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Environmental Conditions in Northern Gulf of Mexico Coastal Waters Following Hurricane Katrina

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Cover photograph ---- GOES Project Science Office

Contents

Acronyms

ADEM	Alabama Department of Environmental Management
AVS	acid volatile sulfide
CDF	cumulative distribution function
CFU	colony forming units
DDT	p,p’-dichlorodiphenyltrichloroethane
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
DO	dissolved oxygen
ELISA	Enzyme-Linked ImmunoSorbent Assay
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
ERL	effects range low
ERM	effects range median
ERM-Q	effects range median quotient
ESB	Equilibrium Partitioning-Derived Sediment Benchmark
FCV	final chronic value
GC/ECD	gas chromatograhy electron capture detector
GC/MS	gas chromatograhy mass spectrometry
GPS	Global Positioning System
ICP/MS	inductively coupled plasma mass spectrometry
KOW	octanol-water partition coefficient
LP	Lake Pontchartrain
LUMCON	Louisiana University Marine Consortium
MDEQ	Mississippi Department of Environmental Quality
MS	Mississippi Sound
MPN	most probable number
NCA	National Coastal Assessment
NOAA	National Oceanic and Atmospheric Administration
OSV	Ocean Survey Vessel
PAH	polyaromatic hydrocarbon
PBDE	polybrominated dephenylether
PCB	polychlorinated biphenyl
QAPP	Quality Assurance Project Plan
SEM	simultaneously extracted metals
TOC	total organic carbon
TSS	total suspended solids
USGS	U.S. Geological Survey
WQI	Water Quality Index

Acknowledgments

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Executive Summary

On the morning of August 29, 2005, Hurricane Katrina struck the coast of Louisiana, between New Orleans and Biloxi, Mississippi, as a strong category three hurricane on the Saffir-Simpson scale. The resulting winds, storm surge, and flooding created the potential for a tremendous environmental impact along the northern Gulf of Mexico coast. The U.S. Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and U.S. Geological Survey (USGS) conducted a joint study in October 2005 to assess potential ecological effects of the hurricane in coastal waters of Lake Pontchartrain, Louisiana, and Mississippi Sound from Dauphin Island, Alabama, to the western side of Lake Borgne, Lousiana. Post-hurricane conditions were compared to pre-hurricane conditions using data collected from the same areas in 2000 to 2004 with similar indicators and protocols.

Monitoring surveys were conducted at 30 stations in Lake Pontchartrain from October 11-14, 2005, using small trailerable boats and at 30 stations in Mississippi Sound from October 9-15, 2005, using small boats staged from EPA's OSV *Bold* in Gulfport, Mississippi. A major focus of these surveys was on the collection and analysis of water and sediment samples using standard protocols and core indicators applied in EPA's Environmental Monitoring and Assessment Program (EMAP) and National Coastal Assessment (NCA) programs. Water analyses included nutrients, chlorophyll *a*, total suspended solids, carbon, water-borne pathogens (fecal coliforms and enterococci), and chemical contaminants (organochlorine pesticides, PCBs, PAHs, oil and grease, and metals). Sediment was collected from multiple grabs at each site, combined into single station composites, and then sub-sampled for toxicity testing and the analysis of chemical contaminants, microbial/pathogenic indicators, TOC, and grain size. One additional sediment grab (0.04 m^2) was collected at each site for analysis of benthic macroinfauna (> 0.5 mm). These data were compared to similar data collected prior to the storm and to environmental evaluation thresholds available in the literature.

Dissolved oxygen increased after the hurricane in both Lake Pontchartrain and Mississippi Sound/Lake Borgne due most likely to mixing of the water column from wind and tidal action. Storm-related changes in bottom-water salinity also occurred in both systems though with contrasting patterns. The salinity change was particularly pronounced in Lake Pontchartrain, which shifted from a predominantly oligohaline system prior to the hurricane to predominantly mesohaline after, due possibly to storm surge and the intrusion of more saline water from Lake Borgne and Mississippi Sound. Portions of Mississippi Sound, particularly on the west side, became slightly less saline after the hurricane, due most likely to dilution from runoff and mixing of water from Lake Pontchartrain and Lake Borgne.

Total suspended solids (TSS) in the water column increased in Lake Pontchartrain and decreased in Mississippi Sound following the hurricane. As a result, water clarity decreased in Lake Pontchartrain and increased in Mississippi Sound. Average concentrations of chlorophyll *a* (Chla) in the water column increased in Mississippi Sound following the hurricane, while there was little storm-related change in Lake Pontchartrain. Overall water quality following Hurricane Katrina, as assessed using the five core water-quality parameters (DO, Chla, DIN, DIP, and water clarity), did not differ significantly from previous years based on five years of probabilistic survey data.

There were no significant elevations of organic or inorganic chemical contaminants in the water column and indicators of pathogen contamination were extremely low as well. There also were no exceedances of Effects Range Median (ERM) sediment quality guideline values for chemical contaminants (Long et al., 1995) in any of the sediment samples collected from Lake Pontchartrain or Mississippi Sound following the hurricane. While lower-threshold Effects Range Low (ERL) values were exceeded for arsenic, cadmium, and nickel at several stations in both survey areas, similar levels of contamination have occurred prior to the hurricane, indicating very little change in the concentrations and type of contaminants due to the hurricane. The insecticide Fipronil® was detected in post-hurricane sediments from both Lake Pontchartrain and Mississippi Sound. However, no sediment quality guideline value or pre-hurricane data on Fipronil® concentrations are available for comparison. When concentrations of chemical contaminants were normalized to aluminum concentrations, it was determined that there was little risk to benthic fauna from metals, PAH's, and most pesticides with the exception of Fipronil®. However, there are insufficient data on the toxicity of Fipronil® to assess the biological significance of its low, yet detectable levels.

There were notable changes in several benthic community characteristics between the pre- and post-hurricane periods that are suggestive of storm-related effects in both Lake Pontchartrain and the more open waters of Mississippi Sound. These included shifts in the composition and ranking of dominant taxa and reductions in number of taxa, H' diversity, and total faunal abundance. Such changes did not appear to be linked to chemical contamination, organic enrichment of sediments, or hypoxia at least as major causes. Storm-related changes in salinity were a more likely cause of the observed benthic changes in both systems. Storm-induced scouring of sediments could have contributed to these effects as well.

The results from this study represent a snapshot of ecological condition in coastal waters of Lake Pontchartrain and Lake Borgne-Mississippi Sound two months after the passing of Hurricane Katrina. The comparison of ecological indicators before and after the hurricane suggests considerable stability of these systems with respect to short-term ecological impacts. While some storm-related changes could be detected (e.g., effects on benthic communities associated with shifts in salinity), there was no consistent evidence to suggest widespread ecological damage. These coastal ecosystems in general appeared to have absorbed much of the physical impact of the storm along with any anthropogenic materials that may have been mobilized by the floodwater and storm surge. Yet, it must be noted that the present study, conducted shortly after the hurricane, was not designed to assess potential long-term chronic environmental effects. Follow-up studies are recommended to evaluate such impacts.

1. Introduction

On the morning of August 29, 2005, Hurricane Katrina struck the coast of Louisiana between New Orleans and Biloxi, Mississippi, as a strong category three hurricane on the Saffir-Simpson scale, with sustained winds of 125 mph and central pressure of 920 mb (NOAA/NCDC 2005). Within 24 hours prior to landfall, Katrina was a category five hurricane reaching maximum sustainable winds of 170 mph. Rainfall accumulations were in excess of 8-10 inches along much of the coast, and there was coastal storm-surge flooding of 20-30 feet above normal tidal levels. The massive winds and flooding resulted in enormous losses of human lives and property.

The U.S. Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and U.S. Food and Drug Administration (FDA) have been engaged in a comprehensive interagency effort to assess human-health and environmental impacts of Hurricane Katrina in affected coastal waters of Louisiana, Mississippi, Alabama, and northern Gulf of Mexico. By integrating response activities conducted in estuarine and near-coastal waters aboard EPA's OSV *Bold* and the NOAA Ship NANCY FOSTER, with numerous field activities in shallower inland and wetland environments, this combined effort has sought to characterize the magnitude and extent of coastal contamination and associated human-health and ecological effects resulting from this unprecedented storm. The present report provides a summary of initial results of one component of this overall coordinated effort, i.e., an assessment of environmental condition of Lake Pontchartrain, Louisiana, sub-tidal waters and the more open near-coastal waters of Mississippi Sound from Dauphin Island, Alabama, to the western side of Lake Borgne, Louisiana (Fig. 1-1).

Monitoring surveys were conducted in Lake Pontchartrain from October 11-14, 2005, using small trailerable boats and in Mississippi Sound from October 9-15, 2005, using small boats staged from the OSV *Bold* in Gulf Port, Mississippi. A major focus of these surveys was on the collection and analysis of water and sediment samples using standard protocols and core indicators developed by EPA's Environmental Monitoring and Assessment Program (EMAP) and National Coastal Assessment (NCA) programs (USEPA 2002, 1999), prior NCA assessments conducted in the same area from 2000 to 2004. As in prior NCA assessments, a probability-based sampling design consisting of 30 randomly selected sites in each of the two post-hurricane survey areas was used to support statistical estimates of ecological condition relative to the various indicators measured. These included standard NCA ecological indicators of sediment quality, water quality, and benthic condition. Additional water and sediment samples were collected and analyzed for microbial indicators of human-health risks and newly emerging contaminants of concern.

Our goal was to provide a comprehensive and scientifically sound assessment of initial human-health risks and environmental impacts of Hurricane Katrina in the affected waters and to establish a useful benchmark for determining how these conditions may be changing with time. Results were made available to local, state, regional and federal decision-makers to support related environmental and public-health decisions, recovery, and restoration efforts.

2. Methods

2.1 Pre- and post-hurricane sampling designs and field collections

Table 2-1 provides a summary of the number of stations included in both the pre- and post-hurricane surveys of Mississippi Sound (MS) and Lake Pontchartrain (LP) survey areas. Locations of the 60 post-hurricane stations, including 30 each in Lake Pontchartrain and Mississippi Sound, are presented in Fig. 1-1b. All stations were selected using a random probability-based survey design. This approach is a powerful assessment tool for making unbiased statistical estimates of the spatial extent of a study area that is in degraded condition, based on the comparison of measured ecological indicators to desired management thresholds. A similar approach has been applied throughout EPA's EMAP and NCA programs (USEPA 2002, 1999). Methods for estimating the proportion of area of each system meeting certain criteria, and its associated variance, are based on published formulae for stratified random sampling designs (Cochran 1977).

The survey design required that various measurements and samples be obtained at each of the sampling stations during the post-hurricane surveys in Lake

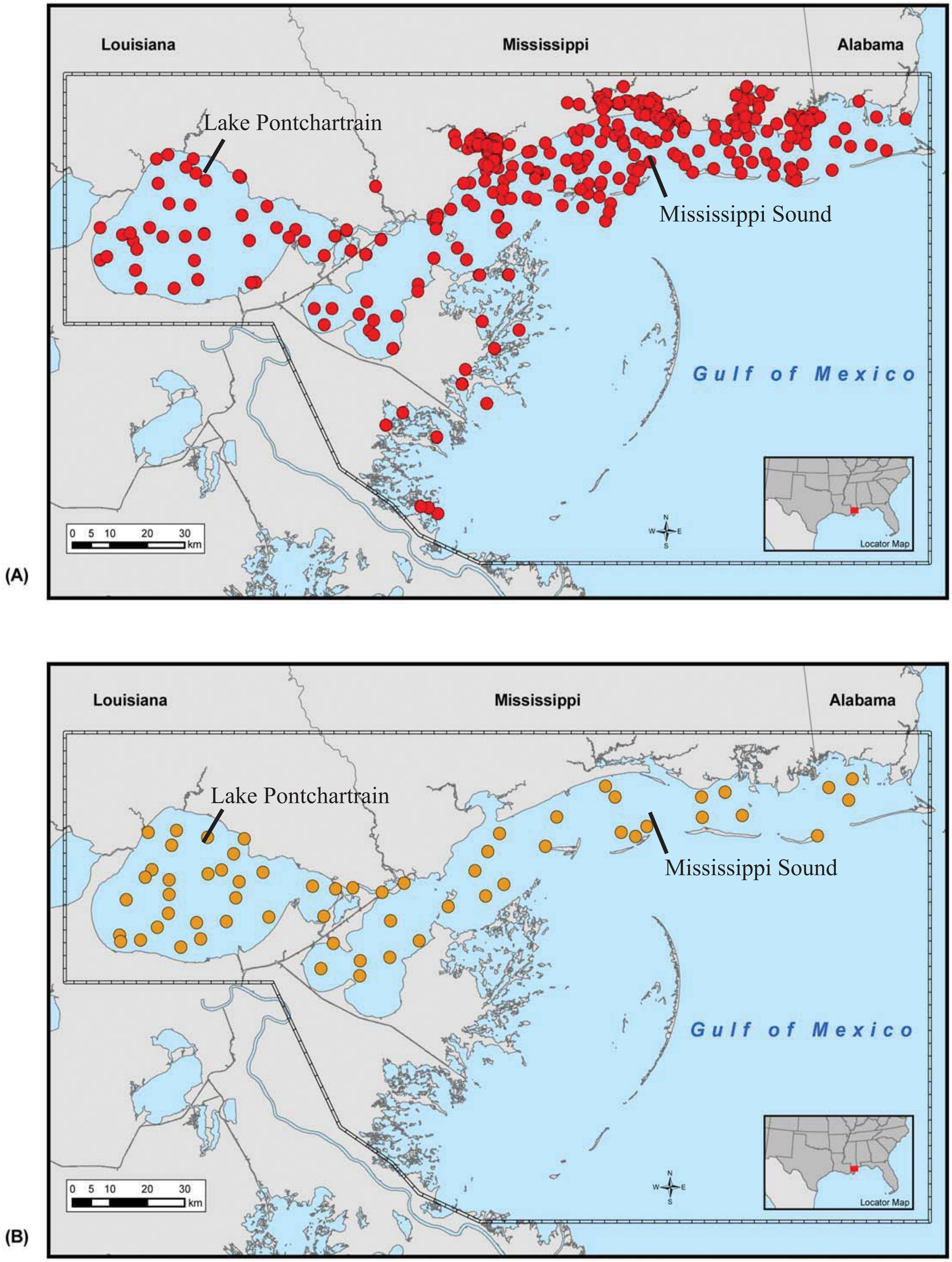

Fig. 1-1. Study area and sampling locations in Mississippi Sound and Lake Pontchartrain during (a) pre-Hurricane Katrina (2000-2003) and (b) post-Hurricane Katrina (October 2005) surveys.

Sampling Period	MS	LP
Pre-Hurricane		
2000	29	6
2001	36	10
2002	34	10
2003	37	13
2004	36	10
Total	172	49
Post-Hurricane (Oct 05)	30	30

Table 2-1. Summary of number of stations included in pre- and post-hurricane surveys of Mississippi Sound (MS) and Lake Pontchartrain (LP) survey areas.

Pontchartrain and Mississippi Sound (October 2005). These included sediment samples for the analysis of chemical contaminants (DDT and other conventional chlorinated pesticides, PCBs, PAHs, metals), microbial/pathogenic indicators (*Clostridium perfringens*), grain size and organic carbon content (TOC), condition of resident benthic fauna, and sediment toxicity (Microtox®) as measures of contaminant exposure and biological effect. Hydrographic parameters (DO, salinity, temperature, pH, depth, water clarity), were measured, and water samples were collected and analyzed subsequently for nutrients (total N and P, dissolved nitrate, nitrite, orthophosphate, and ammonium), chlorophyll *a*, total suspended solids, dissolved organic carbon, chemical contaminants (conventional organochlorine pesticides, PCBs, PAHs, oil and grease, metals), and microbial/pathogenic indicators (*Enterococcus*, fecal coliforms, and viral indicators). Additional contaminants of concern were analyzed, including atrazine in water, flame retardants (e.g., PBDEs) in sediments, and Fipronil® in sediments, as their potential human-health and ecological impacts have only recently become apparent in coastal and marine environments.

All sites were sampled in accordance with the standard procedures in the NCA Field Methods Manual (USEPA 2001a) and in accordance with the NCA Quality Assurance Project Plan (USEPA 2001b) where applicable. Each station was located using the Global Position System (GPS). Sediments were collected using a 20 cm^2 Young-modified Van Veen benthic grab. Grab samples were collected to a maximum depth of 10 cm and rejected if < 5 cm or if there was other evidence of sampling disturbance (e.g., major slumping, debris caught in jaws). Sediment for toxicity testing and the analysis of chemical contaminants, microbial/pathogenic indicators, TOC, and grain size was composited from multiple grab samples at each station until there was sufficient volume for the analyses. The entire contents of one additional grab were sieved (0.5 mm) and the material remaining on the screen fixed in 10% buffered formalin with rose bengal for benthic infaunal community analysis. Nutrients and chlorophyll *a* samples were collected 0.5 m below the surface and 0.5 m above the bottom using a Beta Plus® sampler. A Hydrolab® H20 sonde was used to measure salinity, temperature, pH, and dissolved oxygen at 1.0 m intervals from surface to bottom at each station. Secchi depth was also measured. Individual water samples were collected for organic and inorganic contaminants, oil and grease, and total suspended solids at 0.5 m below the surface and 0.5 m above the bottom. Separate surface water samples were collected in sterile bottles for measurement of microbial and pathogen indicators.

2.2 Laboratory processing and QA/QC

All sample analyses were performed in accordance with the NCA Quality Assurance Project Plan (QAPP) (USEPA 2001) unless otherwise stated. Sample analyses were performed by a contract laboratory or the NOAA - NCCOS laboratory in Charleston, South Carolina.

Sediment samples were analyzed for pesticides, PAHs, and PCBs using GC/ECD with dual-column output or GC/MS methodologies. Analysis for metals, with the exception of mercury, was performed using an ICP/MS. Mercury was analyzed with a mercury analyzer using cold vapor methodology. Determination of "Total Organic Carbon" concentration in the sediment was done using a C:H:N analyzer. Benthic infaunal samples were sent to a contract laboratory and transferred from formalin to 70% ethanol. Animals were sorted from the sample debris under a dissecting microscope and identified to the lowest practical taxon (usually species). The toxicity potential of sediment samples from Mississippi Sound was evaluated using the Microtox® assay. This assay provides a measure of toxicity potential based on the attenuation of light production by the photoluminescent bacterium, *Vibrio fischeri*. Sediments were classified as either toxic or non-toxic using criteria developed by Ringwood and Keppler (1998).

The concentrations of dissolved nitrate, nitrite, orthophosphate, and ammonium were measured using standard wet chemistry methodologies on an autoanalyzer. Total nitrogen and total phosphorus concentrations were determined using a persulfate digestion method, followed by wet chemistry analyses. Samples for chlorophyll *a* and total suspended solids were filtered in the field, with the filters returned to the laboratory for final processing. Chlorophyll *a* was extracted using 100% methanol and the concentration determined using fluorometric methods. Filters for total suspended solids were dried at 110° C, weighed, and the concentration calculated per liter of water filtered.

Water samples for contaminant analyses of pesticides and PAH's were extracted and concentrations determined using GC/MS methodologies. Metals analyses, with the exception of mercury, were performed using an ICP/MS. Mercury was analyzed using a mercury analyzer using cold vapor methodology. Water samples were analyzed for oil and grease using a gravimetric methodology in accordance with EPA Method 1664. A commercially available ELISA kit was used to estimate atrazine concentrations in water samples from Mississippi Sound.

Indicators of fecal contamination, enterococci and fecal coliform bacteria, were enumerated to assess potential human-health risks of pathogen exposure in the Gulf of Mexico. Both Mussel Watch and Joint Inter-Agency assessments used membrane filtration and m FC agar to enumerate fecal coliforms (APHA, 1998). Sample volumes ranging from 0.1-100 ml of water were filtered through 0.45 µm nitrocellulose membranes and the membrane placed on appropriate media and incubated at 44.5 ± 0.5° C for 24 ± 2 hours. Indicative blue fecal coliform colonies were counted and the density of fecal coliforms colony forming units (CFUs) per 100 ml of sample was calculated.

The Enterolert system was used to enumerate enterococci (IDEXX, 2004) in samples from Mississippi Sound. Ten ml of the seawater sample were diluted with 90 ml of sterile water and pre-measured and prepackaged media was added to the sample. The mixture was then added to the specialized plastic tray containing one large well and 50 small ones. The tray was sealed and incubated at 41 ± 0.5° C for 24 hours. Wells positive for growth fluoresce under ultraviolet light. The numbers of positive wells were counted, and a Most Probable Number (MPN) table was used to estimate the MPN of enterococci per 100 ml of water sample.

Membrane filtration with m Enterococcus agar was used to enumerate enterococci (IDEXX, 2004) in samples from Lake Pontchartrain (APHA, 1998). This method involved filtering 0.1, 1, 10, 50 and 100 ml of sample water through a 0.45 µm nitrocellulose membrane. Each membrane was placed on m Enterococcus agar and incubated for 48 hours at 35 ± 0.5° C. Pink and red enterococci colonies were counted and the number of enterococci CFU/100 ml of sample was calculated.

Clostridium perfringens spores were enumerated by passing an appropriate volume of water sample through a membrane filter (0.45 µm) that retains the bacteria present in the sample. The membrane filter was placed on Perfringens agar (OSCP) and incubated anaerobically for 24 hours at 37° C. To enhance color formation the filter was often overlayed with an additional coating of media. Perfringens agar (OPSP, Oxoid) is based on the formulation of Handford. The medium utilizes sulphadiazine (100 µg/ml), oleandomycin phosphate (0.5 µg/ml) and polymyxin B sulphate (10 IU/ml) to give a high degree of selectivity and specificity for *C. perfringens* which produces black colonies on this medium. Because of the selectivity of the mCP medium, a presumptive count is normally reported for routine monitoring purposes.

2.3 Data analysis

The cumulative distribution function (CDF) analysis (Horvitz-Thompson Normal approximation) was used to describe the distribution and confidence intervals of water quality indicator values for both the pre-Katrina and post-Katrina survey areas. Each indicator measure was compared to water quality criteria or guidance values to estimate condition (good, fair, poor) at each site. The CDF was used to estimate the areal extent of condition for each indicator and for the water quality index (WQI) (Diaz-Ramos et al., 1996).

Water quality indicators were evaluated using the criteria and guidance values in Appendix 1. The WQI was calculated from the scores of the following indicators: DO, DIN, DIP, Chla, and water clarity. The WQI was based on the number of indicators scored as poor. If ≥2 indicators were poor, then WQI= poor; if 1 indicator scored poor or ≥ 3 scored fair, WQI= fair, else WQI=good.

A "Sediment Quality Index" was developed in a similar manner using the following variables: sediment toxicity, sediment total organic carbon content, and concentrations of contaminants above the Effects Range Low (ERL) or Effects Range Median (ERM) values from Long et al., (1995). ERL values are lower-threshold concentrations below which adverse biological effects are expected to occur < 10% of the time, and the ERM values are higher-threshold concentrations above which adverse effects are expected to occur 50% or more of the time.

