±SD) reported are representative of the routine bi-weekly sampling period, 20 July 2007 through 21 June 2008.

3.3 Bacterial load

The system-wide mean value of (±SD) heterotrophic aerobic bacteria was 32,432 ± 6557 Colony Forming Unit/mL (CFU/mL). The highest and lowest mean (±SD) heterotrophic aerobic bacteria (CFU/mL) among sampling dates were 170,800 ± 77,992.47 CFU/mL (Figure 7). There was no difference in the mean (±SD) heterotrophic aerobic bacteria (CFU/mL) among samplings sites. The mean (±SD) heterotrophic aerobic bacteria (CFU/mL) for sites 1-5 respectively were 20,793 ± 31,270 CFU/mL, 35,938 ± 64,658 CFU/mL, 49,211 ± 76,819 CFU/mL, 39,054 ± 50,148 CFU/mL, and 25,980 ± 47,750 CFU/mL. There was a difference of the mean (±SD) heterotrophic aerobic bacteria (CFU/mL) between Winter and Fall. The mean (±SD) heterotrophic aerobic bacteria (CFU/mL) during the Winter, Fall, Spring, and Summer, respectively were 48,243 ± 65,573 CFU/mL, 10,149 ± 16,998 CFU/mL, 47,213 ± 73,759 CFU/mL, and 21,846 ± 27,513 CFU/mL.

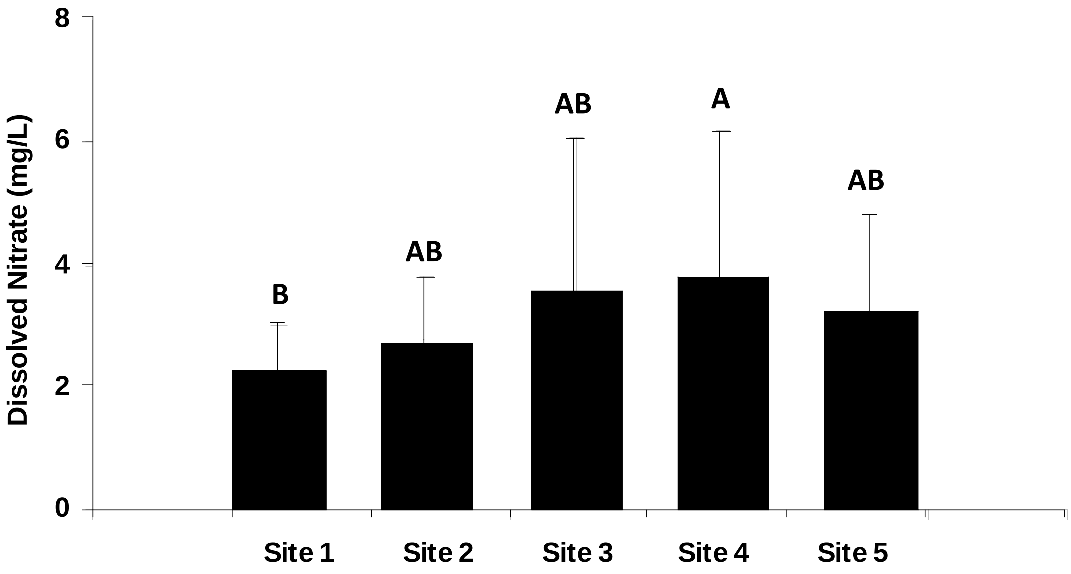

Figure 4 Mean (±SD) dissolved nitrate (mg/L) for each site combined in the upper Barataria Estuary for each sampling date from 20 July 2007 to 21 June 2008. Means with a similar letter are not different

