Building a Cooperative Monitoring Program for Gulf of Mexico Hypoxia and Interrelated Issues

A proceedings paper by the Steering Committee of the:

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

The workshop was convened by the NOAA National Ocean Service's National Centers for Coastal Ocean Science and the 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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Executive Summary

The *6th Annual NOAA/NGI Hypoxia Research Coordination* *Workshop: Establishing a Cooperative Hypoxic Zone Monitoring Network* was convened on 12-13 September 2016 to develop a framework for a sustainable, multi-partner Gulf of Mexico hypoxic zone monitoring program, and plan the follow-up coordination needed to move forward with implementation. A Steering Committee of federal, state, and academic partners produced a comprehensive monitoring strategy white paper prior to the workshop that provided a framework for a cooperative monitoring program based on programmatic and financial requirements designed to meet key management needs. This workshop proceedings report builds off the pre-workshop white paper, incorporating discussion points from presentations and working sessions to identify monitoring requirements linked to key management needs and the mechanisms, resources, and potential collaborations necessary to implement and sustain a cooperative monitoring program that includes the hypoxic zone and other Gulf ecosystem conservation and restoration issues.

The workshop strategy for building a cooperative hypoxia monitoring program was framed around the need to generate data products that meet management needs. Five management products were identified that require monitoring at various temporal and spatial scales:

Management Product 1: Hypoxia Task Force (HTF) annual mid-summer hypoxic zone areal extent

> *Management Need*: The HTF requires the ability to assess progress towards achieving the Coastal Goal of reducing the size of the mid-summer hypoxic zone areal extent to 5,000 km^2.
>
> *Monitoring Requirement*: Mid-summer shelf-wide ship survey at fixed transects from the Mississippi River Delta west to the Texas-Louisiana border

Management Product 2: Scenario forecast model guidance on nutrient reduction requirements to meet HTF coastal goal

> *Management Need*: The HTF requires the ability to: a) assess progress towards the interim nutrient reduction goal (20% nitrogen and phosphorus loading reduction by 2025); and b) support empirical model evaluations of the effectiveness of alternative nutrient reduction strategies for meeting their Coastal Goal to reduce the hypoxic zone size.
>
> *Monitoring Requirement*: In addition to mid-summer ship survey (Product 1), riverine nutrient concentration data (N and P) and river discharge for the Mississippi and Atchafalaya Rivers to estimate nutrient loading to the northern Gulf.

Management Product 3: 3D time variable model characterization of hypoxic zone spatial and temporal dynamics

> *Management Need*: Data are needed to support 3D time variable (deterministic) model characterization of the hypoxic zone and controlling factors, to inform the HTF and other

management groups of the effectiveness of mitigation strategies that takes into account abiotic and biotic controls of hypoxia and their environmental (natural and anthropogenic) drivers.

Monitoring Requirement: A complement of ship surveys (shelf-wide and monthly transects in the MARB influenced zone and at regional edges at the far eastern and western extent to differentiate river sources), observing systems, and autonomous vehicles (e.g. gliders) to collect data on model forcing and validation variables.

Management Product 4: Hypoxia effects on living resources and habitats

Management Need: The HTF and other management groups need to quantify the current and future ecosystem services of reducing the size of the hypoxic zone in order to; a) evaluate the cost/benefits of mitigation actions, and b) refine the hypoxia mitigation goals if warranted. Data are specifically needed to support population- and ecosystem-based ecological models to quantify the predicted relationships between hypoxic zone properties and the distribution, production, and health of ecologically and commercially important finfish and shellfish.

Monitoring Requirement: Ecological monitoring of ecosystem services (e.g. fish surveys) to support ecological model development and coupling to deterministic models of hypoxia (Product 3).

Management Product 5: Scenario forecasts that include interactive ecosystem stressors

Management Need: Predictive models are needed that provide 3D time variable scenario forecasts of hypoxia that can be used to evaluate the effects of climate change or human interventions (i.e. models predicting the impact of alternative nutrient management actions including Mississippi River diversions or the impact of various nutrient reduction targets).

Monitoring Requirement: Observations required to provide Product 3 and Product 4 are required if the model must relate the forecasted output to economic or ecological impact. In addition, data must be collected associated with any specific management intervention, such as a particular river diversion.

A breakout session addressed the minimum monitoring requirements for ship surveys, moored observing systems, and gliders needed to support analysis tools (primarily models) that are used to develop the hypoxia management products. The group consensus included the following key points for supporting management products:

- Management Product 1 (hypoxic zone areal extent):
  - The mid-summer ship survey should continue to ensure that the HTF metric is generated consistently over time. A suitable vessel with long term funding is imperative.
- Management Product 2 (Scenario forecasts for nutrient reduction guidance)

    - Nutrient (USGS) and river discharge (USACE) measurements at lower Mississippi River Basin sites should continue.
- Management Product 3 (3D time variable model characterization of hypoxic zone)
    - The F and C transects that capture Atchafalaya River and Mississippi River runoff, respectively, should continue and are a higher priority than additional shelf-wide ship surveys from a cost-benefit perspective (cost of operations versus the benefit of the relevant data).
    - An additional transect(s) west of F and C would be valuable for distinguishing hypoxia formation from Mississippi/Atchafalaya vs Texas river discharge. Transect K of the typical shelf-wide cruise station occupation could provide one transect, and another further west would be useful.
    - Monitoring east of the Mississippi Delta is valuable for differentiating between hypoxia influenced by Mississippi River runoff and hypoxia driven by other riverine sources.
    - Continuous observations at fixed sites are needed to ensure adequate model forcing and validation; Sites CSI-6, CSI-9, C, and G (west of Delta), and USM 3M01 (east of Delta) should be restored including ensuring bottom DO is collected.
    - Underwater gliders cannot map the shallower portions of the hypoxic zone under high density gradient conditions, and supplementation with autonomous surface vehicles should be tested.
    - One of the plans presented in the Glider Implementation Plan (Howden et al. 2014) was recommended based on glider tracks covering areas around four transects (Fig. 9 in Plan).

Another breakout session explored potential synergies between hypoxia-focused and other Gulf monitoring programs. Numerous opportunities for program collaboration were identified, including programs that collect DO, have plans to collect it, or would benefit from DO collection. Nutrient loading was an important factor in meeting objectives for many programs, and while already included in several of these, others would benefit from inclusion. The issue of program sustainability was addressed by considering funding commitments for the next five years.

The findings from this session and those from a third session that explored partnering opportunities across agencies and institutions were used to inform a whole group discussion whose goal was to identify thematic or region-based workgroups that would serve as focal points for future partner collaborations. These were later reorganized into eight workgroups that are tasked with advancing implementation of the Gulf Cooperative Hypoxia Monitoring Program:

- Fisheries Monitoring Workgroup
- Hypoxia Task Force Monitoring Workgroup
- Oil and Gas/Ocean Acidification Monitoring Workgroup
- RESTORE Act Monitoring Workgroup

- Louisiana Coastal Monitoring Workgroup
- Mississippi/Alabama Monitoring Workgroup
- Texas Monitoring Workgroup
- Autonomous Vehicle Monitoring Workgroup

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Introduction

The hypoxic zone that forms annually over the Louisiana/Texas continental shelf is highly dynamic, controlled by multiple processes, and occurs over a large region of the northern Gulf of Mexico, creating a challenge to providing adequate monitoring support for hypoxia management goals. 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. The advancements are owed largely to consistent monitoring, improved monitoring technology, development of hypothesis driven approaches, advances in analytical methodology (e.g. model advancements), and improved computational technology. A competitive grant mechanism (NOAA's Northern Gulf of Mexico Hypoxia and Ecosystems Assessment Program, NGOMEX) has been the principal source of funding for this research, including longstanding support for monitoring requirements such as shelf-wide ship surveys, cross-shelf transects, and fixed observation systems, and more recently, glider deployments. Additional process and paleontological measurements have provided input to the models and a context for recent change against a multi-century context. A competitive process is not a sustainable mechanism for supporting monitoring operations, and NGOMEX can no longer support hypoxic zone monitoring, as the research has matured beyond experimental hypothesis driven science to operational monitoring, capable of delivering consistent management products. 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*, brought together partners whose missions would benefit from a consistent and sustained northern Gulf hypoxic zone monitoring program. A Steering Committee of federal, state, and academic partners produced a comprehensive monitoring strategy white paper prior to the workshop that provided a framework for a cooperative monitoring program based on programmatic and financial requirements designed to meet key management needs. This workshop proceedings report builds off the pre-workshop white paper, and incorporates discussion points from presentations and working sessions to principally identify monitoring requirements linked to key management needs. The report outlines the potential funding mechanisms, current resources, and the collaborations necessary to implement and sustain the proposed cooperative monitoring program that includes the hypoxic zone and other Gulf ecosystem conservation and restoration issues.

