2010 Forecast of the Summer Hypoxic Zone Size, Northern Gulf of Mexico

Abstract

As the environmental catastrophe from the Deepwater Horizon oil spill unfolds along the northern Gulf of Mexico, the persistent and unacceptable "Dead Zone" along the Louisiana shore continues to threaten living resources including humans that depend on fish, shrimp and crabs. Excess nutrients, particularly nitrogen and phosphorus, cause huge algae blooms whose decomposition leads to oxygen distress and even organism death in the Gulf's richest waters.

The June forecast of the size of the hypoxic zone in the northern Gulf of Mexico for July 2010 is that it will cover between 19,141 to 21,941 km^2 (average 20,140 km^2; equal to 7,776 mi^2) of the bottom of the continental shelf off Louisiana and Texas. The area is about the size of the state of New Jersey. The estimate is based on the May nitrogen loading (as nitrate+nitrite) from the Mississippi watershed to the Gulf of Mexico estimated by the U.S. Geological Survey. If the area of hypoxia becomes this large, then it will be the fifth largest since systematic mapping of the hypoxic zone began in 1985.

Caveats: 1) This predictions discounts the effect of large storm events which will temporarily disrupt the physical and biological system attributes promoting the formation of the low oxygen zone in bottom waters; 2) The potential space on the shelf where hypoxia occurs is limited by the bathymetry; 3) The predictions assume continued above average discharge through June and July; 4) unusual weather patterns affecting coastal winds, as experienced in 2009, may skew the prediction to be higher, or lower.

Furthermore, the effects of the Deepwater Horizon oil spill are undefined, but potentially significant.

Introduction

Hypoxic water masses in bottom waters of the northern Gulf of Mexico occur when the oxygen concentration falls below 2 mg l^{-1}. This hypoxic water is distributed across the Louisiana shelf west of the Mississippi River and onto the upper Texas coast, from near shore to as much as 125 km offshore, and in water depths up to 60 m (Rabalais et al. 2007). It has been found in all months, but is most persistent and severe in summer (Turner 2005; Rabalais et al. 2007). The July distribution of hypoxic waters most often is a single continuous zone along the Louisiana and adjacent Texas shelf. Hypoxia also occurs east of the Mississippi River delta, but covers less area and is ephemeral. These areas are sometimes called "Dead Zones" because of the absence of commercial quantities of shrimp and fish in the bottom layer. The number of Dead Zones throughout the world has been increasing in the last several decades and currently number well over 400 (Díaz and Rosenberg 2008; Rabalais et al. 2010; Díaz unpubl. data; Conley et al.

unpubl. data for the Baltic Sea). The Dead Zone off the Louisiana coast is the second largest human-caused coastal hypoxic area in the global ocean.

Systematic mapping and monitoring of the area of hypoxia in bottom waters began in 1985. Its size has ranged between 40 to 22,000 km^2 during July and averaged 13,600 km^2 from 1985-2010 (5,200 mi^2). There are no comparable coastwide data for other months, but monthly monitoring is conducted along two transects off Terrebonne Bay, LA, and the Atchafalaya delta, LA. In addition, two coastal ocean observing stations off Terrebonne Bay and Caminada Pass (125 and 75 km west of the Mississippi River delta, respectively) record continuous bottom-water oxygen conditions. These data indicate that hypoxia has been present along the Louisiana shelf since March-June 2010 on the transect off Terrebonne Bay and at the continuously recording oxygen meter sites off Terrebonne Bay and Caminada Pass, and since May-June off the Atchafalaya River delta. [See Appendix for map and oxygen meter data.]