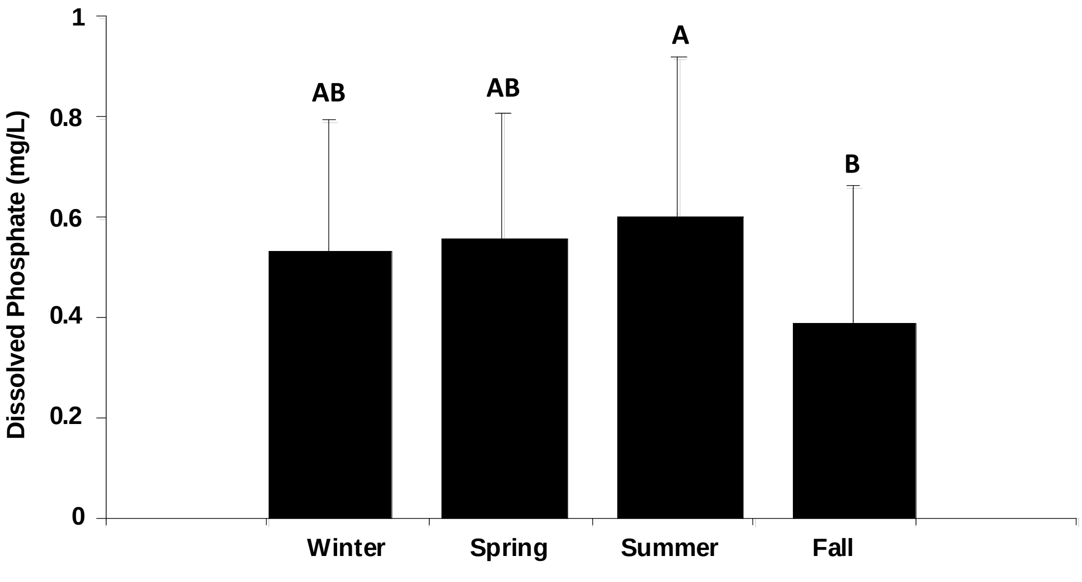

Figure 5 Mean (±SD) dissolved phosphate (mg/L) for each season in the upper Barataria Estuary for each sampling date from 20 July 2007 to 21 June 2008. Means with a similar letter are not different

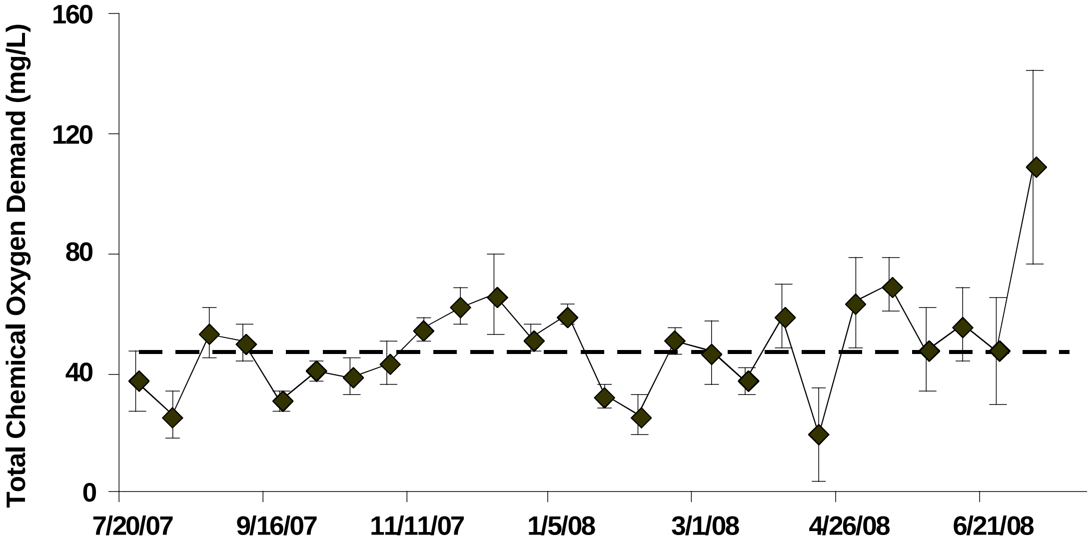

Figure 6 Mean (±SD) total chemical oxygen demand (mg/L) representing organic carbon for all sites combined in the upper Barataria Estuary for each sampling period from 20 July 2007 to 21 June 2008 and 7 September 2008 (N = 26). Dashed line represents the overall mean total chemical oxygen demand for the sampling period