Mean ERM-Quotients (ERM-Qs), which are the means of individual contaminant concentrations in a sample relative to corresponding ERM values, were used to quantify potentially harmful mixtures of multiple contaminants present at varying concentrations (Hyland et al., 2003). Samples with mean ERM-Qs > 0.062 were regarded as having a high level of chemical contamination associated with a corresponding high risk of impaired benthic condition.

Benthic species occurrence data were used to compute density (m^{-2}) of total fauna (all species combined), densities of numerically dominant species (m^{-2}), numbers of species, H' diversity (Shannon and Weaver 1949) derived with base-2 logarithms, and a multi-metric index of benthic condition (BI, Engle et al., 1994; Engle and Summers 1998,1999). Scoring criteria used to classify samples as healthy or impaired with respect to the latter benthic index were based on the following breakpoints as applied in refinements to the index by Engle and Summers (1998, 1999): > 5 healthy, < 3 degraded, and 3-5 intermediate). Differences in the above benthic variables before vs. after the hurricane were examined using a combination of statistical (*t*-tests) and graphical comparisons including Cumulative Distribution Functions (CDFs).

3. Water Quality Results and Discussion

3.1 Water Quality Index

Post-Katrina water quality data were analyzed to determine the areal extent of condition for water clarity, dissolved oxygen, chlorophyll *a*, nitrogen, and phosphorus. These data were compared to previous NCA survey data collected from 2000 - 2004. Each water quality parameter was compared pre- and post-storm. After that, the water quality index was calculated to compare overall water quality before and after the storm. This index consists of five components: water clarity, dissolved oxygen, chlorophyll *a*, nitrogen, and phosphorus. Each of the components was assigned a rating of good, fair, or poor. The ratings were then combined to rank each of the sites. The areal extent of the ratings was assessed based on the rankings. Concentrations of water-borne contaminants were also measured and compared to existing water quality criteria. Water samples for the analyses of contaminants (oil and grease, metals, pesticides, and PAHs) were only collected after Hurricane Katrina.

From 2000-2004, the percent area with bottom DO > 5 mg/L averaged 64% while the percent area hypoxic (DO < 2 mg/L) averaged 3%. In 2004, the year prior to Hurricane Katrina, approximately 56% of the area surveyed from Lake Borgne-Mississippi Sound had bottom DO concentrations >5 mg/L (Fig. 3-1). Forty-one percent of the area was scored as fair with bottom DO concentrations between 2 and 5 mg/L and <3% of the area had bottom DO concentrations < 2 mg/L. Following the storm, the area with bottom DO concentrations >5 mg/L increased to 96% and approximately 4% of the area had bottom DO concentrations between 2 and 5 mg/L. No bottom DO concentrations < 2 mg/L were observed after Hurricane Katrina. Increases in bottom DO concentrations may be attributed to mixing of the water column from wind and tidal action.

From 2000-2004, an average of 60% of the area of Lake Pontchartrain had more bottom DO concentrations > 5 mg/L and 15% of the area was hypoxic. After Hurricane Katrina an estimated 97% of the area of Lake Pontchartrain had bottom DO concentrations > 5 mg/L, up from 80% in 2004 (Fig. 3.1). Ten percent of the area of Lake Pontchartrain had bottom DO concentrations < 2 mg/L in 2004. Bottom DO concentrations < 2 mg/L were not observed during the post-Katrina survey in Lake Pontchartrain. Again, physical forces are mostly likely the driving factors resulting in increased DO concentrations in Lake Pontchartrain after the storm.

Prior to Hurricane Katrina (2004), 12% of the Mississippi Sound survey area was oligohaline, 51% mesohaline, and 37% polyhaline based on average surface to bottom salinities (Fig. 3-2). Following the hurricane, the oligohaline areas of the Mississippi Sound survey area were eliminated by storm surge of high salinity Gulf of Mexico water. The resulting salinity regime within the survey area was 50% of the area being characterized as mesohaline and 50% polyhaline. For 2000-2004, the average areal distribution of salinity for the survey area was 35% oligohaline, 53% mesohaline, 32% polyhaline and 3% marine.

Mississippi Sound, particularly on the western side, became slightly less saline after the hurricane, due most likely to dilution from runoff and mixing of water from Lake Pontchartrain and Lake Borgne (see discussion below in the benthic Section 4.4).

The areal percentage of Lake Pontchartrain characterized as oligohaline steadily increased from 2000-2004 based on average surface to bottom salinity (Fig. 3.2). In 2004, approximately 90% of the area was oligohaline and 10% mesohaline. Average water-column salinities in Lake Pontchartrain were slightly higher following Hurricane Katrina, due most likely to the storm surge and intrusion of more saline water from Lake Borgne and Mississippi Sound. The salinity regime shifted to a more saline system with only 3% of the surveyed area characterized as oligohaline and 97% of the area as mesohaline. Such rapid changes in salinity stresses benthic and pelagic communities and negatively affects submerged aquatic vegetation.

Total suspended solids (TSS) concentrations increased in Lake Pontchartrain post-Katrina. The area exhibiting > 20 mg/L TSS increased from 0 to 17%. However, the amount of area with TSS concentrations <10 mg/L did not change (Fig. 3-3). Lake Pontchartrain is a shallow system and would have been susceptible to re-suspension of bottom sediments due to wind and wave action from the storm. Increased runoff into Lake Pontchartrain may have also been a factor contributing to the increased TSS concentrations. Although the area of Lake Pontchartrain with TSS concentrations > 20 mg/L increased from 2004, this area (17%) was similar to the average area observed to have concentrations > 20 mg/L (19%) during the survey period from 2000-2004.

Conversely, the area in Mississippi Sound with TSS concentrations > 20 mg/L following Hurricane Katrina decreased from that observed in 2004 (Fig. 3-3). The open exchange of the Mississippi Sound survey area with the Gulf of Mexico may have allowed for purging

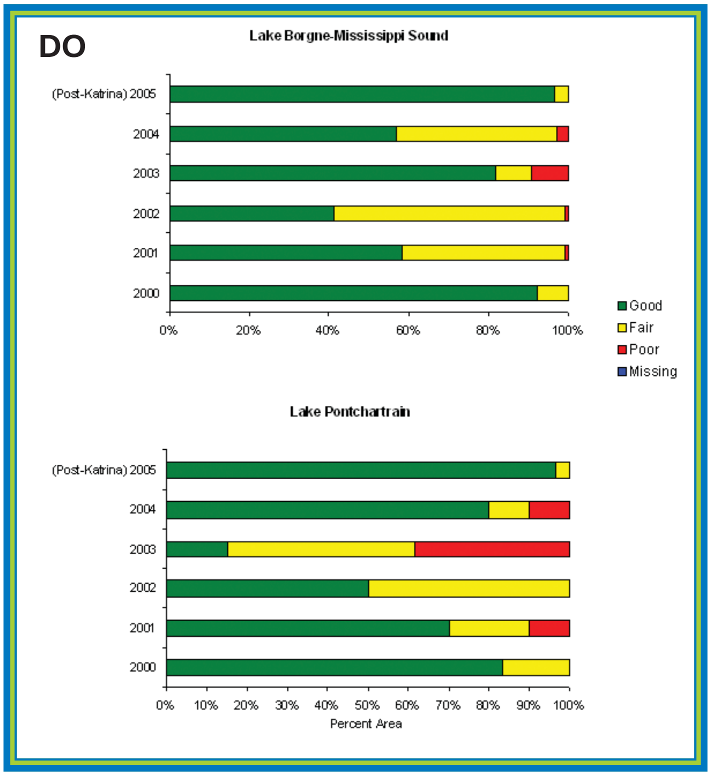

Fig. 3-1. Area of Lake Borgne-Mississippi Sound and Lake Pontchartrain exhibiting good-fair-poor bottom dissolved oxygen concentrations pre- and post-Hurricane Katrina (threshold values are listed in Appendix 1.0).

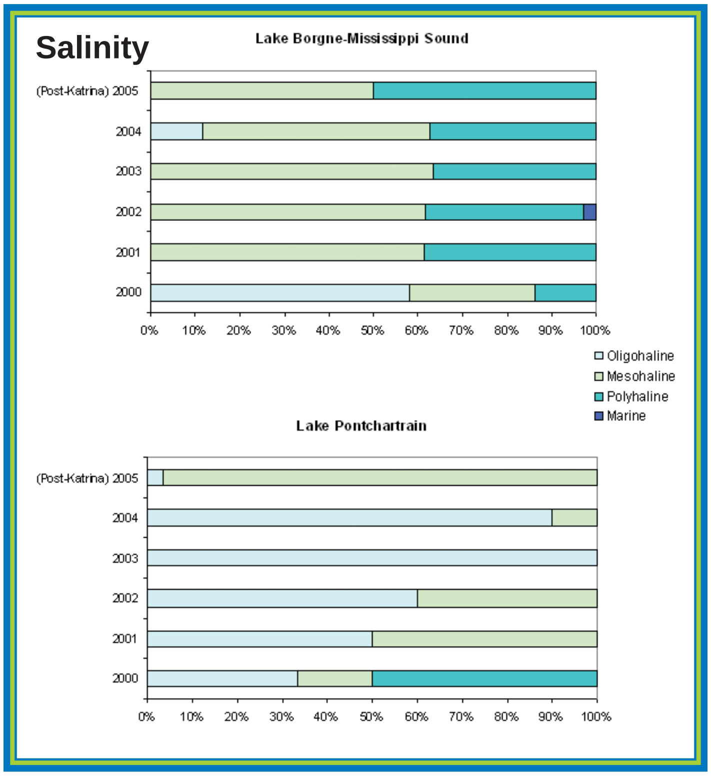

Fig. 3-2. Area of Lake Borgne-Mississippi Sound and Lake Pontchartrain exhibiting oligohaline-mesohaline-polyhaline conditions pre- and post-Hurricane Katrina.

of the system. The area with TSS concentrations > 20 mg/L following Katrina was nearly 4 times less than the average area with these concentrations estimated from 2000-2004 survey data.

Water clarity decreased in Lake Pontchartrain and increased in Mississippi Sound following Katrina (Fig. 3-4). The areal extent of good water clarity in Lake Pontchartrain decreased from 90% in 2004 to 43% post-Katrina and increased from 16% to 33% in Mississippi Sound. Poor water clarity was not observed in Lake Pontchartrain surveys prior to Katrina. The area with poor water clarity in the Mississippi Sound survey area decreased from 46% to 10%. Increases in TSS concentrations may have contributed to decreased water clarity in Lake Pontchartrain following Hurricane Katrina. The area of Lake Pontchartrain with good water clarity was approximately half the average area estimated to have good water clarity between the years 2000-2004. The biggest change in water clarity in Lake Pontchartrain was from good to fair after the hurricane. The percent area of the Mississippi Sound survey area with good water clarity post-Katrina was less than the 2000-2004 average (33% vs 48%); however, the percent area with poor water clarity was lower than the 5-year average (10% vs 26%).

Average concentrations of chlorophyll *a* (chla) in the water column increased in the Mississippi Sound survey area in the month following Katrina. The biggest difference between 2004 and post-Katrina was in the area with chla concentrations between <5 ug/L and 5-20 ug/L. Three percent of the area had chla concentrations >20 ug/L compared to none in 2004 (Fig. 3-5). Five-year averages of the Mississippi Sound survey show a combined area of 99% with chla concentrations ≤ 20 ug/L. In Lake Pontchartrain, the cumulative distribution of chla concentrations did not change. However, the area with concentration in the fair category has increased each year since 2000.

Over the past 5 years, the percentage of the Mississippi Sound survey area with concentrations of dissolved inorganic nitrogen (DIN) >0.1 mg/L has decreased, while dissolved inorganic phosphorus (DIP) concentrations >0.01 mg/L have increased (Fig. 3-6). Post Hurricane Katrina, the entire Mississippi Sound survey area had DIN concentrations <0.1 mg/L. The percent of the Mississippi Sound survey area

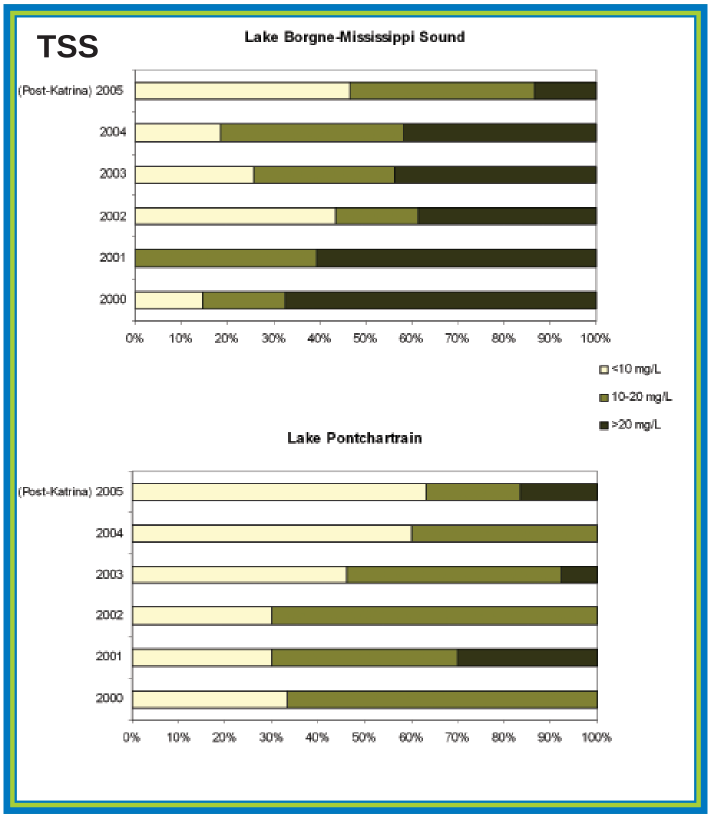

Fig. 3-3. Area of Lake Borgne-Mississippi Sound and Lake Pontchartrain exhibiting < 10 mg\L, 10-20 mg\L, and > 20 mg\L of total suspended solids concentrations pre- and post-Hurricane Katrina.

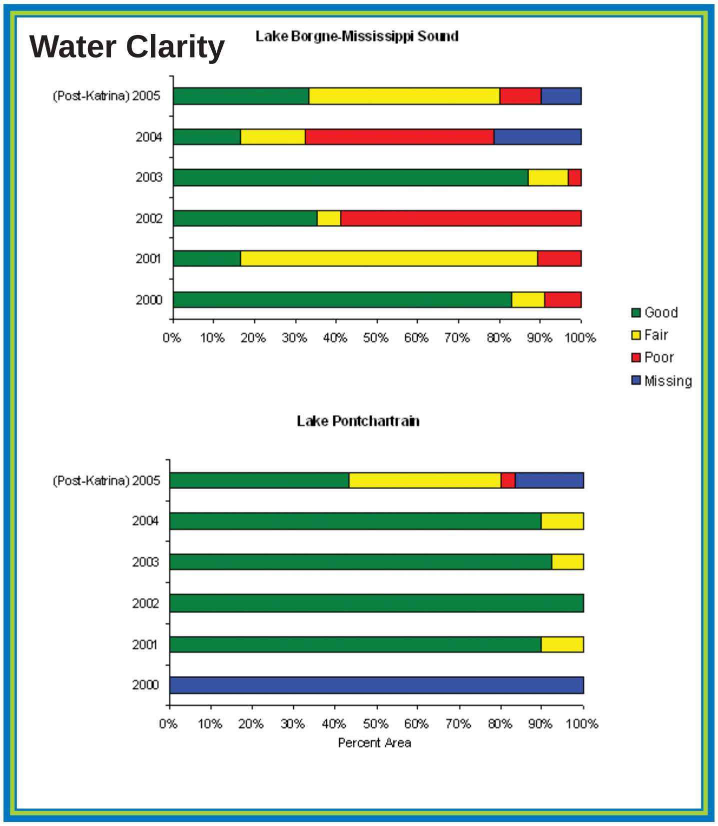

Fig. 3-4. Area of Lake Borgne-Mississippi Sound and Lake Pontchartrain exhibiting good, fair, and poor water clarity pre- and post-Hurricane Katrina (threshold values are listed in Appendix 1.0).

with DIP concentrations between 0.01 and 0.05 mg/L increased after the storm compared to the average area surveyed from 2000-2004; however, percentage of area with DIP concentrations > 0.05 mg/L was 0% compared to the 5-year average of 13%. Increased runoff may have elevated nutrient concentrations in some portions of the survey area while Gulf waters may have diluted nutrient concentrations. Excess nutrients, especially nitrogen are quickly utilized by phytoplankton in this system and diluted by oligotrophic marine waters, (Smith, 2006).

Compared to 2003, Lake Pontchartrain DIN and DIP concentrations decreased. DIN concentrations < 0.1 mg/L were observed for 97 % of the area after the hurricane compared to 82% for the average area from 2000-2003. No DIP concentrations > 0.05 mg/L were observed in Lake Pontchartrain following the storm compared to the average percent area of 24% observed from 2000-2003. If excess nutrients were introduced into Lake Pontchartrain as a result of runoff, they were mostly likely rapidly utilized.

Overall water quality post-Katrina in the Mississippi Sound survey area was similar to 2004. Water quality from an ecological perspective was not severely altered as assessed using 5 years of probabilistic survey data. When sampled approximately 6 weeks after the storm the percent area with good and fair

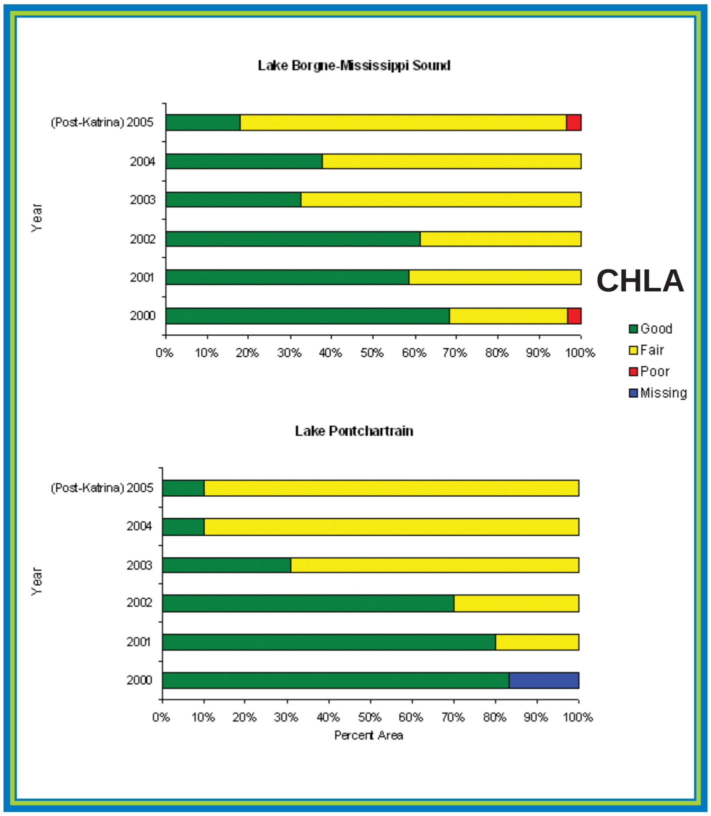

Fig. 3-5. Area of Lake Borgne-Mississippi Sound and Lake Pontchartrain exhibiting good, fair, and poor concentrations of chlorophyll a, pre- and post-Hurricane Katrina (threshold values are listed in Appendix 1.0).

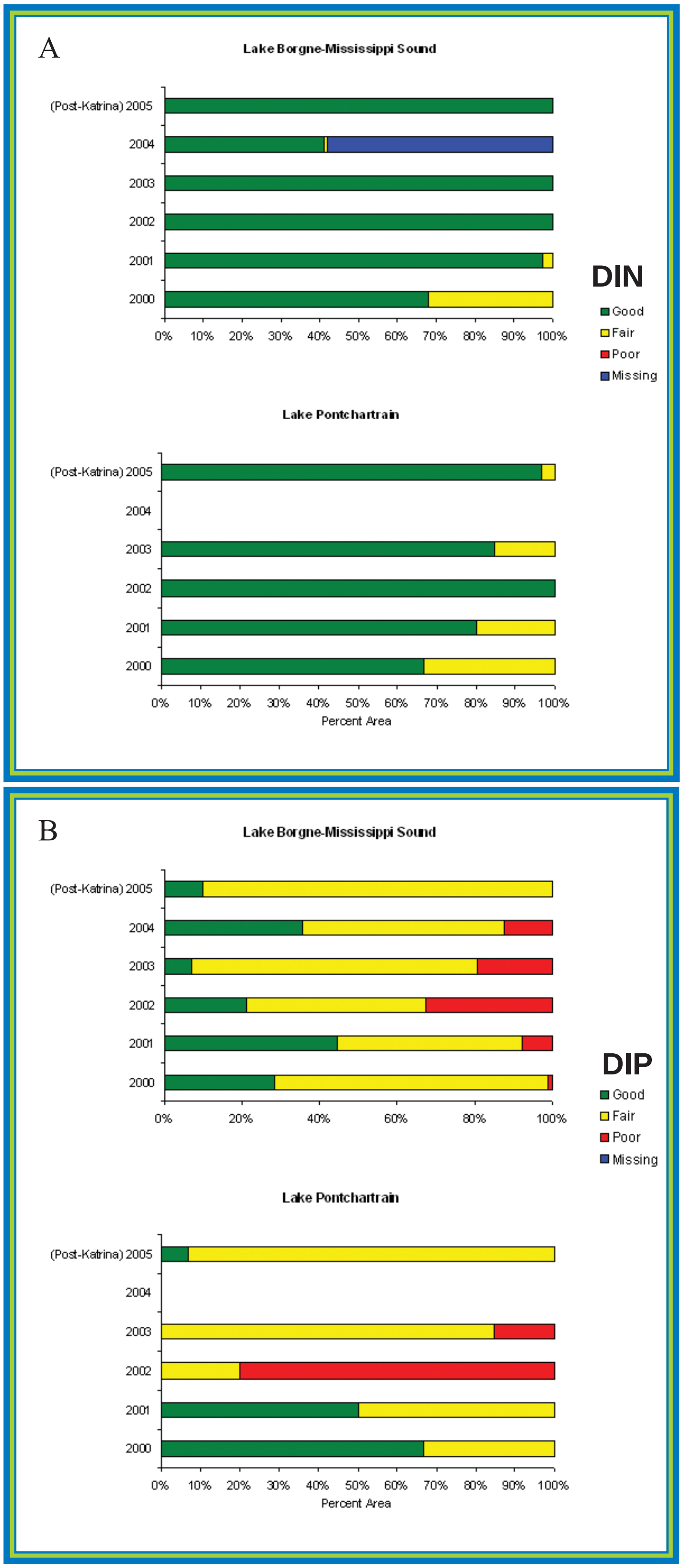

Fig. 3-6. Area of Lake Borgne-Mississippi Sound and Lake Pontchartrain exhibiting good, fair, and poor concentrations of dissolved inorganic nitrogen (a) and dissolved inorganic phosphorus (b) pre- and post-Hurricane Katrina (threshold values are listed in Appendix 1.0).

water quality was 13% and 87% respectively (Fig. 3-7). The 5 year pre-storm areal average for overall water quality was 32% and 64%, respectively, and 4% for good, fair and poor water quality, respectively. In Lake Pontchartrain, a similar trend was observed. The average areal percentages for water quality from 2000-2003 were 23% good, 62% fair and 15% poor. Following Hurricane Katrina, poor water quality was not observed in Lake Pontchartrain. Thirteen percent of the area had good water quality, and 87% had fair water quality.

