2011 Forecast:
Summer Hypoxic Zone Size,
Northern Gulf of Mexico

Abstract

The record-breaking floods from the Mississippi River in 2011 are predicted to create the largest "Dead Zone" along the Louisiana shore. This zone 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 2011 forecast of the size of the hypoxic zone in the northern Gulf of Mexico for July 2011 is that it will cover between 22,253 to 26,515 km^2 (average 24,400 km^2; 9,421 mi^2) of the bottom of the continental shelf off Louisiana and Texas. The predicted hypoxic area is about the size of the combined land area of New Jersey and Delaware, or the size of Lake Erie. 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 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 promotes 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 lower.

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; Figures 1 and 2). 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). In 2010 it was 20,000 km^2 (Figure 2). There are few 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 on the transect off Terrebonne Bay since March and off the Atchafalaya River delta since April. [See Appendix Figure 1 for a map of the study area.]

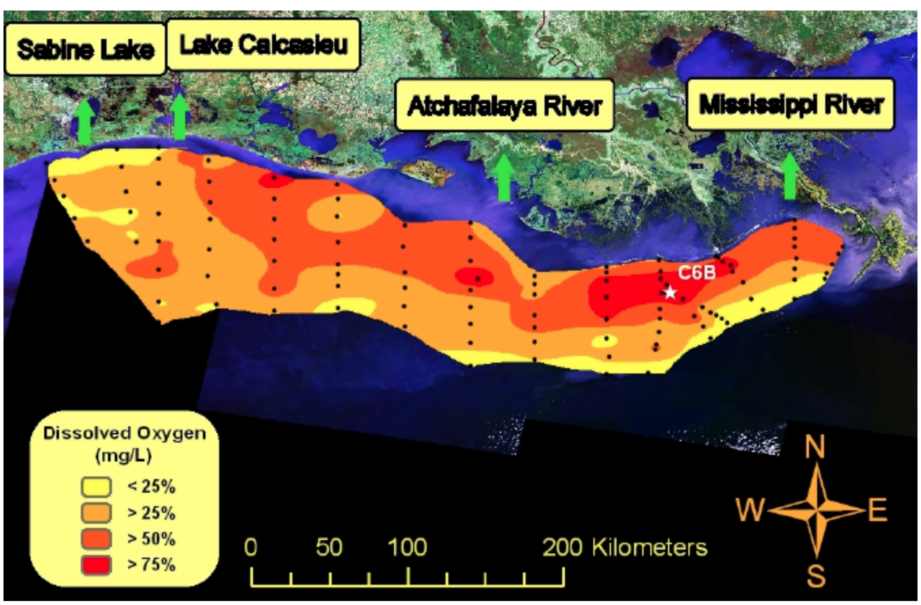


Figure 1. Frequency of mid-summer hypoxia over the 60 to 80 station grid from 1985 to 2008. Data source: N.N. Rabalais, Louisiana Universities Marine Consortium, and R.E. Turner, Louisiana State University; funded by NOAA, Center for Sponsored Coastal Ocean Research.