The cooperative monitoring program would meet the management needs of the Hypoxia Task Force (HTF) in several ways. Meeting minimum requirements for an operational monitoring program would mean that modeling tools needed to meet program objectives would no longer suffer severe data limitation; competitive research resources would be freed up to support improvements of models and other management tools; data turnaround and accessibility would be improved with the goal to make data access real- or near-real time; and the metric generated to assess progress toward the HTF Coastal Goal to mitigate hypoxia would be developed in a structured, consistent, and sustainable manner.

Three core principles key to the vision of an effective long-term monitoring program were emphasized:

- **Management Outcomes -** monitoring requirements are driven by management, decision maker, and sound science needs;
- **Broad User Community** - the monitoring program will extend beyond hypoxia, and integrate with monitoring programs that target other interrelated issues that also value collection of bottom oxygen and other variables important to modeling hypoxia (see Aikman et al. 2014 for variables);
- **Cooperative Support Network –** cooperative support from multiple partners with diverse interests is critical to sustainability of a comprehensive and robust monitoring program, and can provide monitoring and data sharing efficiencies.

Management Outcomes: Justification for Establishing a Cooperative Hypoxia Monitoring Program

The workshop strategy for building a cooperative hypoxia monitoring program was framed around the need to generate data products that meet management needs. Five management products were identified that require monitoring at various temporal and spatial scales. We will discuss each of these products in sequence of increasing monitoring requirements and complexity.

The cooperative program is not a rigid requirements list, where success is only achieved when all partners have supported all components. The choice of monitoring building blocks to implement depends on management goals, and the criteria for success is that specific management information gaps are filled and management decision-making is better informed as a result. Each system requirement listed in Tables 2 and 3 below has value for advancing management goals if it alone were implemented (e.g. a single fixed observing system), but it is also important to consider that the return on investment (monitoring and data-sharing efficiencies) may be synergistic as more building blocks are added to the program.

Management Product 1: Hypoxia Task Force (HTF) annual estimate of the mid-summer size of the hypoxic zone areal extent (Figure 1, upper half).

- <u>Management Need</u>: The HTF requires the ability to assess progress towards achieving the 2008 Action Plan's Coastal Goal of reducing the size of the mid-summer hypoxic zone areal extent to less than 5000 km^2 by 2035.
- <u>Minimum Monitoring Requirement</u>: The product requires measurement of the size of the hypoxic zone during mid-summer, the timeframe of maximal hypoxia extent. This is

traditionally derived from a shelf-wide ship survey at fixed transects west of the Mississippi River Delta (Figure 4).

Background: The HTF 2008 *Action Plan* Coastal Goal, which was reaffirmed during a 2013 Reassessment, calls for reducing the hypoxic zone size to a five-year annual average of below 5,000 km^2 (1,928 mi^2) by 2035. An interim target established during the 2013 Reassessment of the 2008 Action Plan, sets a 20% reduction of nitrogen and phosphorus loading by 2025. A 31-year monitoring data set, based on annual ship surveys that estimates the size of the mid-summer hypoxic zone areal extent, is used to provide the HTF with a metric to assess progress toward the Coastal Goal. There are no alternatives to the mid-summer shelf wide surveys that would be consistent with the long-term dataset, as some types of data collected require special handling that can only be achieved from shipboard operations, and autonomous vehicles are not yet capable of collecting the necessary data to match the long-term survey (Howden et al. 2014). If the collection methodology were to change (i.e. cruise replaced by gliders or unmanned surface vehicles), the baseline estimate would need to be calibrated with respect to the long-term methodology for consistency.

Management Product 2: Guidance on nutrient reduction requirements to meet the HTF Coastal Goal (Fig. 1, lower half).

- Management Needs: The HTF needs to evaluate the effectiveness of a suite of nutrient reduction strategies across the Mississippi/Atchafalaya River Basin (MARB), and if necessary, adjust nutrient reduction targets accordingly based on sound science.
- Minimum Monitoring Requirement: In addition to the annual mid-summer hypoxic zone areal extent (Product 1), this product requires information on instream nutrient concentration (nitrogen and phosphorus) and river discharge estimates for the Mississippi and Atchafalaya Rivers to calculate monthly and annual average nutrient loading. Empirical models are used to provide estimates of nutrient reduction targets based on the relationship of nutrient loading and hypoxic zone areal extent. Several watershed and Hydrologic Unit Code (HUC) nutrient loading models are available for more regional or smaller catchment load calculations.

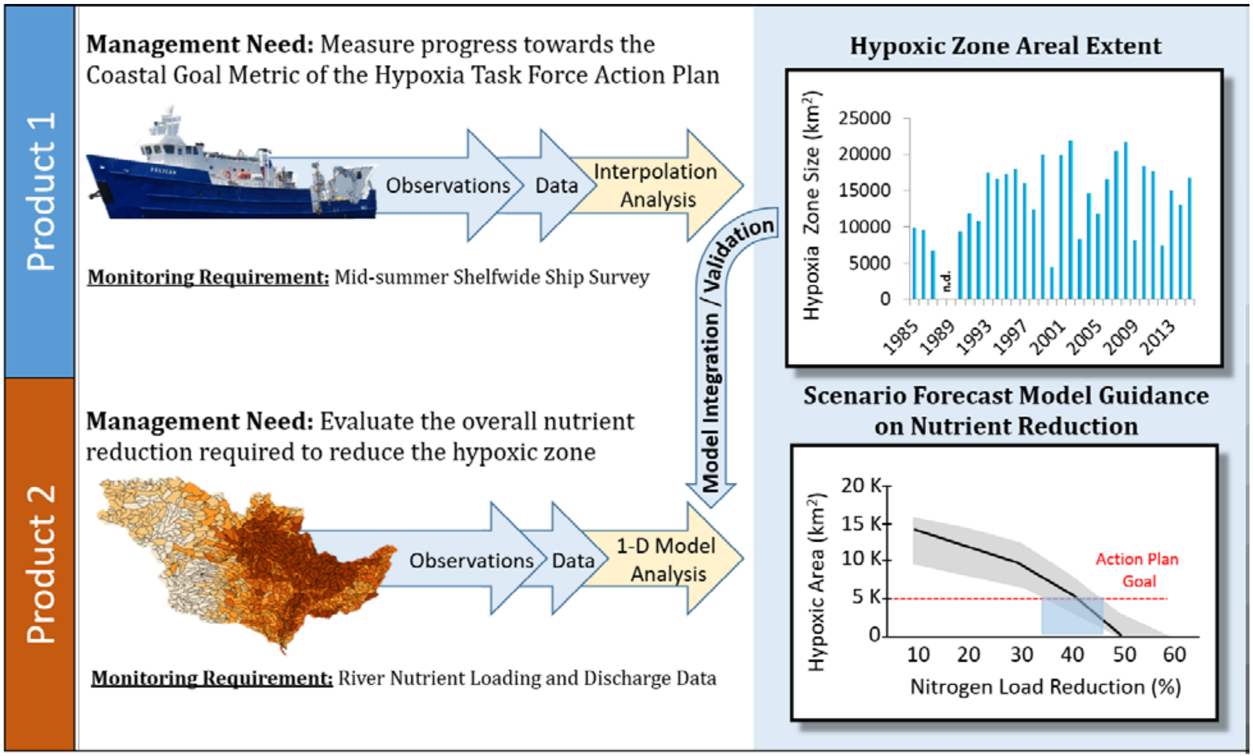


Figure 1. (Upper half): Management Product 1 - Hypoxia Task Force Coastal Goal Metric (annual mid-summer hypoxic zone areal extent). Shown in upper right are the long-term data of mid-summer areal extent generated from shelf-wide ship surveys (Monitoring Requirement) that is used to measure progress towards the Hypoxia Task Force Coastal Goal (Management Need). (Lower half): Management Product 2 - Guidance on nutrient reduction requirements to meet Hypoxia Task Force Coastal Goal. Shown in lower right is the relationship between hypoxic zone areal extent and nitrogen load reduction generated from empirical models as a basis for the Hypoxia Task Force to evaluate the overall nutrient reduction required to reduce the hypoxic zone (Management Need). The Monitoring Requirements needed to generate Management Product 2 are river nutrient loading and discharge data. Figures for Products 1 and 2 are adapted from Rabalais et al. (2002) and Scavia et al. (2004), respectively.

Background: The nutrient loading estimates (from USGS- and LSU-collected data) are directly indicative of progress toward the HTF interim nutrient reduction targets, while the nutrient reduction targets needed to meet the HTF Coastal Goal for hypoxic zone size are informed by empirical models that estimate the quantitative relationship between nutrient loading and hypoxic zone size (from the mid-summer ship survey). The NOAA National Centers for Coastal Ocean Science (NCCOS) is supporting a study to determine the costs and procedures necessary to transition four scenario forecast models or "empirical models" from Research and Development status to a long-term sustained operational capability. These empirical models include:

- Scavia et al. (2013), S-P Bayesian scenario and forecast model;

- Turner et al. (2012), regression model;
- Forrest et al. (2011), multivariable regression model; and,
- Obenour et al. (2015), Bayesian biophysical model.

