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PROGRESS TOWARDS AN INTEGRATED ECOSYSTEM ASSESSMENT FOR THE GULF OF MEXICO

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SUMMARY

The Gulf of Mexico (GOM) is a semi-enclosed coastal sea with a vast array of topography and moderately high productivity that supports biological diversity and high biomass of fish, sea birds and marine mammals. Along with supporting a large recreational and commercial fishing industry, the GOM also provides vital services such as oil and gas production, tourism, habitat for endangered species, and support for many Gulf state economies. It is also the only known spawning ground for the western stock of the bluefin tuna. However, despite the many ecological services provided by the GOM Large Marine Ecosystem (LME) management of the system historically has been done on a case by case or single species basis with little or no integration. First conceived in 2008, the GOM Integrated Ecosystem Assessment (IEA) is an interdisciplinary, interagency effort whose goal is to address all the various ecological services in one unified management framework. The intent of the IEA is to make more obvious the tradeoff between often conflicting ecosystem services. Through state of the art ecosystem models such as Atlantis, OSMOS, and Ecopath_Ecosim, management strategy evaluations (MSE) will be performed that seek to manage the GOM LME from a more holistic, broader perspective than the current single species models are capable of.

RÉSUMÉ

Le golfe du Mexique (GOM) est une mer côtière semi-fermée possédant une topographie variée et une productivité modérément élevée qui appuie la diversité biologique et une forte biomasse de poissons, oiseaux de mer et mammifères marins. Tout en soutenant une grande industrie de la pêche récréative et commerciale, le golfe du Mexique fournit également des services vitaux, tels que la production de pétrole et de gaz, le tourisme, l'habitat des espèces menacées, et il vient en aide à de nombreuses économies des États du golfe. Il s'agit également de la seule zone de frai connue pour le stock occidental de thon rouge. Toutefois, malgré les nombreux services écologiques fournis par le Grand écosystème marin (LME) du golfe du Mexique, la gestion du système a historiquement été réalisée au cas par cas ou espèce par espèce, avec peu ou aucune intégration. Conçue en 2008, l'Évaluation écosystémique intégrée (IEA) du golfe du Mexique constitue un effort interdisciplinaire et inter-institutionnel dont le but est d'aborder tous les divers services écologiques dans un cadre de gestion unifié. L'IEA est destinée à mettre davantage en lumière l'interaction entre des services écosystémiques souvent contradictoires. Par le biais de modèles écosystémiques de pointe, tels que Atlantis, OSMOS et Ecopath_Ecosim, des évaluations des stratégies de gestion (MSE) seront réalisées afin de tenter de gérer le grand écosystème marin du golfe du Mexique selon une perspective plus holistique et plus large que ne le permettent actuellement les modèles pour espèces uniques.

RESUMEN

El golfo de México (GOM) es un mar costero semi-cerrado con una vasta gama de topografías, una productividad moderadamente elevada que respalda la diversidad biológica y que contiene una gran biomasa de peces, aves marinas y mamíferos marinos. Además de respaldar una importante industria pesquera comercial y de recreo, el golfo de México también proporciona servicios vitales como la producción de gas y petróleo, el turismo, un hábitat para especies en peligro, y también contribuye a muchas economías de los estados del Golfo. También es la única zona conocida de reproducción para el stock occidental de atún rojo. Sin embargo, a pesar de los muchos servicios ecológicos que presta el Gran Ecosistema Marino (LEM) del

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golfo de México, la ordenación del sistema se ha realizado históricamente caso por caso o para especies individuales con poca o ninguna integración. Concebida en 2008, la evaluación ecosistémica integrada (IEA) del golfo de México es un esfuerzo interdisciplinar y de varias agencias cuyo objetivo es abordar todos los servicios ecológicos en un marco de ordenación unificado. El propósito de la IEA es hacer más obvio el intercambio entre los servicios ecosistémicos que a menudo entran en conflicto. Mediante modelos ecosistémicos de última generación como Atlantis, OSMOS y Ecopath-Ecosim, se llevarán a cabo evaluaciones de estrategias de ordenación (MSE) para intentar gestionar el LEM del GOM desde una perspectiva holística y más amplia que la que se puede aplicar con los modelos actuales de especies individuales.

