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Simulating environmental effects on brown shrimp production in the northern Gulf of Mexico

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ABSTRACT

Brown shrimp (*Farfantepenaeus aztecus*) support a commercially important fishery in the northern Gulf of Mexico, and juveniles use coastal estuaries as nurseries. Production of young shrimp from any given bay system, and hence commercial harvest of sub-adults and adults from the Gulf, is highly variable from year to year. We describe development of a spatially-explicit, individual-based model representing the cumulative effects of temperature, salinity, and access to emergent marsh vegetation on the growth and survival of young brown shrimp, and we use the model to simulate shrimp production from Galveston Bay, Texas, U.S.A. under environmental conditions representative of those observed from 1983 to 2012. Simulated mean annual (January through August) production ranged from 27.5 kg ha^{-1} to 43.5 kg ha^{-1} with an overall mean of 34.3 kg ha^{-1} ($\pm$0.70 kg ha^{-1} SE). Sensitivity analyses included changing values of key model parameters by $\pm$10% relative to baseline. Increasing growth rates 10% caused a 16% increase in production, whereas a 10% decrease resulted in an 18% decrease in production. A 10% increase in mortality probabilities resulted in a production decrease of 15% while a 10% decrease resulted in an 18% increase in production. We also changed values of environmental input data by $\pm$10%. Mean production estimates increased 11% in response to increasing tide heights (and thus, marsh habitat access) and decreased 19% with a decrease in tide height (and marsh access). The thirty year mean production was affected negatively by both the 10% increase and decrease in air temperature ($-$2% and $-$14%, respectively). Simulations in which bay water salinities were entirely low (0–10 PSU), intermediate (10–20 PSU), or high (>20 PSU) resulted in mean baseline production rates being reduced by 55, 7, and 0%, respectively. Uncertainty in model estimates of shrimp production were related to the magnitude and the timing of postlarval shrimp recruitment to the bay system. Simulations indicated that mean production decreased when recruitment occurred earlier in the year under all environmental conditions. Mean production varied with environmental conditions, however, when recruitment was delayed. The model reproduced biomass and size distribution patterns observed in field data. Although annual variability of modeled shrimp production did not correlate well ($R^2 = 0.005$) with fisheries independent trawl data from Galveston Bay, there was a significant correlation with similar trawl data collected in the northern Gulf of Mexico ($R^2 = 0.40$; $p = 0.0005$). Identifying and representing spatially variable factors such as predator distribution and abundance among bays, therefore, may be the key to understanding bay-specific contributions to the adult stock.

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1. Introduction

Brown shrimp (*Farfantepenaeus aztecus*) is a commercially important fishery species of the northern Gulf of Mexico, and landings generated over $245 million (US dollars) in 2013 (National Marine Fishery Service, Fishery Statistics Division, 2015). The life history and population dynamics of brown shrimp have been studied extensively, and processes occurring during the juvenile phase in coastal estuaries appear to be important in determining population size (Zimmerman et al., 2000). Brown shrimp usually spawn and are harvested within one year (Cook and Lindner, 1970). Adults spawn offshore with peak activity from October to December and March to May (Christmas and Etzold, 1977; Renfro and Brusher, 1982). Eggs hatch within 14–18 h and pass through several larval stages (Cook and Lindner, 1970; Cook and Murphy, 1971) before moving into estuaries as postlarvae and settling as juveniles in

