

ADVANCING ECOSYSTEM MODELING OF HYPOXIA AND DIVERSION EFFECTS ON FISHERIES IN THE NORTHERN GULF OF MEXICO

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EXECUTIVE SUMMARY

The *5th Annual NOAA/NGI Gulf Hypoxia Research Coordination [Workshop](#)* brought Louisiana state officials together with federal and other state agencies, NGOs, and academic scientists with interests in discussing a path forward to achieve a balance of (1) restoring Louisiana's coastal wetlands, (2) reducing the size of the annual Gulf of Mexico hypoxic zone, and (3) sustaining ecological and socioeconomic benefits of fisheries. The main drivers for these efforts – the Louisiana Coastal Protection and Restoration Authority's (CPRA) [Coastal Master Plan](#) and the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force's (Hypoxia Task Force or hereafter HTF) [Action Plan](#) – committed to adaptive management approaches based largely on the limited ability to predict how restoration practices will achieve the intended outcomes. The timing of the workshop was ideal in that:

- an adaptive management implementation plan was in preparation by CPRA, based on recommendations from The Water Institute of the Gulf (Water Institute);
- the HTF was entering a goal reassessment phase of their adaptive management process, and the proper analysis of the optimal mitigation goal that depends on restored ecosystem benefits includes the interactive effects of diversions;
- recent major advances in ecological modeling may provide the scientific foundation for effective adaptive management of ecosystem response to diversions and hypoxia; and
- several ongoing efforts were ready to apply their approaches and tools to advance the assessment and prediction of the environmental, social and economic effects of diversions and hypoxia.

Workshop discussions were productive and energetic, reflecting a common mission toward informing adaptive management implementation plans that would allow the best chance of achieving an agreed upon balance of restoration outcomes. This proceedings paper continues that momentum by presenting discussion points from the workshop to help inform the adaptive management of diversions and hypoxia.

Management Needs

A diverse group of managers, biophysical and social scientists, and stakeholders gained group consensus on priority fisheries management needs, related to expected interactions with planned river diversions, through a ranking exercise combining the results from four breakout groups. These groups ranked a series of priority science needs for the near-term (3-5 years) and for the long-term (10-50 years) related to hypoxia, diversions, and fisheries management.

From a short-term perspective (3-5 years), the highest ranked needs (in order) were to improve the body of knowledge surrounding:

1. diversion effects on juvenile fishery species and their prey;
2. the effects of diversion-induced changes in marsh properties on key fisheries species habitat and nutrient loading to the Gulf (linkage to hypoxia);
3. diversion effects on oysters;
4. (tie) the effects of diversion-induced changes in prey-predator interactions on fisheries production;

4. (tie) hypoxic zone effects on fishery resources; and
6. diversion effects on downstream nekton communities.

Another short-term need that was introduced as a top priority by one group during the breakout session, but not ranked by the other groups was the socioeconomic effects of diversions.

The breakout groups also ranked what they felt were the most important long-term (10-50 years) priority needs (differences from short-term in bold). These long-term needs included improving the body of knowledge surrounding:

1. diversion effects on juvenile fishery species and their prey;
2. **(tie) influence of climate change on diversion effects on fisheries;**
2. (tie) the effects of diversion-induced changes in marsh properties on key fisheries species habitat and nutrient loading to the Gulf (linkage to hypoxia);
4. **diversion effects on the hypoxic zone;**
5. the effects of diversion-induced changes in prey-predator interactions on fisheries production;
6. (tie) **the effects of diversion-induced changes in fishing pressure on fisheries production;**
6. (tie) diversion effects on downstream nekton communities.

For both short-term and long-term needs, socioeconomic effects of diversions was introduced as a high priority long-term need by one group in their breakout session.

Adaptive Management Recommendations

From plenary presentations and breakout group discussions, key points follow that provide recommendations for predicting and assessing the effects of diversions and hypoxia. Some of these recommendations are already incorporated into State of Louisiana guidance documents.

- A **user-based approach** was recommended for developing an adaptive management strategy – stakeholder needs should be considered, and management scenarios developed to reach meaningful endpoints based on quantifiable targets and goals. The public should be part of the conversation and their input should help drive the approach. Public feedback should begin early in the adaptive management decision-making process, so attributes could be included up-front and throughout the process.
- Because of the high level of uncertainty in modeling fisheries responses to diversions and changes in the hypoxic zone, the **adaptive management approach should:**
 - define quantifiable ecosystem-related and/or fisheries metrics to evaluate effects;
 - evaluate alternative operations and mitigation strategies, both before and after project implementation;
 - ensure that management and regulatory decisions are based on sound science;

- identify and fill information gaps that limit regulatory decision-making (see “modeling and monitoring” bullet below);
 - include explicit identification of the triggers (including social triggers) that would lead to adaptive actions;
 - identify decision-makers for establishing triggers and for implementation of actions;
 - develop a course of action with pre-determined evaluations of tradeoffs (e.g. one fishery vs. another; short-term vs. long-term habitat effects) under varying diversion and hypoxia management scenarios; and
 - anticipate, and be flexible (adaptive) to, unintended outcomes.
- Meeting **environmental compliance** requirements may be challenging – diversion projects are large and complex, with few analogues at similar scales. The scientific basis for understanding impacts is still evolving, and there is a high degree of uncertainty in model predictions (especially of synergistic effects) and data deficits to support modeling. Regulatory requirements must be met for project scoping, siting, design, construction, and operations. Regulatory compliance warrants consideration of both intended and unintended effects.
- An adequate **monitoring and modeling** system needs to exist to ensure effective assessment and prediction of the effects of management actions, and ensure that triggers are detected on useful time scales.
 - An adequate monitoring program is needed to evaluate progress toward achieving goals, through both observational assessments and enhanced model predictions of ecosystem changes. Monitoring gaps should be evaluated based on the purpose of monitoring and specific modeling data needs. Consistency is needed in fisheries monitoring data input – e.g. fish samples collected with the same gear types as the historical data feeding the predictive models. Monitoring needs include, but are not limited to:
 - nutrient and water flow;
 - marsh vegetation above-and below-ground productivity, elevation, soil strength, and herbivory;
 - fisheries salinity zones;
 - protected species (e.g. Barataria dolphins);
 - larval fish; and
 - benthic surveys – species composition lower in food web (e.g. SAV, invertebrates, non-target species).
 - Quantifiable ecosystem-based scenario forecast models are needed to predict the effects of alternative operations practices on fisheries and habitats, and to assess the effectiveness of alternative mitigation strategies.
 - There is value in application of multiple models. The choice of ecological models will depend on management goal, and the use of several may be justified because they vary in application – short-term vs. longer-term responses; landscape vs. smaller spatial scales; pulsed vs. continuous freshwater flow; individual vs. multiple species.

- Model selection should follow determination of targets and goals – i.e. management outcomes should drive selection of models to achieve those outcomes.
- Application of ecological models to address the diversion and hypoxia fisheries responses is currently limited by:
 - data availability for parameterization, baselines, calibration, and validation;
 - availability of (and linkage to) spatial hydrodynamic and landscape evolution models;
 - availability of longer scale models, including incorporation of climate change effects;
 - the need for optimization methods; and
 - the need for communicating output in effective ways.
- Advances in **socioeconomic modeling** application to ecosystem responses are needed. A holistic ecosystem research approach is needed to capture the breadth of outcomes (biophysical and socioeconomic) that will result from diversion implementations. Using this approach, socioeconomic studies can help resolve how management decisions (e.g. diversions) impact the effects of environmental change on ecosystem function, and the capacity to support resilient communities and economies. An ecosystem research approach should identify links between ecosystem services and ecosystem management goals, including the effects of management strategies on ecosystem services and their value to society.

Planning the Path Forward

The *5th Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop* helped facilitate coordination of adaptive management planning by partners from a number of ongoing efforts focused on the responses of the Gulf ecosystem to restoration practices. The discussion points from the workshop will inform follow-up integration of these efforts toward development of an effective adaptive management program that strives to balance ecological, economic, and social benefits.

