Preliminary Results of Recently Observed Hypoxia Development in the Chandeleur Sound and Breton Sound of Southeastern Louisiana, East of the Mississippi River Delta

A Technical Report

July 2013

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Introduction

The Lake Pontchartrain Basin Foundation (LPBF) performs basin-wide water quality assessments throughout the Pontchartrain Basin, and has done so extensively for a number of years. More recently, LPBF's Coastal Sustainability Program has monitored water quality in, and around, Chandeleur Sound to locate areas of low dissolved oxygen concentrations, or hypoxia. Since 2008, monitoring in the Chandeleur Sound area of southeastern Louisiana has revealed the development of seasonal bottom hypoxia. The Chandeleur Sound is the shallow-water (up to 6 meters or 20 feet deep) area located between the Chandeleur Islands and the Biloxi Marsh, north of the Mississippi River delta and south of the barrier islands (Cat Island and Ship Island) along the Mississippi Coast. The Chandeleur Sound extends southward behind remnants of the Curlew and Gossier barrier islands and connect to Breton Sound to the south. Breton and Chandeleur Sounds are separated by the Mississippi River Gulf Outlet (MRGO) conveyance. The seafloor at the north end of Chandeleur Sound forms a broad trough which slopes seaward toward the Gulf of Mexico and narrows westward to the Cat Island Channel, south of Cat Island, Mississippi.

LPBF monitored water quality in the Chandeleur Sound in 2008, 2010, 2011 in partnership with the Marine Research Assistance Council (MRAC) and in conjunction with the Louisiana Universities Marine Consortium (LUMCON) in 2012. During the June 2013 sampling, LPBF used a CTD, an oceanographic instrument borrowed from the University of Southern Mississippi (USM), as another method of capturing water quality data. The cumulative observations to date provide evidence that suggests the seasonal development of bottom hypoxia on a yearly basis. During the June 2013 monitoring, the survey area was expanded into Breton Sound in an attempt to capture the boundaries and overall extent of the regionally developing hypoxia in order to better understand the dynamics of the initiation, transport, and fate of the hypoxic regions. LPBF will continue seasonal monitoring in 2014. Reports outlining the results of 2008, 2010, 2011, and 2012 monitoring can be found at http://www.saveourlake.org/PDF-documents/our-coast/Chandeleur-2012-Hypoxia-Final.pdf. This report summarizes the preliminary data analyses on the 2013 water quality observations collected by LPBF.

Hypoxia

Hypoxia is an environmental phenomenon where dissolved oxygen concentrations in the water column fall below the minimum threshold necessary to induce respiratory distress among aquatic organisms in the system (Rabalais et al., 2002; Rabalais et al., 2010). In the northern Gulf of Mexico, hypoxia is defined as a concentration of dissolved oxygen below 2 mg/L (Rabalais et al., 2010; EPA, 2012). Hypoxic waters, often termed "dead zones" are most prevalent in the coastal waters of the United States from late spring through late summer and are becoming more frequent, widespread, and persistent (CENR, 2010; Rabalais et al., 2010).

The development of hypoxia (**Figure 1**) may be a result of a number of factors, both natural and anthropogenic , but is mainly driven by excess nutrients to a system (eutrophication – see below), and stratification of the water column due to salinity and temperature gradients and lack of mixing (EPA, 2012; LUMCON, 2012). Freshwater discharge from rivers introduces nutrient-rich water into an ecosystem. Phytoplankton, like algae and other larval species, feed on these nutrients which increase their size and biomass, causing them to sink deeper into the water column (Bricker et al., 1999). Further transport of nutrient-rich matter occurs throughout the water column when zooplankton eat algae and other types of phytoplankton. As the phytoplankton are consumed, zooplankton excrete fecal pellets which sink to the seafloor where decomposition by bacteria breaks down the nutrient-rich fecal pellets through bacterial respiration. This process consumes most of the life-giving oxygen supply in the bottom waters, resulting in organism stress and mortality (Howarth et al., 2011).

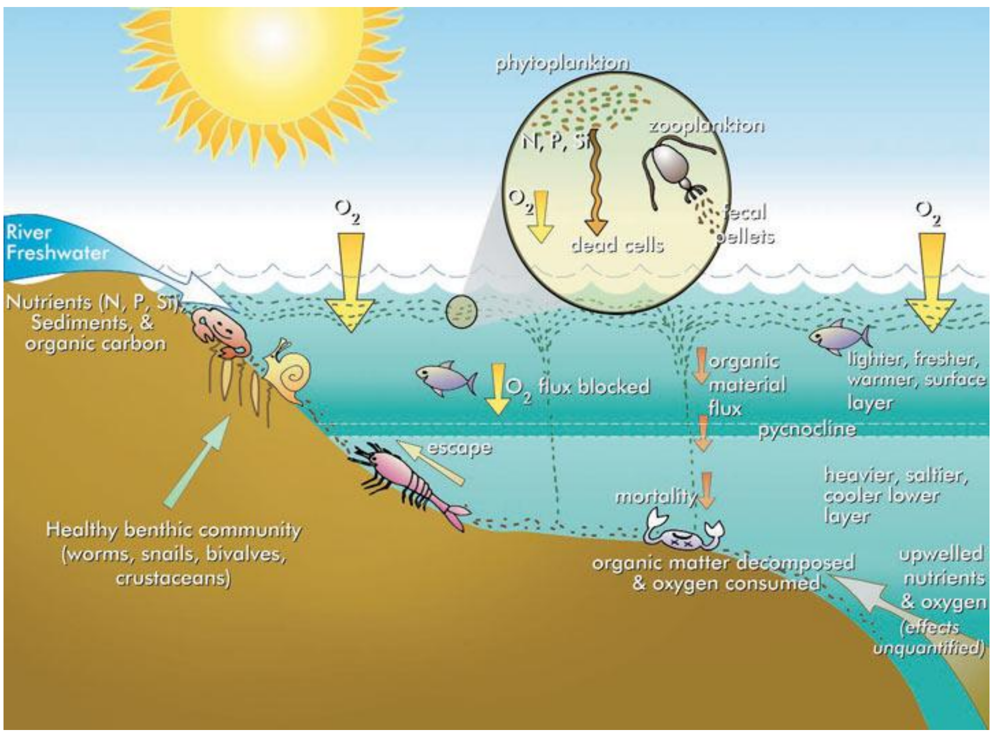

Figure 1. Schematic showing how hypoxia can develop at depth in the water column. Source: http://water.epa.gov/type/watersheds/named/msbasin/hypoxia101.cfm

The increased turbidity in Gulf of Mexico coastal waters from the sediment laden Mississippi River discharge limits phytoplankton production in bottom waters because light cannot penetrate past a certain depth of the water column. As phytoplankton sink below the euphotic zone, or 1 % light level, there is not enough energy for phytoplankton to produce oxygen through photosynthesis in the bottom waters and therefore undergo cellular respiration, a process that consumes oxygen (Bricker et al., 1999; Anderson et al., 2002; Howarth et al., 2011).

In addition to an increased nutrient supply delivered to the system, stratification of the water column is essential to the development of hypoxia. Freshwater discharge contains fresh (zero salinity) water which is less dense than the saline and cold bottom water of the ocean. As river discharge brings warmer, freshwater to a coastal environment, the freshwater floats on top of the more dense (higher salinity, lower temperature) oceanic water. As a result of this process, a pycnocline (a layer where the density gradient is greatest) develops which prevents mixing, especially in the absence of strong winds or currents. The development of this pycnocline prevents vertical mixing of oxygen-rich surface water with oxygen-depleted bottom water of the Gulf of Mexico (EPA, 2012).

Evidence suggests that as a result of seasonal stratification of the water column in the absence of strong winds or currents, oxygen consumption rates in the bottom water exceed the rate of resupply of oxygen from both primary production and diffusion of oxygen from the atmosphere into the lower reaches of the water column, resulting in hypoxia (Howarth et al., 2011). The most efficient mechanism for replenishing bottom waters with oxygen is mixing by wind. The strongest wind forces occur in the fall and winter seasons from regional cold fronts and hurricanes (LUMCON, 2012). As discussed later, this mechanism and/or others, may explain the development of hypoxia documented along this portion of the coast.

Eutrophication

Eutrophication is an increase in the rate of supply of organic matter and chemical nutrients (primarily nitrogen and phosphorus) to an ecosystem, so extreme that the supply of nutrients drives an increase in primary productivity in the ecosystem. In recent years, eutrophication has been accelerated by human, or anthropogenic, activities through the introduction of sewage effluence and agricultural run-off carrying fertilizers into an aquatic system (Jorgensen and Richardson, 1996; Bricker et al., 1999).