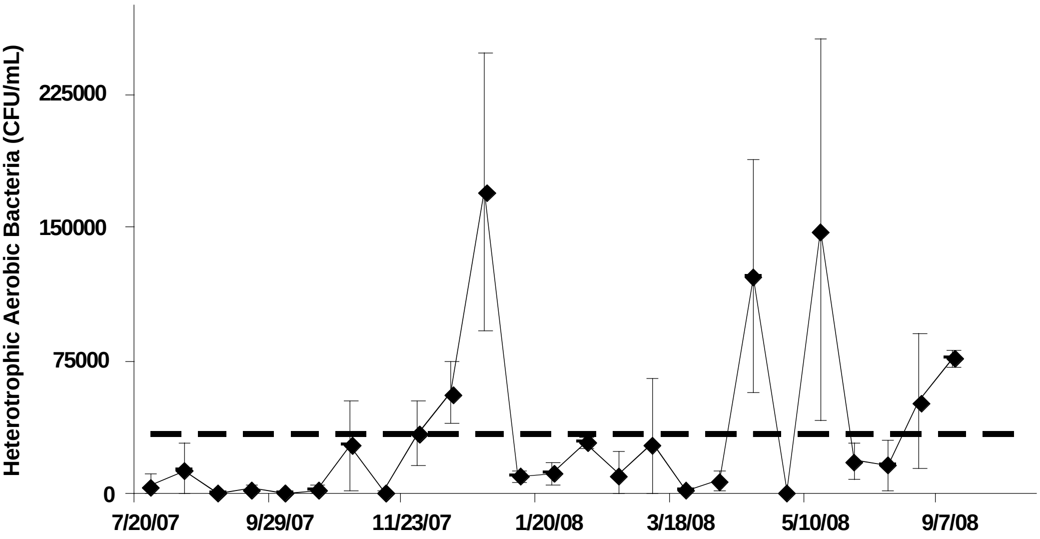

Figure 7 Mean (±SD) heterotrophic aerobic bacteria (CFU/mL) for all sites combined in the upper Barataria Estuary for each sampling date from 20 July 2007 to 21 June 2008 and 7 September 2008 (N = 25). Dashed line represents the overall mean heterotrophic aerobic bacteria (CFU/mL) for the sampling period

The mean value of (±SD) heterotrophic anaerobic bacteria was (CFU/mL) 4850 ± 9489 CFU/mL (Figure 8). There was no significant difference among sampling sites. The mean (±SD) heterotrophic anaerobic bacteria was (CFU/mL) for sites 1-5 respectively were 2583 ± 5087 CFU/mL, 4579 ± 12358 CFU/mL, 6651 ± 11368 CFU/mL, 6720 ± 9220 CFU/mL, and 3233 ± 6120 CFU/mL. The mean (±SD) heterotrophic anaerobic bacteria (CFU/mL) was 6873 ± 9074 CFU/mL during the Winter, 2963 ± 7675 CFU/mL during the Spring, 9710 ± 15614 CFU/mL for the Summer, and 1684 ± 2253 CFU/mL during the Fall. The mean (±SD) heterotrophic anaerobic bacteria (CFU/mL) during the Summer was significantly different from Spring and Fall. All means (±SD) reported are representative of the routine bi-weekly sampling period, 20 July 2007 through 21 June 2008.