KEYWORDS

Integrated Ecosystem Assessment, ecosystem, Gulf of Mexico

1. Introduction

The Gulf of Mexico (GOM) Large Marine Ecosystem (LME) has long been recognized as not only providing highly productive recreational and commercial fisheries, but also a great deal of other ecosystem services such as oil and gas production, tourism, habitat for endangered species, and support for many Gulf state economies (**Plantier-Santos 2012**). It is also the only known spawning ground for the western stock of the bluefin tuna. Because of all the services the GOM LME provides, it is subject to a great deal of anthropogenic pressures including overfishing, eutrophication, habitat destruction, hypoxic zones, coastal development, and the inadvertent spillage of petroleum products. In addition to these anthropogenic pressures there are a number of naturally occurring pressures that impact the system. These natural pressures include the highly variable oceanographic processes in the Gulf of Mexico, dominated by Loop Current and the gyres and eddies it produces, as well as seasonal hurricanes, and the vast amount of freshwater runoff. All of these ecosystem services and the natural and anthropogenic pressures interact with each other across a wide range of spatial and temporal scales. Because management of this LME has remained single-sector or single-species focused, decisions on how best to balance the overall equation has remained arbitrary or non-existent.

Two additional stressors which must be considered are natural hazard impacts and anticipated climate change. Climate change is likely to impact estuarine salinity, salt marsh sustainability, commercial fisheries (especially shrimp), species distributions, and low oxygen zones (Turner 2003). The devastating hurricanes of 2005 demonstrated the level of destruction that such natural phenomena can have on coastal ecosystems and communities. VanderKooy (2007) reported that marshes, other wetlands, and oyster resources were severely damaged by Hurricane Katrina. The impact on GOM fisheries due to loss of docks, marinas, ice plants, water and fuel facilities, dealers, fishing vessels, and support industries was significant, resulting in economic loss (VanderKooy 2007).

The Gulf of Mexico LME is also a politically complex ecosystem to manage. There are three separate nations that have management authority over various regions (Mexico, United States, and Cuba) within the Gulf of Mexico. Within the U.S., there are five U.S. states that have coastline along the Gulf of Mexico and 31 of the 50 states have at least portions of their area within the Gulf of Mexico watershed. Although, the GOM-IEA is being led by the U.S. through NOAA we have already begun to engage and integrate our colleagues from Mexico and hope to be able to do the same with Cuba in the future to make this truly a Gulf-wide program.

The first goal of the GOM IEA is to ensure that it is built on a solid data infrastructure. The second goal is to begin to build our ecosystem modeling and assessment capabilities. Predictive ecosystem models work in concert with ecosystem indicators to the development of Management Strategy Evaluations (MSE), which are one of the primary products of the IEA process. The third goal of the GOM IEA is to construct an Ecosystem Status Report for the Gulf of Mexico. This report will be targeted towards scientists and managers to try and bring an overall view and state of the ecosystem as well as to tune and calibrate output from the various ecosystem models being used. The ultimate goal of an IEA is to support sustainable, scientifically and ecosystem-based decision-making. The IEA will allow managers to evaluate the impact of their decisions not solitarily on the parameters being targeted, but on the entire ecosystem. This will enable management to consider indirect effects and thus unintended consequences of their decision on the natural and human components of the ecosystem.

2. Methods

Efforts to develop the formal IEA for the GOM LME are in the very beginning stages. To our advantage though, a certain amount of material necessary to facilitate further development already exists and our efforts will focus on collating and integrating this existing material as well as identifying and developing new tools for the next steps in the GOM IEA process.