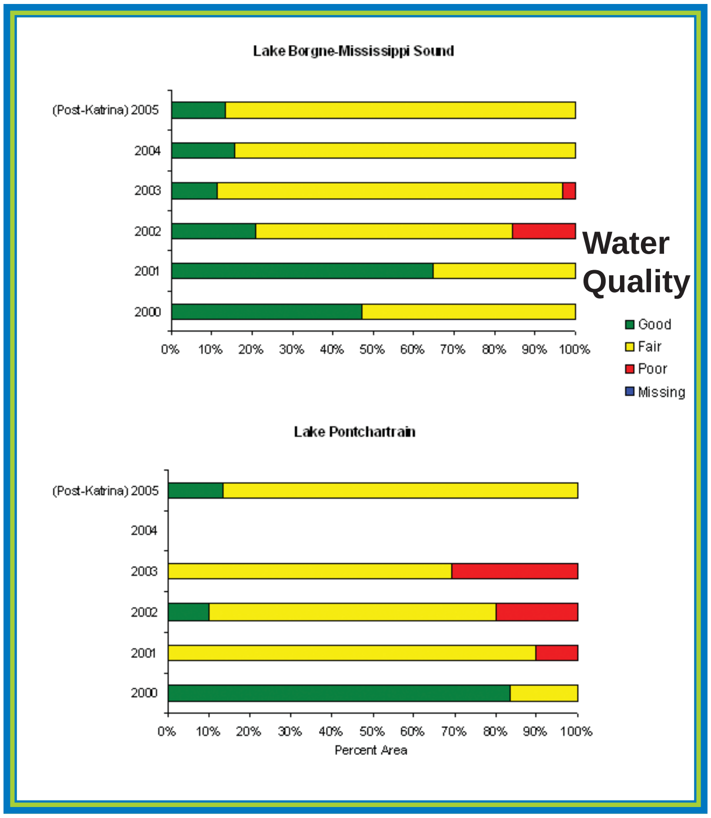

Fig. 3-7. Area of Lake Borgne-Mississippi Sound and Lake Pontchartrain exhibiting good, fair and poor water quality pre- and post-Hurricane Katrina (threshold values are listed in Appendix 1.0).

3.2 Oil and Grease

Oil and grease results for Lake Borgne-Mississippi Sound and Lake Pontchartrain are presented in Fig. 3-8. No samples collected from the Lake Borgne-Mississippi Sound survey area exceeded the 10 mg/L concentration listed for effluent of permitted outfalls in Mississippi surface waters. The majority (63%) of the area had oil and grease concentrations ≤ 5 mg/L. Concentrations between 5.1 and 10.0 mg/L were measured for 37% of the surveyed area. Approximately 90% of the area surveyed in Lake Pontchartrain had concentrations of oil and grease between 5.1 and 10.0 mg/L. Oil and grease concentration at one site in Lake Pontchartrain exceeded 10 mg/L and 6% of the area had oil and grease concentrations ≤ 5 mg/L.

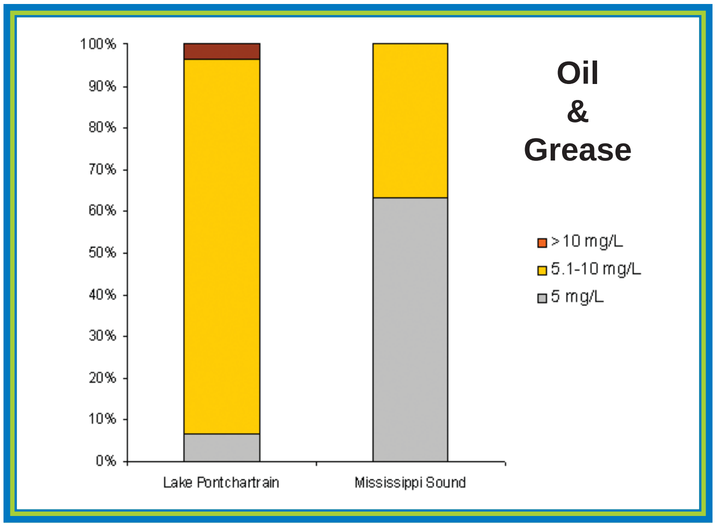

Fig 3-8. Area of Lake Borgne-Mississippi Sound and Lake Pontchartrain exhibiting 5 mg\L, 5.1-10 mg\L, and > 10 mg\L of dissolved oil & grease concentrations post-Hurricane Katrina.

3.3 Metals

Concentrations of metals detected in water samples collected from Lake Borgne-Mississippi Sound and Lake Pontchartrain are presented in Table 3-1. No metals measured exceeded EPA's acute criteria for the protection of aquatic life in marine waters; however, chronic exposure criteria were exceeded for copper at one station, for lead at a second station and for both at a third station in Mississippi Sound (USEPA 2002).

3.4 Pesticides and PAHs

All concentrations measured in water samples collected from Lake Pontchartrain and Lake Borgne-Mississppi Sound survey areas were below detection limits for both pesticides and PAHs.

3.5 Atrazine

Atrazine was detected in water samples from 5 of the 28 Mississippi Sound sampling stations (Table 3-2). Concentrations ranged from 0.10-0.18 ug/L. Concentrations at all sites were well below the currently proposed saltwater water quality criterion of 17 ug/L.

Analyte	Lake Pontchartrain (ppb)	Lake Borgne-MS Sound (ppb)	Acute WQC Value (ppb)	Chronic WQC Value (ppb)
Aluminum	40.06 - 2106.4	85.06 - 1776.8	-	-
Arsenic	0.345 - 0.777	0.49 - 1.11	69	36
Cadmium	0.018 - 0.042	0.016 - 0.213	40	8.8
Chromium	0.142 - 0.763	0.212 - 0.75	-	-
Copper	0.954 - 2.15	0.808 - 5.43	4.8	3.1
Lead	0.049 - 0.724	0.109 - 10.6	210	8.1
Mercury	0.001 - 0.003	0.001 - 0.273	1.8	0.94
Nickel	0.878 - 5.55	0.618 - 3.18	74	8.2
Selenium	0.121 - 0.237	0.076 - 0.297	290	71
Silver	0 - 0.041	0.006 - 0.022	1.9	-
Zinc	0.804 - 39.5	0.781 - 13.7	90	81

Table 3-1. Concentrations of metals in water samples collected from Lake Borgne-Mississippi Sound and Lake Pontchartrain following Hurricane Katrina.

Station	Date Collected	Atrazine Conc. (ug/L)
KAT-0001	10/11/2005	nd
KAT-0002	10/12/2005	nd
KAT-0003	10/12/2005	0.11
KAT-0004	10/10/2005	nd
KAT-0005	10/12/2005	0.11
KAT-0006	10/11/2005	nd
KAT-0007	10/11/2005	nd
KAT-0008	10/10/2005	nd
KAT-0009	10/11/2005	nd
KAT-0010	10/10/2005	nd
KAT-0011	10/10/2005	nd
KAT-0012	10/10/2005	nd
KAT-0013	10/12/2005	0.13
KAT-0014	10/11/2005	nd
KAT-0015	10/11/2005	nd
KAT-0016	10/11/2005	nd
KAT-0017	10/11/2005	nd
KAT-0018	10/11/2005	nd
KAT-0019	10/12/2005	nd
KAT-0020	10/10/2005	nd
KAT-0021	10/12/2005	nd
KAT-0022	10/11/2005	nd
KAT-0025	10/11/2005	nd
KAT-0026	10/12/2005	nd
KAT-0027	10/10/2005	nd
KAT-0028	10/10/2005	nd
KAT-0029	10/12/2005	0.18
KAT-0030	10/12/2005	0.10

Table 3-2. Measured concentrations of atrazine in water samples collected from Mississippi Sound following Hurricane Katrina.

3.6 Waterborne Pathogens

Clostridium perfringens in the water column

Clostridium perfringens is a bacterium found in the intestinal tract of both humans and animals that enters the environment through feces. There are no EPA health-based ambient water quality criteria for *C. perfringens*. However, some scientists recommend using *C. perfringens* spores as a tracer of fecal pollution because its presence is a good indicator of recent or past fecal contamination in water as their spores survive well beyond the typical life-span of other fecal bacteria. Results from the post-Katrina survey in the Lake Borgne-Mississippi Sound survey area show that concentrations of *C. perfringens* spores in the water column were undetectable or low (Fig. 3-9). Microbial samples are not routinely collected under the NCA Program; therefore, no pre-storm data are available to make pre- and post-Katrina comparisons. Due to sampling constraints, there were no post-storm samples collected in Lake Pontchartrain for *C. perfringens.*

3.7 Fecal coliforms in the water column

Fecal coliform concentrations were compared to two criteria for shellfish harvesting waters (USEPA 841/R/00/002). The first criterion (14 CFU/100 ml) is the 30-day median concentration while the second (43 CFU/100 ml) is the criterion that should not be exceeded by >10% of samples collected during a 30-day period. None of the samples from either Lake Pontchartrain or Mississippi Sound exceeded either of these criteria. The highest concentrations measured were 12 CFU/100 ml and 3 CFU/100 ml in Lake Pontchartrain and Mississippi Sound, respectively (Table 3-3).

3.8 Enterococci in the water column

Ambient Water Quality Criteria for Bacteria (USEPA, 1986) recommends the use of enterococci, a group of bacteria found in the gastrointestinal tract of warm-blooded animals, as indicator organisms for measuring fecal contamination of marine waters for the designated use of swimming as required by the Clean Water Act (Section 304). EPA recommends that single sample maximums for bathing waters not exceed 104 CFUs per 100 ml. Bacterial enumeration for enterococci for both the Lake Pontchartrain and Mississippi Sound survey areas indicate that the number of CFUs observed did not exceed the 104 CFU/100 guidance criteria. The maximum number of CFUs/100 ml observed were 2 and 10 for Lake Pontchartrain and Mississippi Sound, respectively (Table 3-3).

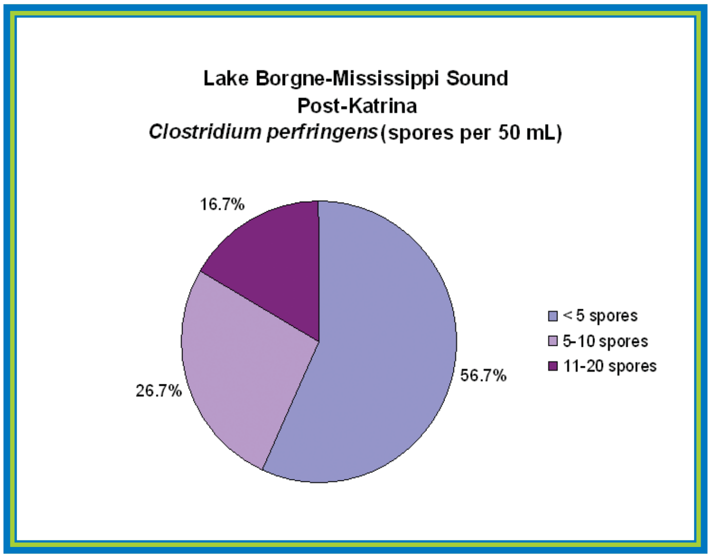

Fig 3-9. Area of Lake Borgne-Mississippi Sound and Lake Pontchartrain exhibiting <5 spores/50 ml, 5.0-10 spores/50 ml, and >10 spores/50 ml of Clostridium perfringens post-Hurricane Katrina.

Lake Borgne-Mississippi Sound	*Enterococci (CFUs/100 mL)	Fecal coliform (CFUs/100 mL)	Lake Pontchartrain	**Enterococci (CFUs/100 mL)	Fecal coliform (CFUs/100 mL)
KAT-0001	<10	<1	LP-0001	<1	<1
KAT-0002	<10	<1	LP-0002	<1	<1
KAT-0003	<10	<1	LP-0003	<1	<1
KAT-0004	10	<1	LP-0004	<1	<1
KAT-0005	<10	<1	LP-0005	<1	1
KAT-0006	<10	<1	LP-0006	<1	1
KAT-0007	<10	<1	LP-0007	<1	<1
KAT-0008	<10	<1	LP-0008	<2	<2
KAT-0009	<10	<1	LP-0009	<1	<1
KAT-0010	<10	<1	LP-0010	<1	2
KAT-0011	10	<1	LP-0011	<1	1
KAT-0012	<10	<1	LP-0012	<2	12
KAT-0013	<10	1	LP-0013	<2	<2
KAT-0014	<10	<1	LP-0014	<1	1
KAT-0015	<10	<1	LP-0015	1	<1
KAT-0016	<10	<1	LP-0017	<1	2
KAT-0017	<10	<1	LP-0018	<1	<1
KAT-0018	<10	<1	LP-0019	<1	1
KAT-0019	<10	<1	LP-0020	1	8
KAT-0020	<10	<1	LP-0021	<2	2
KAT-0021	<10	<1	LP-0022	<1	4
KAT-0022	<10	2	LP-0023	<1	<1
KAT-0023	<10	<1	LP-0024	<2	<2
KAT-0024	10	<1	LP-0025	1	4
KAT-0025	<10	<1	LP-0026	<1	<1
KAT-0026	<10	3	LP-0026	<1	<1
KAT-0027	<10	<1	LP-0027	<1	3
KAT-0028	<10	<1	LP-0028	<2	10
KAT-0029	<10	1	LP-0029	<2	4
KAT-0030	<10	<1	LP-0030	<1	<1
			LPALT-0058	<2	6

Methodology = Enterolert ®
** Methodology = Membrane Filtration

Table 3-3. Enterococci and fecal coliform concentrations in surface water samples collected in Lake Borgne-Mississippi Sound and Lake Pontchartrain following Hurricane Katrina.

4. Sediment Quality Results and Discussion

4.1 Contaminants

Comparisons of sediment-associated contaminants measured in Lake Pontchartrain and Mississippi Sound following Hurricane Katrina to sediment quality guidelines are shown in Tables 4-1 and 4-2, respectively. There were no ERM exceedances measured at any of the sampling sites in either Lake Pontchartrain or Mississippi Sound (Tables 4-1 and 4-2). The number of ERL exceedances per site in Lake Pontchartrain ranged from 0-5 while the number of ERL exceedances per site in Mississippi Sound sites ranged from 0-3. There were no ERL exceedances for any organic contaminants (pesticides, PCBs, PAHs) at any sites sampled in either Lake Pontchartrain or Mississippi Sound. The analytes most often detected at concentrations above the ERL were arsenic, cadmium, and nickel. Mean ERM quotients in Lake Pontchartrain sediments ranged from 0.004 to 0.080 and in Mississippi Sound sediments from 0.002 to 0.056.

The insecticide Fipronil® was detected in sediments from seven sites in Mississippi Sound and two sites from Lake Pontchartrain following Hurricane Katrina. In the Mississippi Sound samples, concentrations ranged from 0.036-1.40 ng/g while concentrations in the Lake Pontchartrain samples ranged from 0.55-0.96 ng/g.

Flame retardants (PBDEs) were not detected in sediment samples collected following Hurricane Katrina from either Mississippi Sound or Lake Pontchartrain. The mean detection limit was 0.962 ng/g.

The levels of contamination in sediments from Lake Pontchartrain and Mississippi Sound following Hurricane Katrina were compared to levels measured prior to the Hurricane (2000-2003). The number of ERL exceedances in the 39 sediment samples collected from Lake Pontchartrain from 2000-2003 ranged from zero to four. The analytes most often detected at concentrations above the ERL were arsenic, cadmium, and nickel (the same as after the hurricane). One sediment sample collected in 2001 had an ERL exceedance for total DDT. There was one ERM exceedance for silver in a single sample collected in 2000. Mean ERM quotients in these Lake Pontchartrain sediments ranged from 0.006 to 0.092.

The number of ERL exceedances in the 136 sediment samples collected from Mississippi Sound from 2000-2003 ranged from zero to four. The analytes most often detected at concentrations above the ERL were arsenic, nickel, chromium, mercury and cadmium. There were no ERM exceedances for any of the sediment samples collected from 2000-2003. Mean ERM quotients in these Mississippi Sound samples ranged from 0.000 to 0.083.

In general, comparisons of contaminant levels in sediments from Lake Pontchartrain and Mississippi Sound following Hurricane Katrina with levels prior to the storm indicated little change in the overall concentrations or distribution of contaminants.

4.2 Toxicity

The potential toxicity of sediment-associated contaminants from Mississippi Sound was assessed using the Microtox® assay (Table 4-3). Sediments were classified as either toxic or non-toxic using criteria developed by Ringwood and Keppler (1998). Analyses indicated that three of the 28 sites sampled in Mississippi Sound were classified as toxic using this approach. These sites were KAT-0001, KAT-0017, and KAT-0022. This observed toxicity did not appear to be related to the presence of contaminants with existing ERL/ERM guidelines since there were no ERL exceedances for any of these sites. One of the sites classified as toxic (KAT-0001) did have detectable concentrations of the currently used insecticide Fipronil®, but concentrations at this site were lower than at several other sites that were not classified as toxic.

Station	Number of ERL Exceedances	Number of ERM Exceedances	Analytes Exceeding ERL	Mean ERMQ
LP-0001	3	0	As, Cd, Ni	0.043
LP-0002	0	0	none	0.004
LP-0003	3	0	As, Cd, Ni	0.052
LP-0004	3	0	As, Cd, Ni	0.038
LP-0005	2	0	As, Ni	0.033
LP-0006	3	0	As, Cd, Ni	0.040
LP-0008	3	0	As, Cd, Ni	0.040
LP-0009	3	0	As, Cd, Ni	0.047
LP-0010	0	0	none	0.031
LP-0011	3	0	As, Cd, Ni	0.049
LP-0012	3	0	As, Cd, Ni	0.042
LP-0013	3	0	As, Cd, Ni	0.060
LP-0014	3	0	As, Cd, Ni	0.040
LP-0015	0	0	none	0.010
LP-0017	1	0	Cd	0.037
LP-0018	0	0	none	0.029
LP-0019	3	0	As, Cd, Ni	0.052
LP-0020	3	0	As, Cd, Ni	0.042
LP-0021	3	0	As, Cd, Ni	0.044
LP-0022	0	0	none	0.022
LP-0023	0	0	none	0.016
LP-0024	3	0	As, Cd, Ni	0.049
LP-0025	4	0	As, Cd, Cr, Ni	0.070
LP-0026	3	0	As, Cd, Ni	0.041
LP-0027	5	0	As, Cd, Cr, Ni, Zn	0.080
LP-0028	2	0	Cd, Ni	0.037
LP-0029	3	0	As, Cd, Ni	0.062
LP-0030	3	0	As, Cd, Ni	0.052
LPALT-0058	2	0	Cd, Ni	0.039

Table 4-1. Contaminants in sediments collected from Lake Pontchartrain following Hurricane Katrina.

Station	Number of ERL Exceedances	Number of ERM Exceedances	Analytes Exceeding ERL	Mean ERMQ
KAT-0001	3	0	As, Cd, Ni	0.054
KAT-0002	1	0	Cd	0.031
KAT-0003	1	0	Cd	0.023
KAT-0004	3	0	As, Cd, Ni	0.045
KAT-0005	2	0	As, Cd	0.035
KAT-0006	0	0	none	0.009
KAT-0007	0	0	none	0.030
KAT-0008	3	0	As, Cd, Ni	0.056
KAT-0009	0	0	none	0.002
KAT-0010	0	0	none	0.003
KAT-0011	0	0	none	0.025
KAT-0012	3	0	As, Cd, Ni	0.048
KAT-0013	0	0	none	0.027
KAT-0014	0	0	none	0.012
KAT-0015	2	0	Cd, Ni	0.034
KAT-0016	0	0	none	0.002
KAT-0017	2	0	As, Ni	0.045
KAT-0018	0	0	none	0.021
KAT-0019	0	0	none	0.024
KAT-0020	0	0	none	0.017
KAT-0021	0	0	none	0.017
KAT-0022	0	0	none	0.024
KAT-0023	0	0	none	0.028
KAT-0024	1	0	As	0.039
KAT-0025	1	0	As	0.038
KAT-0026	0	0	none	0.030
KAT-0027	0	0	none	0.002
KAT-0028	1	0	As	0.035
KAT-0029	1	0	Cd	0.029
KAT-0030	0	0	none	0.009

Table 4-2. Contaminants in sediments collected from Lake Borgne-Mississippi Sound following Hurricane Katrina.

Station	Date Collected	EC50 (%) Corrected for dry weight	Toxicity	% Sand	% Silt/Clay
KAT-0001	10/11/2005	0.1221	Yes	4.83	95.17
KAT-0002	10/12/2005	0.5655	No	26.01	73.99
KAT-0003	10/12/2005	0.2682	No	28.60	71.40
KAT-0004	10/10/2005	1.0149	No	18.68	81.32
KAT-0005	10/12/2005	0.7221	No	25.94	74.06
KAT-0006	10/11/2005	2.3007	No	87.92	12.08
KAT-0007	10/11/2005	2.3643	No	nd	nd
KAT-0008	10/10/2005	0.4675	No	3.64	96.36
KAT-0009	10/11/2005	>16.8533	No	99.56	0.44
KAT-0010	10/10/2005	>15.4698	No	nd	nd
KAT-0011	10/10/2005	2.5104	No	61.27	38.73
KAT-0012	10/10/2005	0.7160	No	12.35	87.65
KAT-0014	10/11/2005	0.7840	No	75.89	24.11
KAT-0016	10/11/2005	>15.3471	No	98.96	1.04
KAT-0017	10/11/2005	0.0179	Yes	0.64	99.36
KAT-0018	10/11/2005	0.2160	No	42.34	57.66
KAT-0019	10/12/2005	2.8793	No	16.55	83.45
KAT-0020	10/10/2005	0.9035	No	55.20	44.80
KAT-0021	10/12/2005	11.5172	No	68.17	31.83
KAT-0022	10/11/2005	0.1906	Yes	55.19	44.81
KAT-0023	10/11/2005	0.5944	No	55.25	44.75
KAT-0024	10/10/2005	0.2636	No	25.51	74.49
KAT-0025	10/11/2005	0.3292	No	33.52	66.48
KAT-0026	10/12/2005	3.1035	No	44.44	55.56
KAT-0027	10/10/2005	>15.4451	No	99.12	0.88
KAT-0028	10/10/2005	1.9789	No	27.26	72.74
KAT-0029	10/12/2005	0.3297	No	43.50	56.50
KAT-0030	10/12/2005	1.8528	No	85.86	14.14

a. Toxic if % EC50 < 0.2 and % Silt/Clay >20 or % EC50 < 0.5 and % Silt/Clay < 20 (Ringwood *et al.*, 1997)

b. Not determined

Table 4-3. Microtox® Results for sediments collected from Lake Borgne-Mississippi Sound following Hurricane Katrina.

