Annual Progress Report

A. Grant Number: NA16NOS4780202

B. Amount of Grant: $900,000

C. Project Title: NGOMEX 2016: User-Driven tools to predict and assess effects of reduced nutrients and hypoxia on living resources in the Gulf of Mexico

D. Grantee Organization: George Mason University

E. Award Period: From: 09/01/2016 To: 08/31/2020

F. Period Covered by this Report: From 06/01/2018 To: 05/31/2019

G. Summary of Progress and Expenditures to Date:

1. Work Accomplishments: (as related to project objectives and schedule for completion)

    a. Provide a brief summary of progress, including results obtained to date, and their relationship to the general goals of the grant

Overall Progress and Status:

An expansive hypoxic zone in the Northern Gulf of Mexico (NGOMEX) will affect ecologically and economically important living resources, but the magnitude, predictability and even the direction of these changes remain elusive. Managers and stakeholders alike need readily available and quantitative tools to assess the effects on living resources of planned nutrient reduction strategies aimed to minimize the hypoxic zone. Our proposed program couples spatially-explicit ecosystem, bioenergetics, and water quality models to evaluate alternative management strategies, interannual differences in water flows, nutrient loading and water temperatures, and longer-term climate changes on living resources.

Our work thus far and our plan for the future both focus on the development of user friendly, management-scale relevant forecasting tools and our project is on target as originally proposed. We have made substantial progress towards our goals this year. It has also been a very productive project to date, with 7 manuscripts accepted for publication, 3 manuscripts in review, progress on drafts of 4 manuscripts, 16 papers given or accepted for presentation, 5 special sessions or symposia at major scientific conferences, and two management committee workshops, one held during the Fisheries Monitoring Workgroup Meeting, May 2018 in Stennis, MS, and one planned for June, 2019 in Miami, FL.

<u>Bioenergetics Models:</u> We proposed that we would improve species bioenergetics, food web, and spatially/temporally explicit modeling capabilities of key living resources in the NGOMEX in response to changing hypoxic and climatic conditions. We have made substantial progress towards completion of this goal over the past year. We now have five bioenergetics models ready that are being applied to simulations. We have developed a bioenergetics-based growth rate potential model for brown shrimp (*Farfantepenaeus aztecus*). We have also refined bioenergetics-based growth rate potential models for red snapper (*Lutjanus campechanus*), Atlantic croaker (*Micropogonias undulatus*), and Gulf menhaden (*Brevoortia patronus*) (Figure 1). We prepared a previously developed bioenergetics model for bay anchovy (*Anchoa mitchelli*) to be used in simulations by coding the model in R statistical language. These models have been developed and revised in collaboration with Kenny Rose's lab to ensure the results of our research can be compared. Finally, we scoped out a bioenergetics model for Atlantic bumper but were unable to locate enough basic information on bumper metabolism to create a full bioenergetics model.

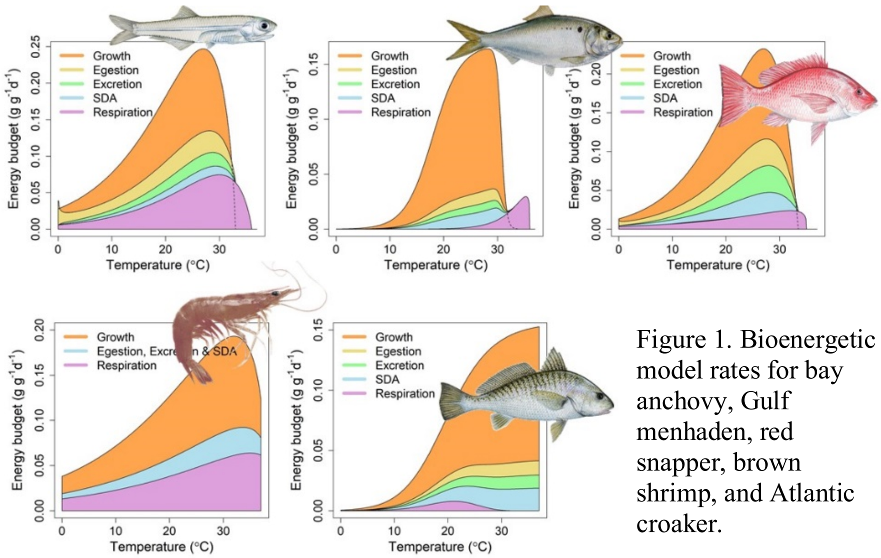

Figure 1. Bioenergetic model rates for bay anchovy, Gulf menhaden, red snapper, brown shrimp, and Atlantic croaker.

<u>Connecting Nutrient Loading to Fish Habitat Quality:</u> We proposed that we would determine effects of nutrient loading and hypoxic volume reduction scenarios on growth rate potential, habitat quantity and quality, and fish population size. We have made substantial progress toward this goal in the past year. We examined the effects of nutrient loading and hypoxic volume reduction scenarios on growth rate potential, habitat quantity and quality and made direct linkages of Fish Habitat models to the 3-D water quality model output under various nutrient loading scenarios. Code was developed in Matlab and R to run GRP models on ROMS model output. Additional code was developed to produce time series and maps of GRP for each depth layer. This year we specifically focused on completing the ROMS-to-GRP linkage for Gulf menhaden,bay anchovy, and red snapper. The GRP model for these species was run on over 160,000 cells on a daily basis over 16 years (2000 – 2016)in the 3D hydrodynamic/water quality model for the following scenarios: 60N/60P, 80N/80P, and 100N/100P. Phytoplankton and zooplankton output from the ROMS model were used as the prey source for the menhaden and anchovy GRP models, respectively. The procedure is mostly automated, described by a detailed workflow, and can be customized and replicated for additional scenarios and species.

Habitat quality for menhaden in this model does not appear to be impacted by prey (phytoplankton) density (Figure 2). Menhaden GRP increased in areas where hypoxia decreased (Figure 1). There were few changes in menhaden GRP with a 20% reduction in nutrients, but a larger difference in menhaden GRP with a 40% reduction in nutrients, indicating that fish response to nutrient reduction is unlikely to be linear.

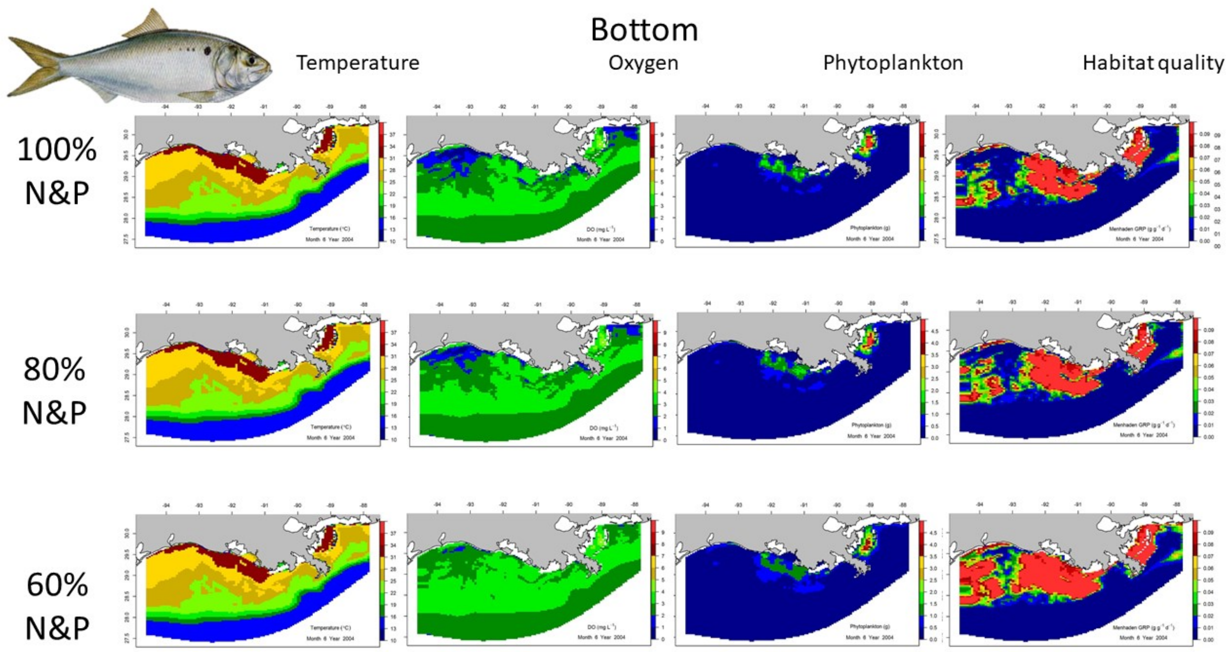

Figure 2. Maps of temperature, oxygen, phytoplankton, and GRP for menhaden at the bottom of the water column in June 2014 under scenarios of 100% N&P, 80% N&P, and 60% N&P.

In our models, a reduction in nutrients means lower habitat quality for anchovy, because lower nutrients means less zooplankton (Figure 3). Anchovy habitat quality is rarely impacted by hypoxia in these models because GRP is low in the summer, largely due to high temperatures and low zooplankton concentration (Figure 3).

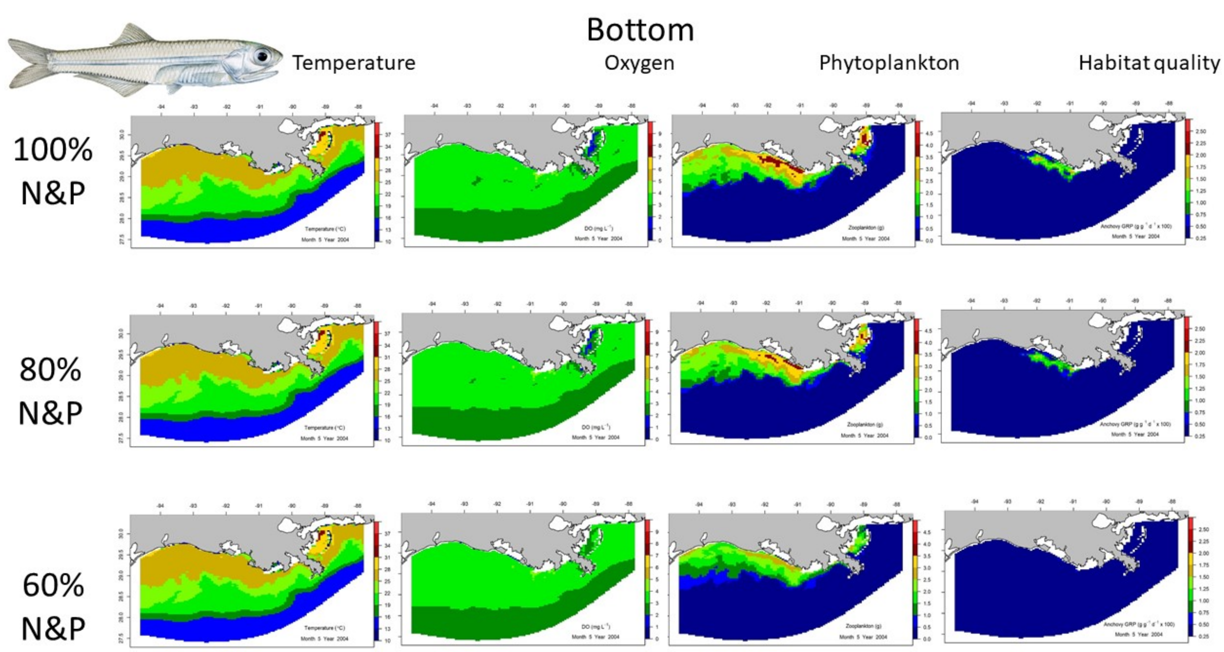

Figure 3. Maps of temperature, oxygen, phytoplankton, and GRP for anchovy at the bottom of the water column in June 2014 under scenarios of 100% N&P, 80% N&P, and 60% N&P.

Time series of hypoxic volume show little reduction in hypoxia when nutrients are reduced (Figure 4). This is likely because our model domain extends well beyond the shallow waters where hypoxia occurs. If the model domain were restricted to shallow waters, the time series would show a reduction in hypoxic volume when nutrients are reduced.