Hypoxic water masses form from spring to fall on this coast because the consumption of oxygen in bottom water layers exceeds the re-supply of oxygen from the atmosphere. The re-aeration rate is negatively influenced by stratification of the water column which is primarily dependent on the river's freshwater discharge and accentuated by summer warming. The overwhelming supply of organic matter respired in the bottom layer is from the downward flux of organic matter produced in the surface layer. The organic matter production rate is directly related to the nitrogen supply rate from the Mississippi River watershed. The transport to the bottom layer is the result of sinking of individual cells (considered a minor contribution), as the excretory products of the grazing predators (zooplankton) that 'package' them as fecal pellets, or as aggregates of cells, detritus and mucus. The respiration of this organic matter declines as it falls through the water column (Turner et al. 1998), but the descent rate alongshore the Louisiana-Texas shelf is rapid enough so that sufficient oxygen consumption on the shallow shelf occurs in the bottom layer and sediments to create a zone of hypoxia that is constrained by the geomorphology of the shelf and water movement. The significance of reducing nutrient loads to these coastal waters rests on this coupling between the organic matter produced in response to these nutrients and its respiration in the bottom layer (MRGOM WNTF 2001, 2008; Rabalais et al. 2002, 2007, 2010; SAB 2007).

Prediction for 2010

The forecast of the size of the hypoxic zone in the northern Gulf of Mexico for July 2010 is that it will cover between 19,141 to 21,941 km^2 (average 20,140 km^2; equal to 7,776 mi^2) of the bottom of the continental shelf off Louisiana and Texas (Figure 1). If the area of hypoxia becomes this large, it will be the 5th largest since systematic mapping of the hypoxic zone began in 1985. This Model 1 estimate is equivalent to an area about the size of the state of New Jersey (7,417 mi^2, 7,840 mi^2, respectively). The average size of the annual hypoxia-affected area since 1990 has been approximately 15,000 km^2 (5,800 mi^2). The largest size was 22,000 km^2 (8,900 mi^2) in 2002.

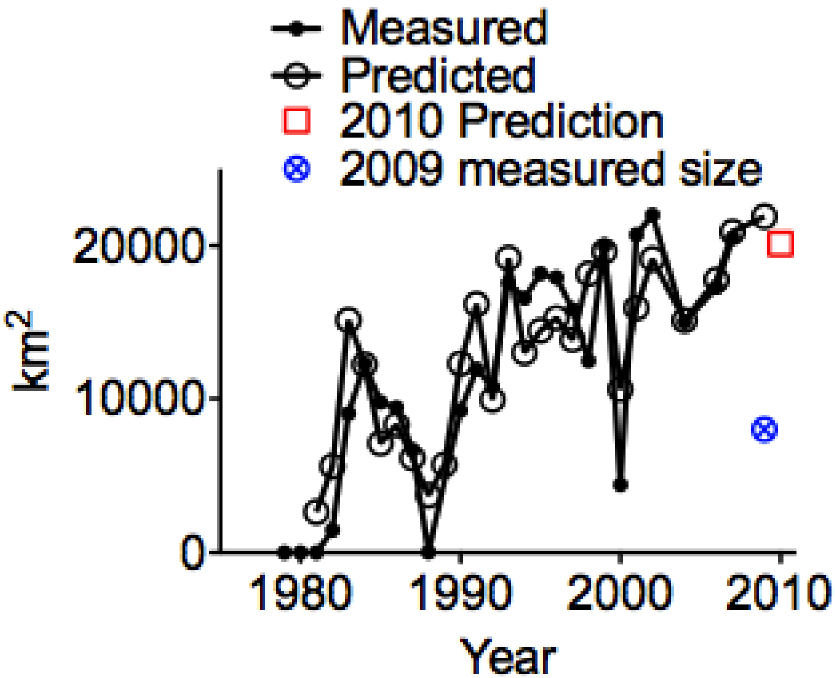

Figure 1. The measured size, the modeled size, and the predicted the size of the hypoxic zone for 2010. This Model 1 estimate uses data for nitrogen loading (USGS estimates) to the Gulf of Mexico from 1980 to present.

Supporting information on the dissolved nitrate+nitrite concentration in the Mississippi River at Baton Rouge, LA, the nitrogen flux from the Mississippi River to the Gulf of Mexico, river discharge, are in the Appendix. A post-cruise assessment will be made at the end of the summer and posted on the same website where this report appears.

