Aligning ecosystem modeling efforts with ecosystem-based fisheries management and restoration needs in the Gulf of Mexico

Hilton Tampa Airport Westshore

Tampa, Florida

August 2 – 4, 2016

This workshop was supported through a grant of NOAA’s RESTORE Act Science Program to Texas A&M University-Corpus Christi, the University of Miami and the University of South Florida. Additional travel support courtesy of The Pew Charitable Trusts.

Table of content

[Executive summary 4](#_Toc461816785)

[1. Introduction 6](#_Toc461816786)

[2. Summaries of presentations 9](#_Toc461816787)

[2.1. Tuesday August, 2nd 2016 9](#_Toc461816788)

[2.2. Wednesday August, 3rd 2016 24](#_Toc461816789)

[2.3. Thursday August, 4th 2016 44](#_Toc461816790)

[3. Recommendations 50](#_Toc461816791)

[4. Discussion 57](#_Toc461816792)

[References 59](#_Toc461816793)

[Appendix A – Agenda 61](#_Toc461816794)

[Appendix B – Participant list 63](#_Toc461816795)

[Appendix C - Abstracts of presentations (provided by presenters) 65](#_Toc461816799)

[Appendix D – Questions for small group discussions 74](#_Toc461816803)

[Appendix E – Background material 75](#_Toc461816804)

[Appendix F – Glossary of frequently used abbreviations 84](#_Toc461816805)

# Executive summary

The workshop entitled “Aligning ecosystem modeling efforts with ecosystem-based fisheries management and restoration needs in the Gulf of Mexico” took place from August, 2nd to August, 4th 2016 in Tampa, Florida. This event was organized under the auspices of NOAA’s RESTORE Act Science Program project entitled “Ecosystem modeling efforts in the Gulf of Mexico: current status and future needs to address management and restoration activities”. It gathered a diversity of ecosystem modelers, empiricists, non-governmental employees, fisheries managers and fishing industry representatives. Its main purpose was to discuss and align ecosystem models of the Gulf of Mexico (GOM) with ecosystem-based fisheries management (EBFM) needs and restoration projects.

Diverse presentations were giving during the workshop to: (1) highlight critical EBFM and restoration needs in the GOM; (2) provide understanding to managers, fishing industry representatives and other stakeholders on the applicability, utility, and benefits of ecosystem models for more informed and comprehensive decision-making on EBFM and restoration needs; and (3) provide to the audience an inventory of existing ecosystem models of the GOM and modifications needed on these models, as well as an inventory of new ecosystem models that could be designed for the GOM.

Presentations were complemented by breakout and plenary sessions for generating recommendations to enhance the ability of future ecosystem modeling efforts in the GOM to address EBFM questions and assess the impacts of restoration activities, in a manner that is fully rigorous, efficient and transparent to stakeholders. The recommendations that emerged from breakout and plenary sessions can be grouped into four categories: (1) streamlining the use of ecosystem models in the GOM; (2) best practices for ecosystem modeling; (3) future needs; and (4) priority questions to address with ecosystem models in the GOM.

Workshop participants agreed on the need to streamline the use of ecosystem models in the GOM. Firstly, in the GOM, one should make more use of conceptual and qualitative models to reach agreements on ecosystem’s components and connections, and as first steps towards the development of quantitative ecosystem models. We should also restrict the investigation of tactical questions to simple ecosystem models, such as extensions of single-species assessment models (ESAMs), at least for now. More complex ecosystem models, such as aggregated models (e.g., Ecopath with Ecosim) and biogeochemical-based end-to-end models (e.g., Atlantis), are more appropriate for investigating strategic questions and addressing data gaps. These more complex ecosystem models are meant to complement conventional fisheries research tools (e.g., single-species assessment models), not replace them.

Best practices for future ecosystem modeling efforts in the GOM include: (1) identifying the most critical research and management questions to address during the coming years; (2) enhancing the calibration and validation processes of ecosystem models; (3) conducting thorough sensitivity and uncertainty analyses with ecosystem models; (4) increasing the transparency of ecosystem models; (5) improving communication between ecosystem modelers, and stock assessment scientists, empiricists, managers, fishers and other stakeholders of the GOM; (6) better documenting ecosystem modeling efforts; (7) making efforts to maintain existing ecosystem models; and (8) improving existing ecosystem models or developing new ecosystem models only to address management needs.

Regarding future needs, given strong environmental influences in the GOM, non-fishing drivers should be explicitly considered in more ecosystem models of the region. Then, ecosystem models should be used to investigate the consequences of climate change and ocean acidification in the GOM. Also, forage fish, which are the backbone of the GOM ecosystems, should be given more attention to in ecosystem models of the region. Other future needs include: (1) establishing multispecies reference points with ecosystem models; (2) evaluating the cumulative impacts of stressors and management/restoration measures with these models; and (3) introducing socio-economic considerations in these models.

Restoration impacts are the top priority question to address with ecosystem models in the GOM during the coming years. Lionfish invasion is also a key topic to address. Moreover, several workshop participants supported that ecosystem modelers should quantify the impacts of seagrass restoration efforts for juvenile gag (*Mycteroperca microlepis*), because they felt it will be easier to restore the seagrass habitats than to manage gag spawning stock to improve gag recruitment. Other top priority question to address with ecosystem models in the GOM during the coming years include: (1) environmental influences on gray triggerfish (*Balistes capriscus*) recruitment; (2) the impacts of artificial reefs; and (3) the impacts of marine protected areas.

Participants felt that the workshop offered them a good background on ecosystem models. One of the key outcomes of the event was that, so far, ecosystem models have paid much more attention to evaluating the structure and functioning of GOM ecosystem and to tackling EBFM questions than to addressing restoration issues. However, the uptake of ecosystem research by fisheries managers is going to be slow, because EBFM is in a pretty immature state in the GOM currently. Meanwhile, many restoration projects are ongoing or planned in the GOM, and all these projects would benefit from being informed by ecosystem models. According to many workshop participants, ecosystem models are more immediately applicable and determinative for restoration issues than for EBFM issues.

# 1. Introduction

The workshop entitled “Aligning ecosystem modeling efforts with ecosystem-based fisheries management and restoration needs in the Gulf of Mexico” took place from August, 2nd to August, 4th 2016 at the Hilton Tampa Airport Westshore hotel in Tampa, Florida. This event was organized under the auspices of NOAA’s RESTORE Act Science Program project entitled “Ecosystem modeling efforts in the Gulf of Mexico: current status and future needs to address management and restoration activities”. This project started on September, 1st 2015 and will end on August, 31st 2017. It is articulated around four components: (1) a comprehensive review of all ecosystem modeling efforts in the U.S. Gulf of Mexico (GOM) and GOM large marine ecosystem (LME); (2) a workshop to align modeling efforts with ecosystem-based fisheries management (EBFM) needs and restoration activities; (3) a gap analysis of the potential predictive capabilities of some current Ecopath with Ecosim, OSMOSE, and Atlantis models of the GOM; and (4) the creation of bridges between widely-used marine life databases and the OSMOSE modeling approach.

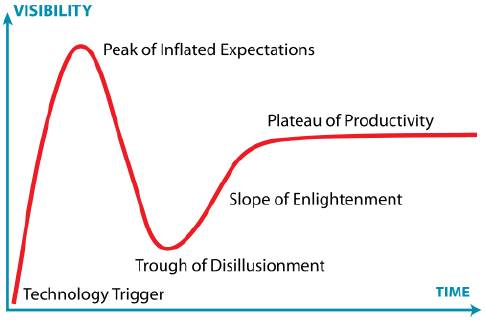
The workshop gathered a diversity of ecosystem modelers, empiricists, non-governmental employees, fisheries managers and fishing industry representatives. Its main purpose was to discuss and align ecosystem models of the GOM with EBFM needs and restoration projects. The specific objectives of the workshop were to:

1. Highlight critical EBFM and restoration needs in the GOM.
2. Provide understanding to managers, fishing industry representatives and other stakeholders on the applicability, utility, and benefits of ecosystem models for more informed and comprehensive decision-making on EBFM and restoration needs.
3. Provide to the audience an inventory of existing ecosystem models of the GOM and modifications needed on these models, as well as an inventory of new ecosystem models that could be designed for the GOM.
4. Provide recommendations to enhance the ability of future ecosystem modeling efforts in the GOM to address EBFM questions and assess the impacts of restoration activities, in a manner that is fully rigorous, efficient and transparent to stakeholders.

The agenda of the workshop and list of workshop participants are given in Appendices A and B, respectively. Kenneth Rose, professor at the Louisiana State University and internationally-recognized ecosystem modeler, was the facilitator of the workshop.

The workshop started in the afternoon of August, 2nd 2016. Jim Simons, lead PI of NOAA’s RESTORE Act Science Program project entitled “Ecosystem modeling efforts in the Gulf of Mexico: current status and future needs to address management and restoration activities”, introduced the event. He explained the purpose of the workshop, provided an overview of his NOAA’s RESTORE Act Science Program project, made a few administrative announcements, and asked all workshop participants to introduce themselves.

Jim Simons’ introductory presentation was followed by a short presentation by Kenneth Rose, who explained how the workshop was going to be run, and detailed the expected outcomes of the workshop. Kenneth Rose showed the audience a figure entitled “The Hype Cycle” by American IT firm Gartner (Figure 1). This figure describes the evolution of the visibility, adoption and social application of new technologies over time. Kenneth Rose wanted to come back to this figure at the end of the workshop, so that the audience could determine where ecosystem modeling in the GOM could be located on the figure.



**Figure 1.** “The Hype Cycle” by American IT firm Gartner.

After Kenneth Rose’s presentations, six presentations were given in the afternoon of August, 2nd to provide the audience with an overview of stressors, EBFM, restoration activities, and needs in the GOM.

The second day of the workshop, i.e., August 3rd, started with a presentation of Isaac Kaplan, from NOAA’s Northwest Fisheries Science Center, who reported the lessons learnt from the use of a multi-ecosystem model approach to understanding the role of Pacific sardine in the California Current ecosystem. Isaac Kaplan’s presentation was followed by an overview of ecosystem modeling approaches and ecosystem modeling efforts to tackle EBFM and restoration issues in the GOM. Then, presentations about four representative ecosystem models of the GOM were given. These presentations provided an overview of the four ecosystem models, and described how these models have been used to tackle EBFM and restoration issues, and their main current limitations and future needs. Presentations about representative ecosystem models of the GOM were followed by small-group discussions about the modifications needed in existing ecosystem models of the GOM to address EBFM and restoration needs in the region. Three questions were provided to small groups to initiate discussions (Appendix D). Finally, a plenary session took place at the end of the day, during which a summary of small group discussions was provided, and the key points of small-group discussions were identified.

The third and last day of the workshop, i.e., August, 4th, started with a presentation about future ecosystem modeling efforts in the GOM to address EBFM and restoration activities in the region. Next, small group discussions took place to discuss the new ecosystem models that could be designed to fully address EBFM and restoration needs in the GOM. Four questions were provided to small groups to initiate discussions (Appendix D). Then, a plenary session took place, during which a summary of small group discussions was provided, and the key points of small-group discussions were identified. Finally, Kenneth Rose facilitated a final plenary session to wrap up the workshop.

For practical reasons, the workshop focused on the U.S. GOM. However, Mexican scientists were invited to the workshop with the aim to examine ecosystem modeling efforts and needs in the different regions of the GOM LME in the future. The background material that was provided to workshop participants shortly before the workshop is given in Appendix E.

In the following, we provide the summaries of the different presentations that were given at the workshop. Then, we give recommendations for ecosystem modeling in the GOM based on the outcomes of small group discussions and plenary sessions that followed these small group discussions. Finally, we provide the conclusions of the workshop as well as perspectives.

# 2. Summaries of presentations

## 2.1. Tuesday August, 2nd 2016

***2:30 pm -*** ***Overview of NOAA’s RESTORE Act Science Program (Becky Allee)***

Becky Allee, Science advisor of NOAA’s RESTORE Act Science Program provided an overview of the Program.

The RESTORE Act was passed in 2012. NOAA’s RESTORE Act Science Program was created under that Act. To establish and administer NOAA’s RESTORE Act Science Program, NOAA consulted with the U.S. Fish and Wildlife Service (USFWS), as well as with the Gulf States Marine Fisheries Commission (GSMFC) and the Gulf of Mexico Fishery Management Council (GMFMC). NOAA’s RESTORE Act Science Program gives the priority to integrated, long-term projects that address management needs. Funds allocated by the Program may not be used for: (1) any existing or planned research led by NOAA; (2) the implementation or initiation of new NOAA regulations; and (3) the development of or approval of a fisheries catch share program.

The mission of NOAA’s RESTORE Act Science Program is to carry out research, observation, and monitoring to support, to the maximum extent practicable, the long-term sustainability of the ecosystem, fish stocks, fish habitat, and the recreational, commercial, and charter-fishing industry. The key attributes of the program are that: (1) it focuses on an applied holistic understanding of the ecosystem; (2) it encourages push-pull dynamic between the research and resource management communities; and (3) it encourages partnership and coordination to accomplish its outcomes. The total remaining funding for the Program is $130M.

The primary goal of NOAA’s RESTORE Act Science Program is to support the science and coordination necessary for better understanding and management of the Gulf of Mexico ecosystem, leading to: (1) healthy, diverse, sustainable, and resilient estuarine, coastal, and marine habitats and living resources (including wildlife and fisheries); and (2) resilient and adaptive coastal communities.

The funds allocated to NOAA’s RESTORE Act Science Program come from civil penalties over the *Deepwater Horizon* oil spill. These civil penalties resulted in $5.33B for the RESTORE Act. Of this $5.33B, Centers of Excellence received $133M and NOAA’s RESTORE Act Science Program received $133M.

“Coordination” is a key word of NOAA’s RESTORE Act Science Program. Coordination is required by the RESTORE Act, encouraged by stakeholders, and necessary to achieve NOAA’s RESTORE Act Science Program outcomes. NOAA’s RESTORE Act Science Program promotes complementary and joint activities that address shared issues, and wants grant recipients to demonstrate wise stewardship of funding.

NOAA’s RESTORE Act Science Program delivered a Science Plan. This plan: (1) highlights the areas of investment for the Program, and long-term priorities; (2) describes the competitive Program approach; and (3) identifies partners with which the Program will leverage future opportunities.

Projects funded by NOAA’s RESTORE Act Science Program can conduct research for any region of the GOM large marine ecosystem. Also, research is not restricted to the evaluation of the impacts of oil spill and post-oil spill restoration. The long-term priorities of NOAA’s RESTORE Act Science Program include: (1) research on coupled and ecological social systems; (2) research on freshwater, sediment and nutrient impacts; (3) research on living coastal and marine resources, food webs and habitats; (4) research on climate change and weather effects; (5) the development of management-ready ecosystem models; (6) the evaluation of the impacts of long-term trends on ecosystem status; (7) the development and use of environmental and socioeconomic indicators; (8) the development of decision support tools; (9) the compilation of integrated data and information; and (10) the development of advanced technologies.

The factors being considered within NOAA’s RESTORE Act Science Program include: (1) current management needs; (2) scientific gaps and interdependencies; (3) expected impact of and return on investments (i.e. outcomes); (4) new research results; (5) work of other science initiatives; and (6) additional stakeholder input.

Seven projects are currently funded by NOAA’s RESTORE Act Science Program. These projects include the project led by Jim Simons, which is entitled “Ecosystem modeling efforts in the Gulf of Mexico: current status and future needs to address management and restoration activities”. This year, the Program called for proposals focusing on living coastal and marine resources and their habitats. Two priorities of NOAA’s RESTORE Act Science Program are considered: (1) Research in six specific areas; and (2) Decision-support Tools. Project must demonstrate a strong link to management. The specific areas of research for the Research priorities include: (1) movement between and among habitats; (2) habitat use measurements; (3) recruitment of juvenile fish to offshore fisheries; (4) food web structure and dynamics, trophic linkages, and/or predator-prey relationships; (5) impact of multiple stressors on food web structure and dynamics and/or habitat quality and quantity; and (6) connections between restored habitat and surrounding habitats. Regarding the Decision-support Tools Priority, proposals should address a current or near-term management decision, and clearly describe the path for the continued use or adoption of the tool by a resource manager (i.e., the process should be collaborative, end-users should be trained to the use of the tool, and the tool should be operational and maintained). Improvement of an existing tool with active user community will be given priority.

Currently, there are several *Deepwater Horizon*-related science initiatives focused on the GOM, which when combined with existing science activities, represent an extraordinary opportunity. Communication and coordination between funded projects are important. There are many research and management needs in the GOM, and NOAA’s RESTORE Act Science Program and other related programs will have to prioritize these needs.

***3:00 pm - Federal fisheries management in the Gulf of Mexico (John Froeschke)***

The Magnuson Stevens Fishery Conservation Act is the bible of the Gulf of Mexico Fishery Management Council (Gulf Council). From the Magnuson Stevens Fishery Conservation Act, The Gulf Council and NOAA Fisheries develop policy documents collaboratively based upon the best available scientific information. This information can come from many sources, including NOAA fisheries, university research or other. Regulations are submitted to NOAA fisheries by the Gulf Council and ultimately approved or disapproved by the Secretary of Commerce.

The Gulf Council includes 17 voting members: the Regional Administrator of NOAA Fisheries, the directors of the five Gulf state marine resource agencies, and 11 members who represent different interests in the fishery. The Council also includes four non-voting members: one representing the U.S. Coast Guard, one representing the U.S. Fish and Wildlife Service, one representing the Department of State, and one representing the Gulf States Marine Fisheries Commission.

The Council manages federally managed species but does not manage Highly Migratory Species. The Gulf Council manages fish species in eight fishery management plans: Reef Fish, Shrimp, Spiny Lobster, Coral, Coastal Migratory Pelagics, Red Drum, Aquaculture, and Essential Fish Habitat (available at [www.gulfcouncil.org](http://www.gulfcouncil.org)).

U.S. marine fisheries are scientifically monitored, regionally managed, and legally enforced under a number of requirements, including ten national standards. The National Standards are principles that must be followed in any fishery management plan (FMP) to ensure sustainable and responsible fishery management. As mandated by the [Magnuson-Stevens Fishery Conservation and Management Act](http://www.fisheries.noaa.gov/sfa/laws_policies/msa/documents/msa_amended_2007.pdf), NOAA Fisheries has developed guidelines for each National Standard. When reviewing FMPs, FMP amendments, and regulations, the Secretary of Commerce must ensure that they are consistent with the National Standard guidelines, which are the following:

1. Prevent overfishing while achieving optimum yield;
2. Use the best scientific information available;
3. Manage stocks as a unit;
4. Allocate fair and equitably, promote conservation, and prevent excessive shares;
5. Consider efficiency but not base management solely on economic allocation;
6. Consider and allow for variations among fisheries, fishery resources, and catches;
7. Minimize costs/avoid duplication;
8. Provide for sustained participation by fishing communities;
9. To extent practicable, minimize bycatch and bycatch mortality;
10. To extent practicable, promote safety at sea.

Typically, the Council Management Process takes one year. A typical process includes the identification of specific fishery management issues. The public is made aware of the issue through public scoping where the public provides comment or propose management actions to address the specific issue. Results of the scoping process are developed into an options paper, that describes the scope of the problem and usually outlines management options for Gulf Council consideration. The Council develops these documents into public hear drafts with necessary supporting information (i.e., Environmental Impact Statement) that the Council considers before taking a final action (i.e., selecting course of action of management), and altering rule making if the status quo is affected.

In addition to the Magnuson Stevens Fishery Conservation Act, the laws affecting management in the GOM include: (1) the National Environmental Policy Act (NEPA); (2) the Marine Mammal Protection Act (MMPA); (3) the Endangered Species Act (ESA); (4) the Coastal Zone Management Act; and (5) the National Marine Sanctuaries Act.

The Council draws upon the expertise of knowledgeable people from other state and federal agencies, universities, and the public. The summary report of each Advisory Panel (AP) – typically consisting of fishermen and other stakeholders - or Scientific and Statistical Committee (SSC) – the Council’s scientific advisors - meeting is presented to the appropriate Council committee along with a summary of motions. Once given recommendations, it is up to the Council committee to decide what action to take. The Council committee recommendations are then handled by the full Council. There are numerous opportunities for the public to participate at various stages of the Council Management Process.

