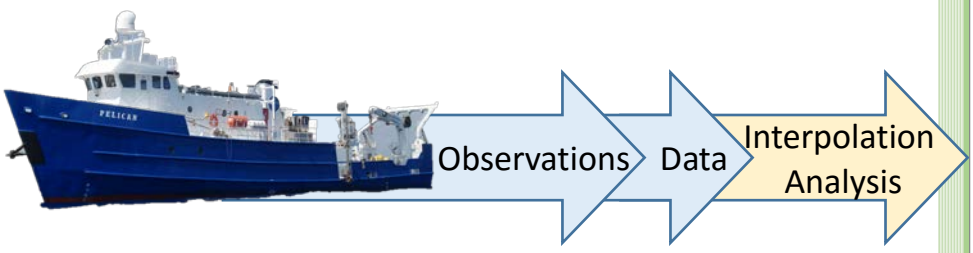
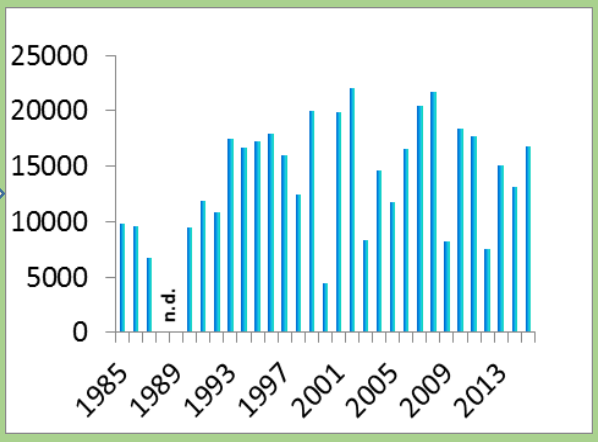
Gulf of Mexico Hypoxia Monitoring Strategy



Hypoxia Zone Areal Extent (km^2)



A White Paper by the Steering Committee of the:

6th Annual NOAA/NGI Hypoxia Research Coordination Workshop: Establishing a Cooperative Hypoxic Zone Monitoring Program

convened by the NOAA National Centers for Coastal Ocean Science and Northern Gulf Institute on 12-13 September 2016 at the Mississippi State University Science and Technology Center at NASA's Stennis Space Center in Mississippi.

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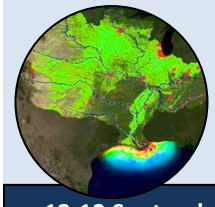
Abstract

The Gulf of Mexico Hypoxia Monitoring Strategy is a resource to inform the proceedings of the *6th Annual NOAA/NGI Hypoxia Research Coordination Workshop: Establishing a Cooperative Hypoxic Zone Monitoring Program*. It provides a framework for a cooperative hypoxia monitoring program based on programmatic and financial requirements that are designed to meet management needs. The Monitoring Strategy includes sections on management drivers, current monitoring capabilities and gaps, and projected programmatic, data, and financial requirements based on the input of multiple partners and the responses from a survey of modelers currently applying deterministic 3D time variable models to Gulf hypoxia assessment and prediction. The programmatic framework in this Monitoring Strategy will be refined at the workshop to identify the optimal monitoring requrements for management needs, and funding mechanisms and logistics of implementation based on the needs and constraints of partners.



6th Annual NOAA/NGI Hypoxia Research Coordination Workshop

Establishing a Cooperative Hypoxic Zone Monitoring Program

12-13 September, 2016 **Mississippi State University Science and Technology, Stennis Space Center, MS**

Workshop Goal: Identify and coordinate partner interests for establishing a cooperative monitoring program for the Gulf hypoxic zone that achieves management-driven objectives.

Workshop Objectives:

1. Identify the agency, interagency, private sector and institutional potential partners whose missions would be advanced by a robust and sustained Gulf hypoxia monitoring program.

2. Determine the monitoring program components most beneficial to potential partners.

3. Document potential partner roles in establishing a cooperative hypoxia monitoring program.

4. Determine the steps needed to establish a cooperative monitoring program, including available resources from ongoing, planned, or newly coordinated programs.

Expected Output: A workshop report will identify monitoring requirements linked to key management needs and the mechanisms, resources, and potential collaborations necessary to implement and sustain a monitoring program that includes the Hypoxic Zone and other Gulf ecosystem restoration issues.

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Hypoxia Monitoring Programmatic Framework

Background: Great progress has been made over the last 30 years in characterizing the magnitude, seasonality, and duration of the hypoxic zone in the northern Gulf of Mexico to reveal the conditions that influence hypoxia, develop hypoxia-based nutrient reduction targets in the basin, and to understand the widespread ecological and economic impacts of hypoxia. A competitive mechanism (Northern Gulf of Mexico Hypoxia and Ecosystems Assessment Program, NGOMEX) has been the principal source of funding for monitoring support of this effort by supporting shelf-wide ship surveys (including an annual mid-summer ship survey), cross-shelf transects, fixed observation systems, and more recently, glider technology development for monitoring the hypoxic zone. A competitive process is not a sustainable mechanism for supporting monitoring operations, and NGOMEX can no longer support hypoxic zone monitoring. A more robust and sustainable monitoring program is needed to assess management efficacy in mitigating hypoxia in the northern Gulf of Mexico, and to support ongoing hypoxia modeling and ecological forecasting efforts.

The *6th Annual NOAA/NGI Hypoxia Research Coordination Workshop*, titled *Establishing a Cooperative Hypoxic Zone Monitoring Program*, brings together partners whose missions would benefit from a strong hypoxic zone monitoring program. The objectives of the workshop are driven by management requirements for mitigating hypoxia but could also meet other Gulf restoration management needs that would benefit from observations and models supported by the monitoring program. Meeting minimum requirements for an operational monitoring program would mean that:

- The metric (mid-summer hypoxic zone areal extent) generated to assess progress toward the Hypoxia Task Force (HTF) Coastal Goal to mitigate hypoxia would be produced in a structured, consistent, and sustainable manner;
- Modelling tools needed to meet program objectives would no longer suffer severe data limitation;
- Data turnaround and accessibility would be improved with the goal to make data access real- or near real-time.

Establishing a cooperative monitoring program is not only urgently needed, but also achievable given the interests of multiple partners in hypoxia and related issues in the movement toward ecosystem approaches to Gulf restoration.

Management Drivers: This workshop builds upon efforts initiated in 2007 by *the Summit on Long-Term Monitoring of the Gulf of Mexico Hypoxic Zone: Developing the Implementation Plan for an Operational Observation System*, which led to the development by Gulf-based

Steering, Technical, and Stakeholder Committees of the Gulf of Mexico Hypoxia Monitoring Implementation Plan (2009, revised in 2012). The present workshop is framed by management drivers adapted from the Monitoring Implementation Plan.

Management Driver 1 - Define the HTF monitoring needs associated with determining the annual maximum areal extent and volume of the Gulf of Mexico hypoxic zone.

Management Need:

- provide monitoring data to ensure that management is informed of progress of hypoxia mitigation actions (e.g. progress toward the Coastal Goal of the HTF Action Plan, which calls for the hypoxic zone to be reduced to an annual average size of 5,000 km^2 by 2035).

The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force or Hypoxia Task Force (HTF) is an interagency collaborative that aims to "take action to reduce the size of the hypoxic zone, while protecting and restoring the human and natural resources of the Mississippi River Basin." The HTF *Action Plan's* Coastal Goal calls for the hypoxic zone to be reduced to a five year annual average size of 5,000 km^2 (1,928 mi^2) by 2035, with an interim target of a 20% reduction of nitrogen[1] and phosphorus[2] loading by 2025, relative to the baseline average Mississippi River/Atchafalaya River Basin nutrient loading to the Gulf of Mexico during the 1980-1996 period. A 31-year monitoring data set based on an annual ship survey that measures the mid-summer hypoxic zone areal extent (Fig. 1) is used to provide the HTF with a metric to base assessment of progress toward the Coastal Goal. This data set is the only long-term baseline upon which changes in hypoxic zone properties can be compared, and so its sustenance is important to all management efforts that aim to mitigate Gulf hypoxia (e.g. Louisiana Coastal Master Plan, Landscape Conservation Cooperative Mississippi River Basin/Gulf Hypoxia Initiative) or that target ecosystem restoration goals that include the hypoxic zone region (see Appendix C. *Potential hypoxia monitoring program collaborators and beneficiaries*). Management Driver 1 focuses on the requirements needed to most effectively continue to obtain this metric (mid-summer hypoxic zone areal extent) as well as hypoxic zone volume as an additional analytical metric of hypoxia magnitude.

[1] Total N baseline (1980-1996): 1.58 million metric tons. Nitrogen would need to be reduced to approximately 1.26 million metric tons by 2025.

[2] Total P baseline (1980-1996): 138,033 metric tons, predicted by composite method. Phosphorus would need to be reduced to 110,400 metric tons by 2025.

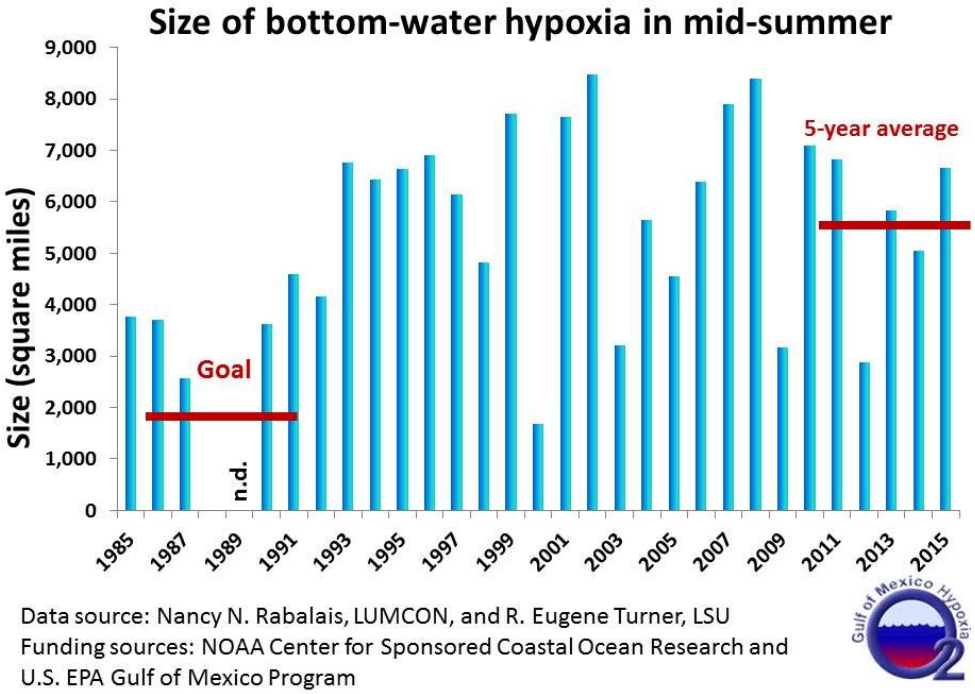


Figure 1. Long-term monitoring data set showing mid-summer areal extent of hypoxic zone.

Management Driver 2 - Define monitoring variables and the spatial and temporal sampling needs to support robust modeling and forecasting capabilities for both empirical and coupled 3-dimensional modeling platforms that are required to meet critical management objectives for hypoxia mitigation and other Gulf ecosystem restoration goals.

Management Needs:

- provide data for predictive models to develop scenario forecasts of hypoxia given alternative management targets for nutrient reduction and alternative scenarios of river diversions, climate change, and other interactive factors;
- provide data to support models to quantify the relationship between hypoxic zone magnitude, timing, and distribution, and the distribution, production, and health of ecologically and commercially important finfish and shellfish.

The nutrient reduction targets needed to meet HTF hypoxia mitigation goals are informed by scenario forecast models that predict the quantitative relationship between nutrient loading (from USGS collected data) and hypoxic zone areal extent (from the mid-summer ship survey described under *Management Driver 1* section above). For example, the EPA Science Advisory Board report (USEPA 2007) that provided guidance for the HTF 2008 Action Plan used model

estimates from three scenario forecast models (described in Scavia et al. 2004 and Scavia and Donnelly 2007) to recommend 45% TN and 45% TP reductions needed to achieve the 5,000 km^2 Coastal Goal:

- Bierman et al.'s (1994) complex 3-D, food-web-nutrient-oxygen dynamics model;
- Justic´ et al.'s (1996, 2002) box model simulating two-layer, time-dependent, oxygen dynamics; and
- Scavia et al.'s (2003) model simulating summer steady-state, one-dimensional horizontal dynamics of nutrient-dependent production, respiration of organic matter, and resulting oxygen balance.

In order to facilitate continued application of scenario forecast models to inform HTF nutrient reduction targets, the NOAA National Centers for Coastal Ocean Science (NCCOS) is supporting a study to transition four "empirical models" from R&D status to operational capability. These are relatively simple models, structured by observed relationships or correlations between experimental or observed data. The models include:

- Scavia et al.'s (2013) S-P Bayesian scenario and forecast model;
- Turner et al.'s (2012) regression model;
- Forrest et al.'s (2011) multivariable regression model; and
- Obenour et al.'s (2015) Bayesian biophysical model.

These four models are also used to produce an ensemble seasonal forecast to predict the mid-summer areal extent based on USGS measurements of nutrient loading in May. The forecast is issued via a joint NOAA/USGS press release, which greatly heightens public awareness of the importance of the HTF mission.