These four models also are used to produce an ensemble seasonal forecast to predict the mid-summer areal extent of the hypoxic zone based on USGS estimates of nutrient loading in the month of May. The forecast is issued via a joint NOAA/USGS press release, which greatly heightens public awareness of the importance of the HTF mission and serves to validate the accuracy of the models when compared to measurements from the annual mid-summer survey.

Management Product 3: 3D time variable model characterization of the spatial and temporal dynamics of dissolved oxygen through the water column (Figure 2, upper half).

- Management Need: The HTF and other management and outreach groups (e.g. Gulf of Mexico Alliance, Landscape Conservation Cooperative, Louisiana Nutrient Management Strategy Interagency Team, Louisiana Coastal Protection and Restoration Authority, The Nature Conservancy) need an improved understanding of how basin-scale nutrient management efforts influence the temporal and spatial dynamics of Gulf hypoxia and the physical, chemical and biological processes regulating water column nutrient cycling and dissolved oxygen dynamics.
- Minimum Monitoring Requirements: Information is needed to support hindcast model estimates that provide a comprehensive 3D space/time characterization of the hypoxic zone and controlling factors. The underlying physical 3D circulation, stratification, and biogeochemistry models require data in three major areas: a) model forcing variables (e.g. surface winds, solar radiation, shortwave radiation, heat fluxes, ocean current boundary conditions, riverine nutrient loads, and Mississippi and Atchafalaya River discharges); b) regularly gathered validation variables (e.g. moored ocean currents, water temperature, salinity, dissolved oxygen, inorganic nutrients, chlorophyll *a*, water level, and primary productivity); and c) infrequently required validation variables (e.g. water column primary production and respiration rates, exchange fluxes between sediments and water column, zooplankton biomass and grazing rates, sediment accumulation, and light attenuation).

Background: There is a great need to both understand how the dynamic Gulf of Mexico hypoxic zone varies during the entire year and to understand which attributes contribute to the formation, volume, and intensity of the hypoxic zone. This capacity requires the application of "deterministic models" (relatively complex mechanistic models that are based on an explicit representation of the physical, biological, and 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. The empirical models are useful, especially in addressing questions of the gross system response to nutrient loads; however, they are not designed to address dynamic changes in the timing of riverine inputs. Without deterministic 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. This could delay recognition of progress and limits how well scientists understand the mechanisms driving hypoxia. Without deterministic models and a long term monitoring program, the success of management actions aimed at reducing hypoxia will be difficult to measure. Deterministic models developed under the NOAA NGOMEX and/or the U.S. Integrated Ocean Observing System's (IOOS's) Coastal Ocean Modeling Testbed (COMT) programs, currently include:

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

Management Product 4: Hypoxia impacts on living resources and habitats (Figure 2, lower half).

- Management Needs: The HTF and resource management groups need to quantify the current and future ecosystem services of reducing the size of the hypoxic zone. Data are needed to support population- and ecosystem-based ecological 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.
- Minimum Monitoring Requirements: Ecological monitoring of any ecosystem service (e.g. fish survey). This allows for coupling of ecological models with deterministic models of hypoxia.

Background: Product 4 relies on the prior development of deterministic models described in the Product 3 section. Deterministic modeling efforts that focus on both: a) predicting the severity and duration of hypoxia from underlying physical and biogeochemical processes, and b) understanding hypoxia effects on fish population and/or community dynamics have largely proceeded in parallel, but are now being integrated into coupled modeling platforms. Integrating these two modeling approaches is challenging given the complexity of ecological modeling and the different spatial and temporal scales on which organismal and water quality modeling are typically conducted. However, this integration is necessary to develop a better predictive understanding of how nutrient enrichment and associated hypoxia influence the capacity of the Gulf ecosystem to support upper trophic levels that are a primary source of economic value in the Gulf of Mexico.

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 considered to be important management tools for evaluating fisheries responses to a dynamic Gulf ecosystem (which includes human dimensions). Some long-term data support for model calibration is available from the existing Southeast Area Monitoring and Assessment Program (SEAMAP) summer groundfish survey, which also collects dissolved oxygen (DO) used to generate bottom DO maps for the Gulf of Mexico Hypoxia Watch program jointly operated by the NOAA National Centers of Environmental Information (NCEI) and National Marine Fisheries Service (NMFS) (http://www.ncddc.noaa.gov/ecosystems/hypoxia).

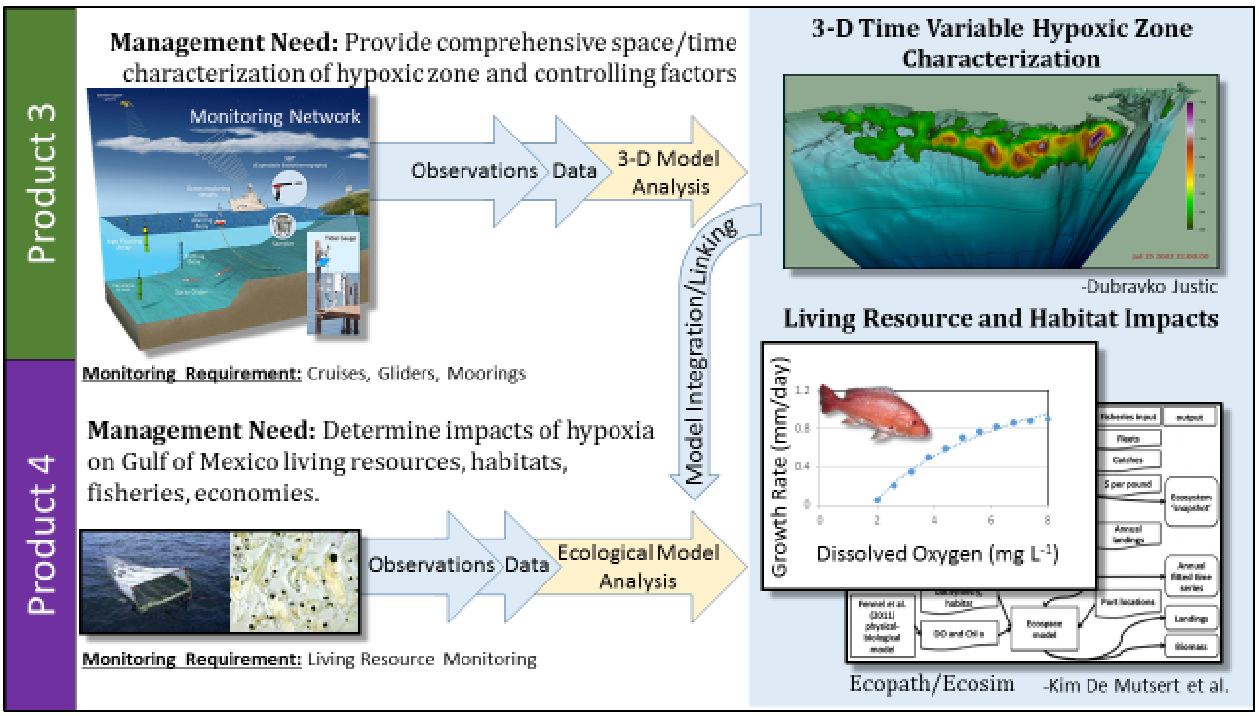


Figure 2. (Upper half): Management Product 3 – Characterization of hypoxic zone dynamics by 3D time variable deterministic models. Shown in upper right is a 3D simulation of the hypoxic zone. Such model simulations allow greater understanding of hypoxia properties and controlling factors (Management Need). (Lower half): Management Product 4 – Hypoxia impacts on living resources and habitats. Shown in lower right is a depiction of the relationship between growth rate and dissolved oxygen concentration (for population-level model assessments) overlaying the framework for an ecosystem-level model approach. These ecological models are used to determine hypoxia ecosystem effects (Management Need). The Monitoring Requirements needed to generate Management Products 3 and 4 include a suite of ship surveys, observing system measurements, and glider deployments. The upper right figure for Product 3 was adapted from Justić et al. (2014), and figures for Product 4 from de Mutsert et al. (2016) (back) and adapted from Szedlmayer et al. (1999) (front).

Management Product 5: Strategic guidance on nutrient reductions through scenario forecasts (Figure 3).

- Management Need: Predictive models that provide 3D time variable scenario forecasts of hypoxia that can be used to evaluate the impacts of alternative management actions (e.g. Mississippi River diversions, various nutrient reduction targets) or climate change.
- Minimum Monitoring Requirements: Observations required to provide Products 3 and 4 are required if the model result is to relate the forecasted output to economic or ecological impact. In addition, data must be collected associated with any specific management intervention (such as reduced nitrogen fertilizer applications, increased conserved lands, or a specific river diversion) or altered climate scenarios.

Background: The HTF and other management users (*Gulf of Mexico Hypoxia Monitoring Strategy*, Appendix C) require a sophisticated understanding of the link between hypoxia and nutrient loading, with 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 and climate. Deterministic modeling offers the only practical approach to informing restoration management actions. 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 of ecosystem responses (i.e. "adaptive management").