4.3 Sediment Toxicity Prediction

Aluminum normalization techniques were used to look for metals enrichment in the sediments. Equilibrium partitioning-derived sediment benchmarks (ESBs) were also employed to analyze the sediment metals and organics data. In some cases, some of the data normally applied with these approaches were not available, so worst-case approximations were used in their place. Consequently these approaches cannot be used to positively predict the toxicity of the samples but can be used to rule out samples which should not result in ecological risk and to identify sediments or chemicals which may deserve further investigation.

The ESBs used were:

- Equilibrium Partitioning Sediment Benchmarks for Metals Mixtures (cadmium, copper, lead, nickel, silver, and zinc) (USEPA, 2005)
- Equilibrium Partitioning Sediment Benchmarks for PAH Mixtures (USEPA, 2003a)
- Equilibrium Partitioning Sediment Benchmarks for individual non-ionic organic chemicals (for six pesticides) (USEPA, draft)
- Equilibrium Partitioning Sediment Benchmarks for Dieldrin (USEPA , 2003b)
- Equilibrium Partitioning Sediment Benchmarks for Endrin (USEPA, 2000c).

4.3.1 Metals: Aluminum Normalization

The degree of metal contamination in the sediments was assessed by comparing measured concentrations with estimated background concentrations using aluminum normalization. The procedure is based on a simple model in which background sediments are treated as mixtures of coarse material, low in metal content (i.e., silica), and metal-rich, fine-grained aluminosilicate silts and clays. If all the aluminum in sediment is assumed to come from these aluminosilicates, then metal concentrations in background sediments should vary linearly with aluminum concentration. In this model, total concentrations of a metal in sediment which exceed background concentrations are due to additional, presumably anthropogenic, components.

An iterative statistical procedure was used to eliminate sediments with apparent contamination, reducing the data set to just apparent background sediments. In this procedure metal concentrations are regressed against aluminum concentrations and the residuals (the differences between measured values and those predicted from the regression) tested for normal distribution. If the residuals are not normally distributed, samples with the largest statistically significant residuals (studentized residual >2) are assumed to be contaminated and are eliminated from the data set, and the regression is repeated until either a normal distribution is obtained (p=0.01) or there are no more samples with large, positive residuals. In the latter case, the deviation from a normal distribution is caused by samples with unusually low metal concentrations relative to aluminum, but without a reason to eliminate these samples from the data set, they are included in the "background" sediments.

This procedure was used to derive metal-aluminum relationships in EMAP data from the NE using 1990-1993 sediment data (Strobel et al., 1995). Because the geology contributing lithogenic material to background sediments might be different in the Gulf region from those in the NE, the procedure was repeated using EMAP Gulf of Mexico 1991-1994 data. Regression coefficients so obtained were similar to those for the NE (within 30%) except for the elements cadmium, copper, lead, and tin (Appendix 2, 2-1), and of those, only the cadmium slope differed by more than a factor of 2.

Our approach to aluminum normalization of Gulf of Mexico EMAP data differs somewhat from that of Summers et al., (1996). We chose to use the approach outlined in Strobel et al., (1995) because it applies a consistent model across all metals and makes no *a priori* assumptions about which sediments comprise background (Summers et al. applied different statistical transformations to different metals and eliminated sediments from consideration as background on the basis of sediment quality guidelines based on biological response).

Measured and estimated background concentrations of metals in post-Katrina sediments were compared with those from the EMAP National Coastal Assessment (NCA) 2002-2003 data. (NCA sediment metals data from 2000-2001 were not included in the analysis because of a shift in apparent concentrations of some metals between the 2001 and 2002 samples.) The comparison shows that metal contamination in the coastal region is slight and not substantially different from conditions prior to the hurricane. Metal enrichment relative to background is generally slightly higher in sediments from Lake Pontchartrain than in Mississippi Sound sediments, but for most metals, this enrichment factor is less than 3 (Table 4-4). Only cadmium was slightly more enriched in sediments after Hurricane Katrina (Fig. 4-1). For a few metals (Sn, Zn, and perhaps, Cu), the degree of contamination was no higher but may be spread more uniformly across the region (e.g., Sn in Fig. 4-2). Tin appears to be perhaps the most highly enriched

Estuary	Sampling		Ag	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sb	Se	Sn	Zn
Mississippi Sound	Pre-Katrina	Mean	1.85	1.45	1.13	1.23	2.09	1.69	1.03	2.30	1.42	1.62	1.02	1.64	6.63	1.34
		S.D.	3.52	0.71	0.94	0.62	2.18	0.38	0.74	1.06	0.78	0.57	0.73	2.20	4.52	0.45
		N	68	68	68	68	68	68	68	68	68	68	68	68	68	68
	Post-Katrina	Mean	1.79	1.89	2.55	1.35	1.61	1.90	1.25	2.05	1.60	2.03	1.14	4.88	5.69	1.67
		S.D.	0.43	0.54	1.09	0.39	0.68	0.64	0.45	0.84	0.62	0.42	0.37	1.71	1.46	0.45
		N	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Lake Pontchartrain	Pre-Katrina	Mean	2.63	2.04	3.55	1.51	2.43	2.11	1.66	4.17	1.87	2.35	3.98	6.03	7.15	1.84
		S.D.	0.64	0.98	1.92	0.50	0.89	0.80	0.79	2.14	0.74	0.67	4.81	4.75	2.43	0.61
		N	23	23	23	23	23	23	23	23	23	23	23	23	23	23
	Post-Katrina	Mean	2.70	2.27	3.62	1.66	2.53	2.31	1.57	3.90	2.15	2.54	1.80	4.63	6.25	2.09
		S.D.	0.65	0.83	1.15	0.57	1.06	0.87	0.64	1.77	0.86	0.73	0.49	1.48	1.39	0.80
		N	29	29	29	29	29	29	29	29	29	29	29	29	29	29

Table 4-4. Statistical summary of enrichment factors for metals in Lake Pontchartrain and Mississippi Sound sediments pre- and post-Hurricane Katrina.

of the elements analyzed, but individual enrichment factors are still less than 10X for almost all samples. By comparison, enrichment factors of 20 to 100 X are found for contaminant metals (e.g., zinc, copper, lead, chromium, cadmium and silver) in sediments from industrialized harbors, such as New Bedford, Massachusetts, and even outside the harbor, enrichment factors remain ~3 to 5X (Latimer et al., 2003).

4.3.2 Metals ESBs

The equilibrium partitioning sediment benchmark (ESB) for metals mixtures utilizes the concept that the bio-availability of cadmium, copper, lead, nickel, silver, and zinc in a sediment can by predicted by subtracting the concentration of acid volatile sulfide (AVS) from the concentration of the simultaneously extracted metals (SEM) isolated using the AVS procedure, and then dividing the result by the fraction of total organic carbon (f_{OC}) in the sediment [(SEM – AVS)/ (f_{OC})]. The (SEM – AVS)/ (f_{OC}) value is interpreted as follows: sediments for which (SEM – AVS)/ (f_{OC}) < 130 μmol/g_{OC} should not be toxic; sediments for which 130 μmol/g_{OC} < (SEM – AVS)/ (f_{OC}) < 3000 μmol/g_{OC} may be toxic to benthic organisms, sediments for which (SEM – AVS)/ (f_{OC}) >3000 μmol/g_{OC} are likely to be toxic to benthic organisms (USEPA, 2005).

The use of the (SEM – AVS)/ (f_{OC}) method on the post-Katrina samples was complicated because neither AVS nor SEM were measured on the samples (Appendix 2, 2-2a & -b). A worst-case substitution, however,

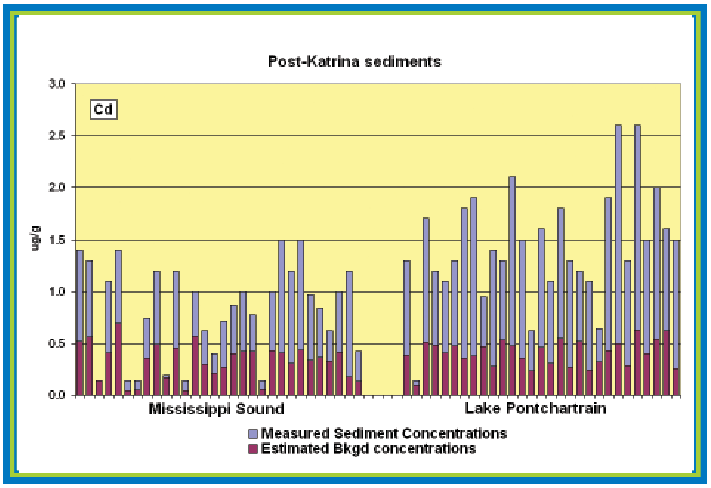

Fig 4-1. Cadmium in Gulf region sediments pre- and post-Hurricane Katrina.

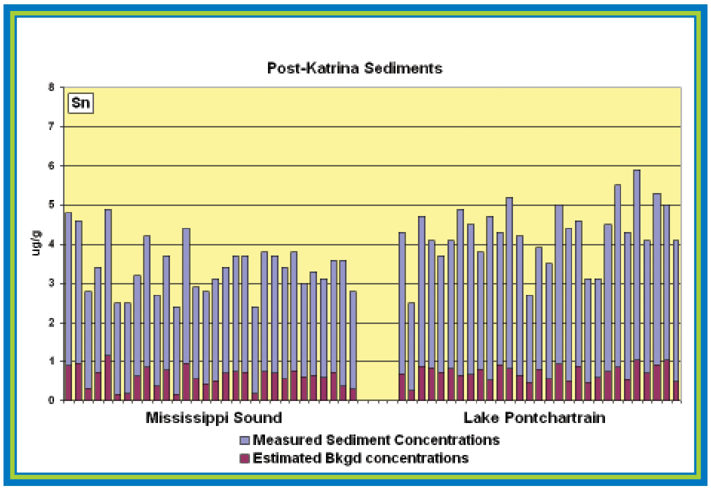

Fig 4-2. Tin in Gulf region sediments pre- and post-Hurricane Katrina.

was performed using total metals instead of SEM, and setting the AVS equal to zero. The use of total metals instead of SEM probably introduces a factor of conservatism of approximately two. It is difficult to estimate the level of conservatism added by setting AVS equal to zero without some estimate of the AVS. Even using these worst-case assumptions none of the samples were above the 3000 $\mu mol/g_{OC}$ benchmark (which would predict that the sediments should be toxic), and most were barely above the 130 $\mu mol/g_{OC}$ benchmark (below this value the sediments would be predicted to be non-toxic) (Appendix 2, 2-3 a, b). Thus, given the conservatism of assumptions used in the calculation, it seems unlikely that cadmium, copper, lead, nickel, silver, and zinc in these samples would pose much risk to benthic organisms.

4.3.3 PAHs: ESBs

The ESB for polycyclic aromatic hydrocarbon (PAH) mixtures utilizes narcosis and equilibrium partitioning theories to estimate the toxic contribution of the PAHs measured in a sample, and then sums those contributions (as toxic units) to estimate the toxicity of the sample due to the presence of PAHs (USEPA, 2003a). The benchmark is designed for use with measurements from a suite of 34 PAHs. Correction factors have been developed for use with data sets with 23 or 13 PAHs (USEPA, 2003a). The magnitude of the correction factor used depends on the number of PAHs analyzed and the degree of certainty desired in the extrapolation from the full set of 34 PAHs to the analyzed set of PAHs (Appendix 2, 2-4).

The post-Katrina samples had data appropriate for use with extrapolation from a set of 13 PAHs, so $\sum ESGTU_{FCV,\,13}$ (toxic or benchmark units) values were calculated (USEPA, 2003a). Only 12 samples had any detectable total PAHs. The PAH ESB calculations were made on the data from all of these samples. None of these samples were higher than the benchmark (of one toxic unit), even when using the largest correction factor. This correction factor allows 99% confidence that the guideline will be protective, given the ratio of toxicity of 13 to 34 PAHs seen in field samples (USEPA, 2003a). Given these results, it seems unlikely that PAHs in any of these samples would cause adverse impacts to benthic organisms.

4.3.4 Non-ionic Organic Chemicals: ESBs

Given an appropriate water-only toxicity value, like the final chronic value (FCV) from a water quality criterion, and a good estimate of the octanol-water partition coefficient (KOW), it is theoretically possible to calculate an ESB for any non-ionic organic compound (USEPA, draft). ESBs are available for four pesticides in the post-Katrina data set: alpha endosulfan and beta endosulfan (USEPA, draft), dieldrin (USEPA, 2003b) and endrin (USEPA, 2003c). ESBs were also calculated for two other pesticides for which KOWs and FCVs are available: heptachlor, and toxaphene. Finally, an ESB was calculated for Fipronil®, even though there is not as much information on Fipronil®'s biological effects or partitioning as there is for the other pesticides, because Fipronil® was of special interest in the data set (Table 4-5).

No alpha endosulfan, beta endosulfan, heptachlor, heptachlor epoxide, toxaphene, or dieldrin was detected in any of the samples. Endrin was detected in one sample, but the measured value (0.39 ng/g dry wt, or 0.021 µg/gOC) was barely above the detection limit and was well below the ESB for endrin (0.44 µg/gOC).

Fipronil® is a relatively new insecticide that is used for control of termites, fire ants, and other pests (USEPA, 1996). The fact that Fipronil® operates with similar efficacy for many invertebrates has given rise to concerns about impact on non-target organisms (Walse et al., 2004).

The only available spiked sediment data for Fipronil® is from a test with *Amphiascus tenuremis*, a harpacticoid copepod (Chandler et al., 2004a). The organic carbon content of the sediment was 3.85% (G.T. Chandler, personal communication). There were reproductive effects at all concentrations, including the lowest tested, 1.7 µg/gOC. There was no increased mortality at any concentration, including the highest concentration tested, 7.8 µg/gOC. These results are consistent with predictions derived using equilibrium partitioning theory (USEPA, draft) and corresponding water-only effects data (Chandler et al., 2004a).

A Fipronil® ESB of 0.044 µg/gOC was calculated using a KOW of 4.01 and the lowest available chronic value for an estuarine organism, < 0.005 µg/L. This value is for impaired reproduction in the mysid, *Americamysis bahia* (USEPA, 1996). Of these 9

Chemical	FCV (ug/L)	Log KOW	Log KOC	ESB (ug/gOC)	Source
Dieldrin	0.0019			28	U.S. EPA 2003b. (Dieldrin ESB.)
Alpha endosulfan	0.0087			0.05	U.S. EPA draft. (Compendium ESB.)
Beta endosulfan	0.0087			0.24	U.S. EPA draft. (Compendium ESB.)
Endrin	0.0023			0.44	U.S. EPA 2003c. (Endrin ESB.)
Heptachlor	0.0036	6.26	6.15	5.13	Karickhoff and Long 1985. (KOW)
Heptachlor epoxide	0.0036	5	4.92	0.30	Karickhoff and Long 1985. (KOW)
Toxaphene	0.0002	5.5	5.41	0.05	Karickhoff and Long 1985. (KOW)
Fipronil®*	0.005	4.01	3.94	0.0438	USEPA, 1996. (KOW and mysid data)
Fipronil®*	0.005	4.68	4.60	0.20	SPARC and Mysid data

* A Fipronil® FCV is not available. The mysid chronic value (< 5 ng/L) was used for the computation.

** KOC calculated using the formula KOC = KOW x 0.983 + 0.00028 (USEPA, Draft)

Table 4-5. Equilibrium partitioning derived sediment benchmarks for eight pesticides.

samples with detectable Fipronil®, seven exceeded the ESB, (Table 4-6). If a less conservative Fipronil® ESB is calculated using the higher KOW calculated by the SPARC program (Hilal et al., 2004), only three of the samples violate the criterion (Tables 4-5 and 4-6a & 4-6b).

The Fipronil® ESB needs to be interpreted with caution because it is based on a single KOW determination and a single toxicity endpoint. However, given the highly toxic nature of Fipronil®, its relatively low KOW (USEPA, 1996), and the persistence and toxicity of the breakdown products (Walse et al., 2004), sediments with detectable Fipronil® should probably prompt further investigation. USGS (2003) found that Fipronil® did not accumulate in bedded sediment in any appreciable amount, while the degradates accumulated in sediments to much higher concentrations. Therefore it is possible that some sediments that did not show contamination with the parent compound, have measurable concentrations of the degradates, and possibly at higher concentrations than that of the parent compound.

The fact that some of the post-Katrina sediments have Fipronil® concentrations higher on an organic carbon basis than those sediments shown to have reproductive effects in *Amphiascus* (Chandler et al., 2004a) seems to support the conclusion that Fipronil® may be of concern in these sediments. This is especially true because reproduction was affected in even the lowest concentration in the *Amphiascus* test, and because the other estuarine organisms tested to date with Fipronil® are more sensitive (at least acutely) than *Amphiascus* (USEPA, 1996).

These data need to be treated with caution, however, because the sediments with the highest Fipronil® concentrations on an organic carbon basis (KAT0009 and KAT0016) appear high primarily because their TOC concentrations were very low. Also, high

STA_NAME	Fipronil® (ng/g)	TOC (%)	Fipronil® (μg/goc)
KAT-0001	0.47	1.36	0.03461
KAT-0002	0	0.78	0
KAT-0003	0	0.34	0
KAT-0004	0	1.11	0
KAT-0005	0	0.74	0
KAT-0006	0	0.20	0
KAT-0007	0	NA	NA
KAT-0008	0	1.42	0
KAT-0009	1.4	0.03	4.087591
KAT-0010	0	0.04	0
KAT-0011	0	0.46	0
KAT-0012	0	1.11	0
KAT-0013	0.77	0.82	0.094052
KAT-0014	0	0.32	0
KAT-0015	0	0.87	0
KAT-0016	0.61	0.02	2.935515
KAT-0017	0	1.88	0
KAT-0018	0	0.66	0
KAT-0019	0.53	0.19	0.276618
KAT-0020	0	0.44	0
KAT-0021	0	0.19	0
KAT-0022	0	0.72	0
KAT-0023	0	0.65	0
KAT-0024	0	1.06	0
KAT-0025	0	0.83	0
KAT-0026	0.36	0.79	0.045842
KAT-0027	0	0.03	0
KAT-0028	0	0.96	0
KAT-0029	0	0.54	0
KAT-0030	0.79	0.22	0.358114

Table 4-6a. Fipronil® concentrations in sediment collected from Mississippi Sound stations following Hurricane Katrina.

Fipronil® concentrations in these samples do not correlate with the observed absence of toxicity in corresponding Microtox® assays.

As far as we know, there are no data available on Fipronil® in the sediments of the Gulf and Lake Pontchartrain before the hurricane, so it is not possible to know if the hurricane had any effect on the concentrations of Fipronil® in these sediments.

STA_NAME	Fipronil® (ng/g)	TOC (%)	Fipronil® (μg/goc)
LP-0001	0	1.04	0
LP-0002	0	0.01	0
LP-0003	0.96	1.11	0.086878
LP-0004	0	1.98	0
LP-0005	0	0.76	0
LP-0006	0	1.10	0
LP-0008	0	0.82	0
LP-0009	0	1.26	0
LP-0010	0	1.09	0
LP-0011	0	1.00	0
LP-0012	0	0.96	0
LP-0013	0	1.32	0
LP-0014	0	1.16	0
LP-0015	0	0.12	0
LP-0017	0	0.91	0
LP-0018	0	0.74	0
LP-0019	0	1.21	0
LP-0020	0	0.84	0
LP-0021	0	1.05	0
LP-0022	0	0.72	0
LP-0023	0	0.21	0
LP-0024	0	0.96	0
LP-0025	0	0.94	0
LP-0026	0	0.89	0
LP-0027	0	1.68	0
LP-0028	0.55	1.27	0.043478
LP-0029	0	1.32	0
LP-0030	0	1.47	0
LPALT-0058	0	1.09	0

Table 4-6b. Fipronil® concentrations in sediment collected from Lake Pontchartrain stations following Hurricane Katrina.

4.4 Benthic community characteristics and condition

A statistical comparison was performed with *t*-tests to assess the significance of mean differences in benthic response variables (total faunal abundance, number of taxa, H' diversity, and the benthic index) before (2000-2004) vs. after (2005) the hurricane for each of the two survey areas (Table 4-7). A listing of the individual values of each variable by station is also provided in Appendix 3. Results showed significant reductions (at $\alpha = 0.05$) in numbers of benthic taxa and total faunal abundance (no/m^2) following the hurricane at

	Lake Pontchartrain			Mississippi Sound/Lake Borgne		
	Pre-Hurricane Mean	Post-Hurricane Mean	P-Value	Pre-Hurricane Mean	Post-Hurricane Mean	P-Value
	(n = 46)	(n = 29)		(n = 165)	(n = 30)	
Abundance (#/m²)	1428	175	0.040*	2835	1412	0.010*
# Taxa (per grab)	6	3	0.002*	22	13	< 0.0001*
H´ (per grab)	1.52	1.12	0.081	3.23	2.67	0.003*
Benthic Index	3.21	3.38	0.798	5.02	5.49	0.393

*Table 4-7. Comparison of infaunal abundance, number of taxa, and H´ diversity in Lake Pontchartrain and Mississippi Sound/Lake Borgne before (2000-2004) versus after (2005) Hurricane Katrina. P-values (based on results of T-tests) are also included. * indicates significant difference at α=0.05.*

sites in Lake Pontchartrain. Similarly, in Mississippi Sound there were significant post-hurricane reductions in numbers of taxa, H' diversity, and total faunal abundance. While the changes in these variables are suggestive of hurricane-related impacts, there were no significant differences in the benthic index between pre- and post-hurricane periods in either survey area.

Box plots of these variables by year showed similar results (Figs. 4-3, 4-4). There was a consistent pattern of lower values of most benthic variables (number of species, diversity, and density) after the hurricane. In Mississippi Sound/Lake Borgne, the means and ranges of these values over the various pre-hurricane sampling periods were consistently higher than post-hurricane values with little inter-annual variability (Fig. 4-3). While post-hurricane reductions in these variables were also evident in Lake Pontchartrain, there was considerable inter-annual variability prior to the hurricane (Fig. 4-4). Means and ranges of most variables (except the benthic index) showed a downward trend with time from 2000-2003, signs of some recovery in 2004, and a decline again in 2005 following the passage of the hurricane. Benthic abundance and richness were especially reduced after the hurricane with values at record lows. The benthic index showed a similar downward trend prior to the hurricane in Lake Pontchartrain, but the trend persisted into 2004 and was followed by higher values in 2005. Such data suggest that benthic community structure was fairly stable over time in Mississippi Sound/Lake Borgne prior to the passage of Katrina (i.e., from 2000-2004) and much more variable in Lake Pontchartrain. In addition to such background variability in the latter case, some hurricane-related changes in these assemblages occurred in both systems.