Nutrient reduction results in a lower (and less variable) proportion of the water column with phytoplankton biomass densities > 2 g m^{-3} (Figure 4). This reduction in lower trophic level biomass occurs in the spring and summer. Similar trends are evident in zooplankton biomass (not shown). A 40% reduction in nutrients made a much larger impact on phytoplankton biomass than a 20% reduction in nutrients, indicating the lower trophic level response to nutrient reduction is nonlinear.

Menhaden GRP increased with nutrient reduction in the summer months due to reduction in hypoxic volume near shore (Figure 4). However, a decline in menhaden habitat quality was observed every year in late summer. These declines were attributed mainly to high temperatures and in part to hypoxic volume.

Anchovy GRP declined with nutrient reduction (Figure 4). These declines were attributed to declines in zooplankton biomass. Similar to trends in phytoplankton biomass, a 40% reduction in nutrients made a much larger impact on anchovy GRP than a 20% reduction in nutrients, indicating a nonlinear response to nutrient reduction.

We compared the numerical means of the growth rates across the year. As an example, for modelled year 2004, the arithmetic mean growth rate of menhaden increased by 2.5% and 7.7%, respectively, under a 20% and 40% nutrient reduction strategy (Figure 5). These modest increases occurred mainly in summer. These changes were less than those calculated at +/- 15% change in growth on an interannual basis (Figure 6). In contrast, anchovy growth decline by over 11% under a 40% reduction in nutrients because of the reduction of zooplankton abundances (Figure 7). Very little of the water volume supports anchovy growth and these areas were significantly reduced.

Red snapper experienced a modest increase in mean growth rates (6.2%) under nutrient reduction of 40% (Figures 8 and 9). Changes in food availability were not considered for these model runs.

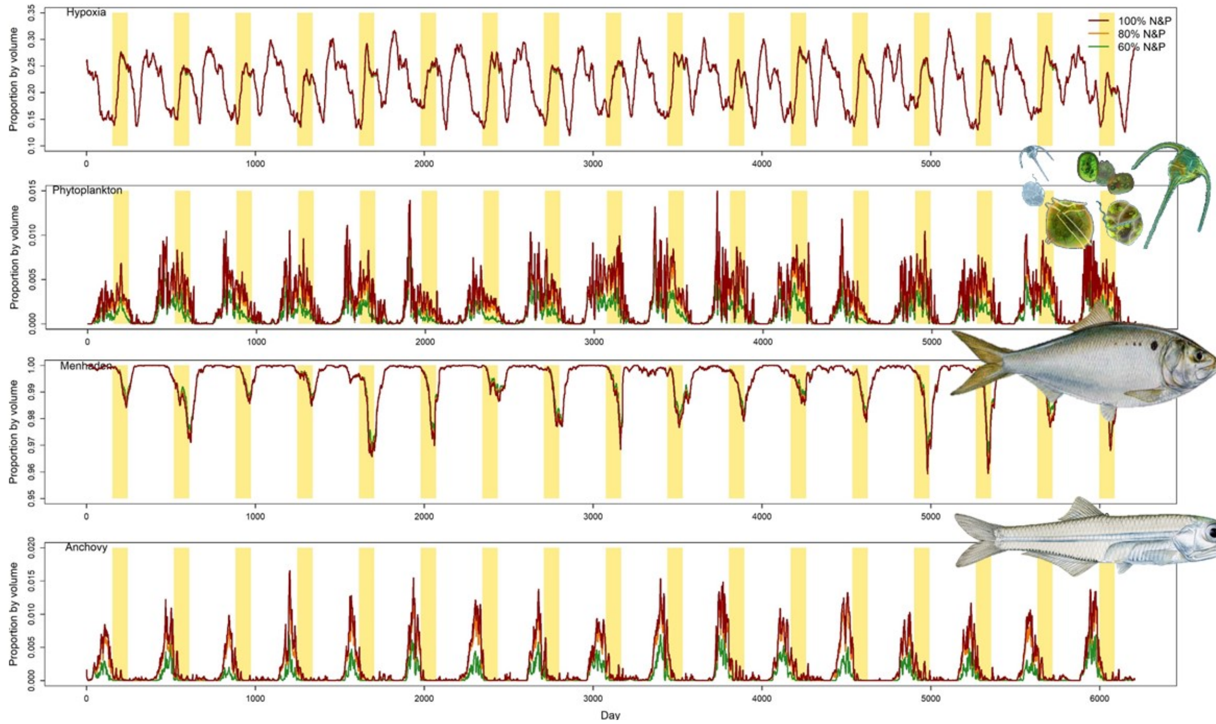

Figure 4. Time series from beginning of 2000 to end of 2016. Proportion of the water column by volume of hypoxic water (dissolved oxygen < 2 mg L^{-1}), phytoplankton (> 2 g m^{-3}), menhaden GRP (> 0 g g^{-1} d^{-1}) and anchovy GRP (> 0 g g^{-1} d^{-1}). Yellow shading are summers (June-August).

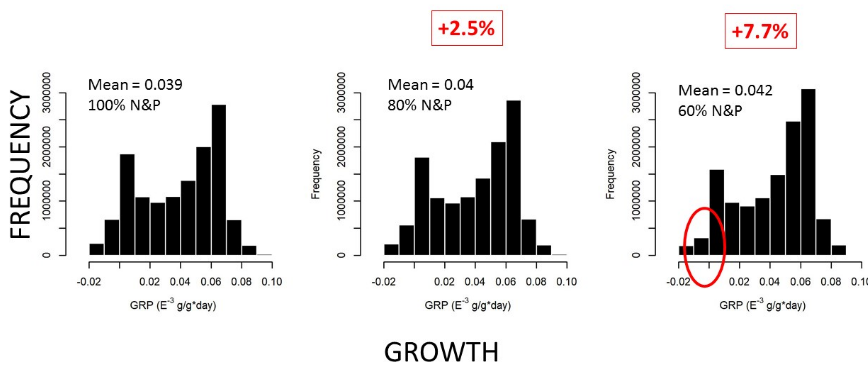

Figure 5. Frequency histograms of menhaden GRP for 100%N&P (left), 80%N&P (center), and 60%N&P (right). On average, GRP increased by 2.5% under 80%N&P and 7.7% under 60%N&P. These averages do not take into account water volume of individual cells in the ROMS model.

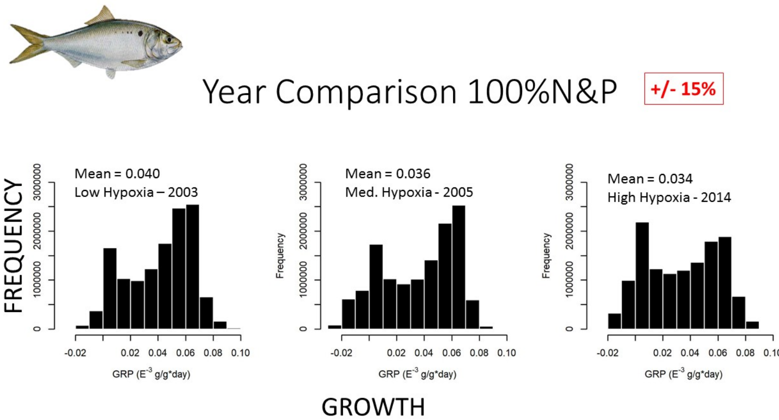

Figure 6. Frequency histograms of menhaden GRP for three years, one with low hypoxia (left), moderate hypoxia (center), and high hypoxia (right). On average, GRP varied by 15% interannually, under a given nutrient reduction scenario. These averages do not take into account water volume of individual cells in the ROMS model.

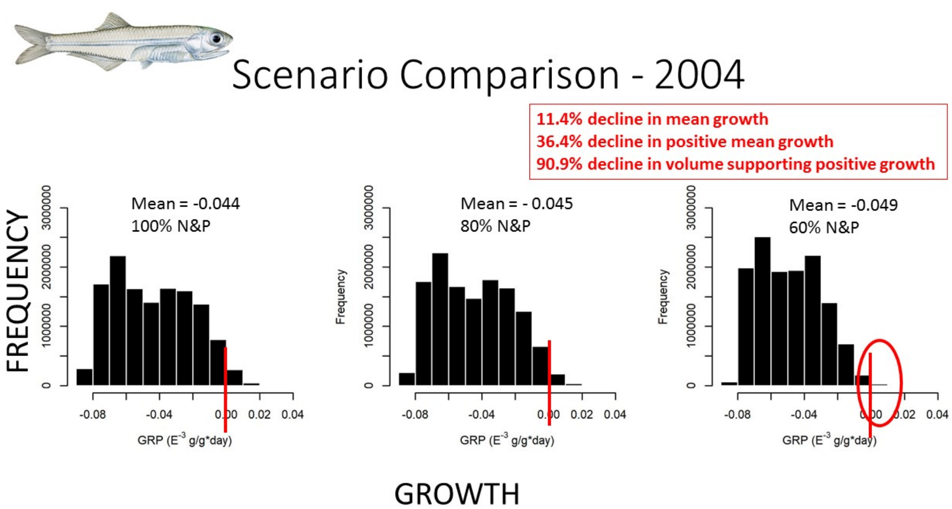

Figure 7. Frequency histograms of anchovy GRP for 100%N&P (left), 80%N&P (center), and 60%N&P (right). On average, GRP decreased by 11.4% under 60%N&P. There was a 36.4% decline in cells with positive GRP (positive scope for growth), and a 90.9% decline in volume supporting positive growth.

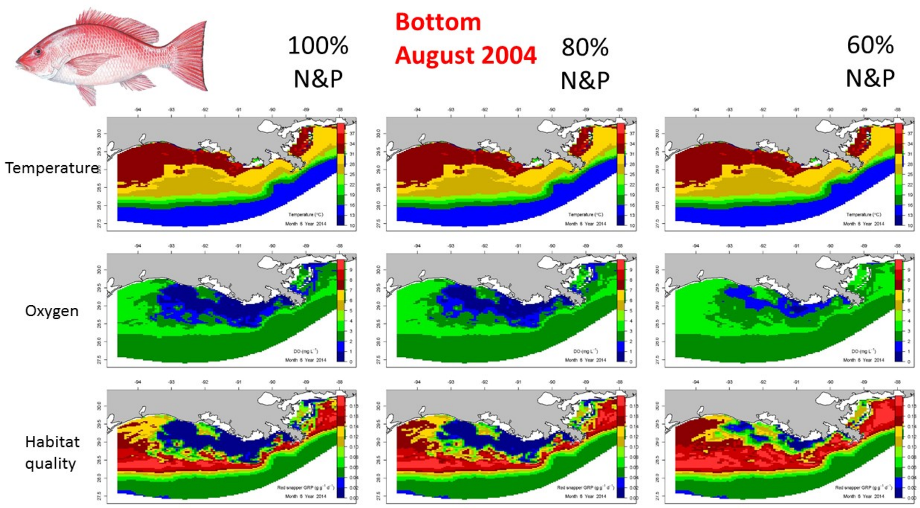

Figure 8. Distribution of temperature (top), dissolved oxygen (middle) and red snapper GRP (bottom), for 100%N&P (left), 80%N&P (center), and 60%N&P (right). These are for the bottom layer of the ROMS model in August 2004.

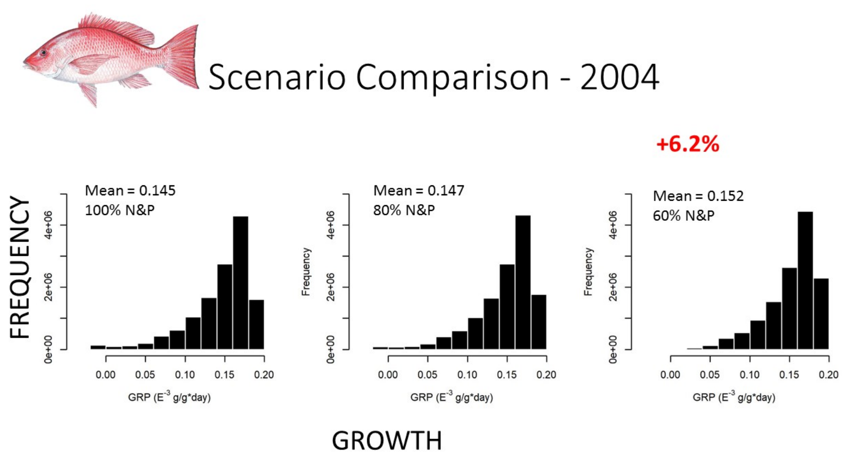

Figure 9. Frequency histograms of red snapper GRP for 100%N&P (left), 80%N&P (center), and 60%N&P (right). On average, GRP increased by 6.2% under 60%N&P. These averages do not take into account water volume of individual cells in the ROMS model.