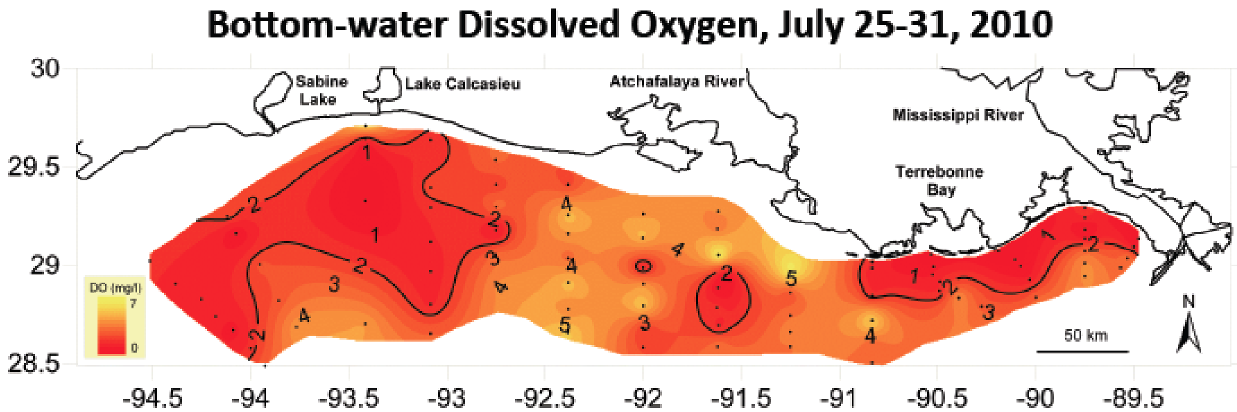


Figure 2. Oxygen concentration in bottom-water across the Louisiana-Texas shelf from July 25-31, 2010. The black line outlines values less than 2 mg/L, or hypoxia. Letters indicate transects. Black dots are sampled stations. The hypoxic area in 2010 was 20,000 km^2. Data source: N.N. Rabalais, Louisiana Universities Marine Consortium, and R.E. Turner, Louisiana State University; funded by NOAA, Center for Sponsored Coastal Ocean Research.

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, 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), and the descent rate is rapid enough so that respiration occurs mostly in the bottom layer and sediments. The oxygen consumption therein creates a zone of hypoxia that is constrained by the geomorphology of the shelf, water movement and vertical mixing. 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).

2011 Mississippi River Discharge

Hypoxic conditions are dependent on river discharge because of the influence it has on the physical structure of the water column and on the nutrient load delivered to the coastal zone. The nutrient load is dependent on the concentration of nutrients, primarily nitrogen, and on the discharge. River discharge is, therefore, a key environmental parameter of interest.

The Mississippi River discharge in May 2011 exceeded the daily discharge recorded back to 1930 (Appendix Figure 2), and was the highest since 1973 (Figure 3). As in 1973, the

Morganza and Bonnet Carré spillways were opened to reduce the water height downstream, (Appendix Figure 3). Thirty percent of the water flowed into the Atchafalaya Basin (average 21,205 cms, including the Morganza Spillway flow). About 694 cms of this amount went into the intracoastal waterway. The larger proportion flowed through the Wax Lake Outlet (6,938 cms) and the Atchafalaya delta (9,876 cms; 232 cms of this flowed into Bayou Penchant). The flow past Baton Rouge was 36,698 cms, after which 7,169 cms was diverted through the Bonnet Carré Spillway and into Lake Pontchartrain. The total flow through the Birdfoot delta and into the Gulf of Mexico was about 31,404 cms.

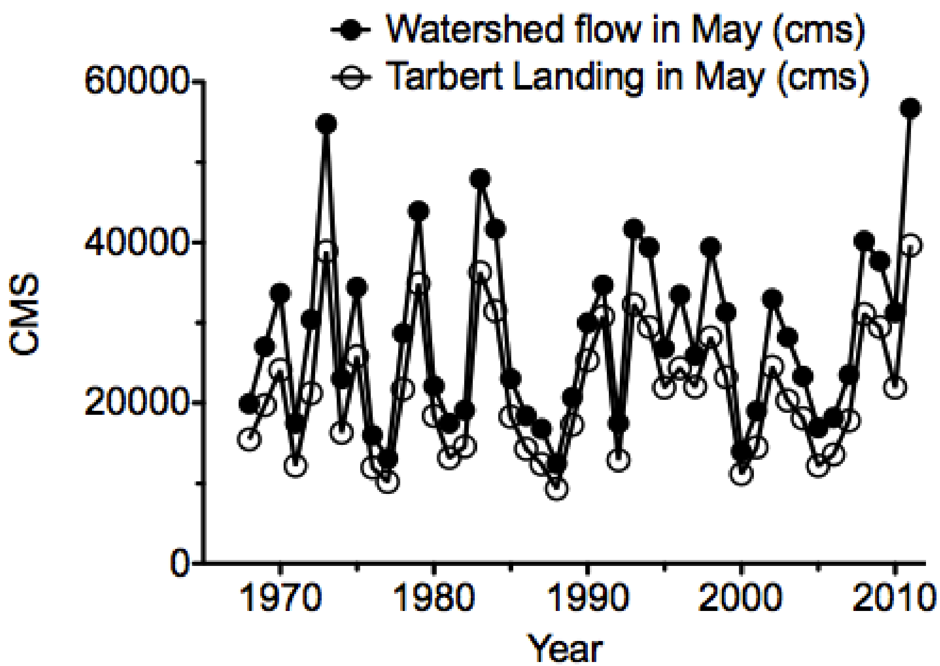


Figure 3. The discharge in May for the Mississippi River watershed and south of St. Francisville, LA at Tarbert Landing, MS.