Three follow-up planning meetings addressing the socioeconomic effects of diversions have already taken place (convened by the NOAA Gulf of Mexico Regional Collaboration Team, Louisiana Sea Grant, and CPRA), and a “Socioeconomic Work Group” formed. A workshop is planned for late 2015 to further advance plans to address socioeconomic effects of diversions. The socioeconomic workshop will be convened in conjunction with another workshop co-led by NOAA and CPRA that will address adaptive management needs for large-scale sediment diversions in Louisiana.

Both efforts will extend the collaborations established or strengthened at the *5th Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop*, providing a forum for coordinated integration of the management tools and approaches advanced by CPRA, the NOAA IEA, NOAA ERA, and NGOMEX partners that would lend value to improving understanding of the

relationships between large-scale river diversions, Gulf hypoxia, and assessing ecosystem responses in the Gulf of Mexico.

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INTRODUCTION

In the northern Gulf of Mexico, large-scale ecosystem restoration efforts such as Mississippi River diversions and hypoxic zone mitigation will have a great 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 of Mexico have advanced in recent years and are being considered as important management tools for evaluating fisheries responses to a dynamic Gulf ecosystem (which includes human dimensions). Management adoption of these modeling approaches will improve assessment and prediction of the effects of diversions and hypoxia, which are closely linked by the overlap in ecosystem model domains, affected species and habitats, and by the intersection of mitigation efforts in influencing estuarine and shelf water quality (e.g. changing salinity and nutrient properties).

On 14-16 July 2014, the [5th Annual NOAA/Northern Gulf Institute Hypoxia Research Coordination Workshop](#) was convened at Stennis Space Center, Mississippi, to advance the prediction and assessment of the ecological and socioeconomic effects of diversions and hypoxia in the northern Gulf. The workshop gave federal, state, NGO, and academic managers and researchers an opportunity to chart a course forward for adaptive management based on presentations on the state-of-knowledge on Gulf ecosystem management and science. Working sessions were conducted to prioritize fisheries management and habitat conservation needs, and identify ecological modeling capabilities and science needs that would most effectively integrate fisheries ecosystem management into diversions and hypoxia restoration plans.

The goals of the workshop were to:

- provide a forum for strengthening communication and coordination between physical, biological, and socioeconomic modelers of Gulf of Mexico hypoxia and Mississippi River diversions, and the users and stakeholders (e.g. Hypoxia Task Force, fisheries managers);
- validate and refine key fisheries management and habitat conservation needs associated with ecosystem (including socioeconomic) effects of hypoxia and large-scale river diversions in the Gulf of Mexico; and
- articulate adaptive management recommendations for advancing ecosystem modeling of hypoxia and diversion effects on habitats and living resources in the northern Gulf of Mexico.

Adaptive management is an important driver of restoration strategies for Mississippi River diversions and hypoxia mitigation (see Appendix 1) and there is a need to incorporate the ecological and socioeconomic effects on living resources into these adaptive management frameworks. The purpose of this proceedings paper is to present discussion points from the workshop that could help inform the adaptive management of diversions and the factors affecting hypoxia. The paper is organized around three breakout sessions informed by plenary presentations and follow-up discussions:

- Breakout 1: Fisheries Management and Habitat Conservation Needs;
- Breakout 2: Assessing Ecological Modeling Capabilities and Gaps; and

- Breakout 3: Plotting the Adaptive Management Path Forward.

PRINCIPLES FOR EFFECTIVE ADAPTIVE MANAGEMENT

The workshop's first day of plenary talks and ensuing discussions resulted in key principles for guiding adaptive management of diversions and the factors affecting Gulf hypoxia:

- Evaluate tradeoffs under varying diversions and hypoxia management scenarios to individual species and functional groups.

Species-for-species trade-offs need to be evaluated and considered in an adaptive management framework. Given the likely seasonal operation period, marine fishery species which are stenohaline may be adversely impacted by diversion operations. However, euryhaline marine species may not be affected or may even benefit if food web improvements result from diversions. Another trade-off that should be evaluated is related to both short-term and long-term maintenance of habitat. Estuarine-dependent marine species which utilize the estuary during periods when diversions are closed may benefit from the creation or maintenance of productive habitats. Species which would have been negatively impacted by continued degradation and loss of productive habitats may also benefit from the long-term maintenance of habitat, while experiencing some adverse short-term salinity impacts. Other trade-offs include maintenance of habitats providing some level of storm surge protection or maintenance of a diversity of habitats supportive of a variety of wildlife species versus salinity induced loss of production for some marine fishery species. Finally, diversions may have socioeconomic tradeoffs among fishery user groups by shifting areas of greatest productivity or potential harvest in some fisheries relative to the infrastructure supporting those industries.

- Evaluate alternative operations and mitigation strategies, both before and after project implementation.

Quantifiable ecosystem-based scenario forecast models are needed to predict the effects of alternative operations practices on fisheries and habitats, and to assess the effectiveness of alternative mitigation strategies. Adaptive management is needed to “course-correct” or fine-tune operations to improve outcomes. Feasible adaptive management actions include determining: (1) which diversion(s) of several are operated, (2) when diversions may be operated, and (3) what operational parameters (e.g. flow rate) are used during operations. Such adaptive management actions should be clearly articulated in all operational plans for the diversions.

- Define quantifiable ecosystem-related and/or fisheries metrics and goals to evaluate success.

The effectiveness of an adaptive management plan can be greatly increased by establishing quantifiable goals and targets in the initial planning stages. Quantitative goal-setting requires intensive interaction between science and management

communities. Multiple restoration goals linking ecosystem components are most useful (ecosystem-based management). Appropriate models should be selected based on the choice of quantifiable targets and goals. Then, models are chosen that give desirable scenarios and meaningful endpoints. An adequate monitoring program is needed to evaluate progress toward achieving goals, through both observational assessments and enhanced model predictions of ecosystem changes.

- Inform environmental compliance process.

Meeting environmental compliance requirements may be challenging – diversion projects are large and complex, with few analogues at similar scales. The scientific basis for understanding impacts is still evolving, and there is a high degree of uncertainty in model predictions (especially of synergistic effects) and data deficits to support modeling. Regulatory requirements must be met for project scoping, siting, design, construction, and operations.

Regulatory compliance warrants consideration of both intended and unintended effects.

For example, intended effects of diversions would include:

- significantly reducing or stopping net land/wetland losses;
- improving resilience to storms, sea level rise, subsidence;
- protecting, restoring, and enhancing ecological services of wetland and coastal habitats (e.g. water quality enhancement; nursery, refuge & forage habitat for managed species); and
- improving socioeconomic conditions;

while unintended effects may include:

- degraded water quality;
- increased susceptibility of wetlands to perturbations (e.g. severe weather);
- modification or conversion of essential fish habitat;
- temporary/permanent displacement of estuarine/marine species to less supportive habitats; and
- socioeconomic hardship for commercial and recreational fishing industries and other sectors.

To meet these challenges, adaptive management approaches should:

- coordinate, cooperate, and share information as early in the process as is feasible;
- ensure that management and regulatory decisions are based on sound science;
- identify and fill information gaps that limit regulatory decision-making;
- make the best decisions possible using a balanced approach within the applicable frameworks; and
- adjust course when it becomes clear that correction is required to refine benefits.

- Incorporate societal changes and/or effects.

A holistic ecosystem research approach is recommended to capture the breadth of outcomes (biophysical and socioeconomic) that may result from diversion

implementation. Using this approach, socioeconomic studies can help resolve the role of management decisions in environmental change, the impact on ecosystem function, and the capacity to support resilient communities and economies. An ecosystem research approach should:

- strive for a multi-scale understanding of variability in natural and anthropogenic stressors that relate to the ecosystem's ability to provide ecosystem services;
 - identify institutional and cultural contexts for interactions between ecosystems, human communities, and ecosystem services; and
 - identify links between ecosystem services and ecosystem management goals, including the effects of management strategies on ecosystem services and their value to society.
- Evaluate and define uncertainty.

Uncertainty results from natural environmental variability and imperfect representation in models. The Expert Panel on Diversion Planning and Implementation ([Report #1](#), Feb 2014, The Water Institute) provided the following principles:

- There are six specific areas in which diversion uncertainty must be framed and understood (data; analogs; ecological outcomes; economic and social outcomes; design and operations; expectations).
- Uncertainty must be explicitly addressed at the planning and design stages of diversions.
- Modeling plant and animal communities presents a considerably greater challenge than modeling the physics, and nonlinear ecological effects should be expected.
- Biophysical and social outcomes must be linked, and social outcomes cannot be addressed as an afterthought.