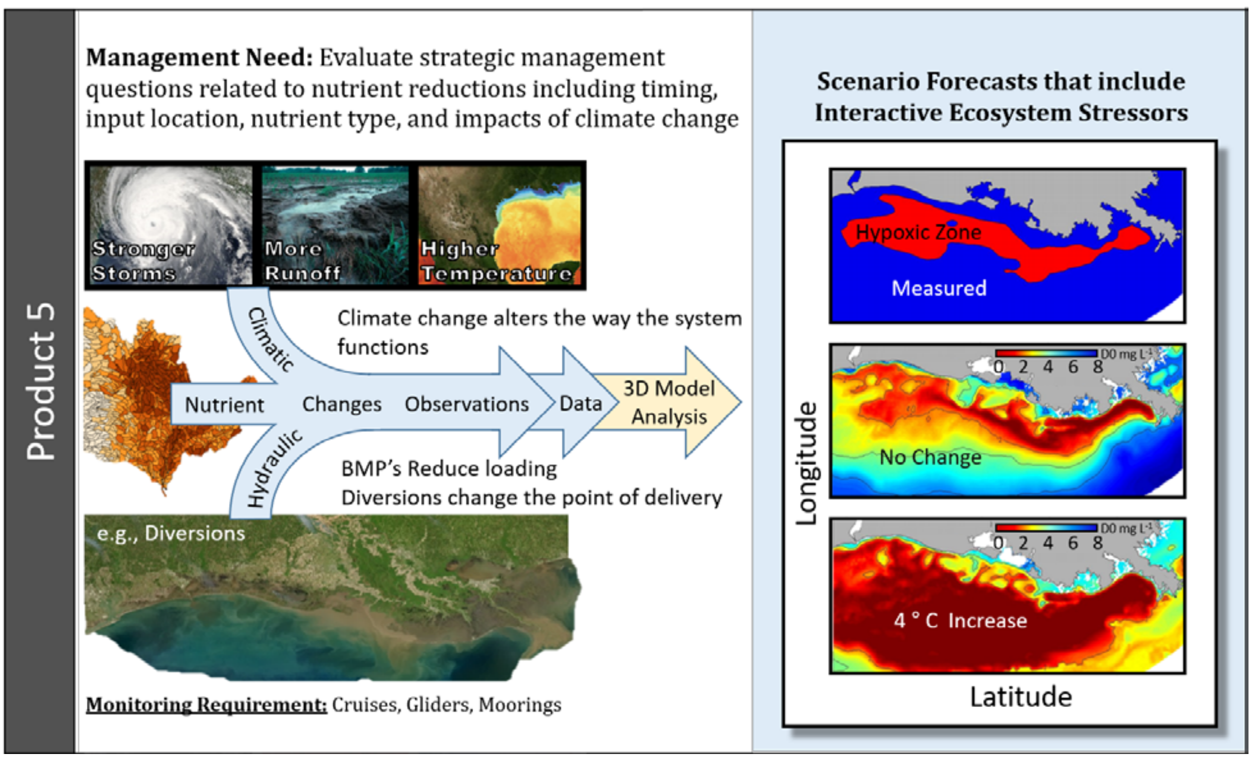


Figure 3. Management Product 5 – Strategic guidance on nutrient reductions through scenario forecasts. At right is a model simulation of climate effects on Gulf hypoxia, showing the measured area of water hypoxia during 21-16 July 2002 (top panel, www.gulfhypoxia.net), and

simulated oxygen concentrations during 21-16 July 2002 for the baseline scenario (middle panel, adapted from Justić and Wang 2014), and for a hypothetical future scenario that assumes a 4°C increase in temperature and a 20% increase in the Mississippi River discharge (lower panel). River diversions represent a unique large-scale management intervention that requires a deterministic modeling platform capable of spatially predicting oxygen concentrations, because these diversions will influence nutrient loading. 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. These model results ensure that evaluation of management strategies can account for the dynamic effects of multiple interactive forcing factors (Management Need). Monitoring Requirements will need to include data capturing spatiotemporal variability of targeted forcing factors. The figure to the right was adapted from Justić and Wang (2014).

Management Outcomes: Program Monitoring Requirements

The Gulf of Mexico Hypoxia Monitoring Strategy (white paper) provided a framework for a proposed cooperative program based on the input of multiple partners and modeler survey responses to refine prior efforts (Rose and Sable 2013, Aikman et al. 2014, Ashby et al. 2015). The minimum monitoring requirements to support the application of models presented in the white paper (Tables 2 and 3 in the white paper) were refined during the workshop in Breakout Session 1. Specifically, the working group was asked to determine the technical monitoring requirements for ship surveys, moored observing systems, and gliders needed to support analysis tools (primarily models) that are used to develop the hypoxia management products. The group summary of monitoring requirements is shown in Table 1. The following are key points of agreement and refinement relative to the monitoring requirements presented in the white paper.

Agreement:

- Continuing to provide a measure of the mid-summer hypoxic zone size (Product 1) and nutrient loading estimates to support the empirical models (Product 2) requires a single mid-summer annual cruise and collection of the instream nutrient concentrations, and daily discharge from the Mississippi and Atchafalaya Rivers.
- More complex management needs, including assessment of strategic nutrient reductions based on a change in timing and location of nutrient loading, assessment of impacts of the hypoxic zone on natural resources, or the ability to forecast future hypoxic conditions, all require deterministic modeling and a more intensive monitoring program (Products 3-5).
- All funded monitoring activities should be accompanied by dedicated support for data management, ensuring the quality and availability of the collected data.

Refinements (based on questions addressed at breakout session):

- **The workshop steering committee found greater support for surveying C and F transects over additional shelf-wide surveys west of the Delta. Do folks agree?** Shelf-wide surveys provide much greater information than transects, however the cost of surveying the entire shelf would be difficult to sustain. Surveying C and F transects monthly, and using these visits to service fixed (stationary) monitoring equipment, would provide a sufficient amount of information to satisfy Products 3-5 at a reduced price tag.
- **Do we need additional transects beyond C and F?** Monthly transects at C and F provide a means of detecting temporal variability as influenced by Mississippi River and Atchafalaya River discharge, respectively. Additional transects west of C and F would be valuable for distinguishing these sources of hypoxia formation from Texas river discharge.
- **Is expansion of the monitoring activities east of the Mississippi River (surveys/transects) worth the additional cost?** Yes, capturing the full extent of influence from Mississippi River runoff on hypoxia is important to refining Management Products 3-5. Monitoring east of the Mississippi Delta is valuable for differentiating impacts from the Mississippi River derived nutrients and inputs from nearby systems (e.g. inputs from Mobile Bay to Mississippi Sound).
- **Is the frequency of ship surveys appropriate, or should this be reduced from a cost/benefit perspective for model support?** Monitoring should be based on minimum needs to support model development and operations. Monthly cruises of the entire zone are unlikely to be achieved as a minimum requirement due to the expense of the cruise. Monthly transects west of the delta would provide model support and allow maintenance of observing systems at an appropriate frequency. Surveys east of the delta are less costly and should be conducted several times per year.
- **Lots of possible locations for fixed stations, what are the key locations?** The key stations include CSI-6, CSI-9, C, USM3M01, and G. CSI-16 is not as valuable.
- **How can we best use the potential for gliders considering their excellent temporal and spatial resolution (e.g. transects, area, or sawtooth patterns)?** Autonomous underwater vehicles such as gliders will be important to monitoring hypoxia in the Gulf of Mexico in the future, but their application is still in development. Of the three plans proposed in the Glider Implementation Plan (Howden et al. 2014), that were based on "transects" (Fig. 7 in Plan), "area" encompassing transects (Fig. 9 in Plan), and a "sawtooth" pattern (Fig. 6 in Plan), the "area" approach was recommended based largely on the difficulty in precisely repeating tracks given the constraints on controlling glider movement under the physical conditions typical of this system. Current plans are to use a combination of two types of autonomous vehicles to compensate for this constraint – underwater autonomous vehicles ("gliders") for the deeper areas of the hypoxic zone where density gradients are not prohibitively high, and autonomous surface vehicles with winch-driven sensor capabilities for the shallow areas where glider buoyancy control is challenging.

- **Is SEAMAP a good potential surrogate for shelf-wide surveys, outside of the primary survey?** No. SEAMAP provides an excellent dataset for guiding other monitoring efforts and for comparing impacts of low oxygen directly on organism presence, as both types of information are collected. SEAMAP does not go any shallower than 20 meters, which prevents monitoring in much of the Gulf of Mexico that is regularly hypoxic, and the sampling stations change for each survey.
- **Are you aware of any leveraging opportunities with other programs and platforms?** Yes, see section below, *Broad User Community: Opportunities for Forging Collaborations*.
- **Is there a role for satellite observation platforms?** Yes. They may not directly measure hypoxia, but they can provide other information such as locations of freshwater plumes or chlorophyll *a* concentration. Satellite information is already used by modelers (e.g. LSU Earth Scan Laboratory).