The GOM IEA program received its first seed funding in fiscal year 2010. In FY 2011 our IEA will follow the general guidelines put forth by the U.S. National IEA Steering Committee, deviating only as much as necessary to ensure that our IEA addresses the specific needs of the GOM LME community. One of the major thrusts of the IEA is to foster scientific collaboration among NOAA line offices to bring together the diversity of expertise required to develop ecosystem level analyses and assessments. Towards this end, a GOM IEA Steering Committee was formed with representation from various NOAA line offices, including Fisheries, Ocean Service, National Environmental Satellite, Data, and Information Service, and the Office of Oceanic and Atmospheric Research. In addition, we have been collaborating with regional partners, such as the Northern Gulf Institute.

2.1 Formulation of Sub Committees

As the GOM IEA grew in both funding and scientific capacity, it became apparent that that it would be neither efficient nor practical to have all participants involved in every aspect of the IEA. For instance, while it was certainly necessary for the parties involved with the data aspect to be in touch with those more concerned with ecosystem indicators, it was not necessary that the data providers attend every meeting of the modeling group. Consequently, four subcommittees were formed, consistent with the IEA process, with each of the subcommittees being chaired by a member of the steering committee. In this way, the chairs of the subcommittees could bring back to the steering committee the concerns and needs of their respective group in terms of funding and other requirements (**Figure 1**).

2.2 Outreach and Management Sub Committee

IEAs begin with an identification of management and policy questions. These questions help to define the scope of information and analyses necessary to inform management (Levin et al. 2009). IEAs will also help to identify potential management options which can be evaluated through the process. Management Strategy Evaluations (MSE) are a critical step in the IEA process. Identified MSEs can be evaluated against management goals in support of policy or answering questions. Throughout identification and evaluation of management options, inclusion of stakeholders, resource managers and policy makers is essential.

Stakeholders are valuable sources for information to identify key issues of concerns and stressors that management actions and policy should address. In anticipation of a larger, Gulf-wide IEA, the Northern Gulf Institute (NGI) implemented an IEA in three small areas of the northern Gulf of Mexico. NGI began by identifying coastal sites with ongoing efforts to collect data, characterize the systems, and engage stakeholders. Once the sites were selected, identification of the issues was initiated. Due to the limited scope of these 'pilot' IEAs, the decision was made to involve existing stakeholder groups as much as possible. A scoping workshop was held August 26, 2009 at the Gulf Coast Research Laboratory in Ocean Springs, MS, to solicit stakeholder input on the important Drivers and Pressures for the Mississippi Sound ecosystem (NGI ref). Using similar approaches and existing networks of stakeholders, Drivers and Pressures were formulated for the other two sites. The identified Drivers and Pressures were then combined into a common list that permitted cross-comparison. Similarly, a NOAA-led Gulf IEA team developed a white paper to discuss the need for a Gulf-wide IEA. The white paper identified perceived Drivers and Pressures, and some preliminary indicators. The outcomes from the NGI work and the NOAA white paper provide a solid starting point for the Gulf LME assessment.

2.3 Data Subcommittee

The need for easy and complete access to historical biological and physical data for the Gulf of Mexico was demonstrated during the recent Gulf oil spill. That same requirement is also a fundamental component of the GOM IEA. Stemming from the Gulf oil spill, NOAA's Next Generation Strategic Plan, and the GOM IEA plan, the collaborative effort to create an online Gulf of Mexico Data Atlas began in FY11 and is continuing (http://gulfatlas.noaa.gov). The Gulf Atlas provides a venue to find and extract relevant data needed in the overall IEA process including the modeling effort. The Gulf Atlas serves as a focal point for a wide variety of relevant data and also serves the IEA effort through the assurance of data quality, data documentation, and peer reviewed summaries, and can allow for repeatable analysis results. The Data Sub Committee also is examining time series information for the Gulf to assess natural variability and trends which may be useful in characterizing the overall assessment.