The Panel recommended in its first report that highest priority be given mainly to near-term needs in the areas of understanding and forecasting ecological outcomes, incorporating economic and social assessments, and in effective communications.

- Plenty of uncertainty, plan to adapt.

Because of the uncertainties surrounding Gulf of Mexico coastal ecosystem responses to: a) Mississippi River large-scale diversions, b) hypoxia mitigation, and c) the influence of diversions on hypoxia distribution and mitigation, management needs for sustainable living resources and habitats should use an adaptive management approach. Formal adaptive management is most valuable under high uncertainty because it is designed to support action when scientific knowledge is limited. Adaptive management functions best when goals are agreed upon, knowledge of pre-manipulation conditions exist, monitoring is done to measure progress toward goals, and there is a process in place to adjust management actions to improve the likelihood that goals can be met.

**BREAKOUT SESSION 1:
FISHERIES MANAGEMENT AND HABITAT CONSERVATION NEEDS**

The purpose of Breakout Session 1 was to identify and refine key fisheries management and habitat conservation needs associated with ecosystem effects of hypoxia and large-scale diversions. The desired output was a consensus-driven prioritized list of management recommendations associated with ecosystem effects. Prioritization was based on the value to informing the adaptive management process (i.e. “Assessment” phase in Table 1 of Appendix 1). The following topical questions were posed to the participants.

- Given the list of management needs (listed in Appendix 1) that should be addressed through ecological modeling applications, what are the top 3-5 priorities in the short-term (3-5 years = one adaptive management cycle)?
- What are the top 3-5 priorities in the long-term (10-50 years = several adaptive management cycles)?

Tables 1 and 2 list short-term and long-term priorities from each of the four breakout groups. Overall rankings were determined by assigning a value corresponding to the ranking of management needs within each group, and averaging the sum of values for each management need. Note that one breakout group introduced “Identification of socioeconomic effects of diversions on ecosystem services and dependent communities” as a newly-identified top priority need, both in the short- and long-term, during their working session. That need was not included in the group-wide rankings.

Table 1. Short-term (3-5 years) priorities in rank order based on breakout group discussions.

Rank	Management Questions/Uncertainties
1	How do shifts in environmental gradients (e.g. salinity, temperature, sediments, nutrient composition and quantity) from the operation of diversions affect the assemblage, diversity, distribution/displacement, growth rate, survival rate, spawning success and production of juvenile fishery species and their prey? Can the above effects be assessed for particular species of interest (e.g. brown shrimp, blue crab, spotted seatrout, red drum, flounder, Atlantic croaker, etc.).
2	How will changes in marsh acreage and morphology affect abundance and habitat of key species? How will nutrient loading to the Gulf change as a result of diversion-induced changes in marsh habitat?
3	How will shifts in environmental gradients from the operation of diversions affect oyster growth, recruitment, and survival, including: <ul style="list-style-type: none"> i. freshwater and temperature impacts to oysters in the lower part of the receiving basin; ii. fall, winter, and spring flows on gonad development to determine how remaining oysters responding reproductively;

	<ul style="list-style-type: none"> iii. impacts to spat set for both spring and fall reproductive seasons; iv. rate and distribution of Dermo infections; v. ability of oyster populations/beds within an estuary to adapt to changing environmental conditions. <p>Would adequate hard-substrates be available for spat settlement if diversions pushed optimum environmental conditions towards the Gulf zone?</p>
4 (tie)	<p>What effects will the response of predator-prey interactions to diversions have on fishery production? For example, if shrimp production is reduced, will that loss of potential prey affect the production of red drum, spotted seatrout or juvenile red snapper?</p>
4 (tie)	<p>What are the current effects of the hypoxic zone on fishery resources due to changes in:</p> <ul style="list-style-type: none"> i. mortality of managed species and their prey; ii. fecundity (sublethal effects of exposure, reduced size); iii. habitat quantity and quality; iv. growth rates; v. susceptibility to predation; vi. migratory patterns; and vii. bycatch quantity and composition.
6	<p>How do alternative flow-management strategies influence downstream nekton communities (abundance, diversity, assemblage)?</p> <ul style="list-style-type: none"> i. Does restored riverine flood pulsing provide an exportable nekton subsidy? ii. Does restored riverine flood pulsing affect short-term nekton growth? iii. How will the timing and duration of flow affect: availability of optimal habitat, physiochemical attributes, flooded habitat, recruitment, growth?

Table 2. Long-term (10-50 years) priorities in rank order based on breakout group discussions.

Rank	Management Questions/Uncertainties
1	<p>How do shifts in environmental gradients (e.g. salinity, temperature, sediments, nutrient composition and quantity) from the operation of diversions affect the assemblage, diversity, distribution/displacement, growth rate, survival rate, spawning success and production of juvenile fishery species and their prey?</p> <p>Can the above effects be assessed for particular species of interest (e.g. brown shrimp, blue crab, spotted seatrout, red drum, flounder, Atlantic croaker, etc.).</p> <p><i>(Same as Short-term Priority #1)</i></p>
2 (tie)	<p>How will climate change (including relative sea level rise, shifts in hydrology, etc.) influence diversion effects on fish abundance, production, and distribution? Are local estuarine nekton governed by large-scale climate forcing?</p>

2 (tie)	How will changes in marsh acreage and morphology affect abundance and habitat of key species? How will nutrient loading to the Gulf change as a result of diversion-induced changes in marsh habitat? (<i>Same as Short-term Priority #2</i>)
4	How will diversions affect the timing, distribution, and duration of coastal hypoxia? How will this affect commercial and recreational fisheries (e.g. fishermen traverse the hypoxic zone in order to reach suitable fishing grounds and incur increased/decreased operating costs due to increased/decreased fuel expenditures and travel times)?
5	What effects will the response of predator-prey interactions to diversions have on fishery production? For example, if shrimp production is reduced, will that loss of potential prey affect the production of red drum, spotted seatrout or juvenile red snapper? (<i>Same as Short-term Priority #4</i>)
6 (tie)	How will fishing pressure change as a result of diversions, and how will that affect fishery assemblages? For example, if changes in fishery pressure occur as a result of changes in species distribution, how will this impact production?
6 (tie)	How do alternative flow-management strategies influence downstream nekton communities (abundance, diversity, assemblage)? Does restored riverine flood pulsing provide an exportable nekton subsidy? Does restored riverine flood pulsing affect short-term nekton growth? How will the timing and duration of flow affect: availability of optimal habitat, physiochemical attributes, flooded habitat, recruitment, growth? (<i>Same as Short-term Priority #6</i>)

No other priorities were listed in the top five by any group; however one group listed the following among their top nine short-term priorities:

- #6: Will diversion effects on fish and shellfish result in changes in recreational and commercial fleet effort? Changes to dependent land-based business? Communities?
- #7: How will hydrologic restoration affect habitat suitability and population sustainability? Does pulsed spring flow affect nekton communities differently than continuous spring flow? Do effects on nekton communities vary by distance from the diversion (up-estuary vs. down-estuary) and over time (during diversion vs. 3 months post-diversion)?
- #8: How will diversions affect fishery species in the nearshore coastal zone? Will estuarine-dependent fisheries be displaced into less than desirable habitats in the nearshore Gulf zone?
- #9: What are the diversion effects on hypoxic zone magnitude based on changes in freshwater and nutrient loading, and what are the consequences on fisheries production?

Summary: The pre-meeting management needs document (Appendix 1) did not list “socioeconomic effects”, but this was clearly acknowledged throughout the meeting as a critical management short- and long-term need requiring immediate attention. The group rankings reflect fisheries managers’ recognition that diversions will have a near-term and near-field influence on juvenile fishes and oysters through direct and indirect (food web interactions, alterations in marsh properties) effects. The influence of diversions on downstream nekton was also identified as a short-term priority requiring improved predictive understanding. Whereas the need for advanced understanding of the hypoxic zone on fisheries resources was recognized as a near-term priority, the interactive effect of diversions on hypoxia was thought to be a longer-term priority need. The needs addressing diversion effects on fisheries were similarly ranked in long-term and short-term assessments, with the exception that effects on oysters were not included in the long-term priorities, perhaps reflecting the more immediate repercussions for this resource. Other long-term priorities included understanding the interactive effects of climate change and the influence of diversions on fishing pressure.