The mean (±SD) total coliforms was 609 ± 457 Most Probable Number/100 mL (MPN/100 mL). The lowest and highest mean (±SD) total coliforms (MPN/100 mL) were 407.88 ± 394.74 and 845.5 ± 394.74 MPN/100 mL respectively (Figure 9). There was no significant difference among sampling sites. The mean (±SD) total coliforms (MPN/100 mL) for sites 1-5, respectively were 472 ± 463 MPN/100 mL, 539 ± 460 MPN/100 mL, 794 ± 396 MPN/100 mL, 589 ± 444 MPN/100 mL, and 650 ± 487 MPN/100 mL. The mean (±SD) total coliforms (MPN/100 mL) for Winter and Fall were different from Spring and Summer. Winter had the highest mean (±SD) total coliforms (MPN/100 mL), while the Summer had the lowest mean (±SD) total coliforms (MPN/100 mL). The mean (±SD) values of total coliforms (MPN/100 mL) for Winter, Spring, Summer and Fall were 845 ± 410 MPN/100 mL, 439 ± 442 MPN/100 mL, 407 ± 394 MPN/100 mL, and 725 ± 437 MPN/100 mL, respectively.

The mean (±SD) fecal coliforms was 256 ± 39 MPN/100 mL (Figure 10). There was no difference among sampling sites. The mean (±SD) fecal coliforms for sites 1-5, respectively were 177 ± 307 MPN/100 mL, 245 ± 391 MPN/100 mL, 297 ± 423 MPN/100 mL, and 289 ± 421 MPN/100 mL, and 288 ± 455 MPN/100 mL. Winter mean (±SD) fecal coliforms MPN/100 mL was different from Fall, Summer, and Spring. Winter had the highest mean fecal coliforms while the Summer had the lowest mean fecal coliforms. The mean values of fecal coliforms for Winter, Spring, Summer and Fall were 549 ± 504 MPN/100 mL, 99 ± 198 MPN/100 mL, 176 ± 362 MPN/100 mL and 220 ± 348 MPN/100 mL, repectively.

The following heterotrophic aerobic bacteria were identified using the Biolog method: *Achromobacter cholinophagum*, *Brevundimonas vesicularis*, *Burkholderia glumae*, *Aeromonas allosaccharophila*, *Aeromonas jandaei* DNA group 9, *Aeromonas* media-like DNA group 54, *Micrococcus luteus*, *Vibrio tubiashii*. *Escherichia coli*, and *Gemella palaticanis*. One heterotrophic anaerobic bacterium, *Prevotella oulora*, was isolated using the Biolog method.

3.4 Statistical correlations among parameters

Dissolved oxygen concentration and pH were significantly positively correlated in the Fall, Summer, and Spring (≥ 0.64). Water temperature (°C) was also significantly positively correlated with pH (0.56) during the routine bi-weekly sampling period. There was a correlation between turbidity and dissolved nitrate concentration (0.58). Also, dissolved nitrate was highly positively correlated to heterotrophic anaerobic bacteria in the Summer (0.72) and at site 2 (0.74).