Fish Diets in Hypoxic Areas

The occurrence of low dissolved oxygen (hypoxia) in coastal waters may alter trophic interactions within the water column. This study identified a threshold at which hypoxia in the northern Gulf of Mexico (NGOMEX) impacts the fish community composition and diet composition (stomach contents) of fishes. Using fish trawl data from summers 2006 - 2008, we examined the impact of hypoxia on fish catch and determined how fish diet differs for fish caught in normoxic and hypoxic areas. Hypoxia in the NGOMEX impacted fish catch per unit effort (CPUE) and diet at dissolved oxygen concentrations between 1.1 and 3.3 mg L^{-1}. CPUE of many fish species was lower at hypoxic sites (≤ 1.6 mg L $^{-1}$) as compared to normoxic regions (> 1.6 mg L $^{-1}$), including the key recreational or commercial fish species blue runner *Caranx crysos* and red snapper *Lutjanus campechanus*. Overall, fish diets from hypoxic sites and normoxic sites differed. Compared to diets of fish in hypoxic regions, the mean mass of prey fish was greater in diets of zooplanktivorous fish caught in normoxic regions, and the mean mass of squid and benthic prey (gastropods, polychaetes) was greater in diets of non-zooplanktivorous fish caught in normoxic regions. Hypoxia may increase predation risk of small zooplankton, with observations of increased mass of small zooplankton in fish stomachs when bottom hypoxia was present. Impacts of hypoxia on fish diet may alter energy flow in the NGOMEX pelagic food web, and should be considered in fisheries management

<u>Interannual Fish Habitat Quality:</u> **We have made substantial progress towards our goal of reconstructing water column fish habitat quality for each of the key species using field data (temperature, oxygen, and chlorophyll) from research cruises conducted between 2003 and 2010.** We analyzed historic field data from research cruises (2003, 2004, 2006, 2007, 2008, 2009 & 2010) to identify fish habitat quantity and quality in the Gulf of Mexico. We plotted dissolved oxygen, water temperature and chlorophyll data for the entire seven years of data and for depths ranging from 0 – 29 meters at one meter intervals. All transects were processed to remove noise caused by non-biological sources (e.g., surface turbulence caused by waves or ship wakes, methane gas bubbles, bottom return effects). We extracted ROMS model output along each transect to validate model results with real field conditions.

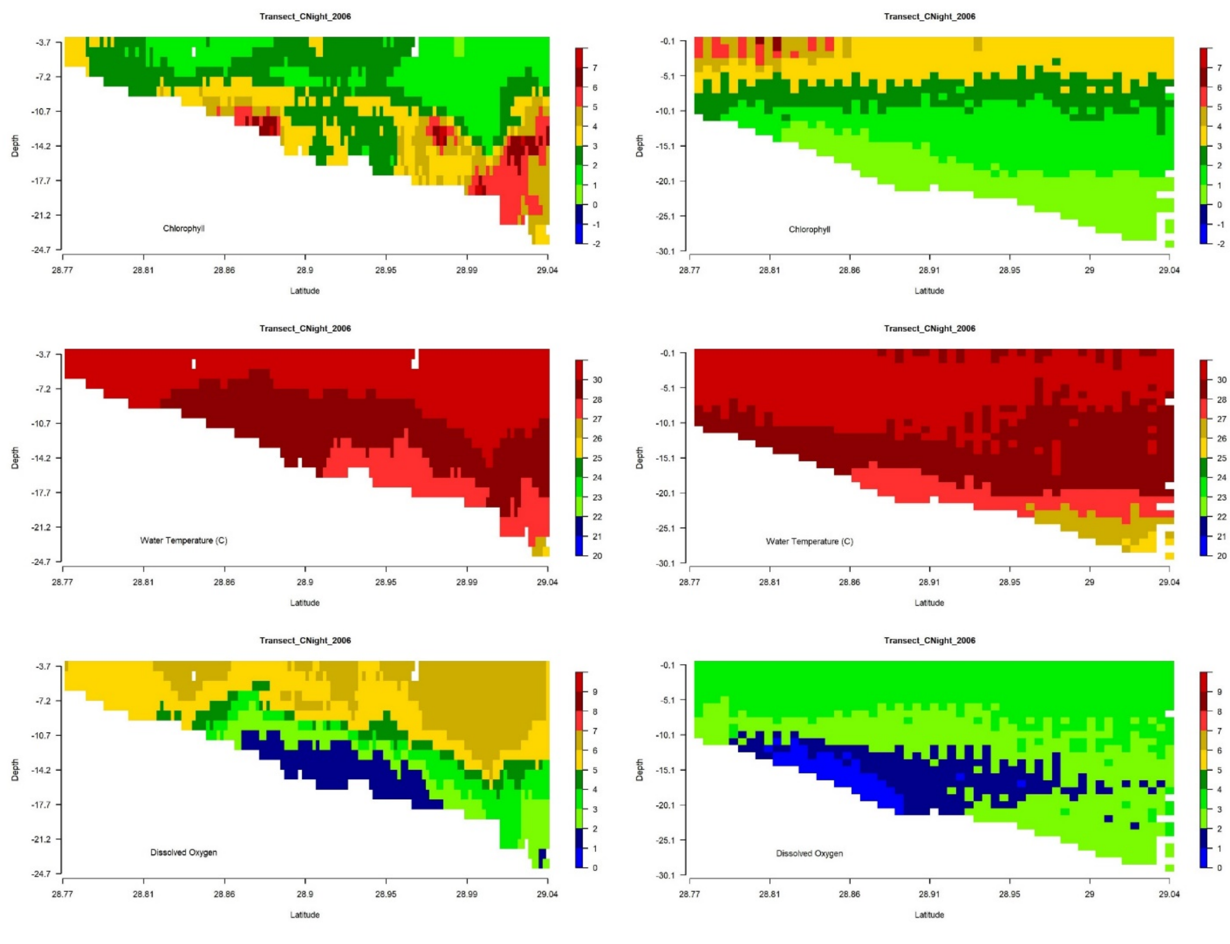

Figure 10. Transects of chlorophyll (top), temperature (mid) and dissolved oxygen (bottom) from field transects (left) and ROMS model output (right).

Transect temperature and dissolved oxygen closely matched model results (Figure 10). The ROMS model was able to replicate stratification in temperature and bottom hypoxia during the summer months. However, the ROMS model's chlorophyll output did not match observed spatial trends in chlorophyll. In the field, a midwater chlorophyll maximum is often observed just outside the hypoxic zone (Figure 10). The ROMS model did not reproduce this midwater chlorophyll maximum, but instead confined high chlorophyll production to surface waters. We are currently exploring the cause of this difference.

Data Coverage Analysis

We analyzed the availability of public ocean environmental data which will aid in examining past, present and future dead zone scenarios. Public available data can be obtained presently from three sources: 1) NOAA's World Ocean Database (WOD); 2) Southeast Area Monitoring and Assessment Program (SEAMAP); and the Biological and Chemical Oceanography Data Management Office (BCO-DMO). Present coverage of the Gulf of Mexico by both WOD (Figure 11), SEAMAP (Figure 12), and BCO-DMO cruise data (Figure 13) are sufficient for the northern Gulf of Mexico. However, there are questions as to the role of the Loop Current in the formation of the Dead Zone. Since the Loop Current is central to the entire Gulf, future coverage should focus efforts on the entire Gulf.

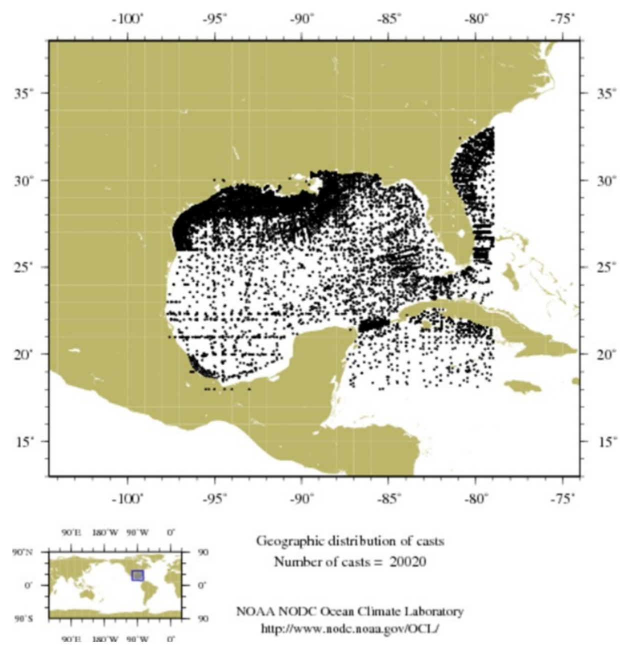

Figure 11. WOD coverage from 1920 – 2017

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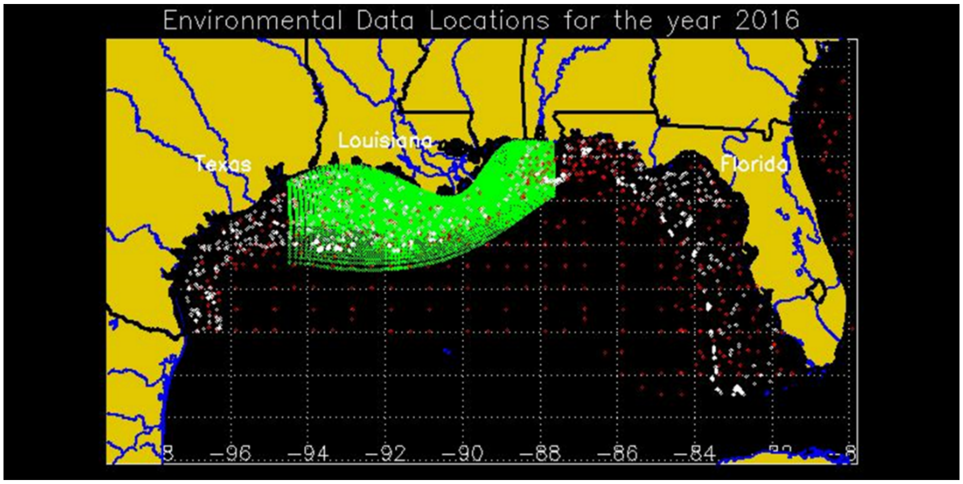

Figure 12. Combined data from WOD and SEAMAP for the year 2016 overlain with the 3-D model range. Green is the ROMS model outline, WOD (red) and SEMAP (white).

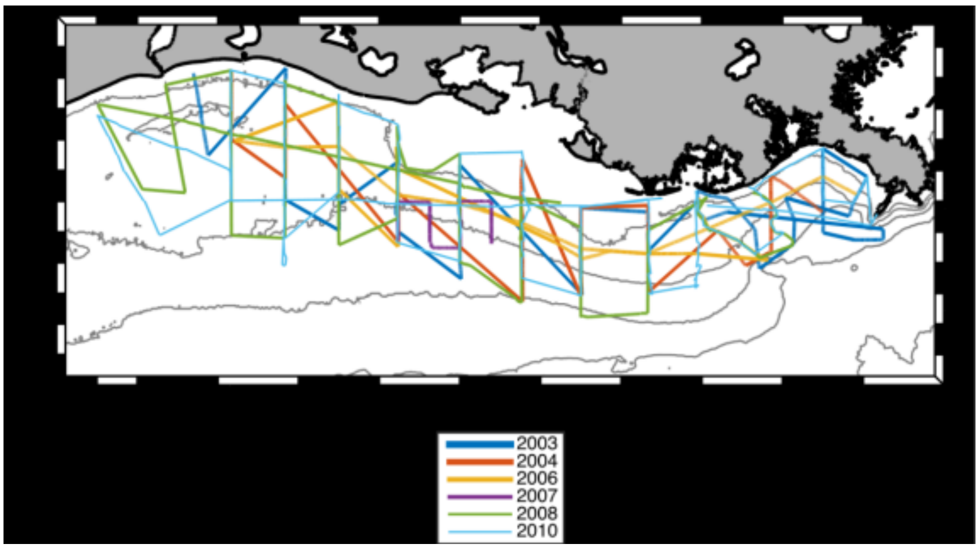

Figure 13. BCO-DMO cruise data contributed by Dr. Stephen Brandt.

