FATE FY15 Proposal

USE OF A BIOPHYSICAL MODELING FRAMEWORK TO DEVELOP A RECRUITMENT INDEX FOR INCLUSION IN STOCK ASSESSMENTS IN THE GULF OF MEXICO AND SOUTH ATLANTIC

Principal Investigator:

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Research Priority #s: 1, 2 & 6

Project Duration: 1 year

Total Funding Request: $97,555

Year 1 Request: $97,555

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Year 1 Budget Breakdown:

North Carolina State University: $53,769
University of Miami: $43,786

Project Summary:

A large body of fisheries oceanography research has focused on improving stock-recruitment relationships through the inclusion of environmental information (Schirripa et al. 2009, Maunder & Watters 2003, and references within). The canonical method for including environmental effects is to link recruitment processes within the stock assessment model to one or more environmental covariates, which may or may not continue to be correlated with recruitment as ecosystems change over time (e.g., Myers 1998). A number of recent advances in hydrodynamic ocean models and in biophysical modeling approaches – and in the computational power to link the two – now allow us to mechanistically understand the environmental processes driving recruitment. Rather than modeling or measuring factors hypothesized to be related to recruitment, we now have the capabilities to simulate recruitment events themselves, which allows us to improve the accuracy of our stock assessments.

The goal of this project is to use a combination of recently-developed hydrodynamic ocean and biophysical modeling approaches to simulate recruitment events of red snapper, *Lutjanus campechanus*, in the Gulf of Mexico and U.S. South Atlantic regions. We combine an individual-based larval transport model (Connectivity Modeling System (CMS); Paris et al. 2013) with an oceanographic hindcast model (Regional Ocean Modeling System; Shchepetkin and McWilliams 2005), to understand sources and sinks of recruits in the region, and to develop indices of recruitment strength. This work builds on a previous approach by Karnauskas et al. (2013), where a recruitment index was developed and used in a stock assessment model. From this previous work, three key improvements will be made here: 1) use of an alternative oceanographic model that better resolves coastal processes in time and space, 2) inclusion of a detailed biological data set identifying red snapper spawning sites, and 3) inclusion of an additional module in the larval transport model which allow a more realistic representation of diffusion processes. This combined effort will lead to the development of a powerful recruitment forecasting tool for the southeastern U.S. Funding this project also represents a future investment for other stocks, because the model improvements envisioned here would serve as a blueprint for application to other species in the region.

Project Background:

Red snapper are a highly valued reef fish found throughout the Gulf of Mexico (GOM) and southeastern US Atlantic (SA). In the GOM, red snapper contribute to a multibillion dollar recreational fishing industry and support an important commercial fishery ($10.2 million ex-vessel landings value in 2010; NOAA 2012). In the SA, where the red snapper fishery has historically been one of the most important in terms of landings and ex-vessel landings value, the fishery has been under a rebuilding plan since 2010 that has included a mix of very limited openings and strict moratoria. Both GOM and SA populations are classified as overfished, but rebuilding (SEDAR 2009, SEDAR 2010, SEDAR 2012).

Given the importance of GOM and SA red snapper fisheries, as well as the controversy in both regions over stock assessments and management approaches, it is imperative for NMFS to fill gaps in knowledge of red snapper life history, ecology and population connectivity. In the SA, there is essentially no published information documenting the occurrence, distribution and habitat preferences of red snapper juveniles. Identifying red snapper nursery areas would serve as a critical first step towards developing surveys to generate recruitment indices for SA red snapper, which could subsequently be incorporated into stock assessments. Probable source populations to the GOM have only been recently studied (Johnson et al. 2013), and those for the SA remain virtually unknown. An understanding of these source populations, and the processes driving recruitment variation, has significant implications for: 1) improving stock-recruitment relationships used in stock assessments, 2) assessing current assumptions about SA-GOM stock connectivity, and 3) determining appropriate spatial and temporal scales for fishery management.

As is the case for many species, stock-recruitment relationships are poorly defined for the red snapper. For both recent GOM and SA assessments, the steepness parameter was estimated at its upper limit, suggesting that available data are uninformative for estimating a meaningful stock-recruitment relationship (Conn et al. 2010). Uncertainties in the steepness parameter and in the functional form of the stock-recruitment relationship carry forward into management quantities, such as benchmarks based on maximum sustainable yield. These uncertainties also affect stock projections and, consequently, annual catch limits. Projections contain the additional uncertainty that recruitment estimates from the end of the assessment period are poorly informed, because new cohorts are not observed in the fishery data until they are several years old. Clearly, a better understanding of recruitment dynamics is essential to improve the reliability of stock assessments for species such as red snapper.