Hypoxia Models and Model Accuracy

Models are used to summarize information, to test assumptions and to make predictions that may be useful for other purposes, including management. There are multiple models of the size of the hypoxic zone that are useful in evaluating the influence of nitrogen load and variations in ocean currents, climate, etc. These models do not always produce similar results, and model improvement is one focus of ongoing research. This model is based primarily on the nitrate+nitrite load delivered to the Gulf of Mexico by the Mississippi River in May. The residence time of the surface waters along this coast is about 2 to 3 months in the summer, hence the 2-3 month lag between the loading rate calculated in May and the size of the hypoxic zone in July. The ecosystem is evolving, however. The size of the hypoxic zone for the same amount of nitrogen loading (as nitrate+nitrite) increases each year (Turner et al. 2008). The model will eventually be adjusted to account for the limited space left on the shelf.

The statistical model used here is the most accurate model based on past performance (Turner et al. 2006, 2008). The prediction in 2006 and 2007, for example, was 99% and 107%, respectively, of the measured size, and 72% of the interannual variation in hypoxic zone area in summer. The equivalent model for the Baltic Sea low oxygen conditions explains 49 to 52% of the variation in the inerannnual variation in bottom water oxygen concentration (Conley et al. 2007).

Nutrient load models are robust for long-term management purposes, but they are less robust when short-term weather patterns move water masses or mix up the water column. Some of the variation in the size of the Gulf hypoxic zone size, for example, is due to re-aeration of the water column during storms. The size of the summer hypoxic zone in 2008 was less than predicted because of the influence of Hurricane Dolly. The long-term trend, however, is that the area of hypoxia is larger for the same amount of nitrogen loading (Turner et al. 2008). Other models that also predict or describe oxygen dynamics on this shelf are discussed in Bierman et al. (1994), Justić et al. (2003), Scavia and Donnelly (2007), and Scavia et al. (2003, 2004). The University of Michigan forecast site is: http://www.sitemaker.umich.edu/scavia

The hypoxic zone size in 2009 was lower than the model predicted. The prediction for 2009 was 23,500 km^2 based on the observed above-average nitrate-N load, but the area measured was 8000 km^2. One explanation for this discrepancy has to do with changes in the longshore currents on the Louisiana shelf that are predominantly from the east to the west, but reverse in summer from west to east dictated by the winds. Persistent winds from the west and southwest in the few weeks preceding the 2009 mapping cruise 'piled' the low oxygen water mass up along the southeastern Louisiana shelf. The volume of hypoxia and often anoxia in the affected area was unusually thick. ADCP data from 2009 confirmed that the main energy of motion for the east component was in the low frequency wind-driven flow band, with a mean surface east velocity much greater than in 2008 (8.7 cm/s versus 3.8 cm/s) (Li et al. unpubl. data). The mean surface north component in 2009 was an order of magnitude less than the east velocity (-0.8 cm/s versus 8.7 cm/s). The wind spectrum for 2008 did not show any major wind energy, with strong wind-driven flow energy for 2009.

Model Parameters for 2010

Nitrogen loading to the Gulf of Mexico

The statistical model used here to predict the size of the hypoxic zone in July 2010 is based on the May total nitrate+nitrite nitrogen load to the Gulf from the main stem of the Mississippi River and the Atchafalaya River. The concentration × discharge equals the nitrate-nitrite load. The estimate of nitrate-nitrate loading from the Mississippi River into the Gulf of Mexico is made by the United States Geological Survey (USGS). The nutrient load estimates also include total phosphorus (TP) and total nitrogen (TN). The nitrate+nitrite loading in May is about 89% of the TN loading (R^2 = 0.91). The USGS includes an estimate of the 95% confidence range for the nitrogen load, which averages 41% of the predicted value. The USGS web site (http://toxics.usgs.gov/hypoxia/mississippi/) has more information on the calculation and data.

A newer model (Model 2) prediction uses the May nitrate+nitrite loading in the Mississippi River at Baton Rouge, LA, and is otherwise the same as in Model 1. The advantage of using these data is that there is usually two to three times more water quality measurements made compared to the May USGS estimates. Exploratory trial runs are underway to determine if other nutrients, e.g., phosphate, ammonium, or silicate, could be included to improve the predictive quality of the models. No other parameters were found that were statistically significant for either Model 1 or Model 2 analyses. Model 2 results will be reported in 2011 if they prove to offer a significant increase in predictive capability.

