Numerical simulations of the transport and dispersal of fish eggs and early larvae from marine protected areas (MPA) in the US Virgin Islands and off the Eastern Puerto Rico shelf

Simulaciones numéricas del transporte y dispersión de huevos y larvas de peces desde áreas marinas protegidas (AMP) en las Islas Vírgenes de Estados Unidos y en la plataforma continental del este de Puerto Rico

Simulations numériques du transport et de la dispersion des œufs de poisson et des premières larves des aires marines protégées (AMP) des îles Vierges américaines et au large du plateau oriental de Porto Rico

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EXTENDED ABSTRACT

The main goal of the present study is to assess the connectivity between spawning locations and recruitment grounds for commercially important fish species that spawn in marine protected areas (MPA) in the US Virgin Islands and off the Eastern Puerto Rico shelf. The idea of protecting fishery resources in well-defined protected areas with the intention of enhancing commercially important fish stocks in their vicinity is well documented in the literature. The effect of protected areas has been studied worldwide and the consensus appears to be that they work well. Historically, the US Caribbean has lagged behind in this type of larval connectivity studies partly due to the lack of accurate models of coastal flows and the scarcity of sustained ocean current observations. However, recent developments in ocean observing and numerical modeling infrastructure and capabilities thanks to the implementation of the Caribbean Coastal Ocean Observing System (CARICOOS) has allowed for recent modeling efforts to advance our understanding of larval connectivity in the US Caribbean. This study is specifically tailored to investigate the impact of the Eastern PR/USVI MPA network on larval recruitment in surrounding areas through the use of FVCOM model. The present study, emphasizing a commercially important reef fish species: red hind *(Epinephelus guttatus*), demonstrates the results of the egg and larvae transport simulations including visualizations of transport pathways, an analysis of self-recruitment patterns, as well as connectivity matrices between MPA's and recruitment locations. Additional questions addressed include:1) Are existing MPA's the best sites to protect in order to enhance recruitment in the most favorable nursery areas? 2) Where should additional MPA nodes be added to the network for maximum synergy with the existing MPAs?

The Finite Volume Community Ocean Model (FVCOM) developed by the University of Massachusetts-Dartmouth (Chen et al., 2012) has been implemented on a high-resolution mesh in the US Caribbean with a focus on coastal areas of Puerto Rico and the US Virgin Islands. FVCOM solves the governing equations on Cartesian or spherical coordinates in integral form by computing fluxes between non-overlapping horizontal triangular control volumes, which combines the best

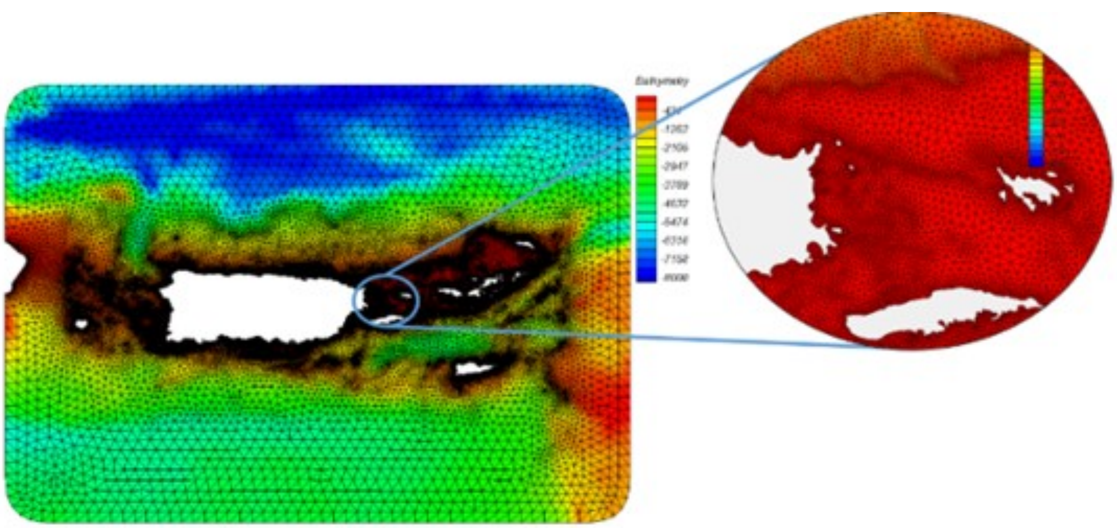

Figure 1. CariCOOS FVCOM Model setup .