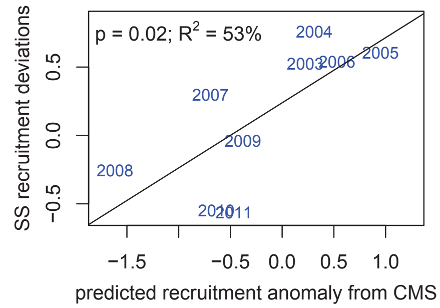

Fig. 1. Correlation between recruitment index produced by biophysical modeling approach (CMS) and recruitment deviations as estimated by the 2013 GOM red snapper stock assessment.

Recent larval dispersal modeling efforts for red snapper in the GOM have indicated the utility of such approaches for understanding larval dispersal and connectivity patterns over large spatial scales (Johnson et al. 2013, Karnauskas et al. 2013). For example, estimates of recruitment strength based on oceanographic factors for red snapper in the GOM explained over 50% of the variation in stock-recruitment anomalies for the most recent red snapper assessment (Karnauskas et al. 2013; Fig 1). This index of recruitment strength was also shown to reduce uncertainty in the stock assessment model projections, thus allowing managers to set more precise quotas over the first several projection years (Fig. 2). We propose to address needs in the SA red snapper assessment by building upon this previous framework, to achieve the following objectives:

1) Identify sources of recruits to the SA red snapper stock.
2) Understand the fate of SA-spawned red snapper larvae.
3) Identify likely areas of age 0 settlement in the SA.
4) Estimate the expected recruitment strength due to environmental factors, for years 2003-2013.

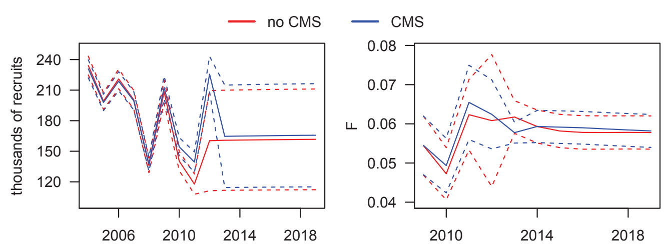

Fig. 2. Derived quantities from the 2013 GOM red snapper assessment model, for runs not including (red) and including (blue) the biophysical model (CMS) index. Left: The CMS index informs recruitment strength, particularly for the most recent years. Right: The CMS index increases the precision of short-term stock projections.

These objectives will allow us to: 1) identify areas of red snapper settlement habitat, which will aid in the development of future fishery-independent indices, and 2) inform the stock assessment model with recent estimates of recruitment strength. This project addresses the following FATE RFP Research Priorities: (1) investigating specific mechanisms driving interactions between fisheries and environmental drivers of managed species, (2) development of spatial and temporal models that investigate climate and environmental variability on population distributions and recruitment, and (6) evaluating the utility of incorporating environmental indices into stock assessment models.

Approach:

This project represents a unique integration of biological information, physical oceanographic information, and a bio-physical modeling framework to combine the two. We first describe the biological and hydrodynamic models available, and then describe how the larval transport model links these to deliver the objectives listed above. Finally, we describe how the outputs of the simulation can inform the stock assessment model.

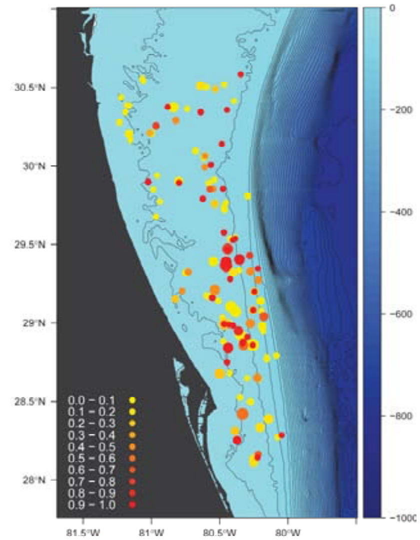

Fig. 3. Map of locations of red snapper active spawners. Bubble size relative to number sampled; color denotes spawning fraction.