The HTF and other management users (Appendix C. *Potential hypoxia monitoring program collaborators and beneficiaries*) also require the capacity to forecast the magnitude, seasonality, duration, and distribution of hypoxia in the Gulf of Mexico based on the timing and magnitude of watershed nutrient loading and in light of a changing landscape (e.g. river diversions) and climate. This capacity requires the application of "deterministic models" (relatively complex mechanistic models that are based on an explicit representation of the physical, biological, and/or chemical processes of an ecosystem) that allow for a more dynamic representation of the effects of nutrient loading and other causative factors on Gulf hypoxia. Without these models, the HTF could only monitor changes in the maximum extent of the hypoxic zone and could not identify changes in the timing or extent of the zone in relation to nutrient loading. For example, scientists studying the Chesapeake Bay first observed improvements in a shorter duration of hypoxia rather than changes in magnitude, and recognized that climatological changes are having an effect that masks some of the desired effects of nutrient reduction (Murphy et al. 2011). Without deterministic models, and a long term monitoring program, positive progress might not have

been recognized in the Chesapeake Bay. Deterministic models currently in development to fill this need for Gulf hypoxia include:

- Justic' and Wang's (2009, 2014) 3-D coupled hydrodynamic (FVCOM-LATEX) water quality model
- Hetland and DiMarco's (2012) 3D dynamically coupled (ROMS hydrodynamic model)
- Fennel et al.'s (2011) 3D dynamically coupled (biogeochemical model)
- Ko et al.'s (2008) EPA-COMGEM 3D hydrodynamic biogeochemical model

These models, developed under the NGOMEX and/or the U.S. Integrated Ocean Observing System's (IOOS') Coastal Ocean Modeling Testbed (COMT) programs, are in the implementation plan of the NOAA Ecosystem Forecast Roadmap Initiative for eventual transition to an operational framework.

River diversions represent a large-scale management intervention that requires a mechanistic modeling platform capable of spatially predicting oxygen concentrations, because these diversions may relocate nutrient loading, as well as potentially reducing it. The Louisiana Coastal Protection and Restoration Authority (CPRA) has a coastal master plan aimed at protecting Louisiana's coasts, and river diversions are a key intervention. The plan aims to divert Mississippi River water back to historical flow patterns that inundate wetlands and restore sediment and nutrient delivery to wetland and coastal edges. To assess the progress of this management practice and understand the complex effects this might have on hypoxia and other features, additional localized monitoring will be needed and a well formed mechanistic modeling platform will be required.

Large-scale ecosystem restoration efforts such as the HTF and Mississippi River diversions, independently and in concert, will have a great, but unknown, effect on living resources and their habitats. The ability to assess and predict these effects is important to ensuring that restoration management is informed by the best available science, and that decision-making can adjust to advances in understanding ecosystem responses (i.e. "adaptive management"). A suite of ecological models focused on the northern Gulf has advanced in recent years (reviewed in Rose and Sable 2013, Ashby et al. 2015) and are being considered as important management tools for evaluating fisheries responses to a dynamic Gulf ecosystem (which includes human dimensions).

A proceedings paper (Ashby et al. 2015) from the *5th Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop* emphasized two limitations of ecological model applications to address fisheries responses:

- data availability for parameterization, baselines, calibration, and validation;
- availability of (and linkage to) spatial hydrodynamic and landscape evolution models.

Previous and Current Monitoring Activities

Management Driver 1: Define the HTF monitoring needs associated with determining the annual maximum areal extent and volume of the Gulf of Mexico hypoxic zone.

Mid-summer Ship Survey - The mid-summer ship survey (Fig. 2, blue dots, and Fig. 3) measures the annual hypoxic zone areal extent (Rabalais et al. 2002, 2007). Use of this metric to inform the HTF of progress towards its Coastal Goal to reduce the areal extent to 5,000 km^2 has advantages in terms of longevity, practicality, and public understanding. Over 31 years, the protocol for the LUMCON/LSU cruises was for CTD casts and a rosette with Niskin bottles to measure and collect water. In addition, a separate CTD (Hydrolab or YSI) was lowered to within 0.5 m of the seabed to obtain data 1 to 2 m below where probes on the rosette were able to sample.

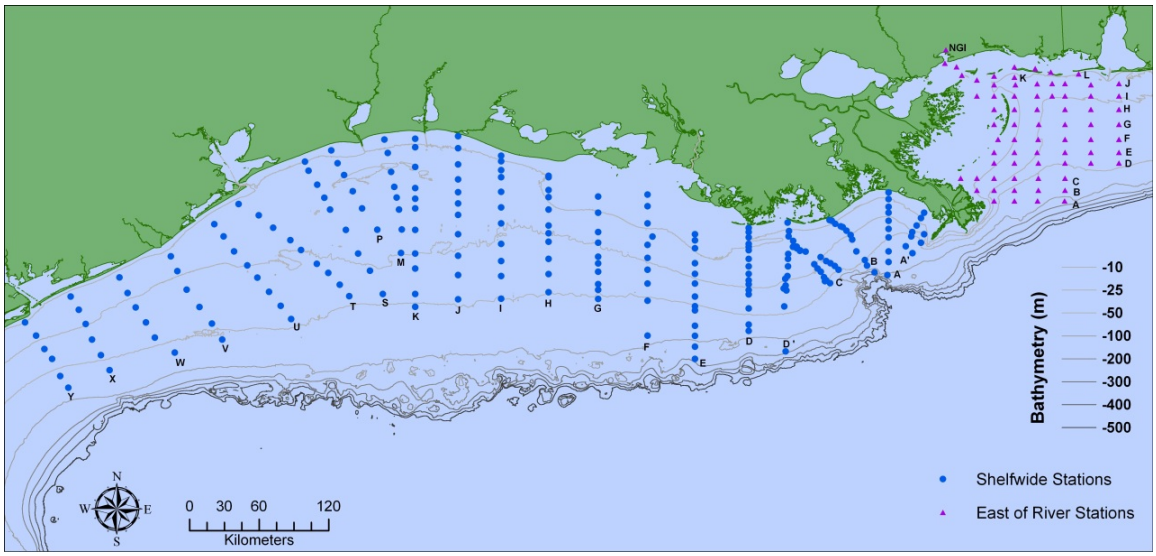
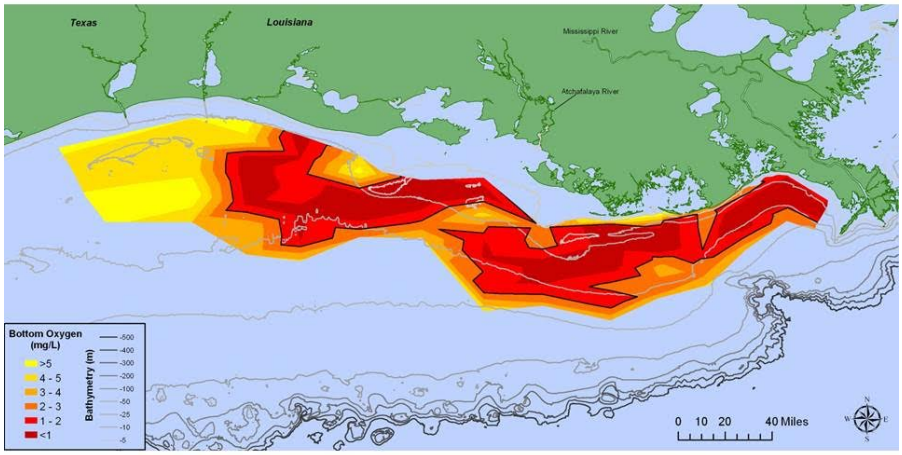


Figure 2. Existing shelfwide grid west of the Mississippi River (blue dots), and sampling sites periodically sampled east of the Mississippi River since 2011 (purple triangles). Map from Rabalais et al.



Distribution of bottom-water dissolved oxygen July 28-August 3, 2015 west of the Mississippi River delta. Black line denotes dissolved oxygen less than 2 mg/L.

Data source: Nancy N. Rabalais, LUMCON, and R. Eugene Turner, LSU
Funding sources: NOAA Center for Sponsored Coastal Ocean Research and U.S. EPA Gulf of Mexico Program

Figure 3. Map of mid-summer hypoxic zone areal extent sampled in 2015.

The mid-summer ship survey was fully supported through the NGOMEX competitive program until 2014, when the EPA Gulf of Mexico Program also provided support. In 2015, NOAA NCCOS funded the cruise, using the R/V *Pelican* following past protocol. NCCOS support was also provided in 2016, and the plan was to use the NOAA vessel, the R/V *Nancy Foster*, in a pilot study to determine the comparative effectiveness of this ship vs. R/V *Pelican* use in generating the hypoxic zone areal extent. Unfortunately, the *Nancy Foster* suffered engine problems, and there was no official measurement of the dead zone in 2016 to extend the 31-year monitoring data set. Although a comparative analysis of the alternative ship sources (*Pelican* vs. *Nancy Foster*) based on data acquisition is not currently possible, the pros and cons of each will be presented at the workshop for attendee assessment of best future practice.

Management Driver 2: Define monitoring variables and the spatial and temporal sampling needs to support robust modeling and forecasting capabilities for both empirical and coupled 3-dimensional modeling platforms that are required to meet critical management objectives for hypoxia mitigation and other Gulf ecosystem restoration goals.

Nutrient Loading - U.S. Geological Survey (USGS) has monitored streamflow and water quality systematically in the Mississippi-Atchafalaya River Basin (MARB) for more than five decades. Estimates of monthly streamflow and nutrient fluxes from the Mississippi and Atchafalaya Rivers to the Gulf of Mexico are based on data from a number of lower Mississippi River basin sampling stations with long-term stream discharge and water-quality data so that the load

estimates provide both a long-term record and a good measure of the delivery of nutrients to the Gulf (see http://toxics.usgs.gov/pubs/of-2007-1080/gulf_site.html). Nutrient fluxes from the MARB to the Gulf of Mexico are calculated as the sum of nutrient loads from the Mississippi and Atchafalaya Rivers. Mississippi River nutrient fluxes are estimated using water quality from a station near St. Francisville, Louisiana, and stream discharge from a station at Tarbert Landing, Mississippi. Atchafalaya River nutrient fluxes are estimated using water quality from a station at Melville, Louisiana, and stream discharge from a station at Simmesport, Louisiana. The statistical load estimation procedure for Mississippi River nutrient fluxes also incorporates the flow diverted to the Atchafalaya River via the Old River Outflow Channel as measured at Knox Landing along with flows from two upstream stations, the Mississippi River at Thebes, Illinois, and the Ohio River at Metropolis, Illinois. Nutrient flux estimates are provided for six water-quality constituents: dissolved nitrite plus nitrate, total organic nitrogen plus ammonia nitrogen, dissolved ammonia, total phosphorous, dissolved orthophosphate, and dissolved silica.

Turner et al. also have been monitoring nutrients in the Mississippi River in Baton Rouge since 1997 on a biweekly or weekly (between March and September) basis (example data in Turner et al. 2007).

Ship Surveys – In addition to the mid-summer ship survey described under the *Management Driver 1* section, other ship monitoring surveys have been conducted in the past but were discontinued due to lack of funding. From 1985 to 2011, cross-shelf transects were conducted by LUMCON/LSU on a monthly to bimonthly basis south of Terrebonne Bay (Fig. 4, Transect C) and off Atchafalaya Bay (Fig. 4, Transect F) from 2004 to 2011. These transects allowed greater temporal coverage of conditions in key areas within the hypoxic area.

Additional shelf-wide cruises west of the Mississippi Delta were conducted from 2009 to 2014 for the months of June and August in which the Texas A&M University (TAMU) hypoxia research group used a towed scan-fish from aboard NOAA's *R/V Manta* to map hypoxia and related parameters over a grid that encompassed the area of the mid-summer cruises aboard the *R/V Pelican* (Fig. 5). The TAMU cruises also conducted CTD profiles at many stations along the scan-fish grid.

Cruises specifically for summer hypoxia have been conducted east of the Mississippi River off Mississippi and Alabama by researchers at the University of Southern Mississippi (USM), Dauphin Island Sea Lab (DISL), and the LUMCON/LSU group, and more inshore by the Lake Pontchartrain Basin Foundation. USM carried out monthly sampling that included bottom

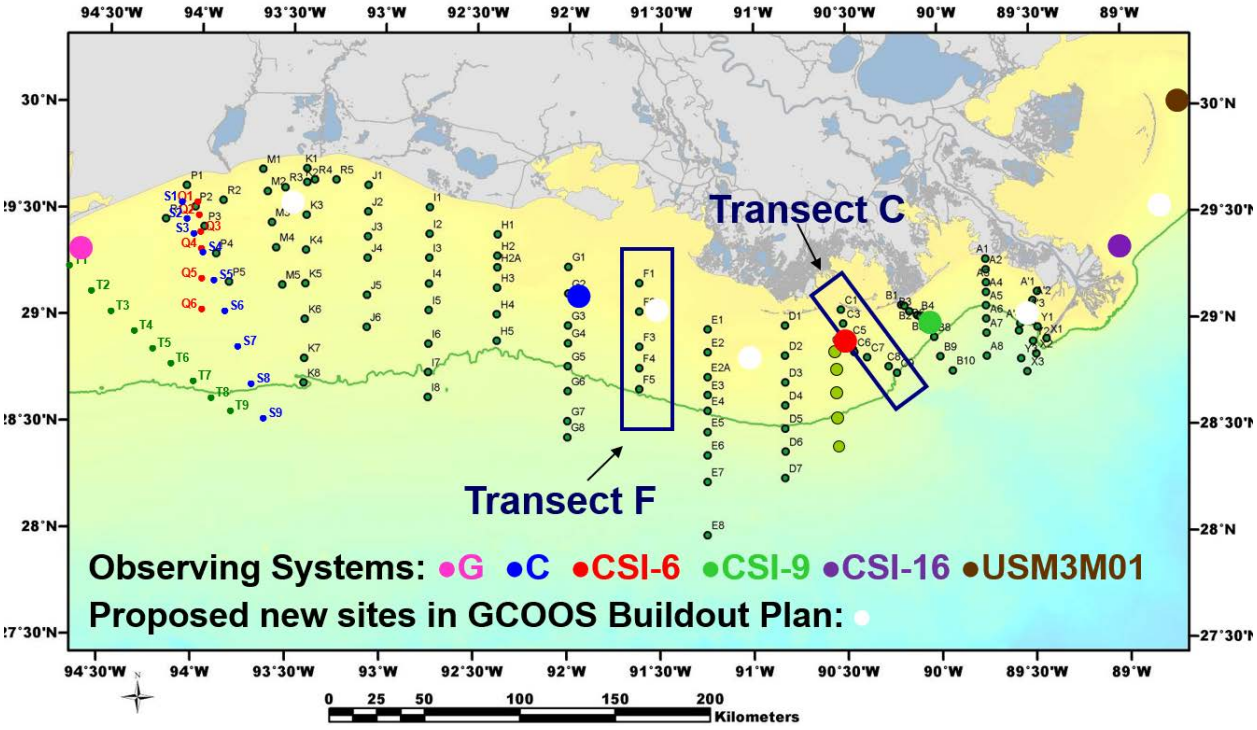


Figure 4. Ship shelf-wide sampling sites and transects west of Mississippi Delta, and observing system sites that currently exist (colored) or are in the Gulf of Mexico Coastal Ocean Observing System (GCOOS) Buildout Plan (white); see Table 1.