In addition the Data Sub Committee is working to assist the Modeling Sub Committee through the combination of the OceanNOMADS model-data portal and development of the NODC Hydrodynamics Toolbox. OceanNOMADS is the ocean component of NOAA's National Model Archive and Distribution System (NOMADS). The Toolbox provides the ability to pull from a variety of ocean hindcast/forecast models/time periods offered by OceanNOMADS to assemble the required oceanographic input for specific ecosystem models, beginning with Atlantis. This approach will simplify the tedious process of assembling model boundary conditions, and facilitate ensemble modeling efforts using various hydrodynamic forcing models [NOAA's Climate Forecast System Reanalysis (CFSR) vs global operational ocean models vs. regional ocean models].

2.4 Modeling Subcommittee

Because each management question will be unique, so will the development of each of the MSE's. So that each MSE will be developed with a model having the most appropriate degree of detail and realism to match the question at hand, in the FY 2011 GOM IEA statement of work we proposed to begin to develop an Ecosystem Modeling Toolbox, similar to the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/). The NOAA Fisheries Toolbox is a collection of software programs which can be used in fisheries generally single species, stock assessments. Many of the models are used in peer-reviewed stock assessments in the U.S. and globally.

The Toolbox concept has several advantages: (1) it provides a single location from which to store and distribute peer reviewed and simulation tested models and subsequent updates; (2) having one site from which to obtain copies of the model promotes an 'open source' philosophy, which should in turn support increased cooperation amongst the partners; (3) the toolbox effort could easily be extended to other NOAA IEA's soon to be developed. Not only can various models be part of this toolbox, but also various configurations within the same modeling platform. In this way, we will develop a library of various models and considerations mentioned above; the IEA data portal will link to the Toolbox so that modelers can find and readily consume relevant data to facilitate the modeling process.

The modeling subcommittee has deemed that a model ensemble approach be best for address the various GOM MSE's it anticipates analyzing. This stems from the fact that the model must be spatially suited for the particular MSE under consideration. There is no one ecosystem model that can address every MSE that might be encountered. Furthermore, most of the models that are suited for the needs of the GOM IEA are simulation models and as such do not specifically characterize the uncertainty in their outputs. Using the model ensemble approach, the GOM IEA intends to use the outcome of various models, all configured in the same manner, to help quantify the uncertainty in and particular MSE.

The first modeling platform to get developed is a gulf-wide Atlantis model. The Atlantis model is an extremely detailed, spatially explicit ecosystem model with sub routines to handle oceanographic, fishery specifications, and movement of water into and out of the defined polygons.

The second modeling platform to be developed will be the Object-oriented Simulator of Marine ecOSystems Exploitation (OSMOSE) model developed at the Institut de recherche pour le développement (IRD, http://en.ird.fr/). OSMOSE is a multispecies and Individual-based model (IBM) which focuses on fish species. This model assumes opportunistic predation based on spatial co-occurrence and size adequacy between a predator and its prey (size-based opportunistic predation). It represents fish individuals grouped into schools, which are characterized by their size, weight, age, taxonomy and geographical location (2D model), and which undergo major processes of fish life cycle (growth, explicit predation, natural and starvation mortalities, reproduction and migration) and a fishing mortality distinct for each species (Shin and Cury 2001, 2004). (MEECE web site). We have recently begun developing an OSMOS model for the Gulf of Mexico.

2.5 Indicators/DPSER Sub-Committee

The indicators sub-committee is 1) developing a conceptual model framework, 2) developing indicators with which we will assess the status of the Gulf of Mexico, 3) preparing an ecosystem status report for the Gulf of Mexico, and 4) conducting a risk assessment. The first steps we have undertaken are to leverage the plethora of existing activities that have been conducted in the Gulf of Mexico. This allows us to minimize redundancies while also making significant progress in a short period of time. We are also trying to strengthen these projects when necessary to allow them to provide the most useful contribution to the GOM LME IEA effort.