Biological data set – Spatio-temporal reproductive behavior in red snapper was recently assessed (Lowerre-Barbieri et al. 2014) All ovaries (n=1,304) were assessed for histological indicators used to determine reproductive phase (Brown-Peterson et al. 2011) and diel periodicity. Actively spawning females were considered to be those undergoing late oocyte maturation, ovulation, or with fresh post-ovulatory follicles. The histological analysis - in conjunction with capture times, dates, and locations - was used to assess reproductive timing (Lowerre-Barbieri et al. 2011), and allows the precise spawning times and locations of red snapper to be parameterized as input into the biophysical model (Fig. 3).

Hydrodynamic model -- The numerical modeling effort of this project will build upon an existing regional-scale ocean prediction system developed by R. He (http://omgsrv1.meas.ncsu.edu:8080/ocean-circulation). The model domain (Fig. 4) covers the entire South Atlantic Bight and its upstream Gulf of Mexico areas (hereafter SABGOM), allowing upstream transport variations and the Loop Current/Florida Current/Gulf Stream dynamics to be properly represented. This model implementation is based on the Regional Ocean Modeling System (ROMS). Spatial resolution of the SABGOM ROMS is 5 km, with 36 vertical layers that are weighted to better resolve surface and bottom boundary layers. For open boundary conditions, the model is nested inside the 1/12^{o} global data assimilative HYCOM (www.hycom.org) and superimposed by tidal harmonics from the ADCIRC western Atlantic tidal database. Surface forcing conditions are obtained from the NCEP North American Regional Reanalysis. Major rivers in the region are also implemented in the model using USGS daily stream flow data from USGS river gauges. The model has already been successfully used in the hindcast mode in multiple investigations (Hyun and He 2010, Xue et al., 2013). With model outputs several times per day over the period 2003 – 2013, the hindcast simulation will provide a high-resolution ocean

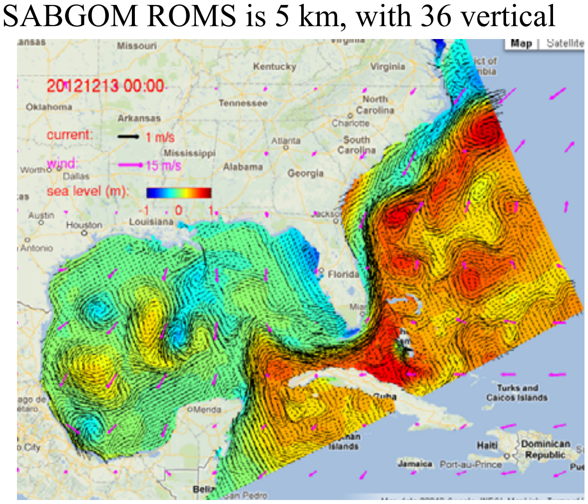

Fig. 4. A screenshot of NCSU SABGOM ocean prediction model web portal. Colors depict model-predicted ocean sea level, with ocean surface current vectors in black and wind vector field in purple.

state estimate that is well suited for the larval transport model.

Larval transport model -- The Connectivity Modeling System (CMS) is a biophysical modeling system based on a Lagrangian framework, and was developed to study complex larval migrations (Paris et al. 2013). The CMS uses outputs from hydrodynamic models and tracks the three-dimensional movements of advected particles through time, given a specified set of release points and particle behaviors. Optional modules are provided to allow for complex behaviors and movements, simulating observed biological phenomena such as egg buoyancy, ontogenetic vertical migration, larval mortality, and tidal stream transport. A recruitment index for the years 2003 – 2013 will be derived by simulating annual egg releases for a single set of dates and locations. Particles representing eggs/larvae are then tracked through time and space, given the parameterized biological behavior and the oceanographic conditions specific to each year. Successful settlers are those particles that reach settlement habitat within the given pelagic larval duration. The relative number of successful settlers each year then represents the expected recruitment trends due solely to environmental and oceanographic factors.

Our simulations will be set up in a similar manner to the methods described in Karnauskas et al. (2013). Briefly, particle releases are carried out from known spawning locations, with the number of particles per location and time scaled to the percent spawning fraction determined from the biological data set described above. For releases from the GOM, the spatial fecundity index developed by Karnauskas et al. (2013) will be used. We will also test particle releases from the Southern GOM (Campeche Bank), but based on previous work (M. Karnauskas, unpublished data) we expect connectivity from Mexico to U.S. populations to be extremely limited. The red snapper larval pelagic duration is 26 – 30 d, and suitable settlement habitat occurs between 15 and 64 m depth (Johnson et al. 2012). Complex vertical migrations will be simulated in the model using parameterizations based on: studies in the Florida Straits (D'Alessandro et al. 2009), MOCNESS sampling from SEAMAP surveys (G. Zapfe, pers comm), and other independent studies (F. Hernandez, pers comm) in the Gulf of Mexico.