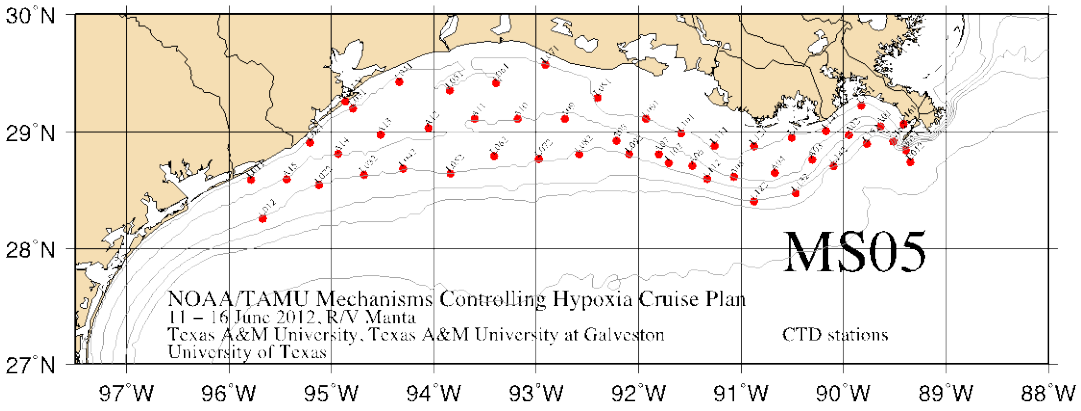


Figure 5. Sample TAMU station grid for CTD profiled. Scan-fish is operated through the water column over the entire area (from Howden et al. 2014; Glider Implementation Plan).

dissolved oxygen measurements on an offshore transect in the Mississippi Bight between 2007 and 2011 (Fig. 6, green dots), and mapped the extent of hypoxia east of the delta in 2006, 2008 and 2011 (Fig. 6). In addition, cruises by LUMCON/LSU on the grid to the east of the Mississippi River (Fig. 2, purple triangles, and Figs. 7-8) occurred in 2011, as well as by DISL in 2012 and 2013.

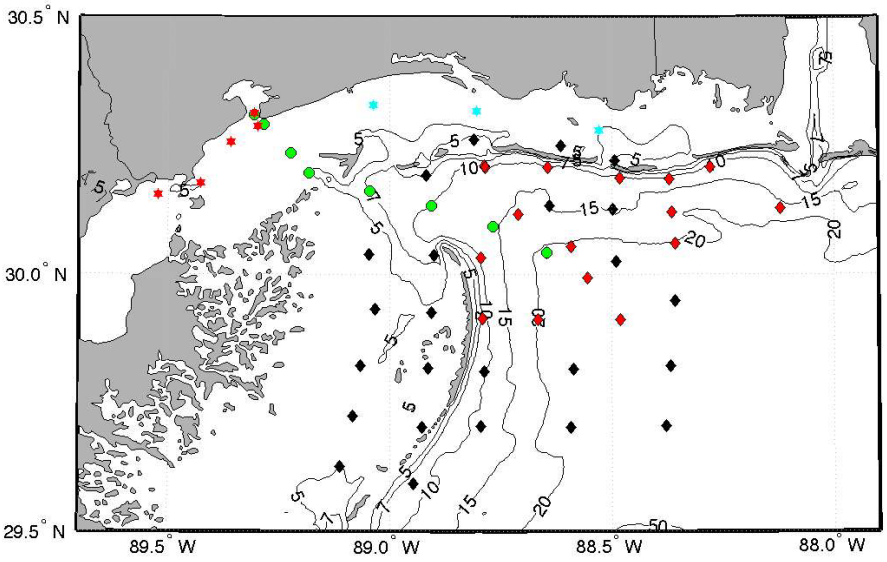


Figure 6. Green dots are the NGI line stations. Red stars are the USM "BCS" line that was established after the Bonnet Carre Spillway was opened in 2008. The red diamonds are the stations that USM occupied during a hypoxia event in 2006. The black diamonds are the additional hypoxia stations USM sampled during hypoxia events in 2008 and 2011. Similar stations sampled by LUMCON/LSU are in Fig. 2 (purple triangles) and Fig. 7 (adapted from Howden et al. 2014; Glider Implementation Plan).

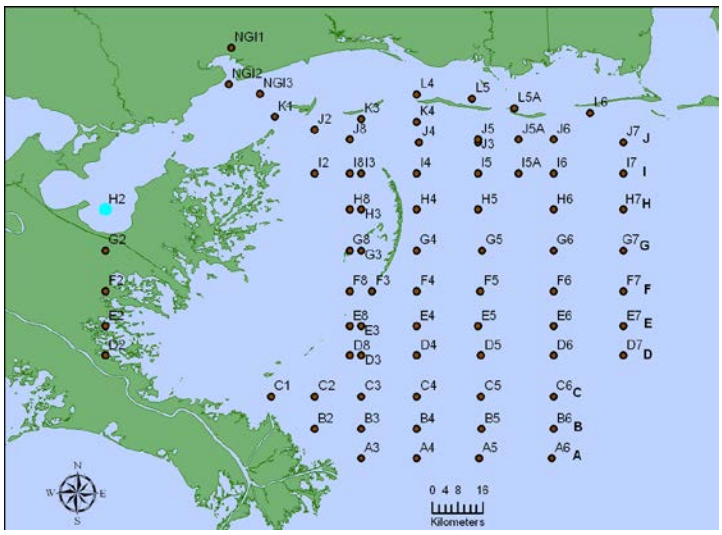


Figure 7. LUMCON/LSU sampled stations in the Mississippi Bight.

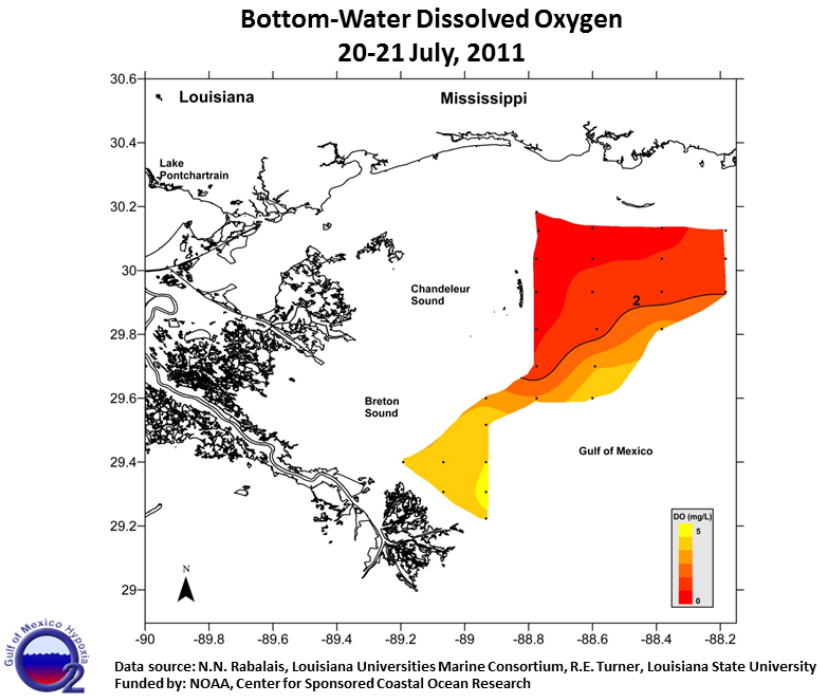


Figure 8. Distribution of hypoxia east of the Mississippi River during the 2011 summer flood. Not all of the hypoxic area was sampled. Hypoxia lasted until September at least off Mobile area. Source: N Rabalais (LUMCON)

The Southeast Area Monitoring and Assessment Program (SEAMAP) includes a summer groundfish survey conducted aboard the NOAA *RV Oregon II* (Fig. 9). The survey follows a stratified random design to sample fishes and invertebrates with a bottom trawl, and ichthyoplankton with neuston and bongo nets, and acquire environmental profile data at stations east of the Mississippi River and in the area between the 10 m and 200 m isobaths in the western and north-central Gulf of Mexico. About 200 to 250 environmental profiles are acquired during three cruise legs conducted in June and July. Since 2001, the bottom dissolved oxygen (DO) data have been available to researchers in near real-time to support hypoxia research. The data are also used to generate bottom DO maps for the Gulf of Mexico Hypoxia Watch program (http://www.ncddc.noaa.gov/ecosystems/hypoxia) jointly operated by the NOAA National Centers of Environmental Information (NCEI) and National Marine Fisheries Service (NMFS). The NOAA vessel *Oregon II* does not operate shallower than 20 m (maybe 18 m at times) and therefore won't capture shallow portions of the hypoxic zone. Since 1996, sampling of nearshore stations for DO has been conducted by the Louisiana Department of Wildlife and Fisheries (LDWF) through funding from the NMFS.

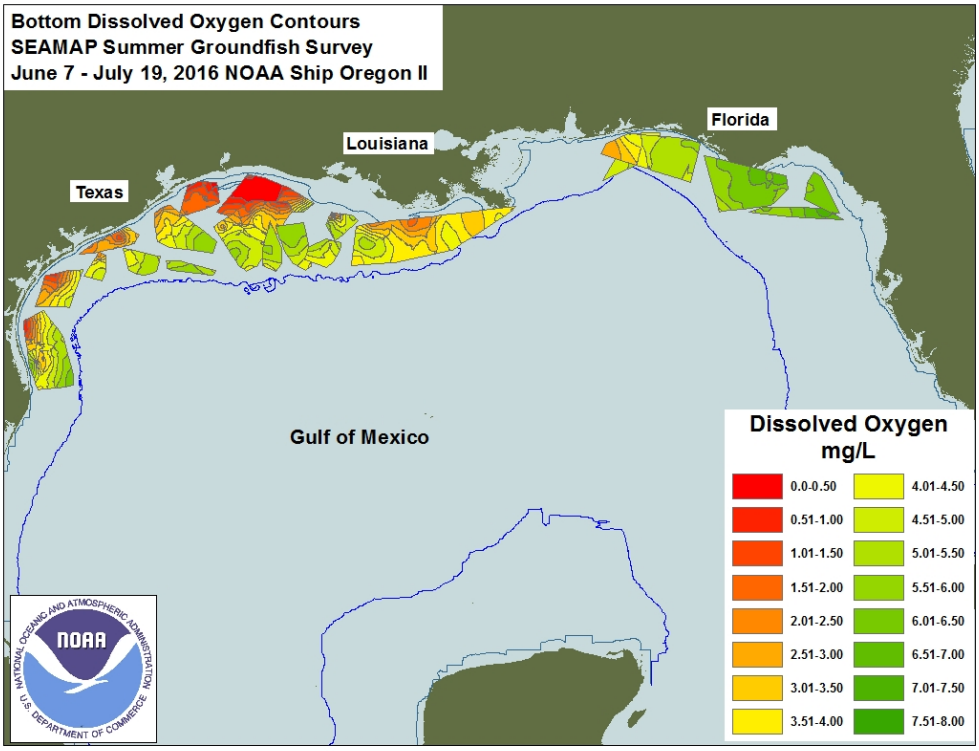


Figure 9. DO contours from 2016 SEAMAP groundfish survey.

Fixed Observation Systems – Deployed oxygen meters at observing systems along the Louisiana/Mississippi shelf have provided high temporal resolution but on limited spatial scales. Platforms for six observing systems within the hypoxic zone area exist, including four west and two east of the Mississippi Delta (Fig. 4, Table 1). None of the four west of the Delta are being periodically maintained due to funding limitations.

Gliders - The use of gliders as a potentially efficient and cost-effective monitoring mechanism for Gulf hypoxia was introduced as a core system requirement in the Gulf of Mexico Hypoxia Monitoring Implementation Plan (2009, revised in 2012), and explored at the *Gulf Hypoxia Glider Application Meeting*, held in April 2013 as part of the *Forum for Gulf of Mexico Hypoxia Research Coordination and Advancement*. The potential application of gliders for operational monitoring of hypoxia was acknowledged at the meeting, and afterward, a plan was developed for implementation - the Glider Implementation Plan.

A project to demonstrate the use of gliders in monitoring hypoxia in the Northern Gulf of Mexico was conducted during the 2014 hypoxia season, supported by NOAA NCCOS and IOOS, and included in-kind support from NCCOS' NGOMEX Program, USM, GCOOS, TAMU, and Teledyne Webb Research. The gliders were deployed in Summer 2014, in conjunction with shipboard hypoxia measurements from a cruise directed by Steven DiMarco,

TAMU Geochemical and Environmental Research Group (GERG). The coordinated mission allowed for comparisons between the glider- and cruise-collected data in a highly vertically stratified, shallow, and heavily ship-trafficked region of the Gulf of Mexico.

Table 1. Hypoxia monitoring stations over the Louisiana-Texas Shelf (MR = Mississippi River; AR = Atchafalaya River); Table 2.4 from GCOOS Buildout Plan V1a.

