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Spatial and temporal shifts in suitable habitat of juvenile southern flounder (*Paralichthys lethostigma*)

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ABSTRACT

Factors influencing suitable habitats of juvenile southern flounder (*Paralichthys lethostigma*) within the Galveston Bay Complex (GBC), Texas, were assessed using generalized additive models (GAM). Fishery independent data collected with bag seines throughout the GBC from 1999 to 2009 were used to predict the probability of southern flounder occurrence. Binomial GAMs were used to assess presence/absence of southern flounder and models included temporal variables, benthic variables such as distance to habitats generated within a geographic information system, and physicochemical conditions of the water column. Separate models were generated for newly settled southern flounder, young-of-the-year (YOY) southern flounder observed in the summer, and YOY southern flounder observed in fall based on size and collection month. Factors affecting southern flounder occurrence changed seasonally, as did the corresponding shifts in the spatial distribution of suitable habitat. Temporal effects (year and month) were retained in all models. Physicochemical conditions (temperature, turbidity, and measures of environmental variability), and the presence of seagrass beds were influential for newly settled southern flounder. Distance to marine and/or freshwater sources were found to be important for YOY southern flounder in the summer and fall seasons. The abundance of brown shrimp was found to only influence the distribution of YOY southern flounder in the fall, when intermediate abundances of the potential prey item increased the occurrence of southern flounder. After model completion, the availability and spatial distribution of suitable habitat within the GBC was predicted using available environmental and spatial data for 2005. Spatial distributions of predicted suitable habitat stress the relative importance of West Bay during the newly settled stage and in the fall season, and Upper Bay during the summer and fall of the first year of life. These models demonstrate the potential dynamics of suitable habitats for juvenile southern flounder and provide insight into ontogenetic shifts in habitat preference during the first year of life.

1. Introduction

Estuarine habitats support increased densities of many fish and invertebrate species, and are often considered nurseries (Beck et al., 2001; Boesch and Turner, 1984). Within estuaries, site-specific differences in benthic and physicochemical characteristics lead to variability in habitat quality, and subsequent distributions of juveniles (Beck et al., 2001). Identifying factors that influence the distribution and abundance of organisms across estuarine seascapes are needed to define nursery habitats of commercially or recreationally important species. Most studies investigating factors affecting distributions among potential nursery habitats focus on newly settled individuals immediately after estuarine ingress when mortality is at its highest (Almany and Webster, 2006; Levin, 1991; Victor, 1986). Mortality rates of teleost fishes often remain elevated throughout the juvenile period (Able et al., 2007) and vary as a function of the estuarine habitats used (Minello et al., 2003; Rooker et al., 1998). Furthermore, habitat requirements can change during ontogeny, even within the same estuarine seascape (Grober-Dunsmore et al., 2009). In response, life-stage-specific habitat requirements are needed for the entire period of estuarine residency and, to date, few studies have attempted to simultaneously compare distributions of multiple size/age groups during the juvenile period (but see Stoner et al., 2001).

Habitat distribution models have become a common method to identify factors influencing species' occurrence and subsequently to visualize the spatial arrangement of habitats in estuarine and marine systems (Valavanis et al., 2008). Currently, a number of methods exist for generating habitat distribution models, including classification regression trees, maximum entropy approaches, general linear models, and generalized additive models. Generalized additive models (GAMs) are extensions of general linear models that allow the inclusion of both

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parametric and nonparametric effects of explanatory variables on the response (Wood, 2006; Wood and Augustin, 2002), and GAMs have been used to successfully identify factors influencing habitat requirements of a wide variety of estuarine-dependent fishes, including spotted seatrout (*Cynoscion nebulosus*) (Kupschus, 2003), winter flounder (*Paralichthys pseudoamericanus*) (Stoner et al., 2001), and juvenile Pacific cod (*Gadus macrocephalus*) (Abookire et al., 2007). More recently, GAMS have been used to identify factors influencing suitable estuarine habitats of juvenile flatfish, allowing for the generation of nursery habitat maps in order to guide habitat conservation and fisheries management (Florin et al., 2009; Zucchetta et al., 2010).

The purpose of this study was to develop habitat distribution models for characterizing the spatial occurrence of suitable habitat of juvenile southern flounder (*Paralichthys lethostigma*) across a large estuarine complex. Southern flounder is a recreationally important flatfish found in coastal waters throughout the Gulf of Mexico, and due to recent declines in population numbers (Froeschke et al., 2011), there is a renewed interest in defining essential habitats of this species, particularly during the first year of life when mortality is high and variable for fishes (Houde, 1989; Winemiller, 2005; Winemiller and Rose, 1992). It has been suggested that the coupling of biotic and abiotic factors drives the distribution of juvenile southern flounder within estuarine habitats (Burke, 1995; Fitzhugh et al., 1996). More specifically, benthic types and physicochemical conditions of the water column appear to influence the distribution and possibly growth and survival of southern flounder (Burke et al., 1991; Del Toro-Silva et al., 2008; Minello et al., 1987). Here, we used a GAM framework to examine the relative importance of temporal (seasonal and interannual), physicochemical, and benthic factors on the distribution of newly settled and young-of-the-year southern flounder. By partitioning the first year of life into discrete life history intervals, we comprehensively examine ontogenetic and seasonal changes in species-habitat relationships of southern flounder.