Table 1. Breakout Session 1 working group compilation of monitoring activities that could contribute to generation of five hypoxia management products. The costs of a subset of these activities are included in Tables 2 and 3 (see "Session Notes" for rationale for items not included). Codes correspond to Ship Surveys (S), Nutrient Loading Estimates (N), Fixed Observing Systems (O), and Gliders (G) used in Tables 2 and 3.

Code	Monitoring Activity	Justification as Monitoring Requirement	Session Notes
S-1	*Mid-summer* shelf-wide ship survey west of Mississippi Delta	Provides long-standing metric that HTF relies on to assess progress towards Coastal Goal; Provides calibration and validation data for statistical and 3D time variable hypoxia models.	Critical for Management Product 1. Sampling sites in Fig. 4. Costs in Table 2.
S-2	*Mid-summer* shelf-wide ship survey east of Mississippi Delta	Area influenced by discharge from the Mississippi River and contributes to Gulf wide hypoxia; Currently missing from most mid-summer dead zone area estimates; Could provide early warning of changes in hypoxia area due to nutrient reductions.	Hypoxia monitoring conducted in past (see discussion and Figs. 6-8 in white paper). Refinements in sampling design needed. Costs in Table 3.
S-3	*Mid-summer* shelf-wide ship survey south of Galveston	Area influenced by discharge from the Texas Rivers and contributes to Gulf wide hypoxia.	Those focused on the Texas coast have a large interest. Costs not included – need development of sampling design.
S-4	Shelf-wide ship surveys west of Mississippi Delta *in other seasons*	Hypoxia processes in region are strongly connected to coast and provide additional information for living resource and habitat impacts in delta region; Provides strong linkages to ongoing State monitoring programs and diversion studies and impacts.	Regular shelf-wide ship surveys will be difficult to maintain financially. Costs not included – C and F transects (Activity S-6) recommended over shelf-wide surveys.

S-5	Shelf-wide ship surveys east of Mississippi Delta *in other seasons*	Hypoxia processes in region are strongly connected to coast and provide additional information for living resource and habitat impacts in delta region; Provides strong linkages to ongoing State monitoring programs and diversion studies.	Establish standardized grid east of river. Costs in Table 3.
S-6	Cross-shelf transects C and F: monthly all year	Key transects at the mouths of the Mississippi and Atchafalaya Rivers; Good for measuring the evolution of hypoxia in the core areas of the dead zone; Smaller scale and temporal resolution would provide critical data for model calibration/validation through time.	Cross-shelf transects are only needed in the absence of monthly shelf-wide surveys. Transects shown in Fig. 4. Costs in Table 3.
S-7	Cross-shelf transects west of C and F (e.g. Transect K in Fig. 4 and one further west along LA/TX border)	Valuable for distinguishing hypoxia caused by Miss/Atchafalaya runoff vs. from Texas river runoff.	Needed if there are no monthly shelf-wide surveys. Costs not included – need development of sampling design.
S-8	SEAMAP groundfish survey mapping hypoxia from June through mid-July; shown in Fig. 5	Provides area snapshots of hypoxia over a several week period during the critical summer months; Oxygen data are collected with fisheries data, so is critical for model parameterization.	The dataset that is integral to revealing hypoxia effects on natural resources, but does not replace other monitoring. Costs in Table 3.
N-1 to N-3	Riverine Nutrient Loading	To identify nutrient loading, discharge and nutrient concentration must be measured.	Critical for product 2 in particular, but also products 3-5. Costs in Table 2.

 O-1 O-2 O-3 O-4	Sites West of Delta CSI-6 CSI-9 C G	Provides key long-term and temporal oxygen data to monitor hypoxia evolution through time in the core of the dead zone; Temporal model validation and calibration data at core areas on the shelf.	Critical monitoring for products 3-5. Sites shown in Fig. 4. CSI-6 and CSI-9 cover different environments, but CSI-9 offers more partners. Station C is the next highest priority. Costs in Table 3.
O-5	Sites East of Delta USM 3M01 CSI-16	Provides key temporal oxygen data to monitor hypoxia evolution through time in an area influenced by Mississippi River runoff; Temporal model validation and calibration data for an area of the shelf expected to be highly dynamic.	CSI-16 considered a relatively low priority and costs are not included. USM 3M01 needs bottom DO sensor. Sites shown in Fig. 4. Costs for USM 3M01 in Table 3.
G-1	"Area" approach of Glider Implementation Plan (4 cross-shelf areas; cover June through Aug; shown in Fig. 6)	Provides opportunity to collect high resolution temporal and spatial oxygen data in concert with other key physical and biological parameters. The data can be used for model calibration, validation, and formulation; and, parameter estimation analysis.	This type of glider operation is not currently feasible, but has promise for future application. Exploring combined use of autonomous underwater vehicles and autonomous surface vehicles (see p. 11). Costs in Table 3.

Maps illustrating monitoring sites corresponding to monitoring activities listed in Table 1. Figure captions include the corresponding codes listed in Table 1.

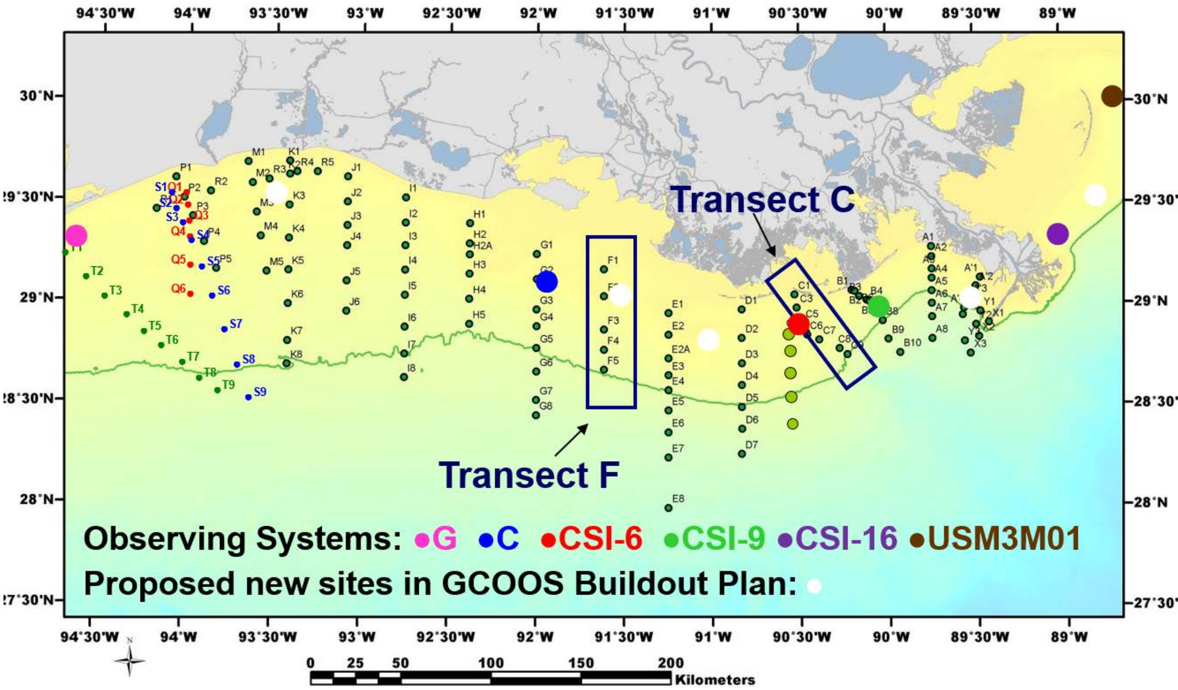
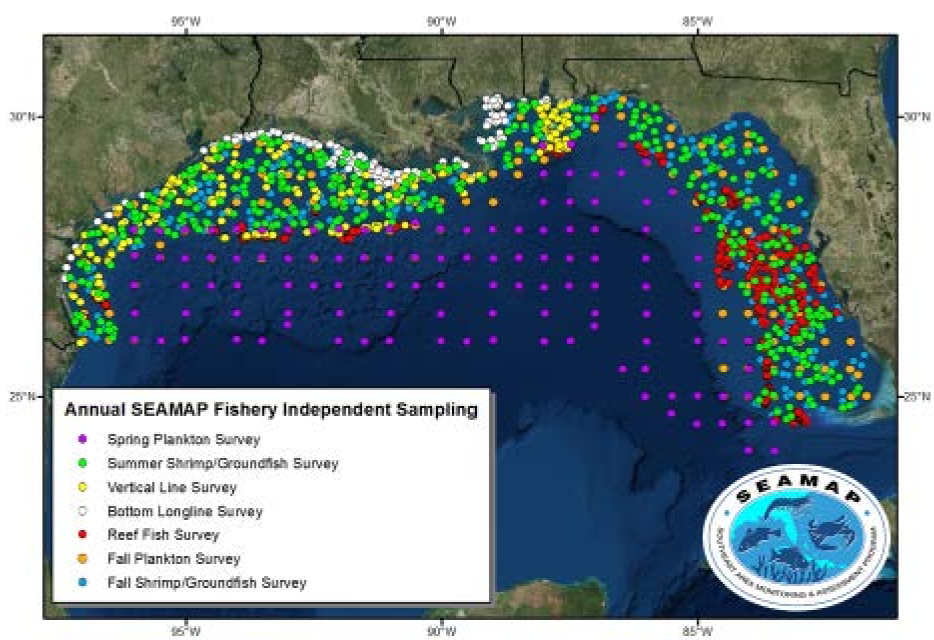


Figure 4. Ship shelf-wide sampling sites (S-1) and transects C and F (S-6) west of Mississippi Delta, and observing systems that currently exist (colored, O-1 to O-4 west and O-5 east of Delta) or are in the GCOOS Buildout Plan (white).