Description	Longitude (°W)	Latitude (°N)	Area	Comment
LUMCON *C6C* or WAVCIS/BIO2 *CSI-6*	-90°29' W	28°52' N;	West of MR	Existing
LUMCON and WAVCIS/BIO2 *CSI-9*	-89°58'W	29°06'W;	West of MR	Existing
TAMU *D*	-93° W	29°20' N;	West of MR	Existing
TAMU *C*	-92° W	29° N.	West of MR	Existing
USM *USM3M01*	-88° 39' W	30° N	East of MR	Upgrade
LSU *CSI-16*	-89° 02' W	29°24' N	East of MR	Upgrade
System 4	-89°35' W	28°57' N	MR Outflow	New
System 1	-93°36' W	29°27' N	West of AR Outflow	New
System 3	-91° W	28°48' N	West of MR	New
System 6	- 88°46' W	29°37' N	East of MR	New
System 2	-91°37' W	28°53' N	West of MR	New

The three main objectives of the project were to demonstrate that gliders can:

1. profile over the full water column, even in the highly vertically-stratified Northern Gulf;
2. take measurements, in profiling mode, very close to the seafloor; and
3. hover within the bottom one meter of the water column.

The research group successfully operated two gliders in the hypoxic zone of the northern Gulf of Mexico during the testing period. Three missions lasted about 100 days total and focused principally on the 20 meter isobath. All of the gliders used Conductivity-Temperature-Depth (CTDs), fluorometers, and DO sensors. The gliders consistently came within 1.6 m of the bottom during the three missions. Dissolved oxygen and salinity were all successfully measured during the runs. The statistics indicate that it may be possible to get closer, within one meter of the bottom, but there is a substantial increase in the probability of encountering the bottom, which will increase the risk of damage or failure of the glider. Data from the project was made available in near real-time on the GCOOS GANDALF: Gulf AUV Network and Data Archiving Long-term Storage Facility Data Portal.

DiMarco is currently conducting a pilot study (NGOMEX award; FY15-FY17) to further determine the efficacy of glider application to Gulf of Mexico hypoxic zone monitoring.

Data Management – Two organizations maintain data management systems that archive physical, chemical, and biological observations from the Gulf of Mexico; GCOOS and NCEI. The general flow of data to these programs can be found below (Fig. 10) for the major monitoring classification types. GCOOS and NCEI archive data from independently funded research projects, externally funded research projects, and federally funded long term monitoring activities, as well as download data from each other's publicly accessible data portals, as needed. In some cases, organizations carrying out research projects or federally funded monitoring activities, provide data directly to both NCEI and GCOOS. Given the wide array of data being collected, from different sources and techniques, formal data management plans are playing an increasingly important part of ongoing and future monitoring programs, see *Monitoring Program Data Requirements* section below.

Data are primarily derived from monitoring program participants that collect in-situ measurements or collect samples for laboratory analyses from 3 major platform types: moored buoys, ships, and autonomous gliders. While the collection of dissolved oxygen is the primary measurement focus of this program, other marine meteorological, physical oceanographic, and biogeochemical data are collected. These can include the following:

- physical parameters: wind speed and direction, air temperature and pressure, relative humidity and radiation; in seawater: bathymetry, velocity, temperature, conductivity, pressure;
- optical parameters: fluorescence, CDOM, PAR, turbidity, transmission, reflectance, attenuation, absorption, and scattering;
- chemical parameters: nutrients, pigments, carbon, pH, pCO2, and total alkalinity;
- biological information planned includes: primary productivity; abundance and taxonomies of: phytoplankton, zooplankton, fish, and coral based on diver surveys, net tows, fish tag telemetry, passive and active acoustics, microscopic imaging and towed cameras.

Users may also collect remotely-sensed or related variables such as AVHRR, MODIS, and VIIRS satellite images to measure sea surface temperature, chlorophyll *a*, seaweed and oil slick density, euphotic depth, and fronts. High-frequency coastal radars can be used to measure surface currents. Genomics, DNA sequencing, and stable isotope tissue analyses can be applied to various developmental stages of fish. Contaminant concentrations in sediments and fish can be measured and fish demographics and health assessed.

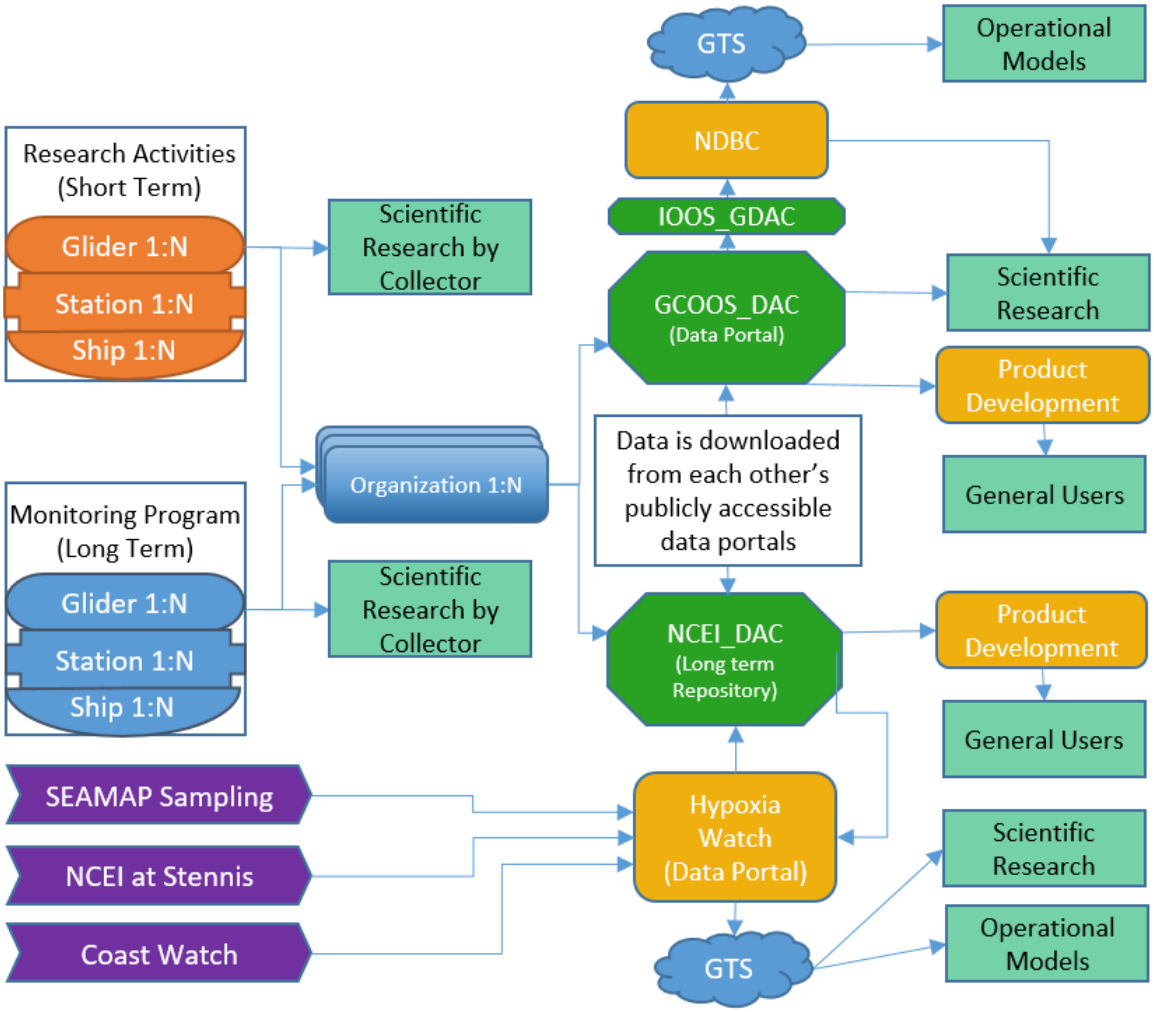


Figure. 10. Data collectors (organizations) in the Gulf of Mexico often provide data to either NCEI, GCOOS, or to both organizations directly. Data are also indirectly transferred through GCOOS and NCEI through their data portals that make data publicly available. NCEI principally operates as a long term digital repository for observations, while GCOOS operates as a data portal that functions to make data available in similar format to improve the usability of the data. Scientific research is able to be accomplished by the original data collector and by others who are able to download the data from NCEI or GCOOS data portals. If models become operational they can be set up to routinely gather the data and provide output. Abbreviations include: DAC – Data Assembly Center, GCOOS – Gulf of Mexico Coastal Ocean Observing System, GDAC – Global Data Assembly Center, GTS – Global Telecommunication Service, IOOS – Integrated Ocean Observing System, NCEI – National Centers for Environmental Information, NDBC – National Buoy Center, NODC – National Oceanic Data Center, SEAMAP – Southeast Area Monitoring and Assessment Program.

Monitoring Data Requirements

Management Driver 1: Define the HTF monitoring needs associated with determining the annual maximum areal extent and volume of the Gulf of Mexico hypoxic zone.

Meeting this management need requires that a ship survey program to derive the mid-summer hypoxic zone areal extent and volume be sustained. See Table 2 for the monitoring requirements to support Management Driver 1.

Management Driver 2: Define monitoring variables and the spatial and temporal sampling needs to support robust modeling and forecasting capabilities for both empirical and coupled 3-dimensional modeling platforms that are required to meet critical management objectives for hypoxia mitigation and other Gulf ecosystem restoration goals.

See Table 3 for the monitoring requirements to support Management Driver 2.

Deterministic Modeler Survey – As preparation for the workshop, the Steering Committee surveyed Gulf hypoxia modelers on monitoring/observational needs to support models used for assessing and predicting hypoxia dynamics. Four modeling groups were selected who currently are developing deterministic models containing a coupling of physically-based three dimensional hydrodynamic models and biogeochemically-based water quality models, and that can specifically make spatial DO predictions in the Gulf throughout the year (see Appendix B). The models were described in Aikman et al. (2014), "Modeling Approaches for Scenario Forecasts of Gulf of Mexico Hypoxia," which was developed by a Modeling Technical Review Panel at the *4th Annual NOAA/NGI Hypoxia Research Coordination Workshop*.

The modelers were asked to provide information on data requirements for model forcing and validation, including the minimum requirements that ensure the model will be able to provide credible estimates of the space and time dimensions of DO, especially during the hypoxic period. The needs are compiled in Table 4.

These models require data to set up (initialization variables) and drive the models (forcing variables, similar to initialization), and to assess how well the model is representing reality (model validation variables). Table 4 includes each model variable requested by the modelers and the model use, and provides details about whether the variable is recorded over the region (collected by ship, glider, or satellite) or at a fixed point (sea floor, buoy, or platform mounted sensor). We also provide details on the location, timing, and interval of collection, and if the data are being collected now. If we report that the data are intermittently collected, it refers to monitoring that is not regularly performed. Those variables listed as required infrequently reflect variables that are important to understanding relationships in the model, but the sampling is too

rigorous to be included as part of an operational program. Competitive funding would be suitable for the study of "infrequent validation" variables.

The sections below on *Ship Surveys, Fixed Observation Systems,* and *Gliders* provide general conclusions on data requirements from the Deterministic Modeler Survey results.

Nutrient Loading - USGS will continue monitoring watershed nutrient loading to the Gulf. The primary improvement suggested in the survey was an increase in sampling interval from monthly to daily to be able to achieve real-time model predictions.

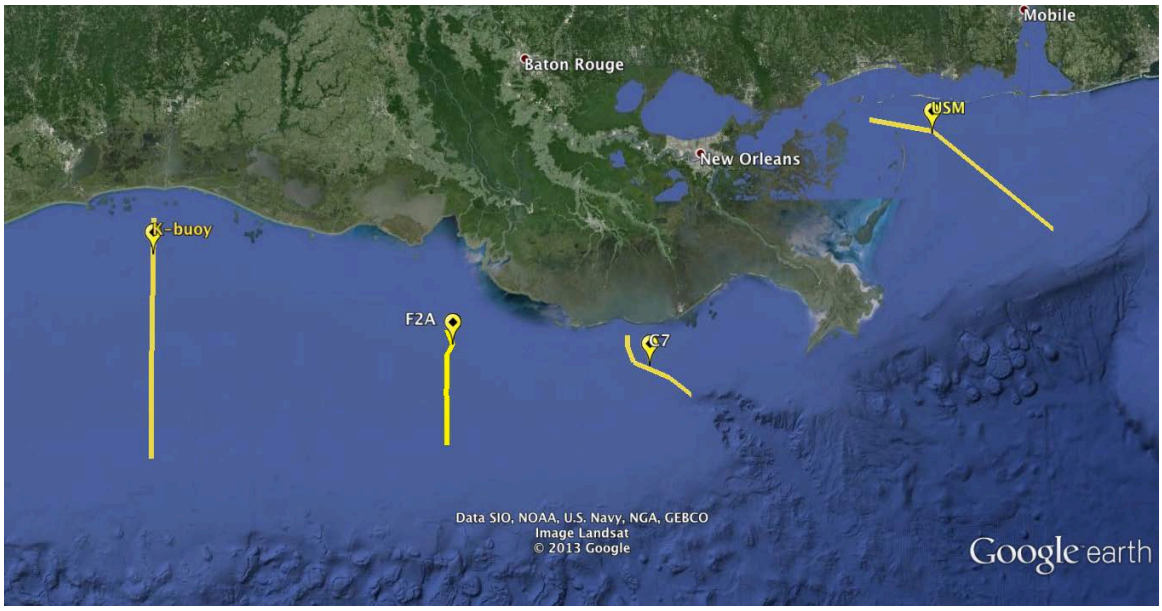
Ship Surveys – The modeler survey indicated that ship surveys were needed in seasonal periods additional to the mid-summer period (typically mid- to late July) and conducted across a larger region to assess progress toward the HTF Coastal Goal (Management Driver 1). Currently the mid-summer survey omits a region east of the Mississippi Delta, known to regularly harbor hypoxic water that is in part driven by Mississippi River discharge (Fig. 2), and does not extend to the Texas shelf making it difficult to delineate between hypoxic waters influenced by Texas watersheds from those linked to Mississippi/Atchafalaya river basin runoff. To support deterministic modeling, the mid-summer cruise should be extended to these regions to create a near-synoptic estimate of the entire region. In addition to measuring hydrographic variables (water temperature, salinity, DO, pH, chlorophyll *a*), only ship surveys are capable of measuring some inorganic nutrients (e.g. NH_4, PO_4) and primary productivity, which requires bottle incubation. For this reason and because other sampling fails to come within 0.5 meters of the bottom, it is difficult to replace ship-based surveys. In addition, the modelers require additional temporal coverage for model validation, which would best be attained through monthly cruises but could be attained through sampling a select number of transects (biweekly to monthly; e.g. Fig. 4, Transects F and C), rather than the entire region.