Summary of 2008, 2010, 2011, and 2012 Results

In 2008, two marine surveys fortuitously documented the occurrence of a low dissolved oxygen layer in Chandeleur Sound. In June 2008, USM was conducting shark research and collected environmental data and water quality data in the Chandeleur Sound. Later that month, the Nekton Research Laboratory at the University of New Orleans (UNO) was en route to do research around the Chandeleur Islands and collected water quality data while crossing the Chandeleur Sound. These two data sets were provided to LPBF and are shown on **Figure 2.**

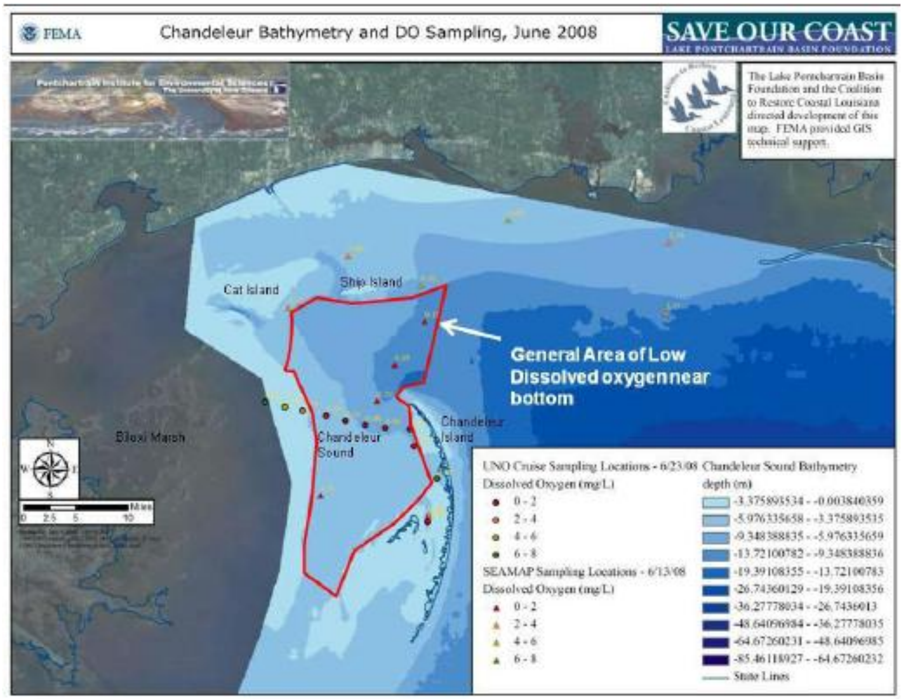

Figure 2. Map of the Chandeleur Sound area and the approximate location of low dissolved oxygen observed in 2008 by USM and UNO.

In July 2010, LPBF, in partnership with MRAC, developed a water quality monitoring protocol for the Chandeleur Sound which was surveyed to ascertain if the low dissolved oxygen detected in 2008 was an anomaly for that year or if it was a reoccurring phenomenon. Briefly, two transects were selected which crossed the deepest axial through portions of the Chandeleur Sound. One transect ran through the Cat Island Channel to the deep hole near the northern end of Chandeleur Sound. A YSI Pro-2030 meter with a 90 foot cable was used to measure salinity, temperature, and dissolved oxygen concentrations. The YSI cable was marked at two-foot intervals. First, the total depth was determined using two on-board acoustic depth finders. Next the probe on the instrument was lowered to take measurements at three depths; two feet beneath the surface, at mid-depth, and one foot from the seafloor. Hypoxia was detected again in the Chandeleur Sound area as indicated in **Figure 3**.

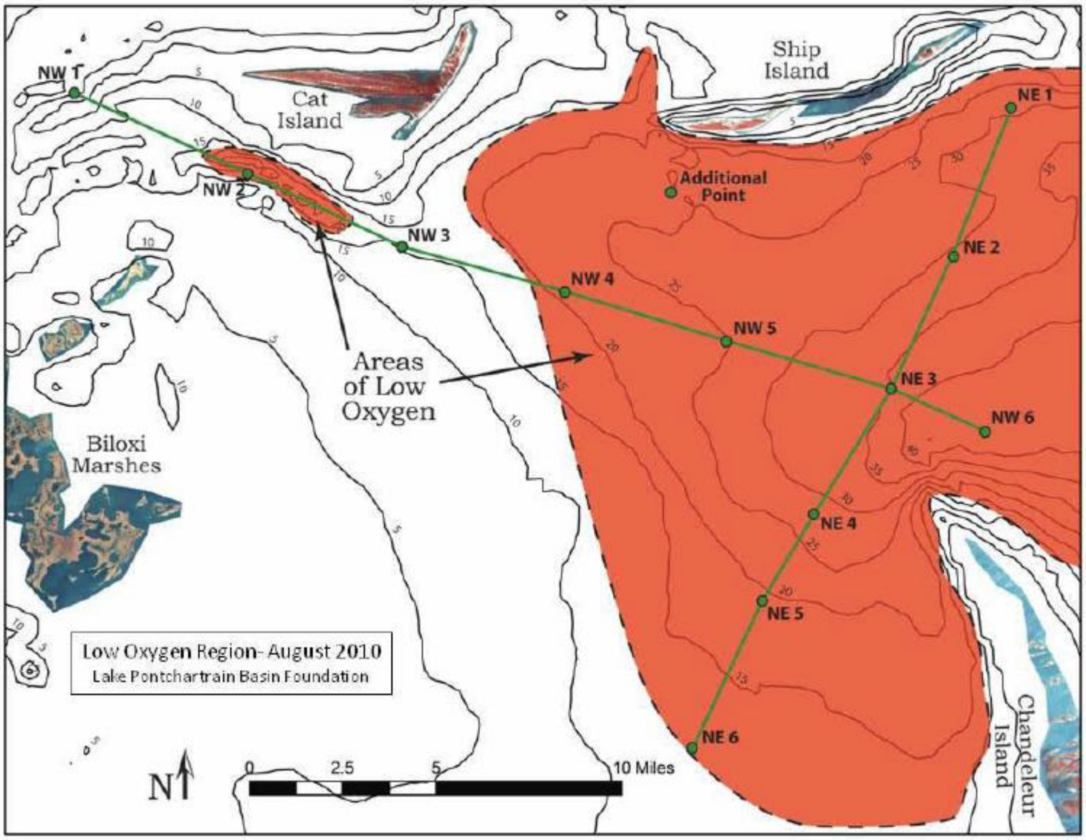

Figure 3. Map of Chandeleur Sound with the area of observed hypoxia in August 2010

In July 2011, a joint effort between LPBF and MRAC measured and collected water quality data and observations using the same transect (**Figure 4, circle**), sampling protocol, and sampling frequency plan developed in 2010. Data at a total of 15 stations were acquired in July 2011. Additional data was collected by LUMCON which measured water quality off the coast of Mississippi during the same time period in July 2011. LUMCON surveyed an area in the Gulf of Mexico starting 8 miles off the coast of Mississippi to 24 miles into the Gulf (**Figure 4, triangles**). The survey was conducted in deeper waters on the continental shelf to measure dissolved oxygen concentrations and other water quality parameters. The specific data collected by LUMCON is not included in this report but the extent of the hypoxia that was detected by LUMCON was combined with the hypoxia detected by LPBF-MRAC to gain a total picture on the extent of hypoxia off of the coast of southeastern Louisiana and coastal Mississippi.

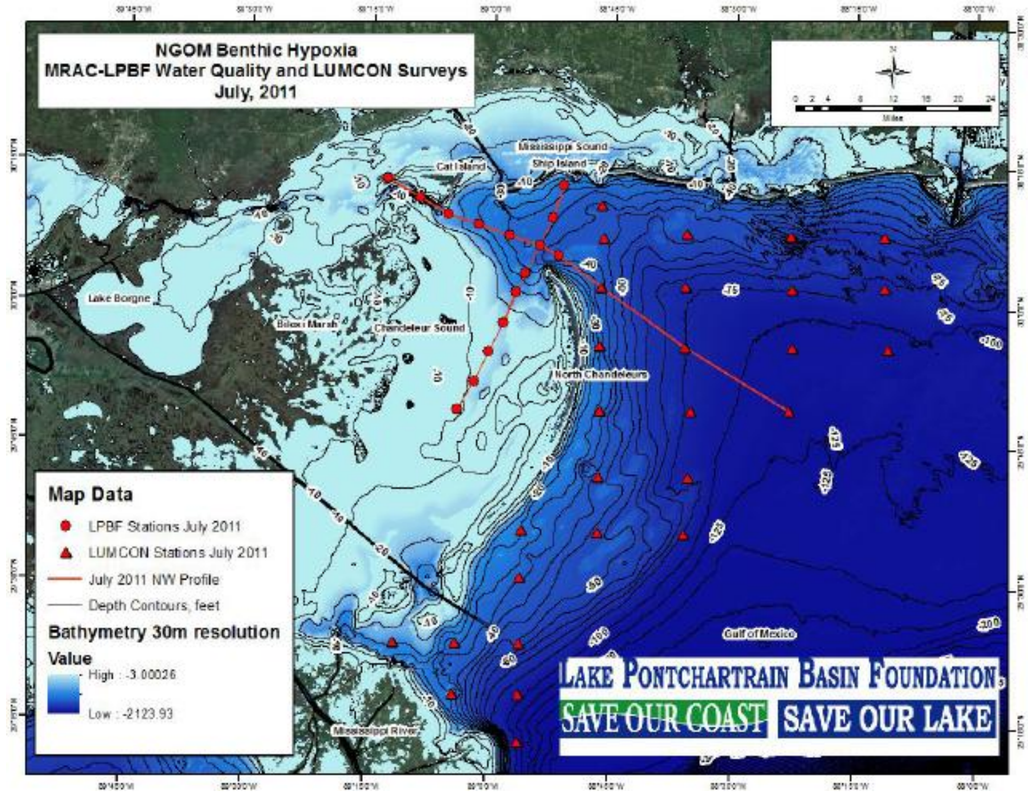

Figure 4. Map of LPBF-MRAC and LUMCON sampling locations in the Chandeleur Sound and Mississippi Bight of the Gulf of Mexico.