The Council pays specific attention to communication and outreach. It benefits from a comprehensive website, a Facebook page and mobile applications.

The public has more and more opportunities to have a look at the data being collected and to comment on the resulting management decision. The Council also allows the public to be engaged in data collections. However, the public is less informed about the backend obligations to manage data.

Next Generation Stock Assessments (ecosystem approach to fisheries management or EAFM), which consist of enhancing traditional forecasts by incorporating information collected through advanced technologies, habitat assessments, and ecosystem analysis (including climate impacts) into stock forecast models, is happening in the GOM. There have been some efforts to communicate about EBFM in the GOM, such as workshops about EBFM. Although recently dissolved, an Ecosystem SSC had advised the Gulf of Mexico Fishery Management Council. However, ecosystem scientists are now designated to serve on the Standing SSC.

Regarding the consideration of ecosystem factors in the assessment and management processes, current efforts include: (1) NOAA’s Integrated Ecosystem Assessment (IEA) program incorporating red tide events into red grouper stock assessment model; (2) incorporating environmental parameters into management advice; (3) integrating environmental data in stock assessments; (4) testing ABC (Acceptable Biological Catch) Control Rules integrating environmental covariates; (5) finding a balance between wants and needs; (6) identifying Habitat Areas of Particular Concern; (7) implementing gear restrictions; and (8) encouraging the development of ecosystem models.

What is needed includes: (1) expanding the assessment process to include ecosystem modeling; (2) setting specific ecosystem management objectives (Maximum Sustainable Yield (MSY)-like); (3) developing models that provide insight; (4) better understanding larval recruitment mechanisms/year class strength; (5) understanding the effects of climate change; (6) understanding shifting baselines; (7) developing decision-support tools; (8) evaluating management alternatives; (9) improving communication, data and information sharing, and timeliness.

Regarding decision-support tools, the Council staff developing web-based, interactive and useful tools to support management. These tools include a tool for spiny lobster, which can, among other things, indicate when spiny lobster landings exceeded Annual Catch Limits (ACLs); and a tool for deep water corals, which provides new information about the spatial distribution of deep water corals, and is useful for evaluating new HAPC (Habitat Area of Particular Concern) designations to protect habitat.

The Council encouraged the development of ecosystem models via the Ecosystem SSC. Ecosim and Ecopath grouper models were reviewed by the Ecosystem SSC. Recently, the Ecosystem SSC merged with the Standing SSC. NOAA’s IEA program delivered interesting products to the last red grouper assessment, particularly a Stock Synthesis (SS) model for red grouper that integrates mortality associated with red tides. However, despite recent efforts, ecosystem modeling is not yet directly used to provide management advice in the GOM. The major issue being that quotas established when considering several species and/or the environment are usually lower than the quotas ignoring the abiotic environment and/or other species; this deters people from using ecosystem model outcomes to take management decisions. Also, there are many regulations in place in the GOM that almost all ecosystem models cannot consider at present; or ecosystem models can consider only a few of the many management measures that are implemented for species of the GOM.

There is a need to better define objectives in the future to render the management process more transparent and efficient. Objectives should be clear and measurable.

Kenneth Rose emphasized that ecosystem modelers should look for low-hanging fruits to really get in the management arena.

***3:45 pm - Overview of stressors and basics of restoration in the Gulf of Mexico (Halie O’Farrell)***

Stressors can be classified as drivers, pressures, or states.Drivers are overarching stressors that cause ecosystem change and lead to a cascade of other stressors. Drivers in the GOM include: climate change, nutrient loading, and population growth. Pressures are stressors caused or intensified by drivers that afflict the ecosystem and change its state. Pressures in the GOM include: urban sprawl/coastal development, oil and gas exploration, overfishing and unsustainable fishing practices, invasive species, storms/hurricanes, dredging, levees and canals, subsidence, and sea-level rise. Finally, states describe the status of the ecosystem and/or communities resulting from pressures created or intensified by drivers. States in the GOM include: hypoxia, eutrophication, habitat and vegetation loss/degradation, water quality degradation/pollution, marine debris, noise pollution, changes in water quantity, reduced storm protection, cold snaps, and harmful algal blooms. Many stressors are related with one causing or interacting with another. Often, the effects of different stressors cannot easily be separated.

Climate change is the result of increasing levels of greenhouse gases in the atmosphere trapping and containing heat. Population growth, land alteration, burning of fossil fuels, and industrial activities are some of the many factors that contribute to high levels of greenhouse gases in the atmosphere. Human activities can interact with climate change to alter marine ecosystems and the natural resources that reside in these ecosystems. With raising temperatures, changes in rainfall and frequency of storms/hurricanes, fewer freezing events, increased water temperatures, and more frequent harmful algal blooms (HABs) can be expected. Climate change can result in a shift in the distribution range of plants and animals resulting in the alteration of biological communities, changes in biodiversity patterns, and increased opportunity for species invasion. Precipitation will interact with anthropogenic alterations to water flow and exacerbate each other. A wetter climate may lead to increased flooding, which may in turn lead to increased anthropogenic alterations and increased sediment loadings. A drier climate may lead to decreased runoff and freshwater input. The GOM shoreline is especially vulnerable to sea-level rise. Sea-level rise results in submergence of coastal habitats, loss of land, loss and damage to infrastructure, an increase in the occurrence of storm surge, reduced storm protection, and intrusion of saltwater into aquifers.

The Mississippi and Atchafalaya Rivers drain about 40% of the contiguous U.S. into the GOM. Freshwater discharge is diverted onto the Louisiana and Texas continental shelves carrying nutrients. Since the introduction of nitrogen fertilizers in the 1950s, the concentration of nutrients carried into the GOM has increased significantly. This has led to eutrophication. Eutrophication entails that primary production increases without control, sometimes leading to harmful algal blooms. Algal blooms increase water turbidity and they decrease overall water quality. In the GOM, eutrophication has led to hypoxic conditions. Hypoxia occurs because the phytoplankton that is not consumed sinks and decomposes. Decomposition consumes large amounts of oxygen. This can overcome the rate of oxygen diffusion at the surface and lead to anoxia. Stratification further impedes the diffusion of oxygen to the bottom, resulting in bottom waters with dangerously low oxygen concentrations that cannot be inhabited by most organisms. Hypoxia can cause the death of many species and encourage mobile organisms to migrate out of the impacted zone. Hypoxic conditions have been found to enhance the survival and growth of jellyfish. They result in decreased diversity. Efforts to study the economic effects of hypoxia are extremely limited, and their short and long term effects remain uncertain. Hypoxia has been recurring in the GOM since the 1950s. It occurs between June and August. It became large scale in the 1970s. The GOM hypoxic zone is the second largest hypoxic zone in the world.

The population of GOM states, which amounted to 56.2 million people in 2010, will be 15% larger by 2020. This figure greatly surpasses the expected national average population increase of 11% in the same time frame. Because the GOM area is prone to flooding, its population growth will be accompanied by enhanced alterations to coastal lands and estuary water flow. Increases in urbanization and development will alter the quantity of water flows, and aggravate subsidence and erosion. This will decrease water availability and water quality in the GOM estuaries and coastal areas. Population growth will also increase carbon dioxide emissions, thereby further driving climate change.

Currently, of the 29 assessed stocks in Gulf of Mexico Fishery Management Council (GMFMC) management plans, none are experiencing overfishing. Of the 18 stocks with known overfished status in 2007, three remain overfished at present: gray triggerfish (*Balistes capriscus*), greater amberjack (*Seriola dumerili*), and red snapper (*Lutjanus campechanus*). Attempts to reduce overfishing have been less successful for highly migratory species (HMS). Of the 26 Atlantic HMS stocks whose distribution ranges include the GOM, 19 have known status, and of these, six are experiencing overfishing. Six HMS stocks are overfished, while three HMS stocks have been overfished but are now rebuilding. In addition to the federally managed stocks, there are also more than 27 coastal populations that are managed by the GOM states, in some cases coordinated by the Gulf States Marine Fisheries Commission. Of the 10 stocks for which status is known, none are overfished, but stone crab (*Menippe mercenaria*) is thought to be experiencing overfishing on the west coast of Florida. In additional to removing biomass of target species, some fisheries impact the GOM ecosystem through bycatch, habitat damage, and indirect effects.

The GOM is an important region for offshore oil production, providing energy as well as numerous employment opportunities; the sector of offshore oil production employed about 55,000 workers in 2014. Oil platforms are located off the coast of all GOM states, with the exception of Florida, with the majority found off of Louisiana and Texas. While the vast majority of oil spills in the GOM have been minor, the 2010 *Deepwater Horizon* oil spill is a reminder of the hazardous potential. The *Deepwater Horizon* well released about 172 million gallons of oil into the GOM over 87 days following the initial explosion on April 20th, 2010. Furthermore, chemical dispersants were released to help degrade harmful hydrocarbons as part of the response. The event resulted in severe environmental and economic hardships. In the GOM, petroleum platforms function as artificial reefs. This effect is considered to be beneficial to fishes and is even encouraged in the rigs-to-reef program as a cost effective and environmentally favorable way to decommission platforms. While petroleum platforms can serve as habitat and as a rich foraging ground for economically valuable fish species, they have also been found to increase the range of non-indigenous species (NIS), which has a negative impact on fisheries.

Human activities can cause the accidental or intentional introduction of NIS into the marine environment. Vectors of introduction of NIS include ballast water, hull fouling, and aquaria. It was reported that the GOM houses 74 non-native species, ten of which are intentional introductions. Non-natives become invasive when their presence is destructive to the native marine community and when the environment where they are introduced lacks natural population controls. The lionfish invasion has received the most attention. Deliberately or accidently introduced from aquaria and first seen in Florida waters in 1985, lionfish are now considered widespread throughout the western Atlantic, including the GOM. It is likely that lionfish larval dispersal has been aided by the Caribbean, Yucatan, and Loop currents. The first sighting of lionfish in the GOM linked to larval transport was of two individuals off of the northern Yucatan Peninsula in 2009; sightings linked to larval dispersal have since occurred in both the southern and northern GOM. Invaded areas have been found to have higher lionfish densities as well as larger individuals when compared to native habitats in the Indo-Pacific, indicating a low mortality, a lack of predation, and an overall absence of interspecific competition for lionfish in the GOM. Increasing lionfish density in the GOM can cause declines in the biomass of prey-sized native reef fishes.

Regarding metal contaminants, toxic mercury found in the GOM habitats has been linked mainly to Mississippi River transport under strong precipitation events and to petroleum operations. High concentrations of cadmium, which are linked to urban development, have been found in sediments of the northwestern and central GOM.

Abandonment, improper disposal, and storm activity can result in traps, lines, rope, plastic, and buoys left unattended in the ocean. While these objects can provide shelter and habitat, organisms can also become trapped, resulting in ghost fishing. Drifting debris is carried by the local currents, resulting in its accumulation in the western GOM along the Texas coast where it can be pushed up onto the beaches.

Because the GOM is a hub for marine activities, anthropogenic ambient noises occur in the region due to, *inter alia*, drilling, construction, shipping, and recreational boating . The port of New Orleans and port of Houston have a combined traffic flow of 14,000 ships annually, leading to a chronic effect. Cetaceans are known to use acoustics to forage, communicate, and navigate; noise from anthropogenic sources can result in behavioral changes and even mortality in cetaceans if individuals occur very close to the noise source.

EBFM efforts in the GOM include the implementation of marine protected areas (MPAs), measures to reduce bycatch, culling programs, and the integration of ecosystem considerations into single-species stock assessments. Several agencies and groups have developed restoration programs with the common goal of restoring the natural habitats of the GOM that have been degraded by stressors. Specific plans have been put forth for mitigation of land loss in Louisiana and for mitigation of the hypoxic region in northern GOM. Other plans are more general and refer to the entire GOM large marine ecosystems. Lessons can be learned from the successful restoration of the Tampa Bay seagrass habitat. The restoration of the Tampa Bay seagrass habitat has resulted in a decrease in nutrient loading and an increase in water clarity. The restoration of the Tampa Bay seagrass habitat is beneficial to EBFM, since seagrasses are part of the foundation of the Tampa Bay watershed and affect the entire Tampa Bay ecosystem, particularly because they provide habitat for ecologically and economically important fish and shellfish species.

According to a workshop participant, aquaculture was missing from the list of stressors provided during the presentation.

***4:05 pm - Ecosystem-based management in the Gulf of Mexico (Elizabeth Babcock)***

Single-species fisheries management (SSFM) focuses on one single species and relies on Fishery Management Plans (FMPs). The ecosystem approach to fisheries management (EAFM) also focuses on one single species, but also takes into account climate, habitats and/or predators; EAFM relies on FMPs. Ecosystem-based fisheries management (EBFM) considers multiple species, and takes into account climate, habitats and/or predators; EBFM relies on Fisheries Ecosystem Plans (FEPs). Finally, ecosystem-based management (EBM) consider all sectors of activities/all management issues, i.e., fisheries, development, energy, ecotourism, oil and gas, conservation, shipping, sanctuaries, and aquaculture. EBM relies on Regional Ocean Plans (ROPs). Patrick and Link (2015) provide the following definitions. EAFM consists of the inclusion of ecosystem factors into a (typically single species) stock focus to enhance our understanding of fishery dynamics and to better inform stock-focused management decisions. EBFM recognizes the combined physical, biological, economic, and social tradeoffs for managing the fisheries sector as an integrated system, and specifically addresses competing objectives and cumulative impacts to optimize the yields of all fisheries in an ecosystem. EBM is a multi-sectored approach to management that accounts for the interdependent components of ecosystems, and the fundamental importance of ecosystem structure and functioning in providing humans with a broad range of ecosystem services. Fogarty (2013) defines EBFM as a process that recognizes that humans are an integral part of the system and interact with environmental processes, and as a place-based approach. Berkes (2012) defends that EBFM should be a revolution, contrary to some authors like Kenneth Rose, who contend that EBFM should be an evolution.

There is a real need for EBFM in the GOM, because GOM fisheries catch over 400 species, the GOM has complex food webs, multiple sectors of activities operate in the GOM, and environmental drivers are numerous in the region. Currently, BFM/EBM actions in the GOM include: marine protected areas (promoting habitat protection, biodiversity, and resilience), bycatch reduction measures, and culling of introduced species (e.g., lionfish).

Science needs for EBFM in the GOM include: (1) evaluating cumulative impacts; (2) evaluating tradeoffs; (3) understanding and considering the spatial distribution of ecosystem components and processes (including people); and (4) confronting uncertainty (including uncertainty due to human actions/behavior). Tools needed for EBFM in the GOM include: ecosystem level indicators and management procedures, and ecosystem level management strategy evaluation.

EBFM does not have to be a data rich process. For instance, in the absence of data, one can simply conduct a scoping procedure and determine the processes at risk (qualitatively) (e.g., Ecological Risk Assessment of the Effect of Fishing in Australia). However, in the GOM, we want to move toward quantitative approaches and, therefore, we need to define and use indicators. Indicators can come from data or models. Reference points are the targets of management. One wants to define a performance measure to know how far we are from the target and then determine how to reach the target. There is a huge literature on empirical indicators. Empirical indicators are indicators that respond to fishing and can be calculated from fishery or survey data (e.g., mean length of fish in the community, trophic level of landings). Model-based indicators are indicators that measure ecosystem complexity and size to evaluate ecosystem status (e.g., mean ecotrophic efficiency, mean trophic level of the community, keystoneness).

Integrated Ecosystem Assessment (IEA) is a useful process to implement EBFM. IEA involves the six following steps: (1) scoping (spatial scale, aspects to manage, etc.); (2) the definition of indicators; (3) the evaluation of reference levels: (4) risk assessment; (5) the evaluation of management scenarios; and (6) monitoring and evaluation.

Management Strategy Evaluation (MSE) can be a key component of EBFM. MSE is a process consisting of using an ecosystem model to simulate ecosystem dynamics and a management procedure to evaluate management scenarios. A MSE framework includes a management system with control rules, a survey module, an assessment model, and an implementation module. MSE can be a way to test a management procedure and evaluate it based on indicator targets. MSE can be used to identify tradeoffs.

Ecosystem models can be used to address a number of questions on indicators: Which indicators are strongly correlated with important system attributes? What are the relevant reference points for the indicators? Which ecosystem based management procedures will be effective? What are the system level impacts of stressors and management actions?

A modeled system will always be less complex than the real system. All sources of uncertainty must be kept in mind even if they are not accounted for in a model. Uncertainties include: natural variability, observation error, structural complexity, communication uncertainty, lack of clarity, and outcome uncertainty.

The successful management of ecosystem depends on the human system and community involvement. Therefore, the dynamics of human systems should be much more considered in ecosystem models in the future.

***4:30 pm - Gulf of Mexico Restoration: An unparalleled testbed for ecosystem-based fisheries management (Bonnie Ponwith)***

Modelers are innovators and managers are pragmatic people. The combination of these two categories of people will be powerful.

In April 2016, a crucial restoration plan was released, which provides guidance for the next 15 years: the *Deepwater Horizon* Natural Resource Damage Assessment (NRDA) Restoration plan. This plan provides a natural resource damage assessment and restoration plan, under the Oil Pollution Act, and presents an examination of the environmental impacts of various restoration alternatives, under the National Environmental Policy Act (NEPA).

Eighty percent of the Clean Water Act civil penalties from the *Deepwater Horizon* oil spill went to the Gulf Coast Restoration Trust Fund. Two and a half percent of this money (plus 25% of fund interest) is going to NOAA’s RESTORE Act Science Program.

Ecosystem models can play a huge role in EBFM and restoration. They form a continuum of model types, including conceptual and heuristic ecosystem models, strategic ecosystem models, and tactical ecosystem models. Ecosystem models can inform the management of living marine resources (LMRs) by conducting science to understand ecosystems, i.e., by modeling the processes, drivers, threats, status, and trends of our ecosystems. Ecosystem models can also explore and address trade-offs within an ecosystem. There is a need to establish sufficient EBFM modeling capacity to analyze trade-offs in the GOM. There is also a need to develop Management Strategy Evaluation capabilities to better conduct ecosystem-level analyses to provide ecosystem-wide management advice. Finally, ecosystem models can assist the incorporation of ecosystem considerations into management advice. There is a need to: (1) develop and monitor Ecosystem-Level Reference Points; (2) incorporate ecosystem considerations into appropriate LMR assessments, control rules, and management decisions; and (3) provide systematic advice for other management considerations, particularly applied across multiple species within an ecosystem.

Regarding the analysis of tradeoffs, ecosystem models could be employed, for example, to explore: whether the sequential rebuilding of stocks could cause difficult-to-reverse setbacks for downstream stocks, and the carrying capacity implications of prey and habitat management. Ecosystem models could also be used as tools to negotiate with “owners” of stressors/pressures on LMRs but outside of fishery management authority. Finally, ecosystem models could be employed to analyze the ecosystem implications of complex human behavior/adaptation.

Some ecosystem models could be used as tactical tools to reduce uncertainties around the impacts of management measures. For instance, some ecosystem models could help fisheries managers in setting the buffers between the overfishing limit (OFL; which corresponds with Maximum Sustainable Yield (MSY)), acceptable biological catch (ABC), annual catch limit (ACL) and annual catch target (ACT; which corresponds with optimal yield (OY)). Four priority areas of research were identified for tactical ecosystem modeling: (1) characterizing and communicating uncertainty and risk; (2) conducting Multi-model inference (MMI); (3) conducting simulation studies to evaluate the skill of models to be used in MMI; and (4) conducting Management Strategy Evaluation.

To advance ecosystem science, it is crucial to continue investments in the collection of long-term time series data. Those data collections are expensive, but invaluable for ecosystem models.

Some take-home messages of this presentation are the following: (1) restoration efforts in the GOM are an opportunity to advance EBFM; (2) ecosystem modeling is important for communicating choices and trade-offs in the restoration process; (3) communicating modeling objectives is important to understanding and perception of value; and (4) a focused strengthening of the social science component of EBFM is needed.

***5:00 pm - Overview of Lenfest Task Force (Felicia Coleman)***

In 1999, the Lenfest Program was created. The same year, the Program delivered a report entitled “ecosystem-based fisheries management” to the congress. This report called for the amendment of Fishery Management Plans (FMPs) to incorporate ecosystem approaches for each major ecosystem under Council jurisdiction. The specific objectives of the report were to: (1) provide the fundamental physical, biological, and human/institutional context of ecosystems within which fisheries are managed; (2) direct how that information should be used in the context of FMPs; and (3) set policies by which management options would be developed and implemented.