Comparisons also were made of the dominant (10 most abundant) taxa occurring before vs. after the hurricane for both study areas (Table 4-8). There were notable shifts in the composition and ranking of these dominants between the pre- and post-hurricane periods. In Lake Pontchartrain, only three taxa (the polychaete *Mediomastus* spp., bivalves of the family Mactridae, and the bivalve *Rangia cuneata*) occurred

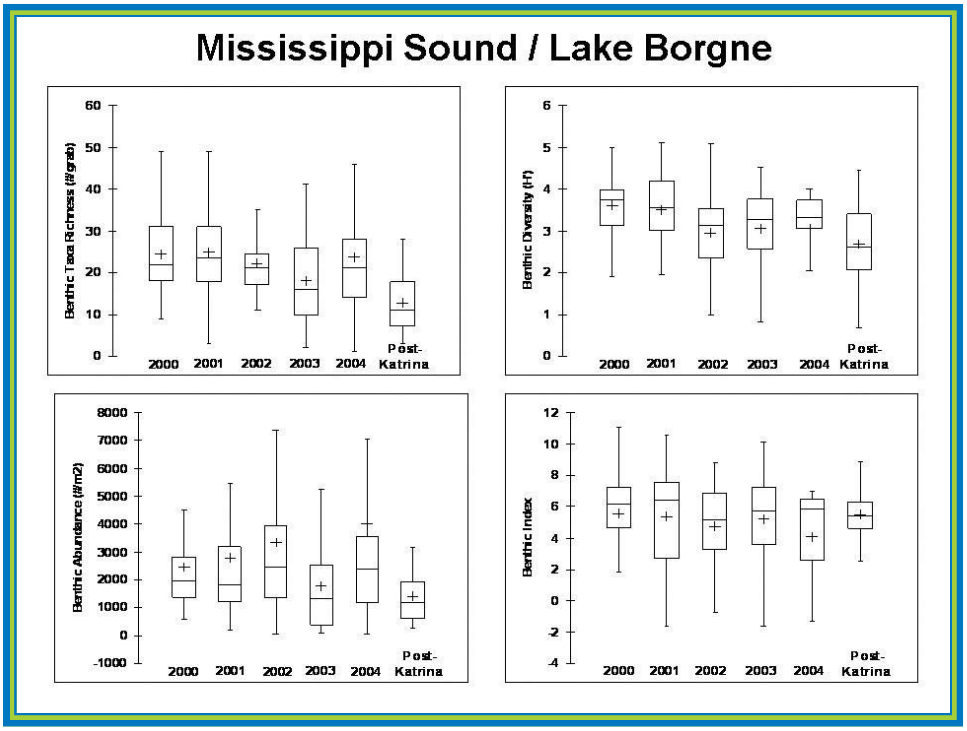

Fig 4-3. Comparison of observed ranges in various benthic parameters in Mississippi Sound/Lake Borgne before (2000-2004) and after (2005) Hurricane Katrina. Boxes are inter-quartile ranges, horizontal lines within boxes are medians, plus marks are means, and whisker endpoints are 5th and 95th percentiles.

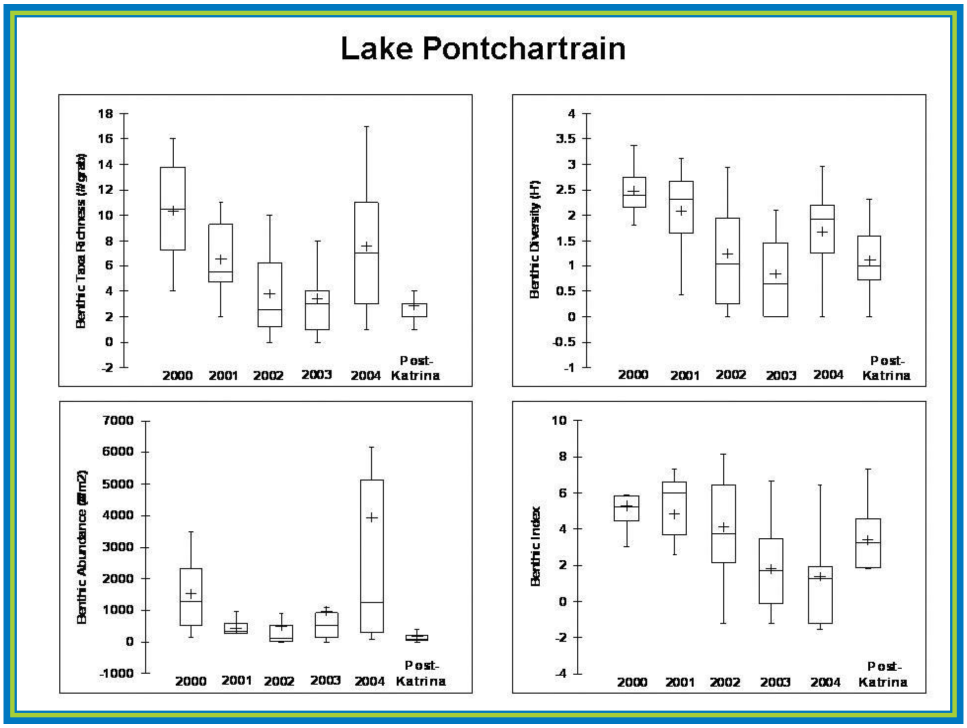

Fig. 4-4. Comparison of observed ranges in various benthic parameters in Lake Pontchartrain before (2000-2004) and after (2005) Hurricane Katrina. Boxes are inter-quartile ranges, horizontal lines within boxes are medians, plus marks are means, and whisker endpoints are 5th and 95th percentiles.

among the 10 most dominant taxa during both periods. It is also interesting that the classic opportunistic/pollution-tolerant polychaete *Streblospio benedicti* (Pearson and Rosenberg 1978) was the top dominant taxon after the hurricane but was ranked 18th in dominance prior to the hurricane.

Similar changes in dominant taxa were evident within the more open waters of Mississippi Sound/Lake Borgne. Only two taxa (the polychaetes *Mediomastus ambiseta, Paraprionospio pinnata*) were among the top-10 dominants both before and after the hurricane. Although opportunistic species were present in these waters during both periods (e.g., *Mediomastus* and *Paraprionospio pinnata*, Pearson and Rosenberg 1978), *Streblospio benedicti* did not appear as a dominant in Mississippi Sound samples until after the hurricane, similar to its pattern of stronger post-hurricane dominance in Lake Pontchartrain.

While such results indicate hurricane-related effects on several benthic community characteristics, pre- vs. post-hurricane changes in benthic condition based on the benthic index were less apparent (Table 4-7, Figs. 4-3 & 4-5). For example, in Lake Pontchartrain, the proportion of estuarine area with poor to intermediate benthic condition after the hurricane was more extensive than average pre-hurricane conditions but was well within the range observed over individual pre-hurricane sampling periods (Fig. 4-5a). In Mississippi Sound (Fig. 4-5b), the proportion of area with poor to intermediate benthic condition was less extensive after the hurricane than in all but one of the pre-hurricane periods (i.e., 2000). Also, as noted above, differences in mean values of the benthic index between the two overall pre- vs. post-hurricane periods were not statistically significant ($\alpha = 0.05$, Table 4-7) in either survey area.

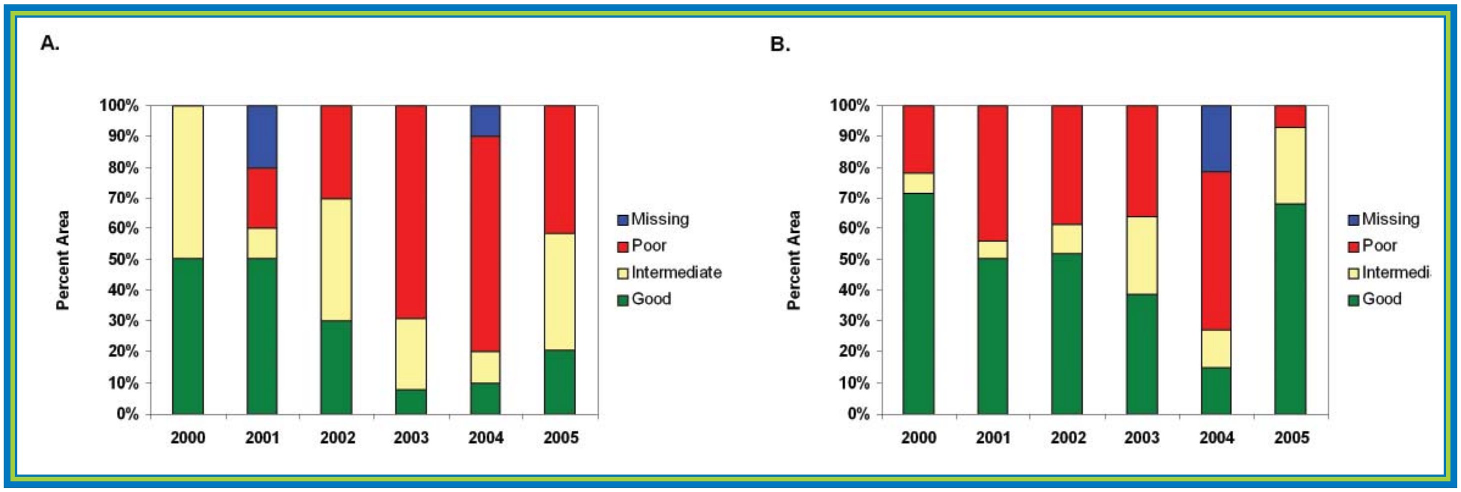

Fig. 4-5. Comparison of benthic condition in Lake Pontchartrain (A) and Mississippi Sound (B) before (2000-2004) vs. after (2005) Hurricane Katrina. Good benthic condition: Benthic Index (BI) > 5, intermediate: BI = 3-5, poor: BI < 3.

Survey Area	Pre-Hurricane (2000-2004)				Post-Hurricane (2005)			
	Taxa	Mean # Ind./m^2	% Cum. Density	% Occurrence	Taxa	Mean # Ind./m^2	% Cum. Density	% Occurrence
Lake Pontchartrain	**(n = 46)**				**(n = 29)**			
	Rangia cuneata	278	19	59	*Streblospio benedicti*	41	24	48
	Texadina sphinctostoma	199	33	22	*Coelotanypus spp.*	37	45	59
	Mediomastus spp.	111	41	39	*Mediomastus spp.*	21	57	21
	Mulinia lateralis	110	49	11	*Parandalia tricuspis*	19	67	21
	Cerapus benthophilus	82	55	4	*Rangia cuneata*	9	73	14
	Probythinella louisianae	76	60	9	*Mediomastus ambiseta*	9	78	28
	Ischadium recurvum	72	65	22	*Mactridae*	8	82	10
	Hobsonia florida	60	69	13	*Americamysis almyra*	3	84	7
	Mactridae	45	72	22	*Ameroculodes miltoni*	3	86	7
	Amphicteis spp.	39	75	2	*Nemertea*	3	88	10
Mississippi Sound	**(n = 165)**				**(n = 30)**			
	Mediomastus ambiseta	475	17	68	*Paraprionospio pinnata*	170	12	73
	Nemertea	112	21	60	*Mediomastus spp.*	127	21	60
	Paraprionospio pinnata	105	24	68	*Mediomastus ambiseta*	102	28	53
	Owenia fusiformis	68	27	36	*Parandalia tricuspis*	96	35	43
	Scoletoma verrilli	54	29	44	*Lepidactylus triarticulatus*	68	40	3
	Cerapus benthophilus	53	31	4	*Gemma gemma*	66	44	3
	Caecum pulchellum	49	32	1	*Mysella planulata*	45	48	20
	Microphiopholis atra	47	34	35	*Streblospio benedicti*	41	51	37
	Paraonis fulgens	43	35	2	*Cossura soyeri*	36	53	33
	Cossura delta	43	37	38	*Lineidae*	36	56	33

Table 4-8. Comparison of dominant infaunal species (10 most abundant in decreasing order) in Lake Pontchartrain and Mississippi Sound before (2000-2004) versus after Hurricane Katrina (2005). Also shown in parentheses is the number of samples (n) for each sampling period combination.

Because of their relatively stationary existence within sediments, benthic communities can serve as reliable indicators of potential environmental disturbances from a variety of stressors, including hypoxia, sediment contamination, and organic enrichment. Although benthic community data were available for 2000-2004, pre-hurricane data on chemical contaminants and other sediment-associated stressors (e.g., TOC as a measure of organic enrichment) were only available for 2000-2003. Thus, the following analyses of benthic condition in relation to these stressors are based on comparisons of 2000-2003 data (pre-hurricane) with 2005 data (post-hurricane). References to the effects of DO and salinity, however, do include 2004 data (Figs. 4-6 and 4-7).

Patterns of benthic fauna in Mississippi Sound did not appear to be strongly correlated with sediment contaminants. Seventy percent of these waters had a healthy benthos along with low levels of chemical contaminants (below expected bio-effect ranges) following the hurricane, compared to 55% prior to it (Fig. 4-8a). Co-occurrences of poor-intermediate benthic condition and high sediment contamination represented only 1.7% of these waters before the hurricane and were not observed at any of the post-hurricane sites (Fig. 4-8a). High sediment contamination, independent of benthic condition, in fact represented only 4% of the area before the hurricane and 0% after. This suggests that the limited contaminants present in these open coastal waters of Mississippi Sound prior to the hurricane may have been flushed farther from the system with the passing of the storm.

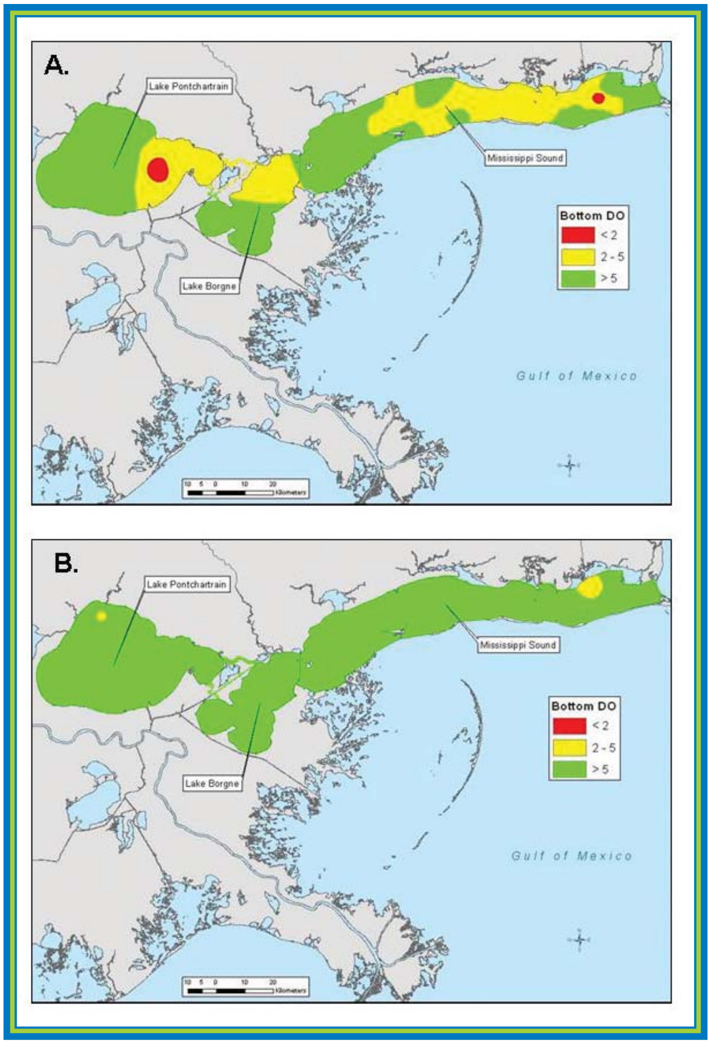

Fig 4-6. Comparison of bottom-water dissolved oxygen (mg/L) in Lake Pontchartrain and Mississippi Sound before (A; 2004) vs. after (B; 2005) Hurricane Katrina.

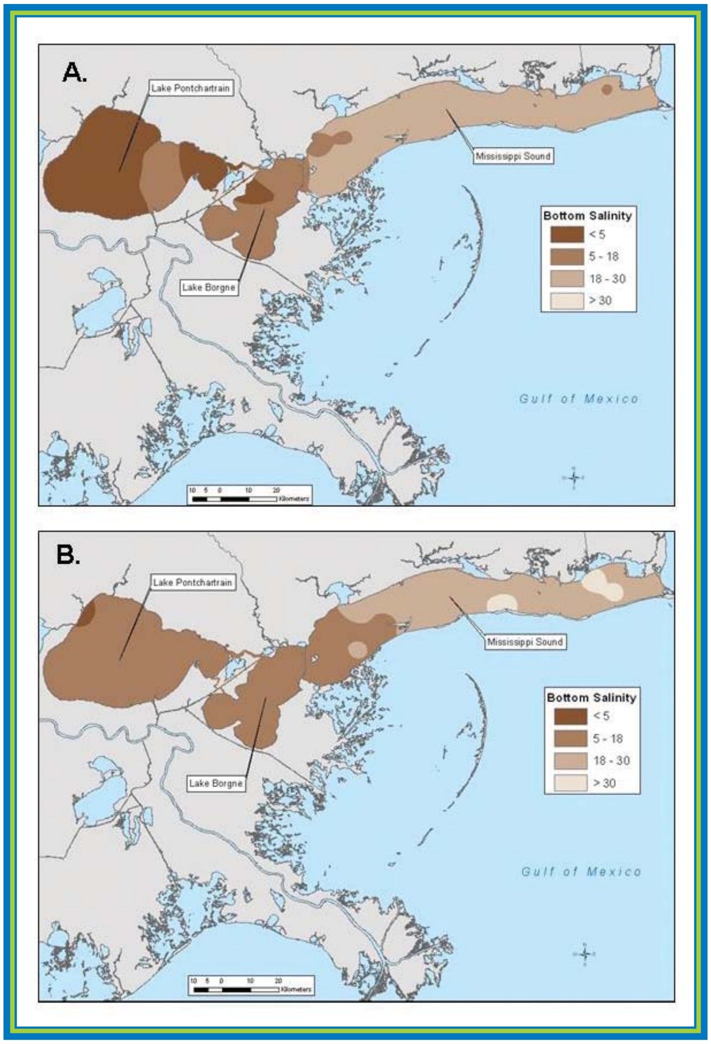

Fig 4-7. Comparison of bottom-water salinity in Lake Pontchartrain and Mississippi Sound before (A; 2004) vs. after (B; 2005) Hurricane Katrina.

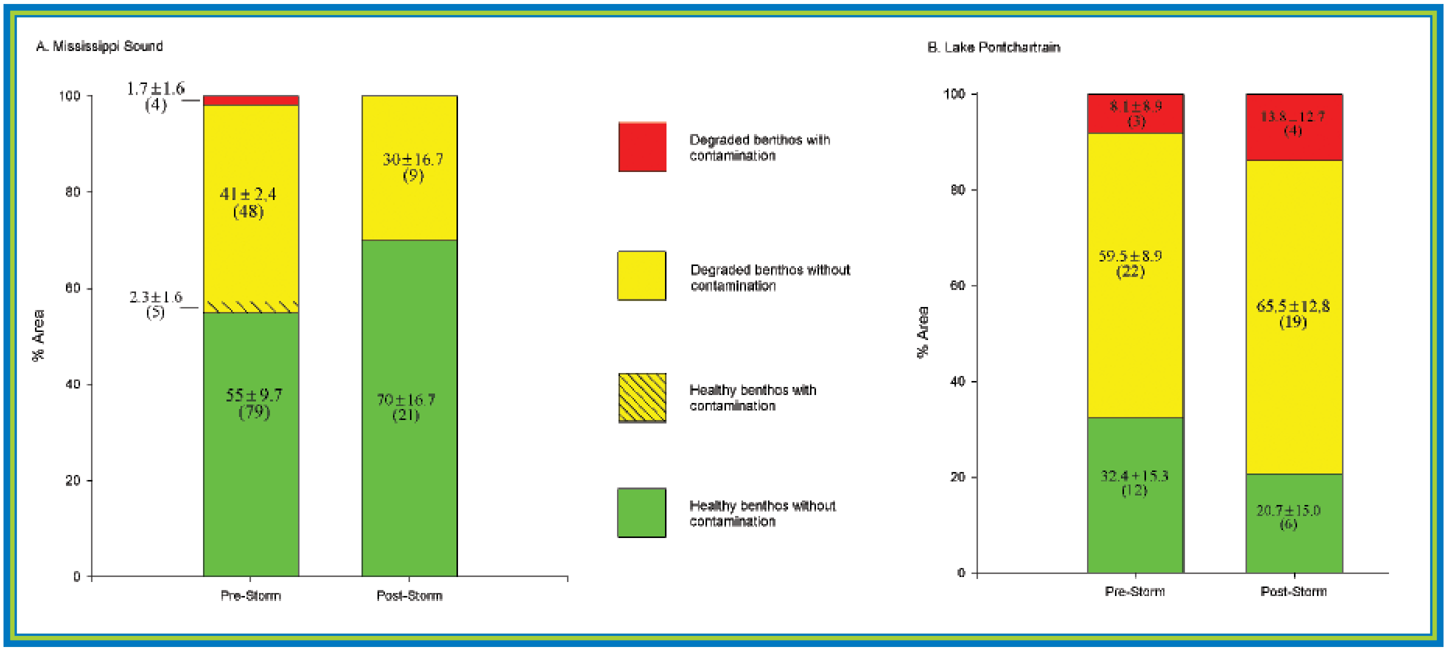

Fig. 4-8. Pre- vs. post-hurricane comparison of sediment quality in (A) Mississippi Sound and (B) Lake Pontchartrain, based on combined measures of benthic condition and sediment contamination. Healthy benthos = BI > 5; degraded benthos = BI < 3 (poor condition) or BI between 3-5 (intermediate). Contaminated sediment = One or more contaminants in excess of ERM (from Long *et al.*, 1995), or mean ERM-Quotient > 0.062 (from Hyland *et al.*, 2003).

Given these results, it seems unlikely that chemical contaminants were a major cause of the observed changes in benthic communities. However, one possible contributor may have been the insecticide Fipronil®, which was detected in nine of the post-Katrina sediment samples (see sections 4.3.4). The two stations where Fipronil® concentrations were the highest on an organic carbon basis (Mississippi Sound stations KAT0009 and KAT0016) showed evidence of degraded benthic condition in one or more of the measured indicators (Appendix 3).