Hypoxic zone data

These models use data for the size of the hypoxic zone in July because no comparable shelfwide data exist for other months. Data on the size of the hypoxic zone in late July from 1985 to 2009 are based on annual field measurements (data available at http://www.gulfhypoxia.net). The 2010 mapping cruise will be conducted from 24 July to 2 August and the data posted daily at the same web site. The values for 1989 (no funding available) and 1978-1984 are estimated from contemporary field data. The values for before 1978 assume that there was no significant hypoxia then and are based on results from various models. Data for four years were not included in the analysis because there were strong storms just before or during the cruise (1998, 2003, 2005 and 2008). These storms, by comparison to the pre-cruise sampling and data collected during the cruise, disrupted the water column and re-aerated the water column. It may take a few days to several weeks, depending on water temperature and initial dissolved oxygen concentration, for respiration to reduce the dissolved oxygen concentration to <2 mg l^{-1} after the water column stratification is re-established.

Deepwater Horizon Oil Spill impacts

It is unclear what impact, if any, the Deepwater Horizon oil spill will have on the size of the dead zone since there are numerous factors at work. The oil spill could enhance the size of the hypoxic zone through the microbial breakdown of oil, which consumes oxygen, but the oil could also limit the growth of the hypoxia-fueling algae because of its toxicity, or because a surface sheen reflects light. It is clear, however, that the combination of the hypoxic zone and the oil spill is not good for local fisheries.

Acknowledgments

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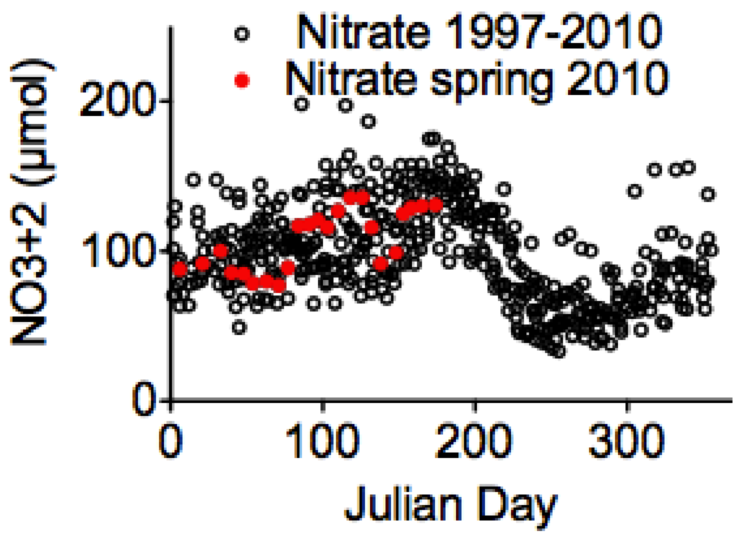
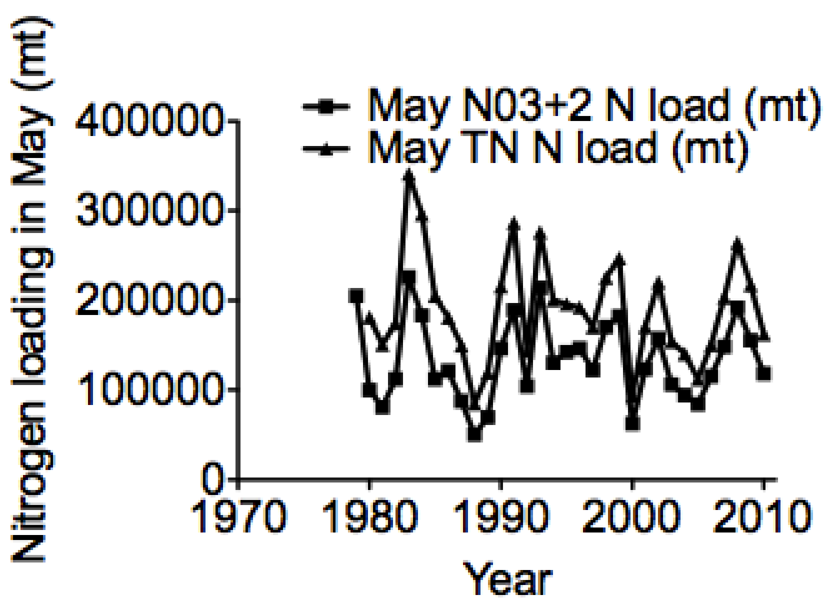
Appendix