In 2014, the Lenfest Program put together a Fisheries Ecosystem Task Force. The missions of the Lenfest Task Force are to determine: (1) the key principles of EBFM that should be included in a fisheries ecosystem plan (FEP); (2) the current status of fisheries management that incorporates these principles; (3) the gaps between ecosystem knowledge and fishery ecosystem planning; and (4) the approaches that can be used to fill these gaps.

Before planning EBFM, it is necessary to determine to what degree ecosystem interactions are accounted for within single species assessments; and what factors lead to the inclusion of ecological information in some stock assessments but not others. To some extent, all FMPs include ecosystem considerations. Stock assessment models have advanced to reflect the step-wise expansion of conventional management. For instance, some stock assessments link recruitment to environmental conditions, track changes in mortality due to predators, or use information on habitats to better standardize abundance indices. In fact, the review of 207 quantitative stock assessments conducted by the Lenfest Task Force found that roughly 45 stock assessments included explicit habitat or oceanographic conditions and three stock assessments explicitly included predation. (An additional 23 assessments included data on predation in the report for context). This progress demonstrates both the capacity to improve stock assessments by including ecosystem information and the tremendous opportunity to expand the application of EBFM in stock assessments.

The need for a wider use of EBFM in the U.S. and worldwide is demonstrated by several case studies. For instance, in the Gulf of Maine, high fishing pressure led to the depletion of cod and the disappearance of the cod fishery. The cod fishery was replaced by a sea urchin fishery, which itself disappeared due to intense fishing. Kelps, which have been intensively grazed due to trophic cascades, have also disappeared, replaced by algae. Another example is the Northern Benguela ecosystem, which used to be a very productive ecosystem. The small pelagic fisheries of the Northern Benguela (which fished anchovies and sardines) collapsed in 1970s, going from about 10 MT to almost zero ton due to a combination of fishing pressure and changing environmental conditions creating huge hypoxic areas. Now, jellyfish and gobies (low energy prey) proliferate in the Northern Benguela ecosystem.

Barriers to EBFM are numerous. They include: setting objectives; data; complexity; costs/resources; boundaries; institutions; communication; stakeholder engagement; distrust; and demonstration effectiveness. The people and institutions responsible for managing fisheries (Regional Fishery Management Councils, Council staff, and the agencies that support the council process) are overextended. Simply adding EBFM to their list of responsibilities with no consideration of existing workloads is a recipe for failure. Another issue is that managers have often approached EBFM as an added layer of science or models on top of conventional management (e.g., adding new parameters to stock assessments), without a reconsideration of the goals, strategies, or allocation process inherent to EBFM. Once you start thinking about the fishery as a system, the potential complexity can be overwhelming. There are lot of parts and a lot of connections, so a lot of things to consider which seems impossible. The Lenfest Task Force hopes to frame its recommendations not as a framework that requires a highly precise ability to predict outcomes, but rather a framework for decision making that acknowledges this complexity. The actual tools and decisions may be simple, but are ones that have a track record of performing well given this kind of uncertainty.

EBFM hurdles are surmountable via FEPs. Ideally, FEPs will: streamline management; produce informative, deliberative, multi-objective decisions; and increase stability and long-term planning.

The Lenfest Task Force has learnt a lot from case studies. The Task Force bases its recommendations from case studies around the world that provide clear cross cutting linkages that require an ecosystem approach. The analysis of several case studies is useful to identify barriers to adoption, and solutions that should be used. What case studies reveal is that the implementation of EBFM has been relatively piecemeal.

The FEPs currently recommended by the Lenfest Task Force are called “NextGen” or “Gen2”. G2 FEPs should: (1) explicitly embrace fishery systems as linked, interacting biophysical and human systems; (2) support streamlined management to relieve, rather than aggravate administrative burdens; and (3) create a framework for deliberate, informed and transparent decision-making that highlights rather than obscures the difficult allocation decisions of EBFM. G2 FEPs should promote iterative, adaptive management planning processes, involving the following steps: (1) inventorying the state of the social-ecological system; (2) setting strategic objectives for management of the system and prioritizing issues that will be addressed; (3) developing projects and evaluating management strategies to achieve objectives; (4) implementing management strategies; and (5) monitoring progress and evaluating impacts.

Regarding the science tools for implementing FEPs, many science tools already exist that can achieve FEP objectives. We already benefit from a rich toolbox for identifying threats and vulnerabilities, selecting indicators and reference points, and evaluating management alternatives. A variety of tools exist and “one size does not fit all”. Moreover, best practices for tool selection have been laid out (see, e.g., Rose et al. (2015)).

The Lenfest Task Force recommend future EBFM actions to: (1) focus on action; (2) be evolutionary rather than revolutionary; (3) be aspirational and ambitious; and (4) be based on existing science and policy tools.

## 2.2. Wednesday August, 3rd 2016

***8:30 am - A multi-model approach to understanding the role of Pacific sardine in the California Current ecosystem (Isaac Kaplan)***

Isaac Kaplan, from NOAA’s Northwest Fisheries Science Center, reported the lessons learnt from the use of a multi-ecosystem model approach to understanding the role of Pacific sardine in the California Current ecosystem. This work was conducted within NOAA’s IEA program, with the aim of evaluating the role of sardines in the broader ecosystem. The modeling work was partly structured in response to findings from a 2013 workshop of the Pacific Fishery Management Council, which found that “available ecosystem models are not sufficiently well developed to form the basis for an evaluation of the impact of sardine control rules on broader ecosystem impacts.” In response to this, the Ocean Modeling Forum ([www.oceanmodelingforum.org](http://www.oceanmodelingforum.org)) began to develop a California Current sardine case study.

After the initiation of the case study, NOAA stock assessments determined that the sardine population had declined sharply, and the sardine fishery was curtailed. At the same time, the biomass of anchovy declined. Predators of sardine and anchovy, such as brown pelican and sea lion, demonstrated low reproductive success. Both are likely to be impacted by altered ocean conditions (e.g., as associated with El Niño).

A multi-model approach was adopted for the case study: 1) A focus on diets in an Ecopath model (Koehn et al. 2016). 2) Application of the PREP equation (Predator Response to the Exploitation of Prey (Pikitch et al. 2014). 3) A MICE (Model of Intermediate Complexity) integrating harvest control rules and climate (Punt et al. 2016). 4) An Atlantis model to evaluate strategic risk at the ecosystem level. Aspects of the MICE and Atlantis model benefited from collaboration among modelers and learning from other experts, in particular with respect to sardine and anchovy diets and migration patterns.

Key differences between the MICE model and Atlantis convey advantages and disadvantages to each. Atlantis has a higher spatial and taxonomic (species) resolution than the MICE, but MICE has a sophisticated representation of harvest control rules and fishing. Atlantis has extremely simple recruitment dynamics, while the MICE offers sophisticated representations of uncertainty related to recruitment dynamics for sardine and anchovy. Most of these model differences stem from or lead to differences in computing time, which is fast in MICE but requires 3-5 days in Atlantis.

MICE and Atlantis were used to project impacts on the rest of the food web that would result from depletion of sardines. Comparing these two models required binning MICE model output from thousands of simulations to force comparability with Atlantis results. The MICE identified brown pelican as most sensitive to low sardine abundance. The MICE and Atlantis identified sea lions as less sensitive to low sardine abundance, and brown pelican as more sensitive. Atlantis identified additional species that the MICE should consider: other birds, dolphins, and large flatfish (halibut). Atlantis predicted some positive indirect effects of low sardine abundance (e.g. on zooplankton and myctophids), which cannot arise from a one-way coupled model such as MICE.

The California Current Atlantis model went through a thorough review process in 2014, involving external experts and ecosystem modelers from different institutes (Kaplan and Marshall 2016). This review coincided with the application of Atlantis in strategic Tier I Environmental Impact Assessment (Pacific Fishery Management Council and National Marine Fisheries Service (NMFS)). The Atlantis review process was somewhat similar to the review process of single-species model on the U.S. West coast, including a review panel held over three days, presentations to the Fishery Council, and expectations of future iterative improvements.

***9:30 am - Overview of ecosystem modeling approaches and ecosystem modeling efforts to tackle ecosystem-based fisheries management and restoration issues in the Gulf of Mexico (Halie O’Farrell)***

Ecosystem models have the ability to deliver insights into the potential effects of stressors and management measures. They complement traditional single-species modeling approaches with the added consideration of trophic effects and/or abiotic environmental influences on species dynamics. A variety of ecosystem models exists. The models differ in their structure, assumptions and complexity. They address a range of situations, questions, and management objectives.

Ecosystem models can be classified by their major purpose as: (1) conceptual models for developing an understanding of processes in the study ecosystem; (2) strategic models; or (3) tactical models. Alternatively ecosystem models can be classified by their structure as: (1) conceptual and qualitative models; (2) extensions of single-species models; (3) dynamic multispecies models; (4) aggregated (whole ecosystem) models; (5) biogeochemical-based end-to-end models; or (6) coupled and hybrid model platforms.

Regarding conceptual and qualitative ecosystem models – Currently, there is one conceptual model (Kelble et al. 2013) and one loop analysis in the GOM. These models integrate knowledge of ecosystem components while focusing management attention on the most important aspects of the ecosystem. Their potential is limited to providing qualitative or semi-qualitative insights into the potential impacts of management measures. Kelble et al (2013)’s EBM-DPSER model is a conceptual DPSIR (driver-pressure-state-impact-response) model of the Florida Keys and Dry Tortugas ecosystem integrating ecosystem services instead of impacts. The loop analysis uses a qualitative representation of the Galveston Bay (Texas) food web to evaluate the expected direction of changes in ecosystem components in response to perturbations.

Regarding extensions of single-species models – Currently, there are seven extensions of single-species assessment models (ESAMs) in the GOM. Increased capacity in terms of relatively long-term environmental and ecological data series combined with the ability of stock assessment models to handle these factors has enabled ecosystem considerations within the assessment process, which has substantially improved the consideration of ecosystem factors in assessments in the southeast U.S., meeting the recommendations of the revised Magnuson-Stevens Act. The main advantage of ESAMs of the GOM is that, by integrating ecosystem considerations, ESAMs can sometimes improve the fits of stock assessment models to time series data. However, there remains little formal consideration of when and how these factors should be considered. The incorporation of ecosystem processes in stock assessments is generally viewed with caution throughout the U.S. This is largely due to concerns about data limitations, that observed correlations between environmental indices and recruitment may be due to chance, and that using model outputs as inputs for subsequent models may introduce bias. Two famous ESAMs of the GOM are those that were used within the assessment process of gag grouper in 2013-2014 and the assessment process of red grouper in 2015. These two ESAMs account for the elevated natural mortality of groupers in 2005 due to a severe red tide event. A red tide index was developed for the assessment models of red and gag groupers. This index was incorporated into the base stock assessment model of red and gag groupers as a pseudo-fishing fleet.

Extensions of single-species individual-based models (ESIBMs) are another category of extensions of single-species models. ESIBMs have the ability to integrate data across hierarchical scales of organization and can yield insights useful to single-species sock assessments. However, their potential is limited because they are single-species models. Creekmore (2011)‘s ESIBM is a model with an hourly time step, which was designed to assess the effects of hypoxia on Atlantic croaker (*Micropogonias undulatus*) dynamics in the northwestern GOM. Another ESIBM was developed for the Florida Keys; this ESIBM is a model with a daily time step, which was developed to investigate the impacts of environmental events on spiny lobster recruitment.

Dynamic multispecies models are models that represent a limited number of species or functional groups most likely to exhibit large interactions with a focal species. Dynamic multispecies models include multispecies virtual population analysis (MSVPA) and Gadget; which have never been used in the GOM. MSVPA and Gadget are suited to simpler ecosystems with lower biodiversity and fewer stressors. They are of limited interest for the GOM.

Models of Intermediate Complexity or MICES are another category of dynamic multispecies models. Two MICEs were developed for the GOM. MICEs focus on a few species/functional groups most likely to have significant interactions with a species of interest. They offer a sophisticated representation of abiotic influences on marine organism, thereby allowing for realistic simulations. One of the two MICEs of the GOM is Sable and Rose (in review)’s MICE; this is a spatially explicit model of a tidal marsh community with an hourly time step, which was specifically designed to evaluate how enhanced marsh degradation and hypoxia imposed on individuals can be scaled to population and community responses.

Aggregated (whole ecosystem) models attempt to consider all the trophic levels of a given ecosystem to explore energy flows among ecosystem components. They typically represent a large number of functional groups/species. Three of the aggregated models of the GOM are energy flow models. In these models, ecosystem compartments are connected by trophic relationships and nutrient cycling. Energy flow models were the first ecosystem models to be developed for the GOM. The three existing energy flow models of the GOM focus on the north-central GOM and they all address the issue of bycatch in GOM shrimp fisheries.

Ecopath with Ecosim with Ecospace models also belong to the category of aggregated models. There are four Ecopath models in the GOM. One of them is Sagarese et al (in review)’s model, which was designed to assess the structure of the U.S. GOM ecosystem in the 2000s. The diet matrix of this Ecopath model is based on a comprehensive literature review and meta-analysis. Diet compositions were statistically derived for this Ecopath model. This estimation of diet compositions enhanced the biological realism of trophic dynamics, and increased system omnivory and resilience in the Ecopath model. Sagarese et al (in review)’s Ecopath model was validated using the PREBAL diagnostics of Link (2010).

There are 11 Ecopath with Ecosim (EwE) models in the GOM. One of them is Chagaris et al. (2015a)’s EwE model exploring the impacts of lionfish invasion in the West Florida Shelf ecosystem. Chagaris et al. (2015a)’s model is the only model in the GOM to include lionfish as an individual model component. This model predicts large increases in red lionfish biomass over the next 30 years under all scenarios explored. However, it indicates that management strategies for reef fish and lionfish removal efforts have the potential to result in a partial mitigation of the impacts of lionfish invasion. Walters et al. (2008)’s model is another EwE model of the GOM. This model was used, among other purposes, to explore the consequences of a reduction of bycatch mortalities by the GOM shrimp fisheries. Walters et al. (2008)’s model made the somewhat counterintuitive prediction that reducing bycatch in the GOM shrimp fisheries may have negative impacts on the productivity of some important functional groups due to the recovery of some benthic predators. This result was due to the diet matrix input into the model and the resulting (too) high predation pressure of benthic predators on juveniles of species such as red drum and red snapper.

There are seven EwE with Ecospace models in the GOM. One of them is Vidal and Pauly (2004)’s Ecospace model for the whole GOM LME. This model is original in that it was constructed from one Ecopath model for the whole GOM LME integrating ten different Ecopath models. This model predicts that when predation and/or fishing mortality in offshore regions is high, low fishing mortality in inshore regions does not result in a substantial increase in biomass of inshore functional groups; this result suggests a strong coupling between inshore and offshore regions of the GOM. Another Ecospace model of the GOM is that of Lewis et al. (2016). This model employs a recently developed feature of Ecospace called the habitat capacity model to add land to active water cells over time, i.e., to simulate changes in the physical habitat.

The Comprehensive Aquatic System Model or CASM is another type of aggregated model. There is only one CASM in the GOM currently; this model focuses on the Mississippi River Delta. CASM is similar to Ecospace, but dynamics in CASM are simulated using a bioenergetics-based process-oriented approach, and fish movement not represented. Also, CASM does not represent fishing. CASM is suited to the evaluation of the effects of freshwater diversion projects in the GOM.

There is only one biogeochemical-based end-to-end model in the GOM, which is the Atlantis model for the entire GOM LME or Atlantis GOM. This model was primarily designed to investigate the consequences of the *Deepwater Horizon* oil spill. It has an irregular polygon grid structure. Many ecosystem processes can be represented in Atlantis.

NEMUROMS.FISH is another type of biogeochemical-based end-to-end models. There is no NEMUROMS.FISH model in the GOM currently. NEMUROMS.FISH consists of four coupled submodels: a hydrodynamic submodel, a biogeochemical submodel, an individual-based fish submodel, and an agent-based fishing fleet submodel. These four submodels are coded within the ROMS (regional ocean modeling system) model, employ the same spatial grid, and are all solved simultaneously to permit for feedbacks among them.

Currently, the only instances of coupled and hybrid modeling platforms in the GOM are the three successive versions of the OSMOSE model of the West Florida Shelf or OSMOSE-WFS. OSMOSE is a multispecies, individual-based model that does not use a diet matrix and instead makes the assumption that predation is opportunistic and will occur as long as: (1) the predator and its potential prey overlap in space; (2) there is size adequacy between the predator and the potential prey; and (3) the potential prey is accessible to the predator. OSMOSE models represent the entire life cycle of a few functional groups and are forced by the biomasses of other functional groups. The OSMOSE-WFS model was used to: (1) estimate natural mortality rates for gag grouper and deliver input to the SEDAR (SouthEast Data, Assessment, and Review) process (assessment process); (2) estimate natural mortality rates for red grouper and examine the impacts of fishing scenarios for the species to deliver inputs to the SEDAR process and the Gulf of Mexico Fishery Management Council (GMFMC); and (3) conduct Management strategy evaluation (MSE) to evaluate the acceptable biological catch (ABC) strategies for red grouper in the face of episodic events of natural mortality, with the intent to inform the GMFMC.

InVitro is another type of coupled and hybrid modeling platforms, which is not used in the GOM currently. InVitro is a highly sophisticated three dimensional modeling approach with a very small time step, whose components are all “agents” and which has the potential to evaluate numerous EBFM and restoration scenarios.

Size spectrum models also belong to the category of coupled and hybrid modeling platforms; they have never been used in the GOM. They are non-spatial model representing the entire life cycle of a few functional groups and are forced by the biomasses of other functional groups. They assume that predation in the marine realm is a size-based process.

In total, 45 different models have been developed for the U.S. GOM and the GOM LME since 1983. Over half of them were developed for a specific GOM state. Many were developed for Florida. Mississippi is the only Gulf state without an ecosystem model. The majority of the ecosystem models of the GOM have at least in part a trophodynamic structure (61%). The majority of them are aggregated (whole ecosystem) models. Fish are represented in almost all models, while more than half of the ecosystem models of the GOM represent invertebrates, phytoplankton, marine plants, and detritus. Less than half of the ecosystem models of the GOM represent marine mammals, seabirds, and sea turtles.

The majority of the ecosystem models of the GOM are strategic (82%), one of them is conceptual, and the remaining are tactical (16%). The EBFM and restoration issues addressed by ecosystem models of the GOM include the integration of ecosystem considerations into stock assessments, followed by fishing pressures suited for a sustainable marine ecosystem, reduction of bycatch, MPAs, and changes to water flow. The following EBFM and restoration issues were each addressed by only one ecosystem model of the GOM (not the same model): mitigation of species invasion, MSE integrating ecosystem considerations, and the management of nutrient loads. Much more attention has been given to EBFM issues then to restoration issues in existing ecosystem models of the GOM.

***10:45 am - Exploring effects of hypoxia on fish and fisheries in the Northern Gulf of Mexico using a dynamic spatially-explicit ecosystem model (Kim de Mutsert)***

Kim de Mutsert from George Mason University talked about the NGOMEX Ecospace model, which focuses on the issue of hypoxia in the northwestern GOM (de Mutsert et al. 2016), as well as about another Ecospace model for the northwestern GOM, which focuses on estuarine issues (de Mutsert et al. 2015).

Hypoxia is notorious for having high impacts for fish and shrimps. Fish and shrimp can detect and avoid oxygen deficient sea water, resulting in shifts in spatial distributions. An absence of behavioral response in some species can result in reduced growth rate, reduced reproduction and/or increased mortality. The combination of these factors can result in reduced abundance/biomass in areas affected by hypoxia. Hypoxia does not come alone; it is a consequence of nutrient loading. A paradox is that the “dead zone” is a very rich zone. The zone is fueled by nutrients. So, models are welcome to disentangle the positive effects of hypoxia from their negative effects.

The research questions that were identified are: (1) Does hypoxia have an effect on the biomasses and landings of fisheries species? And (2) How do both positive and negative effects of nutrient loading affect fish biomasses and landings?

