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A Modeling and Field Approach to Identify Essential Fish Habitat for Juvenile Bay Whiff (*Citharichthys spilopterus*) and Southern Flounder (*Paralichthys lethostigma*) Within the Aransas Bay Complex, TX

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Abstract The goal of this study was to use an ecosystem-based approach to consider the effect of environmental conditions on the distribution and abundance of juvenile bay whiff and southern flounder within the Aransas Bay Complex, TX, USA. Species habitat models for both species were developed using boosted regression trees. Juvenile bay whiff were associated with low temperatures (<15 °C, 20–23 °C), moderate percent dry weight of sediments (25–60 %), salinity >10, and moderate to high dissolved oxygen (6–9 mg O_2/l, 10–14 mg/l). Juvenile southern flounder were associated with low temperatures (<15 °C), low percent dry weight of sediment (<25 %), seagrass habitat, shallow depths (<1.2 m), and high dissolved oxygen (>8 mg O_2/l). Our results indicate that conservation measures should focus along the eastern side of Aransas Bay and the north corner of Copano Bay to protect essential fish habitat. These findings provide a valuable new tool for fisheries managers to aid in the sustainable management of bay whiff and southern flounder and provide crucial information needed to prioritize areas for habitat conservation.

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Introduction

Habitat loss due to human impacts is a primary cause of population depletion in fishes (Ruckelshaus et al. 2002; Dulvy et al. 2003; Pyke 2004; Levin and Stunz 2005; Lotze et al. 2006). Declining fish stocks and loss of habitat threaten the health of marine ecosystems (Jackson et al. 2001; Pauly et al. 2002; Hilborn et al. 2003; Pyke 2004; Hughes et al. 2005; Lotze et al. 2006; Crowder et al 2008; Halpern et al. 2008; NMFS 2008; Worm and Lotze 2009; Zhou et al. 2010), and it has been hypothesized that the overfished populations and ecosystems that they inhabit are more susceptible to other anthropogenic impacts (Jackson et al. 2001; Halpern et al. 2008). In the Gulf of Mexico, declining populations of important fish stocks such as southern flounder (*Paralichthys lethostigma*; Froeschke et al. 2011) accentuate the importance of defining critical habitats as well as the processes that contribute to habitat quality (Houde and Rutherford 1993; Allen and Baltz 1997). Southern flounder support an important fishery in the Gulf of Mexico, yet essential fish habitat (EFH) has not been described distribution-wide for this species (VanderKooy 2000). An improved understanding of the relationship between abiotic (e.g., temperature, hydrodynamics, oxygen, salinity) and biotic factors (e.g., organic content, habitat) with respect to life history and habitat requirements is essential for robust management of this fishery.

Along the Texas coast, flounder have historically supported a multi-million dollar commercial and recreational fishery (Matlock 1991; VanderKooy 2000). Southern flounder represent over 95 % of harvested flounder and is one of the top three fish species targeted by recreational anglers (Riechers 2008). Despite increased commercial and recreational fishing regulation in Texas, the southern flounder population is declining at an alarming rate (Froeschke et al. 2011). A fisheries management plan for the Gulf of Mexico flounder fishery was developed and determined that identification of EFH for the flounder fishery is crucial for effective management (VanderKooy 2000). Initial studies on EFH for young-of-the-year southern flounder in Aransas Bay and Copano Bay, TX, USA showed that they occur in vegetated habitats (seagrass and marsh edge) near tidal inlets in Aransas Bay (Nañez-James et al. 2009). However, their abundance and distribution in conjunction with abiotic factors were not evaluated. Texas estuaries are physically dynamic, and the distribution of fishes is strongly affected by environmental conditions (Froeschke et al. 2010; Froeschke and Froeschke 2011).

Flatfish as a group are important components of coastal ecosystems. For example, bay whiff are among the most common flatfishes in Gulf of Mexico estuaries (Allen and Baltz 1997; Castillo-Rivera et al. 2000) and North Carolina (Walsh and Peters 1999). Bay whiff are not a recreational or commercially targeted species and little is known about their habitat use along the Texas coast. However, they exhibit similar temporal recruitment patterns to southern flounder. Moreover, it has been hypothesized that bay whiff are habitat generalists (Allen and Baltz 1997; Walsh and Peters 1999). For example, in North Carolina, the abundance of bay whiff was not significantly different among 21 stations sampled, which included marsh, seagrass, and non-vegetated habitats, implying that bay whiff are associated with all estuarine habitats (Walsh and Peters 1999).