BREAKOUT SESSION 2: ASSESSING ECOLOGICAL MODELING CAPABILITIES AND GAPS

The purpose of Breakout Session 2 was to identify ecological modeling capabilities and gaps in addressing priority management needs identified in Breakout Session 1. The desired outputs were an updated modeling matrix (see Appendix 2) and an assessment of modeling approach(es) that best meet prioritized management needs. The session was divided into three sections, each with specific topical questions outlined below.

The following are the recommendations of each Section’s members.

Section 1: How do the models differ in structure and application relative to priority management needs?

Model selection should follow determination of targets and goals – i.e. management outcomes should drive selection of models to achieve those outcomes.

There is an ongoing effort to create a holistic modeling approach that addresses all of these priority management needs concurrently. Hydrodynamic models (ADH, Delft 3D, ROMS, FVCOM) and landscape evolution models would address management needs #1, 8, and 12 in Appendix 1; ecological models (e.g. EwE, CASM, TroSIM, IBMs, HSI) would address management needs #1, 2, 4, 8, and 12; and socioeconomic models would address management needs #7 and 14. All could be coupled to hydrodynamic models. All models have similar forcings with physical and/or biogeochemical models, but one challenge to consider in model application is the functioning of complex models (e.g. those that include complex food web dynamics).

Choice of model is also dependent on:

- the granularity of the question;
- level of uncertainty – multiple models are recommended when uncertainty is high;

- time scale;
- specific indicators (metrics);
- goals/targets – e.g. fisheries yield, amount of wetlands, mortality/spatial distribution, etc.;
- ability to link estuary with shelf;
- potential to facilitate information flow between models; and
- integration of hypoxia and diversions dynamics.

In terms of applications,

- EwE/Atlantis is good for predicting fisheries response over the long term and on a landscape scale;
- CASM/TroSim is better for pulsed events;
- IBM and CASM are good for assessing behaviors related to pulse events, and for smaller temporal and spatial scales;
- Atlantis, CASM, EwE, and TroSIM are good for ecosystem-level (multispecies); and
- IBM is good for key species.

Section 2: What are the primary limitations of the current suite of modeling approaches for addressing management priorities?

- **Data limitation** for parameterization, baselines, calibration, and validation:
 - It is better to use “ground-truthed” data than model output as driver for models but the amount of available data to calibrate and validate models is limited; refinement of monitoring methods, and strategic modification of temporal and spatial sampling protocols are needed to fill gaps in some monitoring activities. In addition, continuity of monitoring programs must be maintained. For example, the current hypoxia monitoring system needs sustained funding, and if current hypoxia modeling ends, it will be hard to continue the other work;
 - Lack of data on fish response to environmental factors (e.g. marsh effect – will fish do better or worse with changing marsh area?);
 - Type and location of vegetation is a missing element of some models.
- Limitations in **model capabilities**:
 - Point-based fish population models must engage spatial capacity in order to go from point-based to larger scale. This would necessitate development of spatial hydrodynamic and landscape evolution models, which require additional funding, communications, and coordination;
 - Landscape scale diversions/hypoxia models don’t yet exist;
 - Longer time-scale models – e.g. do we need decadal-scale models? Need to consider cost-benefit of longer scale. Is a 50 year model useful? If calibrated every 5 years (adaptive management), is it truly a 50 year model?
 - Models to quantifiably predict the dynamic effects of climate change, including sea level rise;
 - Future without action is just as hard to model with physical models;
 - Models to quantifiably predict the dynamic effects of climate change, including sea level rise, are limited at the regional landscape level;

- Future without action is just as hard to model with physical models; and
 - If planned diversions are operated under a pulsing regime, considerations should be made for the effects when the diversion pulse has ended. Current hydrodynamic models do not adequately address salinity rebound after a river pulse is shut off.
- **Limitations in model integration:**
 - Coupling of physical (e.g. hydrodynamic, water quality) and ecological models so managers can use them as decision points will require same forcing functions for both. The need for two-way coupling requires the additional development of a feedback loop between models. Different ecological models will be used for different questions, and there are a limited number of physical models currently capable of coupling to a suite of ecological models.
 - Coupling of physical and ecological models is recommended so resource managers can use them as decision points. This will require utilizing the same forcing functions for both. Need two-way coupling – is there a feedback loop between physical and ecological models? Also different ecological models will be used for different questions; are physical models currently capable of coupling to a suite of ecological models?
- **Need for communicating output in effective way:**
 - A communication strategy is recommended to ensure open and effective articulation of model results. Need two-way communication for decisions on linking monitoring, research, and assessments (e.g. decision makers/modelers). Strategy of providing information to the public should include:
 - Use models to illustrate effect of doing nothing;
 - Forecasts;
 - Diversions and hypoxia in holistic ecosystem response concept; and
 - Consideration of social and economic tradeoffs.
- **Limitations in socioeconomic assessments:**
 - Spatial outputs may be too large scale to inform socioeconomic models;
 - There may be a need to prioritize which socioeconomic questions are assessed first? For example, should litigation relevant factors be considered to avoid lawsuits and liability?;
 - Need to consider beyond fisheries – e.g. other services such as cultural value;
 - Need to know appropriate scale and ecosystem services for socioeconomic models to get proper information from environmental models to support socioeconomic models;
 - Where will the data come from for social models?; and
 - Voice of residents – trade-offs between living on land and maybe having to change livelihood; how to incorporate the voice of stakeholders? Lack of data on stakeholders' interests and investments.

Section 3: Should ecological modeling focused on shelf hypoxia and river diversions be coordinated?

Ecological modeling of diversion and hypoxia effects can be coordinated, but whether or not they should be coordinated depends on the question you're asking. Diversions may affect hypoxia but not vice-versa. Because of the potential influence of diversions on the characteristics of nutrient delivery to the Gulf of Mexico, and the resultant effects of the size of the hypoxic zone and subsequent effects on fisheries, it is important to incorporate the interactive effects of diversions when assessing the ecosystem benefits of hypoxia mitigation. However, models to cover the interactive effects of these two factors do not currently exist.

BREAKOUT SESSION 3: PLOTTING THE ADAPTIVE MANAGEMENT PATH FORWARD

The purpose of Breakout Session 3 was to plot a path forward with focus on adaptive management to ensure future progress. The desired outputs were identified science priorities to address management needs identified in Breakout Session 1, and to develop guidance in next steps for developing an adaptive management framework. The session was divided into three sections. Topical questions for these sections included:

Section 1: What are the 3-5 key science priorities to advance ecological modeling capabilities to address priority management needs?

Section 2: What is the best approach for holistic application of ecological models within an adaptive management framework?

- Lessons learned from other issues or past application?
- Integration with socioeconomic and other relevant observations/data?

Section 3: What are your recommendations for next steps over the next 3-5 years?

- Is the current rate of model advancement adequate? Where should the state of ecological modeling capabilities be in 5 years?
- How can we best communicate model output to be useful for adaptive management?

Section 1: What are the key science priorities to advance ecological modeling capabilities to address priority management needs?

- Improve models with advanced **monitoring**:
 - Start with an analysis of monitoring gaps based on the purpose of monitoring and specific modeling data needs, including but not limited to:
 - nutrient and water flow;
 - marsh vegetation above-and below-ground productivity, elevation, soil strength, and herbivory;
 - fisheries salinity zones;
 - protected species (e.g. *Barataria* dolphins);
 - larval fish; and

- benthic surveys – species composition lower in food web (e.g. SAV, invertebrates, non-target species).
 - Consistency needed in fisheries monitoring data input – e.g. fish samples collected with same gear types.
 - Continue funding ongoing monitoring for continuous/long-term data sets in addition to new monitoring studies specifically designed to address modeling needs.
 - Need for senior-level managers to discuss cross-agency long-term funding for monitoring.
- Gaps in current **baseline data for fisheries**:
 - Fishing effort data;
 - Inclusion of protected species as diet input to food web models;
 - Stock assessment programs need stable funding to provide key data;
 - Lack ability to recognize natural variability; and
 - Current monitoring is not specifically designed to investigate effects of diversions on fisheries. For example, inefficient gear types currently used and there are a low number of monitoring stations currently in the receiving basins.
- **Modeling socioeconomic effects:** e.g. environmental, economic or social science models.
- **Data management:** “Home” for data, data management, and data access ongoing into future.
- **Biogeochemical process measurements:** i.e. links between model “boxes”.
- **In-channel Mississippi River impacts:**
 - Increasing the density of long-term gauging stations in the Mississippi River, increasing the parameters (i.e. nutrients) measured and securing long-term funding.
- Ability to measure **subsidence**.