2011 Nitrogen Loading

The estimate of nitrate-nitrate loading from the Mississippi River into the Gulf of Mexico is made by the US Geological Survey (USGS; http://toxics.usgs.gov/hypoxia/mississippi/). The USGS web site has more information on the data calculation. The USGS includes an estimate of the 95% confidence range for the nitrogen load. The May nitrate+nitrate (NO_{3+2}) and total nitrogen (TN) load for the Mississippi River watershed for May is shown in Figure 4. The estimates used in this prediction exclude water flowing into the Bonnet Carré spillway that delivers water to the east bank of the Mississippi River. Comparative information on the seasonal concentration of dissolved nitrate+nitrite concentration in the Mississippi River at Baton Rouge, LA, are in the Appendix Figure 4.

The concentration of nitrate was about as high in the beginning of May as it was in 2010, but the concentration dropped by about 25% by the end of May, probably due to the diluting effect of the high discharge. The river discharge was high enough, however, to result in the 9th highest May nitrate+nitrate loading since 1973.

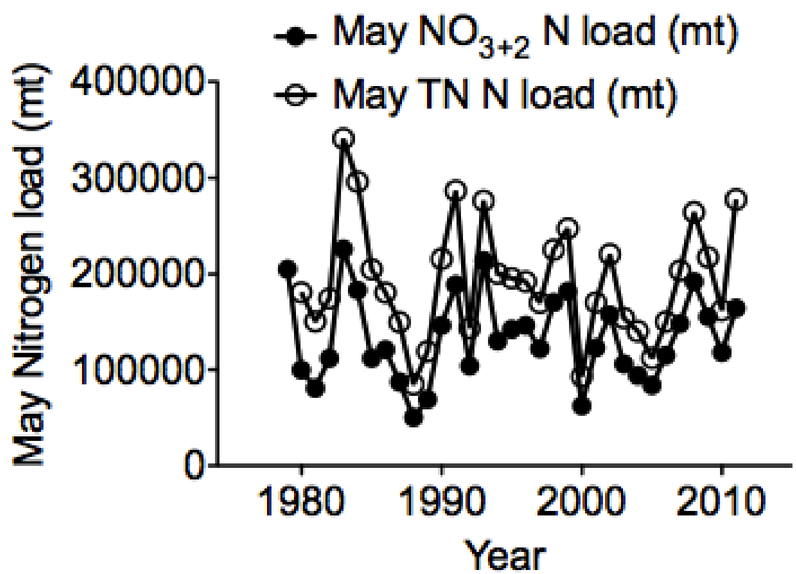


Figure 4. The annual nitrate+nitrate (NO_{3+2}) and total nitrogen (TN) load for the Mississippi River watershed for May. The estimates are from the USGS and exclude water flowing into the Bonnet Carré spillway that delivers water to the east bank of the Mississippi River.

Hypoxic Zone Size

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 2010 are based on annual field measurements (data available at http://www.gulfhypoxia.net). The 2011 mapping cruise will be conducted from 24 July to 6 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, 2008 and 2010). 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.

Prediction for 2011

The June 2011 forecast of the size of the hypoxic zone in the northern Gulf of Mexico for July 2011 is that it will cover between 22,253 to 26,515 km^2 (average 24,400 km^2; equal to 9,421 mi^2) of the bottom of the continental shelf off Louisiana and Texas (Figure 5). The predicted hypoxic area is about the size of the combined land area of New Jersey and Delaware or the size of Lake Erie. If the area of hypoxia becomes this large, then it will be the largest since systematic mapping of the hypoxic zone began in 1985 (22,000 km^2 or 8,900 mi^2; 2002).