The objective of this study was to develop species habitat models for two important flatfish species, southern flounder and bay whiff. Specifically, the relationship between abiotic (temperature, salinity, turbidity, dissolved oxygen, and pH) and biotic factors (habitat, depth, and organic content) with the frequency of occurrence of bay whiff and southern flounder was investigated within the Aransas Bay Complex (Mission-Aransas National Estuarine Research Reserve—MANERR), TX, USA. To examine this relationship, we developed spatially explicit distribution patterns of juvenile bay whiff and southern flounder. We used boosted regression trees (BRT) (De'ath 2007; Elith et al. 2008), a powerful yet relatively new approach to modeling species–environment relationships. Boosted regression trees is an ensemble method that combines statistical and machine learning techniques and has shown to be an effective method to identify relationships between fish distribution patterns and environmental predictors (Leathwick et al. 2006; 2008; Froeschke et al. 2010a; Froeschke and Froeschke 2011). The species habitat models of southern flounder and bay whiff will provide natural resource managers crucial information needed to conserve habitats for various developmental stages of flatfish within the Aransas Bay Complex, TX, USA.

Study Site

Field collections were conducted in the estuarine waters of the northern Gulf of Mexico in the Aransas Bay Complex (Fig. 1) within the MANERR. The reserve encompasses 752 km^2 of seagrass beds (primarily *Halodule wrightii*), oyster reefs (*Crassostrea virginica*), salt marsh (*Spartina alterniflora*), and non-vegetated bottom (sand with small amounts of clay and silt). Aransas Bay contains extensive coastal wetlands and submerged aquatic vegetation, while Copano Bay is the largest secondary bay connected to Aransas Bay; freshwater inflow (mean daily inflow of 28 m^3/s) occurs primarily via the Aransas and Mission Rivers, and virtually all of the saltwater exchange occurs via the Aransas Pass tidal inlet (Fig. 1).

Materials and Methods

Field Collection

A stratified, randomized experimental design was used to identify EFH for juvenile bay whiff and southern flounder within the Aransas Bay Complex from February to May 2010 during peak flatfish recruitment season (Nañez-James et al. 2009; Froeschke et al. 2011). Sites were selected by converting the study area into 100-m^2 grid cells. Habitat type for each cell was determined using existing habitat maps (http://www.csc.noaa.gov/digitalcoast/data/benthiccover/download.html). Using this grid, 40 100-m^2 sites were sampled each month in three habitat types: seagrass (n=10), oyster (n=10), and non-vegetated bottom habitats (n=20). Sampling effort per habitat type was determined based on the proportion of each habitat within the Aransas Bay Complex. Sample sites were selected without replacement using a randomized selection of sites from the sampling grid.

Physical Environment

Prior to sampling at each site, environmental variables were measured just above the substrate using a Hydrolab 5S Sonde. Variables measured included temperature (°C), dissolved oxygen (DO, in mg O_2/l), pH, salinity, and depth (m). Turbidity was measured using a Secchi disk (cm). Sediment