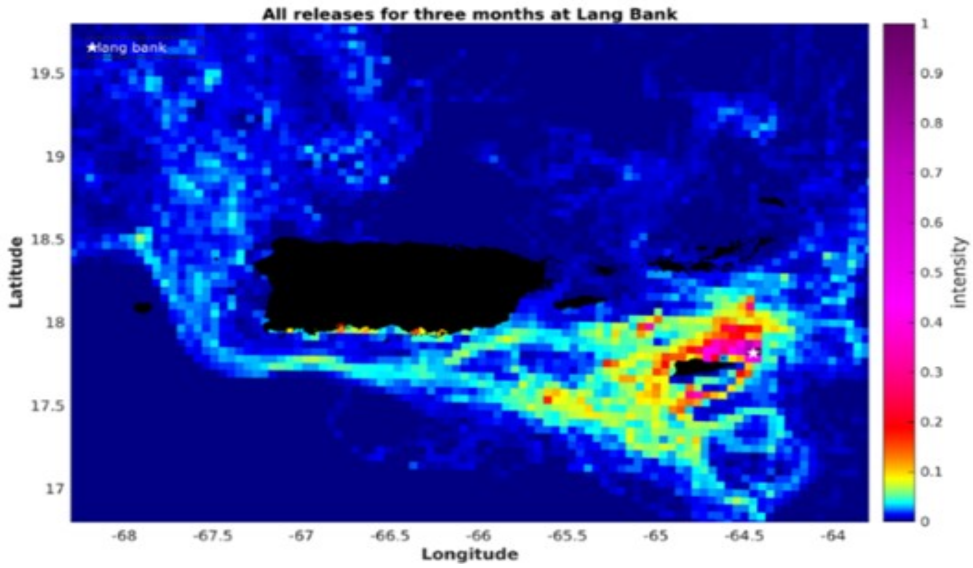

Figure 2. Particle density (colros) for all egg releases with probabilistic vertical distribution from Lang Bank.

features of the finite-element methods for geometric flexibility and finite-difference methods for code simplicity and numerical efficiency. (Chen et al., 2012).

A variable spatial resolution of 80m-3000 m is applied in for the study area, with increasing mesh resolution closest to the coast (Figure 1). The FVCOM model is nested in an offline mode to and initialized daily from NOAA's Real-Time Ocean Forecast System (RTOFS), which is based on an eddy-resolving 1/12° global HYCOM (HYbrid Coordinates Ocean Model) (Chassignet et al., 2009). Moreover, to improve the model capabilities, our FVCOM prediction system implements data assimilation using remotely sensed observations of sea surface temperature, sea surface heights, in situ temperature, and salinity profiles from various sources (Mehra and Rivin, 2009). The Tidal Prediction Software (Egbert and Erofeeva, 2002) is used to impose tidal boundary conditions at the open boundary and the CARICOOS Weather Research and Forecasting Models (WRF) is used to provide wind stress forcing to FVCOM. This circulation model has been calibrated and validated in detail by comparing model predictions to CARICOOS buoy data, ADCP data obtained as part of the project, and surface current data from CARICOOS' high-frequency radar (HFR) systems, with favorable results (not shown).

In order to numerically investigate the characteristics of potential oceanographic pathways leading to the dispersal patterns of eggs and early-stage larvae from marine protected areas, we also improved an existing off-line Lagrangian particle tracking model embedded in FVCOM where the species-specific vertical behavior was considered to accurately predict the dispersal of early-stage target species. One hundred (100) virtual particles were released at Hind Bank and Lang Bank at dusk for several days before and after the full moon during spawning season. Red hind has been reported to form spawning aggregations starting from December to February with a peak in January (Colin et al., 1987; Nemeth et al., 2007). Therefore, three consecutive months were used to simulate egg and larval transport. The statistical fish larvae data for initializing the transport model was obtained from larval abundance cruise surveys conducted by Southeast Fisheries Science Center (CFMC) in 2019, which provided the vertical distribution of larval abundance in the mixed layer. This matrix will allows us to estimate depth-dependent larvae distribution after larvae reached the flexion or post-flexion age when these larvae gain enough swimming ability. Red hind is reported to reach flexion around 12 days after fertilization and 18 days to complete post-flexion (Cherubin et al., 2011). In our study, the sensitivity of the larvae trajectories to the release date and release hour is analyzed (not shown). A significant self-recruitment pattern for the particles released from Lang Bank was observed. Moreover, many larvae ended up in southern PR and coastal regions in St. Croix, suggesting strong connectivity among those sites. This study has contributed to increasing our understanding of the role of these fish spawning sites and their relative contribution to local vs. far-field recruitment. It is expected that these results will aid the Caribbean Fishery Management Council in their evaluation of the marine protected areas as larval sources and determine the sinks for the eggs and larvae spawned off the USVI.

KEYWORDS: ocean modeling, larval connectivity, numerical circulation modeling.

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