To answer these research questions, Ecopath with Ecosim with Ecospace was used. Ecopath provides a mass-balance “snapshot” of an ecosystem. Ecosim allows for temporal dynamic simulations. Finally, Ecospace allows for spatial-temporal modeling (framework of the NGOMEX model). The key inputs of Ecopath are: (1) the average biomass of species representative of the northwestern GOM; (2) parameters quantifying turnover and growth (P/B, Q/B, EE, age at maturity, von Bertalanffy growth parameters); (3) representative fishing fleets and annual landings; and (4) the diet matrix. Kim de Mutsert and colleagues used SEAMAP (Southeast Area Monitoring and Assessment Program) shrimp trawl data to determine which species should be added to the NGOMEX model and with which biomass. Kim de Mutsert and colleagues formed their model from the average catch between 2005 and 2008. All years were used to create biomass time series per species which were used later in comparison with Ecosim model runs.

Sixty functional groups are represented in the NGOMEX model, including the stanzas of several multistanza species. Biomasses from 1982-2010 (SEAMAP data) and landings from 1950-2010 (NOAA data) were used to calibrate the Ecosim component of the NGOMEX model. The Ecospace component of the NGOMEX model uses a 5 km2 grid. Spatial and temporal dissolved oxygen (DO) and chlorophyll-a (Chl a) are used as environmental drivers of Ecospace: DO and Chl a values are provided per grid cell, per month. Ecospace considers the location of ports and the price per pound of landings to simulate fishing fleet dynamics. DO estimates measured during SEAMAP trawls were used to create empirically derived oxygen tolerance functions for NGOMEX. To get estimates of Chl a and DO, NGOMEX relies on a coupled physical-biological model. This model is a physical model coupled to a biological model (up to phytoplankton). Kim de Mutsert and colleagues used the average monthly DO and Chl a output converted to their spatial grid (so one value per cell, per month in their grid) as spatial and temporal environmental forcing in their model. Therefore, the Chl a estimates from the coupled physical-biological model are affecting phytoplankton biomass distribution in NGOMEX, and the DO estimates from the coupled physical-biological model, in combination with NGOMEX species specific response curves, affect consumers in NGOMEX.

The scenarios considered in NGOMEX include: (1) No forcing: no nutrient fueling of coastal primary productivity by riverine sources, no hypoxia; (2) Enrichment only: nutrient fueling affects primary productivity, but hypoxia has no effect on organisms; and (3) Enrichment plus Hypoxia: simulated reality (physical-biological model DO and Chl a output drives the NGOMEX model).

NGOMEX results show that nutrient loading has many positive impacts in terms of increasing total biomass and landings. The Mississippi River fuels the Gulf of Mexico coastal ecosystem. However, the effects of hypoxia and nutrient enrichment are species-specific. Red snapper is negatively impacted, while menhaden, shrimp and jellyfish are positively affected. The landings of the different fleets are positively impacted by nutrient loading/hypoxia. The general trend is that Mississippi River discharge increases biomasses and landings, and hypoxia reduces what could optimally be achieved.

In the future, the “No forcing” scenario should be replaced with a reduced loading scenario, so as to determine the optimal nutrient loading from the perspective of living marine resources, and the effects that proposed nutrient load reductions could have. It should also be determined whether hypoxia in the northwestern GOM affect the fish and fisheries to such an extent that it needs to be included in stock assessment and fisheries management. Also, one should thoroughly explore how proposed reductions in nutrient load and size of the hypoxic zone affect fish and fisheries. Finally, there is a need to: (1) evaluate alternative management strategies, and varying nutrient loading and water temperatures on living resources with coupled water quality, bioenergetics, and ecosystem models; (2) create user-driven predictive tools to assess effects of reduced nutrients and hypoxia on living resources in the GOM; and (3) connect model predictions and management actions in an adaptive management and adaptive-science framework with continuous feedback for improvement.

The other Ecospace model developed by Kim de Mutsert and colleagues is a fish and shellfish model used in delta management decisions. This model was developed to tackle the issue of wetland loss in Louisiana, which is a major issue because 90% of coastal wetland loss in the lower 48 states of the U.S. occurs in Louisiana. Wetlands should be preserved to protect the coastal population, coastal ports, coastal energy, and coastal fisheries.

The overarching goals of the management of the Mississippi River Delta are to: (1) reconnect Mississippi River resources (freshwater, sediment and nutrients) to the delta; (2) restore and sustain a healthy, diverse coastal ecosystem; (3) develop a long-term strategy for the management of the lower Mississippi River and the surrounding delta; and (4) balance multiple authorized uses of Mississippi River resources including navigation, flood risk reduction and ecological restoration.

Diversions are implemented within the Louisiana master coastal plan. It is necessary to know if these measures have only positive impacts or both positive and negative impacts for fish and fisheries. It was recommended to test the effects of planned restoration features with loosely coupled hydrodynamic, vegetation, and fish and shellfish models.

The research question identified here was: “How does a select combination of river diversions affect fish and shellfish in the receiving basins?” To address this question, Kim de Mutsert and colleagues developed and used an EwE model that accounts for the effects of environmental changes, fishing, and predator-prey interactions. This EwE model simulates changes in biomass (t.km-2) and catch (t.km-2.year-1) of fish and shellfish species over 50 years. It makes use of end-to-end model construction: the output of a Delft3D hydrodynamic model drives the fish and shellfish model. The functional groups represented in the EwE model are in most part the species that the Louisiana coastal plan required models to represent.

The Ecospace component of the EwE model uses a 1 km2 grid. Annual patterns of fishing effort are kept constant for the future in the model. The model uses spatial and temporal dynamic environmental drivers: values for these environmental drivers are defined per grid cell, per month for each decadal simulation. The model represents habitat features, which can be dynamic when habitat changes through time. The key outputs of the model are monthly estimated biomasses and catch projections for each km2 grid cell for every 50-year simulation. These estimates were used to determine if/where increases and/or decreases in biomasses and catches can be expected under selected diversion operation scenarios relative to a future without action.

The Ecospace component of the model uses the following drivers: (1) Delft3D environmental drivers (monthly salinity, temperature, and Chl a per Ecospace grid cell (1 km2), annual percent wetland per Ecospace grid cell); (2) OECLs or oyster environmental capacity layers (based on daily Delft3D output of salinity, temperature, and total suspended solids, later used to create capacity (suitability) per grid cell per month); and (3) an oyster cultch map. Response curves were defined, so as to be able to determine the effect of each of the drivers on individual species. The Ecospace component of the model makes use of Ecospace’s habitat capacity model to be able to simulate movements between model cells in response to changes in habitat capacity themselves due to changes in the value of environmental drivers.

Four diversion plans were analyzed with the model. Two flow regimes were considered: (1) diversions open all the time; and (2) a flood pulse flow regime (less aggressive).

The maps emerging under management action scenarios were compared to the maps emerging under the Future without action scenario. Diversions have a negative impact on juvenile menhaden. This is due to the fact that diversions decrease the quantity of plankton reaching some of the zones close to diversions. Moreover, diversions resulted in a decrease of the biomass of species that prefer higher salinities on a sub-basin level, and in an increase of the biomass of a few species that prefer lower salinities. The magnitude of change is dampened on a larger spatial scale, due to the spatial redistribution of species in response to the implementation of diversions. Emerging spatial patterns suggest that the two lower diversions are mostly responsible for the changes noticed.

A workshop participant said that the two models presented by Kim de Mutsert were designed for the northwestern GOM, and that it would be interesting in the future to develop an Ecospace model to explore the impacts of Mississippi River nutrient loading on the region east of the Mississippi River Delta, including Alabama waters. It was also mentioned that it would be good to develop an Ecospace model for the northwestern GOM addressing both the issue of nutrient loading/hypoxia and the issue of freshwater diversion.

***11:30 am - An ecosystem model to inform fisheries management on the West Florida Shelf, (David Chagaris)***

David Chagaris from the University of Florida presented the WFS Reef fish EwE model, which is an EwE model for the West Florida Shelf (WFS) ecosystem. Reference papers for WFS Reef fish EwE include Chagaris (2013) and Chagaris et al. (2015b).

WFS Reef fish EwE focusses on reef fish species. It represents 11 managed reef fish species, and five reef fish functional groups. Age stanzas are represented for some species to represent ontogenetic shifts in diet, habitat, and fishing pressure. WFS Reef fish EwE also represents pelagic groups (competitors and/or potential predators of reef fish) and coastal groups (forage fish, potential predators/competitors of reef fish juveniles). In total, 70 biomass pools are represented in the model: one dolphin, one seabird group, 43 fish groups (of which 11 are non-adult stanzas), 18 invertebrate groups, four primary producers, and three detritus groups. Fourteen “fleets” are represented in the model: four recreational fleets (shore, private boat, charter boat, headboat), and ten commercial fleets (bottom longline, handline, trawl, seines, offshore gill/trammel, fish trap, crab traps, cast nets, troll, pelagic longline). WFS Reef fish EwE was calibrated to time series from 1950-2009. David Chagaris is satisfied with the fits obtained. However, there are some discrepancies between the biomasses and catches predicted by WFS Reef fish EwE and the observed biomasses and catches, especially early in the time series.

WFS Reef fish EwE was used for policy simulations. The impacts of rebuilding gag grouper were explored. This policy was found to have a negative impact on vermilion snapper, black sea bass, and greater amberjack, and modest impacts on other species. WFS Reef fish EwE was also used to estimate natural mortality rates for gag grouper to inform SEDAR (SouthEast Data, Assessment, and Review). The model was also employed to evaluate the impacts of environmental uncertainties on projections and to conduct management strategy evaluation (MSE).

WFS Reef fish EwE was also used for policy optimization. In Ecosim, the productivities of fleets are linked through trophic interactions such that growth of some fleets could enhance or diminish productivity of others. Policy optimization was used to determine the best combination of fishing efforts to achieve particular goals. It searches for the fishing effort combination that maximizes a weighted multi-criteria objective function. The objectives considered in policy optimization are: (1) socio-economic objectives (profits and employment); (2) ecological structure objectives (e.g., reef fish biomass); and/or (3) mandated biomass objectives (rebuilding stocks such as the gag grouper stock). Policy optimization adopts the “multiple fishing rights” approach, where each fleet is its own economic entity and must remain profitable. When only the total economic value is targeted, policy optimization optimizes towards purse seines and shrimp trawls, and sees shrimp and sardines as species with high potential yield. When only reef fish conservation is targeted, fishing effort is reduced for all the fleets that catch reef fish or their prey, while fishing effort increases for the fleets that use a pelagic gear that catch reef fish competitors. When both maximum total profits and reef fish conservation are desired, trade-offs emerge. Then, the outcome of the policy optimization is a curve with convex shape that indicates that “balanced” policies exist where total profits and reef fish biomass are both high (50% increase in biomass, and 30-50% increase in profits). Ecopath’s 2009 (base) condition is suboptimal in both biomass and profits. Rebuilding plans move the WFS system closer to the curve. However, David Chagaris and colleagues found that the optimal policy is sensitive to assumptions about “market” prices. Optimal efforts in forage fisheries are lower when recreational value is higher. Charter boat and headboat fleets are not affected by assumptions about market prices. Finally, the fishing effort of commercial vertical line and longline fisheries was drastically reduced under all the scenarios explored.

Ecospace replicates Ecosim trophic-dynamics over a spatial grid. It represents dispersal, migration, and ontogenetic habitat shifts of biomass among model cells. Multistanza age cohorts are divided into large number of identical “packets” in Ecospace (i.e., an Individual Based Model is implemented for them). In Ecospace, fishing effort is distributed based on profitability of fishing in a given cell (biomass, market price, and sailing costs). Foraging area in each Ecospace cell is determined using the habitat capacity model that defines species relationships with habitat layers. The habitat layers in the WFS Reef fish Ecospace model include rugosity, sea surface temperature, chlorophyll a (Chl a), salinity and bottom temperature. The habitat capacity model determines the relative foraging size of each Ecospace cell (“capacity”) per group. Fish then move towards areas with more foraging habitat resulting in predicted spatial distribution patterns. Generalized Additive Model (GAM) fits were used to define relationships between habitat parameters and marine organisms. Species-habitat functions in WFS Reef fish Ecospace’s habitat capacity model are currently being refined as part of an ongoing project.

WFS Reef fish Ecospace was used to explore marine protected area (MPA) scenarios. The questions addressed with WFS Reef fish Ecospace were: “How large should MPAs be?” and “Are a few large MPAs better than many small MPAs?” These questions were addressed by evaluating the impacts of a bunch of randomly placed MPAs of various shapes, sizes, and locations. MPA placement was determined using point pattern (block) and simple random selection processes. Heavily fished groups (red snapper, vermillion snapper, gag, red grouper, and amberjacks) were found to benefit the most from closures. By contrast, MPAs had a negative impact on other shallow water groupers, goliath grouper and seabass due to an increase in the biomass of their predators and/or competitors. MPAs had little effect on pelagics. Block design was found to be more effective than random selection. Catch declined as more area was closed to fishing, and declined rapidly after about 30% of the WFS was closed to fishing. However, some MPAs resulted in higher catch or only modest losses in catch, due to spillover. Closing 15-30% of the WFS to fishing could be a viable option. Moreover, well-designed MPAs would be expected to outperform randomly placed MPAs.

WFS Reef fish Ecospace makes use of a feature recently developed for Ecospace called the “spatial-temporal framework”. Thanks to this feature, underlying habitat maps in Ecospace are updated on each time step. This feature enables linkages to hydrodynamic models, remote sensing datasets, and ocean-climate prediction models. It allows for more realistic predictions about spatial policy options. It also allows the predictions of impacts that are limited in space (oil spills, red tides).

The spatial-temporal framework allowed the estimation of red tide impacts on gag grouper with WFS Reef fish Ecospace. Monthly red tide maps (cells/liter) were produced from *in situ* cell concentration data and satellite imagery. These monthly red tide maps were overlapped with Ecospace species distribution maps and a logistic response function (proportion dead vs. cell concentration) was applied in each map cell to determine the natural mortality rate of gag grouper due to red tides in each month of each year. The red tide mortality of gag grouper in 2014 was estimated to range between 0.018 – 0.035, while 4-7% of the total mortality of gag grouper may have been caused by red tides in 2005 according to WFS Reef fish Ecospace.

The WFS Reef fish EwE model was recently updated to include lionfish. This was done so that WFS Reef fish EwE could evaluate the impacts of lionfish on native WFS reef fish, the effects of efforts to mitigate lionfish impacts through lionfish removals, and the effects of lionfish control through the management of native predators (e.g., groupers and snappers). David Chagaris initiated Ecopath with a negligible biomass for lionfish (year 2011), a total mortality rate Z equal to 2\*M, and fishing mortality equal to M of 0.66/year (where M is the natural mortality). In Ecosim, the fishing mortality (F) of lionfish was set to zero so the population grows according to M. Predation rate limits by lionfish was scaled to natural mortality of prey. David Chagaris simulated lionfish biomass over a range of Lionfish F and reef fish F values. He found that small increases in lionfish F, up to about 0.33/year (half M) have larger effect on biomass. Lionfish biomass is lower when F on reef fish is reduced. This implies that overfishing may have made the system more vulnerable to lionfish invasion. Lionfish prey underwent severe declines in biomass after a 30-year simulation. Effects were less severe on commercially and recreationally important reef fish, due to the removal of their competitors. Predicted effects were sensitive to predation rate limits.

Another Ecospace model focusing on lionfish invasion is currently being developed for the north-central GOM. The parameterization of this model is based on field studies. This Ecospace model will be used to examine the localized impacts of lionfish and the effects of lionfish removal efforts on insular reef communities.

Some reflections on model limitations and uncertainties: (1) EwE is not a stock assessment model, and cannot be used to determine stock status, estimate selectivity, or provide an overfishing limit (OFL) estimate; (2) EwE is not well-suited for tactical management advice (i.e. size limits, bag limits, etc.); (3) the environmental drivers implemented in Ecosim and Ecospace using forcing functions are difficult to define or measure empirically; (4) some components of the WFS and GOM food webs are poorly understood; (5) foraging arena parameters are difficult to estimate when time series are missing or lacking contrast; and (6) the habitat types considered in WFS Reef fish Ecospace are limited to those that can be mapped over large regions of the WFS.

David Chagaris identified the following data and research needs: (1) enhanced monitoring (better coverage of surveys, diet studies, habitat preferences and movement); (2) habitat mapping; (3) predator-prey functional response experiments; (4) environmental linkages to fish productivity and year class strength; (5) the continued development of ecosystem models in the GOM (EwE, Atlantis, and OSMOSE models) to benefit from multi-model approaches; and (6) the integrating of insights from ecosystem models into management (probably the biggest challenge).

***1:30 pm - Atlantis and ecosystem-based fisheries management in the Gulf of Mexico (Cameron Ainsworth)***

Cameron Ainsworth from the University of South Florida presented the Atlantis model of the Gulf of Mexico (GOM), which is called “Atlantis-GOM”. The reference paper of Atlantis-GOM is Ainsworth et al. (2015). Atlantis-GOM was primarily developed for: (1) evaluating the impacts of the *Deepwater Horizon* oil spill; (2) ecological indicator evaluation; and (3) conducting management strategy evaluation (MSE).

Atlantis is an end-to-end modeling platform, representing an entire ecosystem from bacteria to apex predators. It represents numerous ocean chemistry and physical processes, simulates the dynamics of age-structured vertebrate populations, simulates larval transport, represents biogenic and physical habitats, simulates nutrient and waste cycling, and accounts for fisheries. Atlantis employs polygons to represent important bioregional features. In Atlantis, trophic interactions are dependent upon: (1) a diet matrix, which defines the prey available to each predator; (2) gape limitation, which restricts predation mortality to the functional groups and age classes that belong to a certain body size range; (3) “clearance” parameters, which determine the efficiency of predation when prey abundance is low; and (4) distribution maps, migration rates and vertical distribution profiles, which dictate the allocation of functional group biomasses over space and, thus, determine patterns of spatial overlap between predators, prey and competitors in Atlantis.

The diet matrix of Atlantis-GOM was produced using a sophisticated probabilistic method. This statistical method bootstraps diet composition data, then fits a Dirichlet distribution using a maximum likelihood framework, and provides estimates of diet composition with error ranges.

Error ranges are usable in sensitivity analyses.

The distribution maps fed into Atlantis-GOM were produced from the predictions of generalized additive models (GAMs). These GAMs were fitted to survey data and considered environmental parameters available for the whole GOM large marine ecosystem (LME).

Larval connectivity (Lagrangian passive drift) is represented in Atlantis-GOM. Cameron Ainsworth and colleagues developed code that goes online to get hydrodynamic information, and then use a Lagrangian model to determine the larval trajectories of different species. From these larval trajectories, larval connectivity matrices can be produced and, afterwards, MPA scenarios can be tested. Currently, information on the vertical distribution of larvae is being compiled, which will be integrated in the larval dispersal framework later.

The oil spill did not have much impact on larval recruitment, based on an analysis conducted by Steve Murawski (University of South Florida), which overlayed the oil distribution with larval distributions from the SEAMAP ichthyoplankton survey. Growth and mortality were impacted according to an analysis evaluating red snapper otolith increments for growth and lesions as a proxy for mortality. Claire Paris (Rosenstiel School of Marine and Atmospheric Science, University of Miami) and colleagues developed an oil transport model to project the fate of the oil, which Atlantis-GOM uses. Atlantis-GOM estimated a recovery time from the *Deepwater Horizon* oil spill of 10-20 years for most species, given a perturbation in biomass consistent with field observations. Atlantis-GOM predicts that the *Deepwater Horizon* oil spill had a large impact on demersal fish and forage fish. The effects the *Deepwater Horizon* oil spill spread beyond the areas with oil. Oil caused starvation in groupers as seen in their condition factor. Oil also caused a shift in the age structure of some fish because juveniles were more affected by the oil spill; they are probably more vulnerable physiologically as well.

Atlantis-GOM was also used to evaluate all the indicators reported in the Ecosystem Status Report for the Gulf of Mexico (Karnauskas et al. 2013). Cameron Ainsworth and colleagues evaluated the sensitivity of each indicator to observation error and ranked them by their robustness to error. Many of the indicators were uncorrelated when fishing was low, but became correlated when fishing was high, because they all respond to fishing pressure. At low fishing rates, each indicator gives unique information. At high fishing pressure, it was possible to distinguish only four unique categories of indicators: (1) indicators of forage biomass; (2) indicators of forage quality (age structure); (3) indicators of exploited stock health; and (4) indicators of biodiversity.