Ecopath model improvements

The partnerships established during this project has led to access to stock assessment models and data, most of which had been out of reach to our team before due to the classified nature of some of the data (lead PI Kim de Mutsert has now gone through the process to be allowed to view classified data through a NOAA South East Fisheries Science Center sponsor) or the general lack of access to these products. With integration of environmental factors such as hypoxia into stock assessment as one of our goals, it was deemed worth the time and effort to reparameterize the Ecopath model again for those groups or species in the model for which this information was available, which were Carangidae, Spanish Mackerel, Red Snapper, Serranidae, Other Snappers, Gulf Menhaden, Brown Shrimp, White Shrimp, and Pink Shrimp. In addition, the group 'Mackerel' was split into King Mackerel and Spanish Mackerel and both parameterized as separate species. Such extensive changes required rebalancing the Ecopath model and recalibrating the model by fitting it to new time series in Ecosim. These changes were on top of the changes described in last year's report, where amongst other things diet data were updated using the cruise data collected by Roman and Brandt in our previous NGOMEX project, the GoMexSi diet dataset, and new literature since the previous version of the model was developed (literature since 2012). Gulf Butterfish was added which was one of the recommendations that came out of the first workshop (juveniles and adults). Multiple multi-stanza groups were created for Gulf Menhaden to match the life stages in stock assessment. Fisheries information (fleets and landings) was updated. The reparameterization of groups using stock assessment also requirered the reevaluation of the diet matrix, since the biomass of groups relative to eachother had extensively changed. Most notably, the biomass of Gulf Menhaden, brown Shrimp, White Shrimp, and Pink Shrimp increased dramatically when based on stock assessment data rather than SEAMAP survey. This required some extensive changes in amount of predation and other factors to rebalance the model. A change made in the Ecopath model regarding fleets is that the longline fishery has been removed from the model as that was deemed to occur outside the bounds of the model area by stock assessment scientists that are more informed regarding the spatial distribution of the effort. Structurally the flow diagram is very similar as represented below (Figure 14), but a new one will be constructed when all changes are final.

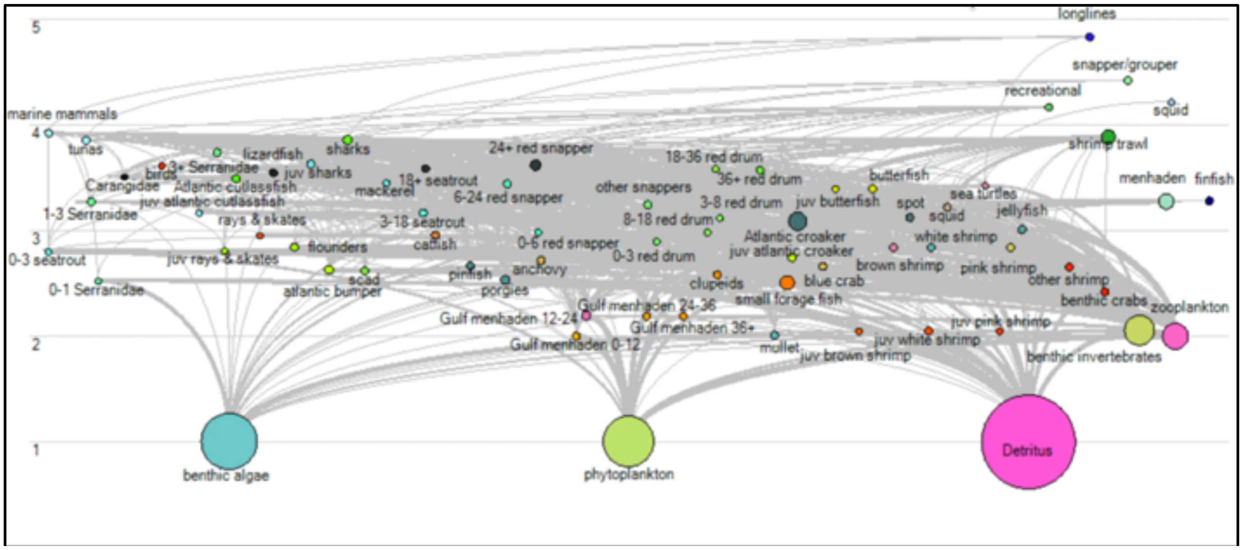

Figure 14. Trophic diagram of the new NGOMEX Ecopath model. The y-axis represents trophic level, the size of the dots the relative size of the biomass pool, the connectors represent predator-prey interactions or in case of the fleets (upper right corner) the connection to the species a particular fleet removes (including bycatch).

Ecosim calibration

When Ecopath biomass comes from a new source as was done for the species described above, the calibration time series need to be replaced with data from the same source as well. In addition to new catch and biomass time series to calibrate the reparameterized groups the stock assessment models also provided fishing mortality to calibrate the model against. The new model was recalibrated in Ecosim, using annual fisheries independent observations (SEAMAP data), and stock assessment biomass estimates to calibrate biomass, and fisheries landings and fishing mortality to calibrate catch (where fishing mortality has an effect on biomass calibrations as well). Environmental driver output from the ROMS model was spatially averaged and included in the calibration process. Using AIC was determined that adding salinity and temperature did not improve the model for calibration, although they will be added in the spatial model. This was to be expected as the average salinity and temperature may not explain much of the variation, while they may provide important contributions to species distribution once in Ecospace and one value per grid cell (per month) is included in each simulation. The model was fitted to biomass (Figure 15) and landings data (Figure 16) with the vulnerability exchange rate as the variable parameter. The best-fit model was determined using AIC and sum of squares deviation.

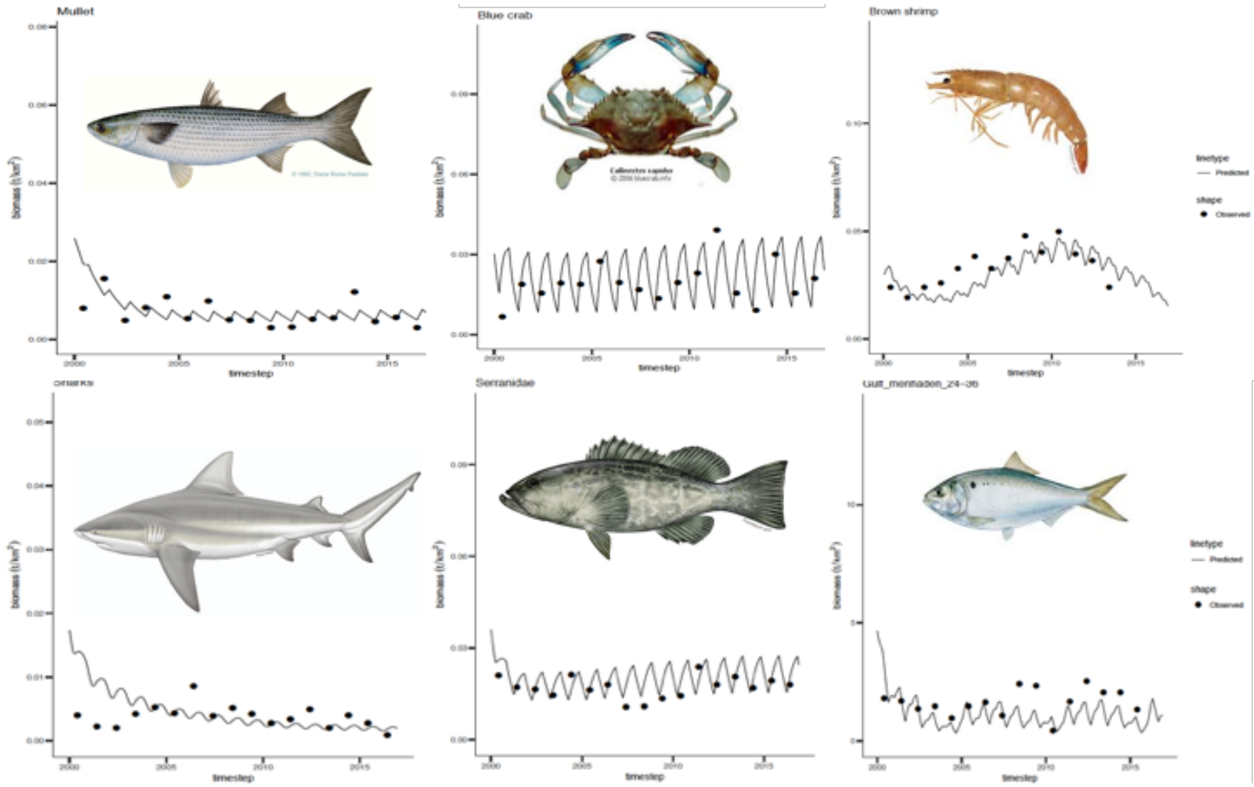

Figure 15. Select biomass calibration plots. The dots are observations, while the lines represent simulated biomass in the model.

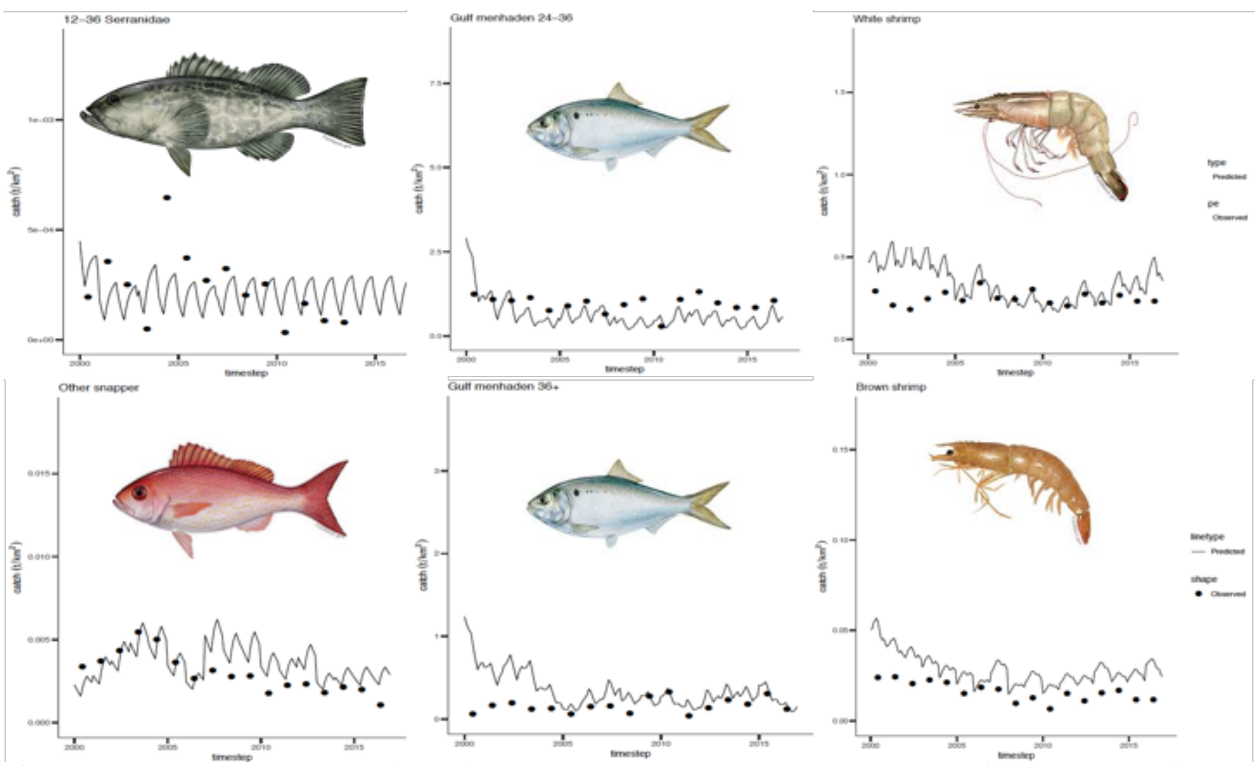

Figure 16. Select catch calibration plots. The dots are annuals landings data, while the lines represent simulated catch in the model.