As a result of the July 2011 water quality sampling, a large area of bottom water hypoxia was detected in the vicinity of the Chandeleur Islands, extending into the Gulf of Mexico (**Figure 5**). The area of the detected hypoxia was approximately 1,050 square miles. However, the hypoxic zone was most likely larger as a data collection did not extend past the Mississippi/Alabama border. A total of 43 points were surveyed between LPBF-MRAC and LUMCON sampling efforts (**Figure 4**). Of these 43 points, hypoxia was measured in the bottom water as 25 sites, over half of the points surveyed.

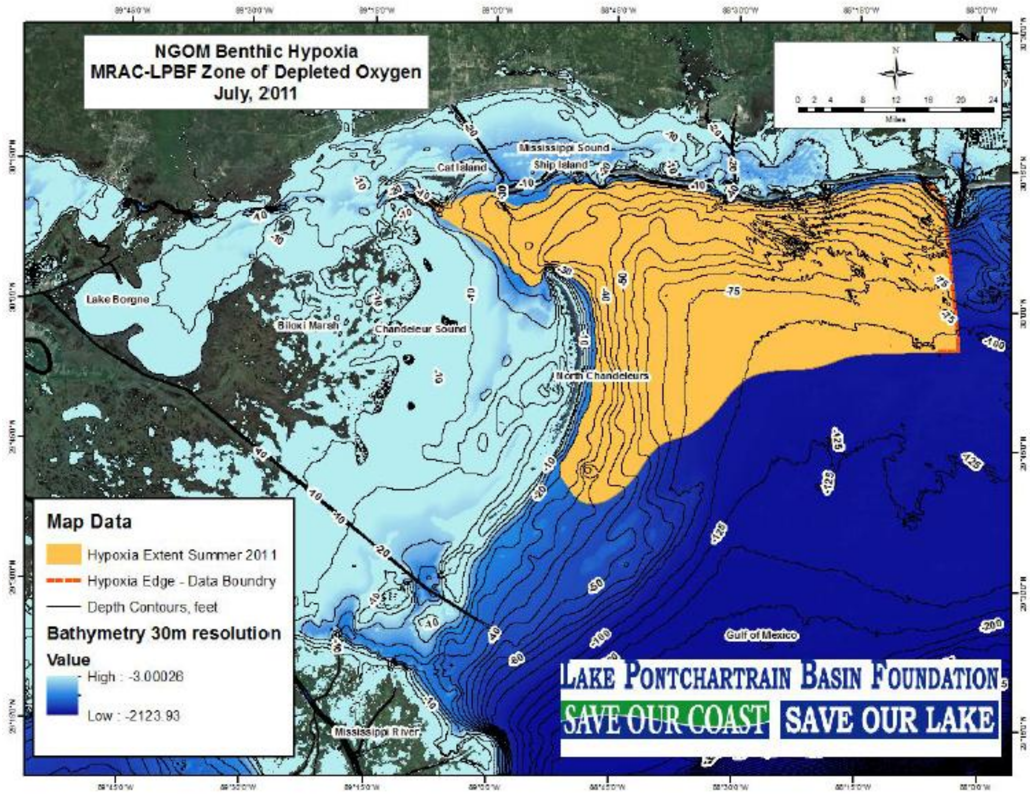

Figure 5. Map showing the area of hypoxia detected in LPBF-MRAC and LUMCON survey in July of 2011. The area of hypoxia most likely extends further east but the survey was terminated at the Mississippi/Alabama border.

In July 2012, LPBF measured and collected water quality data and observations using the same transects (**Figure 4, circles**), sampling protocol, and sampling frequency plan developed in 2010. The two transects named NW## (yellow pushpins) and NE## (green pushpins) were sampled, as well as, five new alternative stations (ALT##; red pushpins) were also sampled to better capture the extent of hypoxia west of the Chandeleur Islands (**Figure 6**). A hypoxic zone at depth was detected in July 2012 in the Chandeleur Sound and Mississippi Bight, at the intersection of the NW and NE transects (**Figure 6**). The area detected was approximately 70 square miles. Similar to results from previous years, the hypoxic zone was most likely larger, however, data collection for 2012 did not expand past the Chandeleur Sound and Ship Island/Horn Island Pass. A total of 18 stations were sampled by LPBF, of which five of these stations bottom hypoxia.

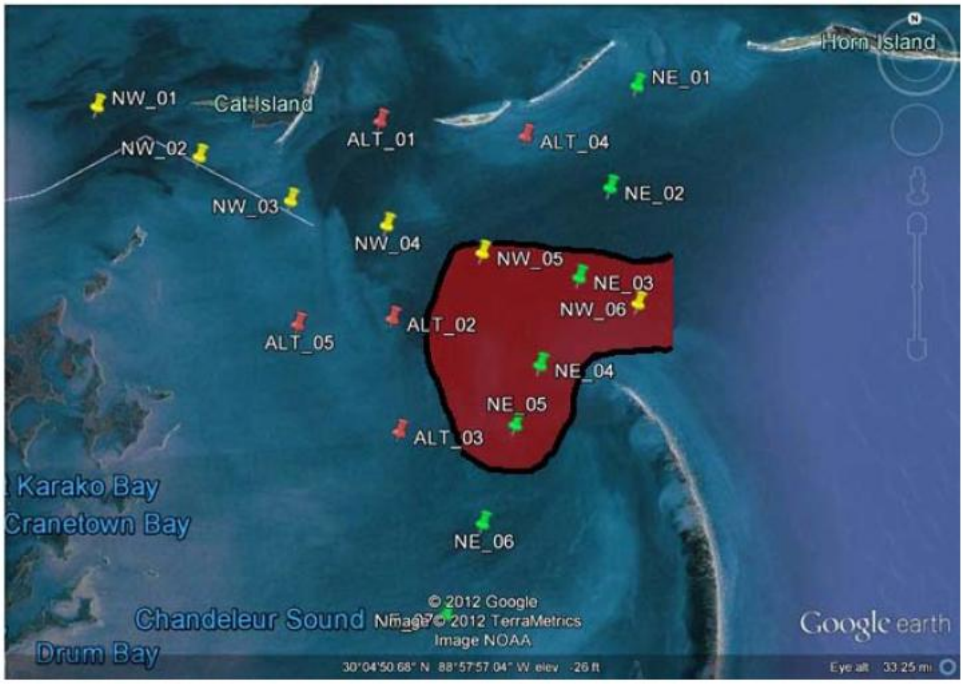

Figure 6. Map showing the sampling stations for LPBF surveys in July 2012. Low oxygen concentrations were measured at five stations, while the red area indicates the estimated extent of hypoxia as a result of the sampling. The eastern extent of hypoxia is unknown.

Figures 7, 8, and 9 illustrate the depth-dependent segregation of dissolved oxygen, salinity, and temperature data, which demonstrates the development of a pronounced boundary, or pycnocline, between lower salinity, oxygen-rich waters above, and higher salinity, oxygen-depleted waters below.

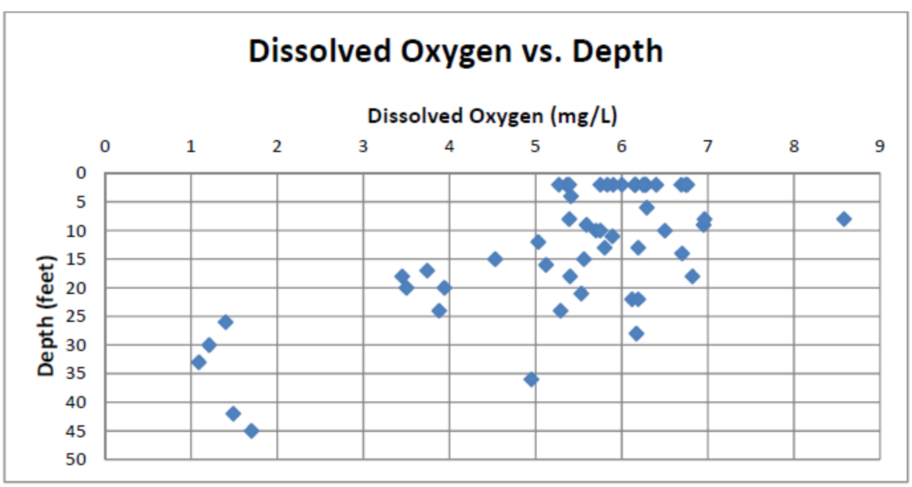

Figure 7. Graph showing dissolved oxygen with depth from data gathered in July 2012. Notice a decline of dissolved oxygen with depth.