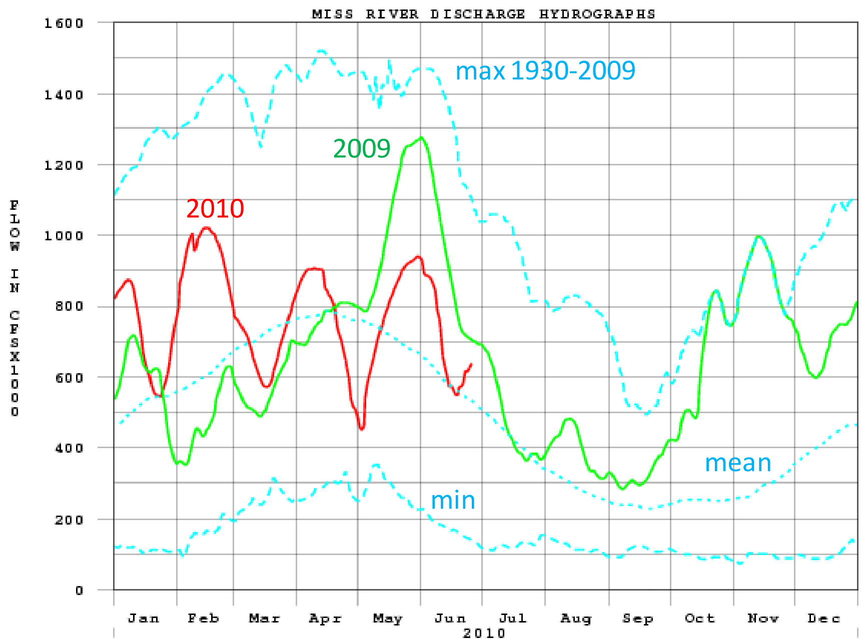
1. Dissolved nitrate+nitrite concentration in the Mississippi River at Baton Rouge, LA
2. Nitrogen loads from the Mississippi River to the Gulf of Mexico
3. River discharge
4. Study area
5. Dissolved oxygen data for bottom waters off Terrebonne Bay and Caminada Pass.



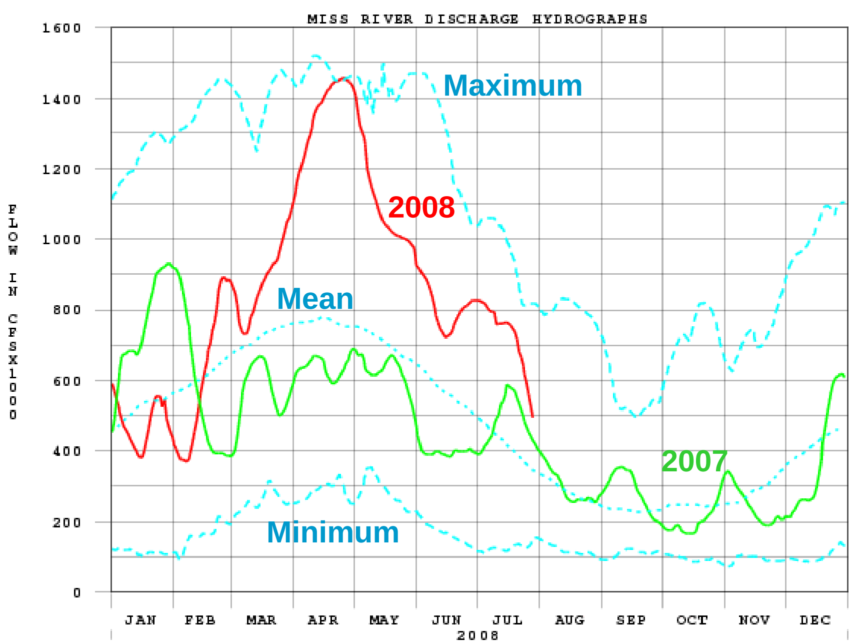
Appendix Figure 1. Nitrate concentration at Baton Rouge from 1997 through 24 June 2010.