Ecospace development and simulations:

The spatial-temporal framework as described in Steenbeek et al. (2013) is incorporated in the model framework, which was not the case with the previous version of the model. While a custom plug-in allowed for spatial and temporal variation of dissolved oxygen and Chl *a* specifically, this was a limited (to those two parameters) spreadsheet-based approach. The spatial-temporal framework is GIS-based and allows for inclusion of an unlimited amount of map layers representing the condition in each cell based on environmental parameters and/or habitat attributes. In a spatial simulation scenario, the value of each cell is updated with each monthly time step (i.e. a new map is read in per parameter at the start of each time step). The environmental drivers loaded in this fashion are based on output from the physical-biological ROMS model. The ecospace domain is adjusted the exactly fit that of the ROMS model as shown in Figure 17.

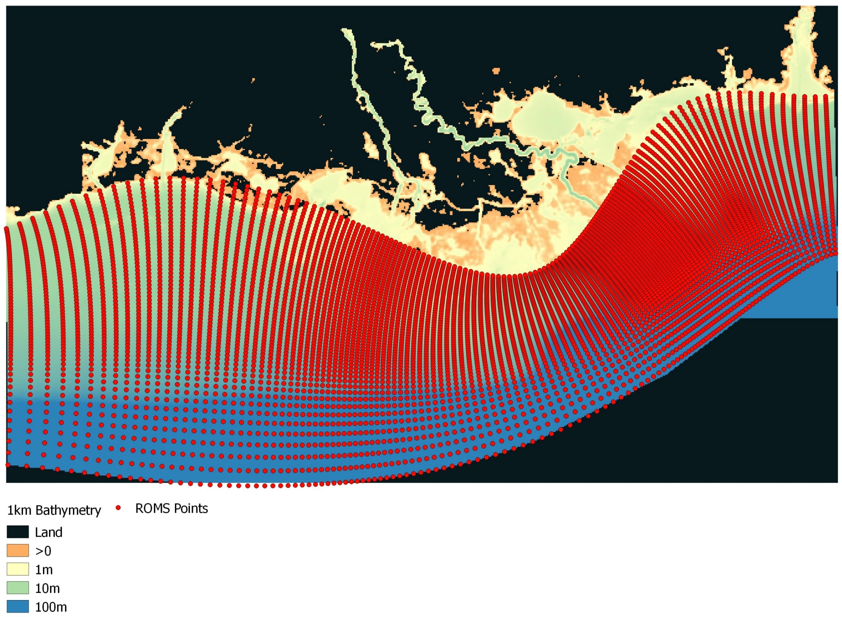

Figure 17. Ecospace model domain. Red dots indicate the ROMS model domain. The Ecospace model domain is fit to the ROMS model domain by applying an exclusion layer over the areas that do not receive ROMS output.

Examples of driver maps are shown in Figure 18 and 19. The groups in the model respond to these drivers as prescribed by species-specific response curves. As part of the spatial-temporal framework, these response curves are loaded as graphs, and can take any shape. This is an upgrade from the previous model as well, where response curves were loaded in a spreadsheet as optimum and standard deviation with either a binomial or sigmoidal shape. Because of this, all new response curves were created for dissolved oxygen, temperature, and salinity based on SEAMAP data where fish and environmental parameters were collected simultaneously, and published salinity and temperature tolerance ranges.

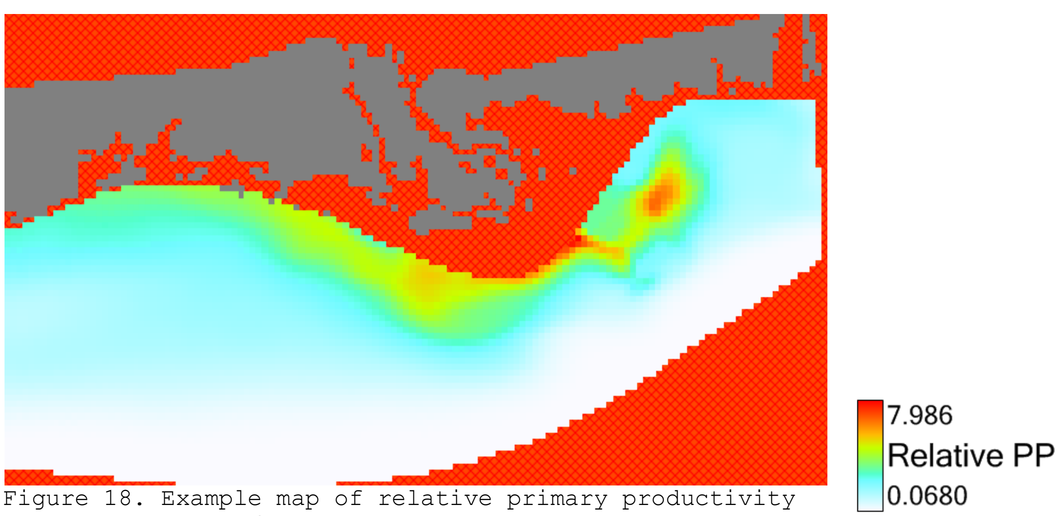

Figure 18. Example map of relative primary productivity based on ROMS Chl a output. This map represents January 2000. The red crossed-out area is an exclusion layer, and ensures only cells that receive ROMS data as drivers are active.

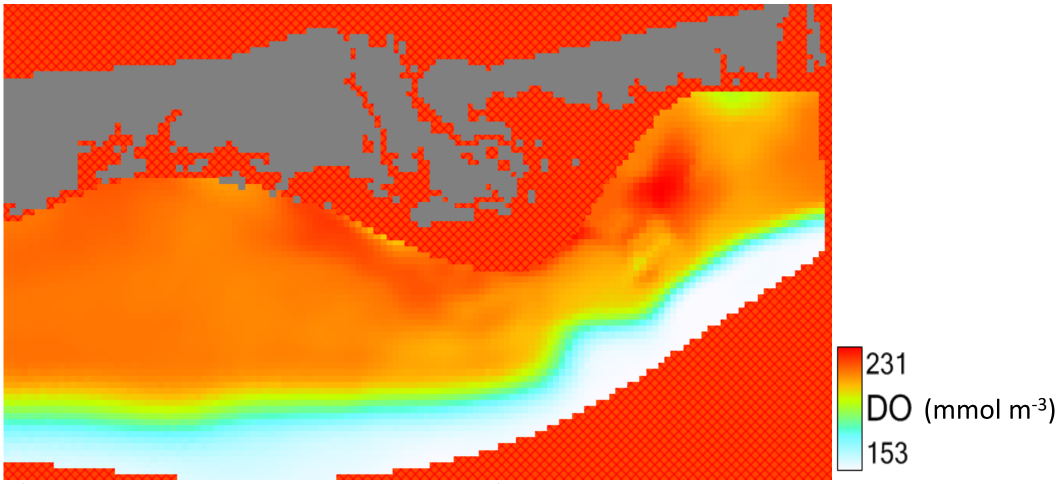

Figure 19. Example map of bottom dissolved oxygen based on ROMS Chl a output. This map represents January 2000. The red crossed-out area is an exclusion layer, and ensures only cells that receive ROMS data as drivers are active.

The ROMS model has now simulated 33 nutrient reduction scenarios with varying combinations of nitrogen and phosphorus reduction (Figure 20). For each nutrient reduction scenario EwE Ecospace needs to be configured to load a time series of spatial raster files that are the output of the ROMS model. This involves configuring the EwE Spatial Temporal Framework with the directory locations, file names and model time stamps for the environmental drive layers DO, chlorophyll a, temperature and salinity. For both the 17-year spin up period, with the N100P100 data, and the 17-year nutrient reduction period i.e. the N60P60 data. There are 33 scenarios that can be run making this time consuming and error prone process. We have developed an application to automate this process from a list of scenarios. For each scenario in the list it will configure the correct inputs and direct EwE Ecospace to write it's results to the correct output files and location. This process can also be shared between multiple computers reducing the total time it takes to rerun the model through multiple scenarios.

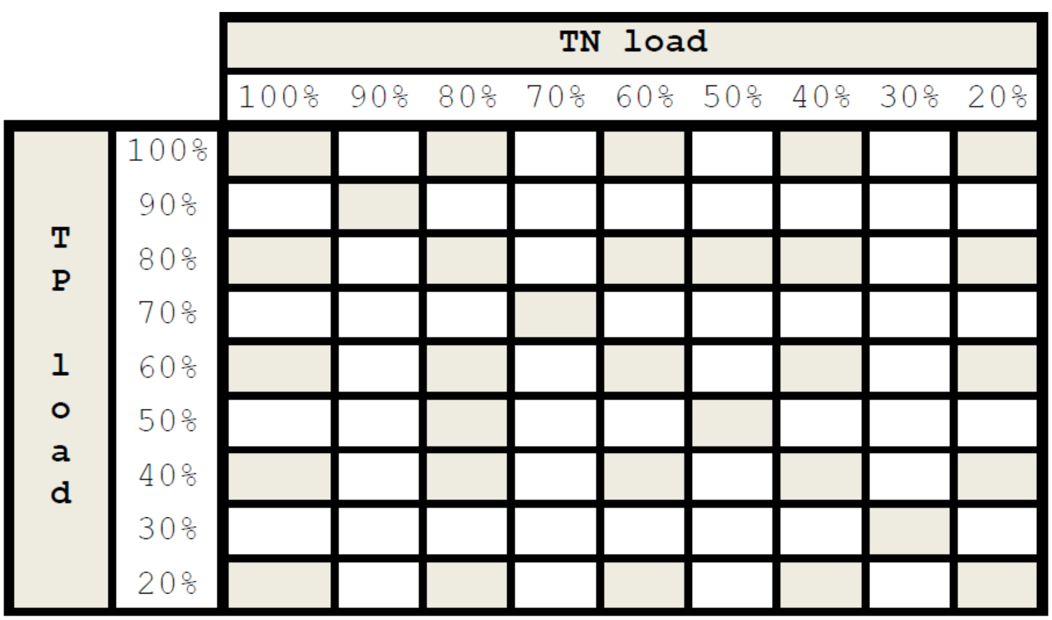

Figure 20. Nutrient reduction scenarios simulated with the ROMS model. The ecru colored squares indicate a completed scenario.

The first nutrient/hypoxia scenarios that were simulated with the new Ecospace model were 100% N&P, which is output from the calibrated ROMS model from 2000-2016, and 60% N&P, which represents a scenario with 40% nitrogen and phosphorus reduction. All simulations were run with the first 17 years (calibration period) at 100 N&P as a spin-up period, after which the second 17 years were either at 100%N&P or 60% N&P so that the scenarios can be compared. Preliminary results of the effects on biomass of select living marine resources are shown in Figure 21, and the effect of hypoxia reduction alone on the same species in figure 22.

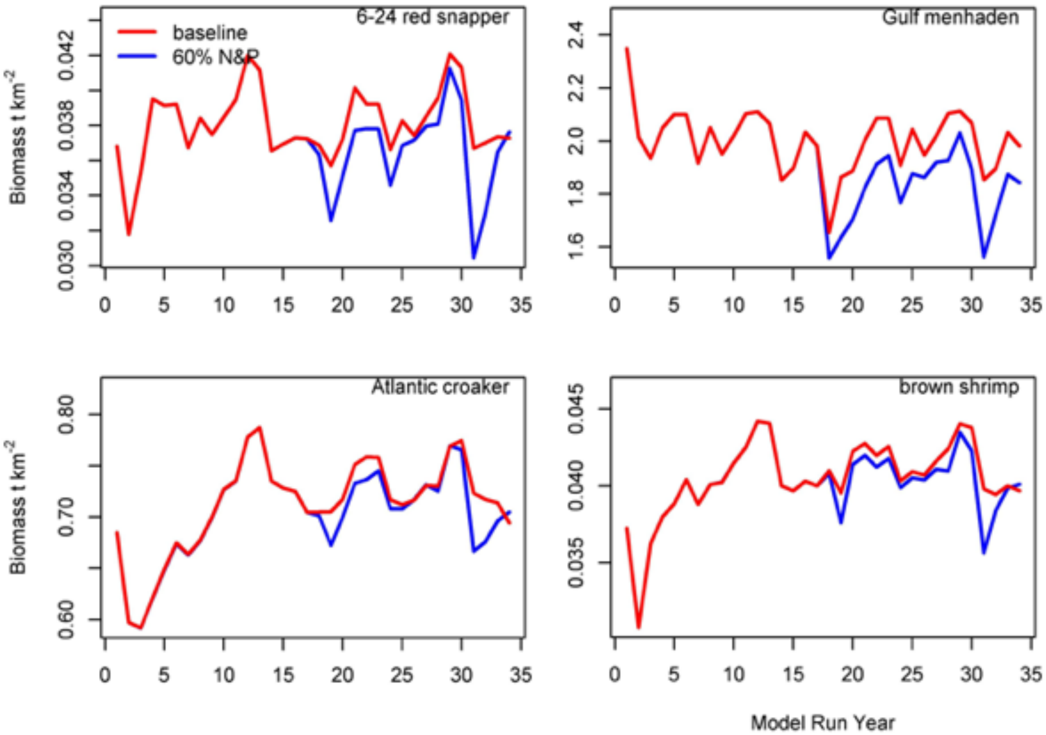

Figure 21. Biomass in t/km^2 of select species of interest under baseline conditions (100 N&P, red line) and a 40% nutrient reduction scenario (60% N&P, blue line).