In addition to these commonly collected measurements, modelers could use additional observations of water column and sediment respiration rates and nutrient exchange, as well as better measures of zooplankton biomass and grazing rates, which must be collected by ship-based surveys. These variables do not need to be measured annually but these variables have important relationships to DO and need to be better understood for the deterministic models to correctly reflect these relationships.

Fixed Observation Systems – Long-term observation systems are extremely valuable to modeling platforms as they can provide consistent sensor-based hydrographic observations over the entire season and can provide the potential for near real-time data availability. A network of observation sites can together provide the only truly synoptic measure of oxygen across the Gulf region. These systems can be costly to maintain operationally but provide the potential to have real-time data, and subsequently models could provide real-time estimates of the hypoxic zone.

Gliders – Autonomous underwater vehicles will likely play an important role in the future for collecting hydrographic variables relevant to the deterministic models. Limitations remain to the use of gliders to produce a hypoxic zone size metric analogous to the long-term HTF areal extent metric. However, they may be an excellent way to attain additional estimates of the hypoxic zone for model comparison and to allow model skill to be tested at specific regions through the year. Gliders should be incorporated into any monitoring program to record hydrographic variables that can be measured by sensors, at specific transects to temporally augment the more expensive ship data. At this time, gliders are mainly used for project specific activities and are not to collect observations at consistent locations and consistent times, a necessity to be included in an operational modeling system. The Glider Implementation Plan has three planning tiers, depending on funding availability. Tier 1 includes four glider transects, each anchored by a fixed observation system (Fig. 11). These observation systems could correspond to, from west to east, G, C, CSI-6, and USM3M01 (see Fig. 4).

Figure 11. Proposed repeat glider transects. Each of these transects runs from the 10 m to the 60 m isobath. (from Howden et al. 2014; Glider Implementation Plan).



Data Management – All directives for sharing environmental data and peer-reviewed publications provided by a funding agency should be followed by those monitoring oceanic conditions in the Gulf of Mexico, however we provide additional guidance, definitions, and suggestions for handling data.

A focused data management system (DMS) is required to ensure data are high-quality, secure, comprehensible, and available both now and into the future. All data collected in a system

should have a detailed data management plan (DMP) that ensures its quality and availability. A typical DMP is specific to each project or activity and describes: roles and responsibilities of data providers, data management staff and end users, data flows from collection to archiving including any transformations such as averaging, sub-setting, and editing, QA/QC, community standards applied to data and metadata (e.g. controlled-vocabularies, metadata content standards, and encoding schema), procedures for backup and archival at a long-term trusted digital repository, and policies for data release, sharing, and publishing. Due to the wide variability of data sources, a data management plan should exist for all federally funded activities within a cooperative monitoring program. All federally funded projects should be encouraged to follow data formats recommended by the Library of Congress for digital preservation and archiving standards outlined by either IOOS or NCEI.

Data Handling and QA/QC*:* The data management plan should cover an end-to-end data inventory control system which enables management to monitor study progress and identify gaps in the information required and to document data availability, data reduction, and data analysis at each reporting period. Before data collection starts a list of the expected datasets, products, and individual responsibilities for delivering them should be provided and subsequently compared to what was collected. Agreements should be established on the content of data logs, data file naming conventions, and sample labeling schemes. These early steps allow the data to be tracked through the various processing steps to archiving without loss of information. The QA/QC steps taken during processing, analysis, and synthesis will be documented along with attribution to the authoritative source of the procedures followed.

Metadata Development: During monitoring activities, for each type of data collected, metadata covering the instrument calibrations and settings, parameters measured and their units, deployment locations and times, and other metadata, should be collected and stored. ISO 1911x standard geospatial metadata shall be used to describe the data and should accompany any data transfer. Additionally, where available, community-based, best practices for capturing metadata elements should be applied.

Data Backup, Data Archival and Final Data Submission: Each individual data management plan should cover strategies for data backup, internal achieving, final formatting, and timing of submission.

Data Sharing, Release, and Publishing: Initially data and products will be treated as proprietary, will always be kept secure, and will not be used except as specified in the contract without prior authorization. All data and analyses will be made public within 6 months following the last retrieval of equipment, unless an alternative date is agreed upon. Data will be shared publicly through IOOS/GCOOS and NCEI data portals.

Financial requirements

Management Driver 1: Define the HTF monitoring needs associated with determining the annual maximum areal extent and volume of the Gulf of Mexico hypoxic zone.

Table 2. Monitoring system requirement options to meet data needs for Management Driver 1. Codes for #: S = Ship Survey; D = Data Management.

#	System Requirement	Collaborators	Estimated Annual Cost	Funding Status
S-1	Mid-summer shelf-wide ship survey west of Mississippi Delta	LUMCON; LSU; NOAA; NGI	$111K using NOAA vessel	NOAA NCCOS support for FY17
			$191K using contract (OMAO) vessel	NOAA NCCOS ($111K) support for FY17; $80K needed
D-1	Maintain a data portal to make data accessible and to facilitate exchange (data management)	GCOOS; NCEI	$35K for 3 months FTE (GCOOS) $35K for 3 months FTE (NCEI)	IOOS support to GCOOS from FY16 to FY20; NOAA NCEI support
D-2	Dissemination of data and findings to research and management communities (communication)	LUMCON; LSU; GCOOS	$35K for 3 months FTE for GCOOS $35K for 3 months FTE LUMCON/LSU	LUMCON/LSU support IOOS support to GCOOS from FY16 to FY20
Total Annual Cost: **1) With NOAA vessel: $251K, all supported in FY17** **2) With contract vessel: $331K, all but $80K supported in FY17**				

Management Driver 2: Define monitoring variables and the spatial and temporal sampling needs to support robust modeling and forecasting capabilities for both empirical and coupled 3-dimensional modeling platforms that are required to meet critical management objectives for hypoxia mitigation and other Gulf ecosystem restoration goals.

Table 3. Monitoring system requirement options to meet data needs of Management Driver 2. Codes for #: N = Nutrient Loading; S = Ship Surveys; O = Fixed Observing Systems; G = Gliders; D = Data Management

#	System Requirement	Collaborators	Estimated Annual Cost	Funding Status
EMPIRICAL MODELS				
N-1	Annual and Spring P and N loading estimates from Miss/Atchafalaya River Basin	USGS (Miss R at St. Francisville; Atch R at Melville); LSU (Miss R at Baton Rouge)	$20K (USGS); ?	USGS support LSU support
N-2	Nutrient monitoring to support P and N load estimations (discrete sampling and real-time nitrate monitoring) from Miss/Atchafalaya River basin	USGS (Discrete sampling - Miss R at St. Francisville; Atch R at Melville; Real-time nitrate – Miss R at Baton Rouge; Atch R at Morgan City); LSU (Miss R at Baton Rouge)	$220K (USGS); ?	USGS support LSU support
N-3	Daily discharge monitoring	USACE	?	USACE support
Empirical Model Monitoring Support **Total Annual Cost: > $240K, all supported in FY17**				
DETERMINISTIC MODELS				
S-2	Mid-summer shelf-wide survey east of Mississippi Delta	USM; LUMCON; LSU	$50K	Needed

	(see Fig. 2, purple triangles)			
S-3	Monthly shelf-wide ship surveys east of Mississippi Delta	USM; DISL; LUMCON; LSU	$50/survey June & Aug = $100K Apr, May, Sept, Oct = $200K	Needed
S-4	Cross-shelf Transects C and F (Fig. 4) in Feb, Apr, June, Aug, Oct, Dec	LUMCON; LSU	$80K/survey X 6 surveys = $480K	Needed
S-5	SEAMAP groundfish survey mapping hypoxia from June through mid-July	NMFS; LDWF	$190K	NOAA NMFS support
O-1	Maintain observation system west of Miss Delta C6/C6C/CSI-6" - (90'29" W, 28'52" N) (CSI-6 in Fig. 4)	GCOOS; LUMCON	Year 1: $100 for new probes and sondes (surface and bottom); $125K/yr to maintain	Needed
O-2	Maintain observation system south of Atchafalaya "TAMU **C**" - (92’ W, 29’ N) (C in Fig. 4)	GCOOS; TAMU	$125K	Needed
O-3	Maintain observation system east of Miss Delta at end of USM transect: “USM 3M01” -88°39' W, 30° N	GCOOS; USM	Outfit with DO sensor = $50K in Yr 1 Maintenance = $125K	Needed
O-4	Maintain observation system east of Miss Delta close to Delta:	GCOOS; LSU	Outfit with DO sensor = $50K in Yr 1	Needed

	"CSI-16" - (89' W, 29'25" N)		Maintenance = $125K	
O-5	Maintain observation system west of Miss Delta close to Delta: "CSI-9" - (-89'58" W, 29'06" N) -W of Miss.	GCOOS; LUMCON	Year 1: $100 for new probes and sondes (surface and bottom); $125K/yr to maintain	Needed
O-6	Maintain observation system west of Miss Delta at western part of shelfwide grid: "TAMU G" - (-94'30"W, 29'20" N) (G in Fig. 4)	GCOOS; TAMU	$125K	Needed
G-1	Deployments of Autonomous Underwater Vehicles (AUVs) with dissolved oxygen sensors; Tier 1 in Glider Implementation Plan (see Fig. 11); deploy 4 glider tracks from June through Aug, with 10-day runs per glider (2 gliders needed per track)	Ongoing Pilot Study: TAMU	Initial investment = $960K for 8 gliders with DO ($120K/glider) + $180K total for cruise deployments (based on $8K/day for ship and $12K per day for personnel)	NOAA NGOMEX funding of Pilot Study, FY16 to FY17; Funding needed starting in FY18
D-1	Maintain a data portal to make data accessible and to facilitate exchange (data management)	GCOOS; NCEI, including Hypoxia Watch	$125K for GCOOS FTE $125K for NCEI FTE	IOOS support to GCOOS from FY16 to FY20; NOAA NCEI support
D-2	Dissemination of data and findings to research and management communities (communication)	GCOOS; LUMCON; LSU; NCEI (Hypoxia Watch)	$125K for GCOOS FTE $125K for LUMCON/LSU	LUMCON/LSU support IOOS support to GCOOS from

			FTE	FY16 to FY20

Deterministic Model Monitoring Support

Total Annual Cost:

Ship surveys: $1.02M [$190K is supported, $830K is needed]

Moored Observation Systems:

Year 1: $1.05M

After Year 1: $750K/year

Gliders:

Year 1: $1.14M

After Year 1: $180K/year

Data management and dissemination: $500K [all supported]

Total Year 1 Cost: $3.71M [$690K is supported, $3.02M in needed]

Total After Year 1 Cost: $2.45M [$690K is supported, $1.76M is needed]

Summary of Total Costs						
Component	**Year 1**			**After Year 1**		
	Total Cost	**Supported**	**Needed**	**Total Cost**	**Supported**	**Needed**
Mid-summer ship survey (with NOAA vessel)	**$251K**	**$251K**	**$0**	**$251K**	**$0**	**$251K**
Mid-summer ship survey (with	**$331K**	**$251K**	**$80K**	**$331K**	**$0**	**$331K**

contract vessel)						
Empirical model support	**>$240K**	**>$240K**	**$0**	**>$240K**	**>$240K**	**$0**
Deterministic model support	**$3.71M**	**$690K**	**$3.02M**	**$2.45M**	**$690K**	**$1.76M**

Table 4. Results of the Deterministic Modeler Survey used to inform monitoring data requirements to support modeling.