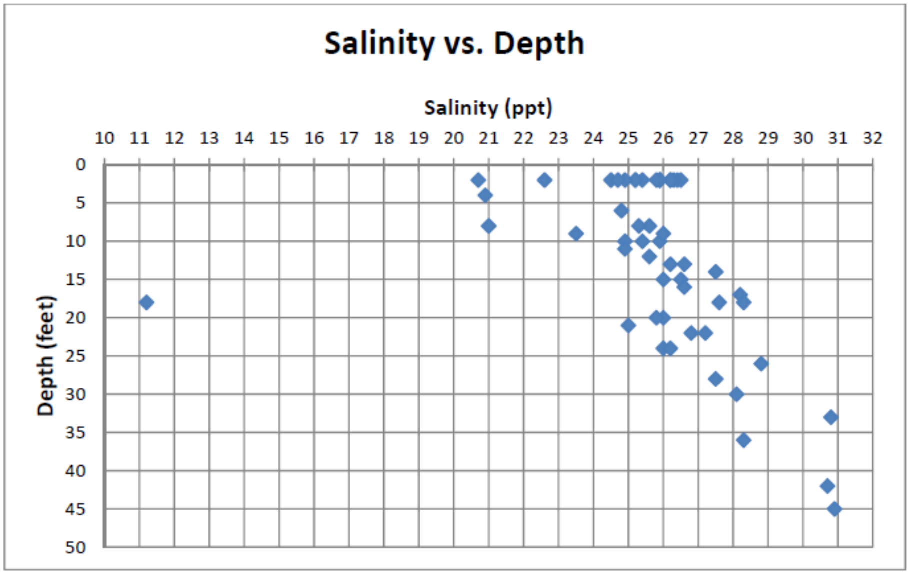

Figure 8. Graph showing changes in salinity with depth from data gathered in July 2012. Notice the increase in salinity with depth. The anomaly, or outlier, at 11 ppt and 18 feet deep was measured three separate times with two different instruments, therefore confirming the accuracy of this data point. This measurement was taken one foot from the seafloor at station NW-02.

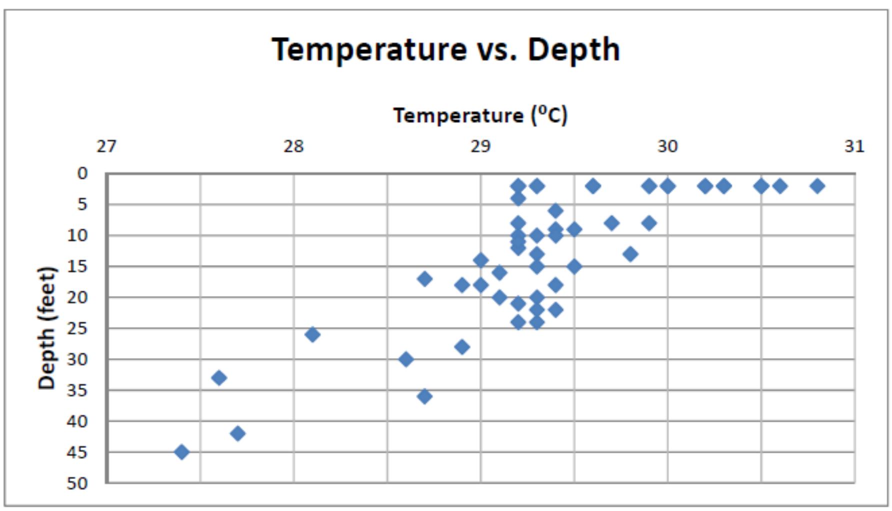

Figure 9. Graph showing change in water temperature with depth from data collected in July 2012. Notice temperatures decrease with depth, as expected.

In July 2012, hypoxia developed in waters deeper than 24 feet. The hypoxia continued into deep water but always developed near the bottom with the hypoxia boundary (pycnocline) growing deeper with increasing water depth. **Figures 10 and 11** show the depth profile and the depth of the pycnocline for data collected by LPBF along the two transects, NW and NE, shown in **Figure 6** as yellow and green, respectively.

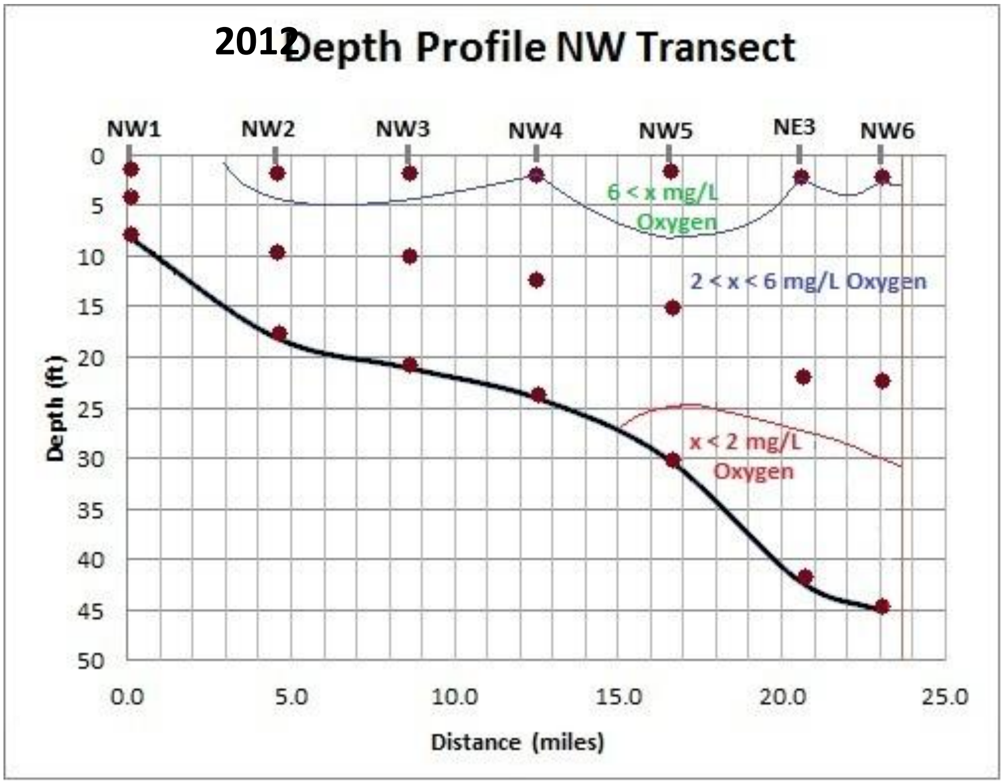

Figure 10. Depth profile from July 2012 data taken along the transect running from the northwest near Cat Island to the southeast crossing just north of the Chandeleur Islands.

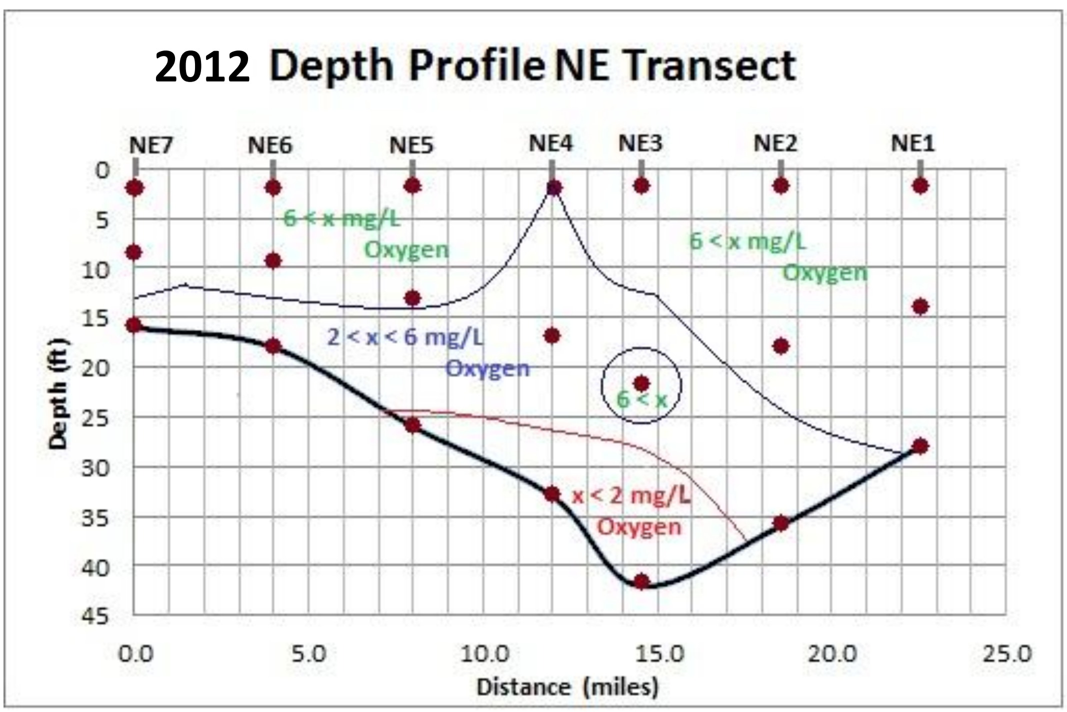

Figure 11. Depth profile from July 2012 taken along the transect running from the southwest in the Chandeleur Sound to the northeast near Ship Island.