The development of the conceptual model is initially being advanced through the integration of several conceptual modeling efforts that have taken place across a broad geographic range across the United States Gulf of Mexico (Fig. 2). These projects have followed the Drivers-Pressures-State-Impacts-Responses (DPSIR) framework or the slightly modified EBM-DPSER framework where impacts have been replaced with ecosystem services to more fully capture human-ecosystem interactions (Kelble et al. In Prep). The switch to ecosystem services also makes the framework directly applicable to Ecosystem-Based-Management and thus the IEA, since EBM should focus on sustaining or maximizing ecosystem services (Rosenberg and McLeod 2005). The development of this conceptual model provides an important tool to be used within and outside of the IEA. The conceptual model depicts our scientific consensus of how the ecosystem functions, including the interactions with humans. This provides an important communication tool for describing the potential ecosystem impacts of a potential management strategy. Because the conceptual model depicts the key ecosystem components and interactions, it is an invaluable tool for identifying potential ecosystem indicators. Initially, we are comparing the different models developed across these regions to create a single EBM-DPSER model for use gulf-wide.

The development of indicators within the Gulf of Mexico has begun by examining currently employed ecosystem indicators relative to a set of established criteria representing EBM goals and objectives. A set of preliminary criteria were developed from previously employed, peer-reviewed criteria. These criteria fall into 3 main categories relating to primary requirements, data and analysis availability, and Communication. The proposed criteria are as follows with their respective citations:

Primary Criteria

1. Does the indicator provide an integrative measure of the overall status of the ecosystem or of essential ecosystem structures, functions or processes? (Doren et al. 2009, Dale & Beyeler 2001, Luckey 2002)
2. Does the indicator relate to ecosystem service(s)? (modified from Feld et al. 2009)
3. Is the indicator relevant to management goal(s)? (Bradley et al. 2010)
4. Is the indicator sensitive to system Drivers and Pressures? (Doren et al. 2009, Dale & Beyeler 2001, ICES 2002)

Data/Analysis Criteria

5. Is the indicator based upon data that can be generated with accuracy and precision relatively easily and for which there is sufficient existing data to evaluate change going forward? (Doren et al. 2009, ICES 2002, Dale & Beyeler 2001, Rice & Rochet 2005)
6. Is it possible to predict how the indicator will respond to changes in the ecosystem (including societal changes) over management-relevant time scales? (Feld et al. 2009, Dale & Beyeler 2001)
7. Does the indicator have a response that is easily detectable above the background variability to make it useful in measuring response to management actions or a change in a pressure that may or may not be a result of management action(s)? (This means the response signal should be attributable to a change in management or pressure.) (ICES 2002, Bradley et al. 2010)

Communication

8. Is the indicator understood by managers and the public? (Rice & Rochet 2005)
9. Does the indicator respond to stress earlier than the rest of the system (i.e. is it a leading indicator?)? (Dale & Beyeler 2001)
10. How long will it take for the indicator to show a response to possible management actions? (Dale & Beyeler 2001)
11. Has the indicator been employed effectively either in the Gulf of Mexico or elsewhere? (NRC 2000)

Once the indicators are identified, the process of setting indicator targets is undertaken. This process is the most controversial as you must define indicator values (levels or concentrations) that reflect progress toward ecosystem management goals. These reference points can be divided into targets and limits; whereby, targets reflect desired conditions for the indicator and limits represent undesirable indicator conditions that should be avoided (Samhouri et al. 2012). Quantifying reference limits are relatively straightforward, because they can be based on ecological thresholds that are to some degree already defined (Dong et al. 2002). However, the identification of reference targets is more complex and to be complete should take into account human desires and goals for the ecosystem that are defined in the scoping step. Thus, the quantification of these targets reflects the integration of human and biophysical dimensions making it a more subjective process.

The first utility of these indicators will be to develop the ecosystem status report for the Gulf of Mexico. This status report will assess the current status and trends of the Gulf of Mexico. This status will initially be assessed relative to historic conditions and aim to define the interactions between the various indicators to further our understanding of the current status and ecosystem, including humans, interactions.