Model Use	Variable Name	Fixed or Regional	Where to sample	When & Why?	Sampling Interval	Is this data currently collected?	Who collects it?
Forcing	Surface Winds	Regional	Lat: -87.7W to -94.8W Lon: 27.5N to 31N 0 and 10 meter above sea level for winds	Over the time frame that model output is desired, ideally all year.	3-hours	Model generated	Model generated (COAMPS/NOGAPS)
Forcing	Solar Radiation: Shortwave Radiation and Heat Fluxes	Regional	Lat: -87.7W to -94.8W Lon: 27.5N to 31N		3-hours	Model generated	Model generated (COAMPS/NOGAPS)
Forcing	Ocean Boundary Conditions: Circulation and Tides	Regional	Along the FVCOM open ocean boundary		3-hours	Model generated	Model generated (IASNFS)
Forcing	Riverine Nutrient Loads	Fixed	St. Francisville (Miss. River) and Melville (Atchafalaya River)		Daily	No - only monthly to bi-monthly	USGS
Forcing	Mississippi and Atchafalaya River discharges	Fixed	Tarbert Landing (Miss.River) and Simmesport (Atchafalaya River)		Daily	Yes	USACE/USGS

Validation	Moored Ocean Currents	Fixed (minimum 3)	"C" - (29 N, 92 W) - In front of Atchafalaya	All Year	Hourly	No	LUMCON/VAWCIS/TAMU
			"C6" - (90'30" W, 28'45" N) - W of Mississippi	All Year	Hourly	Intermittently	LUMCON
			"CSI-16" - (89' W, 29'25" N) - E of Mississippi	All Year	Hourly	No	LSU/WAVCIS

Model Use	**Data Type**	**Fixed or Regional**	**Where to sample**	**When & Why?**	**Sampling Interval**	**Is this data currently collected?**	**Who collects it?**
Validation	Water temperature, Salinity and Dissolved Oxygen	Regional	Shelfwide hypoxia monitoring cruise	July	Annual	No	(LUMCON/NOAA/ TAMU)
			Biweekly to monthly cruises along transects C and F	All Year	Hourly	Intermittently	LUMCON/TAMU
			Additional cruises and glider monitoring	**SEAMAP**- 1 fall and 1 spring **USEPA**-Annual **TAMU**- dictated by research		No	NOAA NMFS SEAMAP CRUISE, TAMU Gliders
		Fixed	Same sites as moored	All Year	15-min	Intermittently at C6	LUMCON
Validation	Inorganic Nutrients	Regional	NO_3 - glider or ships NH_4 and PO_4- ship	(April-October)	Monthly	Annual shelfwide cruise only	LUMCON/NOAA
		Fixed	NO3, On 3 fixed sites (C,C6, CSI-	All Year	Weekly Minimu	No	See Moored sites

			16)		m		
Validation	Chl a	Regional	Lat: -87.7W to -94.8W Lon: 27.5N to 31N	(April-October)	Monthly	No- once annual	LUMCON/NOAA
		Fixed	See Moored Stations	All Year	Hourly	Intermittently at C6	See Moored Sites
Validation	Water-level	Fixed	Tide gauges	2002-Present	Minutely	Yes	NOAA
Validation	Primary Productivity: *And also by Satellite:* chlorophyll, particulate organic carbon, Colored Dissolved Organic Matter (CDOM)	Ship Survey (requires bottle incubation)	Lat: -87.7W to -94.8W Lon: 27.5N to 31N	Ground truth satellite images	Various	No	LUMCON-ANNUALLY
		Satellite Imagery (Regional)	Estimate from satellites but in situ validation required	**All Year**, 300 m - 1 km resolution	Various	Yes - but not regularly used (2002-Present)	LSU Earth Scan Lab, NASA, European Space Agency

Model Use	**Data Type**	**Fixed or Regional**	**Where to sample**	**When & Why?**	**Sampling Interval**	**Is this data currently collected?**	**Who collects it?**
Infrequent Validation	Respiration Rates in Water Column and in Sediments	Regional (a time-intensive ship-board activity)	Not needed or realistic on an operational basis	April-October (not realistic)	Monthly	No	Not Collected

Infrequent Validation	Exchange Fluxes of Nutrients and Oxygen between Sediments and Water Column	Regional (a time-intensive ship-board activity)	Not needed or realistic on an operational basis	April-October (not realistic)	Monthly	No	Not Collected
Infrequent Validation	Zooplankton Biomass and grazing rates	Regional (a time-intensive ship-board activity)	Not needed or realistic on an operational basis	April-October (not realistic)	Monthly	No	Not Collected
Infrequent Validation	Sediment Accumulation Rates	Fixed	Grid	April-October (not realistic)	Monthly	No	Not Collected
Infrequent Validation	Light Attenuation	Either	Not needed or realistic on an operational basis	April-October (not realistic)	Monthly	No	Not Collected

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Appendix A. Reports and plans to help inform cooperative monitoring program

1. AOML Hurricane Underwater Gliders; http://www.aoml.noaa.gov/phod/goos/gliders/docs/gliders_brochure.pdf

2. BOEM: http://www.boem.gov/note11062014/ Long Term Monitoring Plan Being Developed for Marine Mammals Related to Oil and Gas Seismic Data Acquisition in the Gulf of Mexico

3. GCOOS Build Out Plan, sec 3.14: http://gcoos.tamu.edu/BuildOut/BuildOutPlan-V2.pdf

    a. Sustained, Integrated Ocean Observing System for the Gulf of Mexico (GCOOS) Hypoxia Monitoring Plan: http://gcoos.tamu.edu/BuildOut/13-Hypoxia.pdf

4. Gulf Glider Implementation Plan: Glider Implementation Plan for Hypoxia Monitoring in the Gulf of Mexico

5. Gulf Hypoxic Zone Monitoring Implementation Plan: Gulf of Mexico Hypoxia Monitoring Implementation Plan

6. Hypoxia-Nutrient Data Portal for the Gulf: http://data.gcoos.org/nutrients/ ; interactive tool: http://gcoos2.tamu.edu/hndss/vars/dissolved_oxygen

7. IEA:

    a. NOAA Ecosystem Status Report for the Gulf of Mexico, Karnauskas et al. 2013: http://gulfcouncil.org/docs/Gulf%20of%20Mexico%20Ecosystem%20Status%20Report.pdf

    b. Ecosystem Approach to Management for the Northern Gulf of Mexico: http://www.northerngulfinstitute.org/publications/docs/2012/09/10367McAnally_EAM_Report2_2012.09.14reduced.pdf

8. IOOS Underwater Glider Network Plan; http://www.ioos.noaa.gov/glider/strategy/glider_network_whitepaper_final.pdf

9. Louisiana CPRA Coast Wide and Basin Wide Monitoring Plans for Louisiana's System Wide Assessment and Monitoring Program (SWAMP) Version III; TO6.5 SWAMP_Deliverable_VIII_FINAL.pdf

10. Multi-LCC (Landscape Conservation Cooperative) Mississippi River Basin/Gulf Hypoxia Initiative: http://databasin.org/groups/d52de40d017e4ce98c3914dba1bc4ee7

11. NAS 2016 report, "Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico": http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=23476

12. NFWF Gulf Environmental Benefit Fund: “Adaptive Management: Louisiana River Diversions and Barrier Islands”; http://web.tplgis.org/DWH/reports/DWH_Report_273.pdf

13. NOAA’s Ecological Forecast Roadmap: Strategic Vision http://oceanservice.noaa.gov/ecoforecasting/noaa-ecoforecasting-roadmap.pdf

14. NRDA Comprehensive Restoration Plan for the Gulf of Mexico; http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan/

15. Ocean Conservancy:

    a. Love, M., Baldera, A., Robbins, C., Spies, R. B. and Allen, J. R. (2015). Charting the Gulf: Analyzing the gaps in long-term monitoring of the Gulf of Mexico. New Orleans, LA: http://www.oceanconservancy.org/places/gulf-of-mexico/gapanalysis/charting-the-gulf-pdf.pdf

    b. Restoring the Gulf of Mexico: A Framework for Ecosystem Restoration in the Gulf of Mexico: http://www.oceanconservancy.org/places/gulf-of-mexico/restoring-the-gulf-of-mexico.pdf

16. Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act (RESTORE Act) Initial Funded Priorities List; https://www.restorethegulf.gov/sites/default/files/FPL_FINAL_Dec9Vote_EC_Library_Links.pdf

17. RESTORE Act Initial Funded Priorities List; Council Monitoring & Assessment Program Development (p. 228) and GOMA Coordination (p. 234); https://www.restorethegulf.gov/sites/default/files/FPL_FINAL_Dec9Vote_EC_Library_Links.pdf

18. The Water Institute of the Gulf – System-Wide Monitoring and Assessment Program (SWAMP) Framework: http://thewaterinstitute.org/files/pdfs/SWAMP_Framework_11.5.13.pdf

19. USDA Mississippi River Basin Healthy Watersheds Initiative: http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/initiatives/?cid=stelprdb1048200

Appendix B. Parameters of models addressed in deterministic modeler survey; excerpted from Aikman et al. (2014), Modeling Approaches for Scenario Forecasts of Gulf of Mexico Hypoxia**.**

Hetland and DiMarco's (2012) 3D dynamically coupled (ROMS hydrodynamic model)	
Model Developer/Institution:	Rob Hetland /Texas A&M
Contact/Institution:	Rob Hetland /Texas A&M
Water Body:	Gulf of Mexico
Model Name:	Regional Ocean Modeling System (ROMS)
Model Type:	3D dynamically coupled
Model Domain:	The Texas-Louisiana continental shelf from the TX/LA boarder to about the MS/AL boarder
a) Inshore distance:	0 km
b) Nearest offshore distance:	0 km
c) Farthest offshore distance:	200 km
d) Alongshore distance:	700 km
Year of Model Development/Application:	1990 to 2011
Model Grid:	
a) Grid type:	Curvilinear
b) Grid resolution (min, avg, max):	940 m / 21 km / ~ 2 km in the areas of interest.
Purpose of Model:	Examine physical controls on the formation and destruction of seasonal hypoxia on the TX-LA shelf.
Dissolved/Particulate Parameters Simulated:	Temperature, salinity, dissolved oxygen
Dissolved/Particulate Parameters Available in Model Code:	Detritus and noncohesive sediment, River discharge and atmospheric and solar parameteres (wind speed and direction, air temp, cloudiness, etc,)
Data Used for Model Forcing:	Nutrient load, Sediment load
Data Assimilated:	None
Data Needs:	For forcing, data described above (already obtained by us). For validation, any data Is useful.
Simulation Period:	20 yr
Validation with Data?:	Hydrography, moored currents and tracers, satellite derived Chla, some sediment accumulation rates.
Used for Forecasting?:	In 2009.
What kind of review has model undergone?:	Published in the Journal of Marine Research.

Reference:	Hetland, R. D. and S . F. DiMarco, (2007) How does the character of oxygen demand control the structure of hypoxia on the Texas-Louisiana continental shelf? J. Mar. Sys.,doi:10.1016/j.jmarsys.2007.03.002.
	Laurent, A., Fennel, K., Hu, J., Hetland, R. (2012) Simulating the effects of phosphorus limitation in the Mississippi and Atchafalaya river plumes, Biogeosciences 9, 4707-4723, doi:10.5194/bg-9-4707-2012;
	Hetland, R. D. and S. F. DiMarco (2012) Skill assessment of a hydrodynamic model of circulation over the Texas- Louisiana continental shelf, Ocean Modelling, 43-44, 64-76, doi:10.1016/j.ocemod.2011.11.009
	Fennel, K., Hetland, R., Feng, Y., DiMarco, S. (2011) A coupled physical-biological model of the Northern Gulf of Mexico shelf: Model description, validation and analysis of phytoplankton variability, Biogeosciences 8, 1881-1899, doi:10.5194/bg-8-1881-2011;
	Xu, K., C. K. Harris, R. D. Hetland, J. M. Kaihatu (2011) Dispersal of Mississippi and Atchafalaya Sediment on the Texas-Louisiana Shelf: Model Estimates for the Year 1993, Cont. Shelf Res., 31(15), 1558-1575, doi:10.1016/j.csr.2011.05.008
Is GIS shapefile of modeled area available?:	No
Comments:	Developed as part of the NOAA funded Mechanisms Controlling Hypoxia program.
Modeler Names and Contacts	Robert Hetland, 3146 TAMU, College Station, TX 77843-3146, 979-458-0096, hetland@tamu.edu
Fennel et al.'s (2012) 3D dynamically coupled (biogeochemical model)	
Model Developer/Institution:	Katja Fennel /Dalhousie University and Rob Hetland /TAMU
Contact/Institution:	Katja Fennel /Dalhousie University
Water Body:	Gulf of Mexico
Model Name:	Regional Ocean Modeling System (ROMS)
Model Type:	3D dynamically coupled
Model Domain:	The Texas-Louisiana continental shelf from the TX/LA boarder to about the MS/AL boarder
a) Inshore distance:	0 km
b) Nearest offshore distance:	0 km
c) Farthest offshore distance:	200 km
d) Alongshore distance:	700 km
Year of Model Development/Application:	1990 to 2009

Model Grid:	
a) Grid type:	Curvilinear
b) Grid resolution (min, avg, max):	940 m / 21 km / ~ 2 km in the areas of interest.
Purpose of Model:	Examine physical and biogeochemical mechanisms for the formation and destruction of seasonal hypoxia on the TX-LA shelf.
Dissolved/Particulate Parameters Simulated:	Temperature, salinity, nutrients (N+P), phytoplankton, zooplankton, small- and large-particle detrital pools, dissolved oxygen
Dissolved/Particulate Parameters Available in Model Code:	same as previous field
Data Used for Model Forcing:	Nutrient load, freshwater discharge
Data Assimilated:	None
Data Needs:	For forcing, data described above. For validation, many different data types are needed and useful (see below).
Simulation Period:	20 yr
Validation with Data?:	Hydrography, temperature, salinity, Chla, Primary Productivity, inorganic nutrients, dissolved oxygen, respiration rates in water column and sediments, exchange fluxes of nutrients and oxygen between sediments and water column, etc.
Used for Forecasting?:	Not yet.
What kind of review has model undergone?:	Two papers published in Biogeosciences (Fennel et al. 2011, Laurent et al. 2012) and two papers in Journal of Geophysical Research (Fennel et al. 2013, Mattern at al. 2013).
Reference:	Fennel, K., Hetland, R., Feng, Y., DiMarco, S. (2011) A coupled physical-biological model of the Northern Gulf of Mexico shelf: Model description, validation and analysis of phytoplankton variability, Biogeosciences 8, 1881-1899, doi:10.5194/bg-8-1881-2011;
	Laurent, A., Fennel, K., Hu, J., Hetland, R. (2012) Simulating the effects of phosphorus limitation in the Mississippi and Atchafalaya river plumes, Biogeosciences 9, 4707-4723, doi:10.5194/bg-9-4707-2012;
	Fennel, K., Hu, J., Laurent, A., Marta-Almeida, M., Hetland, R. 2013. Sensitivity of hypoxia predictions for the Northern Gulf of Mexico to sediment oxygen consumption and model nesting, Journal of Geophysical Research-Oceans.
	Mattern, P., Fennel, K., Dowd, M. 2013. Uncertainty in hypoxia predictions for the TX-LA shelf, Journal of Geophysical Research-Oceans.
Is GIS shapefile of modeled area available?:	No