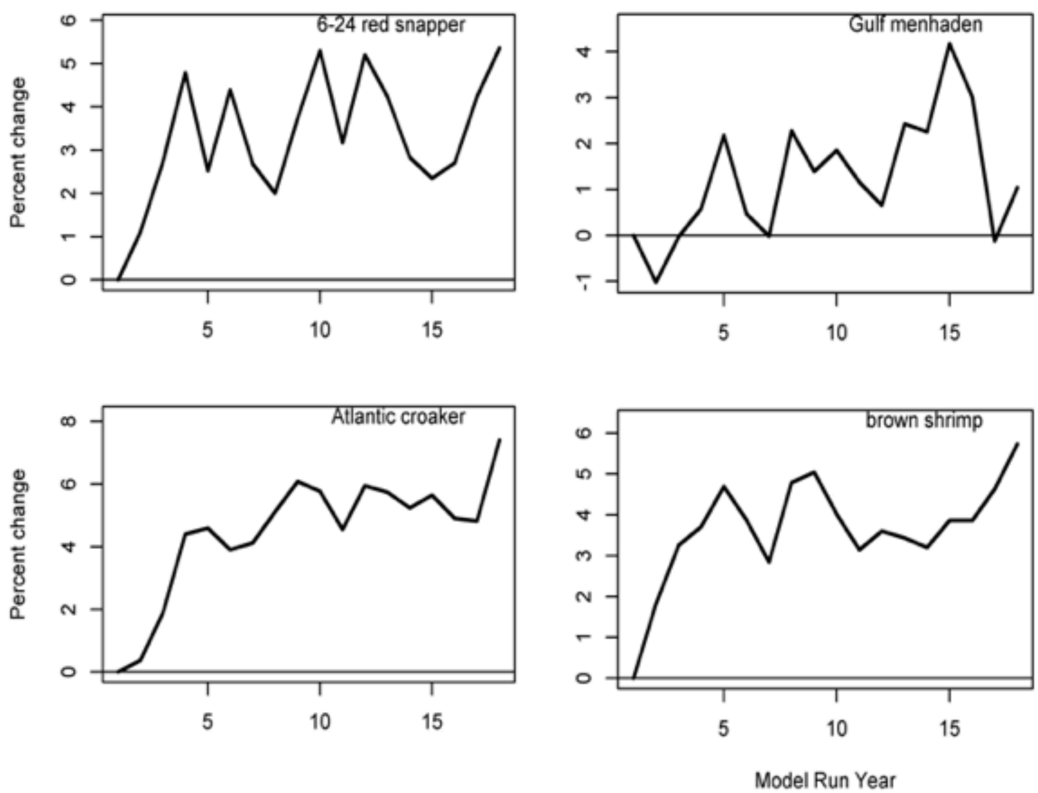

Figure 22. Percent change in biomass if only the hypoxia reduction associated with a 40% nutrient reduction are taken into consideration.

Preliminary results of this nutrient reduction scenario suggest that effects of hypoxia reductions only on biomass or mostly small and positive, but that the net effect of a 40% nutrient reduction is often small and negative due to reductions in phytoplankton. They also show that there is substantial annual variability, suggesting that the original severity of hypoxia in a given year has a big effect on what a 40% nutrient reduction would do in that year. Similar results were found for catch, which is shown for select fisheries species in Figures 23 and 24.

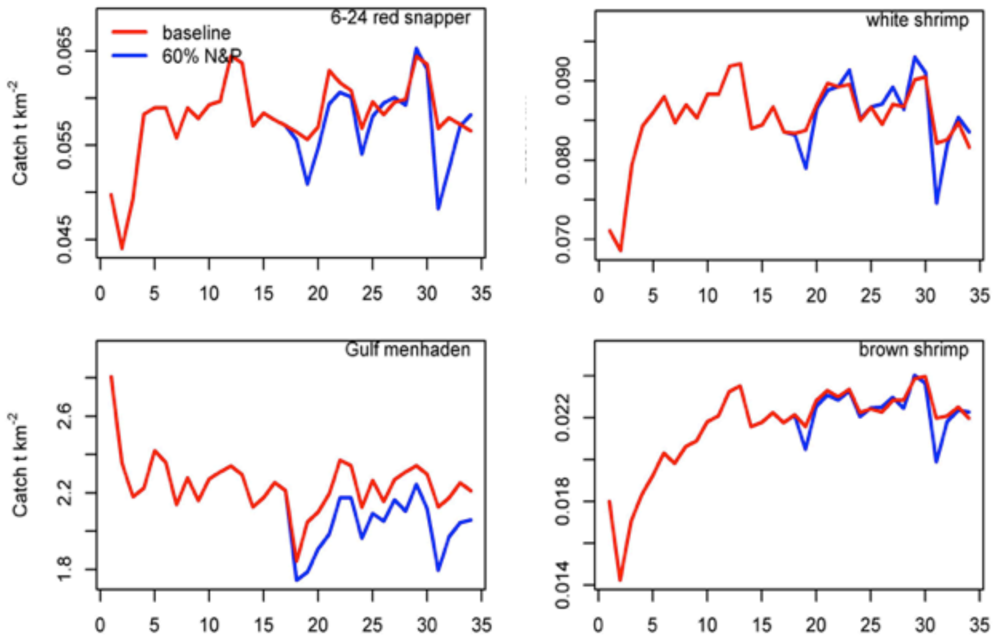

Figure 23. Catch in t/km^2 of select species of interest under baseline conditions (100 N&P, red line) and a 40% nutrient reduction scenario (60% N&P, blue line).

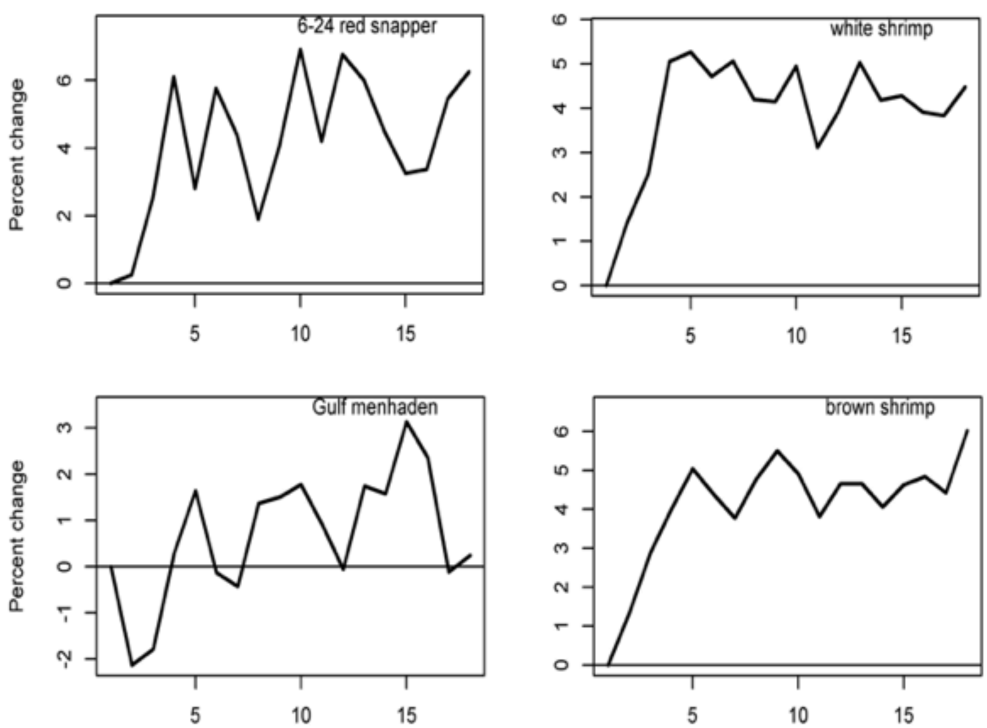

Figure 24. Percent change in catch if only the hypoxia reduction associated with a 40% nutrient reduction are taken into consideration.

Detailed analysis of model results is scheduled in the next period to determine the mechanisms behind the results, and whether these changes can be confirmed as best estimates, or whether more adjustments to the models and the model coupling mechanism needs to occur. Alternative ways to include effects of nutrient reduction scenarios will be tested to strive for realistic reflections of these effects. Calibration will continue since the inclusion of stock assessment information has brought significant changes to the model. Focus of the next period will also be to evaluate uncertainty in model output and include spatial validation of the output.

<u>Connections to Management Needs:</u> **The ultimate goal of this research is to develop management tools in collaboration with fisheries managers that can be readily applied to test alternative management strategies to reduce hypoxic volume, and investigate subsequent effects on fish growth, population dynamics (e.g. abundance and biomass), and fisheries catches. In year 1 of this project, we received valuable feedback from the workshop at GOMOSES.** Throughout years 2 and 3 we incorporated feedback from the advisory panel calls, and through the various workshops, meeting symposia, into our models and experimental approach. Products identified as desirable by attendees were habitat quality maps and a way to interface GRP modeling with observing systems. In addition, the bioenergetics models themselves were of interest to managers. Due to these end-user priorities, **we have developed an open source version of the GRP model that can be freely shared with fisheries managers and adapted to interface with a variety of observing systems**. These models are now mostly automated, described by a detailed workflow, and can be customized and replicated for additional scenarios and species. We intend for these models to be used directly by conference participants and their colleagues. We also anticipate the R platform will allow us the flexibility to apply this modeling framework to existing observing systems.

In year 1 we identified opportunities for collaboration with Kenny Rose (UMCES), who is also completing a project funded under NGOMEX. We have collaborated with the Rose lab to produce Atlantic croaker, Gulf menhaden, red snapper, and brown shrimp bioenergetic models. We anticipate comparing and contrasting our results to validate and assess if different approaches produce similar conclusions. This will strengthen products from both research programs. During the 2018 Fisheries Monitoring Workgroup Workshop in Stennis, MS, the NGOMEX project PIs (de Mutsert, Brandt, Rose, Justic, Obenour, Craig) met with members of the management committees to discuss progress and ensure research is informed by management guidance. The project PIs agreed to run one nutrient scenario in common to allow the results of the projects to be compared.

The area that the management application portion of the project has thus far focused has been communication and establishment of working relationships with assessments scientists and resource managers. Lead PI De Mutsert and her new PhD student Sara Marriott developed a survey that was distributed to the entire advisory panel in preparation for the second workshop. The survey is focused on management needs and expected and desired outcomes of our project. The results of the survey will be presented during the second advisory panel workshop in Miami, Florida. Development of a map-based decision support tool has started and will be a main focus of the next period as well. This will be a GIS-based tool that allows the user to toggle through nutrient reduction scenarios, species of interest, and output metrics (catch, biomass, difference maps) of the spatial output.

b Provide a brief summary of work to be performed during the next year of support, if changed from the original proposal; and indication of any current problems or unusual developments that may lead to deviation of research directions or delay of progress toward achieving project objectives.

In the next year of funding, we will continue to improve species bioenergetics, food web, and spatially/temporally explicit modeling capabilities of key living resources in the NGOMEX in response to changing hypoxic and climatic conditions. GRP models focusing on some of the key ecologically and economically important species of the region will be further refined for this project. A key goal will be to examine 1) volumetric-weighted growth habitats, 2) changes in summer-only conditions under different nutrient loadings and 3) examining historic and ongoing field data collections and 3-D modeling output to explore minimum needs for assessment.