The indicators and conceptual models will be analyzed through connected processes to conduct a risk assessment. The first step will be to quantify the current risk posed by the variety of pressures in the Gulf of Mexico to the diversity of ecosystem services produced by the Gulf of Mexico. This will modified from Altman et al. (2011) to link pressures-to-state then state-to-state and finally state-to-ecosystem services through a series of matrix scores that reflect the magnitude and extent of the connection between all ecosystem components. The end-result will be identification of ecosystem services most at risk under the current ecosystem configuration and the pressures producing the greatest effect on the widest range of ecosystem services. After delineating these linkages, scenario analyses can be undertaken that use these connections in the EBM-DPSER model to determine the impact of a potential changes in management strategies on the whole range of ecosystem services (Tscherning 2012).

3. First Proposed Management Strategy Evaluation

MSE's are the products in which the success of the GOM IEA will be measured. One of the few strictly quantitative management strategies being used in the GOM is the harvest control rule used by the Gulf of Mexico Fishery Management Council (GMFMC). The control rule assumes that an estimate of the overfishing level (OFL), stated in weight, has been calculated and some reasonable measure of statistical uncertainty about the OFL also exists. The concept developed is designed to be objective in nature and operates by adjusting the probability of overfishing or P* value. The control rule generates penalties or reductions based on four characteristics of stock assessments: assessment information, characterization of uncertainty, stock status, and productivity and susceptibility. The assessment information dimension reflects available data and assessment outputs. The characterization of uncertainty dimension reflects how well uncertainty is characterized in the assessment, not the actual magnitude of the uncertainty. Stock status is included among the dimensions so that an additional adjustment to ABC can be added for stocks that are overfished or overfishing. The final dimension addresses biological characteristics of the stock, including productivity, which reflects a population's reproductive potential, and susceptibility to overfishing, which reflects a stocks propensity to be harvested by various fishing gears. Each dimension has a maximum penalty of 10% associated with it. The sum of penalties is subtracted from the base case of P*= 50%, which is when the ABC=OFL. Depending on the characteristics and results of a given stock assessment, the corresponding P*, which is used to determine the ABC value, can range from 50% to 10%. P*, "P-Star", then is the probability of overfishing occurring at a chosen catch level.

There are many episodic events, natural and otherwise, that can results in spikes in the average natural mortality rate of fish. One episode known to cause spikes in natural mortality in red grouper is a Harmful Algal Bloom (HAB) and associated hypoxia (severe oxygen depletion). HAB's are generally associated with red tide events that occur along the eastern GOM.

4. Obstacles to the Ecosystem Based Management of the GOM

As the GOM IEA is a new approach to Ecosystem Based Management, there are several obstacles that will need to be overcome in order for it to effective. Here we list only a very few:

1. Well defined (verbally and mathematically) ecosystem Goals, Objectives, and Products
2. We lack a unified management body to that can reach across the various ecosystem services
3. Of course, the lack of long time series of appropriate data (food habits, trophic linkages past, present, future)
4. Like our colleagues in stock assessment, we need to ensure that uncertainty is propagated throughout the model and clearly communicated (i.e. What is the Risk?)

Surely, more challenges will come to light as we progress and we anticipate that the GOM IEA will need to constantly adapt in order to grow and remain a useful tool to the management and scientific community.