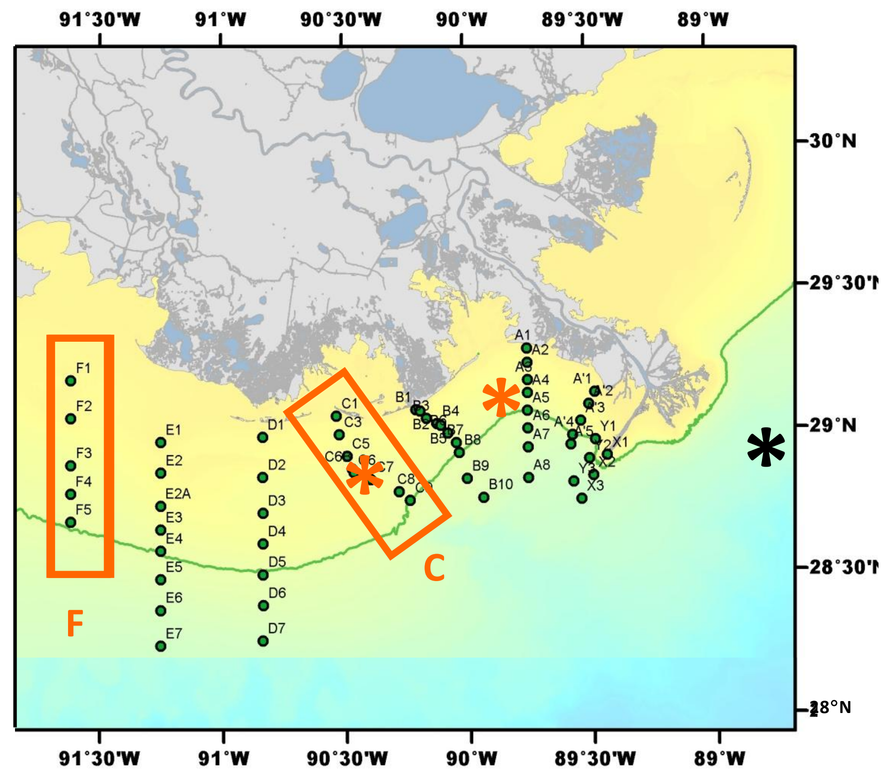
Appendix Figure 2. Nitrate and Total (TN) loading from the Mississippi River watershed to the Gulf of Mexico in May. Data are from the US Geological Survey (http://toxics.usgs.gov/hypoxia/mississippi/nutrient_flux_yield_est.html).