2013 Methods

In May 2013, LPBF measured and collected water quality data and observations using the same transects as in previous years (**Figure 4, circle**), sampling protocols, and sampling frequency plan developed in 2010, with one slight change – if hypoxia was detected, sampling was continued until the furthest extent or boundary was captured. The survey area was expanded further out into the Mississippi Bight in order to try and detect the western boundary of the reoccurring seasonal hypoxia in the Mississippi Bight, as seen in 2011. **Figure 12** contains a map of the May 8th, 2013 sampling stations. Measured dissolved oxygen concentrations in May were above the level considered hypoxic. The data suggests stratification was present during this sampling period, and oxygen levels were decreasing substantially with depth

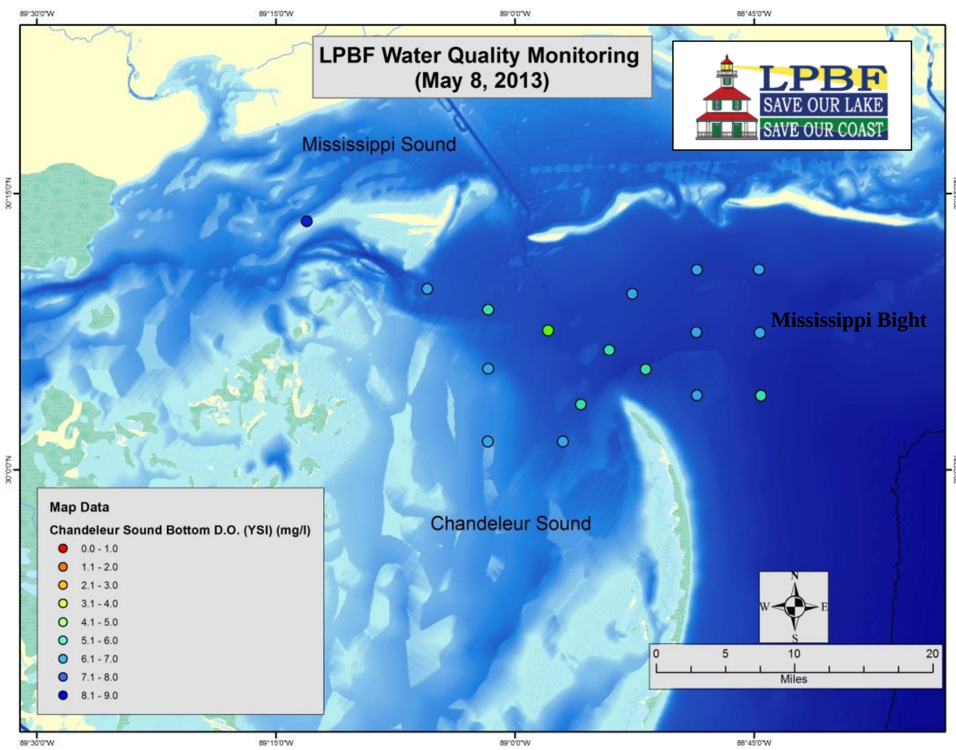

Figure 12. Map of LPBF sampling locations in the Chandeleur Sound, Mississippi Sound, and Mississippi Bight of the Gulf of Mexico on May 8, 2013.

Having observed hypoxia throughout the region during summer months in previous studies, LPBF conducted another survey of Chandeleur Sound and surrounding areas to locate and measure the presence and extent of hypoxia. A basin-wide estuary research cruise of the Pontchartrain Basin conducted a survey of the basin for water quality parameters, in addition to nekton, benthic invertebrates, and submerged aquatic vegetation (SAV), between June 3 and June 21, 2013. As an ancillary task to this research project, water quality sampling to detect hypoxia was conducted at each station. The nekton, benthic invertebrates, and SAV data collected during this study will not be included in this report.

In addition to historical water quality sampling protocol where a handheld YSI probe was used, LPBF acquired a piece of oceanographic instrumentation, called a CTD, from Dr. Stephan Howden from USM's Department of Marine Science (**Figure 13**), to use during this investigation. A CTD is an instrument that measures conductivity, temperature, and depth continuously as it is lowered through the water column. The instrument was equipped with SeaBird 49 FastCAT CTD, a SeaBird 23 Dissolved Oxygen sensor and flourometer (which measures fluorescence or chlorophyll concentration). Flourometer results will not be discussed in this report. The CTD package weighs close to 50 pounds and was deployed manually (**Figure 14**).

Figure 13 . Photos of the USM CTD package with sensors.

Figure 14 . Photo of Andreas Moshogianis and Dr. John Lopez as they prepare to deploy the CTD.

During LPBF's basin-wide water quality surveys spanning from June 3 to June 21, 2013, vertical profiles were taken to measure water temperature, salinity, and dissolved oxygen concentrations throughout the water column. In order to cover more area, LPBF implemented the use of both the YSI-handheld, and the ship-based deploying CTD. **Figure 15** is a map summarizing the use of both methods of sampling, throughout the Pontchartrain Basin from June 3 to June 21, 2013, spanning from the freshest, western-most body of water, Lake Maurepas, through Lake Pontchartrain, Lake Catherine, Lake Borgne, Biloxi Marsh, and into Chandeleur Sound furthest to the east. In addition, the western part of the Mississippi Sound was included in this survey. As a result of data collected in Chandeleur Sound, as described below, the survey also extended into Breton Sound.

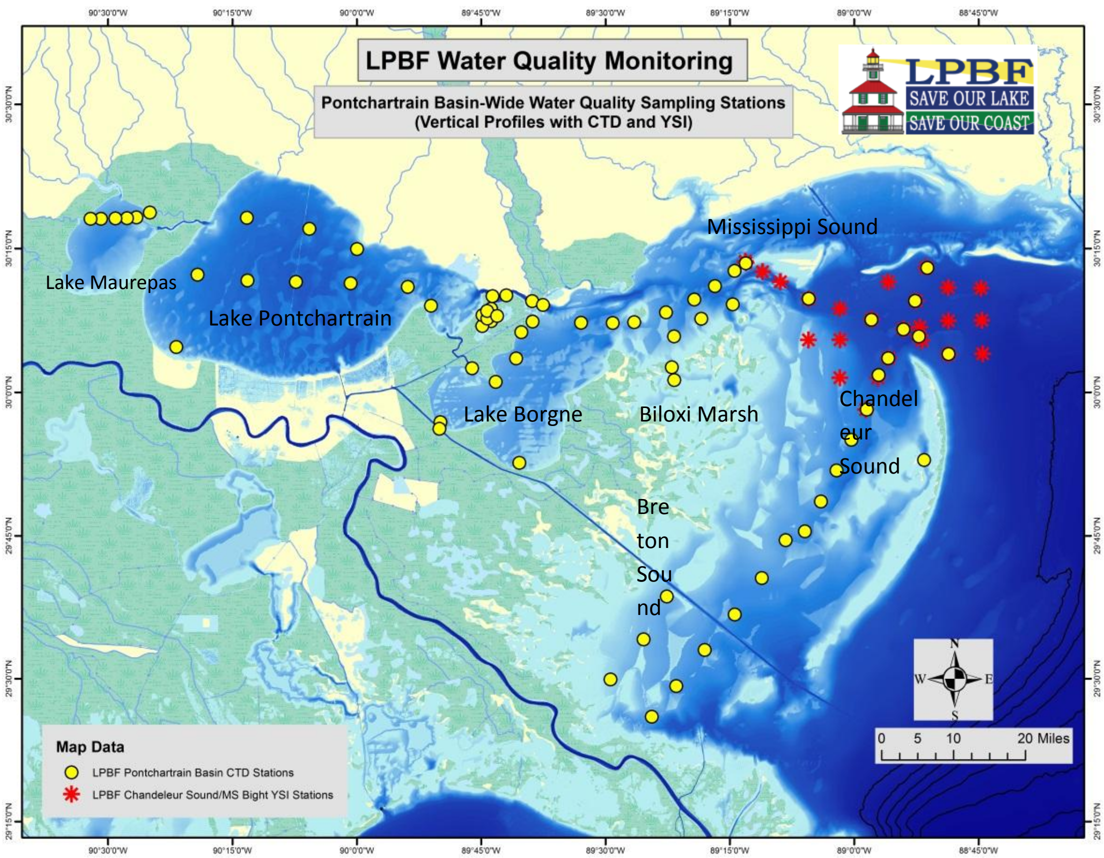

Figure 15. A map of the Pontchartrain Basin, indicating where vertical profiles of the water column were taken, using two different methods, a YSI (red) and the CTD (yellow).