We will continue to make progress examining the effects of nutrient loading and hypoxic volume reduction scenarios on growth rate potential, habitat quantity and quality and make direct linkages of Fish Habitat models to Ecopath with Ecosim (EwE) models. Specific plans to occur early in the next period are to create habitat capacity maps from GRP output and load those into Ecospace for those species we have GRP available. We can then compare this with Ecospace output using the environmental drivers to create habitat capacity maps in the spatial-temporal framework. We will run the GRP model on additional nutrient reduction scenarios as determined by the management committee at the Fisheries Monitoring Workgroup Workshop.

We will reconstruct the inter-annual fish habitat quality for each of the key species using the historical temperature and oxygen data we have compiled from NOAA's World Ocean Data Base. Annual indices will be compared to ROMS model output, historical catches, and monitoring information of fish sizes (from SEAMAP). This information will allow us to validate modeled output through time.

Multiple nutrient reduction scenarios will be simulated in Ecospace. During the Fisheries Monitoring Workshop, there was an interest expressed to see output of a 45% N&P reduction scenario. To answer this question, we are running simulation of 40% reduction and 50% reduction, which brackets the 45% reduction. This approach is chosen not only because the 40% and 50% reduction scenarios are available, but also because the real interest is in seeing results of a nutrient reduction scenario that results in a hypoxic zone of 5000 KM^2, which may not be exactly at 45% nutrient reduction. The 40% and 50% scenarios bracket the reduction necessary to reduce the hypoxic zone to 5000 km2.

The second workshop is planned for June, 2019 in Miami. We have support tools ready to be tested during the workshop and have developed specific training modules to this purpose. We planned this meeting in Miami to facilitate participation of NOAA's Integrated Ecosystem Assessment group at the Southeast Fisheries Science Center.

In fall of 2019, we have been accepted to convene a special session at the biennial meeting of the Coastal and Estuarine Research Federation on "Impacts of coastal hypoxia on fishes, food webs and ecosystems." We have over 20 papers scheduled for this session.

2. Applications:

This section should describe specifically the outputs and management outcomes achieved. Outputs are defined as products (e.g. publications, models) or activities that lead to outcomes (changes in user knowledge or action). In cases where proposed management outcomes are not fully achieved, indicate the progress made during the reporting period. Also, indicate expected outputs and management outcomes for the next year of support.

a. Outputs

i. New fundamental or applied knowledge
ii. Scientific publications

(note: As stated in our proposal some of our tools are being refined and tested in the North Pacific and Great Lakes)

Manuscripts published

De Mutsert, K., Steenbeek, J., Cowan, J.H. Jr., and V. Christensen. 2017. Using ecosystem modeling to determine hypoxia effects on fish and fisheries. Chapter 14 *In*: D. Justic, K.A. Rose, R.D. Hetland, and K. Fennel (eds). Modeling Coastal Hypoxia: Numerical Simulations of Patterns, Controls and Effects of Dissolved Oxygen Dynamics. Springer, New York

Gruss, A., Rose, K.A., Simons, J., Ainsworth, C.H., Babcock, E.A., Chagaris, D.D., De Mutsert, K., Froeschke, J., Himchak, P., Kaplan, I.C., O'Farrell, H. and M.J. Zetina Rejon. 2017. Recommendations for ecosystem modeling efforts aiming to inform ecosystem-based fisheries management and restoration projects. Marine and Coastal Fisheries, DOI: 10.1080/19425120.2017.1330786.

De Mutsert, K., Lewis, K.A., Milroy, S., Buszowski, J., and J. Steenbeek.

2017. Using ecosystem modeling to evaluate trade-offs in coastal management: effects of large-scale river diversions on fish and fisheries. Ecological Modelling 360:14-26.

Glaspie, C. N., Clouse, M., Adamack, A. T., Cha, Y., Ludsin, S. A., Mason, D. M., Roman, M. R., Stow, C. A., and Brandt, S. B. 2018. Effect of hypoxia on diet of Atlantic bumper Chloroscombrus chrysurus in the northern Gulf of Mexico. Transactions of the American Fisheries Society 147: 740-748. DOI: 10.1002/tafs.10063.

Goto, D., Roberts, J. J., Pothoven, S.A., Ludsin, S. A., H. A. Vanderploeg, Brandt, S. B. and T. O. Hook. 2017. Size-mediated control of perch-midge coupling in Lake Erie transient dead zones. Environmental Biology of Fishes 100(2): 1587-1600.

Kolker, A. S., Dausman, A. M., Mead, A. A. Brown, G. L. Chu, P. Y., de Mutsert, K., Fitzpatrick, C. E., Henkel, J. R., Justic, D. Kleiss, B. A., McCoy, E., Meselhe, E. and Parsons Richards, C. 2018. Rethinking the river. Eos: 99, https://doi.org/10.1029/2018EO101169.

De Mutsert, K. and S. Brandt. Impacts of Hypoxia on Fishes and Food Webs in Freshwater, Coastal and Oceanic Ecosystems: A Global Perspective. Conference proceedings in: Fisheries 43 (12): 599-600. DOI: 10.1002/fsh.10195

Roman, M.R., S.B. Brandt, E.D. Houde and J. J. Pierson. 2019. Interactive effects of hypoxia and temperature on coastal pelagic zooplankton and fish. Frontiers in Marine Science. 22 March 2019. Doi: 10.3389/fmars.2019.00139.

Chagaris, D., Sagarese, S., Farmer, N., Mahmoudi, B., De Mutsert, K., VanderKooy, S., Patterson, W. III, Kilgour, M., Schueller, A., Ahrens, R., and M. Lauretta. 2019. Management challenges are opportunities for fisheries ecosystem models in the Gulf of Mexico. Marine Policy https://doi.org/10.1016/j.marpol.2018.11.033.

Manuscripts in review

Glaspie, C. N., Clouse, M., Huebert, K. B., Elliot, D. T., Kimmel, D. G., Ludsin, S. A., Mason, D. M., Pierson, J. J., Roman, M. R., and Brandt, S. B. Impacts of hypoxia on the pelagic food web of the northern Gulf of Mexico. Estuaries and Coasts. Revision submitted.

Kolker, A.S., Renfro, A., Brenner, J., Bargu, S., Chu, P.Y., Conover, J., De Mutsert, K., Fitzpatrick, C., Greenhow, D.R., Justic, D., Montagna, P.A., Lohrenz, S.E., Proville, J., Rhode, R., Roberts, B.J., Peyronnin Snider, N., Taylor, C.M., Wade, T.L., Walker, N.D. and D.J. Wallace. The Central Role of the Mississippi River and Its Delta on the Oceanography, Ecology and Economy of the Gulf of Mexico: A Modern Synthesis. Oceanography.

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Manuscripts In Progress:

Brandt, S. B. A. Laurent, C. E. Sellinger, C. N. Glaspie, and K. de Mutsert, 2019, Predicting the effects of reduced nutrients and hypoxia on fishes in the Gulf of Mexico. All of the data for this manuscript has been analyzed and the figures complete. Intended for Estuaries and Coasts.

Brandt, S. B., Sellinger, C. E., and Glaspie, C. N. Drafted. Seafood diet: Linking fish feeding to habitat, prey availability and bioenergetics in a pelagic predator. For submission to Environmental Biology of Fishes.

Brandt, S.B. Growth rate potential as a Quantitative measure of Fish Habitat Quality. Status: literature reviewed and partially written for Reviews in Fish Biology.

Brandt, S.B., Sellinger C. E. and Glaspie, C. N. Sensitivity of spatially-explicit growth rate potential models to predator swimming speed and reactive distance. Status: initial analyses done and figures drafted. Intended for Trans. Amer. Fish. Soc.

Brandt, S. B., Sellinger, C. E., and Glaspie, C. N. Drafted. Growth rate potential as a causal mechanism for North Pacific salmon returns in a changing climate. For submission to PLOS One.

iii. Patents
iv. New methods and technology
v. New or advanced tools (e.g. models, biomarkers)

New growth rate potential models were developed for red snapper, Atlantic croaker, Gulf menhaden, and brown shrimp.

Growth rate potential modeling framework and plotting/mapping capabilities have been created in an open-source environment (R statistical software).

New Ecospace model, which is an advanced version of the model published in 2016. In the new model, suggestions of the advisory panel are included and the model is representative of 2000, which is the start year of the scenarios run by the hypoxia model we use as driver. The Ecopath model has updated diet and fisheries information and stock assessment data. The spatial-temporal framework is incorporated in the Ecospace model, which was not the case in the old model. For this, new response curves to oxygen, temperature and salinity are included.

vi. Workshops

De Mutsert, K., and S. Brandt. 2019, Co-chairs, Scientific Session on "Impacts of coastal hypoxia on fishes, food webs and ecosystems." Accepted for the 2019 Coastal and Estuarine Research Federation Conference. November, 2019, Mobile, Alabama.

De Mutsert, K., S. Brandt, and M. Campbell. 2019. Hypoxia Effects on Fish and Fisheries: second advisory panel workshop; tools introduction and training. June 24 and 25, 2019. Rosenstiel School of Marine and Atmospheric Science, Miami, Fl.

Brandt, S. B., and de Mutsert, K. 2018, conveners, symposium on "Impacts of hypoxia on fishes and food webs in freshwater, coastal and oceanic ecosystems: A global perspective." American Fisheries Society Meeting, August, Atlantic City, NJ.

De Mutsert, K., Brandt, S., and Roman, M. 2017, conveners, session on "Ecological impacts of hypoxia on coastal ecosystems." Coastal and Estuarine Research Federation Biennial Conference, 5- 9 November, 2017, Providence, RI.

Brandt, S. B., and Mason, D. 2017. Conveners, session on "Pelagic fish seascapes: Integration of new technology and modeling." American Fisheries Society Meeting, 20 – 24 August, Tampa, FL.

Glaspie, C.N. and Brandt, S. B. 2017. Conveners, session on "Response of fishes to extreme climate events." American Fisheries Society Meeting, 20-24 August, 2017, Tampa, FL.

De Mutsert, K., S. Brandt, and M. Campbell. 2017. Hypoxia Effects on Fish and Fisheries: kick-off meeting of decision support tool development. Special workshop during the 2017 GOMOSES meeting: "Ecosystem Approaches to Gulf Response and Restoration". February 6, 2017. New Orleans, LA.

vii. Presentations

(note: As stated in our proposal some of our tools are being refined and tested in the North Pacific and Great Lakes)

Glaspie, C.N., Brandt, S. B. and C. S. Sellinger. 2017. "Defining energy seascapes to predict distribution and production of fish." Annual Meeting of Ecological Society of America, 6 – 11 August, Portland OR.

De Mutsert, K., Brandt, S., Van Plantinga, A., Lewis, K., Laurent, A., Steenbeek, J., and Buszowski, J. 2017. "Assessing effects of reduced nutrients and hypoxia on living resources in the Gulf of Mexico using a coupled ecosystem modeling approach". American Fisheries Society Meeting, 20 – 24 August, Tampa, FL.

Glaspie, C.N., Brandt, S. B. and Sellinger, C. E. 2017. "Hypoxia impacts on small pelagic fishes: Insights from high-frequency acoustic sensing." American Fisheries Society Meeting, 20 – 24 August, Tampa, FL.

Glaspie, C.N., Brandt, S. B. and Sellinger, C. E. 2017. "North Pacific Salmon habitat quality in response to climate regime shifts." American Fisheries Society Meeting, 20 – 24 August, Tampa, FL.

Sellinger, C. E., Brandt, S. B. and Glaspie, C.N. 2017. "Climate, temperature, and hypoxia as multifaceted drivers of West Coast ecosystems." Coastal and Estuarine Research Federation, 5 – 9 November, Providence, RI.

De Mutsert, K., S. B. Brandt, K. A. Lewis, A. Laurent, J. Steenbeek and J. Buszowski. 2017. "Simulating hypoxia and nutrient reduction effects on the Northern Gulf of Mexico fishery Ecosystem". Coastal and Estuarine Research Federation, Providence, RI, November 2017.

Glaspie, C. N., Brandt, S. B. and Sellinger, C. E. 2017. "Hypoxia impacts on marine fish trophic dynamics in the Northern Gulf of Mexico." Hatfield Marine Science Center Seminar Series, Newport, OR, December 2017.