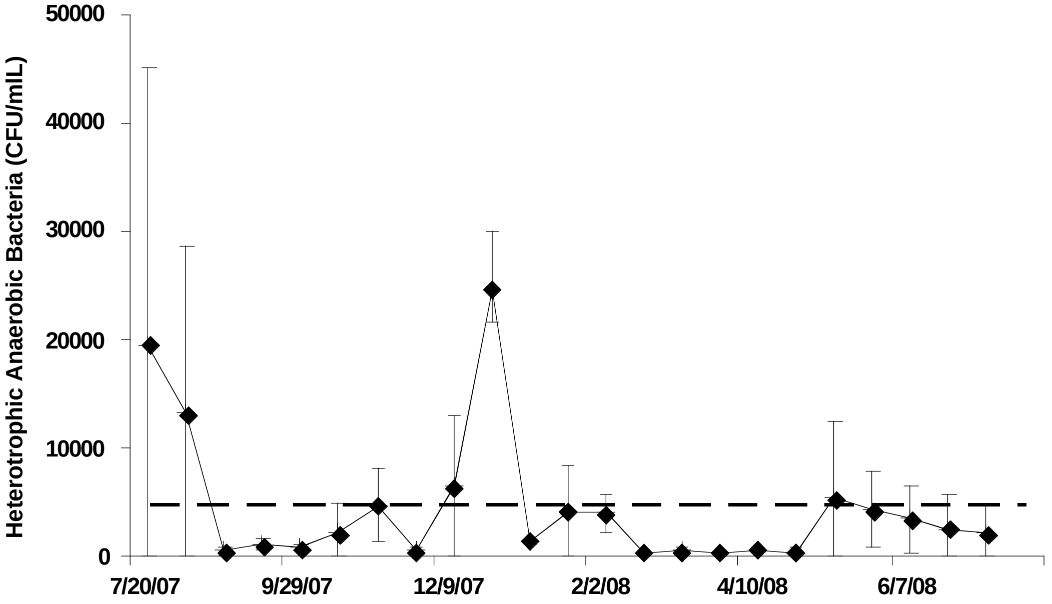

Figure 8 Mean (±SD) heterotrophic anaerobic bacteria (CFU/mL) for all sites combined in the upper Barataria Estuary from 20 July 2007 to 21 June 2008 and 7 September 2008 (N = 23). Dashed line represents the overall mean heterotrophic anaerobic bacteria (CFU/mL) for the sampling period

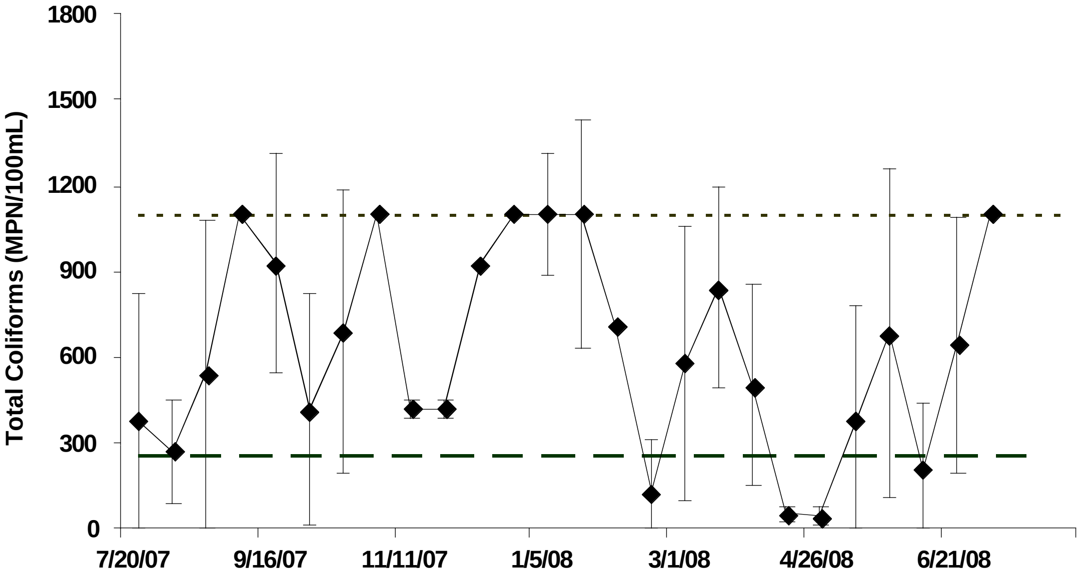

Figure 9 Mean (±SD) total coliforms (MPN/100 mL) for all sites combined in the upper Barataria Estuary for each sampling date from 20 July 2007 to 21 June 2008 and 7 September 2008 (N = 26). Dashed line represents the overall mean total coliforms (MPN/100 mL) for the sampling period. Dotted line represents the maximum level coliforms measured (1100 MPN/100mL)