Section 2: What is the best approach for holistic application of ecological models within an adaptive management framework?

A **user-based approach** is recommended. Stakeholder needs should be prioritized, and management scenarios developed to reach meaningful endpoints based on quantifiable targets and goals. The public should be part of the conversation and their input should help drive the approach. Public feedback should be part of the adaptive management decision-making process. Stakeholders input should also include the private sector (e.g. oil/gas industries). The CPRA, Gulf of Mexico Alliance (GOMA) and Gulf Coastal Ocean Observing System (GCOOS) are good resources for stakeholder identification and engagement. It is imperative to engage stakeholders early and often throughout the project’s life.

A well-defined **communications** plan that: (1) includes frequent engagement with stakeholders, (2) has the ability to effectively transfer and interpret scientific information to the stakeholders, (3) explains changes in diversion operations as a result of adaptive management, and (4) can communicate risk and scientific uncertainty in plain language will be important as a diversion project moves through planning, permitting, construction and operation phases of the project. A demonstration project might be desirable to show how adaptive management might work – the Maurepas project is an example.

There is value in application of **multiple models**. The choice of ecological models will depend on management goal, and the use of several may be justified because they vary in application – short-term vs. longer-term responses; landscape vs. smaller spatial scales; pulsed vs. continuous freshwater flow; individual vs. multiple species. The holistic ecosystem approach should involve parallel modeling efforts that consider ensemble and multiple model approaches and coupling of hydrodynamic, biogeochemical, and ecological models.

Advances in **socioeconomic modeling application** to ecosystem responses are needed. Effort is needed to integrate social (non-monetary) research with the biological side. The pertinent ecosystem services to study should be established at an early stage. Field studies and surveys are needed to understand community responses. The impacts of hypoxia or diversions on tourism should be included in these studies.

It is important to design an **adaptive management framework** that includes explicit identification of the triggers (including social triggers) that would lead to adaptive actions, and for the decision-makers to establish the threshold(s) for implementation of actions. An adequate monitoring and modeling system is recommended to ensure effective assessment of the effects of management actions, and ensure that triggers are detected on useful time scales. Adaptive management should have flexibility to allow changes in regulatory directives and modification of goals and endpoints if warranted.

Section 3: What are your recommendations for next steps over the next 3-5 years?

- Establish goals, targets as a first step. These should be explicitly linked to desired fisheries management outcomes, be quantifiable (including success metrics), and meet priority stakeholder needs. The decision-making process for establishment of goals needs to be instituted up front – there are tradeoffs between different management agency goals (stated and unstated) that need to be resolved. Establishment of a formal multi-agency partnership may be one answer.
- Once the decision-making process is established, the parameters/scope of the adaptive management approach need to be defined:
 - Will the approach encompass long-term and short-term responses?
 - Will it target single projects individually and/or multiple projects collectively?
 - What are the time frames for management actions and their predicted effects?
 - Will adaptive management include preconstruction, short operation, and long operation stages?

- What is the topical scope? Diversions, hypoxia, or both?
- The scientific approach for observations and predictions in support of the adaptive management process should be established early on and based on clear, actionable science. There is a strong need for baseline data, and an effective monitoring program specifically targeted to assess diversion effects early in implementation.
- The adaptive management planning process needs to be open and transparent with much public engagement up front, and findings and data accessible by public throughout. Communication and data management plans need to be a formal part of the process from its initial stages.

MOVING FORWARD: STRENGTHENING ADAPTIVE MANAGEMENT THROUGH PARTNERSHIPS

The *5th Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop* was a forum for coordination by partners from a number of ongoing or planned efforts that will lend value to improving understanding of the relationships between large-scale river diversions, Gulf hypoxia, and ecosystem responses in the Gulf of Mexico. It is envisioned that this proceedings will serve as an important building block for integration of stakeholder recommendations for balancing ecological, economic, and social benefits related to diversions, hypoxia and fisheries. Below are some key efforts that should be integral to furthering the recommended adaptive management process.

Louisiana Coastal Protection and Restoration Authority (CPRA)

The CPRA has been established as the single state entity with authority to articulate a clear statement of priorities and to focus development and implementation efforts to achieve comprehensive coastal protection for Louisiana. The Coastal Protection and Restoration Authority's mandate is to develop, implement, and enforce a comprehensive coastal protection and restoration Master Plan (<http://coastal.la.gov/a-common-vision/2012-coastal-master-plan/>).

Future conditions of coastal Louisiana are highly uncertain, due to the dynamics of riverine and marine processes, storm events, climate change, population growth, economic activity, and ongoing human reliance on the natural resources the coast provides. Managing such a complex system in which the natural and socioeconomic systems are highly integrated is inherently difficult. In addition, deltaic environments are uniquely challenged due to the interdependence and delicate balance of water, land and economic systems and future uncertainties regarding the magnitude and rate of climate change impacts.

As new techniques and projects for restoration and risk reduction are being developed, there exists an opportunity for 1) learning how the system will respond to the coastal protection and restoration program implementation, and 2) using that learning to improve future program management decisions. Adaptive management embraces a scientific approach that involves identifying explicit goals and objectives, developing and implementing management actions,

assessing the system's response to the action(s), and then using that knowledge to make management decisions.

The scale and complexity of Louisiana's Coastal Master Plan requires a robust adaptive management strategy to cultivate a growing body of knowledge related to restoration and protection science. As a part of this effort, CPRA has developed an Adaptive Management Strategy to provide a structured process for making decisions over time through active learning and to enable adjustments in program implementation as new information becomes available. This strategy was based on recommendations in an Adaptive Management Framework commissioned by CPRA ([Water Institute of the Gulf, 2013](#)) that draws from the body of adaptive management knowledge and identifies a sequence of activities that guide adjustments to planning, designing, monitoring, operating, and implementing projects with a programmatic perspective of accomplishment over the next 50 years.

Louisiana has already initiated a number of the recommendations raised by the various breakout panels identified earlier in this proceedings:

- To address ecological modeling and monitoring, the System Wide Assessment and Monitoring Program ([SWAMP](#)) being developed by CPRA has identified many of the data gaps raised by workshop participants above and articulates a strategy to fill many of these gaps. CPRA is also developing a DELFT-3D ecosystem modeling suite to look at and predict smaller-scale changes in the hydrologic basins (Barataria, Breton Sound, and Pontchartrain estuaries) expected to receive diverted water. This ecosystem model includes a variety of landscape, vegetation, water quality elements, and other parameters. In addition, CPRA is developing ecosystem-based forecast modeling tools using EWE and CASM, linked to DELFT to investigate and predict changes in fish population abundance and distribution in the hydrologic basins expected to receive diverted water and sediment.
- CPRA's Master Plan utilizes a series of models to evaluate a range of possible future environmental scenarios with and without diversion projects. These models are being improved for the 2017 revision to the Master Plan. Through this model development process, additional field data have been collected to inform the models and to assist with calibration and validation. CPRA's Master Plan uses a planning-scale model that looks at a 50-year projection of future with- and future without- the master plan portfolio of projects. The future scenarios represented in CPRA's planning-scale models include a range of possible future conditions from more to less optimistic.
- CPRA's Master Plan tools address many of the socioeconomic questions and concerns identified above. Also, the SWAMP includes human system parameters, primarily (but not entirely) based on decadal U.S. Census and Annual Community Survey data. These data can be aggregated at multiple scales to investigate human system changes over time for a variety of interest groups.

CPRA has also established a number of specific stakeholder focus groups which are engaged in Master Plan development and refinement. CPRA regularly hosts a variety of public meetings, periodic Diversion Advisory Group meetings, in addition to the monthly CPRA board

meetings which are open to the public, at various locations around the state to promote a two-way dialog relative to the ongoing implementation of the Master Plan.