Results

In June 2013, there was evidence of hypoxia in bottom waters in and around the Chandeleur Sound. A hypoxic zone was discovered in the north Chandeleur Sound, extending as far west as the Biloxi Marsh, just south of the Mississippi Sound, and stretched as far south as the southern end of the Chandeleur Sound. The hypoxia was detected due west of the intersection of the NW and NE transects (**Figure 16**) but did not extend eastward. A second, and separate hypoxic zone was discovered further south, encompassing a majority of the Breton Sound area. A total of 98 stations were sampled by LPBF, of which 26 of these demonstrated oxygen concentrations less than 2 mg/L, considered hypoxic. Of the 52 stations sampled in the Biloxi Marsh area, Mississippi Sound, Chandeleur Sound, and Breton Sound, 26 of these, or half, demonstrated hypoxic conditions (**Figures 16 and 17**). In addition, the data suggests that the hypoxia was still in the development phase. This will be addressed in more detail in the discussion section of this report.

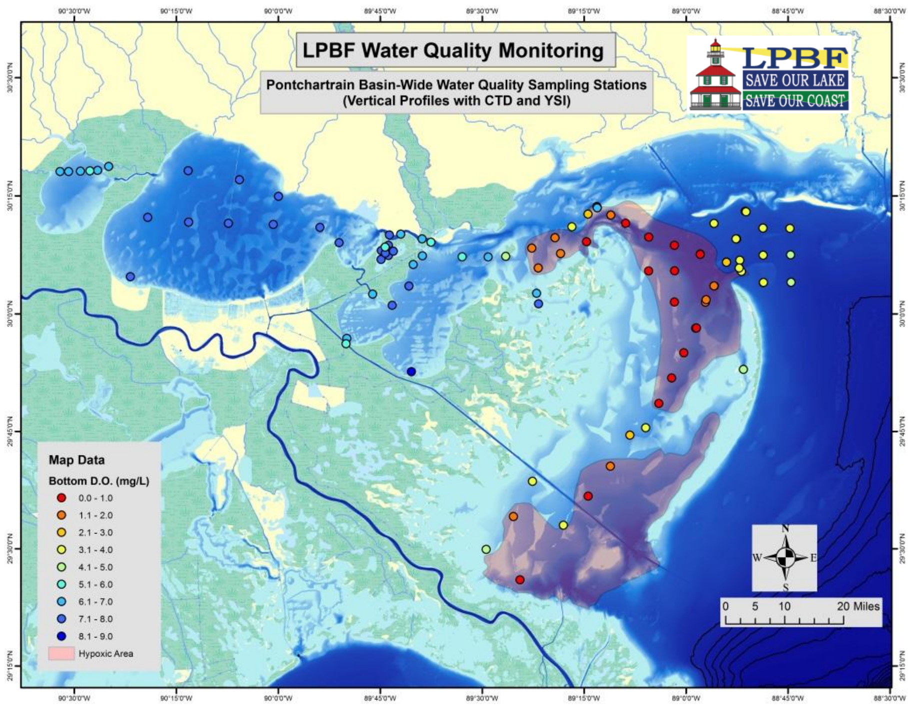

Figure 16. Map showing sampling stations throughout the Pontchartrain Basin with observed bottom dissolved oxygen concentrations.

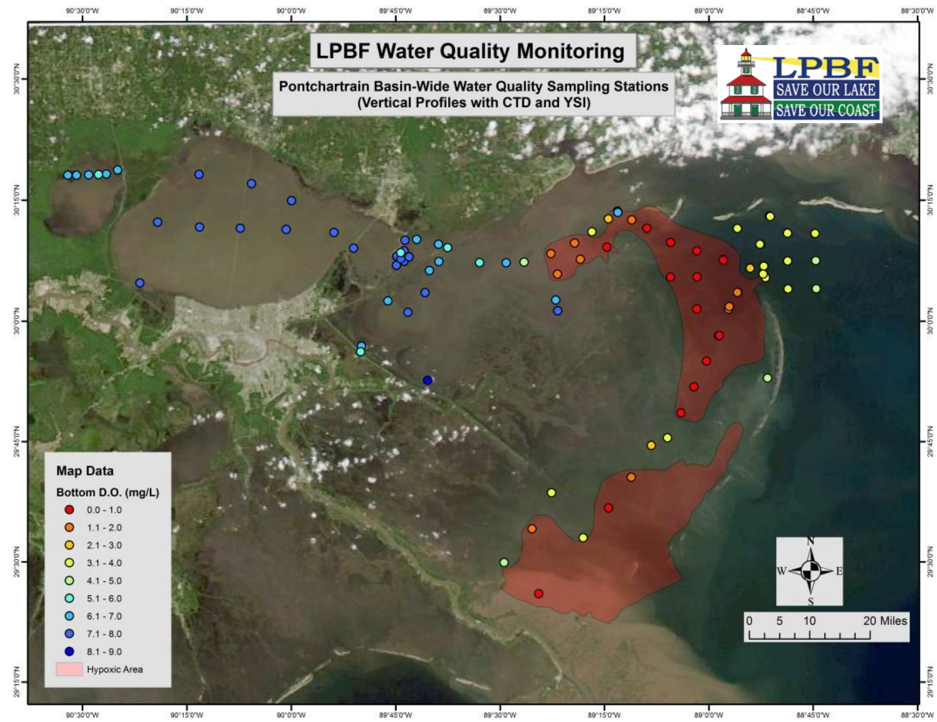

Figure 17. Map with aerial imagery showing sampling stations throughout the Pontchartrain Basin with observed bottom dissolved oxygen concentrations and estimated hypoxic zone.

Figures 19, 20, and 21 illustrate the depth-dependent segregation of dissolved oxygen, salinity, and temperature data. This demonstrates the development of a pronounced boundary between lower salinity, oxygen-rich waters above, and higher salinity, oxygen-depleted waters below. Data included in **Figures 19, 20, and 21** are only from stations where hypoxia was observed.

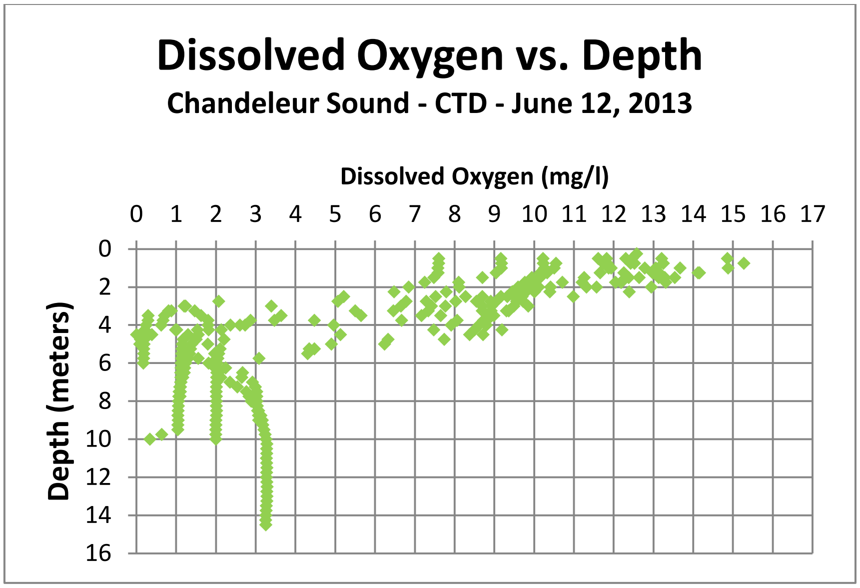

Figure 19. Graph showing dissolved oxygen with depth, measured June 12, 2013 by LPBF using the CTD. Notice, overall dissolved oxygen decreases with depth. Stations where all oxygen levels were above 2.0 mg/L were not included.

