Northern Gulf of Mexico Ecosystems and Hypoxia Assessment (NGOMEX) Program

The Gulf of Mexico dead zone has become a focal point for considerable scientific and policy attention because of its enormous size and implications for watershed management for more than 40% of the contiguous US. Being one of the biggest ecosystem management challenges faced by the nation, Congress established the Interagency Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (or Hypoxia Task Force, HTF) as part of the 1998 Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) legislation. Comprised of seven Federal Agencies, twelve States and one tribal member, the Task Force provides overall direction and leadership for addressing this critical issue which crosses many state boundaries, impacts coastal and offshore waters, with impacts across multiple sectors from watershed management to fisheries management.

The HTF operates within an adaptive management framework with its actions and goals driven by the 2001 Gulf Hypoxia Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico. The Action Plan was updated in 2008 and reassessed in 2013 with the next reassessment planned for 2019. Annual stakeholder meetings are held with periodic scientific assessments conducted and interim strategy documents developed. In 2015 and 2017, reports on activities and progress were delivered to Congress further demonstrating continued interest in this topic at the highest levels. Throughout this time, NOAA has played a foundational role on the HTF in providing the research, monitoring, and modeling necessary to address many of the key actions and goals specified in the action plan and reassessment documents.

Authorized by HABHRCA legislation, the Northern Gulf of Mexico Ecosystems and Hypoxia Assessment (NGOMEX) Program was established to provide NOAA with the framework from which to address the hypoxia problem in the Gulf from an integrated, multi-disciplinary, and long-term approach. The program is organized around three focal areas that provide information and tools critical to the success of the HTF and other management efforts with goals to restore the northern Gulf of Mexico ecosystem. The three focal areas (NGOMEX Objectives) along with the accomplishments, outcomes and relevance of these efforts toward supporting the HTF and Gulf hypoxia issues in general are described below.

NGOMEX Objective 1: Characterize the magnitude and extent of the hypoxic zone

Accomplishments/Outcomes:

As part of ongoing integrated studies to understand the causes and impacts of the dead zone, the program has maintained the only long-term measurement of the hypoxic zone in the Northern Gulf of Mexico (annual mid-summer survey cruise), a record that spans over 30 years and is one of the longest ecological datasets collected.

- ***Relevance****: The Coastal Goal of the Action Plan calls for the hypoxic zone to be reduced to an annual average size of 5,000 km^2. The survey data and the corresponding HTF metric is the only way that the HTF has to assess progress toward achieving this goal. Having the metric has allowed the HTF to assess ongoing progress of watershed nutrient reduction actions by each of the HTF states toward overall mitigation of the dead zone. The results of the annual survey are published via a NOAA press release which creates considerable stakeholder and Congressional interest on the topic. The Louisiana government also recently passed a resolution codifying the importance of maintaining the monitoring cruise.*

The annual summer survey, additional cruises, cross-shelf transects, and continuous measurements from moored observation systems have provided foundational data for multi-year and spatially extensive process and benthic oriented studies of key water-column and benthic dynamics.

- ***Relevance****: NGOMEX-funded monitoring has provided the data sets to support understanding of the critical rate processes involved in hypoxia formation and spread, and to provide critical parameter estimates for hypoxia models. As a result, uncertainty in the processes driving hypoxia (e.g., role of riverine vs water column nutrient input or importance of nitrogen vs phosphorus) has been greatly reduced allowing credible and scientifically defensible nutrient reduction targets to be established for these highly controversial issues.*

The program has successfully moved the annual mid-summer survey cruise from research support to support through the Northern Gulf Institute (NGI) Hypoxia National Office.

- ***Relevance:*** *With the severe reduction in NGOMEX funding availability, there was a need to support the critically important survey cruise via other funding sources. Operational protocols were develop for a standardized cruise as well as analysis on the impacts of various survey designs and frequency of measurement. An analysis was conducted which showed that even the loss of a single cruise greatly diminishes the ability of the HTF to measure progress toward its interim nutrient goal reductions.*

NGOMEX studies fully characterized the pros and cons of using autonomous underwater vehicles (AUV) gliders to provide a cost-effective solution to mapping the

dead zone in higher spatial and temporal resolutions than the current annual survey cruise allows. Gliders have limited capability to map the entire dead zone – they excel at collecting data in deeper waters encompassing the dead zone but were found to be limited in shallow waters with high density gradients due to challenges to buoyancy control and lack of depth control.