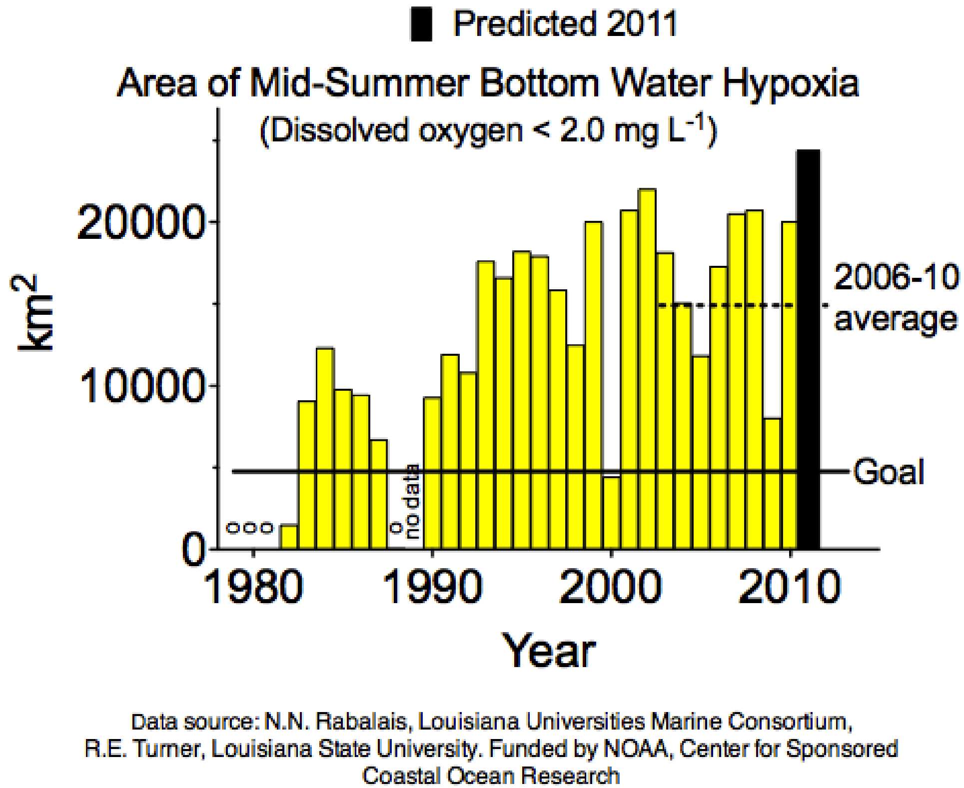


Figure 5. The measured and modeled size of the hypoxic zone from 1979 to 2010 and the predicted size for 2011.

Hypoxia Models and Model Accuracy

The statistical model used here to predict the size of the hypoxic zone in July 2011 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 (concentration × discharge equals the nitrate-nitrite load).

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 efforts supported by the NOAA Center for Sponsored Coastal Ocean 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, however, is evolving. 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 on the shelf (a physiographic constraint).

The statistical model used here is the most accurate model based on past performance (Turner et al. 2006, 2008). The predictions in 2006, 2007, and 2010, for example, were 99%, 107%, and 99%, respectively, of the measured size. This model describes 73% of the total variance in size since 1987 (20 years), and 87% since 2000 (inclusive; Figure 6). 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).

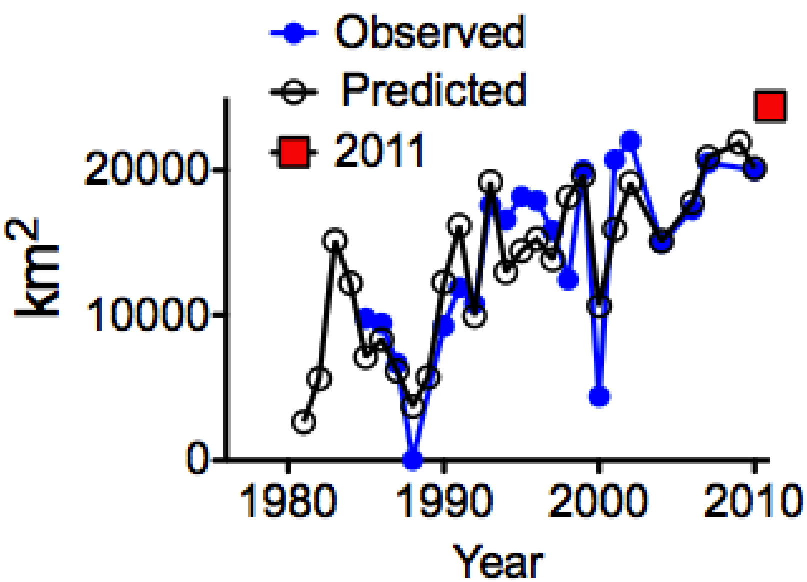


Figure 6. The measured and modeled size from 1976 to 2010, and the predicted size of the hypoxic zone for 2011. Years with unusual weather events (e.g., hurricanes and the anomalous 2009 weather patterns) are excluded.

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, for example, 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

Post-cruise Assessment

A post-cruise assessment will be made at the end of the summer shelfwide hypoxia cruise and posted on the same website where this report appears (www.gulfhypoxia.net).