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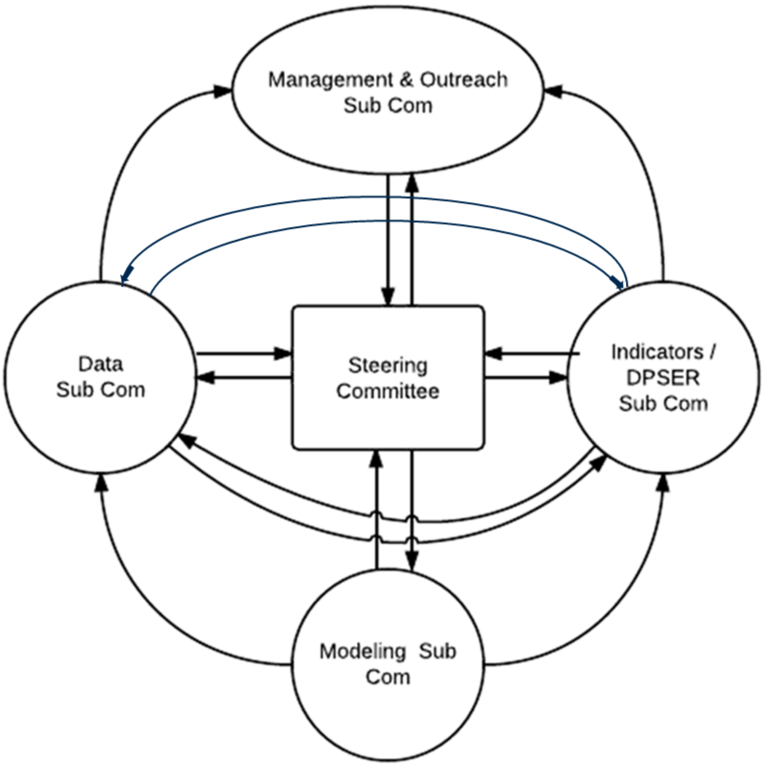

Figure 1. The organizational chart for the Gulf of Mexico IEA is designed to allow scientists to interact within the topic areas most aligned with their area(s), while still allowing the IEA to complete the components outlined in Levin et al. (2009).

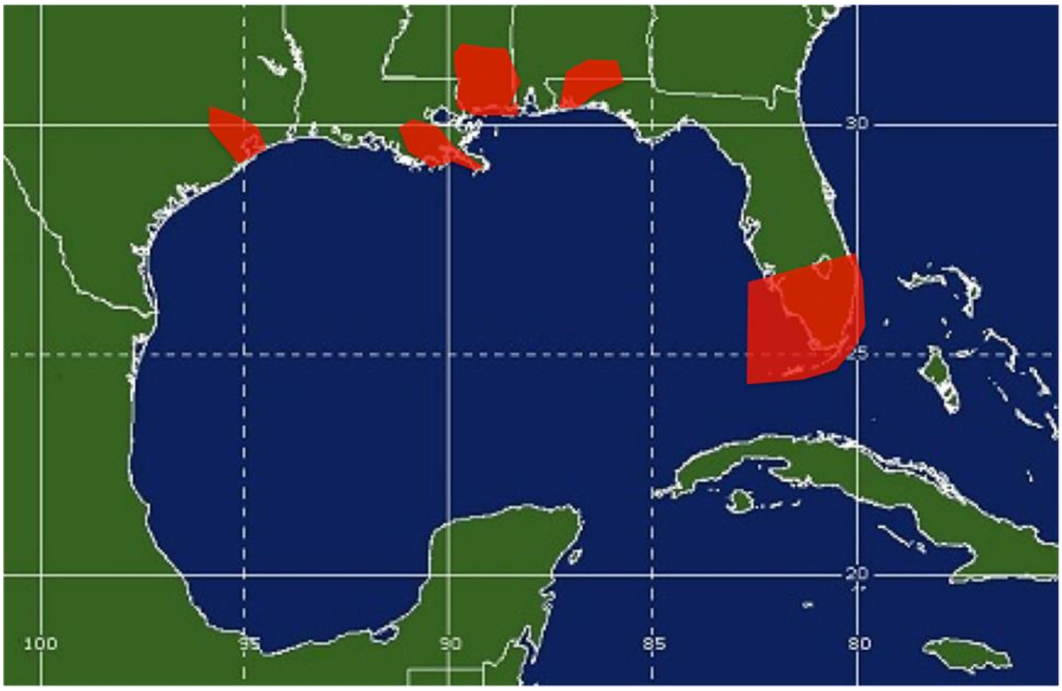

Figure 2. Map showing the Gulf of Mexico Large Marine Ecosystem. The areas in red are where projects have been undertaken to develop conceptual modeling frameworks following either DPSIR or the modified EBM-DPSER framework.