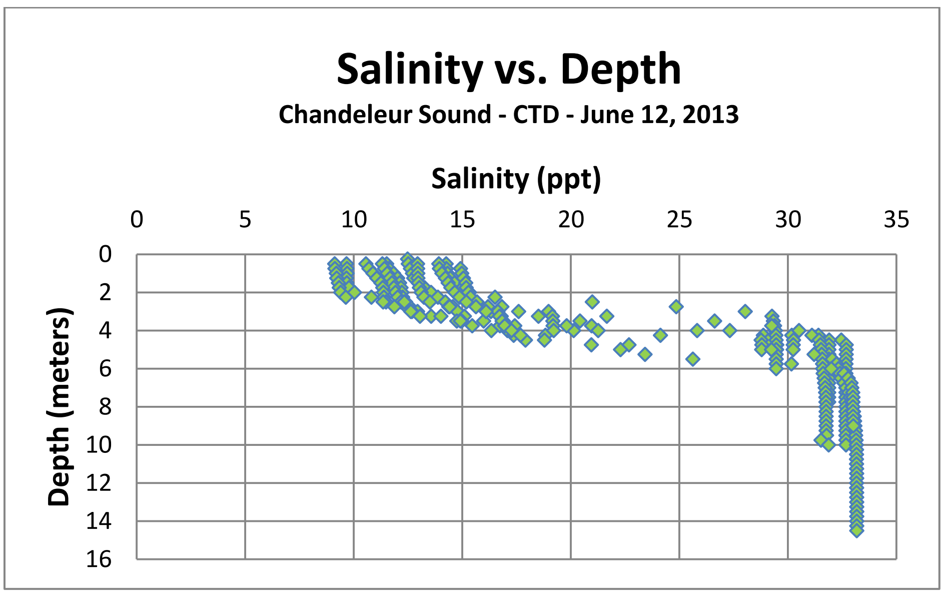

Figure 20. Graph showing changes in salinity with depth on June 12, 2013, measured by LPBF using the CTD. Notice the increase in salinity with depth. Stations where all oxygen levels were above 2.0 mg/L were not included.

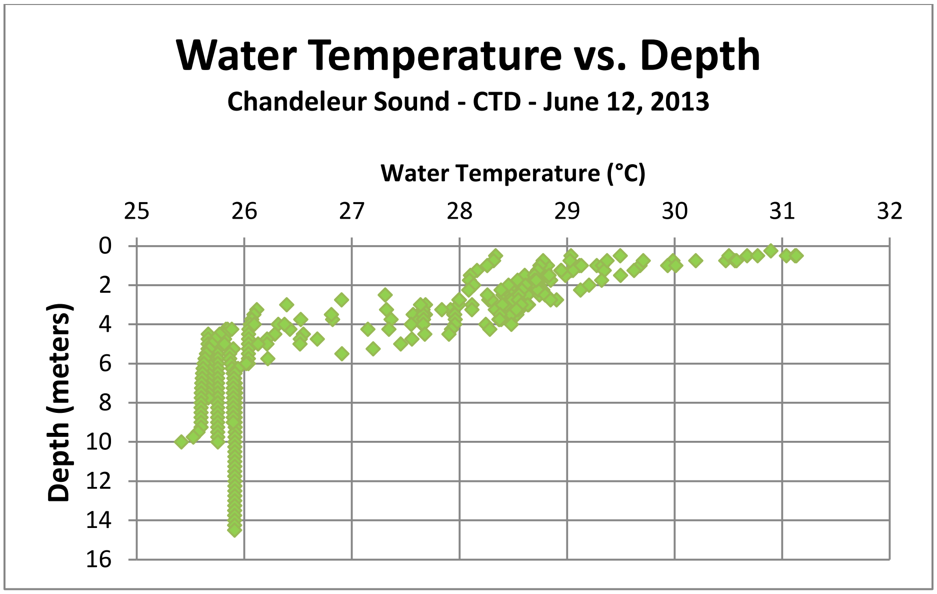

Figure 21. Graph showing change in water temperature with depth on June 12, 2013, measured by LPBF using the CTD. Overall, temperatures decreased as depth increased. Stations where all oxygen levels were above 2.0 mg/L were not included.

Figures 22, 23, and 24 illustrate the data collected using the CTD in Breton Sound, indicating similar patterns of depth-dependent segregation of dissolved oxygen, salinity, and temperature data, which demonstrates the development of a pronounced boundary between lower salinity, oxygen-rich waters above, and higher salinity, oxygen-depleted waters below. Data included in **Figures 22, 23, and 24** are only from stations where hypoxia was observed.

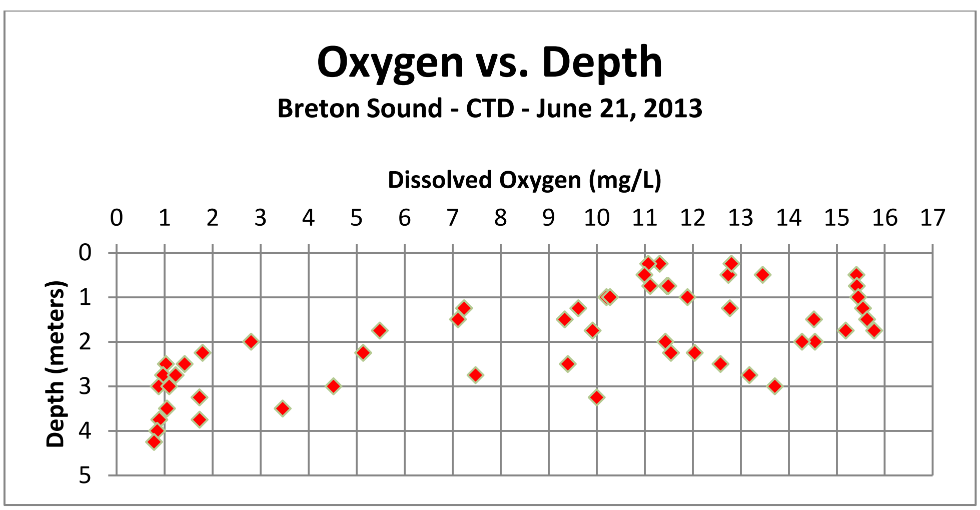

Figure 22. Graph showing Breton Sound measured dissolved oxygen relative to depth. It is not as abrupt, but still evident that oxygen concentrations were decreasing with depth. Stations where all oxygen levels were above 2.0 mg/L were not included.

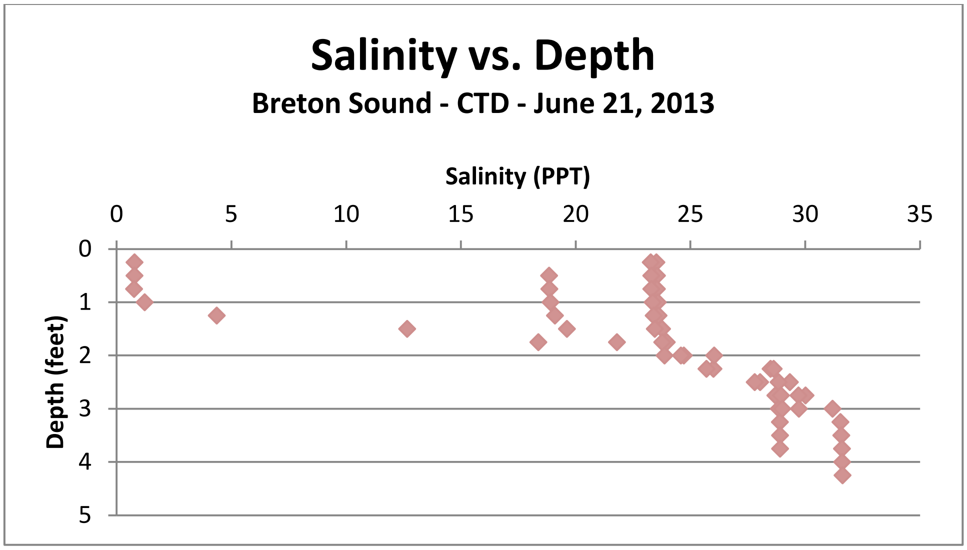

Figure 23. Graph showing salinity relative to depth in Breton Sound using the CTD, measured on June 21, 2013, by LPBF. Overall, salinity increased with depth. Stations where all oxygen levels were above 2.0 mg/L were not included.

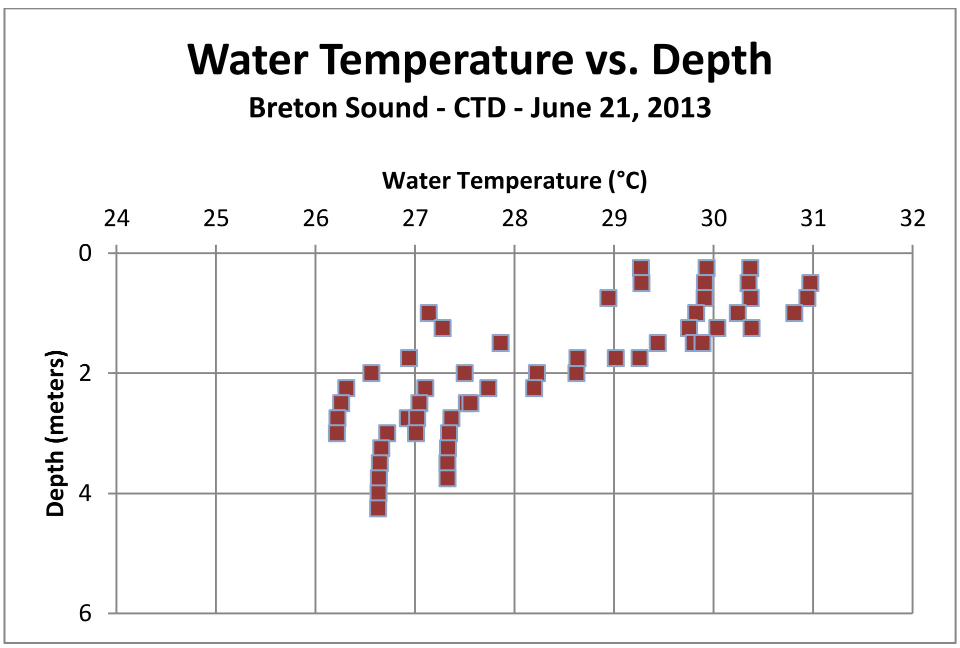

Figure 24. Graph showing change in water temperature with depth on June 21, 2013 in Breton Sound, sampled by LPBF using the CTD. Temperatures decreased as depth increased. Stations where all oxygen levels were above 2.0 mg/L were not included.