Dissolved oxygen (DO) levels also were higher in Mississippi Sound following the hurricane, with only 46% of the area having high DO > 5 mg/L in 2004 and 96% having DO in this range after Hurricane Katrina (Fig. 4-6). Similarly, the average percent area with high DO over the five pre-hurricane sampling periods (2000 to 2004) was much lower, 64% (graphic not shown). None of these waters following the hurricane had low DO (< 2 mg/L) in a range indicative of a high risk of adverse effects on benthic fauna (Diaz and Rosenberg 1995). Prior post-hurricane assessments have shown that reductions in DO and salinity from increased storm runoff can lead to adverse effects on the benthos (Balthis et al., in press, Mallin et al., 2002, Van Dolah and Anderson 1991, Boesch et al., 1976). In the present study, any storm-related effects on benthic fauna in Mississippi Sound (e.g., shifts in dominant taxa and reductions in other variables mentioned above) appear to have been related more to changes in salinity than DO. For example, mesohaline salinity occurred over a larger proportion of this system after the hurricane in comparison to average pre-hurricane levels (47% vs. 37% respectively, Table 4-9). Prior to the hurricane, the majority of the area (55% on average from 2000-2004) was in the higher polyhaline salinity range. Fig. 4-7 provides a spatial illustration of such changes based on a comparison of post-hurricane salinities to the preceding 2004 sampling period. The spread of lower salinity following the hurricane, especially pronounced in the western portion of Mississippi Sound, is assumed to be related to the extensive rainfall and storm runoff.

Bottom Salinity	Pre-Hurricane %	Post-Hurricane %
Lake Pontchartrain:		
Oligohaline (<5)	69.4 ± 13.0 (34)	3.3 ± 6.6 (1)
Mesohaline (5-18)	24.5 ± 6.1 (12)	96.7 ± 6.6 (29)
Polyhaline (>18-30)	6.1 ± 6.1 (3)	(0)
Marine (>30)	(0)	(0)
Mississippi Sound:		
Oligohaline (<5)	1.4 ± 2.8 (1)	(0)
Mesohaline (5-18)	36.7 ± 5.0 (37)	46.7 ± 18.1 (14)
Polyhaline (>18-30)	55.3 ± 3.1 (118)	43.3 ± 10.9 (13)
Marine (>30)	6.5 ± 3.1 (16)	10 ± 10.9 (3)

Table 4-9. Pre-hurricane (2000-2004) vs. post-hurricane (2005) comparison of bottom salinity in Lake Pontchartrain and Mississippi Sound. Included are the percent area ± 95% CI (and number of stations) within each salinity zone.

Co-occurrences of poor-intermediate benthic condition and high sediment contamination were more evident in Lake Pontchartrain, representing 8.1% of the area before the hurricane and 13.8% after (Fig. 4-8b). Lake Pontchartrain waters that had poor-intermediate benthic condition, either before or after the hurricane, were not accompanied by high levels of chemical contaminants in sediments. Such conditions, representing about 60% of the area before the hurricane and 66% after, could be due to: (1) unmeasured chemical contaminants and other sediment-associated stressors (e.g., ammonia and sulfide in porewater), (2) chronic low-DO problems prior to the hurricane in these more confined waters, (3) other physical and biological sources of disturbance, or (4) inherent uncertainty in the predictive ability (classification efficiency) of the benthic index. With respect to this latter point, Engle and Summers (1999) note that, while the index is a useful assessment tool, it delineates healthy from impaired condition correctly about 74-77% of the time, and thus is associated with some inherent variability, as expected for an index that would be applicable across a wide variety of Gulf of Mexico estuarine environments.

Similar to Mississippi Sound, storm-related effects on benthic fauna in Lake Pontchartrain (e.g., shifts in dominant taxa and reductions in other benthic community variables mentioned above) appear to have been related more to changes in salinity than lowered DO. Low DO (< 2 mg/L) was not observed in these waters following the hurricane, though it occurred in 10% of the area in the preceding year of 2004 (Fig. 4-6a), 38.5% of the area in 2003, and 12% of the area on average over the four pre-hurricane years (graphics not included). The pattern of change in salinity in Lake Pontchartrain was opposite from that in Mississippi Sound, with a post-hurricane shift toward higher salinities. For example, most of the area before the hurricane (69% on average from 2000-2004) was in the oligohaline (< 5 ppt) range, whereas after the hurricane most of the area (about 97%) was in the higher mesohaline range (5-18 ppt) (Table 4-9). A similar pattern is displayed when post-hurricane salinities are compared to the preceding 2004 sampling period (Fig. 4-7). This pattern was likely caused by the large storm surge that brought saltier coastal water into the lake.

Storm-related patterns of benthic fauna did not appear to be linked to organic enrichment of sediments. No samples following the hurricane in either survey area had TOC at elevated levels (> 3.6 %) indicative of conditions associated with a high risk of adverse benthic effects (Hyland et al., 2005). All samples in both survey areas after the hurricane had relatively low to moderate levels of TOC below 2%. Throughout the entire pre-hurricane (2000-03) data record, there were only two stations in Lake Borgne (LA01-0026 and LA01-0042) that had high TOC in the upper reported bio-effect range (4.2% and 4.6% TOC, respectively).

In summary, there were notable changes in several benthic community characteristics between the pre- and post-hurricane periods that suggest storm-related effects in both Lake Pontchartrain and the more open waters of Mississippi Sound/Lake Borgne. These included shifts in the composition and ranking of dominant taxa and reductions in number of taxa, H' diversity, and total faunal abundance. The benthic index in general did not reveal such effects, though there was a slight decline in the percentage of Lake Pontchartrain waters with healthy benthic assemblages after the hurricane in comparison to average pre-hurricane periods (Figs. 4-5a, 4-8b). In Lake Pontchartrain, considerably large portions of these waters had poor to intermediate condition both before and after the hurricane. In comparison, the majority of Mississippi Sound waters had healthy benthic assemblages in both post- and most pre-hurricane sampling periods, with a small increase in the spatial extent of such condition following the hurricane in comparison to average pre-hurricane conditions (Figs. 4-5b, 4-8a). Any potential storm-related effects on the benthos did not appear to be linked to chemical contamination, organic enrichment of sediments, or hypoxia at least as primary causes. While increased mobilization of contaminants may have contributed to such effects, storm-related changes in salinity were a more likely cause of the observed benthic effects in both survey areas. Storm induced scouring of sediments could have contributed as well.

4.5 Sediment *Clostridium perfringens*

Clostridium perfringens is an anaerobic, gram positive, spore forming bacterium. It frequently occurs in the intestines of humans and warm blooded animals and as a result can be considered an indicator of fecal waste. Spores of this organism can be found in soils and sediments subject to human or animal fecal pollution (Emerson and Cabelli, 1982; FDA, 2006).

Clostridium perfringens data were developed for three post-hurricane cruises in 2005: NOAA National Marine Fisheries Service sampling cruise on the NOAA Ship *Nancy Foster* (September 13-16), NOAA Mussel Watch field work assisted by the Louisiana University Marine Consortium's (LUMCON) vessel *Acadiana* (September 29 – October 10, 2006), and the EPA's OSV *Bold* cruise (October 9-14, 2005). Samples from all three cruises were analyzed using consistent methods (summarized below) to allow for the comparison of data resulting from the different sampling areas.

Concentrations of *C. perfringens* have been determined in sediments from around the U.S. as recently as the 1996-1997 biennial sampling period by NOAA's Mussel Watch Project. The Project sampling sites are generally located away from hotspots and so provide a general overview of *C. perfringens* in U.S. coastal and estuarine sediments. Sites for which concentrations of *C. perfringens* were quantified ranged from a low of 5 CFUs/g dry weight to a high of 26,000 CFUs/g dry weight. Of the 280 nationwide Mussel Watch monitoring sites, 20 are located in the states of Louisiana, Mississippi and Alabama. These 20 sites were sampled immediately after the passage of Katrina to determine the impact of major hurricanes and flushing events on potential *C. perfringens,* and thus sewage contamination in the sediments of the northern Gulf of Mexico.

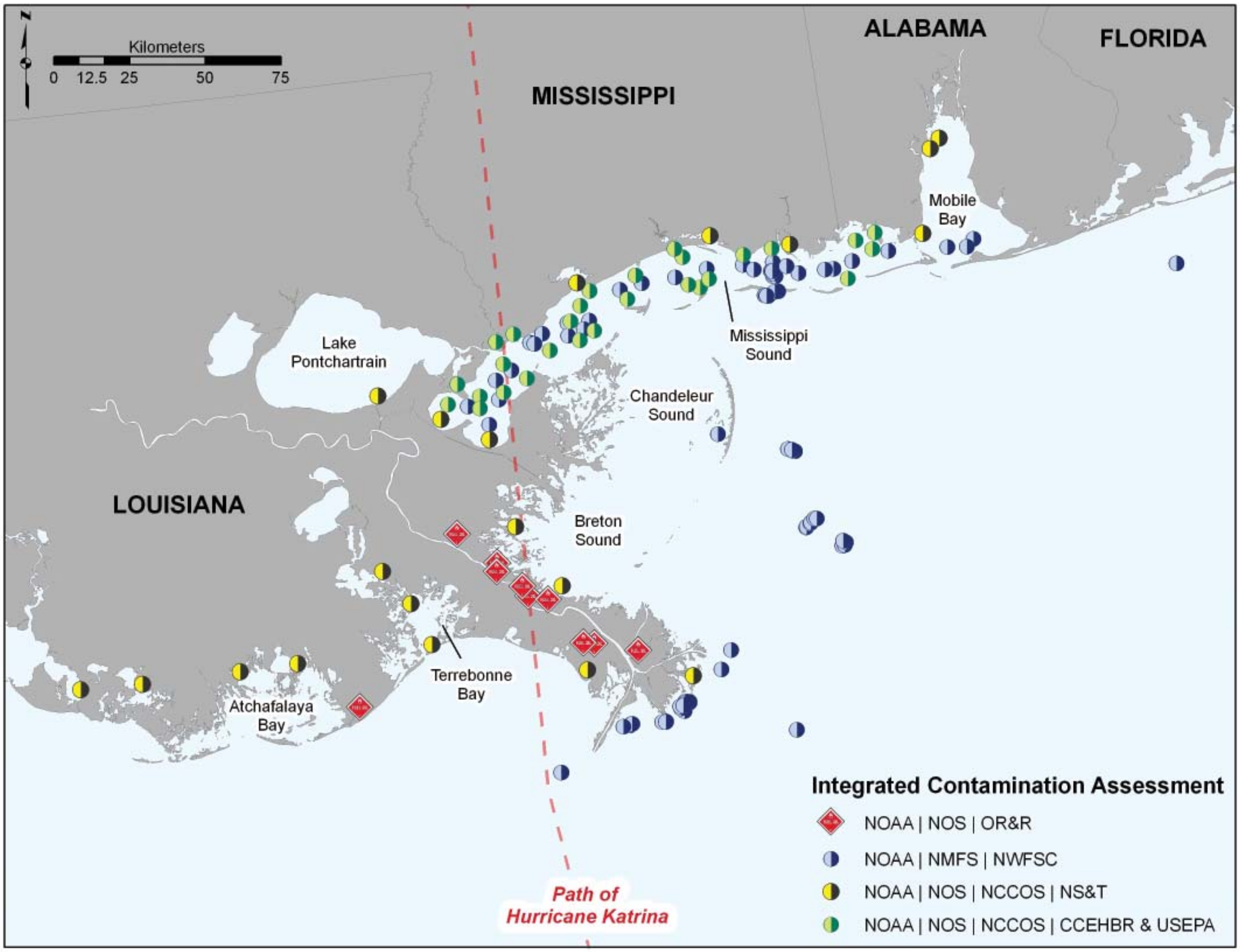

Fig. 4-9 Sites sampled by EPA and NOAA after the passage of Hurricanes Katrina and Rita.

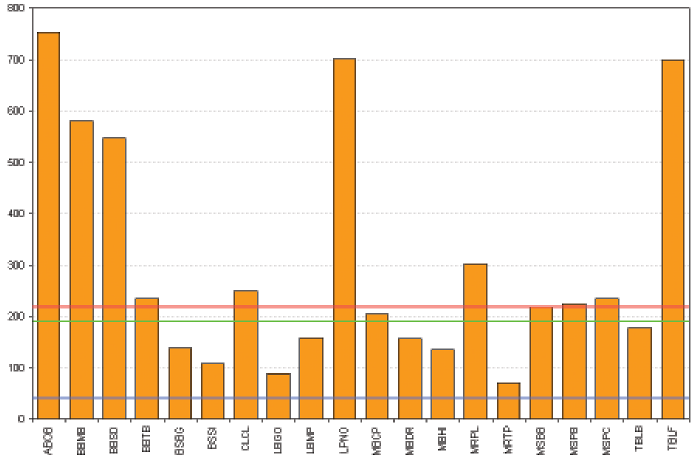

Fig. 4-10 Concentration (CFU/dry weight) of C. perfringens in sediments at Mussel Watch sites in Louisiana, Mississippi and Alabama compared to average concentrations of the Mussel Watch, National Marine Fisheries Service and EPA sites; indicated as red, green and blue lines, respectively.

Sampling cruises (Fig. 4-9) were conducted by NOAA and the EPA with *C. perfringens* analyses all performed by the same NOAA contract laboratory. The *C. perfringens* concentration range for the 11 sites collected during the NOAA National Marine Fisheries Service cruise was 0-285 CFUs/g dry weight. For the EPA OSV *Bold* cruise 26 sediment samples were characterized for *C. perfringens* concentrations. The concentration range was similar to that of the NMFS data with the highest reported value being only slightly higher. The concentration range was 0-292 CFUs/g dry. The NOAA sampling staged from the Louisiana Marine Consortium vessel *Acadiana* was nearly concurrent with that of the EPA cruise and was conducted at the more in-shore sites of the Mussel Watch Project. Concentrations for these sites (Fig. 4-10) ranged from a low of 71 CFUs/g dry weight at Tiger Pass (on the west side of the Mississippi River

Delta) to a high of 754 CFUs/g dry at Oyster Bayou (the eastern boundary of Point au Fer Island, at the lower extreme of Atchafalaya and Four League Bays). Even though a sediment sample was collected at a Lake Pontchartrain site, it did not have the highest reported concentration; that site's concentration was 701 CFUs/g dry weight.

The post-hurricane sediment samples were in the range of concentrations found for sediments collected as part of the regular Mussel Watch but well below the high concentration of 26000 CFU/g dry weight. That high value was found at Rookery Bay, Henderson Creek, Florida, in 1996. The next highest site concentrations for samples collected at that time in decreasing order were: Mississippi River Tiger Pass (12,000 CFU/g dry weight), Louisiana; Everglades Faka Union Bay, Florida (8,100 CFU/g dry weight); and Palos Verdes, Royal Palms, California (6,600 CFU/g dry weight. The highest *C. perfringens* concentrations in samples for the Mussel Watch sampling of 1996 and 1997 exceeded all post-hurricane concentrations. In nearly all cases, when older (1996) Mussel Watch data were compared to the post-hurricane results, including the site within Lake Pontchartrain, the older non-hurricane affected sites had higher concentrations of *C. perfringens*.

To put the post-hurricane *C. perfringens* data into a broader context, data for a select group of marine sewage dumpsites and outfalls were reviewed. Sewage sludge from New York was disposed of at the Deep Water Municipal Sewage Sludge Disposal site 106 miles off the coast of New Jersey (Hill et al., 1993). Dumping reached a maximum in 1988 and decreased until all dumping ceased in 1992 (Draxler et al., 1996). The above authors collected sediments from the 106-mile dumpsite in 1991 and characterized surficial sediments for *C. perfringens*. High concentrations were found to exceed 9,000 CFU/g dry wt. High *C. perfringens* concentrations were also found at other sewage release sites, e.g., Massachusetts Bay (USGS Open-File Report 01-356).

The post-Hurricane Katrina sampling results did not exceed the highest *C. perfringens* concentrations found from regular Mussel Watch sediment sampling that occurred in the same region in 1996. Further, the post-hurricane samples were well below the levels measured in other parts of the U.S. directly exposed to sewage, including the concentrations found from the 106-Mile Sewage Disposal Site and the *C. perfringens* concentrations found at the Boston Sewage Outfall. When the Mussel Watch sites that were sampled in the 1990s were compared to the post-hurricane results from the same sites, the 1990s data were usually higher. Sites sampled by the OSV *Bold* cruise and the *Nancy Foster* cruise generally exhibited lower concentrations of *C. perfringens* than did the Mussel Watch sites. The most likely reason for this is that those sites were further removed from human influence. While numerous wastewater treatment facilities were flooded during the hurricanes and raw sewage was released into the environment, the amount of water introduced both through rainfall and storm surge in all likelihood diluted the sewage inputs and may have contributed to a rapid flushing of the system.

The passage of the hurricanes does not appear to have increased the concentration of *C. perfringens* in the sediments of the hurricane-affected sites sampled.

5. Summary and Conclusions

Wave action, rainfall and runoff, collectively, contributed to the increased turbidity in the near coastal waters affected by Katrina. Increases in dissolved oxygen concentrations were attributed to these same factors. Chlorophyll *a* concentrations increased following the storm. Runoff and re-suspension may have increased nutrient concentrations in these waters resulting in a temporary increase in primary production (Conner et al., 1989).

There were no exceedances of the ERM sediment quality guideline values for chemical contaminants for any of the sediments collected from Lake Pontchartrain or Mississippi Sound. Lower threshold ERL values were exceeded for arsenic, cadmium, and nickel at several sites from both areas. Similar results were obtained for samples collected prior to the hurricane indicating very little change in the concentrations and type of contaminants due to Katrina. The insecticide Fipronil® was detected in post-hurricane sediments from both Lake Pontchartrain and Mississippi Sound and appears to have been in a potential toxic range at a few sites. However, no sediment quality guidance value for, or pre-hurricane data on, Fipronil® concentrations are available for comparison. When the concentrations of contaminants were normalized to aluminum concentrations, it was determined that there was little risk to benthos for metals, PAHs, and pesticides, with the possible exception of Fipronil®. There are insufficient data on the toxicity of Fipronil® to determine potential risk to benthos. Two post-Katrina stations in Mississippi Sound where Fipronil® concentrations were highest did show some signs of degraded benthic condition.

There were notable changes in several benthic community characteristics between the pre- and post-hurricane periods that are suggestive of storm-related effects in both Lake Pontchartrain and the more open waters of Mississippi Sound. These included shifts in the composition and ranking of dominant taxa and reductions in number of taxa, H' diversity, and total faunal abundance. The benthic index in general did not reveal such effects, though there was a slight decline in the percentage of Lake Pontchartrain waters with healthy benthic assemblages after the hurricane than before. Any potential storm-related effects on the benthos did not appear to be linked to chemical contamination, organic enrichment of sediments, or to lowered DO, at least as predominant causes. While increased mobilization of contaminants may have contributed to such effects (e.g., the possible case of Fipronil®), storm-related changes in salinity were a more likely cause of the observed benthic effects in both survey areas. Storm-induced scouring of sediments could have contributed as well.

There were no differences in the concentrations of *C. perfringens* in sediments prior to and following the storm. Concentrations found following the storm were well below those measured from sites throughout the country which are exposed to sewage. Results for samples collected from Mississippi Sound were less than those collected at the in-shore sites used by Mussel Watch. The low abundance of the organisms was likely due to dilution and flushing of the systems by Katrina.

The results from this study represent a snapshot of ecological condition in coastal waters of Lake Pontchartrain and Lake Borgne-Mississippi Sound two months after the passing of Hurricane Katrina. The comparison of ecological indicators before vs. after the hurricane suggests considerable stability of these systems with respect to short-term impacts. While some ecological changes could be detected (e.g., effects on benthic communities associated with shifts in salinity), there was no consistent evidence to suggest widespread ecological damage. These coastal ecosystems in general appeared to have absorbed much of the physical impact of the storm along with any anthropogenic materials that may have been mobilized by the floodwater and storm surge. Yet, it must be noted that the present study, conducted shortly after the hurricane, was not designed to assess potential long-term chronic environmental effects. Follow-up studies are recommended to evaluate such impacts.

There are limitations associated with the data presented in this report. The indicators used for pre- versus post-storm comparisons are appropriate for making estimates about the populations within the geographic area studied, with known confidence. Individual site-to-site comparisons are not supported by this design. The study was logistically limited to a 45-day post storm response. Ideally the study would have commenced within a few days or weeks following the event, followed by a re-assessment during a scheduled period later. Several of the indicators, i.e., waterborne contaminants and pathogens, have short half lives and may not have been present 45 days post-storm. There was still some public concern for the presence of these materials in the estuaries. Our study provided data to alleviate some of the concerns.

The data presented indicate that the coastal ecosystems associated with Lake Pontchartrain and Mississippi Sound responded to the stress created by Hurricane Katrina much better than any of the human-based systems. There may have in fact, been some improvements to coastal ecosystem due to the "flushing" provided by the storm surge and subsequent freshwater inflow. Although, the loss of property and life associated with Hurricane Katrina was devastating, this report demonstrates the resiliency of coastal ecosystems in responding to extreme storm events.

6. References

APHA 1998. Standard Methods for the Examination of Water and Wastewater, 20th edition. American Public Health Association, Washington, DC.

Balthis, W.L., J.L. Hyland, and D.W. Bearden. In Press. Ecosystem responses to extreme natural events: Impacts of three sequential hurricanes in fall 1999 on sediment quality and condition of benthic fauna in the Neuse River estuary, North Carolina. Environ. Monitor. & Assess., 119: 367 - 389.

Boesch, D.F., M.L. Wass, and R.W. Virnstein. 1976. Effects of tropical storm Agnes on soft-bottom macrobenthic communities of the James and York estuaries and the Lower Chesapeake Bay. Ches. Sci., 17(4): 246-259.

Chandler, G.T., T.L. Carey, D.C. Volz, S.S. Walse, J.L. Ferry, and S.L. Klosterhaus. 2004a. Fipronil® effects on estuarine copepod (*Amphiascus tenuiremis*), development, fertility, and reproduction: a rapid life-cycle assay in 96-well microplate format. Environ. Toxicol. and Chem. 23:117-124.

Chandler, G.T., T.L. Carey, A.C. Bejarano, J. Pender, and J.L. Ferry. 2004b. Population consequences of Fipronil® and degradates to copepods at field concentrations: an integration of life cycle testing with Leslie matrix population modeling. Environ. Sci. Technol. 38:6407-6414.

Cochran, W.G. 1977. Sampling Techniques. John Wiley and Sons. 448pp.

Conner, W.H., Day Jr, J.W., Baumann, R. H, and J.M. Randall. 1989. Influence of hurricanes on coastal ecosystems along the northern Gulf of Mexico. Wetlands Ecology and Management, 1(1): 45-56.

Diaz, R.J., and R. Rosenberg. 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioral responses of benthic macrofauna. Ocean. & Mar. Biol.: Ann. Rev., 33: 245-303.