Acknowledgments

Support was received from the NOAA Center for Sponsored Coastal Ocean Research, Coastal Ocean Program Grants No. NA09NOS4780204 to Louisiana Universities Marine Consortium and NA09NOS4780230 to Louisiana State University. Charlie Milan analyzed the nutrient samples for the Mississippi River at Baton Rouge and from offshore waters. Louisiana hypoxia data are from Rabalais et al., LUMCON. We thank Brent T. Aulenbach and colleagues at the USGS for providing the nitrogen loading data for the Mississippi River.

References

Bierman, V.J., Jr., S.C. Hinz, D. Zhu, W.J. Wiseman, Jr., N.N. Rabalais, and R.E. Turner 1994. A preliminary mass balance model of primary productivity and dissolved oxygen in the Mississippi River plume/inner Gulf Shelf region. **Estuaries** 17: 886–899.

Conley, D.J., J. Carstensen, G. Ærtebjrg, P.B. Christensen, T. Dalsgaard, J.L.S. Hansen, and A. B. Josefson 2007. Long-term changes and impacts of hypoxia in Danish coastal waters. **Ecological Applications, Supp.** 17: S165-S184.

Díaz, R.J. and R. Rosenberg 2008. Spreading dead zones and consequences for marine ecosystems. **Science** 321: 926-929.

Justić, D., N.N. Rabalais, and R.E. Turner 2003. Simulated responses of the Gulf of Mexico hypoxia to variations in climate and anthropogenic nutrient loading. **J. Mar. Systems** 42: 115-126.

MRGOM WNTF (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force) 2001 A*ction Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico*; Office of Wetlands, Oceans, and Watersheds, U.S. Environmental Protection Agency; Washington, DC.

MRGOM WNTF (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force) 2008. *Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico*. Office of Wetlands, Oceans, and Watersheds, U.S. Environmental Protection Agency, Washington, D.C.

Rabalais, N.N., R.E. Turner, and D. Scavia 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River**. BioScience** 52: 129-142.

Rabalais, N.N., R.E. Turner, B.K. Sen Gupta, D.F. Boesch, P. Chapman, and M.C. Murrell 2007. Hypoxia in the northern Gulf of Mexico: Does the science support the plan to reduce, mitigate and control hypoxia? **Estuaries and Coasts** 30: 753-772.

Rabalais, N.N., R.J. Díaz, L.A. Levin, R.E. Turner, D. Gilbert, and J. Zhang 2010. Dynamics and distribution of natural and human-caused hypoxia. **Biogeosciences** 7: 585-619.

Scavia, D., N.N. Rabalais, and R.E. Turner 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. **Limnol. Oceanogr**. 48: 951-956.

Scavia, D., D. Justić, and V.J. Bierman, Jr. 2004. Reducing hypoxia in the Gulf of Mexico: Advice from three models. **Estuaries** 27: 419–425.

Scavia, D. and K.A. Donnelly 2007. Reassessing hypoxia forecasts for the Gulf of Mexico. **Environ. Sci. Technol**. 41: 8111-8117.

Science Advisory Board (SAB) 2007. Hypoxia in the northern Gulf of Mexico, An Update. U.S. Environmental Protection Agency, Science Advisory Board (SAB) Hypoxia Panel Advisory, Report EPA-SAB-08-003, Environmental Protection Agency, Washington, D.C.http://yosemite.epa.gov/sab/sabproduct.nsf/C3D2F27094E03F90852573B800601D93/$File/EPA-SAB-08-003complete.unsigned.pdf

Turner, R.E., N.N. Rabalais, E.M. Swenson, M. Kasprzak, and T. Romaire 2005. Summer hypoxia, Northern Gulf of Mexico: 1978 to 1995. **Marine Environmental Research** 59: 65-77.

Turner, R.E., N. Qureshi, N.N. Rabalais, Q. Dortch, D. Justić, R. Shaw and J. Cope 1998. Fluctuating silicate:nitrate ratios and coastal plankton food webs. **Proc. National Academy of Sciences (USA)** 95: 13048-13051.

Turner, R.E., N.N. Rabalais, and D. Justić 2006. Predicting summer hypoxia in the northern Gulf of Mexico: Riverine N, P, and Si loading. **Marine Pollution Bulletin** 52: 139-148.