Continued development of the CMS will also be supported by this project; we will create a new module that will allow for a spatially-explicit diffusivity term which would be linked to the simulated velocities from the underlying hydrodynamic model. Currently, the CMS only allows for the use of a single diffusivity term which is applied to all time steps and the entire spatial extent. However in reality the diffusivity term should vary, for example, being much smaller near convergence zones or frontal features. Thus the incorporation of this additional flexibility in the CMS would provide for more accurate simulation results. Funding will support development, testing, debugging, and public user support of the new features via Google Code (http://code.google.com/p/connectivity-modeling-system/).

Integration into assessment models -- The predicted recruitment index derived from the simulations can be input directly into the assessment model using the "data" method (Schirripa et al. 2009), whereby the index is linked to recruitment anomalies as an unfixed value with a mean and variance (as opposed to defining recruitment anomalies as fixed values). This allows the stock assessment model to weigh the recruitment index as an additional piece of information, and judge its fit relative to all other information in the assessment. The key strength of including the recruitment index is that the last years of the stock assessment, which are typically ill-informed regarding new year-classes, would be provided additional information on recruitment strength. Note that indeed, the recruitment index has a notable effect on the last 4 years of the assessment where other data on cohort strength are lacking (Fig. 2). Thus, despite the relative short length of the index (~10 years), the accuracy and precision of the assessment and short-term projections should be improved by the recruitment index. Improvements in the stock assessment model will be measured by considering changes in model likelihood, convergence gradient, and model fits to indices (measured by RMSE).

The results of this project will also provide a better understanding of effective spawning potential. For example, in the SA assessment, the stock is considered a closed population, with recruitment predicted from the SA spawning biomass of mature females. This modeling approach would likely require modification if the assumption of a closed population is substantially violated, for example if SA recruitment is highly influenced by spawning from the GOM stock, or if larvae from SA spawners are extensively lost from the system.

The focus of this project will be to understand the role of ocean dynamics in setting larval transport patterns, and to create a recruitment index for the SA region, which would inform both the stock assessment model and potential settlement "hot spots." For the GOM, we will identify the improvements to the CMS by comparing the new results to those from the existing version of the red snapper GOM CMS model. We will also assess the sensitivity of the CMS model to the background ocean state by comparing our results, using the SABGOM ROMS hindcast field, to those from Karnauskas et al. (2013) which used an alternative ocean model hindcast (HYCOM).

Benefits:

This project responds to FATE Research Priorities (1), (2) and (6) by: investigating specific mechanisms driving recruitments, developing a spatio-temporal model that investigates the effect of environmental variability on populations, and incorporating the letter into a stock assessment model. The work will provide immediate benefits to upcoming red snapper stock assessments by quantifying the processes driving recruitment strength. The recruitment index developed should improve the stock assessment model fit, and the accuracy of short-term projections of stock status. Note that, while the year a stock assessment is carried out typically includes fisheries data up to only the previous year, the oceanographic modeling is completed real-time and thus the recruitment index gives an estimate for the first projection year, and in this sense is a forecast. A secondary benefit of this project is a better understanding of red snapper recruitment sources and sinks in the SA, which should guide future fishery-dependent or fishery-independent sampling efforts. Finally, this research will elucidate the degree of connectivity between the GOM and SA, which will be useful in considering appropriate scales of management and assessment.

This research links the physical environment to a process highly important to stock assessment – recruitment – through the use of a novel biophysical modeling approach. While the research to be carried out as part of this proposal relates specifically to red snapper in the GOM and SA, the funding serves as an investment into tools that can be used for other species for which reproductive information exists. Funding would partially support improvements to both the SABGOM oceanographic model and CMS biophysical model, and with these tools in hand, recruitment indices can be developed for other stocks with relative ease.

Deliverables:

- A map of recruitment sources for the SA red snapper population, and estimates of connectivity between the GOM and SA
- A map of probable larval sink areas in the SA, to guide future sampling efforts
- A recruitment anomaly index for the SA and an improved index for the GOM for 2003 – 2013, which can be updated with additional years for future stock assessments
- At least one peer-reviewed publication to result from this work
- Presentations at the FATE Annual Science Meeting and at least one other conference

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