An MSE was conducted with Atlantis-GOM to compare a grouper harvest control rule that adjusts fishing mortality F (a two-point harvest control rule) with a constant F strategy. It was found that the harvest control rule that adjusts F performs better. Grouper control rules allow the modeled system to adapt toward Pareto efficiency (efficient use of resources). The use of the harvest control rule resulted in higher grouper biomass and catch and higher biodiversity.

According to Cameron Ainsworth, a number of knowledge gaps remain. These knowledge gaps include larval dispersal patterns. It is still a little bit unclear how larval dispersal connects populations in the GOM. The diel vertical migration patterns of larvae are poorly understood. The spawning locations of many species remain unknown. There are still uncertainties about the influence of mesoscale ocean features on larval dispersal. Finally, the consequences of MPAs and oil spills for larvae are still unclear.

According to Cam Ainsworth, another knowledge gap is the critical habitats in the GOM and their mode of use. There is a real need for improved sediment maps for the GOM, and improved predictions of environmental conditions.

Moreover, there is a need to collect more diet data in the western GOM to improve the diet information fed into Atlantis-GOM; the diet data collected on the WFS may not be representative of all areas of the GOM. Also, the deep ocean is not well represented in Atlantis-GOM currently, and it is not currently known whether linkages between the deep ocean and the GOM shelf are important.

A workshop participant (Felicia Coleman) raised the point that changes in habitat quality caused by land use changes should be included in modeled year class strength. For example, for gag grouper, loss of seagrass habitat may reduce recruitment.

***2:00 pm - OSMOSE-WFS – An OSMOSE model for the West Florida Shelf (Arnaud Grüss)***

Arnaud Grüss from the Rosenstiel School of Marine and Atmospheric Science at the University of Miami, presented the OSMOSE model of the West Florida Shelf, which is called “OSMOSE-WFS”. The reference papers of OSMOSE-WFS are Grüss et al. (2015, 2016).

OSMOSE is a two-dimensional, individual-based, multispecies modeling platform, which relies on size-based interactions. OSMOSE models represent the entire life cycle of a number of high trophic level (HTL) groups of species, and are forced by the biomass of low trophic level (LTL) groups of species (plankton and LTL benthos groups). OSMOSE-WFS is an OSMOSE model for the West Florida Shelf (WFS), which aims to describe the trophic structure of the WFS ecosystem in the 2000s. OSMOSE-WFS has a monthly time step.

Currently, 12 HTL groups are explicitly considered in OSMOSE-WFS; they were selected based on their contribution to total biomass and economic value in the WFS in the 2000s, and/or because they are key to the WFS food web. Each HTL group is made of species that have similar life history traits, size ranges, diets and exploitation patterns. Some HTL groups are made of only one species, emblematic to the WFS and of high economic importance (e.g., red grouper, gag grouper).

Currently, OSMOSE-WFS is forced by the biomass of nine LTL groups that are important to the WFS food web. These LTL groups include two phytoplankton groups, whose biomass varies over space and from one month to the next. LTL groups also include two zooplankton groups and five benthos groups, whose biomass does not vary over space and from one month to the next.

The basic units of OSMOSE-WFS are schools, which consist of organisms that belong to the same HTL group, and that have the same length, age, food requirements and, at a given time step, the same spatial coordinates. Each school belongs to a given cohort (age group), which itself belongs to a given HTL group, which itself belongs to the HTL community. This hierarchical organization of model classes in OSMOSE-WFS allows for the assessment of output variables at different levels of aggregation with the model.

In OSMOSE-WFS, predation is opportunistic and depends on: (1) spatial co-occurrence between the predator and the potential prey, which is determined from distribution maps; (2) size adequacy between the predator and the potential prey, which is determined by means of minimum and maximum predator/prey size ratios; and (3) the accessibility of the potential prey to the predator, which depends on the vertical distribution and morphology of the prey (this being determined by means of accessibility coefficients fed into OSMOSE-WFS).

The succession of events for schools in OSMOSE-WFS is as follows. First, schools are distributed over space, using specific distribution maps. Then, mortalities (fishing mortality, predation mortality, starvation mortality and natural mortality due to causes other than predation and starvation) are applied to schools. Next, the growth of schools is determined based on their predation success. Finally, reproduction takes place.

The first version of OSMOSE-WFS was developed to inform stock assessments (SEDAR), more precisely SEDAR 33 that focused on gag grouper. The first version of OSMOSE-WFS was calibrated using a specific genetic algorithm. In the first version of OSMOSE-WFS, mortality rates are applied to schools using the “iterative mortality algorithm”; this algorithm allows one to apply all types of mortality simultaneously to HTL schools. Thus, the fishing mortality rates (F’s) provided in the output of OSMOSE-WFS are identical to the F’s provided to OSMOSE-WFS. To validate the first version of OSMOSE-WFS, the biomasses predicted by the model at steady state (after 114 to 134 years of simulation) were compared to observed biomasses. To further validate the first version of OSMOSE-WFS, the diets predicted by the model were compared to observed diets, the trophic levels (TLs) predicted by the model were compared to TLs in WFS Reef fish Ecopath, and the gag grouper natural mortality rates (M’s) predicted by OSMOSE-WFS were compared to gag grouper M’s in WFS Reef fish Ecopath. The first version of OSMOSE-WFS delivered estimates of M’s for size classes of gag grouper to SEDAR 33.

The second version of OSMOSE-WFS was developed to inform SEDAR 42 that focused on red grouper, as well as the Gulf of Mexico Fishery Management Council (GMFMC). The second version of OSMOSE-WFS was also calibrated using a specific genetic algorithm. In the second version of OSMOSE-WFS, mortality rates are applied to schools using the “stochastic mortality algorithm”; this algorithm allows one to apply all types of mortality simultaneously to HTL schools, and to make sure that the F’s provided in the output of OSMOSE-WFS are identical to the F’s provided to OSMOSE-WFS. To validate the second version of OSMOSE-WFS, the biomasses predicted by the model at steady state were compared to observed biomasses. To further validate the second version of OSMOSE-WFS, the diets predicted by the model were compared to observed diets, the TLs predicted by the model were compared to TLs in WFS Reef fish Ecopath, and the red grouper M’s predicted by OSMOSE-WFS were compared to red grouper M’s in WFS Reef fish Ecopath. The first version of OSMOSE-WFS delivered estimates of M’s for size classes and age classes of red grouper to SEDAR 42.

The second version of OSMOSE-WFS was also used to estimate a Maximum Sustainable Yield (MSY) and a fishing mortality rate at MSY (Fmsy) for red grouper using a new methodology. Then, OSMOSE-WFS was used to evaluate fishing scenarios for red grouper, consisting of setting the F of red grouper to ½\*Fmsy, Fmsy or 2\*Fmsy. It was noticed that OSMOSE-WFS predicts a very high predation of red grouper, gag and red snapper on their juvenile conspecifics/congeners (which may be too high).

The third version of OSMOSE-WFS was developed to inform the GMFMC. The third version of OSMOSE-WFS is identical to the second version of the model, except that a management strategy evaluation (MSE) framework was developed for the third version of the model, which allows for feedback between HTL groups and fisheries managers. This MSE framework was applied to red grouper to evaluate the impacts of fisheries management measures for red grouper in a context of episodic events of M (red tides, etc.). Three questions were addressed: (1) How does the value of the buffer between the overfishing limit (OFL) and the Acceptable Biological Catch (ABC) influence fisheries management performance for red grouper? (2) How do ABC strategies for red grouper perform in presence of episodic events of M? and (3) Is it worth updating the ABC of red grouper more frequently in a context of episodic events of M?

In the absence of episodic events of M, it was found that the lower the buffer between the OFL and the ABC, the lower the initial catch reduction when fisheries management measures are implemented, the larger the catch of red grouper, the higher the net present value (NPV) of discounted revenues from red grouper catch, and the higher the stability of red grouper catch. In other words, smaller buffers between the OFL and the ABC result in higher fisheries benefits. However, the larger the buffer between the OFL and the ABC, the larger the biomass of red grouper, and the larger the probability that red grouper is not being overfished. In other words, higher buffers between the OFL and the ABC result in higher conservation benefits. Thus, the choice of the value of the buffer between the OFL and the ABC imposes a trade-off between biomass-related and catch-related metrics for red grouper.

It was found that episodic events of M have negative effects on red grouper biomass and the probability that red grouper is not being overfished. They also have negative impacts on red grouper catch for different reasons, a negative impact on the NPV of discounted revenues from red grouper catch, but a positive impact on the stability of red grouper catch.

Finally, it was found that the frequency of ABC updates for red grouper in a context of episodic events of M has a non-significant impact on the performance of ABC strategies. In general, updating ABC more frequently in a context of episodic events of M leads to higher red grouper catch, higher NPV of discounted revenues from red grouper catch, and/or higher stability of red grouper catch. However, differences between ABC update scenarios were very small. Also, increasing the frequency of ABC updates in the real world would entail costs. It can therefore be concluded that it may not be worth increasing the frequency of ABC updates for red grouper in a context episodic events of M.

In the future, it would be good to introduce a few additional HTL and LTL groups in OSMOSE-WFS to increase the number of potential prey for the different predators and, therefore, reduce the predation mortality of juveniles in OSMOSE-WFS. Such modifications in OSMOSE-WFS would greatly improve the realism of the model.

Also, in the future, it would be great to improve OSMOSE MSE framework through the addition of an assessment model (e.g., a Stock Synthesis model) and an implementation model simulating fishers’ behavior to the framework, so as to more accurately simulate human components of the WFS ecosystem in OSMOSE-WFS.

Next, it would be good to improve the fields of LTL biomass fed into OSMOSE-WFS, because, currently, the fields of LTL biomass fed into OSMOSE-WFS allow for very limited spatio-temporal variability of LTL biomass. It is planned to feed OSMOSE-WFS with fields of plankton biomasses produced by Naval Research Laboratory’s “Adaptive Ecosystem Climatology” through the blending of ocean observations (satellite and *in situ*) and outputs from a biogeochemical model.

Finally, it would be good to represent abiotic environmental influences on the biological rates of HTL groups in OSMOSE-WFS. This change would be welcome, since it is planned to develop an OSMOSE model for northwestern GOM in the near future, in order to evaluate the impacts of fisheries management measures in the northwestern GOM in the face of hypoxia, nutrient loading, and freshwater diversion.

## 2.3. Thursday August, 4th 2016

***8:30 am - Ecosystem models of the Gulf of Mexico: Future needs to address ecosystem-based fisheries management and restoration activities (Arnaud Grüss)***

A review of ecosystem modeling efforts in the Gulf of Mexico (GOM) was conducted. This review revealed that a diversity of ecosystem models has been developed for the U.S. GOM and GOM large marine ecosystem (LME) between 1983 and the present. All the ecosystem models that have been developed have greatly advanced our understanding of the different GOM ecosystems, and these models have tackled a number of EBFM and restoration issues. However, the review of ecosystem modeling efforts in the GOM revealed that improvements are needed in ecosystem models of the GOM, so they are better suited for influencing and strengthening EBFM and restoration activities.

More ecosystem models were designed for some regions of the GOM such as the West Florida Shelf than for other regions of the GOM such as the northwestern GOM. However, regions like the northwestern GOM are facing critical EBFM and restoration issues (e.g., freshwater diversion). Also, until now, ecosystem models of GOM have paid less attention to restoration issues (e.g., management of nutrient loading, freshwater diversion) than to EBFM issues (e.g., bycatch reduction measures, marine protected areas (MPAs)).

Therefore, there is a need to enhance existing ecosystem models of the GOM, so that they can deliver more and better insights to EBFM and restoration programs and projects of the GOM. Moreover, the creation of new ecosystem models for the GOM may be beneficial to EBFM efforts and restoration programs and projects of the GOM.

Regarding conceptual and qualitative models - Conceptual models such as the EBM-DPSER model of Kelble et al. (2013) and loop analysis could be used to support any EBFM or restoration project, because: (1) these models are useful for illustrating our understanding of ecosystem components and processes; and (2) they represent a useful first step towards the development of (a) quantitative ecosystem model(s).

Regarding extensions of single-species models - Extensions of single-species models include extensions of single-species assessment models (ESAMs) and extensions of single-species individual-based models (ESIBMs). ESAMs have been used within seven stock assessment processes in the U.S. GOM so far. They could be used within the assessment process of many more species of the U.S. GOM in the future, with the aim to improve the accuracy of stock assessment outcomes. However, in parallel, it would be necessary to conduct comprehensive simulation analyses to determine: (1) for which species of the U.S. GOM ecosystem considerations are necessary; (2) how best to accommodate ecosystem considerations when modeling stock dynamics; (3) the cost of including an ecosystem process in an assessment model when it is not important or does not exist in reality; and (4) the cost of omitting an ecosystem process from an assessment model when it is important in the real world.

ESIBMs can yield insights useful to single-species assessments. Existing ESIBMs of the GOM could be expanded to include more processes; this could increase their utility. Creekmore (2011)'s ESIBM should be applied to species other than Atlantic croaker to inform fisheries management in the northwestern GOM in a context of hypoxia (e.g., brown shrimp).

Models of Intermediate Complexity for Ecosystem assessment or MICEs are the only type of dynamic multispecies models currently used in the GOM. The ALFISH model for the Everglades should represent other functional groups (particularly wading birds) to be able to better inform the Central and South Florida Comprehensive Project Review Study. Sable and Rose (in review)’s MICE, which was developed for evaluating the impacts of marsh degradation and hypoxia in the northern GOM, could represent more species/functional groups and be employed to evaluate management scenarios.

The category of aggregated models includes EwE models. Importantly, the diet matrix of existing Ecopath models should be revisited using recently developed probabilistic approaches to represent more accurate trophic interactions and lend more confidence into Ecopath predictions. Lionfish invasion is an important concern in the GOM. For this reason, it would be a good idea to introduce a lionfish functional group in a number of existing EwE models and to run simulations with these models to deliver information to efforts aiming to mitigate lionfish invasion in GOM ecosystems.

A few additional EwE models could be developed for the GOM. A new Ecospace model could be designed for the Mississippi coastal zone, so as to have an ecosystem model for Mississippi that can address the issues of estuarine MPAs and marsh restoration. A new Ecospace model could be constructed for the Texas coastal zone to address a number of issues, including marsh and oyster reef restoration, efforts to mitigate hypoxia, the management of nutrient loads, and artificial reefs. Finally, a comprehensive Ecospace model could be developed for the northwestern GOM to address the following issues: marsh and oyster reef restoration, efforts to mitigate hypoxia, the management of nutrient loads, and freshwater diversion.

New Ecospace models of the GOM should employ the methodology developed by Lewis et al. (2016) which makes use of Ecospace’s habitat capacity model to simulate changes in the physical habitat. For example; the new Ecospace model of the Texas coastal zone could use Lewis et al. (2016)’s methodology to consider the presence of artificial reefs/proportion of artificial reefs in each Ecospace cell and examine the effects of artificial reefs in Texas waters. The comprehensive Ecospace model for the northwestern GOM could use Lewis et al. (2016)’s methodology to simulate changes in the structure and surface area of essential habitats of the northwestern GOM through time.

Comprehensive Aquatic System Model (CASM) is another type of aggregated models. Currently, only one CASM is available in the GOM; this model focuses on the Mississippi River Delta. However, the issue of the management of water quality and quantity is also important in Alabama and northwestern Florida. Therefore, it would be advantageous to design a CASM for the coastal areas of Alabama and northwestern Florida, which could be used to guide management efforts related to water quality and quantity in the northeastern GOM; oysters and seagrass would be key components of such a model.

Currently, the only biogeochemical-based end-to-end model in the GOM is the Atlantis model for the entire GOM LME, which is called “Atlantis-GOM”. Atlantis-GOM has the ability to address many EBFM and restoration issues of the GOM (post-oil spill restoration, MPAs, and bycatch reduction measures) and to conduct management strategy evaluation (MSE) integrating ecosystem considerations. The diet matrix of this model and the relationships between the presence of oil/oil concentrations and marine organisms defined in this model are currently being revisited, based on the outcomes of recently funded restoration projects. A lionfish functional group could be added to the Atlantis-GOM model, so as to be able to run simulations with Atlantis-GOM that could inform efforts to mitigate lionfish invasion in the GOM.

The GOM LME encompasses many ecosystems that differ greatly in terms of the fish communities they support and the stressors they face. For this reason, it would make sense to design Atlantis models for specific regions of the GOM. In particular, it would be a good idea to develop an Atlantis model for the northwestern GOM, which would complement the comprehensive Ecospace model of the northwestern GOM. Such a model could be used to inform management efforts in a context of severe hypoxia as well as to assess the broad consequences of freshwater diversion and habitat restoration in the northwestern GOM.

NEMUROMS.FISH is another type of biogeochemical-based end-to-end modeling platform. NEMUROMS.FISH is a three-dimensional biogeochemical end-to-end modeling approach, which consists of four coupled submodels: a hydrodynamic submodel, a biogeochemical submodel, an individual-based fish submodel, and an agent-based fishing fleet submodel; these submodels are all coded within the ROMS (regional ocean modeling system) model. A NEMUROMS.FISH model is currently being developed for the northern GOM; this model will primarily focus on Gulf menhaden and will evaluate alternative management strategies for the species under an ecosystem perspective.

The OSMOSE-WFS model, which is an OSMOSE model for the West Florida Shelf ecosystem, is currently the only coupled and hybrid model platform in the GOM. The most pressing improvement in OSMOSE-WFS will be the addition of an assessment model (e.g., a Stock Synthesis model) and an implementation model simulating fishers’ behavior to the OSMOSE MSE framework, which will allow OSMOSE-WFS to more accurately simulate human components of the WFS ecosystem. Once this improvement has been made, a multi-model MSE could be conducted, using OSMOSE-WFS, Atlantis-GOM and the WFS Reef fish Ecospace model, which would allow us to better evaluate uncertainties around the potential impacts of management measures implemented in the WFS.

It would be advantageous to develop an OSMOSE model for the northwestern GOM, complementing the Ecospace and Atlantis models of the northwestern GOM, for evaluating the impacts of fisheries management measures in the northwestern GOM in the face of hypoxia, as well as the consequences of freshwater diversion projects in the northwestern GOM. The development of an OSMOSE model for the northwestern GOM would entail developing new capabilities in OSMOSE to be able to force OSMOSE with abiotic environmental fields and relate the biological rates of HTL groups to changes in environmental parameters.

Size spectrum models are another type of coupled and hybrid model platforms. Size spectrum models are non-spatial, dynamic models simulating the whole life cycle of functional groups and forced by the biomass of other groups (which only serve as food), where predation is a size-based process. It would be interesting to develop a size spectrum model for the northern GOM to reexamine the potential impacts of measures aiming to reduce bycatch in shrimp fisheries.

InVitro is another type of coupled and hybrid model platforms. InVitro is a highly sophisticated three-dimensional, dynamic, individual-based modeling approach, with a very small time step (typically seconds), whose numerous components are all “agents”. These agents include fish and crustaceans, sea turtles, benthic communities, seagrass meadows, mangroves, fisheries, shipping, oil and gas production, coastal development, port maintenance, recreational activities, and storms/cyclones, among many others. Developing an InVitro model for the northern GOM would allow one to evaluate a large number of EBFM and restoration issues with the same model, including the mitigation of oil spill effects and post-oil spill restoration, sustainable coastal development, storm protection, and habitat restoration.

Best practices for future ecosystem modeling efforts in the GOM include: (1) improving the diet matrix of ecosystem models where diet composition is the primary driver of trophic interactions; (2) enhancing the calibration and validation processes of ecosystem models and examining ecosystem model behavior in more detail; (3) allowing empiricists, resource managers and other stakeholders to properly understand and review the strengths and limitations of ecosystem models and to contribute to these models; and fostering capacity building and the maintenance of ecosystem models.

Firstly, the diet matrix of EwE, CASM and Atlantis models of the GOM should be constructed or reconstructed using probabilistic approaches. This would: (1) prevent predation events that are very rare in the real world from happening too often in ecosystem models; and (2) increase the complexity and connectivity of ecosystem models of the GOM and, therefore provide a more realistic representation of ecosystem resilience in these models.