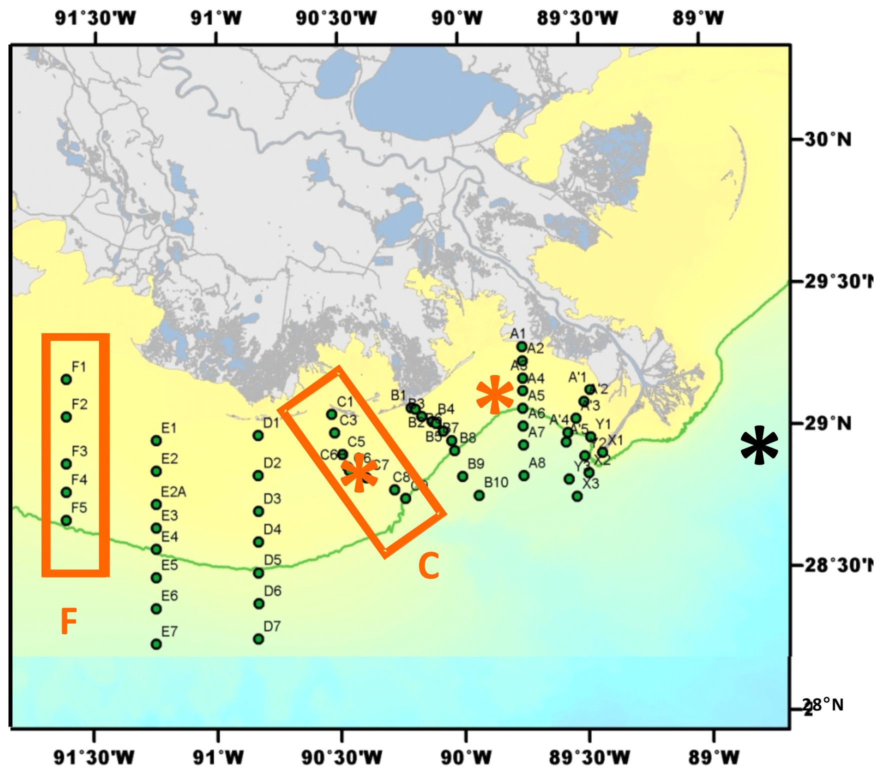
Turner, R.E., N.N. Rabalais and D. Justić 2008. Gulf of Mexico hypoxia: Alternate states and a legacy. **Environmental Science and Technology** 42: 2323-2327.