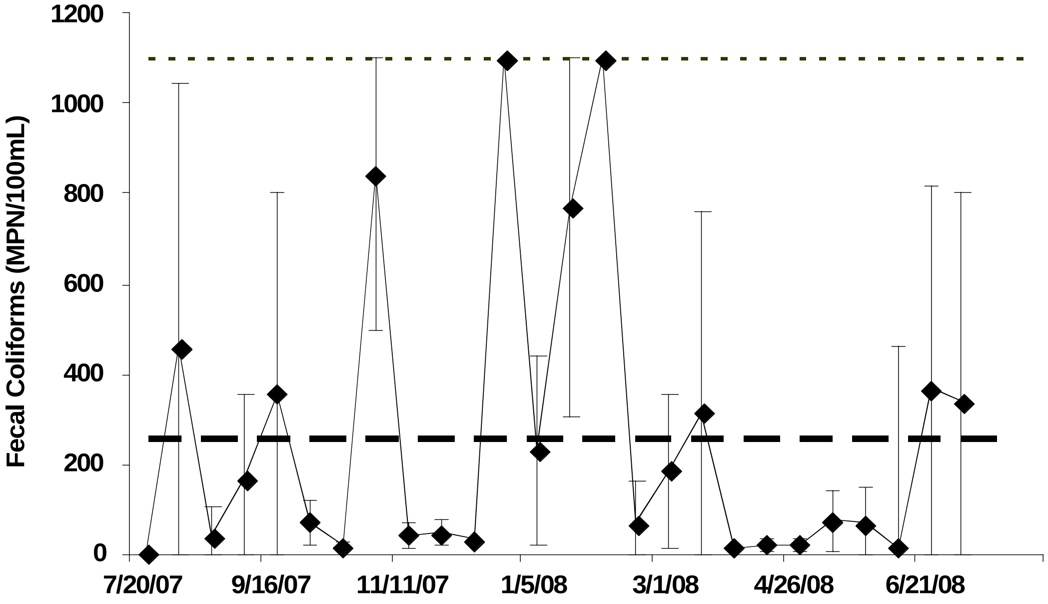

Figure 10 Mean (±SD) fecal coliforms (MPN/100 mL) for all sites combined in the upper Barataria Estuary for all sampling dates from 20 July 2007 to 21 June 2008 and 7 September 2008 (N = 26). Dashed line represents the overall mean (±SD) fecal coliforms (MPN/100 mL) for the sampling period. Dotted line represents the maximum level coliforms measured (1100 MPN/100 mL)

3.5 Hurricane Gustav parameters

Water samples were collected on 7 September 2008, outside of the normal bi-weekly sampling period. The samples were collected six days after Hurricane Gustav. Visual observation indicated a massive fill kill at all sites. The mean (±SD) parameters analyzed were: (1) water temperature, 27.6 ± 1.3°C; (2) pH, 6.4 ± 0.3; (3) dissolved nitrate, 5.4 ± 1.2 mg/L; (4) dissolved phosphate, 0.4 ± 0.1 mg/L; (5) total chemical oxygen demand, 108 ± 32 mg/L; (6) heterotrophic aerobic bacteria, 76450 ± 5138 CFU/mL; (7) heterotrophic anaerobic bacteria, 2151 ± 2654 CFU/mL; (8) total coliforms, 1100 and (9) fecal coliforms, 336 ± 464 MPN/100 mL. Statistical analysis indicated significant differences in these data compared to normal sampling events (Eddelemon, 2007). Dissolved oxygen concentration (mg/L) and specific conductance (μS) were not measured due to unavailable equipment after the hurricane. The dissolved oxygen concentration (mg/L) on 9 September 2008, two days after the sampling date, was 0.23 mg/L at site 3, which is significant as indicated by Eddelemon (2007).

