Using coupled modeling to evaluate effects of nutrient and hypoxia reductions on living marine resources

Uso de modelos acoplados para evaluar los efectos de las reducciones de nutrients e hypoxia en los recursos marinos vivos

Utilisation de la modélisation couplée pour évaluer les effets des réductions des nutriments et de l'hypoxie sur les ressources marines vivantes

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EXTENDED ABSTRACT

An expansive hypoxic zone in the Northern Gulf of Mexico (NGOMEX) affects ecologically and economically important living resources, but the magnitude, predictability and even the direction of these effects are not well-documented. Managers and stakeholders alike need readily available and quantitative tools to assess the effects of nutrient reduction strategies aimed to minimize the hypoxic zone. The goal of our work is to couple spatially explicit ecosystem and water quality models to evaluate effects of hypoxia and nutrient loading on fish and fisheries together and separately, and to develop a decision support tool that visualizes the output. After our initial simulations emphasized the importance of (bottom-up) food web dynamics on NGOMEX living resources (De Mutsert et al., 2016), we focussed on simulating nutrient reduction scenarios recommended by the Mississippi River Gulf of Mexico Watershed Nutrient Task Force, or Hypoxia Task Force. The current Gulf hypoxia action plan goals of the Hypoxia Task Force are to reduce the 5-year running average size of the Gulf hypoxic zone to 5,000 km^2 by 2035, with an interim goal of a 20% reduction in nitrogen (N) and phosphorus (P) loading from the Mississippi Atchafalaya River Basin by 2025. Here we focus on the long-term coastal goal to answer the following research question: "What is the effect of reductions in nutrient loading on living resources to reach the goal of the Hypoxia Task Force to reduce the size of the hypoxic zone to 5,000 km^2?"

To evaluate effects of hypoxia on fish and fisheries, an Ecospace model was developed representing 60 groups of the NGOMEX food web using Ecopath with Ecosim software. Groups in the model include living marine resources, other fish and shellfish that are part of the food web, zooplankton, benthic invertebrates, phytoplankton and detritus. Fish and shellfish groups were split in juvenile and adult life stages, and in some cases multiple life stages to match the age groups in stock assessment (e.g., Gulf menhaden). We focus on the following four species of ecological or economic interest: Atlantic croaker (*Micropogonias undulatus*), Gulf menhaden (*Brevoortia patronus*), red snapper (*Lutjanus campechanus*) and white shrimp (*Litopenaeus aztecus*). The model is coupled to a published ROMS-based physical-biological model from which it receives dissolved oxygen (DO), salinity, temperature, and phytoplankton output (Fennel et al., 2011; Laurent and Fennel, 2013). In the Ecospace model, the environmental factors affect the foraging capacity and movement of nekton. The coupled model was calibrated using existing conditions from 2000-2016, after which scenarios for short-term and long-term hypoxia reduction were explored. Earlier work with the ROMS model has established that reducing the size of the hypoxic zone to 5,000 km^2 requires a reduction in N and P load between 40% and 50% (Fennel and Laurent, 2018), so we decided to run three scenarios: no nutrient reduction (100% N&P), 40% N&P reduction, and 50% N&P reduction. We ran each scenario from 2000 to 2035. Novel spatial Monte-Carlo simulations were performed to estimate the uncertainty of the predictions.

Hypoxia had a clear effect on the spatial distribution of nekton in the model (Figure 1), and avoidance and biomass reduction in the hypoxic area were less when hypoxia was reduced. Total annual biomass output shows that changes in fisheries species biomass in response to nutrient load reductions are small, species-specific and vary by year (Figure 2). The largest nutrient reduction, a 50% nitrogen and phosphorus reduction, results in an annual average change of -3.9% (±4.45) in red snapper biomass, -6.2% (±3.19) in Atlantic croaker biomass, +9.8% (±4.95) in Gulf Menhaden biomass, and +3.5% (±4.96) change in white shrimp biomass. The annual differences are most likely a result of the hypoxic zone size differences by year. If only hypoxia is reduced under the 50% nitrogen and phosphorus reduction scenario (with no effects on phytoplankton of the nutrient reductions) all biomass changes are positive, indicating that reduced productivity under reduced nutrient loading is responsible for the negative or small net effects of nutrient and hypoxia reductions on the biomass of living resources. A decision support tool has been developed to visualize the model output for members of the Hypoxia Task Force, fisheries managers, and other stakeholders. Users can select the nutrient reduction scenario (50%, 40%, 20% and no reduction), and select years, months, and fisheries species (Atlantic croaker, brown shrimp, gulf menhaden, red snapper, and white shrimp). The phytoplankton and dissolved oxygen concentration and distribution representing the environmental conditions of the selected scenario are shown as well.