Figure 5. SEAMAP sampling sites, including the summer shrimp/groundfish survey sites in green (S-8).



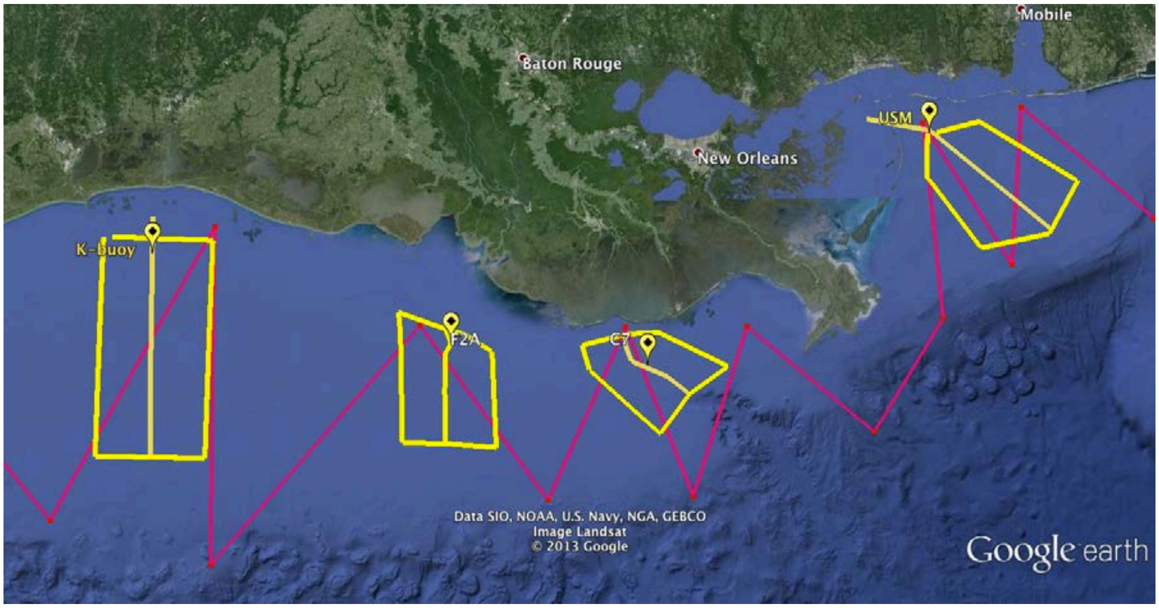


Figure 6. "Area" approach from Glider Implementation Plan (G-1). Superimposed (red) is the GCOOS glider conveyor belt running through the study region proposed in the GCOOS Build-Out Plan. Adapted from Fig. 9 of Glider Implementation Plan (Howden et al. 2014).

The following tables list the collaborators, estimated costs, and funding status for system requirements to meet data needs for Management Products 1 (Table 2) and 2-5 (Table 3). These requirements were developed prior to the workshop and revised at the workshop and, in some cases, in follow-up Steering Committee discussions.

Table 2. Monitoring system requirement options to meet data needs for Management Product 1 (annual mid-summer hypoxic zone areal extent). Codes: S = Ship Survey; D = Data Management.

SHIP SHELF-WIDE SURVEY
Management Product 1: Annual mid-summer hypoxic zone areal extent – metric for Hypoxia Task Force Coastal Goal.

Code	System Requirement	Collaborators	Estimated Annual Cost	Funding Status
S-1	Mid-summer shelf-wide ship survey west of Mississippi Delta	LUMCON; LSU; NOAA; NGI	$190K using contract (OMAO) vessel	Supported: $190K by NOAA NCCOS for FY17 Needed: $190K for FY18 and beyond
D-1	Maintain a data portal to make data accessible & to facilitate exchange (data management)	GCOOS; NCEI	$35K for 3 months FTE (GCOOS)	Supported by NOAA IOOS to GCOOS from FY16 to FY20
			$35K for 3 months FTE (NCEI)	Supported: NOAA NCEI ongoing
D-2	Dissemination of data and findings to research and management communities (communication)	LUMCON; LSU; GCOOS	$35K for 3 months FTE for GCOOS	Supported by NOAA IOOS to GCOOS from FY16 to FY20
			$35K for 3 months FTE LSU/LUMCON	Supported by LSU/LUMCON in FY17 Needed: FY18 and beyond

Total Annual Cost (FY18 and beyond): $330K

- **Supported: $105K; Needed: $225K**

Table 3. Monitoring system requirement options to meet data needs of Management Products 2-5. Codes for #: N = Nutrient Loading Estimates; S = Ship Surveys; O = Fixed Observing Systems; G = Gliders; D = Data Management.

EMPIRICAL MODEL SUPPORT
Management Product 2: Guidance on nutrient reduction requirements to meet the Hypoxia Task Force Coastal Goal.

#	System Requirement	Collaborators	Estimated Annual Cost	Funding Status
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);	$20K (USGS)	Supported: USGS ongoing
		LSU: Miss R at Baton Rouge	$65K (LSU)	Supported: by LSU in FY17 Needed: FY18 and beyond
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	$220K (USGS)	Supported: USGS ongoing
N-3	Daily discharge monitoring	USACE: Discharge for Miss R at Tarbert Landing (01100), and Atch R at Simmesport (03045)	$80K (USACE)	Supported: USACE ongoing

Total Annual Cost (FY18 and beyond): $385K ■ **<u>Supported</u>: $320K; <u>Needed</u>: $65K**				
DETERMINISTIC MODEL SUPPORT **Management Product 3: 3D time variable model characterization of Hypoxic Zone spatial and temporal dynamics** **Management Product 4: Hypoxia impacts on living resources and habitats** **Management Product 5: Scenario forecasts that include interactive ecosystem stressors**				
S-2	Mid-summer shelf-wide survey east of Miss Delta	USM; LUMCON; LSU	$50K	<u>Needed</u>
S-5	Monthly shelf-wide ship surveys east of Miss Delta	USM; DISL; LUMCON; LSU	$50/survey X 11 surveys = $550K	<u>Needed</u>
S-6	Monthly cross-shelf Transects C and F	LUMCON; LSU	$80K/survey X 11 surveys = $880K	<u>Needed</u>
S-8	SEAMAP groundfish survey mapping hypoxia from June through mid-July	NMFS; LDWF	$190K	<u>Supported</u>: NOAA NMFS ongoing
O-1	Maintain observation system west of Miss Delta: CSI-6	GCOOS; LUMCON	Year 1: $100K for new probes and	<u>Needed</u>

			sondes (surface and bottom); Year 2 and beyond: $125K/yr to maintain	
O-2	Maintain observation system west of Miss Delta: CSI-9	GCOOS; LUMCON	Year 1: $100K for new probes and sondes (surface and bottom); Year 2 and beyond: $125K/yr to maintain	<u>Needed</u>
O-3	Maintain observation system south of Atchafalaya: **C**	GCOOS; TAMU	$125K	<u>Needed</u>
O-4	Maintain observation system west of Miss Delta at western part of shelf-wide grid: G	GCOOS; TAMU	$125K	<u>Needed</u>
O-5	Maintain observation system east of Miss Delta at end of USM transect: USM 3M01	GCOOS; USM	Year 1: $50K to outfit with DO sensor Year 2 and beyond: $125K to maintain	<u>Needed</u>
G-1	Deploy gliders; "Area" approach of Glider Implementation Plan:	Ongoing Pilot Study: TAMU	<u>Initial equipment investment</u> = $1.44M based on $960K for 8	<u>Supported</u>: NOAA NGOMEX funding of Pilot Study in FY17

<table>
<tr><td></td><td>4 cross-shelf areas from June through Aug, with 10-day runs per area (2 underwater autonomous vehicles [“gliders”] & 1 autonomous surface vehicle [ASV] needed per area)</td><td></td><td>gliders ($120K each) + $480K ($120K each) for 4 ASVs