4. DISCUSSION

4.1 Seasonal variations

Substantial rainfall events are suspected to be one of the main seasonal factors leading to variations among the analyzed parameters. Prolonged periods of rainfall and slow drainage may lead to periodic inundation of the floodplain (Estay, 2007). It was noted by Estay (2007) that the upper Barataria Estuary was periodically inundated during mid and late Fall and Winter. The following parameters may have increased in the Fall and/or Winter due to floodplain inundation: turbidity, heterotrophic aerobic bacteria, heterotrophic anaerobic bacteria, total coliforms and fecal coliforms. Floodplain inundation may have also lead to decreased dissolved oxygen levels in the Fall. Rainfall and weather data are available in the National weather service report (weather-source.com).

An influx of nutrients can stimulate microbial activity (Gulis and Suberkropp, 2003). After floodplain inundation, there are high amounts of leaf litter, particulate or organic matter, in the water column. Leaf-shredding invertebrates along with heterotrophic bacteria decompose leaf litter, which may cause the dissolved oxygen concentration in the water column to decrease (Uncles et al., 1998). Even though variations in dissolved organic carbon, nitrate concentrations, and phosphate concentrations were not different among seasons, an increased concentration of nutrients in the water column after precipitation has been connected to runoff (Flint, 1985; Hopkinson and Day, 1980; Witzig and Day, 1983). Insignificant rainfall events may not cause floodplain inundation, but runoff is still likely to occur. Also, due to extended periods between water collections, nutrient concentrations in the water column may have been depleted while the bacterial load was in stationary phase. Total and fecal coliforms abundance may have increased in the Winter and Fall due to wildlife foraging and hunting events. Popular hunting seasons, such as deer and duck, open at the beginning of Fall and end in the Winter. During the hunting season, there is more human activity in the upper estuary, which may have lead to increased numbers of fecal coliforms (LA Wildlife and Fisheries, Annual Reports, 2007, 2008). In a study of the Seine Estuary, it was found that the highest amounts of fecal coliforms were in areas receiving runoff from urban areas (Touron et al., 2007). This suggests that the abundance of fecal coliforms in the upper Barataria Estuary during hunting season may be human related.

Aquatic and terrestrial plants may have played a role in decreasing dissolved oxygen levels during the Fall and pH during the Winter. Some terrestrial plants and trees begin to lose leaves in the Fall. Leaves enter the water column by falling directly into the water column, being blown into the water, or by floodplain inundation. Also, during the Fall and Winter there are shorter days, which leads to reduced photosynthesis of aquatic plants. As a result of decreased photosynthesis of aquatic plants and increased respiration of leaf decomposers, there is less oxygen and more carbon dioxide being released into the water column and we speculate carbon dioxide may have decreased the pH in the water column.

4.2 Spatial variations (Figures 3-6)

Runoff from human dominated areas is suspected to be the primary factor affecting parameters investigated due to significant site variations in the following parameters: pH, dissolved oxygen, nitrate, and phosphate. Mean phosphate and nitrate concentrations may have been greater at site 4, St. James Canal, due to runoff from urban areas and agriculture fields. The St. James Canal may contain large amounts of nitrate and phosphate from pesticides and fertilizers (Brock et al., 1993). The mean nitrate concentration at site 4 was not different from site 3 due to site 3 receiving water from site 4. The mean phosphate and nitrate concentration at site 5 was also not different from site 4. The elevations of phosphate and nitrate concentrations at site 5 were most likely due to runoff from both agriculture fields and natural swamp land (Day et al., 1976).

As expected, dissolved oxygen was highest at site 1, Lac Des Allemands; and lowest at site 5, upper Bayou Chevreuil. This may have been due to less mixing of the water column in Bayou Chevreuil than in Lac Des Allemands, and related to the higher concentration of nutrients received at site 5 versus site 1. Dissolved oxygen at sites 1 and 2 and sites 3-5 were not different. Similar dissolved oxygen concentrations at site 1 and 2 were the result of wind pushing water from Lac Des Allemands into the mouth of Bayou Chevreuil. The width of the bayou at sites 3-5 was relatively similar resulting in similar dissolved oxygen concentrations.