2. Methods

2.1. Data used in modeling

Data used in models were based on monthly fishery-independent surveys of the Galveston Bay Complex (GBC) by the Texas Parks and Wildlife Department (TPWD) from 1999 to 2009. Surveys were conducted using bag seines (18.3 m long, 1.8 m deep, 13 mm mesh in the cod end). Bag seines were pulled in shallow water habitats (2 m maximum depth) parallel to shore for a distance of approximately 15 m (Martinez-Andrade et al., 2005). Juvenile southern flounder captured in surveys were enumerated and measured for total length (TL). TPWD recorded location and numerous environmental variables, including water temperature, salinity, dissolved oxygen, sediment types present, and depth. Sediment types recorded by TPWD were simplified to presence of sand, mud, and rocks to reduce the number of explanatory variables used in modeling. Temporal variables of year and month were also retained from TPWD data. In addition, catch data for juvenile southern flounder were separated into three life stages based on size and the months of the year. First, we define the 'newly settled' life stage as individuals captured in the months December through March less than 50 mm total length (TL), which is conservative given growth rates (up to 0.76 mm/day) and hatch dates (predominantly mid December to January) observed by Glass et al. (2008) in Galveston Bay. 'YOY' southern flounder were defined as individuals 50 mm to 200 mm TL and this represents the remainder of the age-0 period well after the winter settlement event. Two YOY life stages were defined using the seasonal periods of April to July and August to November, to further examine ontogenetic and/or seasonal shifts in distribution or habitat use, which for simplicity will be referred to as summer and fall, respectively. Given that the mean size of age-0 southern flounder observed by Stunz et al. (2000) along the Texas coast was 254 mm TL, we are confident that all individuals in the YOY category were less than one year of age. All survey locations were visualized and all spatial analyses were conducted in ArcGIS 9.3 (ESRI, Redlands CA).

Within a Geographic Information System (GIS), variables of distance to benthic habitats (marsh edge, seagrass, oyster reef) and sources of fresh and marine water (freshwater inlets and tidal inlets) were created for each bag seine sample. Marsh edges were defined from georeferenced National Wetlands Inventory maps (NWI; Cowardin et al., 1979). Marsh habitats were defined as Estuarine Intertidal Emergent Persistent vegetation within the NWI habitat classification scheme (E2EM1; Cowardin et al., 1979). Oyster reef and seagrass locations were downloaded from the National Oceanographic Atmospheric Administration National Coastal Data Development Center (NOAA NCDDC) and were originally defined by the Texas General Land Office (GLO). Distances were calculated between features with the shoreline as a barrier, using the cost-distance function within ArcGIS (ESRI, Redlands CA). In addition, monthly surface freshwater inflow values were generated by Texas Water Development Board (TWDB) hydrography models for Galveston Bay (available at http://midgewater.twdb.state.tx.us/bays_estuaries/hydrologypage.html).

Because unstable habitats may prevent fish from ever experiencing optimal conditions (Peterson, 2003), the variance of a location's physicochemical conditions was estimated and included in the modeling process. Temperature variance was defined as the variance in recorded temperatures from all surveys within the same season (newly settled season, summer, or fall) and within 1 minute (1/60 degree) of latitude and longitude. Variance in dissolved oxygen and salinity were collinear and, as a result, a metric was generated by the summation of variances in the two conditions, using the same temporal and spatial scales as temperature variance.

2.2. Model generation

To examine the factors affecting southern flounder occurrence, generalized additive models (GAMs) were employed (Hastie and Tibshirani, 1990; Wood, 2006). GAMs are a nonparametric extension of general linear models (GLM), and provide the flexibility to model non-parametric relationships that can be seen in ecology. In the case of binomial GAMs with a logit link, the equation takes the form of

$$\ln\left[\frac{1-y^*}{y^*}\right] = \beta_0 + \sum_k f_k x_k$$

Where y^* represents the predicted probability of southern flounder occurrence, β_0 equals the intercept, k equals the number of explanatory variables included in the model, f_k equals the smoothing function for the variable x_k. Penalized cubic regression splines determined the shape of nonparametric functions, with the degree of smoothing selected automatically for models and were generated within the "mgcv" library (Wood, 2006, 2008) using R 2.10 software (R Development Core Team, 2010).

Three different life stages of juvenile southern flounder were modeled: 1) newly settled, 2) YOY-summer, and 3) YOY-fall. Our season and life stage definitions resulted in a total of 2500 surveys from 2455 unique sites, with 196 surveys observing appropriately sized southern flounder (Table 1). Manual backward stepwise selection based on minimization of the Akaike information criterion (AIC; Akaike, 1974) was used to select final models. When GAMs indicated that a linear relationship was appropriate, the smoothed fit was replaced with a linear fit. Prior to model selection, collinearity was explored among abiotic variables using Spearman correlation coefficient (Spearman ρ). When the Spearman ρ between two variables > 0.5, the effect of each variable on southern flounder occurrence was examined alone within a separate GAM. The variable that indicated better model