Deployment costs: $705K based on $8K/day for ship, $12K/day for personnel, $1K/day/glider, and $2.5K/day/ASV</td><td>Needed:
Year 1: $2.145M = $1.44M for equipment + $705K for deployment

Year 2 and beyond: $705K for deployment</td></tr>
<tr><td rowspan="3">D-1</td><td rowspan="3">Maintain a data portal to make data accessible and to facilitate exchange (data management), and disseminate data and findings to research and management communities (communication)</td><td rowspan="3">GCOOS; NCEI (including Hypoxia Watch); LSU/LUMCON</td><td>$125K for GCOOS FTE</td><td>Supported: by IOOS to GCOOS from FY16 to FY20</td></tr>
<tr><td>$125K for NCEI FTE</td><td>Supported: NOAA NCEI ongoing</td></tr>
<tr><td>$125K for LSU/LUMCON FTE</td><td>Supported by LSU/LUMCON in FY17

Needed: FY18 and beyond</td></tr>
<tr><td colspan="5">Total Annual Cost (FY18 and beyond): first year: $4.565M; subsequent years: $3.375M

Ship Surveys: Supported: $190K; Needed: $1.48M
Fixed Observing Systems: Supported: $0; Needed (first year): $500K; Needed (subsequent years): $625K
Gliders: Supported: $0; Needed (first year): $2.145M; Needed (subsequent years): $705K
Data Management: Supported: $250K; Needed: $125K</td></tr>
</table>

Broad User Community: Opportunities for forging collaborations

Committed monitoring support to meet empirical and deterministic model needs beyond 2017 is limited to the annual mid-summer hypoxia monitoring cruise, riverine nutrient sampling, and discharge monitoring (Table 2). At the workshop, potential synergies between other Gulf monitoring programs and the hypoxia-focused monitoring efforts were explored, with the purpose of capturing the ways programs could benefit from hypoxia monitoring, and identifying gaps in existing monitoring efforts that could be filled by a cooperative monitoring program. This step was integral to determining common interests that could lead to support of monitoring activity across programs (see section below, *Cooperative Support Network: Building the Cooperative Monitoring Program*).

At the workshop, during Breakout Session 2, attendees a) reviewed existing monitoring efforts of related programs to identify ongoing observations of potential mutual benefit to hypoxia management programs; and b) identified gaps in current monitoring programs that could be supported by related programs and, if filled, could benefit both related programs and hypoxia management programs. The following matrix incorporates information on related programs that was provided prior to, and subsequently refined at the workshop.

Table 4. Monitoring efforts with ongoing observations of potential mutual benefit to hypoxia management programs.

Monitoring Program	Primary Monitoring Purpose	Method of Collection	Is D.O. data collected?	Plans for the activity over the next 1-5 Years	Does your monitoring program overlap with the hypoxic zone region?	Is nutrient loading a factor in your objectives, do you measure?
USM						
USM 3M01 Mooring	Met-ocean and carbon cycle	Mooring, currently sensors only at surface	Yes, but only at surface	Continued operation, add bottom D.O. sensor.	MS Bight has seasonal hypoxia but not in the HTF area	Not Currently collected, but were in the past
HF Radar	Surface currents	Fixed	No	Continued operation	Yes	N/A
Glider network	These gliders were originally intended to monitor hypoxia off the MS coast, but they cannot handle the vertical density gradients that arise during the hypoxia season	Gliders	Yes	Have some funding, but looking for more	MS Bight has seasonal hypoxia but not in the HTF area	Valuable, but not collected
EPA Region 4 (Southeast)						
Mississippi Coastal Assessment (similar also for all coastal states every five years, funded by EPA and each state may	Status and Trends/Clean Water Act Requirement	Fixed probabilistic design	Yes	Indefinitely but dependent on funding	33 locations: Some in the Pearl River	Yes

conduct these more often)						
Mississippi Beach Monitoring Program (All Coastal States)	BEACH Act Requirement	Fixed	Yes	Indefinitely but dependent on BEACH grant funding	Locations are online	No
NFWF						
Oyster reef water quality monitoring	Project seeks to provide information used to improve oyster populations and sustainability in coastal MS. Also, to address significant decline in oyster production over the past 10 years	Ship/boat	Feasible	5 Years in duration	No	Valuable, but not collected
Oyster reef continuous monitoring	Project seeks to address significant decline in oyster production over the past 10 years by providing information used to improve oyster populations and sustainability in coastal MS	Mooring	Yes	5 Years in duration	No	Valuable, but not collected
NOAA OAP						
Mooring network	Constraining carbon chemistry in nGOM	Mooring	Yes, only at surface	Funded FY15-17; potentially sustained in next 5 years	No, in MS Bight	Valuable, but not collected

"Gulf of Mexico Ecosystems and Carbon Cycle" (GOMECC) cruise	Improved spatial understanding of OA, providing a long-term assessment of changes of biogeochemistry and ecology in response to increasing CO_2 atmospheric levels and large-scale changes in coastal dynamics	Ships	Yes	GOMECC-3 2017	Encompasses the entire Gulf of Mexico; should intersect at least on one transect	Yes, project will be measuring nutrients
Ships of opportunity (SOOP-OA)	A pCO_2 monitoring system put on fisheries ships and other commercial vessels	Ships	Yes	GOMECC-3 2017	Yes	Valuable, but not collected
NOAA OAP with NOAA's Coral Reef Conservation Program						
Flower Garden Banks National Coral Reef Monitoring Program (NCRMP)	Monitor ocean acidification over the wider Caribbean and Gulf of Mexico	Diver and Mooring	Yes	Funded FY15-17	No	Valuable, but not collected
Cheeka Rocks National Coral Reef Monitoring Program (NCRMP)	Monitor ocean acidification in the wider Caribbean and Gulf of Mexico	Ships and Mooring	Yes	Funded FY15-17	No, Florida Keys	N/A
GCOOS						
HF Radar station	Surface currents and waves network	Fixed	Yes	Add 6 stations each year for next 5 years	No	N/A
Mooring Network	Physical and biogeochemical variables	Mooring	Feasible	Add sites and variables including oxygen	Yes	Valuable, but not collected
Profiling floats (e.g. ARGO)	Boundary conditions for Gulf of Mexico shelf models	Floats	Feasible	Add Floats to reach goal density	No	Valuable, but not collected

Glider and underwater surface vehicles networks	Physical, biogeochemical	Gliders	Yes Phase 2 and Phase 3	Phase 2: Run onshore offshore transects	Yes	Valuable, but not collected
NOAA NMFS (Funds Cruise)						
SEAMAP Groundfish Survey (Summer/Fall)	To monitor inter-annual estimates of relative abundance for demersal species occurring in the northern and western Gulf of Mexico	Ships	Yes	Active - continued sampling	Yes	Valuable, but not collected
LDWF						
Nearshore Cruise	To monitor inter-annual estimates of relative abundance for demersal species occurring in the northern and western Gulf of Mexico	Ships	Yes	Active - continued sampling	Yes	Valuable, but not collected
NSF - FESD Program						
Fixed platforms in Wax Lake Delta	To measure the reduction of nitrate over the emerging wetlands of Wax Lake Delta	Mooring	No	Six platforms are active on the island monitoring water flow and nitrate. NSF funds end in August 2017	No, in upper Atchafalaya Bay	Have nitrate sensors
EPA Gulf of Mexico Program & ORD Gulf Ecology Division						

Coastal bridges: data sonde, IDEXX	*E. coli*; water quality parameters; correlate nutrients and periphyton community	Fixed	Yes	Currently, continued sampling in Turkey Creek to include virus and bacterial source tracking	No	Yes
Ship survey	Microplastics and Ocean Dredge Material Disposal Sites (EPA Regions 4 and 6)	Ships	Feasible	Continued sampling at various Gulf ODMDS locations (future status depends on budget)	Yes, in some locations.	The capacity is possible, but is not currently collected.
EPA Gulf of Mexico Program & Lake Pontchartrain Basin Foundation						
Data sondes and bacterial plate counts	Health of Lake Pontchartrain and its watershed	Fixed Locations	Yes	Continued sampling	No	Valuable, but not collected
Harte Research Institute, Fisheries Group						
Artificial Reef Surveys	Understanding role of artificial reefs	Ships	Yes	Seasonal sampling during next 5 years (ROV, SCUBA, Vertical Line, Data Sonde for general water parameters)	No	No
Harte Research Institute, Ecosystems Group						

Surveys	Effects of climate change and altered freshwater inflow	Ships	Yes	Quarterly sampling at long-term stations Biweekly sampling at summer hypoxia stations	No	Yes
NOAA NDBC, NAVOCEANO, USM Glider Networks						
Glider networks	Loop Current circulation and dynamics Deployment time frame is based around GOM summer conditions and hurricane season (August - November). Earlier deployments would depend on budget and partner glider availability	Gliders	Yes	Continue annual deployments	Yes, if they are shallow gliders. Deep gliders are hard to fly on the shelf.	No
Shell Stones Project						
Metocean Mooring	BSEE NTL Permit Requirement (currents down to 1000m)	Mooring	No	Outfit mooring line with additional sensors	No, deepwater (3000m)	No
Louisiana CPRA						
System-Wide Assessment and Monitoring Program (SWAMP	Natural System Monitoring, including water quality	Fixed stations	Yes	Will continue	No	One of the objectives of CPRA

Cooperative Support Network: Building the Cooperative Monitoring Program

Breakout Session 3 discussions focused on ways that partners already committed to management of Gulf hypoxia and MARB nutrients, and supporting Gulf hypoxia monitoring to some degree, might sustain and expand upon those commitments to contribute to a sustainable cooperative hypoxia monitoring program. First, attendees identified programmatic tools (strategic plans, budget projections, staffing commitments, long-term funding commitments, etc.) for improving upon and sustaining current efforts for hypoxia monitoring within agencies and institutions that fit within the purview of the cooperative monitoring system requirements. Secondly, attendees identified opportunities to forge new, and strengthen existing, partnerships across agencies and institutions in a manner that would lead to stronger long-term commitments to hypoxia monitoring in a visible and collaborative manner (e.g. interagency working groups, administration ocean plans, operational plan development and cost-sharing agreements).