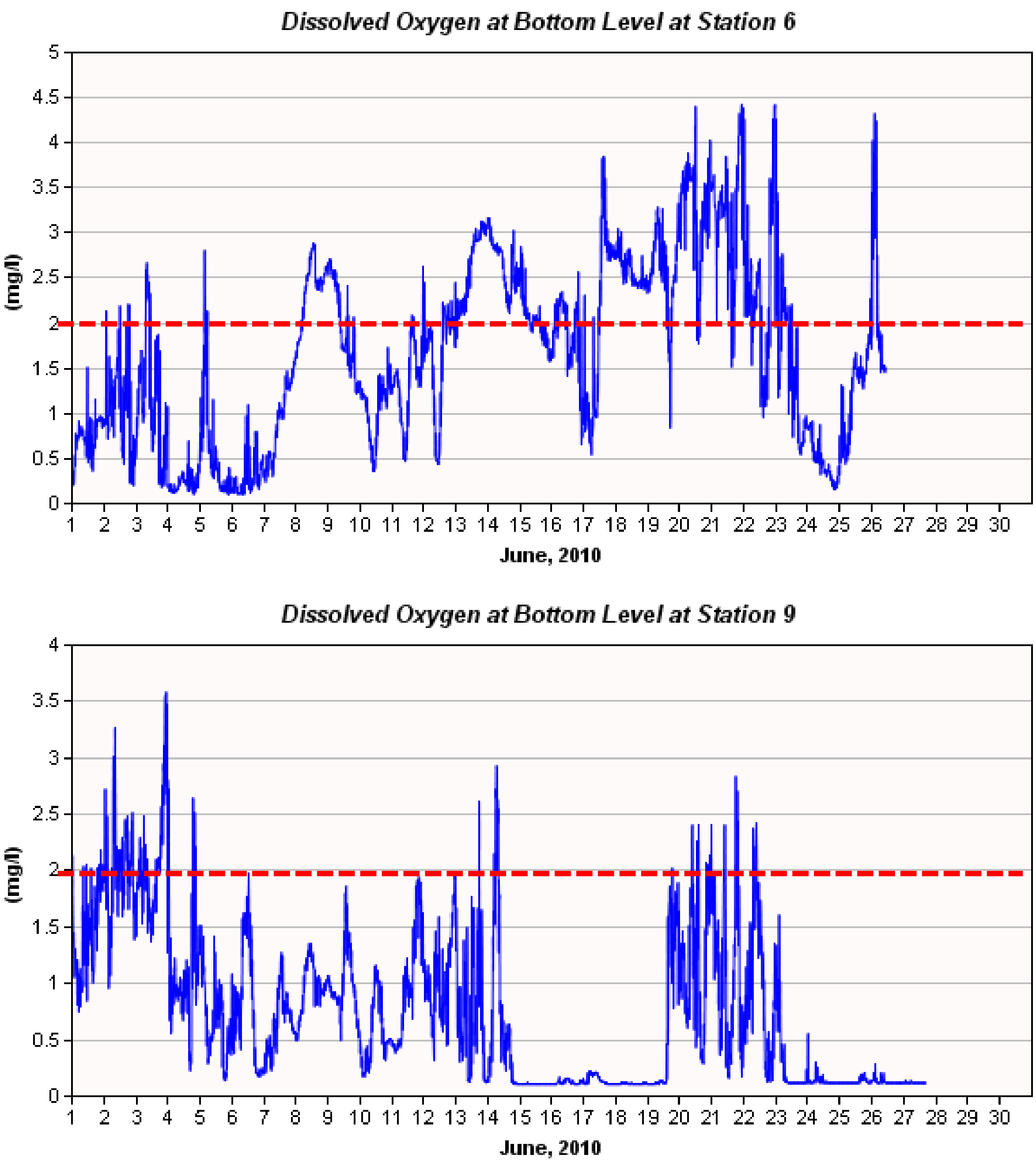
Appendix Figure 3a. Mississippi River discharge (1000 cubic feet per second) at Tarbert Landing, MS from 1930 to 27 June 2010. http://www.mvn.usace.army.mil/eng/edhd/tar.gif



Appendix Figure 3b. Mississippi River discharge (1000 cubic feet per second) at Tarbert Landing, MS from 1930 to July 2008. http://www.mvn.usace.army.mil/eng/edhd/tar.gif. The 2010 discharge pattern is very similar to that of 2007, when the size of the hypoxic zone measured at 20,500 km^2 (7,900 mi^2).



Appendix Figure 4. Location of transects off Terrebonne Bay (transect C) and Atchafalaya Bay (transect F) and ocean observing systems (orange asterisks) off Caminada Pass and Terrebonne Bay. The Deepwater Horizon oil spill (black asterisk) is located 41 miles southeast of the Mississippi River delta.



Appendix Figure 5. Bottom-water dissolved oxygen concentrations at stations C6C (CSI6) off Terrebonne Bay and Station CSI9 off Caminada Pass (Rabalais et al. unpubl. data; http://wavcis.csi.lsu.edu). Values below dashed lines are hypoxic, indicating fairly persistent hypoxia for June 2010.