LPBF has produced a map to show water movement and the most recent distribution of salinity across the basin. The maps LPBF produces to display hydrology for the Pontchartrain Basin are called the "Hydrocoast Map" and have evolved from one map, to a series of maps. LPBF produced a special edition of the Hydrocoast map for June 10 – June 21, 2013, using the vertical profile water quality data captured using the CTD and YSI data (**Figure 25**). This map shows salinity contours across the Pontchartrain Basin. Salinity contours that are close together represent an area where salinity changes quickly over a short distance, which is seen slightly offshore during this time period. Contours that are farther apart represent a more gradual change over longer distances which can be seen throughout the interior of the basin, especially in Lake Pontchartrain and Lake Borgne. In addition, areas where low oxygen concentrations were measured are outlined, and also outlined on the map are where oxygen concentrations were normal, but stratification throughout the water column was observed. For more information on the Hydrocoast Map series, please visit www.saveourlake.org/coastal-hydromap.php.

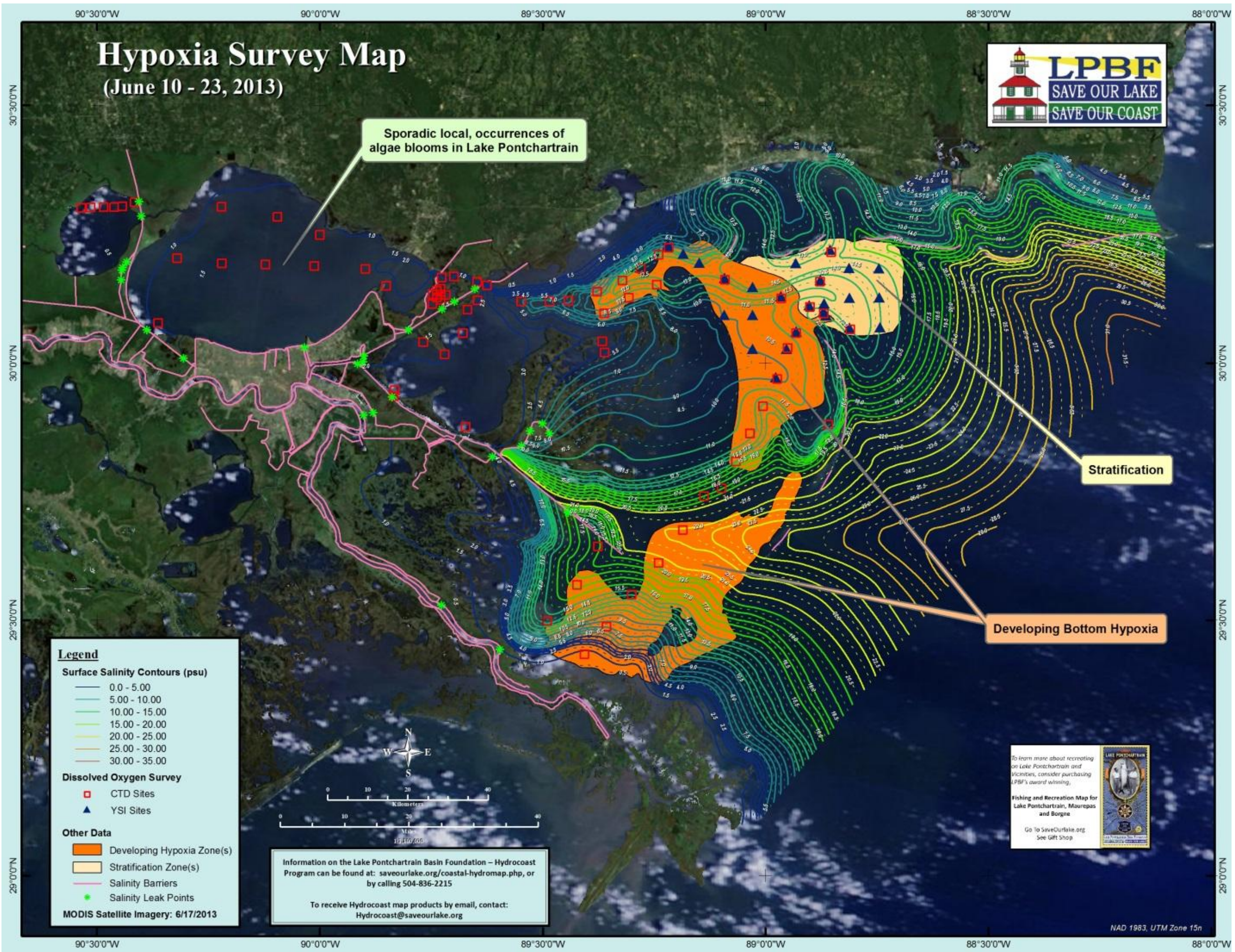

Figure 25. Special edition Hypoxia Survey Hydrocoast Map showing salinity contours throughout the Pontchartrain Basin. The orange area indicates areas of developing bottom hypoxia, while the yellow-shaded region shows an area where stratification was observed, however, dissolved oxygen concentrations were normal.

Discussion

Since LPBF began monitoring the Chandeleur Sound water quality in 2008, LPBF has found areas with low dissolved oxygen concentrations in all years sampled (2008, 2010, 2011, 2012, and 2013). In June 2013, two different zones were found that exhibited hypoxic conditions in the bottom waters. The first area of hypoxia was found in Chandeleur Sound, and extended northwest into the Biloxi Marsh area and Mississippi Sound. The Chandeleur Sound hypoxia was found approximately two miles west of the Chandeleur Islands, six miles east of the Biloxi Marsh. This hypoxic area also extends as far north as Cat Island, approximately nine miles from mainland in Bay St. Louis, Mississippi, and as far south as the southern-most Chandeleur Islands, approximately nine miles to the west. The northwestern extent of the Chandeleur Sound hypoxic area was found less than two miles east of Half Moon Island. The Chandeleur Sound hypoxic area was also measured in Grand Pass, LA. The approximate area of the Chandeleur Sound hypoxic area is 450 square miles (1165 km^2).

The second area of hypoxia was found in Breton Sound, with a small area extending north into the Chandeleur Sound. The Breton Sound hypoxic area was found approximately 10 miles southeast of the remnant Mississippi River Gulf Outlet (MRGO) structure, approximately three miles north of the Mississippi River at Fort St. Philip. This hypoxic area is slightly larger than the Chandeleur Sound hypoxic area, approximately 580 square miles (1502 km^2) and encompasses a majority of Breton Sound. This is the first time LPBF has found hypoxic conditions in Breton Sound, but this is also the first time LPBF has surveyed this area specifically for low dissolved oxygen. During previous investigations of the region, LPBF has never found hypoxic conditions extending as far south in Chandeleur Sound as it did in June 2013, which instigated investigations continuing south into Breton Sound where the second area was discovered.

In previous years, low concentrations of dissolved oxygen (< 2.0 mg/L) were obtained in bottom water near the northeastern corner of the Chandeleur Sound. However, during the 2013 survey, hypoxia (< 2.0 mg/L) was not measured in the northeastern reaches of Chandeleur Sound. Nonetheless, significant stratification was present and oxygen concentrations were decreasing, indicating that the fundamental variables driving hypoxia were present.

Lastly, historical evidence suggests that the hypoxic water masses follow water bottom bathymetry very closely in that the denser, more saline water masses are trapped in the deeper regions of the Chandeleur Sound. With increases in freshwater discharge to the region, the bathymetry supports a suitable scenario for the development of a stratified water column, furthermore, cutting off the bottom waters for oxygen-rich surface water. There is a lot more data from the Pontchartrain Estuary research cruise and the June 2013 hypoxia survey that still needs to be analyzed. A final report summarizing the 2013 efforts with more from this extensive dataset will be published in the near future. LPBF will continue seasonal monitoring throughout the remainder of 2013, and carry on through 2014.

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