Secondly, there is a need to enhance the calibration and validation processes of ecosystem models of the GOM and to examine ecosystem model behavior in more detail. Ecosystem model calibration using empirical data should become a standard procedure in the GOM. Then, ecosystem models aiming to inform fisheries management should be calibrated to historical time series and demonstrate they can adequately replicate historic trends, so as to lend more confidence to their predictions. Also, diagnostics such as the PREBAL diagnostics of Link (2010) should become standard procedures for ecosystem models such as EwE, CASM and Atlantis models, while individual-based models such as OSMOSE and InVitro applications should be assessed using pattern-oriented modeling approach. Finally, the behavior of ecosystem models should be well understood before these models are used to explore management scenarios. Comprehensive sensitivity analyses should be conducted with ecosystem models of the GOM, and these models should be submitted to “extreme” scenarios (e.g., the species/functional groups represented in these models should be exposed to extremely high fishing and/or extreme abiotic environmental pressures).

Thirdly, there is a need for strong multidisciplinary teams in the GOM; the creation of such teams would ensure that the inputs provided to ecosystem models rely on the best available information. Also, long-term exchanges between ecosystem modelers and managers and other stakeholders should take place. These long-term exchanges should start with the construction of conceptual and qualitative models to make sure that all the important resources, processes and stressors of the ecosystem of interest are captured in the ecosystem models to be created.

Lastly, there is a need to foster capacity building in the GOM and the maintenance of ecosystem models. Aggregated models, biogeochemical-based end-to-end models and coupled and hybrid model platforms are all highly complex models, involve many assumptions, concepts and large computational costs, and they require years of experience to be fully appreciated. Therefore, more scientists in the GOM should be trained in the use of modeling platforms such as EwE and Atlantis to foster the effective development and utilization of applications of these platforms for addressing EBFM and restoration needs of the GOM. Furthermore, ecosystem models must be viewed as iterative and adaptive tools, which need to be updated as new information and data become available.

All ecosystem models have their qualities and their flaws, and there is no “best” ecosystem model, even to address a particular research issue. The multi-model approach deals with the issue of the conceptual, structural and predictive uncertainties of ecosystem models. The multi-model approach should be more widely used in the GOM. If several ecosystem models, despite their different structure and assumptions, provide consistent and converging results, then one will have more faith in their predictions and in supporting specific management measures.

The present workshop focuses on the U.S. GOM and GOM LME, for practical reasons. However, it would be advantageous to expand our review of ecosystem modeling efforts to the Mexican and Cuban GOM. In particular, improving and using Vidal and Pauly (2004)’s Ecospace model to guide management efforts in the GOM LME would be a nice project.

Finally, the present workshop focuses on EBFM. However, there is a large number of sectors of activities in the GOM whose management could be informed by ecosystem models. Therefore, in the future, it would be advantageous to determine how we could best align ecosystem modeling efforts in the GOM with ecosystem-based management (EBM) needs in the region.

# 3. Recommendations

Recommendations can be grouped into four categories: (1) streamlining the use of ecosystem models in the GOM; (2) best practices for ecosystem modeling; (3) future needs; and (4) priority questions to address with ecosystem models in the GOM.

***Streamlining the use of ecosystem models in the GOM***

1. Make more use of conceptual and qualitative models in the GOM.

a. To illustrate how the structure and functioning of marine ecosystems are understood.

b. Necessary first step towards the development of (a) quantitative ecosystem model(s).

2. Restrict the investigation of tactical questions to simple ecosystem models, such as extensions of single-species assessment models (ESAMs), at least for now.

a. Stakeholders need to get precise answers that more complex ecosystem models usually cannot provide. For example, one of the main concerns of fishers who are being managed by an input-controlled system (i.e., recreational fishers and a small portion of commercial fishers) is the number of days that they will be allowed to spend at sea, which cannot be determined by more complex ecosystem models, whose insights are generally restricted to target fishing efforts or target fishing mortality levels.

3. Use more complex ecosystem models, such as aggregated models (e.g., Ecopath with Ecosim (EwE)) and biogeochemical-based end-to-end models (e.g., Atlantis), to investigate a number of strategic questions.

a. More complex ecosystem models are invaluable for studying issues that simple ecosystem models cannot (fully) address, such as predator-prey dynamics, the drivers of stock productivity over time, and regime shifts.

b. More complex ecosystem models provide a basis for avoiding (or at least anticipating) surprises and the unintended consequences of management actions (e.g., by providing insights into the responses of species not targeted by management efforts to alternative management actions).

c. They can make trade-offs explicit.

4. Use more complex ecosystem models to complement conventional fisheries research tools (e.g., single-species assessment models), not replace them.

a. Ecosystem modeling should be viewed as an evolution, rather than as a revolution.

b. Some carefully chosen outcomes of more complex ecosystem models can be used to reduce uncertainty in single-species assessments. For example, some ecosystem models have the ability to provide insights into the potential impacts of rebuilding plans under different ecosystem conditions (i.e., under different futures).

c. Some of the estimates of more complex ecosystem models could also be used for the parameterization of ESAMs (e.g., estimates of age- and time-varying natural mortality rates).

d. At the very least, more complex ecosystem models can provide valuable information to the ecosystem section of stock assessment reports.

5. Use more complex ecosystem models also as a means to address data gaps.

a. The prioritization of data collection can be informed by more complex ecosystem models.

b. The parameter values estimated during the mass balance process of Ecopath models could be shared with other ecosystem models that are missing these parameter values.

6. Conduct management strategy evaluation (MSE) using ecosystem models

a. MSE is increasingly being used worldwide for its ability to evaluate the performance of management actions while considering all the components of the fisheries system (biological subsystem, monitoring, assessment, management, and implementation) and the different sources of uncertainty.

b. To address tactical questions, MSE should preferably be conducted using ESAMs.

i. These ESAMs should be parameterized in such a way that they can address the different concerns raised by stakeholders during meetings predating modeling efforts (e.g., determine the number of days that fishers who are being managed by an input-controlled system could spend at sea to target a given species).

ii. Some of the parameters of these ESAMs could be estimated by more complex ecosystem models.

c. To address strategic questions, more complex ecosystem models should be used.

i. MSE using more complex ecosystem models would be useful not only for exploring the performance of management and restoration actions, but also for evaluating the relevancy of collecting new data (e.g., would programs collecting information on fish juveniles significantly benefit fisheries management?).

***Best practices for ecosystem modeling***

1. Identify the most critical research and management questions to address.

a. Ecosystem models of the GOM should pay more attention to restoration issues, which are numerous and need to be addressed rapidly.

b. The top five EBFM issues in the GOM should be identified and those should be the EBFM issues on which ecosystem models of the GOM should focus during the coming years.

c. Ecosystem modelers should establish direct connections with management agencies in order to work into the management cycles and provide timely advice for upcoming actions.

d. While input from managers here is important, it is critical that fishers’s input be collected. Model results lose value when managers cannot do anything with them and when fishers do not see them as addressing a timely and relevant fishery issue.

2. Enhance the calibration and validation processes of ecosystem models.

a. Calibrate ecosystem models using the best available empirical data to have confidence in their predictions.

b. Thorough validation processes for ecosystem models of the GOM would lend more confidence to their predictions.

3. Conduct sensitivity and uncertainty analyses with ecosystem models.

a. Sensitivity analyses consist in varying selected input parameters by a small margin to ensure that small changes in the value of input parameters do not result in large changes in the value of output variables. Sensitivity analyses allow one to determine whether the ecosystem model under consideration is robust.

b. In uncertainty analysis, some small margin is replaced with the variance in those input parameters or other factors that are uncertain (different climate change scenarios for example), then the variation in output allows one to quantify uncertainty.

4. Increase the transparency of ecosystem models.

a. Allow stock assessment scientists, empiricists and stakeholders to properly understand ecosystem models, and to be well aware of the strengths and limitations of these models.

b. Encourage stock assessment scientists, empiricists and stakeholders to review ecosystem models.

c. There is a need for increased transparency regarding the economic implications and legal requirements of ecosystem models.

d. Develop ecosystem model libraries that not only scientist, but also managers, could consult.

e. Develop a more rigorous peer review process for ecosystem models, which would clearly identify the features of ecosystem models that should be scrutinized in priority.

5. Improve communication between ecosystem modelers, and stock assessment scientists, empiricists, managers, fishers and other stakeholders of the GOM.

a. Ecosystem modelers should meet with managers and fishers early in the process, so as to make sure that the questions tackled by ecosystem models are management-driven.

b. To increase the exposure of their work, ecosystem modelers should attend the Gulf of Mexico Fishery Management Council (GMFMC)’s Scientific and Statistical Committees (SSC) meetings and GMFMC meetings more often and present their work during these meetings.

c. MSE using ecosystem models should involve strong collaborative efforts between ecosystem modelers and the GMFMC. Such collaborative efforts would ensure that the interests of all stakeholders are considered within the MSE process, and that objectives and performance metrics are appropriately defined.

d. The use of conceptual and qualitative models (e.g., conceptual diagrams, loop analysis) and the creation of dedicated user-friendly webpages would greatly facilitate the communication of ecosystem modeling efforts.

e. It is important to organize meetings and workshops on a regular basis in the GOM to make sure that: (i) ecosystem modelers are fully aware of the EBFM and restoration issues that need to be most critically addressed; and (ii) insights from ecosystem models into the potential impacts of EBFM and restoration actions are well communicated to managers, fishers and other stakeholders.

6. Document ecosystem modeling efforts

a. The history of ecosystem models should be properly documented. In particular, the choices made regarding parameter values should be reported.

b. There is a need to compile a comprehensive inventory of the assumptions, parameters, relationships, and datasets used by ecosystem models, so that the different ecosystem models of the GOM can leverage each other.

c. The uncertainties around ecosystem modeling predictions should be properly documented.

7. Maintain existing ecosystem models.

a. Ecosystem models should be regularly updated as new data become available.

8. Improve existing ecosystem models or developing new ecosystem models only to address management needs.

a. The improvements made in existing ecosystem models should be guided only by the management questions that models should address.

b. New ecosystem models should be designed for the GOM only if no existing ecosystem model can address specific research/management questions.

***Future needs***

1. Explicitly consider non-fishing drivers in ecosystem models of the GOM.

a. This is critical, since ecosystem models should pay much more attention to restoration issues during the coming years.

b. Habitats and changes in the structure and surface area of habitats through time should be better represented in ecosystem models of the GOM.

c. Freshwater and brackish systems should also be represented in some ecosystem models of the GOM to tackle some pressing issues such as freshwater and sediment diversion.

d. Submerged aquatic vegetation (SAV) should be better represented in ecosystem models of the GOM, given the current push for restoring wetland and seagrass habitats of the GOM.

e. Artificial reefs are gaining more and more interest in the GOM, especially at the GMFMC; they should therefore get more attention in ecosystem models of the GOM.

f. Red tide is a key environmental event in the GOM that should be explicitly considered in more ecosystem models of the GOM during the coming years.

g. Hypoxia and oil spill are two other stressors that raise a lot of concerns in the GOM currently and that should receive increased attention in ecosystem models during the coming years.

h. Many ecosystem models of the GOM should be coupled to physical and biogeochemical models to offer a more realistic representation of the influence of the abiotic environment on species dynamics.

2. Use ecosystem models to investigate the consequences of climate change and ocean acidification.

a. Particularly relevant given the Fisheries Climate Science Strategy recently released by NOAA.

3. Give more attention to forage fish in ecosystem models of the GOM.

a. These fish are the backbone of the GOM ecosystems, especially menhaden. Their role in the GOM ecosystems and the impacts of fishing scenarios for them should receive more attention in the future.

b. Competition between forage fish predators and fisheries is a topic that should be tackled by ecosystem models during the coming years.

4. Make use of ecosystem models to establish multispecies reference points.

a. Multispecies reference points are particularly needed for the management of “complexes” (e.g., the snapper-grouper complex).

5. Evaluate the cumulative impacts of stressors and management/restoration measures with ecosystem models.

a. This need is supported by the results of the NGOMEX Ecospace model that studied the cumulative impacts of nutrient loading (which fuels primary production) and hypoxia in the northwestern GOM.

b. It is critical to examine both the positive and negative impacts of freshwater and sediment diversion projects.

c. Ecosystem models should also evaluate the impacts of implementing several rebuilding plans at the same time.

6. Conduct retrospective analyses.

a. The lessons we will learn from the performance of past management measures and from the consequences of past environmental disasters will be useful to prepare for the future.

7. Introduce socio-economic considerations in ecosystem models of the GOM.

a. Even the best-laid models will lack real-world applicability without analysis of socio-economic drivers and tradeoffs.

b. Economic considerations are different for purely recreational, charter, and commercial fishing sectors and should therefore be treated separately in ecosystem models.

b. Fishing effort in many ecosystem models of the GOM should be driven by socio-economic drivers.

c. Fishing fleet dynamics and fishers’ behavior should be represented in ecosystem models of the GOM whenever applicable.

d. The science of non-market valuation should also be incorporated in ecosystem models of the GOM whenever applicable.

***Priority questions to address with ecosystem models in the GOM***

1. Restoration

a. It is time for ecosystem models to pay much more attention to restoration in the GOM. Many current and planned restoration projects of the GOM could be informed by quantitative ecosystem models.

b. Restoration is a “low-hanging fruit” for ecosystem modelers. The uptake of ecosystem modeling results is faster in the restoration world than in the fisheries management world; the uptake of ecosystem research by the GMFMC and other fisheries management agencies is going to be slow.

2. Lionfish invasion

a. The uptake of ecosystem modeling efforts focusing on the mitigation of lionfish invasion should be rapid, given that everyone in the GOM is concerned about lionfish invasion and wants lionfish to be removed from GOM waters.

3. Recruitment of juvenile gag grouper in seagrass habitats

a. Ecosystem modelers should quantify the impacts of seagrass restoration efforts for juvenile gag grouper, because it will be easier to restore the seagrass habitats than to manage the spawning stock of gag grouper to improve gag grouper recruitment.

4. Environmental influences on gray triggerfish recruitment

a. This is also a “low-hanging fruit” for ecosystem models; managers and fishers want to know the environmental drivers of gray triggerfish recruitment.

5. Impacts of artificial reefs

a. Both the GMFMC and fishers want to clearly understand the relationship between artificial reefs and stock productivity.

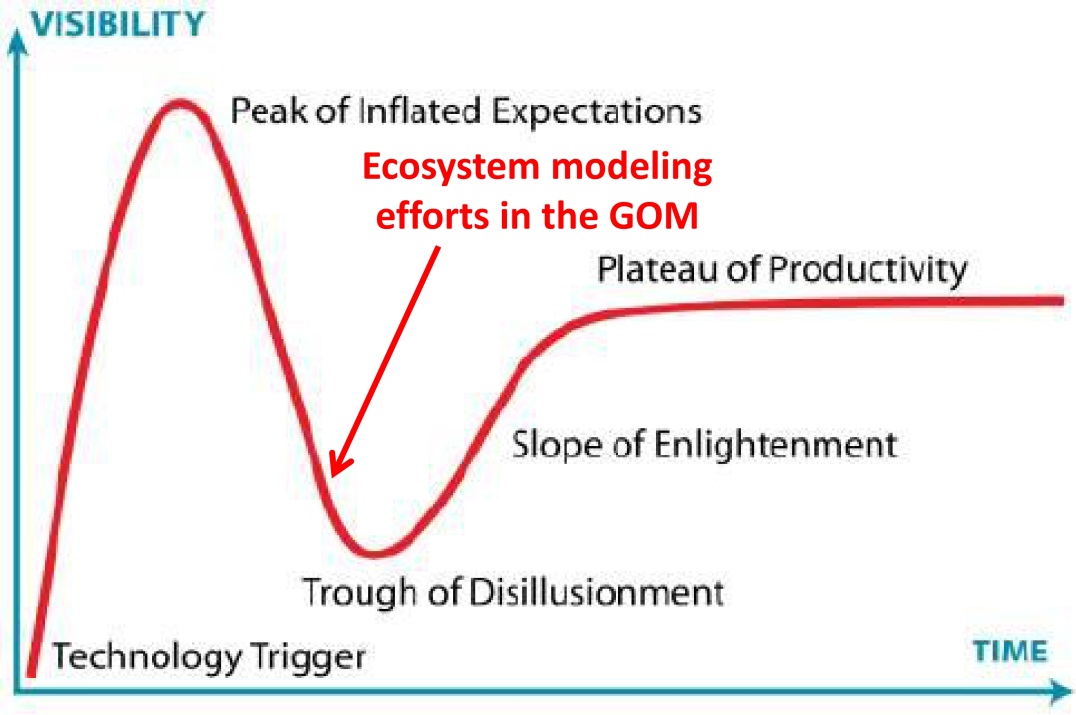
6. Impacts of MPAs

a. The GMFMC also wants to clearly understand the relationship between MPAs and the production of managed stocks.

# 4. Discussion

The workshop offered a good background on ecosystem models to workshop participants. One of the key outcomes of the event was that, so far, ecosystem models have paid much more attention to evaluating the structure and functioning of GOM ecosystem and to tackling EBFM questions than to addressing restoration issues. However, the uptake of ecosystem research by fisheries managers is going to be slow, because EBFM is in a pretty immature state in the GOM currently. Meanwhile, many restoration projects are ongoing or planned in the GOM, and all these projects would benefit from being informed by ecosystem models. According to workshop participants, ecosystem models are more immediately applicable and determinative for restoration issues than for EBFM issues. In other words, restoration activities are the “low-hanging fruits” of ecosystem modelers of the GOM.

Kenny Rose asked the workshop participants to position ecosystem modeling efforts in the GOM on “The Hype Cycle” of American IT firm Gartner. The great majority of workshop attendees considered that ecosystem modeling efforts in the GOM are located somewhere between the “peak of inflated expectations” and the “trough of disillusionment” (Figure 2). Focusing ecosystem modeling efforts on restoration issues during the coming years should move ecosystem models of the GOM to the “slope of enlightenment”.



**Figure 2.** Positioning ecosystem modeling efforts in the Gulf of Mexico (GOM) on “The Hype Cycle” of American IT firm Gartner (red arrow).

Workshops between ecosystem modelers, managers, fishers and other stakeholders should be continued in the future. These workshops should take place on a regular basis (e.g., every two years), so as to ensure the effective uptake of ecosystem modeling research by the resource management community. Managers involved in restoration activities such as freshwater and sediment diversion projects should be invited to future workshops. Empiricists, stock assessment scientists and researchers working with physical and biogeochemical models (which can be coupled to ecosystem models) should be invited to future workshops as well. The next workshop between ecosystem modelers, managers and other stakeholders should focus either on ecosystem modeling efforts for informing restoration activities or on a specific management case study. Most of the organizers of the workshop prefer the former option. A workshop focusing on a specific management case study could offer live ecosystem modeling demonstrations.

Recommended best practices for future workshops include:

1. Increase participation from managers, fishers and other stakeholders.

a. Allow the managers, fishers and other stakeholders to give more presentations at the workshops.

b. Fewer presentations overall and allow more time for small group and plenary discussions and questions/discussions at the end of the workshops.

2. Use conceptual models and other simple tools during the workshops to elicit discussions.

3. Send questionnaires to workshop participants before the workshops to be able to determine the priority questions to address during the workshops.