- ***Relevance:*** *Our studies demonstrated the strengths and limitations of glider application to dead zone mapping, and paved the way for a host of alternative autonomous technological solutions that largely involve combinations of autonomous surface vehicles (with winch-driven sensors) and autonomous underwater vehicles (e.g. gliders). These efforts have led to a new Small Business Innovation Research (SBIR) supported topic area to create an autonomous sampling platform for Gulf of Mexico dead zone mapping. The announcement has generated considerable interest in the private commercial sector, as overcoming this challenge opens up a worldwide commercial market for hypoxia monitoring (i.e., over 400 hypoxic zones around the world) as well as opening up an even larger market related to bottom water sampling in general.*

A Cooperative Hypoxia Assessment and Monitoring Program (CHAMP) has been developed to meet the monitoring needs of the HTF and other complementary management programs. Several workshops since 2007, aimed at improving many individual aspects of monitoring and of the understanding of the dynamics of hypoxia in the Gulf, have been used to provide the basis of this comprehensive multi-platform, multi-state, multi-issue program. Despite recent major investment in the Gulf of Mexico, there still remains a major gap in ocean monitoring support (Watson et al. 2016)

- ***Relevance:*** *A comprehensive monitoring program with good spatial/temporal coverage that encompasses the dead zone region is needed by the HTF and other management entities (e.g. Louisiana Coastal Protection and Restoration Authority, CPRA; Fisheries managers) to; (1) evaluate coastal water quality and ecosystem responses to restoration activities to inform adaptive management; and, (2) to adequately support scenario forecast models needed to predict future responses to changing environmental conditions. Long-term support of CHAMP will be a major achievement for the region by establishing the only long-term sustainable monitoring program that encompasses the hypoxic zone. Sustained system requirements currently include the mid-summer ship survey (NOAA NCCOS), nutrient loading (USGS) and river discharge measurements (USACE), a Hypoxia Data Portal (GCOOS, NOAA NCEI), several NMFS SEAMAP Fisheries surveys, and continuous data from a moored buoy in the hypoxic zone area.*

NGOMEX Objective 2: Develop quantitative models to predict the extent of the hypoxic zone given varying levels of nutrient inputs, physical forcing, and other factors that control hypoxia

Accomplishments/Outcomes

Developed a series of peer-reviewed and extensively published statistical/empirical models capable of accurately predicting the size of the annual dead zone based primarily on nutrient inputs while also accounting for other environmental factors (e.g., stratification, winds, etc).

- ***Relevance:*** *These models are a foundational tool used by the HTF to set nutrient reduction targets in the Mississippi River watershed since the inception of the HTF. The models provide an estimate of hypoxia area for a given nutrient load amount with an estimated confidence interval. Without the models, the HTF would not have been able to set the initial nutrient reduction targets in 2001 and the revised estimates in 2008 and 2013.*

Conducted annual testing and validation of the suite of statistical/empirical models via an annual seasonal forecast of the dead zone size. The forecast is announced through a joint NOAA/USGS press release and then validated against the annual mid-summer survey cruise.

- ***Relevance:*** *The annual NOAA/USGS press releases announcing the seasonal hypoxic zone forecast and observed size are picked up by a large number of media outlets, drawing public and stakeholder attention to the issue – e.g. see 2017 Dead Zone forecast press release and measured size press release. The press release and associated forecast offers an opportunity to discuss nutrient reduction progress and highlights relevant hypoxia science by NOAA and its partners. In recent years, this release has linked to the HTF/EPA website and has resulted in their highest period of website traffic. While the forecasts are not known to be directly used by any industry or group, the same models are used to set the HTF nutrient reduction goals, and confidence in these models (via the annual testing of the forecast accuracy) by the HTF member states is integral to making continued progress in the watershed.*

Successfully transitioned the suite of statistical/empirical models from an external, research environment to an internal and potentially long-term sustained operational environment within NOAA. At the same time, the models have been integrated into an "ensemble" forecast prediction, the first of its kind for a NOAA-based scenario ecological forecasting product.