Diaz-Ramos, S., Stevens, D.L., Jr and Olsen, A.R., 1996. EMAP Statistical Methods Manual. Rep. EPA/620/R-96/002, U.S. Environmental Protection Agency, Office of Research and Development, NHEERL-WED, Corvallis, Oregon.

Draxler, A.F.J., V. Zdanowicz, A.D. Deshpande, T. Finneran, L. Arlen and D. Packeri. 1996. Physical, chemical and microbial properties of sediments at the 106-mile sewage sludge dumpsite. J. Marine Env. Eng. 2:343-368.

Emerson, D.J. and V.J. Cabelli. 1982. Extraction of Clostridium perfringens spores from bottom sediment samples. Applied and Environmental Microbiology 44(5) 144-1149.

Engle, V.D., J.K. Summers, and G.R. Gaston. 1994. A benthic index of environmental condition of Gulf of Mexico estuaries. Estuaries, 17(2): 372-384.

Engle, V.D. and J.K. Summers. 1998. Determining the cause of benthic condition. Environ. Monitor. & Assess., 51: 381-397.

Engle, V.D. and J.K. Summers. 1999. Refinement, validation, and application of a benthic condition index for northern Gulf of Mexico estuaries. Estuaries, 22(3A): 624-635.

FDA (Food and Drug Administration). 2006. Bad Bug Book – Clostridium perfringens. http://www.cfsan.fda.gov/~mow/chap11.html/ April 5, 2006.

Hilal, S.H., L.A. Carreira, and S.W. Karikhoff. 2004. Prediction of the solubility, activity coefficient, gas/liquid and liquid/liquid distribution coefficients of organic compounds. QSAR Comb. Sci. 23:709-720.

Hill, R.T., I.T. Knight, M.S. Anikis, and R.R. Colwell. 1993. Benthic distribution of sewage sludge indicated by Clostridium perfringens at a deep-ocean dump site. Applied and Environmental Microbiology 59(1) 47-51.

Hyland, J.L., W.L. Balthis, V.D. Engle, E.R. Long, J.F. Paul, J.K. Summers, and R.F. Van Dolah. 2003. Incidence of stress in benthic communities along the U.S. Atlantic and Gulf of Mexico coasts within different ranges of sediment contamination from chemical mixtures. Environ. Monitor. & Assess., 81(1-3): 149-161.

Hyland, J.L., L. Balthis, I. Karakassis, P. Magni, A.N. Petrov, J.P. Shine, O. Vestergaard, and R.M. Warwick. 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. Mar Ecol. Progr. Ser., 295: 91-103.

IDEXX. 2004. Enterolert Test System Operations Procedure. IDEXX Laboratories Inc. One IDEXX Drive, Westbrook, Maine. 04092

Karickhoff, S.W. and J.M. Long. 1995. Internal report on summary of measured, calculated, and recommended log K_{OW} values. Internal Report. U.S. Environmental Protection Agency, Athens, GA.

Latimer, J. S., W. S. Boothman, C. E. Pesch, G. L. Chmura, V. Pospelova, and S. Jayaraman. 2003. Environmental stress and recovery: the geochemical record of human disturbance in New Bedford Harbor and Apponagansett Bay, Massachusetts (USA). The Science of The Total Environment, 313:153-176.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder, 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ. Manage., 19: 81–97.

MacDonald, D.D., R.S. Carr, F.D. Calder, E.R. Long, and C.G. Ingersoll. 1996. Development and Evaluation of Sediment Quality Guidelines for Florida Coastal Waters. Ecotoxicology 5: 253-278.

Mallin, M.A., M.H. Posey, G.C. Shank, M.R. McIver, S.H. Ensign, and T.D. Alphin. 2002. Impacts and recovery from multiple hurricanes in a piedmont-coastal plain river system. BioScience, 52(11): 999-1010.

NOAA/NCDC 2005. Climate of 2005. Summary of Hurricane Katrina. NOAA National Climatic Data Center (NCDC) http://www.ncdc.noaa.gov/oa/climate/research/2005/katrina.html.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev., 16: 229–311.

Ringwood, A. H, M. E. DeLorenzo, P. E. Ross, and A. F. Holland. 1997. Interpretation of Microtox® Solid Phase Toxicity Tests: The Effect of Sediment Composition. Environmental Toxicology and Chemistry 16 (No. 6):1135-1140.

Shannon, C. E., Weaver, W. 1949. The mathematical theory of communication. University of Illinois Press, Urbana, Illinois. 117 p.

Smith, VH. 2006. Responses of estuarine and coastal marine phytoplankton to nitrogen and phosphorus enrichment. Limnology And Oceanography, Volume: 51 , Number: 1,2 (JAN) , Page: 377-384.

Strobel, C.J., H.W. Buffum, S.J. Benyi, E.A. Petrocelli, D.R. Reifsteck and D.J. Keith. 1995. Statistical Summary: EMAP-Estuaries Virginian Province - 1990 To 1993. EPA/620/R-94/026. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, RI.

Summers, J.K. T.L. Wade, V.D. Engle, and Z.A. Maleab. 1996. Normalization of metal concentrations in the Gulf of Mexico. Estuaries. 19:581-594.

USEPA. 1986. Ambient Water Quality Criteria for Bacteria. United States Environmental Protection Agency, Office of Water, Criteria and Standards Division, Washington DC, 20460. EPA/440/5-84-002.

USEPA. 1996. Fipronil®: New Pesticide Fact Sheet. EPA-737-F-96-005. Office of Prevention, Pesticides, and Toxic Substances, Washington, DC.

USEPA. 1999. Ecological Condition of estuaries in the Gulf of Mexico. EPA 620-R-98-004. U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL.

USEPA. 2001. National Coastal Assessment: Field Operations Manual. EPA/620/R-01/003. United States Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL. pp72.

USEPA. 2001. Environmental Monitoring and Assessment Program (EMAP). National Coastal Assessment Quality Assurance Project Plan 2001-2004. United States Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL. EPA/620/R-01/002.

USEPA. 2001. Protocol for developing pathogen TMDLs. United States Environmental Protection Agency, Office of Water, 4503F, Washington DC, 20460. EPA/841/R-00/002.

USEPA. 2002. Research Strategy, Environmental Monitoring and Assessment Program. EPA 620/R-02/002. U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Research Triangle Park, NC.

USEPA. 2003a. Procedures for Deriving Equilibrium Partitioning Sediment Guidelines (ESGs) for the Protection of Benthic Organisms: PAH Mixtures. EPA-600-R-02-013. Office of Research and Development, Washington, DC.

USEPA. 2003b. Procedures for Deriving Equilibrium Partitioning Sediment Guidelines (ESGs) for the Protection of Benthic Organisms: Dieldrin. EPA-600-R-02-010. Office of Research and Development, Washington, DC.

USEPA. 2003c. Procedures for Deriving Equilibrium Partitioning Sediment Guidelines (ESGs) for the Protection of Benthic Organisms: Endrin. EPA-600-R-02-009. Office of Research and Development, Washington, DC.

USEPA. 2005. Procedures for Deriving Equilibrium Partitioning Sediment Guidelines (ESGs) for the Protection of Benthic Organisms: Metal Mixtures (Cadmium, Copper, Lead, Nickel, Silver, and Zinc). EPA-600-R-02-011. Office of Research and Development, Washington, DC.

USEPA. Draft. Procedures for Deriving Equilibrium Partitioning Sediment Guidelines (ESGs) for the Protection of Benthic Organisms: Nonionics Compendium. EPA-600-R-02-016. Office of Research and Development, Washington, DC.

U.S. Geological Survey. 2003. Fipronil® and degradation products in the rice-producing areas of the Mermentau River Basin, Louisiana, February-September 2000. USGS Fact Sheet FS-010-03. March 2003.

USGS Open-File Report 01-356, Version 1.0. 2001. Concentrations of Metals and Bacterial Spores in Sediments near the Massachusetts Bay Outfall before and after Discharge Began. http://pubs.usgs.gov/of/2001/of01-356/ July 17, 2006.

Van Dolah, R.F. and G.S. Anderson. 1991. Effects of Hurricane Hugo on salinity and dissolved oxygen conditions in the Charleston Harbor estuary. J. Coastal Res. Special Issue No. 8: 83-94.

Walse, S.S., P.L. Pennington, G.I. Scott, and J.L. Ferry. 2004. The fate of Fipronil® in modular aquatic mesocosms. J. Environ. Monit. 6:58-64.

Appendix 1

Appendix 1.

Threshold/Guidance Values for Evaluating Water Quality*			
Parameter	**Good**	**Fair**	**Poor**
Dissolved Oxygen	> 5 mg/L	2-5 mg/L	<2 mg/L
Chlorophyll <u>a</u>	<5 ug/L	5-20 ug/L	>20 ug/L
Dissolved Inorganic Nitrogen	<0.1 mg/L	0.1-0.5 mg/L	>0.5 mg/L
Dissolved Inorganic Phosphorus	<0.01 mg/L	0.01-0.05 mg/L	>0.05 mg/L
Water Clarity (% light transmission @ 1m)	>20%	10-20%	<10%
Water Quality	≤ 1 indicator scored fair	2 or more indicators scored fair or 1 indicator scored poor	2 or more indicators scored poor

* U.S. Environmental Protection Agency(USEPA): 2004, 'National Coastal Condition Report II,' EPA-620/R-03/002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Appendix 2

Appendix 2-1: Metal-aluminum regression parameters derived from EMAP Louisianan and Virginian Provinces (1990-1994)

		vs. %Al			
Element	**Province**	**Intercept**	**Slope**	**N**	**r2**
Ag	Louisianan	0.034	0.0148	277	0.559
	Virginian	0.010	0.0117	181	0.431
As	Louisianan	0.92	1.00	239	0.801
	Virginian	1.33	1.08	469	0.491
Cd	Louisianan	0.037	0.1139	180	0.444
	Virginian	**0.032**	**0.0275**	**273**	**0.470**
Cr	Louisianan	5.01	7.73	234	0.850
	Virginian	-1.53	10.03	465	0.794
Cu	Louisianan	-0.33	2.14	266	0.821
	Virginian	-2.37	3.96	368	0.703
Fe	Louisianan	-187	4044	266	0.874
	Virginian	-738	5655	525	0.855
Hg	Louisianan	0.010	0.0067	265	0.538
	Virginian	**0.004**	**0.0094**	**329**	**0.500**
Mn	Louisianan	21.3	53.8	203	0.813
	Virginian	**75.9**	**51.4**	**288**	**0.686**
Ni	Louisianan	-0.16	3.75	306	0.811
	Virginian	-2.70	4.62	476	0.744
Pb	Louisianan	1.51	2.49	198	0.947
	Virginian	2.47	4.99	430	0.644
Sb	Louisianan	0.16	0.0777	275	0.462
	Virginian	0.05	0.0659	334	0.503
Se	Louisianan	0.053	0.0462	263	0.475
	Virginian	0.060	0.0672	400	0.475
Sn	Louisianan	0.16	0.172	178	0.709
	Virginian	**0.22**	**0.377**	**330**	**0.730**
Zn	Louisianan	3.53	11.4	252	0.892
	Virginian	0.07	16.5	350	0.782

Bold: normal distribution of residuals not obtained

Appendix 2-2a: Metals chemistry data (dry weight) from Mississippi Sound samples.

STA_NAME	Ag	Cd	Cu	Ni	Pb	Zn
	UG/G	UG/G	UG/G	UG/G	UG/G	UG/G
KAT-0001	0.16	1.4	14	28.7	29.6	114
KAT-0002	0.19	1.5	10.2	18.3	17.5	58.4
KAT-0003	0.17	1.2	6.2	13.7	14.5	45
KAT-0004	0.18	1.3	14.5	26.9	29.4	102
KAT-0005	0.19	1.5	11	20	19.4	65.1
KAT-0006	0.046	0.14	2.9	4.3	5.5	17.9
KAT-0007	0.16	1.1	11.8	18.8	17.5	61.1
KAT-0008	0.21	1.4	18.1	33.2	37.5	126
KAT-0009	0.046	0.14	0.25	0.28	1.4	2
KAT-0010	0.046	0.14	0.51	0.57	2.4	3.4
KAT-0011	0.13	0.74	8.5	15.9	15	54.5
KAT-0012	0.17	1.2	12.9	23.3	27.5	95
KAT-0013	0.16	0.97	8.1	14.3	14.9	49.2
KAT-0014	0.058	0.19	3.4	6.6	8.3	28.3
KAT-0015	0.17	1.2	15.6	25.1	18.6	77.7
KAT-0016	0.046	0.14	0.45	0.4	1	2.7
KAT-0017	0.14	1	12.3	22.2	24.9	100
KAT-0018	0.1	0.62	7	12.4	13	45.4
KAT-0019	0.15	0.84	6.7	13.7	14	47.6
KAT-0020	0.065	0.4	4.8	9.4	11.3	37.8
KAT-0021	0.12	0.62	4	11.1	11.8	34.4
KAT-0022	0.12	0.71	6	10.2	15.4	48.9
KAT-0023	0.15	0.87	9.9	16.5	20	59
KAT-0024	0.16	1	10.5	19	25.1	80.7
KAT-0025	0.11	0.78	9.5	20.7	22.1	86.3
KAT-0026	0.17	1	9	16.1	18.5	62
KAT-0027	0.046	0.14	0.62	0.69	1.7	2.9
KAT-0028	0.15	1	9.4	18.2	21.3	74.1
KAT-0029	0.15	1.2	10.9	20.2	15.8	59.5
KAT-0030	0.072	0.42	2.3	3.5	5.3	12.6

Appendix 2-2b: Metals chemistry data (dry weight) from Lake Pontchartrain samples (µg/g).

STA_NAME	Ag	Cd	Cu	Ni	Pb	Zn
	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
LP-0001	0.2	1.3	16.2	25.6	25.3	94.6
LP-0002	0.046	0.14	1.1	1.6	4	5.9
LP-0003	0.24	1.7	22.1	32.7	27.5	107
LP-0004	0.19	1.2	18.6	25.4	21.4	83.3
LP-0005	0.17	1.1	13.8	20.9	18.9	70.3
LP-0006	0.22	1.3	16.3	26.5	23.4	86.8
LP-0008	0.23	1.8	15.6	23.5	20.8	73.4
LP-0009	0.23	1.9	18.8	29.4	26.4	95.3
LP-0010	0.19	0.95	11.2	18.4	19.7	63.6
LP-0011	0.24	1.4	22.9	34.6	27.7	110
LP-0012	0.23	1.3	18	28.8	25.3	93.2
LP-0013	0.29	2.1	25.4	38.5	36.4	126
LP-0014	0.23	1.5	15.6	24.2	23.5	82.4
LP-0015	0.092	0.62	1.7	4	8.4	13.1
LP-0017	0.22	1.6	13.7	20.7	20.4	69.2
LP-0018	0.17	1.1	10.5	16.9	16.8	57.9
LP-0019	0.24	1.8	22.9	34.4	28.3	113
LP-0020	0.22	1.3	17.5	27.8	25.6	97.4
LP-0021	0.25	1.2	18.3	27.6	27.7	100
LP-0022	0.18	1.1	5.6	9.4	14	36.4
LP-0023	0.14	0.64	3.9	8.5	12.2	28.1
LP-0024	0.27	1.9	18.8	29.9	27.1	91.4
LP-0025	0.37	2.6	28.1	42.3	41.8	142
LP-0026	0.2	1.3	18	28.2	22.9	92.4
LP-0027	0.36	2.6	29.1	45.5	42.4	152
LP-0028	0.23	1.5	13.9	21	21.7	69
LP-0029	0.33	2	25.5	38.7	40.6	129
LP-0030	0.26	1.6	21.4	34.1	33.4	118
LPALT-0058	0.23	1.5	15.2	24.3	23	80.4

Appendix 2-3a: Metals data (dry weight) from Mississippi stations (µmoles/g).

	Ag	Cd	Cu	Ni	Pb	Zn	Total		Total
STA_NAME	µmoles/g	µmoles/g	µmoles/g	µmoles/g	µmoles/g	µmoles/g	µmoles/g	TOC (%)	Metal/fOC
KAT-0001	0.000742	0.012454	0.220313	0.48901	0.142857	1.743386	2.608762	1.36	192.1032
KAT-0002	0.000881	0.013344	0.160514	0.311808	0.084459	0.893103	1.464109	0.78	188.1646
KAT-0003	0.000788	0.010675	0.097567	0.23343	0.069981	0.688179	1.10062	0.34	327.2731
KAT-0004	0.000834	0.011565	0.228181	0.45834	0.141892	1.559872	2.400684	1.11	216.2779
KAT-0005	0.000881	0.013344	0.173103	0.340774	0.093629	0.995565	1.617296	0.74	217.8763
KAT-0006	0.000213	0.001245	0.045636	0.073266	0.026544	0.273742	0.420648	0.20	209.4859
KAT-0007	0.000742	0.009786	0.185692	0.320327	0.084459	0.934394	1.5354		
KAT-0008	0.000973	0.012454	0.284833	0.565684	0.180985	1.9269	2.97183	1.42	209.579
KAT-0009	0.000213	0.001245	0.003934	0.004771	0.006757	0.030586	0.047506	0.03	138.704
KAT-0010	0.000213	0.001245	0.008026	0.009712	0.011583	0.051996	0.082775	0.04	210.3026
KAT-0011	0.000603	0.006583	0.133761	0.270915	0.072394	0.833461	1.317717	0.46	289.608
KAT-0012	0.000788	0.010675	0.203003	0.397001	0.132722	1.452822	2.19701	1.11	198.4653
KAT-0013	0.000742	0.008629	0.127467	0.243653	0.071911	0.752409	1.20481	0.82	147.1614
KAT-0014	0.000269	0.00169	0.053505	0.112455	0.040058	0.432788	0.640765	0.32	200.3016
KAT-0015	0.000788	0.010675	0.245491	0.427671	0.089768	1.188255	1.962649	0.87	224.7394
KAT-0016	0.000213	0.001245	0.007081	0.006815	0.004826	0.041291	0.061473	0.02	295.8258
KAT-0017	0.000649	0.008896	0.193561	0.378259	0.120174	1.529286	2.230824	1.88	118.724
KAT-0018	0.000464	0.005516	0.110156	0.21128	0.062741	0.694296	1.084452	0.66	164.7603
KAT-0019	0.000695	0.007473	0.105435	0.23343	0.067568	0.72794	1.142541	0.19	596.3157
KAT-0020	0.000301	0.003558	0.075536	0.160164	0.054537	0.57807	0.872166	0.44	197.5461
KAT-0021	0.000556	0.005516	0.062947	0.189129	0.05695	0.526074	0.841172	0.19	438.7959
KAT-0022	0.000556	0.006316	0.09442	0.173795	0.074324	0.747821	1.097232	0.72	152.9243
KAT-0023	0.000695	0.00774	0.155793	0.281138	0.096525	0.902279	1.444169	0.65	221.2608
KAT-0024	0.000742	0.008896	0.165235	0.323735	0.121139	1.234134	1.85388	1.06	175.3907
KAT-0025	0.00051	0.006939	0.149498	0.352701	0.10666	1.319774	1.936081	0.83	233.0382
KAT-0026	0.000788	0.008896	0.14163	0.274323	0.089286	0.948157	1.463079	0.79	186.3083
KAT-0027	0.000213	0.001245	0.009757	0.011757	0.008205	0.044349	0.075526	0.03	249.2607
KAT-0028	0.000695	0.008896	0.147924	0.310104	0.102799	1.133201	1.70362	0.96	176.7974
KAT-0029	0.000695	0.010675	0.171529	0.344181	0.076255	0.909925	1.513261	0.54	279.251
KAT-0030	0.000334	0.003736	0.036194	0.059635	0.025579	0.19269	0.318169	0.22	144.2289

Appendix 2-3b: Metals data (dry weight) from Lake Pontchartrain stations (µmoles/g).

STA_NAME	Ag µmoles/g	Cd µmoles/g	Cu µmoles/g	Ni µmoles/g	Pb µmoles/g	Zn µmoles/g	Total µmoles/g	TOC (%)	Total Metal/fOC
LP-0001	0.000927	0.011565	0.254933	0.43619	0.122104	1.446704	2.272424	1.04	217.8738
LP-0002	0.000213	0.001245	0.01731	0.027262	0.019305	0.090228	0.155564	0.01	2525.385
LP-0003	0.001112	0.015123	0.34778	0.557165	0.132722	1.636336	2.690238	1.11	243.4604
LP-0004	0.000881	0.010675	0.292701	0.432782	0.103282	1.273895	2.114217	1.98	106.9406
LP-0005	0.000788	0.009786	0.217166	0.356108	0.091216	1.075088	1.750152	0.76	229.1374
LP-0006	0.00102	0.011565	0.256507	0.451525	0.112934	1.32742	2.160971	1.10	196.0954
LP-0008	0.001066	0.016013	0.245491	0.400409	0.100386	1.122496	1.885861	0.82	230.4327
LP-0009	0.001066	0.016902	0.295849	0.500937	0.127413	1.457409	2.399577	1.26	190.5939
LP-0010	0.000881	0.008451	0.17625	0.313512	0.095077	0.972626	1.566797	1.09	143.8748
LP-0011	0.001112	0.012454	0.360369	0.589538	0.133687	1.682214	2.779376	1.00	278.4388
LP-0012	0.001066	0.011565	0.283259	0.490714	0.122104	1.425294	2.334003	0.96	243.9639
LP-0013	0.001344	0.018682	0.39971	0.655989	0.175676	1.9269	3.178301	1.32	240.7804
LP-0014	0.001066	0.013344	0.245491	0.412336	0.113417	1.260132	2.045786	1.16	177.1243
LP-0015	0.000426	0.005516	0.026752	0.068155	0.040541	0.200336	0.341726	0.12	274.0384
LP-0017	0.00102	0.014234	0.215592	0.352701	0.098456	1.058266	1.740267	0.91	190.6098
LP-0018	0.000788	0.009786	0.165235	0.287954	0.081081	0.885456	1.430299	0.74	194.0705
LP-0019	0.001112	0.016013	0.360369	0.586131	0.136583	1.728093	2.828301	1.21	233.9372
LP-0020	0.00102	0.011565	0.275391	0.473675	0.123552	1.489524	2.374727	0.84	283.2114
LP-0021	0.001159	0.010675	0.28798	0.470268	0.133687	1.529286	2.433055	1.05	231.279
LP-0022	0.000834	0.009786	0.088125	0.160164	0.067568	0.55666	0.883136	0.72	122.0644
LP-0023	0.000649	0.005693	0.061373	0.144829	0.05888	0.429729	0.701154	0.21	329.0256
LP-0024	0.001252	0.016902	0.295849	0.509456	0.130792	1.397767	2.352018	0.96	245.9241
LP-0025	0.001715	0.02313	0.442199	0.720736	0.201737	2.171586	3.561103	0.94	380.6631
LP-0026	0.000927	0.011565	0.283259	0.480491	0.110521	1.41306	2.299823	0.89	257.5678
LP-0027	0.001669	0.02313	0.457936	0.77526	0.204633	2.324514	3.787142	1.68	225.6938
LP-0028	0.001066	0.013344	0.218739	0.357812	0.10473	1.055207	1.750898	1.27	138.4109
LP-0029	0.00153	0.017792	0.401284	0.659397	0.195946	1.972779	3.248727	1.32	247.0515
LP-0030	0.001205	0.014234	0.336764	0.581019	0.161197	1.804557	2.898976	1.47	196.6741
LPALT-0058	0.001066	0.013344	0.239197	0.41404	0.111004	1.229546	2.008196	1.09	185.0872

Appendix 2-4: PAH concentrations from the 13 PAHs used in the calculation of ESB_PAH13. All PAH concentrations are in ng/g dry weight. PAHs that were not detected in any of the sediments (acenaphthene, acenaphthylene, anthracene, fluorene, and naphthalene) are not shown. The correction factor used to reach a 99% confidence level for the extrapolation from 13 to 34 PAHs was 16.9. Sites are ordered by total PAH. KAT-0008 had detectable PAH, but none of the 13 PAHs used in the ESBTU calculation were detected

Station Name	Benzo(a) anthra-cene	Benzo(a) pyrene	Benzo(b) fluoran-thene	Benzo(k) fluoran-thene	Chrysene	Fluoran-thene	Pyrene	Phenan-threne	Total PAH	TOC (%)	ESB_ PAH13	99% ESB_ PAH13
LP-0027	59	32	58	24	78	190	170	20	641	1.678	0.0491	0.83
KAT-0012	14	0	0	0	11	34	29	18	106	1.11	0.0135	0.23
LP-0028	10	0	0	0	11	22	23	0	66	1.27	0.007	0.12
C06	0	26	0	0	0	17	13	0	56	0.73	0.0095	0.16
X01	0	0	0	0	0	16	18	0	34	2.5	0.0019	0.032
KAT-0002	0	0	0	0	14	0	0	0	14	0.78	0.0021	0.035
KAT-0024	0	0	0	0	14	0	0	0	14	1.06	0.0016	0.0274
M04	0	0	0	0	11	0	0	0	11	1.20	0.0011	0.019
X04	0	0	0	0	0	0	10	0	10	6	0.0004	0.0068
KAT-0008	0	0	0	0	0	0	0	0	6	1.42	0	0
KAT-0019	2	0	0	0	0	0	0	0	2	0.19	0.0013	0.022
LP-0025	0	0	0	0	0	0	0	1.5	1.5	0.94	0.0003	0.0051

Appendix 2-5: Equilibrium partitioning derived sediment benchmarks for eight pesticides.