Comments:	Developed as part of the NOAA funded Mechanisms Controlling Hypoxia program with additional support from US IOOS Coastal and Ocean Modeling Testbed (COMT).
Modeler Names and Contacts	Katja Fennel, Dalhousie University, PO Box 15000, Halifax NS, B3H 4R2, CANADA, +1-902-494-4562, katja.fennel@dal.ca
Justic' and Wang's (2009) 3-D coupled hydrodynamics (FVCOM-LATEX)-water quality model	
Model Developer/Institution:	Dubravko Justic´and Lixia Wang, Louisiana State University
Contact/Institution:	Dubravko Justic´, Louisiana State University
Water Body:	Northern Gulf of Mexico
Model Name:	FVCOM-LATEX
Model Type:	3-D coupled hydrodynamics-water quality model
Model Domain:	Louisiana-Texas continental shelf, from Mobile, AL, to Galveston, TX
a) Inshore distance:	0 km
b) Nearest offshore distance:	60 km
c) Farthest offshore distance:	240 km
d) Alongshore distance:	680 km
Year of Model Development/Application:	2002 – present
Model Grid:	
a) Grid type:	Unstructured grid
b) Grid resolution (min, avg, max):	550m - 10km, ~ 1.5 km across the hypoxic zone
Purpose of Model:	Examine physical and biological controls on hypoxia on the TX-LA shelf
Dissolved/Particulate Parameters Simulated:	Temperature, salinity, dissolved oxygen, NH4, NO3+NO2, PO4, ON, OP, BCOD
Dissolved/Particulate Parameters Available in Model Code:	Same as previous field
Data Used for Model Forcing:	River discharge and atmospheric parameters (wind speed and direction, air temp, cloudiness, etc)
Data Assimilated:	None
Data Needs:	Data used for model forcing + calibration/validation data (ambient water temperature, salinity, currents, dissolved oxygen, nutrients, Chlorophyll *a*, MODIS imagery)
Simulation Period:	2002 was used for calibration/validation; 2003-present in works
Validation with Data?:	Extensive
Used for Forecasting?:	No
What kind of review has	Published in the Continental Shelf Research

model undergone?:	
Reference:	Wang L. and D. Justic´ (2009) A modeling study of the physical processes affecting the development of seasonal hypoxia over the inner Louisiana-Texas shelf: Circulation and stratification. Continental Shelf Research (29):1464-1476
	Justic´, D. and L. Wang (2009) Application of unstructured-grid Finite Volume Coastal Ocean Model (FVCOM) to the Gulf of Mexico Hypoxia Zone. Proceeding of the Oceans 2009 MTS/IEEEE BILOXI conference & Exhibition (Biloxi, Mississippi, October 26-29, 2009MTS-IEEE)
Is GIS shapefile of modeled area available?:	No
Comments:	Model development was funded in part by NOAA-CSCOR and NGI
Modeler Names and Contacts	Dubravko Justic´, 2221 Energy, Coast and Environment Bldg., Louisiana State University, Baton Rouge, LA 70803; Tel: 225-578-6394; Email: djusti1@lsu.edu
Ko et al.'s (2008) EPA-COMGEM 3D hydrodynamic biogeochemical model	
Model Developer/Institution:	Dong S. Ko/Naval Research Laboratory; John Lehrter/EPA-ORD
Contact/Institution:	ko@nrlssc.navy.mil; lehrter.john@epa.gov
Water Body:	Louisiana Coastal Water
Model Name:	EPACOM_GEM
Model Type:	Fully 3D hydrodynamic biogeochemical hypoxia model
Model Domain:	From coast to deep water and from TX/LA boarder to MS/AL boarder
a) Inshore distance:	0 km
b) Nearest offshore distance:	0 km
c) Farthest offshore distance:	~ 300 km
d) Alongshore distance:	~ 600 km
Year of Model Development/Application:	2007 – 2011
Model Grid:	
a) Grid type:	Structured lat-lon grid
b) Grid resolution (min, avg, max):	~2 km
Purpose of Model:	Fully 3D simulation of physical and biogeochemcial processes including dissolved oxygen
Dissolved/Particulate Parameters Simulated:	Temperature, salinity, NO3, NH4, PO4, DIC, six groups of phytoplanktons, zooplankton, six types of OMs and DO

Dissolved/Particulate Parameters Available in Code:	All above
Data Used for Model Forcing:	Synoptic 3D circulation including tides, river flow, solar radiation, wind speed and seasonal river nutrient load
Data Assimilated:	Circulation model assimilates satellite altimeter data and MCSST
Data Needs:	All data are collected for the model simulations but need better initial conditions. All data that can be used for validation is useful. For running the model: same as Data Used for Model Forcing. We also need credible lateral boundary condition data for each bio-geo_chemistry species. Additional CDOM data for running the model as well as validation. Need obs data at more horizontal locations and time-periods.
Simulation Period:	2003 – 2009
Validation with Data?:	EPA in-situ observation
Used for Forecasting?:	Not yet
What kind of review has model undergone?:	Original water column-sediment model published (Eldridge and Roelke, 2010)
Reference:	Ko, D.S., P.J. Martin, C.D. Rowley, and R.H. Preller, A real-time coastal ocean prediction experiment for MREA04, J. Marine Systems, 69, 17-28, doi:10.1016/j.jmarsys.2007.02.022, 2008. (for circulation model).
	Eldridge, Peter,M and D.L. Roelke, D.L., Origins and Scales of Hypoxia on the Louisiana Shelf: Importance of Seasonal Plankton Dynamics and River Nutrients and Discharge, Ecol. Model., 221, 1028-1042, 2010.
Is GIS shapefile of modeled area available?:	No
Modeler Names and Contacts	Dong S. Ko/ NRL Code 7320/ Stennis Space Center, MS 39529/ ko@nrlssc.navy.mil ; John Lehrter, EPA Gulf Ecology Division, Gulf Breeze, FL 32570, 850-934-9255, lehrter.john@epa.gov

Appendix C. Potential hypoxia monitoring program collaborators and beneficiaries

British Petroleum Industry Company (BP)	
Interest:	BP is interested in ocean observing efforts in the northern Gulf of Mexico, in physical processes related to MetOcean and the offshore oil and gas industry.
Activities:	BP has recently supported glider monitoring activities in the central Gulf of Mexico.
Bureau of Ocean Energy Management (BOEM)	
Interest:	BOEM manages the development of the Nation's offshore energy and mineral resources in an environmentally and economically responsible way. Responsible for development of oil, gas, and mineral resources in the Gulf of Mexico (regional mission). BOEM has an environmental monitoring mission and duty to develop Environmental Impact Statement (EIS) in oil and gas active regions of the Outer Continental Shelf. The mission is focused towards learning more about the impact of seismic data acquisition on marine mammals but collaboration may be possible to expand monitoring efforts.
Activities:	A Long Term Monitoring Plan Being Developed for Marine Mammals Related to Oil and Gas Seismic Data Acquisition in the Gulf of Mexico; http://www.boem.gov/note11062014/. Flower Banks Garden has been monitored for more than 20 years by BOEM to insure protective measures regulating nearby oil and gas development are effective.
Centers of Excellence: Mississippi Based RESTORE Act Center of Excellence (MBRACE)	

Interest:	The Restore Act requires that 2.5% of Clean Water Act fines levied from the Deepwater Horizon oil spill be dedicated to the research centers of excellence in each of the five Gulf States. MBRACE will focus on science, technology, and monitoring in areas that are relevant to understanding hypoxia in the northern Gulf of Mexico, including tracking hypoxia development in coastal waters and developing and applying coupled physical-biogeochemical models to understand pathways and processes involved with movement of dissolved and particulate materials from estuarine to open ocean. Additional disciplines can be leveraged for a collaborative monitoring program including: coastal fisheries and wildlife ecosystem research and monitoring; coastal and deltaic sustainability; restoration and protection, sustainable and resilient growth, economic and commercial development in the Gulf of Mexico; and, comprehensive observation, monitoring, and mapping of the Gulf of Mexico.
Activities:	The center has not yet received funding.
Consortium for Ocean Leadership – Gulf of Mexico Research Initiative (GoMRI)	
Interest:	The GoMRI will investigate the impacts of the oil, dispersed oil, and dispersant on the ecosystems of the Gulf of Mexico and affected coastal States in a broad context of improving fundamental understanding of the dynamics of such events and their environmental stresses and public health implications. The GoMRI will also develop improved spill mitigation, oil and gas detection, characterization and remediation technologies. The ultimate goal of the GoMRI will be to improve society's ability to understand, respond to, and mitigate the impacts of petroleum pollution and related stressors of the marine and coastal ecosystems, with an emphasis on conditions found in the Gulf of Mexico. Knowledge accrued will be applied to restoration and to improving the long-term environmental health of the Gulf of Mexico. The consortium Leadership, which are connected to GoMRI, are interested in Gulf monitoring and modeling that require large monitoring programs.
Activities:	Monitoring of Gulf fisheries (snapper).
Deepwater Horizon Natural Resource Damage Assessment (NRDA) Trustee Council	

Interest:	A Natural Resource Damage Assessment is the legal process to evaluate impacts of oil spills, hazardous waste site, and ship groundings on natural resources, authorized by the Oil Pollution Act. A collective of experts is formed to evaluate the impacts of oil spills and to plan and carry out restoration efforts. This council's mission is to restore the Gulf Coast region with federal and state partners. This Council includes representatives of the five Gulf Coast States and four federal agencies including DOI, NOAA, EPA and USDA. They have developed a final programmatic damage assessment and restoration plan and final impact statement.
Activities:	A major component of the plan is monitoring impacts of their restoration activities.
Gulf of Mexico Alliance (GOMA)	
Interest:	GOMA's mission is to enhance the ecological and economic health of the Gulf of Mexico through increased regional collaboration. GOMA has broad priorities in coastal resilience, data and monitoring, education and engagement, habitat resources, water resources, and wildlife and fisheries. The Data and Monitoring Priority Issue Team goals are to improve decision making through coordination and provide guidance for monitoring, mapping, and data sharing collaborations; and, enable data and monitoring integration to support Alliance priorities. The Water Resources Team will focus on: hypoxia/nutrients, harmful algal blooms, freshwater in-flow, impaired/ non-impaired streams, and human health (pathogens/mercury). GOMA helped support development of the GCOOS Nutrient/Hypoxia Data Portal.
Activities:	They are working to evolve the Gulf Monitoring Network into a Monitoring Community of Practice to support the Alliance priority issue team and other regional monitoring activities including: identifying and providing input and feedback on minimum monitoring standards and protocols; monitoring needs and indicators; baseline data, gap analysis/inventories, and assessments. They will provide recommendations on the feasibility of a gulf wide monitoring program, provide access to information about ongoing monitoring activities, and provide tools to facilitate coordination of monitoring activities.
Gulf of Mexico Coastal Ocean Observing System (GCOOS - IOOS Regional Association)	

Interest:	The GCOOS mission is to establish a sustained observing system for the Gulf of Mexico to provide observations and products needed by users in this region for the purposes of detecting and predicting climate variability and consequences, preserving and restoring healthy marine ecosystems, ensuring human health, managing resources, facilitating safe and efficient marine transportation, enhancing national security, and predicting and mitigating against coastal hazards.
Activities:	GCOOS Build-Out Plan, sec 3.14: http://gcoos.tamu.edu/BuildOut/BuildOutPlan-V2.pdf; GCOOS 2016 proposal to IOOS: http://gcoos.tamu.edu/documents/RA-Documents/NOAA-NOS-IOOS-2016-2004378.pdf In Build-Out Plan: Sustained, Integrated Ocean Observing System for the Gulf of Mexico (GCOOS) Hypoxia Monitoring Plan; http://gcoos.tamu.edu/BuildOut/13-Hypoxia.pdf
Gulf of Mexico University Research Collaborative (GOMURC)	
Interest:	Advocate for science and education needed for sustained, informed stewardship, coordinate multi-institutional initiatives, and collaborate with other Gulf entities. Identify, share, and engage in opportunities to raise resources for Gulf science and education.
Activities:	Wrote advocacy paper for a Gulf Observing System: a "Gulf-wide science-based, observing and monitoring program (Gulf Observing System, GOS) that integrates interdisciplinary measurements, modeling, and research." Support GCOOS Build-out plan and support collaboration with GCOOS and GOMA to monitor restoration and sustainability.
Harte Research Institute	
Interest:	The goal of the Harte Research Institute for Gulf of Mexico Studies is to be a research center of excellence providing international leadership in generating and disseminating knowledge about the Gulf of Mexico ecosystem and its critical role in the economies of the North American region.
Activities:	Texas RESTORE lead, interests include Texas coastal water quality, human health; interested in gliders for hypoxia monitoring.

Louisiana Coastal Protection and Restoration Authority (CPRA)	
Interest:	The CPRA has an interest in ocean monitoring, especially around regions of the coast that may see an impact from potential remediation measures such as diverting channelized sections of the Mississippi and Atchafalaya rivers back to wetlands where they historically flowed.
Activities:	The CPRA has developed a System-Wide Assessment and Monitoring Plan to support adaptive management of restoration practices.
Landscape Conservation Cooperatives (LCC)	
Interest:	The Mississippi River Basin / Gulf Hypoxia (MRB/GH) Initiative, spearheaded by seven LCCs, is undertaking a strategic and transparent process to create an integrated framework that supports planning, design, configuration, and delivery of wildlife conservation practices within the watershed. This framework consists of multiple quantitative objectives representing three interests (i.e. wildlife, water quality, agriculture), a tiered set of conservation strategies to achieve those objectives within five production agriculture systems, and a modeling approach to determine where to best implement those actions within four key ecological systems of the Mississippi River Basin.
Activities:	The MRB/GH initiative addresses uncertainties associated with design and management of a sustainable ecosystem/floodplain landscape that provides multiple benefits for agricultural productivity, water quality, and wildlife conservation—both locally in the Mississippi River Basin and in the Gulf of Mexico. https://lccnetwork.org/issue/gulf-hypoxia
Louisiana Sea Grant (LA SG)	
Interest:	The LA SG is focused on sustaining fisheries, deltaic ecosystems, coastal communities, and workforce development.
Activities:	LA SG is co-leading an effort to understand the socioeconomic effects of river diversions.

