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Evaluation of the trophic structure of the West Florida Shelf in the 2000s using the ecosystem model OSMOSE☆

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ABSTRACT

We applied the individual-based, multi-species OSMOSE modeling approach to the West Florida Shelf, with the intent to inform ecosystem-based management (EBM) in this region. Our model, referred to as 'OSMOSE-WFS', explicitly considers both pelagic-demersal and benthic high trophic level (HTL) groups of fish and invertebrate species, and is forced by the biomass of low trophic level groups of species (plankton and benthos). We present a steady-state version of the OSMOSE-WFS model describing trophic interactions in the West Florida Shelf in the 2000s. OSMOSE-WFS was calibrated using a recently developed evolutionary algorithm that allowed simulated biomasses of HTL groups to match observed biomasses over the period 2005–2009. The validity of OSMOSE-WFS was then evaluated by comparing simulated diets to observed ones, and the simulated trophic levels to those in an Ecopath model of the West Florida Shelf (WFS Reef fish Ecopath). Finally, OSMOSE-WFS was used to explore the trophic structure of the West Florida Shelf in the 2000s and estimate size-specific natural mortality rates for a socio-economically important species, gag grouper (*Mycteroperca microlepis*). OSMOSE-WFS outputs were in full agreement with observations as to the body size and ecological niche of prey of the different HTL groups, and to a lesser extent in agreement with the observed species composition of the diet of HTL groups. OSMOSE-WFS and WFS Reef fish Ecopath concurred on the magnitude of the instantaneous natural mortality of the different life stages of gag grouper over the period 2005–2009, but not always on the main causes of natural mortality. The model evaluations conducted here provides a strong basis for ongoing work exploring fishing and environmental scenarios so as to inform EBM. From simple size-based predation rules, we were indeed able to capture the complexity of trophic interactions in the West Florida Shelf, and to identify the predators, prey and competitors of socio-economically important species as well as pivotal prey species of the ecosystem.

1. Introduction

Ecosystem-based management (EBM) of marine systems has become a central paradigm in the United States (Lubchenco and Sutley, 2010; USNOC, 2013). EBM considers interactions between exploited marine species and their biotic and abiotic environment to define management strategies. One major strength of EBM is its ability to expose indirect impacts of fisheries and tradeoffs between fisheries management objectives and conservation issues (Levin et al., 2009; McLeod and Leslie, 2009; Pikitch et al., 2004). Integrated ecosystem assessments (IEAs) are increasingly developed to organize science in order to inform decisions in EBM (ICES, 2010; Levin et al., 2009, 2013; Möllmann et al., 2013). A large IEA program has been recently initiated in the Gulf of Mexico (GOM) by the National Oceanic and Atmospheric

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Administration (NOAA). One of the goals of the GOM IEA program is to regularly incorporate ecosystem considerations into single-species stock assessments and deliver estimates of parameters that are highly difficult to evaluate from empirical data (http://www.noaa.gov/iea/gulfofmexico.html). In particular, the GOM IEA program is committed to informing SEDAR (SouthEast Data, Assessment, and Review), a management council process designed to improve the reliability of single-species stock assessments in the GOM (http://www.sefsc.noaa.gov/sedar/). Several ecosystem simulation models have been used toward that goal.

The ecosystem simulation models used within the GOM IEA program include two Ecopath with Ecosim (EwE) models for the West Florida Shelf, one of the main regions of the GOM under high and increasing fishing and environmental pressures (Coleman et al., 2004; Karnauskas et al., 2013; Okey et al., 2004; Steidinger, 2009; Fig. 1). Ecopath is a widely-used trophic mass-balance model which explicitly considers major functional groups in a given ecosystem (fish, invertebrates, marine mammals, seabirds, plankton, etc.), and provides a snapshot of the trophic structure of this ecosystem (Christensen and Walters, 2004; Pauly et al., 2000). Chagaris (2013) constructed the 'WFS Reef fish Ecopath' model to analyze the trophic structure of the West Florida Shelf (WFS) over the period 2005–2009. Biomass, catch and productivity parameters of the WFS Reef fish Ecopath model were rescaled to obtain an Ecopath model for the early 1950s, from which Chagaris (2013) and Chagaris and Mahmoudi (2013) evaluated changes in biomasses, trophic interactions and mortalities in the West Florida Shelf over the period 1950–2009 using the Ecosim module (resulting in a EwE model). Gray et al. (2013) developed an EwE model similar to WFS Reef fish EwE, referred to as 'WFS Red tide EwE', in which they focused on the impacts of red tide (*Karenia brevis*) outbreaks for gag grouper (also simply referred to as gag; *Mycteroperca microlepis*), a socio-economically important species of the GOM, over the period 1980–2009.