Brandt, S., Laurent, A., Glaspie, C., Sellinger, C., and De Mutsert, K. 2018. "Assessing and predicting the effects of reduced nutrients and hypoxia on fishes in the Gulf of Mexico". Ocean Sciences Meeting, February 2018, Portland, OR

De Mutsert, K. 2018. Using ecosystem modeling to evaluate trade-offs in coastal management: effects of large-scale river diversions on fish and fisheries. Network of Experts for ReDeveloping Models of the European Marine Environment (MEME): Innovative modelling in support of Marine Strategy Framework Directive (MSFD) implementation. European Commission Joint Research Centre. Brussels, Belgium, March 2018.

De Mutsert, K. 2018. User-driven tools to predict and assess effects of reduced nutrients and hypoxia on living resources. Fisheries Monitoring Workgroup workshop. May 16, 2018, Stennis Space Center, MS.

Brandt, S., Laurent, A., Glaspie, C., Sellinger, C., and De Mutsert, K. 2018. "Assessing and predicting the effects of reduced nutrients and hypoxia on fishes in the Gulf of Mexico". American Fisheries Society Meeting, Atlantic City, NJ, August 2018.

De Mutsert, K., Van Plantinga, A., Brandt, S., Glaspie, C., Lewis, K., Laurent, A., Buszowski, J. 2018."Using a Coupled Ecosystem Modeling Approach to Evaluate Effects of Reductions in Nutrients and Hypoxia on Living Marine Resources". American Fisheries Society Meeting, Atlantic City, NJ, August 2018.

Glaspie, C. N., Clouse, M., Adamack, A. A., Cha, Y., Ludsin, S. A., Mason, D. M., Roman, M. R., Stow, C. A., and Brandt, S. B. 2019. "Diet composition of Atlantic bumper relative to dissolved oxygen concentration and fish size." Gulf of Mexico Oil Spill and Ecosystem Science Conference, New Orleans, LA, February 4-7.

Glaspie, C. N., Clouse, M., Adamack, A. A., Cha, Y., Ludsin, S. A., Mason, D. M., Roman, M. R., Stow, C. A., and Brandt, S. B. 2019. "Diet composition of Atlantic bumper relative to dissolved oxygen concentration and fish size." Louisiana Chapter of the American Fisheries Society, Thibodaux, LA, May 23-24.

Brandt, S. B., A. Laurent, C. E. Sellinger, C. N. Glaspie, and K. de Mutsert, 2019, Predicting the effects of reduced nutrients and hypoxia on fishes in the Gulf of Mexico. Invited paper to Biennial Coastal and

Estuarine Research Federation Conference. November 3 - 8, 2019, Mobile, Alabama

Glaspie, C.N., M. Clouse, K. B Huebert, S. A Ludsin, D. M Mason, J J Pierson[3], M R Roman, and SB Brandt· 2019 Impact of hypoxia on the pelagic food web of the northern Gulf of Mexico. Invites paper to Biennial Coastal and Estuarine Research Federation Conference. November 3-8, 2019, Mobile, Alabama

de Mutsert, K., S B Brandt, K A Lewis, A Laurent, J Steenbeek[5] and J Buszowski· 2019. Using coupled ecosystem modeling to evaluate nutrient and hypoxia reductions on living marine resources. Invited paper to Biennial Coastal and Estuarine Research Federation Conference. November 3-8 2019, Mobile, Alabama

viii. Outreach activities/products (e.g. website, newsletter articles)

The website has migrated away from wordpress towards the Mason website, so that it has a cleaner look and no more advertisements. The new address is: https://demutsertlab.gmu.edu/ngomex/

b. Management outcomes – I. Management application or adoption of:

i. New fundamental or applied knowledge
ii. New or improved skills
iii. Information from publications, workshops, presentations, outreach products
iv. New or improved methods or technology.

The SEAMAP survey design is planned to change slightly by including DO sensors on the trawls so that catch and DO can more accurately be linked, and by repeating a vertical measurement of dissolved oxygen that occurs at the start of the trawl at the end of the trawl if there seems to be a poor match between bottom oxygen levels and catch.

v. New or advanced tools.

c. Management outcomes - II. Societal condition improved due to management action resulting from output (examples: improved water quality, lower frequency of harmful algal blooms, reduced hypoxic zone area, and improved sustainability of fisheries).

d. Partnerships established with other federal, state, or agencies, or other research institutions (other than those already described in the original proposal).

During year three of the project we are focused on delivering the second of the interactive workshops, in this workshop our advisory panel and invited management entities will have the opportunity to use the models and begin to discover how they could be useful to the fisheries assessment and ecosystem-based modeling efforts ongoing in the Gulf. This workshop is slated for the end of June and will be held at the NMFS Southeast Fisheries Science Center Headquarters in Miami, FL. The intent behind having the workshop was to access as many management entities as possible and in particular the assessment and IEA groups located in that office.

We continue to conduct quarterly calls to obtain to provide project updates to our panel, solicit any further advice on making a useful model, and to raise awareness of any opportunities to bring the model to bear during management decision making processes (e.g. SEDAR). These calls have primarily consisted of short updates on the progress with the modeling tool, querying the panel for scientific advice relative to the models, querying the panel for updates on any pertinent managerial actions that our group should focus attention towards (e.g. upcoming stock assessments), and providing information on scheduled meetings where individuals can interact with the modeling team. We held two ad hoc meetings in association with larger conferences including the American Fisheries Society (AFS) Annual Meeting in Atlantic City, and in Tampa. The team will lead a special session at the upcoming CERF meeting to be held in Mobile Alabama in 2020. Project lead and co-Pi De Mutsert and Brandt organized a special session on hypoxia modeling and have the other NGOMEX funded project leads scheduled as invited speakers. The group continues to collaborate and organize with the Fisheries Monitoring Workgroup to streamline efforts between the two groups. With the help of Kevin Craig (application PI on the other two projects) we have contacted NOAA’s shrimp stock assessment group in Galveston to begin to make use of the modeling outcomes for those assessments. Kim de Mutsert continues to work closely with members of NOAA’s Integrated Ecosystem Assessment (IEA) group on this and other projects and thus we are positioned to interact with this group at upcoming federal assessments. Members of the IEA group will take part in the Miami workshop coming up in June 2019. We will continue to have quarterly calls to maintain dialogue with our advisory panel and will be working to establish better relationship with management level individuals (e.g. Gulf Council members).

3. Expenditures:

a. Describe expenditures scheduled for this period.

The expenses for the reporting period (June 1 2018-May 31, 2019) are listed in the green column called "Expenses Between Start and End Month". The other columns in the budget report represent the total amount of funding received so far ("Funded Amount Thru End Month"), all expenses made so far ("Expenses Inception thru Report End Month"), funding committed but not spent yet ("Commitments Thru End Month), and funding available/not spent yet ("Available Amt"). Expenditures during the reporting period included academic year and summer salary for Dr. de Mutsert ("Faculty Salaries" and "Faculty Special Payments"), Graduate Assistant salary (salary for new PhD student to the project Sara Marriott), "Wages" for student wages assisting in the project, Consulting Serviss for consultants Arnaud Laurent, Joe Buszowski and Jeroen Steenbeek, travel (conference attendance), the Oregon State University subcontract (itemized below), and other direct expenditures, which include computer software upgrade costs.

PI Report by Month Range

GEORGE MASON UNIVERSITY — 06/27/2019 — Start Month: Jun-2018 End Month: May-2019

Fund:	203952	**PI:**	De Mutsert, Kim	**Org Desc:**	PEREC Grants & Contracts
Grant:	203952	**Agency:**	National Oceanic & Atmospheric Admi	**Project:**	NOAA/NGOMEX 2016: Gulf of Mexico
Grant Start:	09/01/2016	**Grant End:**	08/31/2020	**F&A Rate:**	52.0

Pooled Budget Level Group	Pooled Budget Level	Pooled Budget Desc	Funded Amount Thru End Month	Expenses Between Start and End Month	Expenses Inception thru Report End Month	Commitments Thru End Month	Available Amt
Direct	61100	Faculty Salaries	54,125.00	6,599.99	54,893.51	0.00	(768.51)
	61130	Faculty Special Payments	21,191.00	9,106.41	13,808.96	549.22	6,832.82
	61190	Graduate Assistants	18,500.00	18,500.04	18,500.04	0.00	(0.04)
	61400	Wages	10,704.00	5,655.50	11,319.25	0.00	(615.25)
	61900	Fringe Benefits	20,309.00	3,324.07	20,426.17	40.09	(157.26)
	73400	Consulting Services	69,760.00	11,000.00	30,950.00	8,810.00	30,000.00
	73800	Travel	16,344.00	1,940.83	10,537.18	0.00	5,806.82
	73600	Subcontracts (25K or Less)	33,475.00	0.00	25,000.00	8,475.00	0.00
	73700	Subcontracts (GT 25K)	266,903.00	56,923.32	159,386.49	107,516.51	0.00
	70000	Other Direct Expenditures	20,187.00	141.96	3,818.97	0.00	16,368.03
	78500	Tuition and Stipend	0.00	7,569.00	7,569.00	0.00	(7,569.00)
	Direct Total		**531,498.00**	**120,761.12**	**356,209.57**	**125,390.82**	**49,897.61**
Indirect	79000	Indirect	132,386.00	29,259.86	98,412.27	0.00	33,973.73
	Indirect Total		**132,386.00**	**29,259.86**	**98,412.27**	**0.00**	**33,973.73**
Total			**663,884.00**	**150,020.98**	**454,621.84**	**125,390.82**	**83,871.34**

OSU subcontract detail

May 31 marks the completion of 33 months of this project. OSU Expenditures are right on schedule as described in the original proposal. In the original budget, over 85% of costs were planned for salary for Brandt, Sellinger and a Postdoctoral Scholar, (C. Glaspie) and associated Fringe (OPE) and Overhead (F&A) with the balance for Travel and Supplies. There have been no unanticipated costs. We plan to spend funds largely in major categories as originally allocated.

A summary of expenditures (to the nearest dollar) as of 31 May, 2018 is below. Additional encumbered expenditures to cover Salary, OPE and Indirect for Brandt and Sellinger and and planned travel through August total an additional $36,519.

	Expenditures by 31 May	Full allocation
Salaries	92,932	137,556
OPE	20,279	36,163
Supplies	1,856	4,755
Travel	15,338	20,100
F&A	61,290	93,329
Total	191,695	291,903

b. Describe actual expenditures this period.

See budget tables above (under 3a).

c. Explain special problems that led to differences between scheduled and actual expenditures, etc.

A budget reallocation was completed during this reporting period. After more funds were allocated to Cassie Glaspie’s post-doc salary at OSU in the previous budget reallocation, she accepted a job as assistant professor at LSU. The funds were re-allocated back to GMU and now fund a newly attracted PhD student to the project (Sara Marriott) and an additional subcontract to original co-PI Kristy Lewis, who was written in as co-PI as Kim de Mutsert’s post-doc when the project started, but subsequently accepted a job elsewhere. She now actively participates in the project again under a University of Central Florida sub-contract. No expenses were made yet on the UCF sub-contract during the reporting period.

Prepared by:

06/28/2019

Signature of Principal Investigator Date

NOTICE

Subsequently, all NOAA COP recipients with approved grants will be asked to file a COP Project Final Report in the specified format upon expiration or termination of grant support. Consistency in reporting requirements for competitive research grant programs is desirable and this is behind COP's efforts in proposing a standardized format. The use of the Project Final Report format will provide the level of detail required to evaluate the effort invested by investigators and staff on project management; any actual accomplishments and research findings; and what goals and objectives were attained. The proposed final report format is compatible with the format in use by other agencies that participate in joint projects with COP, e.g. the National Science Foundation.

Public reporting burden for this collection of information is estimated to average 300 minutes per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed and completing and reviewing the collection of information.

Send comments regarding this burden estimate or any other aspects of this collection of information, including suggestions for reducing this burden, to the National Ocean Service, CSCOR/COP Office, 1305 East-West Highway, Silver Spring, MD 20910. Grant files are subject to the Freedom of Information Act (FOIA). Confidentiality will not be maintained--the information will be made available to the public. However, unpublished research results shall not be published without prior permission from the recipient.

Notwithstanding any other provision of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the Paperwork Reduction Act, unless that collection of information displays a currently valid OMB Control Number.