Refinements have been made in the second, third and fourth reports from Louisiana's Diversion Advisory Panel. In the fourth report ([March 2015](#)), recommendations from the three previous reports were reviewed and synthesized into the following four recommendations:

- Expand the current conceptual model of the sediment diversion planning process to provide greater detail on the modeling and socioeconomic studies and their respective linkages, leading into the 2015 decision to implement.
- Use this refined conceptual model (science and planning) and detailed description of the socioeconomic valuation approach to communicate with stakeholders and solicit their feedback. This is an important step in this public process that gives CPRA the opportunity to strengthen relationships with key stakeholder groups.
- Provide for the review of monitoring and modeling efforts by independent subject matter experts and make results of the reviews available. Transparent technical review ensures that conclusions drawn from the technical analyses are in fact well supported and will add credibility to difficult or controversial aspects of diversion implementation.
- Design the Basin-Wide socioeconomic study so that operational decisions can be compared in terms of socioeconomic outcomes, and apportion available resources to support this work over other more descriptive studies that do not have clear relevance to diversion decisions.

NOAA Gulf of Mexico Integrated Ecosystem Assessment

NOAA's [Gulf of Mexico Integrated Ecosystem Assessment](#) (IEA) program is developing a thematic project work-plan for using the IEA to inform the evaluation of sediment diversions, including focuses on the effects on essential fish habitat, fisheries, and socioeconomics. An IEA is an analytical toolbox to support holistic ecosystem-based management (EBM). Typically, an IEA is initiated with a series of stakeholder workshops and modeling to identify drivers, pressures, stressors, impacts/ecosystem services, and response at the selected sites. This process can then be used by managers in decision-making exercises (e.g. scenario analysis) for improved planning. The Gulf IEA uses a combined mathematical and conceptual model approach to link ecosystem state to ecosystem services and human well-being. The project proposal aims to apply the IEA approach to inform adaptive management of the diversion issue incorporating a multiple ecosystem model approach for predicting and evaluating diversion effects, and an ecosystem services approach for capturing socioeconomic outcomes and maximizing benefits. In the northern Gulf of Mexico, scenario analysis of varied salinities (associated with different freshwater inflows) is being used with managers and industry representatives to evaluate impacts on local ecosystem services (e.g. oyster production, water filtration, carbon sequestration) and subsequent implications for management decisions.

NOAA's Ecosystem Research Agenda

The long-term goal of NOAA's Ecosystem Research Agenda (ERA) is for the agency to adopt a comprehensive approach to ecosystem research that strategically aligns and integrates

NOAA's science assets, partnerships, and capabilities to support the sustainable use, protection, and restoration of coastal and marine ecosystems, as well as the ecosystem services that they provide. In support of this objective, NOAA's Research Council established an Ecosystem Research Committee and charged the Committee with:

- building synergy between complementary ecosystem research activities;
- enhancing the activities that provide strategic benefits and increased efficiencies;
- identifying and filling gaps in NOAA's ecosystem research portfolio; and
- encouraging partnerships that will build capacity.

The NOAA Research Council asked the Committee to demonstrate how the ERA could augment and enhance an existing research investment by adopting a multidisciplinary, collaborative, and integrated ecosystem research approach. The Committee organized an Ecosystem Research Roundtable discussion among NOAA science staff in January 2014 to solicit input on the appropriate issue and venue for a demonstration project. The Gulf of Mexico was chosen as the pilot region to apply the ERA, with a specific focus on diversions and hypoxia as significant environmental research issues that could benefit from a multidisciplinary, collaborative, and integrated ecosystem research approach. The *5th Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop* marked the initial step in ERA implementation for NOAA. The Committee's role was to ensure that the workshop included a focus on the "human element" when assessing ecosystem effects by integrating social and economic sciences with ecosystem modeling to inform adaptive management decisions.

To further implementation of the ERA, the Committee will continue to work across NOAA such as with the Ecosystem Services Team and the NOAA Habitat Science and Ecological Forecasting Technical Team, as appropriate. It will receive direction and guidance opportunities and venues where an ecosystem research approach can be implemented to improve the understanding of the fundamental ecosystem dynamics to support the sustainable use, protection, and restoration of coastal and marine ecosystems, and the ecosystem services they provide.

FY16 Northern Gulf of Mexico Ecosystems and Hypoxia Assessment Program (NGOMEX)

NOAA administers the two national competitive research programs mandated by the Harmful Algal Bloom and Hypoxia Research and Control Act, one of which (the NGOMEX program) is dedicated to addressing the large seasonal hypoxic zone along the continental shelf in the northern Gulf of Mexico. NGOMEX supports multi-year, interdisciplinary research projects to advance understanding of the causes and impacts of the hypoxic zone, and advance management capability to mitigate hypoxia impacts. NOAA is planning a FY16 NGOMEX competition with a focus on supporting ecological and socioeconomic modeling to advance understanding of the ecosystem impacts of hypoxia. Expected products/outcomes include ecosystem- and population-level ecological models that are ready for transition to operations, and socioeconomic assessments of the ecosystem costs resulting from hypoxic zones of different magnitudes, and the benefits of reducing the hypoxic zone. This is critical information to inform nutrient reduction targets used in the *Gulf Hypoxia Action Plan 2008 for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico and Improving Water Quality in the*

Mississippi River Basin (and its [2013 Reassessment Report](#)), the adaptive management strategy by the HTF.

Gulf Regional Collaboration Team Socioeconomic Workshop

The NOAA Gulf of Mexico Regional Collaboration Team (GMRCT) convened the *Socio-Economic Effects of Diversions* meeting on 16 July 2014, immediately after (and paired with) the *5th Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop* to discuss mechanisms for promoting collaboration between partners to best leverage relevant information on socioeconomic effects of diversions for scientific and decision-making purposes (see Appendix 3 for workshop report). The participants committed to future engagements aimed at fostering understanding of the issue, and working together to enhance the connection between socio-economic and biological/ecological models, and the application of these models to understanding ecosystems and informing decision-making processes. The “Socio-Economic Working Group” role was seen as a communication nexus to articulate joint socioeconomic information needs up individual agencies/organizations. To further the conclusions of that effort, two follow-up planning meetings were held by the GMRCT and Louisiana Sea Grant and with additional involvement by the CPRA in August 2014.

NOAA/CPRA/Louisiana Sea Grant 2015 workshop on Large-Scale Sediment Diversions in Louisiana: Adaptive Management Needs/Socioeconomic Effects

A workshop is planned for late 2015 to further advance plans to address socio-economic effects of diversions. The socioeconomic workshop will be convened in conjunction with another workshop co-led by NOAA, CPRA, and Louisiana Sea Grant that will address adaptive management needs for large-scale sediment diversions in Louisiana, using information from this proceedings paper as a starting point. The planned workshop will continue to facilitate the dialog among scientists, economists, and resource managers from federal and state resource agencies towards building a science-based adaptive management decision-making framework for large-scale Mississippi River diversions.

The planned workshop will extend collaborations established or strengthened at the *5th Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop*, providing a forum for coordinated integration of the management tools and approaches advanced by CPRA and its state, federal, academic, and NGO partners. In articulating fisheries management needs and adaptive management approaches for addressing ecosystem responses to hypoxia and diversions, this proceedings paper will inform the workshop and other efforts of effective collaborative pathways to achieve a balance between restoring Louisiana’s coastal wetlands, reducing the size of the annual Gulf of Mexico hypoxic zone, and sustaining ecological and socioeconomic benefits of fisheries.

APPENDIX 1

[distributed to workshop attendees as guidance for breakout discussions]

Management needs related to living resource and habitat effects of large-scale Mississippi River diversions and Gulf hypoxia

8 July 2014

A White Paper to inform discussions to prioritize management needs (Breakout Session 1) at the 5th Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop, “Advancing Ecological Modeling for Diversions and Hypoxia in the Northern Gulf of Mexico”, 14-16 July 2014 at the Mississippi State University Science and Technology Center at NASA's Stennis Space Center in Mississippi.