Most single-species stock assessment models assume that natural mortality rates are constant across ages and over time due to difficulties to evaluate these rates empirically. Through the development of ecosystem models, we now have alternative means to estimate the natural mortality rates of different life stages of marine species in relation to changes in predator abundance and abiotic conditions (e.g., Fulton et al., 2003; Möllmann et al., 2013; Walters et al., 2006). In 2013, Chagaris and Mahmoudi (2013) and Gray et al. (2013) used, respectively, WFS Reef fish EwE and WFS Red tide EwE, to provide estimates of age- and time-specific natural mortality rates for gag to SEDAR. Chagaris and Mahmoudi (2013) evaluated the instantaneous natural mortality rates of three life stages (stanzas) of gag grouper (younger juveniles, older juveniles and adults) from 1950 to 2009, under alternate assumptions about compensatory survival and predation. The authors found interannual variability of gag natural mortality to decrease with age and compensatory survival during periods of low abundance. Gray et al. (2013) showed that mortality due to red tides was by far greater than predation mortality for adult gag over the period 2005–2009.

In addition to these EwE models, an OSMOSE model was also developed for the West Florida Shelf, referred to as 'OSMOSE-WFS' (Fig. 1). OSMOSE is a two-dimensional, individual-based and multispecies model explicitly representing major processes in the life cycle of high trophic level (HTL) groups of fish and invertebrate species (Shin and Cury, 2001, 2004). The application presented in this paper is a steady-state version of OSMOSE-WFS with a monthly time step, which describes trophic interactions in the West Florida Shelf in the 2000s. OSMOSE-WFS and WFS Reef fish Ecopath share a number of characteristics, such as the spatial domain, reference period and reference biomasses. However, OSMOSE-WFS and WFS Reef fish Ecopath differ greatly in both their structure and assumptions. In particular, diets reconstructed from empirical data are input into Ecopath, while they emerge from size-based processes in OSMOSE. The use of the OSMOSE-WFS, WFS Reef Fish Ecopath/EwE and WFS Red tide EwE models offers different perspectives on the functioning of the West Florida Shelf ecosystem, while being able to identify from where discrepancies between the different models may originate. Using a multi-model approach for the West Florida Shelf will allow us to evaluate uncertainties in our knowledge of the West Florida Shelf ecosystem, and help identify avenues for reducing these uncertainties.

Here, we introduce the OSMOSE-WFS model and describe the trophic structure of the West Florida Shelf in the 2000s with this model, with a focus on the diet patterns and natural mortality rates of gag grouper evaluated for SEDAR in 2013 (SEDAR 33; http://www.sefsc.noaa.gov/sedar/). In the following, we: (1) provide a brief overview of the OSMOSE modeling approach; (2) describe the structure and assumptions of OSMOSE-WFS; (3) detail the parameterization of OSMOSE-WFS; (4) present the methodology we implemented to calibrate OSMOSE-WFS to a reference state matching the mean observed conditions in the West Florida Shelf region over the period 2005–2009; (5) use the calibrated OSMOSE-WFS model to explore the trophic structure of the West Florida Shelf in the 2000s; and (6) discuss our results

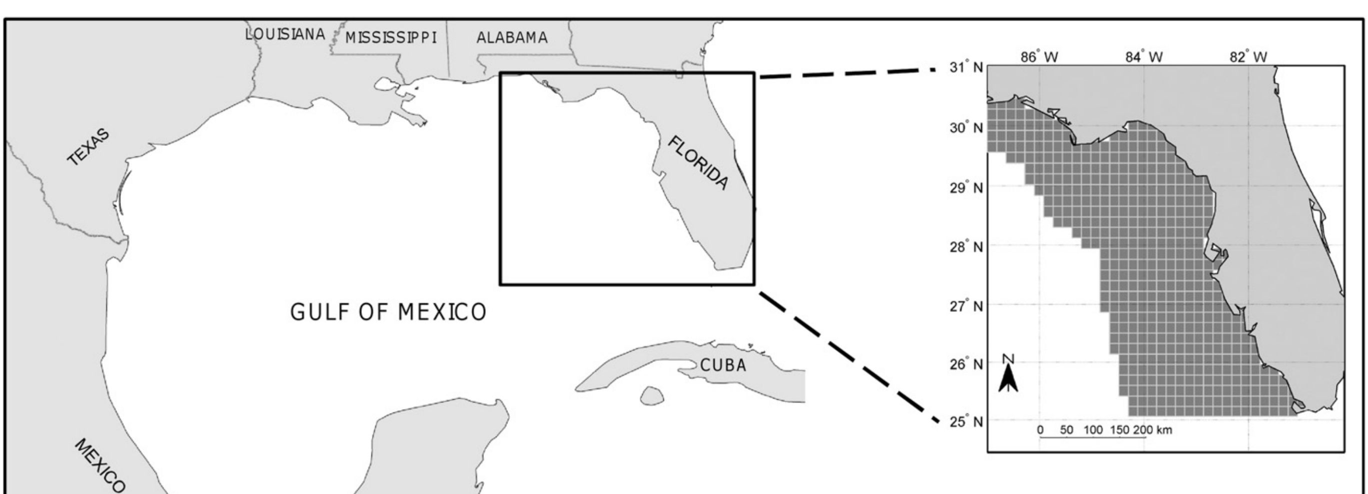

Fig. 1. Map of the West Florida Shelf in the Gulf of Mexico showing the spatial cells of OSMOSE-WFS (filled in dark gray).