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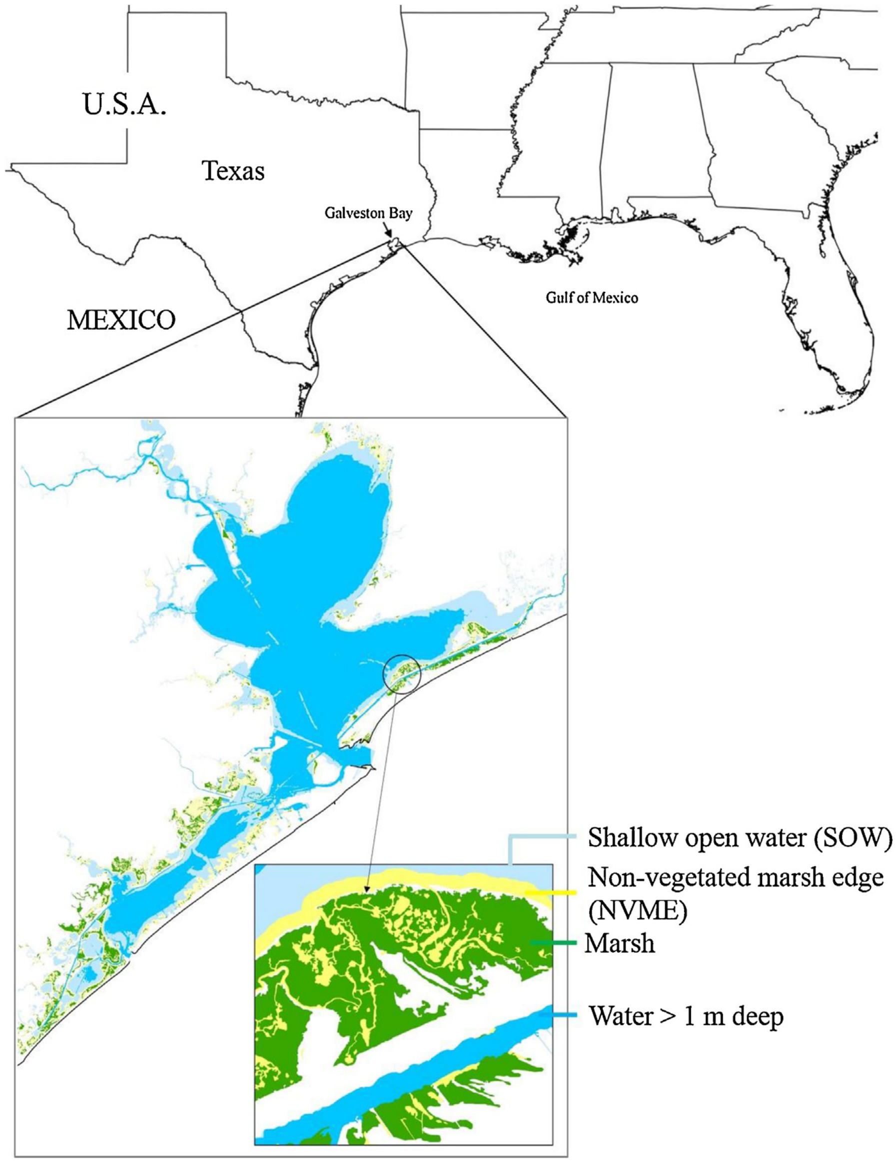

Fig. 1. Map indicating the location of the Gulf of Mexico and Galveston Bay, Texas, U.S.A. Within Galveston Bay, approximate locations of areas of marsh (green), non-vegetated marsh edge (NVME, yellow), shallow open water (SOW, light blue), and deeper (≥1 m deep) water (dark blue) also are indicated.

inshore bays (Fry, 2008). Juveniles grow rapidly to sub-adult size and then migrate offshore to complete their growth to maturity (Trent, 1967). Young brown shrimp in the northern Gulf of Mexico utilize shallow estuarine habitats and grow from postlarvae (10–15 mm TL) to subadults (55–80 mm TL) within a few months (Cook and Lindner, 1970). While brown shrimp juveniles occur in several habitat types including oyster reef (Stunz et al., 2010) and shallow open water (Fry, 2008; Minello, 1999), highest densities are found in seagrass and salt marsh (Minello et al., 2003; Stokes, 1974). Relatively little seagrass habitat exists in Galveston Bay or in many estuaries of the northwestern Gulf of Mexico (Handley et al., 2007), and the majority of brown shrimp are found associated with emergent marsh vegetation (Minello and Rozas, 2002; Zimmerman et al., 1984). Indeed, brown shrimp commercial yield has been correlated on a large scale with the presence of intertidal vegetation (Boesch and Turner, 1984; Turner, 1977).

The Galveston Bay system is the largest estuary in State of Texas, U.S.A. (Fig. 1) and the salt marshes and shallow water surrounding the bay are particularly important habitats for young shrimp (Minello et al., 2008). *Spartina alterniflora* is the dominant shoreline vegetation (Minello and Webb, 1997), and this intertidal habitat supports high densities of young brown shrimp when flooded (Zimmerman and Minello, 1984). Some mechanisms linking salt marsh habitats with brown shrimp production have been identified (Zimmerman et al., 2000). Growth of juvenile shrimp is mainly a function of temperature and food availability (Zein-Eldin and Aldrich, 1965), with growth rates commonly reaching 1 mm day^{-1} (Knudsen et al., 1977). Young brown shrimp feed on benthic invertebrates such as amphipods and polychaete worms (McTigue and Zimmerman, 1991, 1998), which often are most abundant within marsh vegetation (Whaley and Minello, 2002). These studies support the conclusion that growth rates should be highest when the vegetated marsh surface is available for foraging (Minello and Zimmerman, 1991). Shrimp access to the vegetated marsh surface is dependent upon tide height and marsh surface elevation (Childers et al., 1990; Minello et al., 2012). In the northern Gulf of Mexico, tides are microtidal (<1 m), predominantly semidiurnal, and strongly wind driven, resulting in water levels that regularly deviate from predicted tides (Minello et al., 2012; Rozas, 1995). The increased growth rates associated with access to the