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# Appendix A – Agenda

***Tuesday August, 2nd 2016: Overview of ecosystem-based fisheries management and restoration needs and efforts in the Gulf of Mexico***

● 2:00 pm – 2:15 pm: Introduction: what this workshop is about, overview of the agenda, administrative announcements, introduction of attendees (Jim Simons)

● 2:15 pm – 2:30 pm: Explanation of how the workshop will be run, and expected outcomes in the short and long terms (Kenneth Rose)

● 2:30 pm – 3:00 pm: Overview of NOAA’s RESTORE Act Science Program (Becky Allee)

● 3:00 pm – 3:30 pm: Federal fisheries management in the Gulf of Mexico (John Froeschke)

● 3:30 pm – 3:45 pm: Break

● 3:45 pm – 4:05 pm: Overview of stressors and basics of restoration in the Gulf of Mexico (Halie O’Farrell)

● 4:05 pm – 4:30 pm: Ecosystem-based management in the Gulf of Mexico (Elizabeth Babcock)

● 4:30 pm – 5:00 pm: Gulf of Mexico Restoration: An unparalleled testbed for ecosystem-based fisheries management (Bonnie Ponwith)

● 5:00 pm – 5:30 pm: Overview of Lenfest Task Force (Felicia Coleman)

***Wednesday August, 3rd 2016: Ecosystem modeling in the Gulf of Mexico (1)***

● 8:30 am – 9:30 am: A multi-model approach to understanding the role of Pacific sardine in the California Current ecosystem (Isaac Kaplan)

● 9:30 am – 10:30 am: Overview of ecosystem modeling approaches and ecosystem modeling efforts to tackle ecosystem-based fisheries management and restoration issues in the Gulf of Mexico (Halie O’Farrell)

● 10:30 am – 10:45 am: Break

● 10:45 am – 12:00 pm: Short presentations about a few representative ecosystem models of the GOM, how these models have been used to tackle ecosystem-based fisheries management and restoration issues, and their main current limitations (1)

\* 10:45 am – 11:30 am: Exploring effects of hypoxia on fish and fisheries in the Northern Gulf of Mexico using a dynamic spatially-explicit ecosystem model (Kim de Mutsert)

\* 11:30 am – 12:00 pm: An ecosystem model to inform fisheries management on the West Florida Shelf (David Chagaris)

● 12:00 pm – 1:30 pm: Lunch break

● 1:30 pm – 2:30 pm: Short presentations about a few representative ecosystem models of the GOM, how these models have been used to tackle ecosystem-based fisheries management and restoration issues, and their main current limitations (2)

\* 1:30 pm – 2:00 pm: Atlantis and ecosystem-based fisheries management in the Gulf of Mexico (Cameron Ainsworth)

\* 2:00 pm – 2:30 pm: OSMOSE-WFS – An OSMOSE model for the West Florida Shelf (Arnaud Grüss)

● 2:30 pm – 3:30 pm: Small-group discussions about the modifications needed on existing ecosystem models of the Gulf of Mexico to address ecosystem-based fisheries management and restoration needs in the Gulf of Mexico

● 3:30 pm – 4:30 pm: Plenary discussion: A representative of each small group provides a debrief; then the key points of small-group discussions are written down

● 5:30 pm – 8:30 pm: Social event at Roys – 4342 W Boy Scout Blvd

***Thursday August, 4th 2016: Ecosystem modeling in the Gulf of Mexico (2)***

● 8:30 am – 9:15 am: Ecosystem models of the Gulf of Mexico: Future needs to address ecosystem-based fisheries management and restoration activities (Arnaud Grüss)

● 9:15 am – 10:15 am: Small-group discussions about new ecosystem models that could be designed to fully address ecosystem-based fisheries management and restoration needs in the Gulf of Mexico (small groups need to address 2-3 questions)

● 10:15 am – 10:30 am: Break

● 10:30 am – 11:30 am: Plenary discussion: A representative of each small group provides a debrief; then the key points of small-group discussions are written down

● 11:30 am – 12:15 am: Final plenary discussion to wrap up the workshop

● 12:15 am – 12:30 pm: Concluding words (Kenneth Rose)

# Appendix B – Participant list

|  |  |  |  |
| --- | --- | --- | --- |
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# Appendix C - Abstracts of presentations (provided by presenters)

## Tuesday August, 2nd 2016

***2:30 pm -*** ***Overview of NOAA’s RESTORE Act Science Program (Becky Allee)***

The mission of the National Oceanic and Atmospheric Administration’s (NOAA’s) RESTORE Act Science Program is to carry out research, observation, and monitoring to support the long term sustainability of the Gulf of Mexico ecosystem, including its fisheries. NOAA was authorized to establish and administer the Science Program, in consultation with the U.S. Fish and Wildlife Service, by the Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies (RESTORE) of the Gulf States Act of 2012 (Public Law 112141, Section 1604). Identified in the RESTORE Act as the Gulf Coast Ecosystem Restoration Science, Observation, Monitoring, and Technology Program, the Program is commonly known as the NOAA RESTORE Act Science Program. The Science Program’s goal is to support the science and coordination necessary for better understanding and management of the Gulf of Mexico ecosystem, leading to:

• Healthy, diverse, sustainable, and resilient estuarine, coastal and marine habitats and living resources (including wildlife and fisheries); and

• Resilient and adaptive coastal communities.

To achieve this goal, the Science Program supports the application of an ecosystem approach to science and management in the Gulf by emphasizing connections within the ecosystem, building relationships (push/pull dynamic between science and management communities), incentivizing practical innovation, and prioritizing application. The Science Program has a science plan with 10 long term priorities that guide investments and support achievement of the Science Program’s goals. This presentation will provide an overview of program history and development, currently funded projects, and a report on the status of future funding opportunities.

***3:00 pm - Federal fisheries management in the Gulf of Mexico (John Froeschke)***

An overview of the Gulf Council’s fisheries management process for restoring fisheries and preventing overfishing will be provided. The fisheries management council process overall is one of the most transparent decision-making processes within any federal agency. The Councils have a continuous public process for fishermen and other stakeholders who want to learn about management discussions and to provide public comment from beginning to end. The early attempts and future needs to incorporate environmental and other ecosystem factors into fisheries management process are highlighted, with an emphasis on the use of Integrated Ecosystem Analyses in our existing stock assessment process. There is a great need to improve the potential for ecosystem-based fisheries models to establish and monitor management reference points.

***3:45 pm - Overview of stressors and basics of restoration in the Gulf of Mexico (Halie O’Farrell)***

Due to the substantial dependence of humans on its resources, the Gulf of Mexico (GOM) Large Marine Ecosystem (LME) is under strong and increasing anthropogenic pressure as populations continue to grow. The GOM is also frequented with natural stressors, such as hurricanes, whose effects can synergistically interact with anthropogenic stressors and exacerbate the resulting effects on the environment and resources. Stressors can be classified as drivers, pressures, or states. Drivers in the GOM are climate change, nutrient loading and population growth and function as overarching stressors that cause ecosystem change and lead to a cascade of pressures, such as sea-level rise, overfishing, and urban sprawl, that can afflict the ecosystem and change its state, often degrading it. These altered states can reduce the supply of natural resources in terms of quantity, quality, and reliability. Most of the drivers, pressures, and states in the GOM are related and often contribute to one another. Identification of stressors and an understanding of how they interact and contribute to one another are vital in planning, executing, and evaluating ecosystem-based fisheries management (EBFM) and restoration related to EBFM. Several agencies and groups have developed restoration programs with the common goal of restoring the natural habitats of the GOM that have been degraded by stressors. Specific plans have been put forth for mitigation of land loss in Louisiana and for mitigation of the hypoxic region in northern GOM. Other plans are more general and refer to the entire GOM LME.

***4:05 pm - Ecosystem-based management in the Gulf of Mexico (Elizabeth Babcock)***

Ecosystem based management (EBM) manages multiple human uses of an ecosystem in an integrated manner, recognizing the tradeoffs between multiple uses, as well as the linkages between physical, biological, ecological and social processes. Such an approach is particularly necessary in the Gulf of Mexico (GOM). As a semi-tropical sea, the GOM has a high species diversity, and complex food webs. The GOM provides a wide range of ecosystem services (commercial and recreational fisheries, tourism, petroleum extraction), which may be threatened by a number of anthropogenic stressors (overfishing, pollution, coastal development, climate change) all of which may interact to influence the ecosystem in unpredictable ways. In particular, fisheries can incidentally catch non-target species as bycatch and can cause damage to habitat structure, potentially impacting the population dynamics of habitat-dependent species. In a fishery context, ecosystem based fishery management (EBFM) provides a conceptual framework and a set of tools for fisheries managers to assess and manage marine populations that are strongly influenced by species interactions and/or abiotic environmental factors, manage the collateral impacts of fishing, and ensure the sustainability of the marine ecosystem as a whole. An EBFM approach generally includes single species stock assessment and reference points to evaluate the status of particular species, but it also includes additional assessments and references points to evaluate the status of other ecosystem components and of the whole ecosystem. Although ecosystem models may be used in EBFM, simpler data-based indicators may also be used, for example in the context of integrated ecosystem assessment (IEA). In the GOM, there has been considerable recent progress toward EBM and EBFM, but there remains a need to improve data gathering and modeling, and operationalize EBFM through the existing fishery management processes.

***4:30 pm - Gulf of Mexico Restoration: An unparalleled testbed for ecosystem-based fisheries management (Bonnie Ponwith)***

The pace of restoration efforts in the Gulf of Mexico will escalate as funding opportunities under the Final Programmatic Damage Assessment and Restoration Plan and various components of the Restore Act become available. Through careful planning and strong communication, restoration work in the Gulf of Mexico can be orchestrated to provide an unparalleled opportunity to implement ecosystem-based fisheries management (EBFM) in the region. NOAA’s newly-released EBFM policy and EBFM Roadmap, which will be released for public comment early this fall, provide some common language and common-sense guiding principles to that end. Through these means, the Gulf of Mexico represents an unparalleled testbed for EBFM, and an opportunity to contribute to the growing edges of the discipline.

***5:00 pm - Overview of Lenfest Task Force (Felicia Coleman)***

The Lenfest Ocean Program --  recognizing the critical importance of the interconnections between fishing, fished species, humans, and the well-being of the larger marine environment -- appointed a Task Force in 2014 to develop a clear path for implementing ecosystem-based fisheries management where none existed. The Lenfest Ecosystem Task Force spent the last two years holding meetings across the country to gather information and create a practical blueprint that can be adopted by managers to make ecosystem-based fisheries management operational through the development of Fishery Ecosystem Plans (FEPs). While the recommendations have not yet been released, we provide here a review of the foundational aspects of the group's approach and some key messages, including specific questions that every FEP should address. A primary objective is to provide managers with an avenue for using existing data to greater effect in their specific management contexts, ecological dynamics, and socioeconomic circumstances.

## Wednesday August, 3rd 2016

***8:30 am - A multi-model approach to understanding the role of Pacific sardine in the California Current ecosystem (Isaac Kaplan)***

In February of 2013, a workshop of the Pacific Fishery Management Council conducted an extensive review of ecosystem models that might be used to evaluate effects on Pacific sardine harvest on the broader California Current (US West Coast) ecosystem. This workshop found that “available ecosystem models are not sufficiently well developed to form the basis for an evaluation of the impact of sardine control rules on broader ecosystem impacts.” Motivated by this call for improved modeling, a new Ocean Modeling Forum began to develop a California Current sardine case study (<http://oceanmodelingforum.org/working-groups/pacific-sardines/>). The Ocean Modeling Forum supports this and other working groups, with a goal of fostering collaboration among modelers, other scientists and marine resource managers, and stakeholders, to provide clear, decision-critical information.

This case study primarily involved comparing predictions from a suite of ecosystem models, and we benefited from having models that differ in their complexity and the amount of time required to build and run them; similar models exist in the Gulf of Mexico and are being applied to ecosystem based management there. For this California Current sardine case study, we applied several model types

• Koehn et al. (In press, Ecological Modelling) assembled predator diet information to create an Ecopath model, which provided essential accounting of diet composition and predation mortality rates.

• We then applied the PREP equation (Predator Response to the Exploitation of Prey (Pikitch et al. 2012), a generalization based on 10 dynamic food web models (Ecosim), as a rough approximation of what might be expected given California Current diets and general properties of such models.

• We applied a simple multi-species model (Punt et al., in press, Ecological Modelling) focused on sardine, anchovy, other forage fish, and only four predators, i.e. a Model of Intermediate Complexity for Ecosystem assessment (MICE)

• Finally, we applied an Atlantis model (Marshall et al. submitted), that allowed us to look at strategic risk to the broader food web and ecosystem.

Each of these model approaches has costs and benefits associated with its use in providing management guidance. This case study explores the value of using multiple modeling approaches aimed at a single management issue. This work was conducted both as a case study for the Ocean Modeling Forum, and as a component of the California Current Integrated Ecosystem Assessment (<http://www.noaa.gov/iea/regions/california-current-region/index.html>).

***9:30 am - Overview of ecosystem modeling approaches and ecosystem modeling efforts to tackle ecosystem-based fisheries management and restoration issues in the Gulf of Mexico (Halie O’Farrell)***

Ecosystem models are invaluable tools for depicting natural processes and evaluating the effects of potential management measures and restoration. They complement traditional single-species modeling approaches with the added consideration of trophic effects and/or abiotic environmental influences on species dynamics. A variety of ecosystem models exist and differ in their structure, assumptions and complexity to address a range of situations, questions, and management objectives. Ecosystem models can be classified by their structure as: (1) conceptual and qualitative models; (2) extensions of single-species models; (3) dynamic multispecies models; (4) aggregated (or whole ecosystem models); (5) biogeochemical-based end-to-end models; or (6) coupled and hybrid model platforms. Alternately, ecosystem models can be classified by their major purpose as: (1) conceptual models for developing an understanding of processes in the study ecosystem; (2) strategic models; or (3) tactical models. Employing a range of ecosystem models in concert with single-species models can broaden the range of potential management questions and provide additional information for evaluating tradeoffs in optimizing ecosystem-based fisheries management (EBFM) and restoration plans. We conducted a search that revealed that a total of 44 different ecosystem models have been developed for the United States (U.S.) Gulf of Mexico (GOM) and GOM large marine ecosystem (LME) between 1983 and the present. These models range from simple conceptual and qualitative models to complex aggregated and biogeochemical-based end-to-end models and coupled and hybrid model platforms. They have greatly advanced understanding of the different ecosystems of the GOM, and have tackled a number of EBFM and restoration issues. However, the great majority of the ecosystem models of the GOM have been developed to address issues relating to the structure and functioning of ecosystems and the impacts of bycatch reduction strategies and marine protected areas than to restoration issues such as changes to water flow and the management of nutrient loads. Moreover, while the GOM is a highly diverse ecosystem under strong environmental influences, only seven single-species assessment models of the region integrate ecosystem considerations, while only one ecosystem model was used to conduct a management strategy evaluation integrating ecosystem considerations; Finally, efforts to mitigate lionfish invasion, which is a serious concern in the GOM, have been considered in only one ecosystem model.

***10:45 am - Exploring effects of hypoxia on fish and fisheries in the Northern Gulf of Mexico using a dynamic spatially-explicit ecosystem model (Kim de Mutsert)***

The formation of an extensive hypoxic area off the Louisiana coast has been well publicized. However, determining the effects of this hypoxic zone on fish and fisheries has proven to be more difficult. The dual effect of nutrient loading on secondary production (positive effects of bottom-up fueling, and negative effects of reduced oxygen levels) impedes the quantification of hypoxia effects on fish and fisheries. The objective of this study was to develop an ecosystem model that is able to separate the two effects, and to evaluate net effects of hypoxia on fish biomass and fisheries landings. An Ecospace model was developed using Ecopath with Ecosim software with an added plug-in to include spatially and temporally dynamic Chlorophyll a (Chl a) and dissolved oxygen (DO) values derived from a coupled physical-biological hypoxia model. Effects of hypoxia were determined by simulating scenarios with DO and Chl a included separately and combined, and a scenario without fish response to Chl a or DO. Fishing fleets were included in the model as well; fleets move to cells with highest revenue following a gravitational model. Results of this model suggest that the increases in total fish biomass and fisheries landings as a result of an increase in primary production outweigh the decreases as a result of hypoxic conditions. However, the results also demonstrated that responses were species-specific, and some species such as red snapper (*Lutjanus campechanus*) did suffer a net loss in biomass. Scenario-analyses with this model could be used to determine the optimal nutrient load reduction from a fisheries perspective.

***11:30 am - An ecosystem model to inform fisheries management on the West Florida Shelf, (David Chagaris)***

An Ecopath with Ecosim & Ecospace (EwE) trophic-dynamic ecosystem model of the West Florida Shelf (WFS) was developed to evaluate ecosystem effects of fisheries policy options and environmental stressors. The WFS EwE model consists of 72 total biomass pools, 45 of which were fish, and focuses on important predatory reef fishes (e.g. grouper and snapper). The model accounts for bottom-up processes through simple forcing functions and represents habitat associations and spatial processes over a 2-dimensional map. EwE models are limited in their ability to provide tactical management advice (i.e. size limits, bag limits) but are very capable of providing strategic advice and ranking policy options. The WFS EwE model has been used to quantify the trophic impacts of reef fish harvest policies, identify tradeoffs in conflicting fisheries management objectives, evaluate community effects and management strategies of invasive lionfish, estimate red tide mortality on gag and red grouper, and evaluate size and placement of marine protected areas. Uncertainty in EwE predictions can largely be attributed inadequate data on food habits, misspecification of modeled predator-prey functional responses, lack of informative time series data, and lack of species-habitat relationships and synoptic habitat maps.

***1:30 pm - Atlantis and ecosystem-based fisheries management in the Gulf of Mexico (Cameron Ainsworth)***

The Gulf of Mexico Atlantis model was developed from 2011 to 2015. Methodological papers describe biomass distributions, the diet matrix, larval connectivity, and toxicological responses to oil. A follow-on diet study expanded the diet information and tested model performance to show an improved fit to historical catch and biomass information. The model is currently being used in several applications including Deepwater Horizon oil spill impacts research, ecological indicator evaluation, and management strategy evaluation. These are presented with major findings. We show the range of outputs that can be taken from Atlantis results including biomass, catch, spatial distributions, condition factor, and age structure. We identify outstanding data gaps that impact ecosystem model development.

***2:00 pm - OSMOSE-WFS – An OSMOSE model for the West Florida Shelf (Arnaud Grüss)***

OSMOSE is a spatially-explicit, individual-based, multispecies modeling platform, which is increasingly being used worldwide. The basic units of OSMOSE are schools, which are individuals that belong to the same functional group and cohort, and which have the same length, food needs and, at a given time step, the same spatial coordinates. OSMOSE models represent a few high trophic level (HTL) functional groups (e.g., 10-15 fish and invertebrate groups), and are forced by fields of low trophic level (LTL) group (e.g., plankton and benthos group) biomasses, which provide additional food to the HTL groups represented in OSMOSE. Contrary to Ecopath with Ecosim and Atlantis, OSMOSE does not use a diet matrix, but rather makes the assumption that predation is an opportunistic process and that a predator school will feed on any prey item if: (1) the predator school and the potential prey overlap over space; (2) there is size adequacy between the predator and the potential prey; (3) the potential prey is accessible to the predator, in relation to its vertical distribution and morphology. OSMOSE-WFS is an OSMOSE model for with a monthly time step, which simulates dynamics on the West Florida Shelf (WFS) in the 2000s. The first version of OSMOSE-WFS was employed to examine the trophic structure of the WFS in the 2000s and estimate size-specific natural mortality rates for gag grouper (*Mycteroperca microlepis*), in order to inform gag grouper stock assessment. The second version of OSMOSE-WFS was used to evaluate size- and age-specific natural mortality rates and fishing scenarios for red grouper (*Epinephelus morio*), with the intent to provide inputs to red grouper stock assessment and the Gulf of Mexico Fishery Management Council. Finally, the third version of OSMOSE-WFS is two-way coupled to a management procedure integrating decision rules and accounting for scientific uncertainty and the acceptable risk of overfishing; this management strategy evaluation framework was applied to red grouper, so as to evaluate acceptable biological catch strategies for the species in the face of episodic events of natural mortality (due to, e.g., red tides or oil spill).