In conclusion, hypoxia affects species distribution, which leads to additional indirect effects of hypoxia. Distribution of most fisheries species is more strongly affected than total biomass. Nutrient reductions reduce bottom-up energy flow into the food web, reducing secondary production. Associated hypoxia reductions have positive effects on fisheries species and most other groups in the food web. The net effect on living marine resource biomass is small, species-specific, and varies by year.

KEYWORDS: food web, ecosystem model, hypoxia, Ecopath, fish

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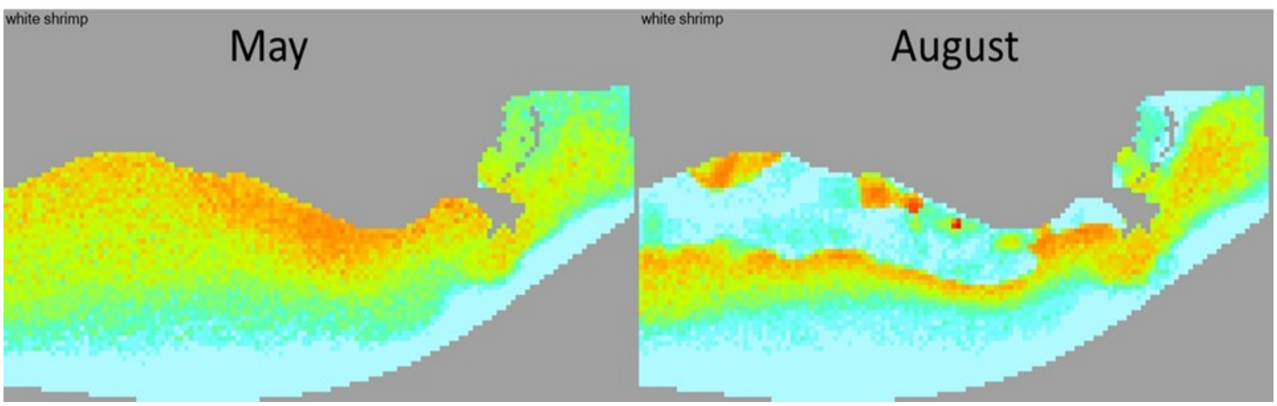

Figure 1. . Distribution of white shrimp in May (no hypoxia) and August (hypoxia) of 2035 under a no nutrient reduction scenario. Warmer colors indicate higher biomass

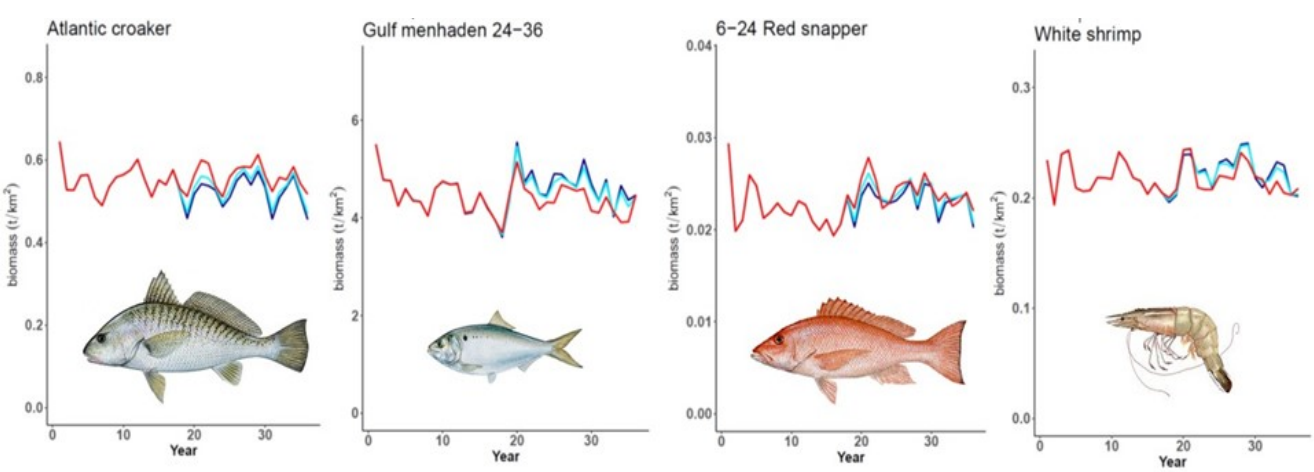

Figure 2. Biomass of the four focus species over the 36-year model run (2000-2035) under 40% (light blue line), 50% (dark blue line) and no nitrogen and phosphorus load reduction (red line). The nutrient reductions start following a calibration period representing actual conditions from 2000-2016.