Chemical	FCV (ug/L)	Log KOW	Log KOC	ESB (ug/gOC)	Source
Dieldrin	0.0019			28	U.S. EPA 2003b. (Dieldrin ESB.)
Alpha endosulfan	0.0087			0.05	U.S. EPA draft. (Compendium ESB.)
Beta endosulfan	0.0087			0.24	U.S. EPA draft. (Compendium ESB.)
Endrin	0.0023			0.44	U.S. EPA 2003c. (Endrin ESB.)
Heptachlor	0.0036	6.26	6.15	5.13	Karickhoff and Long 1995. (KOW)
Heptachlor epoxide	0.0036	5	4.92	0.30	Karickhoff and Long 1995. (KOW)
Toxaphene	0.0002	5.5	5.41	0.05	Karickhoff and Long 1995. (KOW)
Fipronil®*	0.005	4.01	3.94	0.0438	USEPA, 1996. (KOW and mysid data)
Fipronil®*	0.005	4.68	4.60	0.20	SPARC and Mysid data

*A Fipronil® FCV is not available. The mysid chronic value (< 5 ng/L) was used for the computation.

** KOC calculated using the formula KOC = KOW x 0.983 + 0.00028 (USEPA, Draft)

Appendix 2-6a: Fipronil® data from Mississippi stations.

STA_NAME	Fipronil® (ng/g)	Fipronil® (µg/g)	TOC (%)	Fipronil® (µg/goc)
KAT-0001	0.47	0.00047	1.36	0.03461
KAT-0002	0	0	0.78	0
KAT-0003	0	0	0.34	0
KAT-0004	0	0	1.11	0
KAT-0005	0	0	0.74	0
KAT-0006	0	0	0.20	0
KAT-0007	0	0	NA	NA
KAT-0008	0	0	1.42	0
KAT-0009	1.4	0.0014	0.03	4.087591
KAT-0010	0	0	0.04	0
KAT-0011	0	0	0.46	0
KAT-0012	0	0	1.11	0
KAT-0013	0.77	0.00077	0.82	0.094052
KAT-0014	0	0	0.32	0
KAT-0015	0	0	0.87	0
KAT-0016	0.61	0.00061	0.02	2.935515
KAT-0017	0	0	1.88	0
KAT-0018	0	0	0.66	0
KAT-0019	0.53	0.00053	0.19	0.276618
KAT-0020	0	0	0.44	0
KAT-0021	0	0	0.19	0
KAT-0022	0	0	0.72	0
KAT-0023	0	0	0.65	0
KAT-0024	0	0	1.06	0
KAT-0025	0	0	0.83	0
KAT-0026	0.36	0.00036	0.79	0.045842
KAT-0027	0	0	0.03	0
KAT-0028	0	0	0.96	0
KAT-0029	0	0	0.54	0
KAT-0030	0.79	0.00079	0.22	0.358114

Appendix 2-6b: Fipronil® data from Lake Pontchartrain stations.

STA_NAME	Fipronil® (ng/g)	Fipronil® (µg/g)	TOC (%)	Fipronil® (µg/goc)
LP-0001	0	0	1.04	0
LP-0002	0	0	0.01	0
LP-0003	0.96	0.00096	1.11	0.086878
LP-0004	0	0	1.98	0
LP-0005	0	0	0.76	0
LP-0006	0	0	1.10	0
LP-0008	0	0	0.82	0
LP-0009	0	0	1.26	0
LP-0010	0	0	1.09	0
LP-0011	0	0	1.00	0
LP-0012	0	0	0.96	0
LP-0013	0	0	1.32	0
LP-0014	0	0	1.16	0
LP-0015	0	0	0.12	0
LP-0017	0	0	0.91	0
LP-0018	0	0	0.74	0
LP-0019	0	0	1.21	0
LP-0020	0	0	0.84	0
LP-0021	0	0	1.05	0
LP-0022	0	0	0.72	0
LP-0023	0	0	0.21	0
LP-0024	0	0	0.96	0
LP-0025	0	0	0.94	0
LP-0026	0	0	0.89	0
LP-0027	0	0	1.68	0
LP-0028	0.55	0.00055	1.27	0.043478
LP-0029	0	0	1.32	0
LP-0030	0	0	1.47	0
LPALT-0058	0	0	1.09	0

Appendix 3

Appendix 3-1: Summary of benthic variables by station in Mississippi Sound and Lake Borgne before (n=172) and after (n=30) Hurricane Katrina.

Station	Taxa Richness (#/grab)	Total Abundance (#/grab)	Shannon-Wiener H' ($\log_2$)	Density (#/m^2)	Benthic Index
Mississippi Sound - pre-Katrina (n = 172)					
AL00-0020	31	152	3.98	3040	6.88
AL00-0022	43	145	5.00	2900	8.19
AL00-0023	34	82	4.76	1640	7.76
AL00-0024	40	260	3.60	5200	-1.73
AL00-0025	22	225	2.48	4500	4.22
AL00-0038	23	116	3.62	2320	-0.16
AL00-0044	17	36	3.78	720	7.25
AL01-0020	19	68	3.49	1360	6.75
AL01-0022	49	195	4.53	3900	2.72
AL01-0023	35	132	4.50	2640	3.54
AL01-0024	23	61	3.85	1220	6.14
AL01-0025	36	518	2.82	10360	4.85
AL01-0038	20	59	3.55	1180	6.27
AL01-0044	12	56	2.17	1120	5.18
AL02-0020	36	165	3.91	3300	3.46
AL02-0022	21	37	3.88	740	7.16
AL02-0023	18	54	3.76	1080	6.88
AL02-0024	18	32	3.54	640	5.86
AL02-0025	41	508	3.11	10160	5.80
AL02-0038	21	83	3.43	1660	0.89
AL02-0044	22	73	3.14	1460	1.87
AL03-0020	30	170	3.49	3400	4.31
AL03-0022	21	75	3.40	1500	6.87
AL03-0023	27	59	4.37	1180	10.12
AL03-0024	8	12	2.86	240	6.94
AL03-0025	18	65	3.37	1300	7.22
AL03-0038	16	66	3.00	1320	-0.75
AL03-0044	7	11	2.55	220	7.05
LA00-0001	33	420	3.33	10500	1.82
LA00-0003	19	42	3.92	1050	11.04
LA00-0033	17	106	1.92	2650	5.81
LA00-0034	19	71	3.79	1775	9.83
LA01-0018	3	8	1.06	200	1.52
LA01-0026	18	524	2.51	13100	10.59
LA01-0027	10	39	3.07	975	1.78

Station	Taxa Richness (#/grab)	Total Abundance (#/grab)	Shannon-Wiener H' ($\log_2$)	Density (#/m^2)	Benthic Index
LA01-0033	12	29	2.79	725	1.98
LA01-0042	17	218	2.69	5450	9.22
LA02-0008	2	2	1.00	50	-0.74
LA02-0013	21	279	2.60	6975	8.77
LA02-0014	1	11	0.00	275	1.82
LA02-0015	5	13	1.89	325	5.39
LA03-0003	4	6	1.79	150	3.94
LA03-0010	3	11	1.49	275	3.63
LA03-0014	2	4	0.81	100	1.90
LA03-0015	3	23	0.81	575	1.73
LA03-0016	7	14	2.61	350	1.90
LA03-0018	11	54	2.57	1350	5.71
MS00-0013	22	72	3.87	1440	6.89
LA04-0008	8	132	1.06	3300	2.29
LA04-0010	21	68	3.79	1700	3.05
LA04-0014	2	3	0.92	75	2.58
LA04-0015	7	22	2.28	550	0.18
LA04-0016	1	2	0.00	50	-1.22
MS00-0014	22	69	3.73	1380	7.10
MS00-0016	10	39	2.70	780	5.39
MS00-0017	49	340	4.74	6800	-2.70
MS00-0022	16	39	3.13	780	5.83
MS00-0023	30	142	4.08	2840	6.87
MS00-0024	18	98	3.86	1960	6.79
MS00-0025	34	100	4.60	2000	7.41
MS00-0026	21	109	3.00	2180	5.81
MS00-0027	28	109	3.86	2180	6.65
MS00-0028	21	77	3.61	1540	5.95
MS00-0029	19	74	3.18	1480	4.68
MS00-0030	36	181	3.47	3620	4.66
MS00-0031	12	29	2.93	580	6.15
MS00-0032	9	100	2.16	2000	3.25
MS00-0033	17	63	3.08	1260	5.03
MS00-0034	22	83	4.10	1660	7.29
MS00-0035	23	54	4.06	1080	7.73
MS01-0026	22	73	3.54	1460	7.31
MS01-0027	30	98	4.32	1960	7.74
MS01-0028	30	157	3.76	3140	2.67

Station	Taxa Richness (#/grab)	Total Abundance (#/grab)	Shannon-Wiener H' ($\log_2$)	Density (#/m^2)	Benthic Index
MS01-0029	15	64	2.64	1280	6.55
MS01-0030	19	46	3.38	920	2.15
MS01-0031	20	120	3.40	2400	6.76
MS01-0032	25	86	4.20	1720	7.54
MS01-0033	31	151	3.78	3020	2.00
MS01-0034	24	83	4.15	1660	7.65
MS01-0035	9	12	3.08	240	2.04
MS01-0036	27	67	4.32	1340	7.91
MS01-0037	28	94	3.95	1880	7.05
MS01-0038	32	133	3.20	2660	-0.81
MS01-0039	35	116	4.24	2320	8.67
MS01-0040	65	332	5.12	6640	2.99
MS01-0041	8	22	2.70	440	7.83
MS01-0042	19	65	3.65	1300	7.33
MS01-0043	31	170	4.36	3400	8.16
MS01-0044	29	196	3.68	3920	5.91
MS01-0045	52	400	4.20	8000	-1.62
MS01-0046	36	164	4.23	3280	8.15
MS01-0047	20	81	3.35	1620	6.61
MS01-0048	9	31	1.95	620	5.05
MS01-0049	27	133	3.57	2660	7.22
MS02-0018	20	87	3.50	1740	6.83
MS02-0019	25	164	3.05	3280	4.89
MS02-0021	29	113	3.83	2260	7.29
MS02-0022	19	108	3.53	2160	6.31
MS02-0023	31	97	4.16	1940	7.13
MS02-0024	23	198	3.12	3960	5.05
MS02-0027	21	192	2.30	3840	3.23
MS02-0031	17	117	3.17	2340	6.53
MS02-0032	35	121	4.12	2420	7.19
MS02-0033	17	332	1.98	6640	2.48
MS02-0035	33	215	3.66	4300	-0.75
MS02-0036	18	67	3.30	1340	3.28
MS02-0037	17	147	2.82	2940	4.31
MS02-0038	68	394	5.08	7880	8.24
MS02-0039	23	260	1.83	5200	2.72
MS02-0040	13	188	2.18	3760	3.58
MS02-0041	18	369	2.23	7380	4.66

Station	Taxa Richness (#/grab)	Total Abundance (#/grab)	Shannon-Wiener H' ($\log_2$)	Density (#/m^2)	Benthic Index
MS02-0042	32	620	2.57	12400	-0.38
MS02-0043	18	60	3.52	1200	8.29
MS02-0044	21	197	2.96	3940	5.22
MS02-0045	14	126	1.60	2520	7.18
MS02-0046	22	125	3.07	2500	5.60
MS02-0048	11	49	2.54	980	4.56
MS03-0010	11	132	1.40	2640	1.57
MS03-0016	11	14	3.38	280	8.13
MS03-0018	14	58	3.45	1160	7.20
MS03-0019	31	263	3.05	5260	0.83
MS03-0023	24	126	3.57	2520	-0.36
MS03-0024	25	117	3.86	2340	7.26
MS03-0028	16	27	3.75	540	7.75
MS03-0029	16	122	2.84	2440	5.65
MS03-0031	34	96	4.54	1920	7.92
MS03-0033	25	92	3.81	1840	7.26
MS03-0034	34	291	2.79	5820	4.30
MS03-0035	41	206	4.34	4120	8.04
MS03-0036	8	20	2.32	400	5.34
MS03-0037	14	59	2.77	1180	4.49
MS03-0038	28	57	4.45	1140	8.55
MS03-0039	22	170	3.60	3400	6.56
MS03-0040	14	64	2.65	1280	4.97
MS03-0041	35	210	3.99	4200	7.29
MS03-0042	21	87	3.88	1740	7.89
MS03-0043	11	20	3.28	400	2.54
MS03-0044	7	15	2.52	300	5.61
MS03-0045	32	204	3.97	4080	7.22
MS03-0046	26	178	3.66	3560	7.80
MS03-0048	10	61	2.37	1220	-1.60
MS04-0016	25	122	3.47	2440	6.03
MS04-0017	40	415	3.32	8300	-3.98
MS04-0018	14	110	2.05	2200	4.81
MS04-0020	21	94	3.82	1880	6.77
MS04-0021	26	133	3.77	2660	6.36
MS04-0022	19	114	3.29	2280	6.48
MS04-0027	28	177	3.83	3540	6.50
MS04-0029	29	153	3.41	3060	5.70

Station	Taxa Richness (#/grab)	Total Abundance (#/grab)	Shannon-Wiener H' ($\log_2$)	Density (#/m^2)	Benthic Index
MS04-0030	14	33	3.22	660	6.93
MS04-0032	23	120	3.85	2400	6.98
MS04-0033	67	589	3.70	11780	-3.61
MS04-0034	13	44	3.06	880	6.05
MS04-0036	27	159	4.01	3180	2.79
MS04-0037	23	136	3.66	2720	6.55
MS04-0038	13	33	3.33	660	6.55
MS04-0039	13	30	3.30	600	6.94
MS04-0040	51	749	3.58	14980	-1.31
MS04-0041	14	58	3.10	1160	5.85
MS04-0042	34	353	3.12	7060	6.00
MS04-0043	15	58	2.92	1160	6.36
MS04-0044	56	955	3.75	19100	5.77
MS04-0046	23	290	3.47	5800	2.73
MS04-0047	46	501	3.79	10020	6.28
MS04-0048	17	112	1.92	2240	2.58
Mississippi Sound - post-Katrina (n = 30)					
KAT-0001	15	64	3.17	1600	5.02
KAT-0002	8	22	2.57	550	6.43
KAT-0003	9	45	2.31	1125	4.53
KAT-0004	21	97	3.14	2425	5.32
KAT-0005	8	46	1.91	1150	3.94
KAT-0006	27	110	3.58	2750	6.09
KAT-0007	9	18	2.63	450	5.17
KAT-0008	7	16	1.92	400	5.43
KAT-0009	12	159	2.06	3975	2.48
KAT-0010	6	90	0.67	2250	6.35
KAT-0011	11	37	2.54	925	5.87
KAT-0012	13	66	2.93	1650	5.05
KAT-0013	6	15	1.69	375	5.49
KAT-0014	28	63	4.44	1575	7.08
KAT-0015	11	26	2.79	650	6.55
KAT-0016	5	15	1.93	375	3.77
KAT-0017	19	126	2.58	3150	4.78
KAT-0018	7	25	2.07	625	5.11
KAT-0019	6	48	1.96	1200	2.54
KAT-0020	17	60	3.50	1500	6.20
KAT-0021	9	22	2.80	550	7.47

Station	Taxa Richness (#/grab)	Total Abundance (#/grab)	Shannon-Wiener H' ($\log_2$)	Density (#/m^2)	Benthic Index
KAT-0022	21	101	3.52	2525	4.27
KAT-0023	3	10	1.30	250	4.33
KAT-0024	13	40	3.06	1000	5.87
KAT-0025	20	64	3.84	1600	6.29
KAT-0026	7	52	2.12	1300	3.48
KAT-0027	18	45	3.55	1125	8.47
KAT-0028	18	81	3.56	2025	6.36
KAT-0029	17	94	3.69	2350	8.91
KAT-0030	9	37	2.30	925	6.03

Appendix 3-2: Appendix 3-2: Summary of benthic variables by station in Lake Pontchartrain before (n=47) and after (n=30) Hurricane Katrina.

Station	Taxa Richness (#/grab)	Total Abundance (#/grab)	Shannon-Wiener H' (log_2)	Density (#/m^2)	Benthic Index
Lake Pontchartrain - pre-Katrina (n = 47)					
LA00-0023	7	15	2.42	375	4.36
LA00-0024	13	104	2.85	2600	4.74
LA00-0025	8	41	2.35	1025	5.69
LA00-0030	4	6	1.79	150	5.87
LA00-0031	16	61	3.37	1525	8.04
LA00-0032	14	140	2.08	3500	3.03
LA01-0013	5	15	1.77	375	4.10
LA01-0014	11	39	2.83	975	7.03
LA01-0015	2	11	0.44	275	-0.79
LA01-0016	10	24	3.12	600	6.27
LA01-0017	4	11	1.28	275	2.56
LA01-0041	6	10	2.45	250	6.48
LA01-0047	5	10	2.17	250	5.71
LA01-0048	9	23	2.63	575	7.34
LA02-0001	4	6	1.92	150	8.10
LA02-0002	2	2	1.00	50	3.20
LA02-0003	10	24	2.94	600	8.16
LA02-0004	1	1	0.00	25	1.82
LA02-0005	2	2	1.00	50	3.26
LA02-0006	1	1	0.00	25	-1.22
LA02-0007	8	35	2.43	875	7.12
LA02-0009	3	11	1.10	275	4.49
LA02-0011	0	0	0.00	0	1.82
LA02-0012	7	115	1.94	2875	4.22
LA03-0001	4	39	1.00	975	1.67
LA03-0006	5	28	1.59	700	3.48
LA03-0008	0	0		0	1.82
LA03-0011	12	279	2.08	6975	4.86
LA03-0012	3	25	1.27	625	2.87
LA03-0013	1	3	0.00	75	-1.22
LA03-0017	1	11	0.00	275	-1.22
LA03-0019	3	6	1.46	150	4.39

Station	Taxa Richness (#/grab)	Total Abundance (#/grab)	Shannon-Wiener H’ (log_2)	Density (#/m^2)	Benthic Index
LA03-0020	2	6	0.65	150	1.51
LA03-0022	2	21	0.45	525	-0.11
LA03-0023	3	44	0.31	1100	0.13
LA03-0024	8	37	2.10	925	6.67
LA03-STR03-01	1	4	0.00	100	-1.22
LA04-0001	4	12	1.73	300	-1.56
LA04-0002	7	50	1.93	1250	-1.24
LA04-0003	17	802	2.18	20050	1.97
LA04-0005	1	3	0.00	75	-1.22
LA04-0006	11	57	2.43	1425	1.26
LA04-0007	2	35	0.42	875	0.63
LA04-0011	8	206	2.05	5150	6.48
LA04-0012	3	6	1.25	150	1.85
LA04-0013	15	246	2.97	6150	4.40
Lake Pontchartrain post-Katrina (=29)					
LP-0001	1	1	0.00	25	-3.01
LP-0002	2	2	1.00	50	3.18
LP-0003	1	1	0.00	25	-3.01
LP-0004	3	27	1.12	675	2.23
LP-0005	4	6	1.79	150	4.43
LP-0006	2	4	0.81	100	3.31
LP-0008	0	0		0	1.82
LP-0009	3	3	1.58	75	5.53
LP-0010	2	2	1.00	50	4.19
LP-0011	2	2	1.00	50	3.18
LP-0012	1	3	0.00	75	1.82
LP-0013	1	2	0.00	50	1.82
LP-0014	4	11	1.28	275	4.90
LP-0015	10	16	3.02	400	6.96
LP-0017	3	3	1.58	75	4.47
LP-0018	4	10	2.17	250	1.82
LP-0019	0	0		0	1.82
LP-0020	3	3	1.58	75	5.62
LP-0021	3	8	1.56	200	4.29
LP-0022	2	5	0.72	125	1.80

Station	Taxa Richness (#/grab)	Total Abundance (#/grab)	Shannon-Wiener H’ ($\log_2$)	Density (#/m^2)	Benthic Index
LP-0023	9	37	2.30	925	7.36
LP-0024	2	2	1.00	50	4.24
LP-0025	2	3	0.92	75	2.92
LP-0026	2	2	1.00	50	3.24
LP-0027	2	11	0.44	275	2.59
LP-0028	6	20	2.32	500	6.77
LP-0029	3	4	1.50	100	4.58
LP-0030	2	8	0.95	200	2.82
LPALT-0058	4	7	1.84	175	6.25

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