Contacts for Further Information

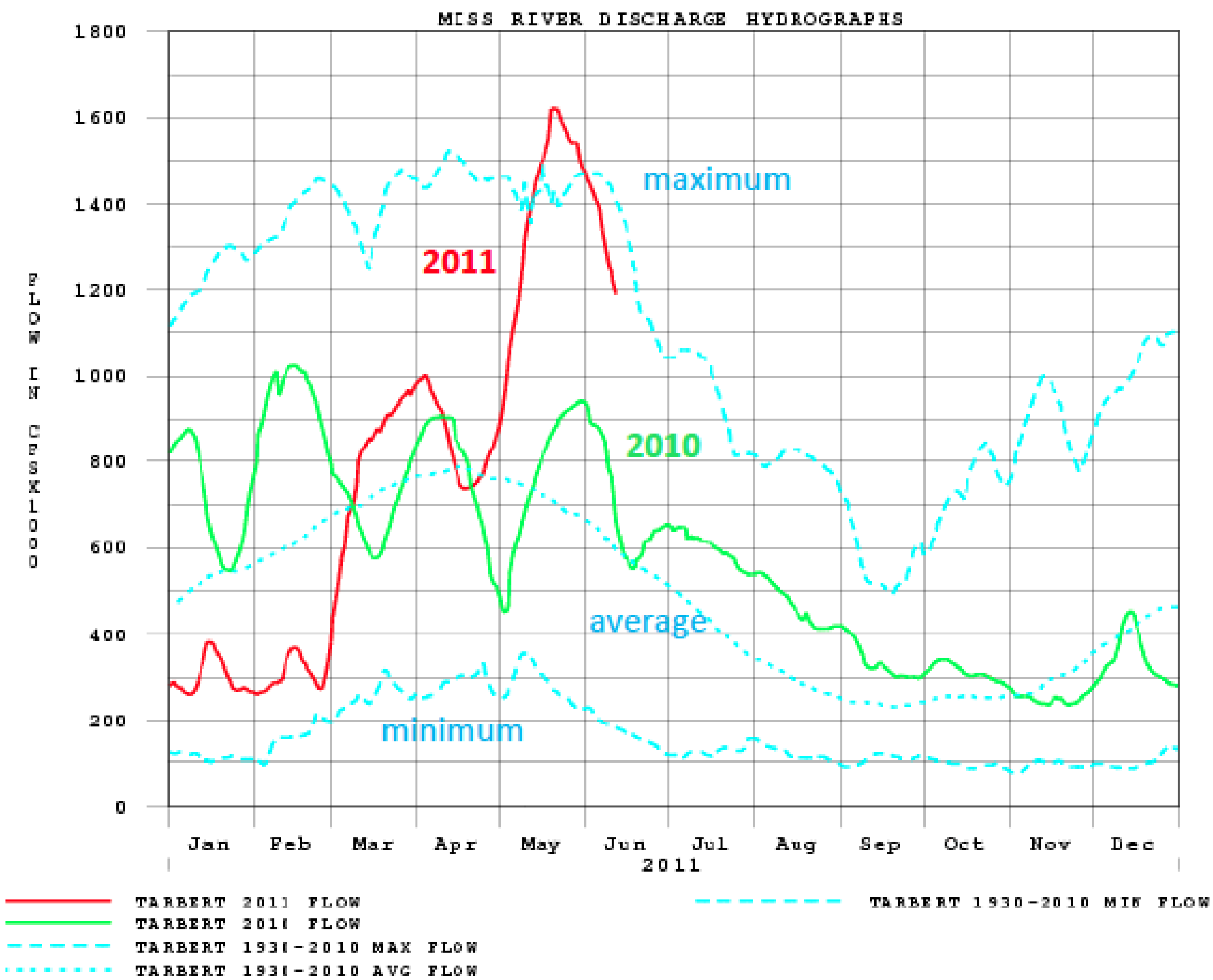
Nancy N. Rabalais (LUMCON, nrabalais@lumcon.edu)
R. Eugene Turner (LSU, euturne@lsu.edu)

Appendices

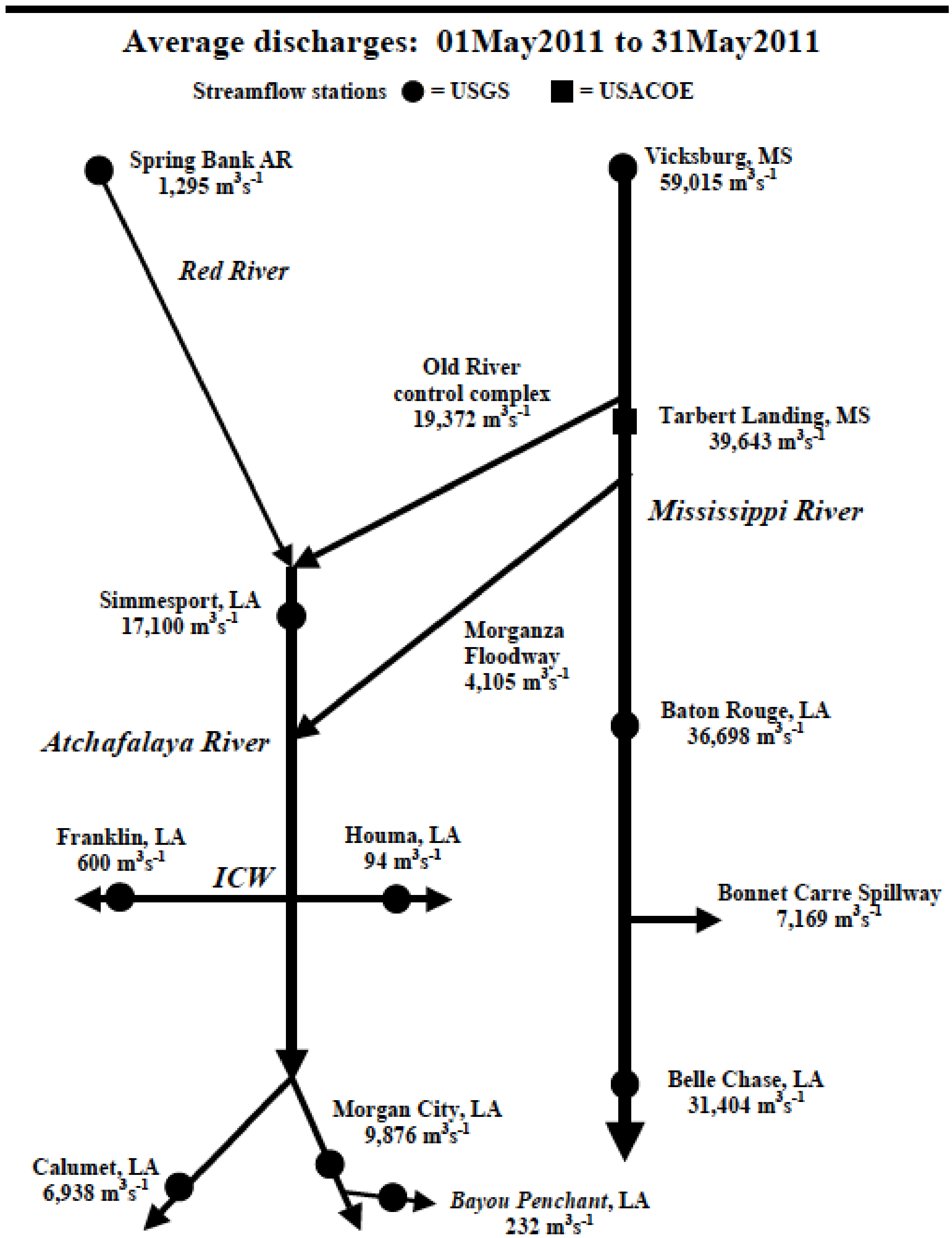
Appendix Figure 1. The study area.
Appendix Figure 2. The daily river discharge at Tarbert Landing through 12 June 2011.
Appendix Figure 3. The distribution of water into various entry points flowing into the Gulf of Mexico in May 2011.
Appendix Figure 4. Dissolved nitrate+nitrite concentration in the Mississippi River at Baton Rouge, LA.