- ***Relevance:*** *Without continued long-term institutional support these models will not be available for future HTF adaptive management cycles. Securing this capability, internally in NOAA, ensures that these models will be available to the HTF for the upcoming planned reassessment in 2019. With the development of*

the ensemble forecast, NOAA will be able to provide a more robust and integrated forecast which takes advantage of the capabilities of the individual modeling platforms.

Supported development of coupled 3D-hydrodynamic and biogeochemical models of hypoxia to allow examination of hypoxia dynamics through space and time. This has been a missing capability of the HTF for many years and is advancing their understanding of past hypoxic events, how hypoxia evolves, and in the development of potential new monitoring metrics.

- ***Relevance:*** *These models allow the HTF to answer complex management questions (not possible with the statistical/empirical models) despite the fact that the Gulf of Mexico is very large, contains a large pool of residual nutrients, and the biogeochemical cycle is complex and varies spatially and temporally. The models have been used to inform the HTF of the estimated size of the dead zone in 2016 in the absence of the annual survey cruise and then again in 2017 as part of a new annual assessment on hypoxic zone dynamics. This review has now been incorporated into the annual HTF meetings. The models also provide a bridge connecting to living resource models and will allow for resource and economic impacts due to hypoxia to be quantified and balanced against restoration cost (e.g., impacts of river diversions).*

The statistical/empirical and 3D coupled hydrodynamic/biogeochemical models have been repeatedly used to provide critical goal-setting guidance to the HTF related to the action plans and reassessment and more recently with the development of the interim nitrogen and phosphorous goals. Two key questions were addressed in NOAA's presentation to the HTF based on modeling capabilities developed from the program.

- ***Relevance:*** *Question 1 - What reductions in N and P loading are needed to shrink the Dead Zone to 5,000 km^2 (Coastal Goal)? The models demonstrated the need for a dual nutrient reduction strategy; verified that the 2008 Action Plan N and P reduction targets of 45% would lead to achievement of Coastal Goal if both N and P targeted. Question 2 – How much will 20% reductions in N and P loading shrink the zone (Interim Goal)? The 3D Model simulations showed that the sensitivity of changes in hypoxia to nutrient load reductions is variable – reaching the 20% interim nutrient reduction goal will not reduce hypoxia significantly, but will bring us closer to the point where the amount of hypoxia reduction per unit nutrient reduction increases - i.e. moving beyond 20% reduction will have an impact on the size of the hypoxic zone. Without these models, the HTF would have had unrealistic expectations for the impact of their interim 20% reduction will have on the size of the hypoxic zone. Failing to realize an impact from successful reductions can have major negative consequences on commitment by managers in a management program.*

The program has led the development of the modeling capability available to the HTF since its inception with evolution and development of modeling platforms closely tied to

the needs of the HTF. The needs from the HTF were further refined through a series of targeted workshops, led by the program in conjunction with the Hypoxia National Office, and which brought together the modeling and stakeholder communities in the Gulf. The reports from these workshops often then became foundational materials for future NGOMEX FFOs.

- ***Relevance:*** *Some key workshops include the 3rd and 4th Annual NOAA/NGI Hypoxia Research Coordination Workshops (see Appendix). The first workshop focused on providing the HTF with state-of-knowledge and information gaps on biogeochemical processes and living resource impacts to inform the 2013 science reassessment of the 2008 Gulf of Mexico Action Plan. This led to two synthesis reports, one on hypoxia impacts on living resources and another understanding the role of biogeochemical processing to simulating hypoxia. The second workshop used a modeling technical review panel to assess the state of scenario forecast models and developed conclusions on approaches to most effectively meet needs of management efforts such as the HTF. The output, Modeling Approaches for Scenario Forecasts of Gulf of Mexico Hypoxia, was key to informing future modeling approaches targeted by NGOMEX and NCCOS.*

NGOMEX Objective 3: Develop quantitative models to determine the impacts of the hypoxic zone on ecologically and economically important living resources

Accomplishments/Outcomes:

Supported the first studies of its kind to make a direct link between hypoxia and sub-lethal effects on commercially important and ecosystem relevant species in the region. Sub-lethal effects (in croaker) include reproductive impairment (masculinization of females) and growth impairment. The studies included the identification of hypoxia-exposure genetic biomarkers that result in elevating gene expression that can be measured in the lab and field.