Based on deliberations from Breakout Sessions 2 (Table 4) and 3, workshop participants came together to discuss strategies for ensuring that the partnerships and specific mechanisms for coordination identified at the workshop would be sustained and applied toward implementation of a cooperative monitoring program. Discussions led to the identification of eight workgroups that have a stake in dissolved oxygen monitoring in the Gulf of Mexico and could provide monitoring support in some capacity. This support could come in the form of direct financial support, in-kind support, or support for hypoxia as a primary issue or as a major variable of concern when considered from an individual or multi-stressor perspective. The eight workgroups represent different organizations with mutual interest, titled: 1) Fisheries; 2) Hypoxia Task Force; 3) Oil and Gas Industry and Ocean Acidification; 4) the RESTORE Act; 5) the state of Louisiana; 6) the states of Mississippi and Alabama; 7) the state of Texas; and, 8) Autonomous Vehicle Workgroups. The Workgroup Leads are members of the Gulf of Mexico Cooperative Hypoxia Monitoring Program Implementation Team and the groups will continue to function into the foreseeable future. Goals and objectives of the Workgroups follow.

Gulf of Mexico Cooperative Monitoring Program Workgroups:

Fisheries Monitoring Workgroup

Team Leads –
Kevin Craig (NOAA NMFS)
Alan Lewitus (NOAA NOS)

Goal – To leverage and expand upon current monitoring activities and compile available data, in an effort to broaden our understanding of the lethal and sub-lethal impacts of hypoxia on key fisheries, for the purpose of recognizing hypoxia impacts and managing fisheries according to these impacts.

Objectives:

- Identify monitoring programs for red snapper, menhaden, and brown shrimp;

- Develop plan to incorporate DO and pH measurements in fish monitoring surveys in hypoxic zone;
- Serve as Management Committee to provide guidance to hypoxia researchers for fisheries management applications.

Hypoxia Task Force Monitoring Workgroup

Team Leads –
Daniel Wiegand (EPA Gulf Program)
Alan Lewitus (NOAA NOS)

Goal – Maintain current monitoring to meet the needs of Management Products 1 and 2, and find ways to achieve additional monitoring activities to meet the data needs of more advanced modeling that satisfies products 3-5.

Objectives:

- ID programmatic tools (strategic plans, budget projections, EFR budget, etc.) for improving upon and sustaining current efforts for hypoxia monitoring within agencies;
- ID opportunities to forge new, or strengthen existing partnerships in a manner that will lead to long-term commitments to hypoxia monitoring program (e.g. interagency work groups, administration ocean plans).

Oil and Gas Industry and Ocean Acidification Monitoring Workgroup

Team Leads –
Barb Kirkpatrick (GCOOS)
Nancy Rabalais (LSU/LUMCON)
Steve DiMarco (TAMU)

Goal – To identify interest from the Oil/Gas industry to leverage monitoring on platforms and to identify intersections between all groups interested in monitoring ocean acidification parameters that benefit hypoxia monitoring.

Objectives:

- Engage with BOEM and Oil and Gas industry to identify platforms on the continental shelf on which DO and pH data collection would mutually benefit the industry and the Cooperative Hypoxia Monitoring Program;
- Coordinate with the Gulf of Mexico Coastal Acidification Network (GCAN) to identify opportunities to advance understanding of ocean acidification and associated stressors (i.e. temperature, oxygen) on biological resources of the Gulf of Mexico.

RESTORE Act Monitoring Workgroup

Team Lead –
Steve Giordano (NOAA NMFS)

Goal - Identify opportunities for leveraging RESTORE Act monitoring plans and funded monitoring activities in the implementation of the Cooperative Hypoxia Monitoring Program.

Objective:
- Maintain communications with RESTORE Act efforts with monitoring objectives (e.g. RESTORE Council Monitoring and Assessment Program, Monitoring Community of Practice) to ensure that leveraging opportunities in support of Cooperative Hypoxia Monitoring Program system requirements are recognized and implemented as appropriate.

Louisiana Coastal Monitoring Workgroup

Team Leads –
Angelina Freeman (LA CPRA)
Dubravko Justić (LSU)

Goal – To identify monitoring required to assess the impacts of a diversion on hypoxia in the Gulf of Mexico and to identify ways to fund the monitoring.

Objectives:
- Identify requirements for a monitoring transect extending from nearshore to the hypoxic zone that would capture quantification of nutrient flux and bottom-water DO with the goal to assess the effects of diversions in reducing nutrient loading;
- Identify mechanisms and opportunities to support the monitoring transect.

Mississippi/Alabama Monitoring Workgroup

Team Leads –
Steve Ashby (NGI)
Stephan Howden (USM)
Brian Dzwonkowski (U. Southern Alabama/DISL)

Goal – To identify monitoring the states of Mississippi and Alabama are doing now and how it can be improved upon, expanded, or otherwise leveraged to support federal and nearby state monitoring for hypoxia and other stressors.

Objectives:
- Compile Mississippi and Alabama coastal monitoring efforts and identify mechanisms to fill gaps in DO and pH monitoring capabilities;

- Coordinate Mississippi and Alabama monitoring activities and identify opportunities to transition these to a sustainable cooperative monitoring program.

Texas Monitoring Workgroup

Team Lead –
Steve DiMarco (TAMU)

Goal – To identify monitoring the state of Texas is doing now and how it can be improved upon, expanded, or otherwise leveraged to support federal and nearby state monitoring for hypoxia and other stressors.

Objectives:
- Compile Texas coastal monitoring efforts and identify mechanisms to fill gaps in DO and pH monitoring capabilities;
- Coordinate Texas monitoring activities and identify opportunities to transition these to a sustainable cooperative Texas monitoring program.

Autonomous Vehicle Monitoring Workgroup

Team Lead –
Steve DiMarco (TAMU)

Goal – To identify the autonomous vehicle monitoring needs of, and funding opportunities for the Cooperative Hypoxia Monitoring Program.

Objective:
- Design and test a method to map the hypoxic zone with autonomous vehicles (combination of underwater gliders (for deeper regions) and autonomous surface vehicles (for shallower regions)

List of Attendees:

Becky Allee	NOAA RESTORE
Steve Ashby	NGI
Julie Bosch	NOAA NCEI
Laura Bowie	GOMA
Debra Butler	NAS Fellow, EPA Gulf Program
Lael Butler	EPA Gulf Program
Doug Daigle	LSU
Padmanava Dash	MSU
Chris D'elia	GOMURC
Steve DiMarco	TAMU
Mary Erickson	NOAA NCCOS
Angelina Freeman	LA CPRA
Steve Giordano	NOAA NMFS
Chris Gledhill	NOAA NMFS
Dwight Gledhill	NOAA OAR
Monty Graham	MBRACE
Rick Greene	EPA Gulf Breeze Lab
Alex Harper	NOAA OAR
Stephan Howden	USM
Dubravko Justić	LSU
Barb Kirkpatrick	TAMU GCOOS
Kirsten Larsen	NOAA NCEI
Julien Lartigue	NOAA RESTORE
Kristen Laursen	NOAA NMFS
Alan Lewitus	NOAA NCCOS
Robert Magnien	NOAA NCCOS
Jan Mandrup-Poulsen	Dynamic Solutions
Nelson May	NOAA NMFS
Ehab Meselhe	TWIG
Paul Montagna	TAMU Harte Institute
Robert Moorhead	MSU
Ruth Perry	Shell
Troy Pierce	EPA Gulf Program
Antoinetta Quigg	TAMU
Nancy Rabalais	LSU, LUMCON
Rick Raynie	LA CPRA
Denise Reed	TWIG
Jeff Rester	Gulf States Marine Fisheries Commission
Angela Sallis	NOAA NCEI
Ben Scaggs	EPA Gulf Program
David Scheurer	NOAA NCCOS

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