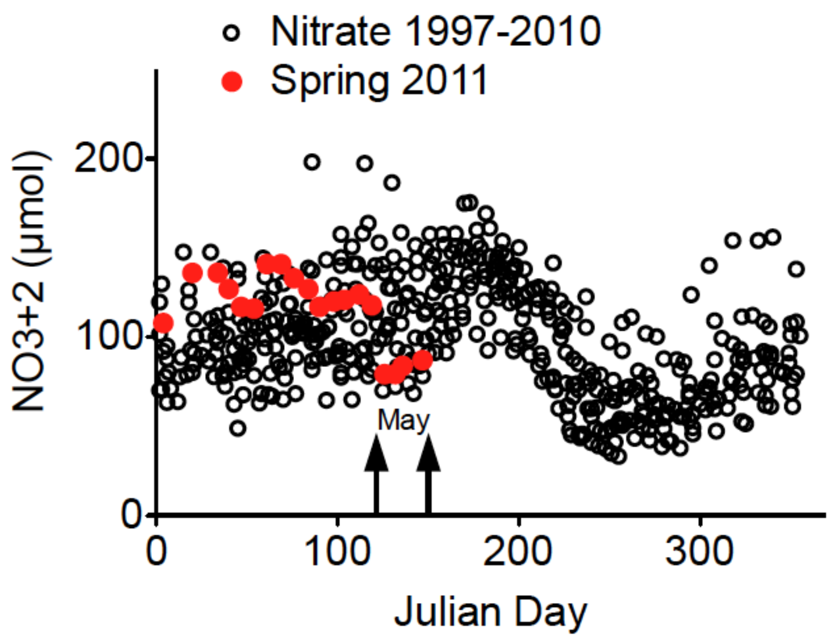
Appendix Figure 1. Location of transects off Terrebonne Bay (transect C) and Atchafalaya Bay (transect F) and ocean observing systems (orange asterisks) off Caminada Pass and Terrebonne Bay. The Deepwater Horizon oil spill in 2010 (black asterisk) is located 41 miles southeast of the Mississippi River delta.



Appendix Figure 2. The daily river discharge at Tarbert Landing through 12 June 2011. http://www.mvn.usace.army.mil/eng/edhd/tar.gif



Appendix Figure 3. The distribution of water from the Mississippi River in May, 2011. The data sources are the USACOE and USGS. The Figure was prepared by EM Swenson, LSU, 6 June 2011. These are preliminary calculations and subject to adjustment.



Appendix Figure 4. Nitrate concentration at Baton Rouge from 1997 through 26 May 2011.