Because of the uncertainties surrounding Gulf of Mexico coastal ecosystem responses to: a) Mississippi River large-scale diversions, b) hypoxia mitigation, and c) the influence of diversions on hypoxia distribution and mitigation, management needs for sustainable living resources and habitats should use an adaptive management approach. As stated in Report #1 from the Expert Panel on Diversion Planning and Implementation (submitted to Coastal Protection and Restoration Authority, Feb. 2014):

“Decisions about the design and construction of diversions must deal with significant challenges posed by a complex socioecological system that is dynamic and highly uncertain, as only limited knowledge exists on how the coupled system works. Adaptive management is well suited for dealing with these challenges. An adaptive management framework for diversions should be based on scenarios that project alternative future system conditions, flexible strategies for system-wide projects and individual diversion project design that account for a range of possible scenarios, and a monitoring program to track diversion project performance and required adaptive adjustments in project design and operation to deal with uncertainty and realistic expectations.”

Adaptive management frameworks exist for both the diversion and hypoxia issues:

- An Adaptive Management Framework for Coastal Louisiana was developed by The Water Institute of the Gulf (2013) “to identify the principles of adaptive management and provide recommendations for integrating adaptive management concepts and ideas into the current coastal [protection and restoration] program. The framework also serves as the foundation for developing an Adaptive Management Plan (AMP) that will create a formalized structure for implementing adaptive management.”
- Action 11 from Hypoxia Task Force 2008 Action Plan: “In five years (2013) reassess nitrogen and phosphorus load reductions, the response of the hypoxic zone, changes in water quality throughout the Mississippi/Atchafalaya River Basin, and the economic and social effects, including changes in land use and management, of the reductions in terms of the goals of this Action Plan. Evaluate how current policies and programs affect the

management decisions made by industrial and agricultural producers, evaluate lessons learned, and determine appropriate actions to continue to implement or, if necessary, revise this strategy.”

This white paper presents management needs that would inform the knowledge base and assessment components for the adaptive management processes, with a focus on the ecological modeling needs to ensure effective assessment of fisheries responses. The Water Institute of the Gulf (2013) Adaptive Management Framework (AMF) describes four key elements of the Knowledge Base to inform decisions:

- Research studies that explain system dynamics.
- Conceptual models that illustrate chains of cause-effect relationships and how they influence program objectives.
- Data derived from ongoing monitoring, periodic surveys, and research campaigns.
- Predictive models. Coastal responses to changes in system configuration or dynamics can be predicted using a combination of statistical and process models.

Ecosystem response through model predictions at the start of the adaptive management cycle are adjusted (“improved”) at the end of the cycle based on knowledge gained through research, monitoring, and project implementation effects (Table 1, excerpted from The Water Institute of the Gulf 2013).

Table 1. Comparison of available information at different phases of an adaptive management cycle

Information	Start of adaptive management cycle, e.g. planning	End of adaptive management cycle, e.g. assessment
System drivers including uncertainties (e.g. storm impacts) and boundary conditions (e.g. river discharge regime)	Assumed	Known
Knowledge utilization	Captured in models used for prediction	Improved models based on research/monitoring/project implementation
Action Implementation (timing/detail)	Assumed	Known
Operation of existing projects	Assumed	Known

System state	Predicted using assumed conditions	Measured using system monitoring Predictions using known externalities
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The following table lists a suite of fisheries management and habitat conservation needs, in no particular order, associated with ecosystem effects of Gulf of Mexico hypoxia and large-scale Mississippi River diversions. It will provide a foundation for Breakout Session 1 of the Hypoxia/Diversion Modeling Workshop, which will prioritize these needs based on their importance in informing adaptive management of diversions and hypoxia over two time frames:

- Shorter-term: over an adaptive management cycle (3-5 years)
- Longer-term: greater than one cycle (10-50 years)

<p style="text-align: center;">Management Needs</p> <p>Note: Needs #1-20 were included in document developed by Steering Committee prior to workshop and were not necessarily listed in order of priority, and #21-23 were added by workshop participants during Breakout Session 1</p>	<p>Diversions (D), Hypoxia (H), or Diversions and Hypoxia (D&H)</p>
<p>1. How do shifts in environmental gradients (e.g. salinity, temperature, sediments, nutrient composition and quantity) from the operation of diversions affect the assemblage, diversity, distribution/displacement, growth rate, survival rate, spawning success and production of juvenile fishery species and their prey? Can the above effects be assessed for particular species of interest (e.g. brown shrimp, blue crab, spotted seatrout, red drum, flounder, Atlantic croaker, etc).</p>	<p style="text-align: center;">D D&H</p>
<p>2. What effects will the response of predator-prey interactions to diversions have on fishery production? For example, if shrimp production is reduced, will that loss of potential prey affect the production of red drum, spotted seatrout or juvenile red snapper?</p>	<p style="text-align: center;">D</p>
<p>3. How will diversions affect fishery species in the nearshore coastal zone? Will estuarine-dependent fisheries be displaced into less than desirable habitats in the nearshore Gulf zone?</p>	<p style="text-align: center;">D D&H</p>
<p>4. How will shifts in environmental gradients from the operation of diversions affect oyster mortality, larval recruitment/spat dispersal?; e.g.</p> <ul style="list-style-type: none"> - freshwater and temperature impacts to oysters in the lower part of the receiving basin; - fall, winter, and spring flows on gonad development to determine how remaining oysters responding reproductively; - impacts to spat set for both spring and fall reproductive seasons; - rate and distribution of Dermo infections; - ability of oyster populations/beds within an estuary to adapt to changing environmental conditions. Would 	<p style="text-align: center;">D</p>

adequate hard-substrates be available for spat settlement if diversions pushed optimum environmental conditions towards the Gulf zone?	
5. How will fishing pressure change as a result of diversions, and how will that affect fishery assemblages? For example, if changes in fishery pressure occur as a result of changes in species distribution, how will this impact production?	D
6. How will climate change (including relative sea level rise, shifts in hydrology, etc.) influence diversion effects on fish abundance, production, and distribution? Are local estuarine nekton governed by large-scale climate forcing?	D
7. Will diversion effects on fish and shellfish result in changes in recreational and commercial fleet effort ? Changes to dependent land-based business? Communities?	D
8. How will changes in marsh acreage and morphology affect abundance and habitat of key species? How will nutrient loading to the Gulf change as a result of diversion-induced changes in marsh habitat?	D D&H
9. How will hydrologic restoration affect habitat suitability and population sustainability? Does pulsed spring flow affect nekton communities differently than continuous spring flow? Do effects on nekton communities vary by distance from the diversion (up-estuary vs. down-estuary) and over time (during diversion vs. 3 months post-diversion)?	D
10. What is the potential threat of salt water intrusion on fisheries, and how could diversions be operated to mitigate for this possibility?	D
11. Will frequent, rapid disturbances during diversion operations favor invasive species ?	D
12. How do alternative flow -management strategies influence downstream nekton communities (abundance, diversity, assemblage)? Does restored riverine flood pulsing provide an exportable nekton subsidy? Does restored riverine flood pulsing affect short-term nekton growth? How will the timing and duration of flow affect: availability of optimal habitat, physiochemical attributes, flooded habitat, recruitment, growth?	D

<p>13. Will the diversion of large quantities of nutrient laden waters into the system result in a higher potential for eutrophication (e.g. HABs, hypoxia) and consequent impacts on fisheries?</p>	<p>D D&H</p>
<p>14. What are the current effects of the hypoxic zone on fishery resources due to:</p> <ul style="list-style-type: none"> - direct mortality of managed species and their prey; - decreased fecundity (sublethal effects of exposure, reduced size); - loss of habitat and reduced habitat quality; - decreased growth; - increased susceptibility to predation; - altered migratory patterns; - bycatch. 	<p>H</p>
<p>15. How will hypoxia effects on fisheries populations change over the long-term given scenarios of constant, decreased, and increased annual hypoxic zone size? What are the socioeconomic consequences?</p>	<p>H</p>
<p>16. What are the effects of hypoxia on food web structure, and what are the consequences on individual and reproductive fitness of important fish and shellfish species.</p>	<p>H</p>
<p>17. What is the ecological resilience of coastal systems to hypoxia, especially tributary nursery habitats, and their collapse threshold?</p>	<p>H</p>
<p>18. What are the diversion effects on hypoxic zone magnitude based on changes in freshwater and nutrient loading, and what are the consequences on fisheries production?</p>	<p>D&H</p>
<p>19. How will diversions affect the timing, distribution, and duration of coastal hypoxia? How will this affect commercial and recreational fisheries (e.g. fishermen traverse the hypoxic zone in order to reach suitable fishing grounds and incur increased operating costs due to increased fuel expenditures and travel times)?</p>	<p>D&H</p>
<p>20. Could freshwater diversions “push” estuarine and marine species into the dead zone?</p>	<p>D&H</p>