## Thursday August, 4th 2016

***8:30 am - Ecosystem models of the Gulf of Mexico: Future needs to address ecosystem-based fisheries management and restoration activities (Arnaud Grüss)***

A diversity of ecosystem models has been developed for the United States (U.S.) Gulf of Mexico (GOM) and GOM large marine ecosystem (LME) between 1983 and the present. Existing ecosystem models of the GOM have paid more attention to understanding the structure and functioning of ecosystems and the impacts of bycatch reduction strategies and marine protected areas than to issues such as changes to water flow and the management of nutrient loads. Only seven single-species assessment models of the region integrate ecosystem considerations, while only one ecosystem model was used to conduct a management strategy evaluation integrating ecosystem considerations. Finally, efforts to mitigate lionfish invasion, which is a great concern in the GOM, have been considered in only one ecosystem model. To comprehensively address the different EBFM and restoration needs in the GOM, we propose the development of a larger number of conceptual and qualitative models, the improvement of some existing ecosystem models to tackle specific questions, and the use of a few modeling approaches that have not been utilized in the GOM yet. Conceptual models and loop analysis could be employed in support of any EBFM/restoration project of the GOM, primarily to adequately prepare the conception/improvement of quantitative ecosystem models. Extensions of single-species assessment models should be used within the assessment process of more stocks of the U.S. GOM and GOM states. Many complex ecosystem models should be improved or designed in the future. Notably, Ecospace, Atlantis and OSMOSE models should be developed for the northwestern GOM and Texas, especially to investigate the effects of efforts to mitigate hypoxia and manage nutrient loads, freshwater and sediment diversion, marsh and oyster reef restoration and artificial reefs. Moreover, a lionfish functional group should be introduced in some existing EwE models to assess the effectiveness of efforts aiming to mitigate red lionfish invasion in the different GOM ecosystems. Finally, a beneficial undertaking during the coming years would be the construction of an InVitro model for the northern GOM, which would permit to tackle a wide range of EBFM and restoration questions with the same model, such as strategies for mitigating oil spill impacts, post-oil spill restoration, sustainable coastal development, storm protection and habitat restoration.

# Appendix D – Questions for small group discussions

**Small-group discussions #1 about the modifications needed in existing ecosystem models of the Gulf of Mexico (GOM) to address ecosystem-based fisheries management (EBFM) and restoration needs in the GOM**

Q1) Which EBFM and restoration issues should be addressed by existing ecosystem models in the future?

Q2) Among the existing ecosystem models of the GOM, which ones should be improved in priority, and why?

Q3) What are the most important modifications to make in existing ecosystem models of the GOM?

**Small-group discussions #2 about new ecosystem models that could be designed to fully address EBFM and restoration needs in the GOM**

Q1) Are there specific management issues that can be informed by, or require, ecosystem models in the GOM?  Specifically, how can we use ecosystem models to inform EBFM and restoration efforts? Are these issues region-specific or Gulf-wide?

Q2) Among the ecosystem modeling platforms currently used in the GOM, which ones should be applied to a different region of the GOM, and why?

Q3) Which of the ecosystem modeling platforms that have never been applied to the GOM could be used in the GOM in the future, and why?

Q4) What are the next steps needed to more fully incorporate ecosystem models into management and resource decision-making?

# Appendix E – Background material

**Stressors in the Gulf of Mexico**

Due to the substantial dependence of humans on its resources in a context of continual population growth and coastal development, the Gulf of Mexico (GOM) is under strong and increasing anthropogenic pressure. We classify stressors in a drivers, pressures, and states framework (Table 1). Drivers are overarching stressors, such as human population growth, that cause ecosystem change and lead to a cascade of other stressors. Pressures are stressors caused or intensified by drivers that afflict the ecosystem and change its state, such as coastal development. Finally, states describe the status of the ecosystem and/or communities resulting from pressures created or intensified by drivers. Most of the drivers, pressures, and states in the GOM are related, and one often contributes to another (Figure 1). Stressors, which are numerous in the GOM, are listed in Table 1.

Table 1. Classification of Gulf of Mexico stressors into drivers, pressures and states.

|  |  |  |
| --- | --- | --- |
| Drivers | Pressures | States |
| Climate change  Nutrient loading  Population growth | Urban sprawl/coastal development  Oil/gas exploration  Overfishing/unsustainable fishing practices  Invasive species  Storms/hurricanes  Dredging, levees and canals  Subsidence  Sea-level rise | Hypoxia  Eutrophication  Habitat and vegetation loss/degradation  Water quality degradation/pollution  Marine debris  Noise pollution  Changes in water quantity  Reduced storm protection  Cold snaps  Harmful algal blooms |

**Figure 1. Illustration of the relationships between stressors in the Gulf of Mexico (GOM). Many stressors in the GOM are related and one often causes or contributes to another.**



**Ecosystem-based fisheries management efforts in the Gulf of Mexico**

Ecosystem-based fisheries management (EBFM) efforts in the GOM include the implementation of marine protected areas (MPAs), measures to reduce bycatch, culling programs, and the integration of ecosystem considerations into single-species stock assessments.

*MPAs*

The GOM is home to 295 MPAs, with varying levels of protection. While 40% of United States (U.S.) GOM waters include some form of MPAs, only 0.5% are “no-take” (i.e., “marine reserves”). The majority of the MPAs of the GOM (278 MPAs; about 94% of the MPAs of the region) are designated multiple use. MPAs are created in the GOM for one or a combination of the following reasons: solve allocation issues by spatially or temporally separating conflicting fisheries (e.g., stone crab (*Menippe mercenaria* and *M. adina*) and shrimp fisheries), increase fisheries yields by protecting under-sized individuals (e.g., shrimp fisheries), reduce fishing effort with seasonal or area closures of spawning aggregations (e.g., groupers), and protect ecological structure and function through the closure of essential fish habitat to fishing activities.

*Bycatch reduction*

NOAA Fisheries works with regional management agencies to monitor and address regional bycatch concerns. Regulations, such as gear requirements, are in effect to reduce catch and mortality of non-target species. Methods to reduce bycatch include, *inter alia*, bycatch reduction devices (BRDs) in the shrimp trawl fishery and the use of circle hooks rather than J hooks in the longline fishery. Bycatch of turtles and large fish, including some sharks, has decreased in the shrimp trawl fishery since the implementation of turtle excluder devices (TEDs) in 1990; however, the discard to target species ratio is still relatively high at 0.64. The menhaden purse seine fishery has used large fish excluder devices and the hose and cage device since the 1950s, primarily to improve pumping efficiency and prevent equipment damage by large fish; this has reduced bycatch of non-target species.

*Culling*

There is currently only one culling program underway in the GOM for red lionfish (*Pterois volitans*). This program is meant to control the invasive species, which is intended to result in habitat improvement and increased abundance and diversity of native species. Currently, targeted removal efforts are in the form of small-scale derbies throughout the GOM. Bycatch removals in lobster (*Panulirus argus*) traps have created a small market for lionfish and have spurred the “Eat Lionfish Campaign” encouraging the consumption of lionfish as a delicious and environmentally friendly seafood option. NOAA and the REEF (Reef Environmental Education Foundation) non-governmental organization sponsor and plan derbies in the Florida Keys and train divers to safely remove lionfish from the Florida Keys National Marine Sanctuary. In addition, REEF tracks lionfish sightings with the Volunteer Fish Survey Project. Managers are optimistic that these efforts will make a difference, although a complete eradication of red lionfish is unlikely.

*Stock assessments integrating ecosystem considerations*

To date, there have been seven extensions of stock assessments incorporating ecosystem considerations in the GOM. Recent benchmark base-case stock assessment models of both GOM gag grouper (*Mycteroperca microlepis*) and red grouper (*Epinephelus morio*) accounted for elevated natural mortality in 2005 due to a severe red tide event based on anecdotal evidence. Although not incorporated within the base model and instead tested as a sensitivity analysis, recent stock assessments for gag grouper, red grouper and red snapper (*Lutjanus campechanus*) considered the inclusion of an index of recruitment anomalies due to oceanographic conditions to reduce uncertainty in recent recruitment. The 2013 assessment for North Atlantic Swordfish (*Xiphias gladius*), which includes the GOM in its modeling domain, allowed an environmental linkage between catchability and the Atlantic Warm Pool in a Stock Synthesis model, although this model was not used for management advice due to limited time to scrutinize the model. The 2012 assessment for white shrimp (*Litopenaeus setiferus*) includes a seasonal linkage on catchability to allow for potentially higher selectivity for the large shrimps present during the spring fishing season. Finally, the 2013 stock assessment for common snook (*Centropomus undecimalis*) accounted for elevated natural mortality due to red tide and cold snaps, and the 2013 stock assessment for blue crab (*Callinectes sapidus*) accounted for elevated natural mortality due to precipitation and stream flow.

**Restoration activities related to ecosystem-based fisheries management in the Gulf of Mexico**

Several agencies and groups have developed restoration programs to address stressors affecting the GOM, all aiming to restore the natural habitats that have been. In general, restoration programs of the GOM are intended for application to the U.S. GOM and have very broad goals. An exception to this general pattern is the specific plan put forth by the state of Louisiana for addressing land loss. Details about restoration programs of the U.S. GOM and GOM large marine ecosystem (LME) are provided below. In general, while restoration programs of the GOM provide many recommendations and suggestions, they propose only a few direct action projects, and it is often unclear if proposed projects have been carried out in actuality.

After the *Deepwater horizon* oil spill, an executive order was issued to establish the Environmental Protection Agency (EPA)’s Gulf Coast Ecosystem Restoration Task Force (GCERTF), so as to “address the persistent and significant decline of the Gulf ecosystem”. The GCERTF developed a framework focused on using sound science and public and stakeholder involvement to restore environments, marine resources and community resilience. Rather than addressing particular stressors such as oil impacts and oil dispersal, this task force focuses on overall ecosystem and community health. The GCERTF identified restoration priorities for the GOM and created an appropriate set of corresponding action plans. The task force also developed a framework for decision-making, resolving uncertainties, and assessing the short and long-term effectiveness of restoration efforts in the GOM.

The primary goal of the Gulf of Mexico Research Initiative (GoMRI) is to understand the dispersal and effects of oil and oil dispersants, as well as the impacts of the *Deepwater horizon* oil spill, so that we can better respond to future oil spills in the GOM. GoMRI has selected fifteen research consortia focusing on the physical dispersion, chemical evolution, environmental effects, and public health effects of oil, as well as technology developments for improved response to oil spills.

NOAA’s GOM Integrated Ecosystem Assessment (IEA) program is an “interdisciplinary, interagency effort whose goal is to address all the various ecosystem services in one unified management framework”. The GOM IEA program aims to develop a toolbox, including a suite of ecosystem models and management strategy evaluation (MSE) tools, to allow resource managers to evaluate the potential impacts of EBFM efforts and restoration activities and assess potential tradeoffs between conflicting management goals.

The RESTORE Act directed NOAA to establish the NOAA RESTORE Act Science Program as a means to expend restoration funds. NOAA RESTORE Act Science Program is tasked with identifying and funding projects that address EBFM and restoration information needs and support healthy, diverse, sustainable, and resilient habitats and resources, as well as resilient coastal communities. NOAA RESTORE Act Science Program’s short-term investments are strategic and focus on the identification and assessment of the GOM ecosystem science and health.

Other restoration programs and projects in the GOM focus on improving the state of coastal habitats to restore ecosystem function. In the process, they address many of the stressors listed in Table 1. These restoration programs, in general, focus on pressures and states, essentially treating symptoms rather than addressing the causes. One exception to this general pattern relates to the nutrient loading driver. Action plans were put forth in 2001 and 2008 by the Hypoxia Task Force, with the ultimate goal to reduce the area of the hypoxic zone to a five-year running average of less than 5,000 km² by 2015 through the decrease of nutrient loadings. In February of 2015, the Hypoxia Task Force announced that the time frame would be extended to 2035 with an interim target of a 20% reduction of nitrogen and phosphorus loadings by 2025.

Several projects in the GOM involve freshwater diversion, including freshwater diversion that alters natural water flows and freshwater diversion to restore natural hydrologic patterns. Freshwater diversion is a key issue in Louisiana; freshwater diversion projects in Louisiana focus on building and sustaining existing land, and reducing future risks to infrastructures and humans while maintaining ecosystem services. Hydrological restoration projects involve installing features that prevent saltwater intrusion into naturally fresh bodies of water, and reconnecting freshwater to areas previously cut off by other man-made features. Sediment diversion and channel realignment projects aim to divert river water and sediment from the Mississippi and Atchafalaya Rivers into adjacent basins to prevent flooding, rebuild land, and act as physical barriers against storm surge.

The creation of artificial reefs is an important restoration undertaking in the entire U.S. GOM. Artificial reefs have been recommended to restore coastal reefs, provide additional habitat and settlement surfaces, and increase physical protection against storms as they can dampen wave energy, decrease erosion, and stabilize sediments. Artificial reefs can support a diversity of marine life where they are located as well as in adjacent areas, thereby benefiting the fishing industry and making coastal communities more resilient. Artificial reef development programs are implemented in all GOM states, including the decommissioning of oil platforms.

Finally, lessons can be learned from the successful restoration of the Tampa Bay seagrass habitat. Untreated sewage, dredging and coastal development, nutrient loading, and population growth contributed to the degradation and die off of seagrasses in Tampa Bay. To address this issue, restoration efforts were initiated, which consisted of controls on eutrophication and dredging, including the installation of wastewater treatment systems, the implementation of state-legislated water treatment standards, and the cessation of dredging in 1975. In 1998, the Nitrogen Management Council developed the Nitrogen Management Action Plan to mitigate the effects of nitrogen loading. Projects dealing with point sources of pollution and nutrients have been implemented and maintained. The restoration of the Tampa Bay seagrass habitat has resulted in a decrease in nutrient loading and an increase in water clarity. Monitoring shows that the trend in seagrass loss has been reversed, yet, not at the same rate in all locations. If current trends continue, restoration goals will be met in 2050. Remaining threats to continued success include non-point pollution sources, population growth, and sea-level rise. The restoration of the Tampa Bay seagrass habitat is beneficial to EBFM, since seagrasses are part of the foundation of the Tampa Bay watershed and affect the entire Tampa Bay ecosystem, particularly because they provide habitat for ecologically and economically important fish and shellfish species.

**Ecosystem modeling efforts in the Gulf of Mexico**

Ecosystem models are invaluable for their ability to deliver relatively rapid, detailed and inexpensive insights into the potential effects of fishing and other stressors and into the effects of management measures under an ecosystem perspective. Ecosystem models complement traditional, single-species modeling approaches by taking into consideration the impacts that trophic interactions and/or abiotic environmental influences on species dynamics may have on the effects of stressors and management measures. Many different types of ecosystem models exist and vary largely in terms of structure, assumptions and complexity to address a variety of ecological situations and ecosystem management objectives. Employing a range of ecosystem models in concert with single-species models can allow one to address a broader range of resource management questions and provide added information for evaluating trade-offs between management objectives and optimizing EBFM and restoration activities

Ecosystem models can be classified by their structure as:

(1) Conceptual and qualitative models, which represent the ecosystem of interest qualitatively, using simple depictions that show the ecosystem’s components or connections, or implying the first steps towards the development of (a) quantitative ecosystem model(s).

(2) Extensions of single-species models, which expand on existing single-species models, including only a few additional features such as the influence of the abiotic environment on the biological rates of the focal species.

(3) Dynamic multispecies models, which represent a limited number of species/functional groups most likely to exhibit large interactions with the species of focal interest.

(4) Aggregated (or whole ecosystem) models, which attempt to consider all trophic levels in the study ecosystem to explore energy flows among ecosystem components; these models typically represent a large number of species/functional groups. The trophodynamic Ecopath with Ecosim (EwE) with Ecospace modeling platform is the most famous and most widely used aggregated modeling approach.

(5) Biogeochemical-based end-to-end models, which consider both bottom-up and top-down forces interacting in the study ecosystem via the representation of a very large number of ecosystem components. Atlantis is one example of a biogeochemical-based end-to-end modeling platform.

(6) Coupled and hybrid model platforms, which also consider both bottom-up and top-down forces interacting in the study ecosystem through the coupling or combination of different types of models. The most recent versions of the multispecies, individual-based OSMOSE modeling approach are one example of a coupled and hybrid model platform.

Alternately, ecosystem models can be classified by their major purpose as: (1) conceptual models whose goal is to develop an understanding of processes in the study ecosystem; (2) strategic models, i.e., models delivering strategic advice to resource management; or (3) tactical models, i.e., models providing short-term advice to resource management.

We conducted a search that revealed that a total of 44 different ecosystem models have been developed for the U.S. GOM and GOM LME between 1983 and the present. These models range from simple conceptual and qualitative models to complex aggregated and biogeochemical-based end-to-end models and coupled and hybrid model platforms. Regarding the major purpose of ecosystem models of the GOM, the majority of these models are strategic (82%), 16% are tactical (the seven extensions of single-species assessment models (ESAMs) developed for the GOM), and one is conceptual. Only 9% of the ecosystem models identified were designed for the entire GOM LME, while over half of them (55%) were developed for a specific GOM state. Thirty nine percent of these models focus on Florida ecosystems, and 11% on Louisiana ecosystems. Texas, the northwestern GOM, and Alabama each have one ecosystem model, while Mississippi is the only GOM state without an ecosystem model.

Existing ecosystem models of the GOM have greatly advanced understanding of the different ecosystems of the GOM, and have tackled a number of EBFM and restoration issues. However, the great majority of the ecosystem models of the GOM have been developed to address issues relating to the structure and functioning of ecosystems and the impacts of bycatch reduction strategies and marine protected areas than to restoration issues such as changes to water flow and the management of nutrient loads. Moreover, while the GOM is a highly diverse ecosystem under strong environmental influences, only seven single-species assessment models of the region integrate ecosystem considerations, while only one ecosystem model was used to conduct an MSE integrating ecosystem considerations. Finally, efforts to mitigate lionfish invasion, which is a serious concern in the GOM, have been considered in only one ecosystem model. Therefore, there is a critical need to enhance existing ecosystem models of the GOM and to develop new ecosystem models, potentially using new modeling platforms, to comprehensively address the different EBFM and restoration needs in the region.

To comprehensively address the different EBFM and restoration needs in the GOM, we propose the development of a larger number of conceptual and qualitative models, the improvement of some existing ecosystem models to tackle specific questions, and the use of a few modeling approaches that have not been utilized in the GOM yet. Conceptual models and loop analysis could be employed in support of any EBFM/restoration project of the GOM, primarily to adequately prepare the conception/improvement of quantitative ecosystem models. ESAMs should be used within the assessment process of more fish and shellfish stocks of the U.S. GOM and GOM states. Many complex ecosystem models should be improved or designed in the future. Notably, Ecospace, Atlantis and OSMOSE models should be developed for the northwestern GOM and Texas, especially to investigate the effects of efforts to mitigate hypoxia and manage nutrient loads, freshwater and sediment diversion, marsh and oyster reef restoration and artificial reefs. Moreover, a lionfish functional group should be introduced in some existing EwE models to assess the effectiveness of efforts aiming to mitigate red lionfish invasion in the different GOM ecosystems. Finally, a beneficial undertaking during the coming years would be the construction of an InVitro model for the northern GOM, which would permit to tackle a wide range of EBFM and restoration questions with the same model such as, strategies for mitigating oil spill impacts, post-oil spill restoration, sustainable coastal development, storm protection and habitat restoration.

Best practices for future ecosystem modeling efforts in the GOM include: (1) improving the diet matrix of ecosystem models where diet composition is the primary driver of trophic interactions and resulting ecosystem metrics; (2) enhancing the calibration and validation processes of ecosystem models of the GOM and examining the behavior of these models in more detail; (3) allowing empiricists, resource managers and other stakeholders to properly understand and review the strengths and limitations of ecosystem models and to contribute to these models; and (4) fostering capacity building and the maintenance of ecosystem models.

# Appendix F – Glossary of frequently used abbreviations

ABC: Acceptable biological catch

Chl a: Chlorophyll a

DO: Dissolved oxygen

EBFM: Ecosystem-based fisheries management

EBM: Ecosystem-based management

EwE: Ecopath with Ecosim

F: Fishing mortality rate

FEP: Fisheries Ecosystem Plan

FMP: Fisheries Management Plan

Fmsy: Fishing mortality rate at the Maximum Sustainable Yield

GAM: Generalized additive model

GMFMC: Gulf of Mexico Fishery Management Council

GOM: Gulf of Mexico

HTL species: High trophic level species

IEA: Integrated Ecosystem Assessment

LME: Large marine ecosystem

LMR: Living marine resource

LTL: Low trophic level species

M: Natural mortality rate

MPA: Marine protected area

MSE: Management Strategy Evaluation

MSY: Maximum Sustainable Yield

NEPA: National Environmental Policy Act

NOAA: National Oceanic and Atmospheric Administration

OFL: Overfishing limit

OY: Optimal Yield

ROMS: Regional Ocean Modeling System

SEAMAP: Southeast Area Monitoring and Assessment Program

SEDAR: SouthEast Data, Assessment, and Review

SSC: Scientific and Statistical Committee

TL: Trophic level

WFS: West Florida Shelf

Z: Total mortality rate