4.3 Date specific correlations

The relationship between organic carbon and heterotrophic bacteria was captured on 23 December 2007. The total organic carbon concentration (mg/L) and heterotrophic aerobic and anaerobic bacteria (CFU/mL) were elevated while the dissolved oxygen was significantly depleted. The relationship between these parameters may have been captured on 23 December 2007 due to bacterial growth in the exponential phase. Bacteria were multiplying due to an influx of organic carbon in the water column (Gulis et al., 2004). The abundance of bacterial activity decreased the dissolved oxygen concentration (Song et al., 2006). The dissolved oxygen concentration on 23 December 2007 was severely hypoxic which resulted in a small scale fish kill.

4.4 Correlated parameters

One factor that may influence the concentration of dissolved nitrate is runoff. Runoff is suspected due to the high correlation between turbidity and dissolved nitrate concentration. The high positive correlation between nitrate concentrations and heterotrophic anaerobic bacteria in lower Bayou Chevreuil may have been due to a decreased flow rate as it enters the lake allowing more sediment to collect at this site. The relationship between nitrate concentrations and turbidity is highly documented (Lane and Day, 1999; Miao et al., 2006; Plummer et al., 1987; Stow et al., 1985). Site 2 may be the shallowest among sampling sites and receives more wind action than sites 3, 4 and 5. Depth and wind action may have allowed sediment and nitrate to easily mix into the water column periodically. This would allow more sediment and nitrate to be available at site 2 than other sites during water sample collections. The high positive correlation of these two parameters during the summer may have been a result of higher temperatures and lower dissolved oxygen concentrations (Flint, 1985). Higher temperatures stimulate more microbial activity, while low dissolved oxygen concentrations may increase the load of anaerobic bacteria more than heterotrophic aerobic bacteria, total coliforms, or fecal coliforms (Dedieu et al., 2007).

4.5 Hurricane Gustav parameters

An abundance of large woody debris and dead fish of various sizes were noted while collecting water samples six days after Hurricane Gustav. Flow rate appeared stagnant. As expected after a hurricane event, the dissolved oxygen was significantly decreased and organic carbon was high due to reintroduction of the bottom sediment into the water column along with decomposition of leaf litter and large woody debris (Gulis and Suberkropp, 2003; O’ Connell et al., 2000). The organic carbon was 43% higher than the system-wide mean concentration of all sites combined for the sampling dates 20 July 2007 to 21 June 2008. Dissolved nitrate and phosphate concentrations (mg/L), heterotrophic aerobic and anaerobic bacteria (CFU/mL), and fecal coliforms (MPN/100 mL) were not as elevated as expected. This may have been the result of an increased flow rate of water exiting the upper Barataria Estuary immediately after the hurricane event.

CONCLUSIONS

This study showed the water quality of the upper Barataria Estuary. Among nutrients, dissolved nitrates play a significant role in stimulating heterotrophic anaerobic microbial activity in the upper Barataria Estuary. Organic carbon concentrations stimulate both heterotrophic aerobic and anaerobic activity. Phosphate in this study did not appear to induce significant microbial activity. Heterotrophic aerobic bacteria dominated the water column of the upper Barataria Estuary. Results suggest that heterotrophic anaerobic bacteria dominated the bottom sediment of the upper Barataria Estuary. Windy conditions can mix up the water column with bottom sediments interrupting the delicate balance of dissolved oxygen concentration. Management of runoff from urban and agricultural lands may help improve the stressed conditions of the upper Barataria Estuary by eliminating or decreasing the amount of nitrate released into the water column. An increased flow rate of the channels in the upper Barataria Estuary will also help to manage low dissolved oxygen levels.

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