Louisiana Department of Wildlife and Fisheries (LDWF)	
Interest:	LDWF has expressed interest in becoming part of the Hypoxia Task Force; they are considering extending some fish monitoring into coastal areas. Additional collection of data could be leveraged through collaboration.
Activities:	Nearshore monitoring of SEAMAP.
Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (Hypoxia Task Force)	
Interest:	The Hypoxia Task Force was established in the fall of 1997 to understand the causes and effects of eutrophication in the Gulf of Mexico; coordinate activities to reduce the size, severity, and duration; and ameliorate the effects of hypoxia. Activities include coordinating and supporting nutrient management activities from all sources, restoring habitats to trap and assimilate nutrients, and supporting other hypoxia related activities in the Mississippi River and Gulf of Mexico watersheds. The annual measure of the hypoxic zone size in the Gulf and nutrient loads leaving the Mississippi and Atchafalaya rivers, provides measures of progress towards short-term and long-term management targets for the HTF. Without this monitoring, it is not possible to measure the progress made in reducing nutrient loading in the basin.
Activities:	Many HTF members perform or support monitoring in the Mississippi/Atchafalaya River Basin and in the Gulf of Mexico.
National Academy of Science (NAS) - Gulf Research Program	
Interest:	To enhance oil system safety and the protection of human health and the environment in the Gulf of Mexico and other U.S. outer continental shelf areas by seeking to improve understanding of the region's interconnecting human, environmental and energy systems in a way to benefit the Gulf community, ecosystem, and the nation. Environmental monitoring is one of the three broad approaches the NAS will support in this research program.

Activities:	2016 report from Committee on Effective Approaches for Monitoring and Assessing the Gulf of Mexico Restoration Activities, "Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico".
National Fish and Wildlife Foundation (NFWF)	
Interest:	NFWF works with both the public and private sectors to protect and restore our nation's fish, wildlife, plants and habitats. The NFWF specifically runs many nationwide portfolios, designated in each case for specific purposes benefitting natural resources and the environment Due to the NFWF role in restoration work, monitoring is seen as key to assessing progress.
Activities:	NFWF Gulf Environmental Benefit Fund has funded an environmental project designed to monitor barrier islands, wetlands, marshes, and estuaries. The project aims to systematically monitor and analyze new information gathered in response to barrier island and river diversion project implementation, and to make appropriate adjustments to planning, designing, monitoring, operating, and implementing barrier island and river diversion projects to ensure continued progress toward achieving restoration objectives of the Louisiana Coastal Master Plan.
National Water Quality Monitoring Network (NWQMN)	
Interest:	Provide information about the health of our oceans and coastal ecosystems and inland influences on coastal waters for improved resource management. These networks include federal agencies, IOOS, and many regional users (NFRA). NWQMN supports monitoring and sharing of water quality data.
Activities:	The NWQMC provides some data to the Water Quality Portal (WQP). They continue to have an annual meeting focused on monitoring water quality and sharing data.
Natural Resource Damage Assessment and Restoration Program (NRDAR)	

Interest:	The U.S. Department of the Interior's (DOI) Natural Resource Damage Assessment and Restoration Program (NRDA Restoration Program) goal is to restore natural resources injured as a result of oil spills or hazardous substance releases into the environment. In partnership with affected state, tribal and federal trustee agencies, the NRDA Restoration Program conducts damage assessments which are the first step toward resource restoration and used to provide the basis for determining restoration needs that address the public's loss and use of natural resources.
Activities:	NRDAR performed assessment and restoration activities based on damage done by private industry. The assessment of impacts requires long term monitoring.
NOAA Office of Oceanic and Atmospheric Research (OAR): Atlantic Oceanographic and Meteorological Laboratory (AOML)	
Interest:	The Atlantic Oceanographic and Meteorological Laboratory conducts research to understand the physical, chemical, and biological characteristics and processes of the ocean and the atmosphere, both separately and as a coupled system. The principal focus of these investigations is to advance knowledge that leads to more accurate forecasting of severe storms, better use and management of marine resources, better understanding of the factors affecting both climate and environmental quality, and improved ocean and weather services for the nation. AOML requires physical ocean observations. AOML supports both ship-based observations obtained from CTD sensors and water samples collected using the CTD rosette that sense salinity, oxygen, nutrient, and heat content of the ocean; and, moored sensors. They also support the global drifter program for capturing water movement.
Activities:	AOML Hurricane Underwater Gliders; http://www.aoml.noaa.gov/phod/goos/gliders/docs/gliders_brochure.pdf
NOAA - Ecological Forecast Roadmap Initiative	
Interest:	The mission is to provide science-based solutions through collaborative partnerships to address evolving economic, environmental, and social pressures on the oceans and coasts. Hypoxia is one of 4 themes in EFR, and hypoxia forecasting in the Gulf is the main focus of the Hypoxia Team; ultimate goal is to transition hypoxia forecasting system to operations, which includes observations and monitoring.

Activities:	Establishment of an operational observations and monitoring program is an action in the EFR Implementation Plan.
NOAA – RESTORE Act Science Program. AKA: Gulf Coast Ecosystem Restoration Science, Observation, Monitoring, and Technology Program	
Interest:	Carry out research, observation, and monitoring to support, to the maximum extent practicable, the long-term sustainability of the ecosystem, fish stocks, fish habitat, and the recreational, commercial, and charter-fishing industry in the Gulf of Mexico. 2.5 % of the Gulf Coast Restoration Trust Fund Allocation goes to this sub priority. Improve monitoring, modeling, and forecasting of climate change and weather effects on the sustainability and resiliency of the ecosystem. Network and integrate existing and planned data and information from monitoring programs. Develop and implement advanced technologies to improve monitoring
Activities:	In the research category, observing systems and ecosystem management, four projects focused on monitoring and modeling in the Gulf are being funded, including one to evaluate the current oceanographic observation networks in the Gulf of Mexico. The titles of the four projects are: "Cooperative Monitoring Program for Spawning Aggregations in the Gulf of Mexico: An Assessment of Existing Information, Data Gaps and Research Priorities" "Ecosystem modeling efforts in the Gulf of Mexico: Current status and future needs to address management and restoration activities", "The Central Role of the Mississippi River and its Delta in the Oceanography and Ecology of the Gulf of Mexico Large Marine Ecosystem" "Inventory of Gulf of Mexico Ecosystem Indicators using an Ecological Resilience Framework"
NOAA - Gulf of Mexico Regional Collaboration Team	

Interest:	The Gulf regional collaboration team incudes NOAA experts with expertise that span the breadth of environmental and social issues in the Gulf of Mexico region, including the areas of hurricane response, climate change, integrated assessments of ecosystems, community resilience, citizen engagement, coral reefs, habitat restoration and conservation, protected resources' critical habitats, fisheries and aquaculture, energy resources, and ports and shipping. The Gulf of Mexico Regional Collaboration Team is a regional collaboration effort, which coordinates activities from across the agency with those of partners to accomplish larger-picture outcomes. There is a specific interest by this group to understand what remediation role river diversions can have and what effects diversions might have on hypoxia. Monitoring will be needed to assess this type of remediation.
Activities:	Perform workshops and events that encourage coordination throughout NOAA line offices and between headquarters, regional staff, and partners. These events intend to identify gaps in communication, coordination, and resources.
NOAA - National Centers for Coastal Ocean Science (NCCOS)	
Interest:	NCCOS has been responsible for funding much of the hypoxic zone ship survey activities and have been pushing the development of support tools and technologies including both empirical and deterministic hypoxia modeling through a competitive grant program called the Northern Gulf of Mexico Ecosystems and Hypoxia Assessment (NGOMEX).
Activities:	Multiple individuals with NCCOS participate in the HTF. NCCOS has organized the annual maximum hypoxic zone ship survey for 2016 from noncompetitive base funds for the first time. CSCOR funds competitive projects in the NGOM through the Northern Gulf of Mexico Ecosystems and Hypoxia Assessment program (NGOMEX), and nationally focused projects through the Coastal Hypoxia Research Program (CHRP). NCCOS and NGI lead the development of pertinent workshops on modeling and monitoring in the Gulf of Mexico and are leading the effort towards a cooperative hypoxia monitoring program in the Northern Gulf of Mexico.
NOAA - National Marine Fisheries Service (NMFS) - Integrated Ecosystem Assessment (IEA)	

Interest:	The IEA program supports ecosystem based management (EBM), an emerging stewardship concept that focuses on transferring scientific knowledge to management. The program covers 5 regions including the Gulf. The IEA is interested in monitoring that provides management with key answers on the effect and value of specific restoration activities.
Activities:	The Gulf IEA was recently funded to extend to include the Louisiana Mississippi River diversion issue.
NOAA - Ocean Acidification Program (OAP)	
Interest:	The NOAA Ocean Acidification Program works to monitor the changes in ocean chemistry, research potential effects on marine organisms and ecosystems, and understand the socio-economic impacts of those changes.
Activities:	OAP collects environmental data with ships, gliders, and buoys; and, manages and stores the data at the NOAA National Centers for Environmental Information. The OA monitoring program in Gulf could intersect with activities used for hypoxia monitoring. The Gulf Coastal Acidification Network (GCAN) is in the planning stages and could leverage other efforts to maximize monitoring.
Ocean Conservancy	
Interest:	Create science-based solutions for a healthy ocean and the wildlife and communities that depend upon it.
Activities:	OC has conducted workshops with GOMA and NOAA on monitoring needs. A gap analysis has been published, titled "Analyzing the gaps in long-term monitoring of the Gulf of Mexico". http://www.oceanconservancy.org/places/gulf-of-mexico/gap-analysis.html. A Framework for Ecosystem Restoration in the Gulf of Mexico has also been published: http://www.oceanconservancy.org/places/gulf-of-mexico/restoring-the-gulf-of-mexico.pdf.
RESTORE Council Monitoring and Assessment Program	

Interest:	Science-based comprehensive Gulf ecosystem restoration. The proposed monitoring and assessment program, administered jointly by NOAA and USGS, would fund the development of basic, foundational components for Gulf region-wide monitoring in order to measure beneficial impacts of investments in restoration.
Activities:	The Council Monitoring and Assessment Program will conduct an inventory and gap analysis of existing data and monitoring systems; develop and provide recommendations to the Council for common standards and protocols for monitoring; establish metrics needed to measure the influence of water quality and habitat restoration; establish baseline conditions; and provide recommendations to the Council on how to address gaps and future needs.
Shell Global	
Interest:	Mission: Delivering energy in a responsible way to meet the world's growing needs. Ocean observing efforts in the northern Gulf of Mexico, regional interest in physical processes related to MetOcean and the offshore oil and gas industry.
Activities:	Shell recently provided support for Glider activities in the northern Gulf of Mexico.
Southeast Area Monitoring and Assessment Program in the Gulf (SEAMAP)	

Interest:	The Gulf subcommittee of the Southeast Area Monitoring and Assessment Program aims to promote better use of the fisheries, marine, shell and anadromous, of the seaboard of the Gulf of Mexico, by the development of a joint program for the promotion and protection of such fisheries and the prevention of the physical waste of the fisheries from any cause. The SEAMAP program is interested in understanding the effects of low oxygen regions on ground fish. SEAMAP summer groundfish survey generates hypoxia maps (through NCEI's **Hypoxia Watch**) that are complementary to the mid-summer survey by Rabalais; the combined use of both datasets is used to support 3-D mechanistic models; operational monitoring program planned here could enhance SEAMAP assessment of hypoxia impacts on groundfish by expanding temporal/spatial coverage of hypoxic conditions, and by improving support of ecological models (e.g. three new FY16 NGOMEX projects). The objective of **Hypoxia Watch** is to develop new near real-time data and map products using shipboard measurements of bottom-dissolved oxygen and disseminate them over the Internet.
Activities:	The SEAMAP program completes plankton surveys across a set grid in the spring fall and winter, completes a summer and fall ground fish survey, vertical line survey and video sampling for reef fishes, and inshore longline surveys that target sharks and finfish. During all of these studies environmental data including climatological and physical water parameters are recorded at the surface, bottom and middle of the water column (water temperature, salinity, chlorophyll, dissolved oxygen, and turbidity). Oxygen data is reported during June and July sampling periods. Data collected from annual SEAMAP summer groundfish surveys are used to generate products that form the basis for summertime advisories on anoxic and hypoxic conditions in the north-central Gulf of Mexico - products accessed on the Gulf Hypoxia Watch web site, http://www.ncddc.noaa.gov/hypoxia/
Texas A&M University at Corpus Christi	
Interest:	Creating and demonstrating environmental information systems that couple sensor measurements with end-to-end cyberinfrastructure to improve understanding of hypoxia, especially in Corpus Christi Bay. Texas Coastal Water Quality.
Activities:	Propose water quality observations along Texas coast.

Texas General Land Office (TXGLO): Coastal Management Program (CMP)	
Interest:	CMP ensures the long term environmental and economic health of the Texas Coast. Physical observations of Texas coast, they are interested in effects from the DWH oil spill.
Activities:	TXGLO has funded TABS buoy observations since 1985, autonomous surface vehicles, and HF Radar observations.
The Water Institute of the Gulf	
Interest:	Goal is to increase understanding of natural and human aspects of deltaic, coastal, and water systems; to develop tools that apply knowledge to restore coasts and ecosystems; and to reduce risk for people and infrastructure Supporting monitoring that addresses applied research questions.
Activities:	System-Wide Monitoring and Assessment Program (SWAMP) Framework: http://thewaterinstitute.org/files/pdfs/SWAMP_Framework_11.5.13.pdf