21. Identification of socioeconomic effects of diversions on ecosystem services and dependent communities – also identification of stakeholders and their views (now and how they change)	D
22. Marsh morphology – how will diversions change it and acreage and species composition across geography?	D
23. Figure out management endpoints and stakeholders and work backwards to model and plan; building land – providing ecosystem services (\$ and non\$)	D&H

APPENDIX 2

Hypoxia and Mississippi River Diversion Ecological Modeling Workshop: Model Matrix adapted from Rose and Sable (2013)*

Model	Location	Type	Currency	Biological Organization	Spatial	Temporal Scale	Purpose
Ecopath with Ecosim (EwE) <i>Walters et al., 2008</i>	GOM	Food-web	Age-structured for several populations; State variables for others	Ecosystem	Point	1950-2004	Ecosystem function
EwE <i>de Mutsert et al., 2012</i>	Breton Sound	Food-web	Age-structured for several populations; State variable for others	Ecosystem	Point	Multiple years	Assess diversion effects
EwE <i>de Mutsert et al., in progress</i>	LA Shelf	Food-web	Age-structured for several populations; State variable for others	Ecosystem	Point Spatially explicit w/ Ecospace	Multiple years	Assess impacts of hypoxia
EwE <i>Chagaris et al., 2013</i>	West Florida Shelf	Food-web	Age-structured for several reef fish populations; State variable for others	Ecosystem	Point Spatially explicit w/ Ecospace in development	1950-2009	

EwE <i>Lewis & Cowan, in progress</i>	Barataria Basin	Food-web	Age-structured for several populations; State variable for others	Ecosystem	Point Spatially explicit w/ Ecospace in development	Multiple years	Assess impacts of diversions
CASM <i>Bartell et al., 2010</i>	Pontchartrain Basin	Multiple species bioenergetics	State variables	Ecosystem	Point	1989-2007	Population Functional Response

Model	Location	Type	Currency	Biological Organization	Spatial	Temporal Scale	Purpose
CASM <i>Watkins & Sable, in progress</i>	Barataria Basin	Multiple species bioenergetics	State variables	Ecosystem	Point	One year	Population Functional Response
TroSim <i>Milroy et al, in progress</i>	MS Sound	Multiple species bioenergetics	State variables	Food web	Point	One year	Population Functional Response
Atlantis <i>Ainsworth et al., in progress</i>	GOM	Integrated spatial	Age-structured	Ecosystem	Spatially explicit w/ crude or no movement	Under development	Ecosystem-based Management

Atlantis <i>Mason et al., in progress</i>	GOM	Integrated spatial	Age-structured	Ecosystem	Spatially explicit w/ crude or no movement	Under development	Ecosystem-based Management
Atlantic croaker IBM <i>Creekmore, 2011</i>	Northern Gulf shelf	Agent-based	Individual Atlantic croaker	Single species	Spatially explicit	Multiple years	

APPENDIX 3

Report from the Socio-economic Effects of Diversions Workshop

Prepared by:
Kristen Laursen (NOAA NMFS) and Russell H. Beard (NOAA NESDIS/NCDDC)
on behalf of the NOAA Gulf of Mexico Regional Collaboration Team

16 July 2014

Purpose:

River diversions, a major component of some Gulf restoration plans, might have significant positive or negative socio-economic impacts on surrounding communities and their economies. The existing socio-economic information on such potential impacts resides with different entities. The NOAA Gulf of Mexico Regional Collaboration Team saw an opportunity to benefit the region by bringing these groups together, and organized this meeting aimed to focus on potential socio-economic impacts and how collaboration across the groups could best leverage relevant information for scientific and decision-making purposes. This does not imply “ownership” of the topic; all partners in the effort play essential roles in the larger picture of assessing and applying socioeconomic information.

Notes:

Due to synergies in topics and expected attendees, the meeting was paired with the larger “NOAA/Northern Gulf Institute Gulf Hypoxia Research Coordination Workshop: Advancing Ecological Modeling for Diversions and Hypoxia in the Northern Gulf of Mexico.” Approximately 40 people attended in person or by phone, representing NOAA, USACE, universities, Louisiana state government (CPRA), Sea Grant, the Northern Gulf Institute, non-profit entities, and others (see Appendix 4).

As a first meeting to bring relevant entities together, the agenda focused on:

- Identifying why participants saw value in the topic of the socio-economics of diversions and their desired outcomes for the discussions;
- How the themes of socioeconomic, diversions, and hypoxia connect;
- Ensuring all relevant participants were present or will be contacted for future inclusion; and
- Steps to move forward.

Overarching aims and goals brought out in discussion included:

- Learn about each other’s work and how different activities can be leveraged;
- Work together to enhance the connection between socio-economic and biological/ecological models, and the application of these models to understanding ecosystems and informing decision-making processes;
- Continue to connect regularly as a group and foster communication and transparency with each other, including on timelines for useful input; and
- Improve and promote quality communication with stakeholders/public.

Several comments focused on data, research, and modeling. It was noted that the data gathered must be meaningful to stakeholders and the public/residents, and their input needs to be heard and valued to ensure consensus on decisions and impacts. On connecting data and information, it was also mentioned that it's important to maintain sight of impacts to all relevant industries (e.g. not just fisheries, or energy, or tourism, etc., but all industries) in an area due to land loss and storm impacts in conjunction with diversions. Connections between socioeconomic impacts and potential future disasters may also be valuable. Such information can provide feedback that helps to model delta management and development. In addition, linking economic modeling and ecological modeling, and integrating good research in both areas, will be essential to proper evaluation. The ability to quantitatively link socio-economic information to an adaptive management cycle in this way may improve decisions with regard to cumulative impacts and environmental compliance. It is important to assess what we know and the capabilities currently available, and what gaps exist.

The main items discussed as steps moving forward were:

- The group's role was seen as a communication nexus to articulate joint socioeconomic information needs up individual agencies/organizations. A vision statement will be developed to guide this and other potential roles;
- Maintaining a strong socio-economic focus is crucial to the group;
- Inventory ongoing efforts related to socioeconomics and diversions, and conduct a gap analysis;
- Consider reviewing potential agency scopes of work as appropriate and provide relevant input to inform, not determine, agency plans;
- Anticipate appropriate timelines for providing the right information at the right time to be useful;
- Develop a white paper incorporating a gap analysis, a path forward, and how these efforts may connect to RESTORE activities;
- Plan a second meeting for Fall 2014, and anticipate continued regular meetings;
- Build on existing relationships and develop new ones as appropriate;
- Build on connections between resources and activities;
- Consider leadership options for the group.

Other items included connecting with the Gulf of Mexico Fishery Management Council Scientific and Statistical Committee, as it is looking at socioeconomics in the context of ecosystem-based management. A discussion of how to improve and standardize socioeconomic studies with regard to diversions and conduct adequate analysis to ensure its usefulness for applications may be considered. It may be beneficial to conduct a series of workshops mapping data to analysis to results. Rex Caffey and Dan Petrolia are coauthors on a methodological options paper to share with the group; it may be useful to consider in this process. A Steering Committee will be determined, plus a larger group of everyone involved/interested in the topic.

Participants were grateful for the opportunity to come together as one group and focus as partners on the socioeconomics of diversions. Russ Beard as Regional Team Lead is meeting with Louisiana Sea Grant and the Louisiana Coastal Protection and Restoration Authority

(CPRA) to set up and determine the convener for the next meeting, to be held in Baton Rouge, LA.

Supporting cross-entity collaboration in a neutral setting regarding the potential socioeconomic impacts of diversions and ensuring open participation and access to information will be essential to the group's success. This collaboration is also essential to connecting socio-economic research with broader ecosystem research and decision-making processes.

APPENDIX 4

Attendees of 5th Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop (14-16 July 2014) and Gulf of Mexico Regional Collaboration Team Socio-Economic Effects of Diversions Meeting (16 July 2014)

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