- ***Relevance:*** *Quantifying the current and future effects of hypoxia on living resources and their habitats is a great need for fisheries managers, who need to plan for the impacts of hypoxia and interactive factors (e.g. climate change, restoration activities such as freshwater diversions) at population and ecosystem levels. This is a great challenge, given the complexity of quantifying direct and indirect sublethal effects, food web controls, and the need to account for interactive stressor effects. Sub-lethal and indirect effects of hypoxia are important because organisms occupy moderately low DO habitat in the field and habitat loss induces strong aggregations near hypoxic edges where organisms are exposed to persistent low DO levels. Being able to see these impacts via biomarkers is a valuable tool to identify and monitor exposed populations.*

NGOMEX projects are developing multiple modeling approaches that incorporate bioenergetics and growth potential effects of hypoxia, and couple these ecological models to hydrodynamic and biogeochemical models to fully capture the environmental and biogeochemical effects of hypoxia at the individual and population level. Long-term forecasts from hydrodynamic/biogeochemical/ecological coupled models (using bioenergetics modules incorporating sublethal hypoxia effects) predict that nutrient reductions will have a net positive effect on croaker populations because the increase in croaker populations due to reduced hypoxia will outweigh the decreases due to reduced food availability.

- ***Relevance:*** *Understanding the effects of a spatially/temporally dynamic stressor that varies through the water column is difficult. Considering impacts on mobile organisms and the fact that nutrients increase primary productivity, means that, in theory, a mobile organism could take advantage of increased production while avoiding some negative impacts due to hypoxia. Despite these challenges, for the first time, NGOMEX provided the HTF, managers, and stakeholders with compelling scientific evidence that Gulf hypoxia has widespread sublethal impacts on important fish species, affecting reproduction and growth rates, as well as economic impacts on the shrimp fishery.*

Supported critically needed research on the bioeconomic modeling of hypoxia impacts on fishing fleets and their target species. Studies on brown shrimp and menhaden

fisheries indicate that fishing fleets are responsive to hypoxia (or hypoxia-induced effects on target species) and these shifts in spatial distribution likely influence catchability, or the proportion of the stock harvested by a given unit of fishing effort. When hypoxia is severe, prices of large shrimp increase relative to small shrimp and this result is consistent with known or hypothesized mechanisms: catchability, growth, and mortality skew size distributions to smaller sizes so that fewer large shrimp are available.

- ***Relevance:*** *These results are the first demonstration of an economic effect of hypoxia on a major commercial fishery. In addition to being able to begin quantifying this impact in economic terms for local fishermen, the spatial effects of hypoxia on catchability and abundance estimates can now be investigated and understood with these tools and provide important information for stock assessment models for brown shrimp and menhaden. We are now at the threshold of being able to provide an end-to-end capability for understanding the cascading hypoxia effects from the watershed to consumer.*

NGOMEX science has reached a maturity in the understanding and modeling of hypoxia to enable major advances in our understanding of the impacts of hypoxia on natural resources within an ecosystem based management framework. The three ongoing FY16 awards are advancing scenario forecasting of the interactive ecosystem effects of freshwater diversions and hypoxia, using models coupled from the watershed to fish, and have a strong fisheries management involvement, including: (1) NMFS Application PIs to lead Management Committee engagement and feedback; (2) Management Committees that include numerous federal (NMFS) and state fisheries managers, and members from the Gulf States Marine Fisheries Commission and Gulf of Mexico Fishery Management Council.

- ***Relevance:*** *The interest/concern of Gulf fisheries managers and Fisheries Councils on hypoxia has grown in recent years due in large part to NGOMEX research advancing understanding of sublethal effects of hypoxia on living resources, including the association with habitat and behavioral changes. The seminal work on croaker sublethal responses, as applied in Individual-Based Models, suggests long-term consequences on populations. Also, ecosystem-based studies have shown that some commercially important species (e.g. red snapper) can be adversely affected if current hypoxia levels are sustained or increased. Large-scale Mississippi River diversions are being implemented as part of the Coastal Protection and Restoration Authority's Louisiana's Comprehensive Master Plan for a Sustainable Coast, and will have a great influence on hypoxia and its effects on fisheries. Through NCCOS led workshops and NGOMEX, a strong collaborative network of researchers, fisheries managers, and other stakeholders is actively incorporating model outputs into fisheries management strategies to improve sustainability.*