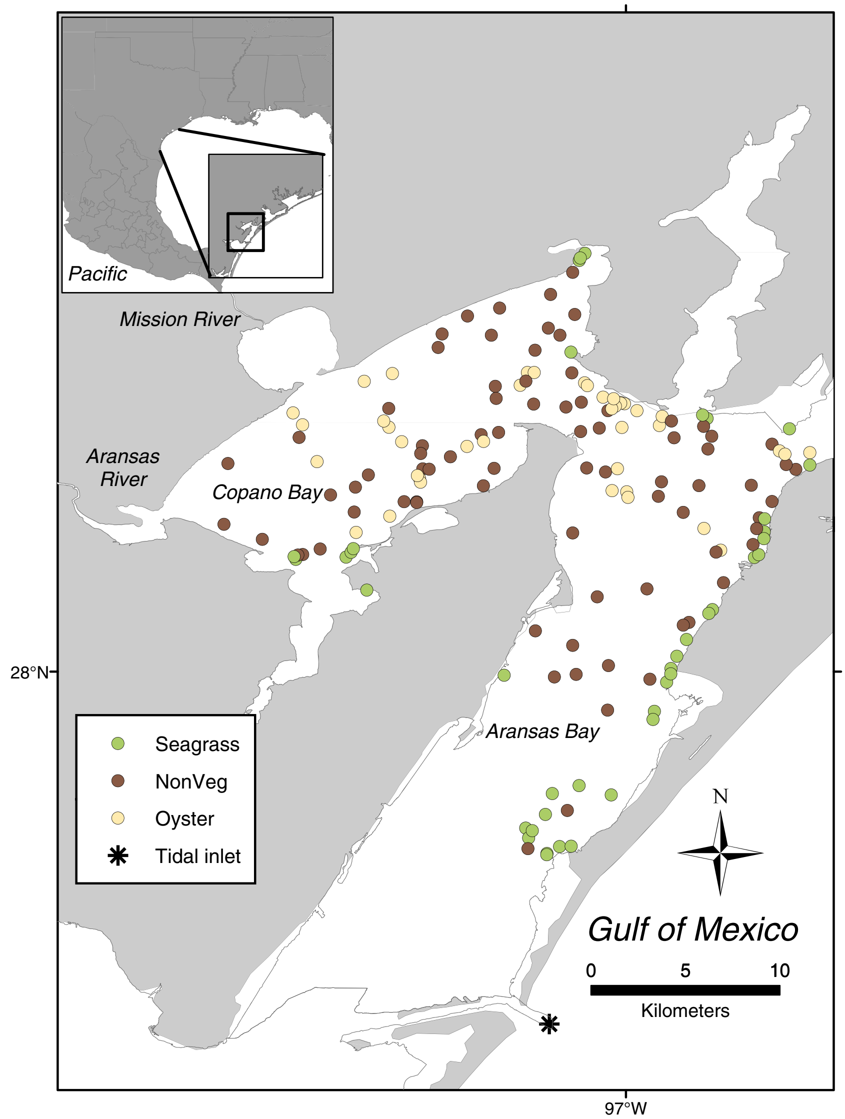

Fig. 1 Map of Aransas Bay Complex located along the Northwestern Gulf of Mexico. Sampling locations (n=160 sites) within the Aransas Bay Complex from February to May 2010: 80 non-vegetated bottom (*brown circles*), 40 seagrass sites (*green circles*), and 40 oyster sites (*tan circles*)

samples were taken at non-vegetated and seagrass sites using a modified Van-Veen grab. Sediment samples were not collected at oyster sites as shells prevented sediment collection. Sediment samples were placed on ice and transported back to the laboratory for dry weight analysis as an indication of organic content. Analyses were conducted by placing 25 g of sediment from each sample into an oven at 104 °C for 24 h. After drying, samples were re-weighed and the new weights (dry weights) were subtracted from the original wet weight using the following formula:

$$\text{Dry weight} = (\text{sediment after drying (g)})/(\text{wet weight (g)})$$

Samples with a low percent of dry weight were considered to have a higher percentage of organic content than samples with a higher percent of dry weight. Thus, low percentage of dry weight is correlated with higher quality of sediments.

Fish Sampling

Juvenile bay whiff and southern flounder were collected using a 2-m-wide beam trawl with 6-mm-stretch mesh liner towed for 50 m (total area 100 m^2) at a constant speed (5 knots). Trawl samples were rough-sorted in the field to remove excessive algae, seagrass, and debris, preserved in 10 % formalin, and returned to the laboratory for further processing. All flatfishes were identified, enumerated, and measured to the nearest millimeter standard length (SL).

Spatial Analyses

Saltwater and larval exchange occurs via the Aransas tidal inlet, and flatfish use the tidal inlet to migrate offshore for spawning as adults and as an ingress pathway during the larval stage. Therefore, to examine a potential relationship between juvenile bay whiff and southern flounder with the

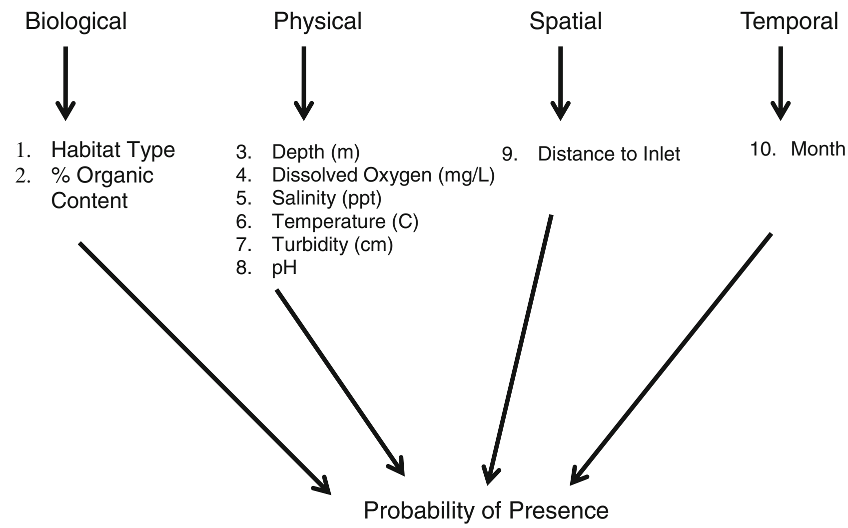

Fig. 2 Flowchart for boosted regression trees to identify essential fish habitat for juvenile bay whiff and juvenile southern flounder within the Aransas Bay Complex

connection to the Gulf of Mexico, the distance from the Aransas tidal inlet to each sampling location was calculated using the cost distance function in the spatial analyst extension in ArcGIS (ESRI, Redlands, CA, USA), using the shoreline as a buffer (Whaley et al. 2007). The cost distance function is used to calculate the shortest distance between two points that are constrained within a geographic boundary to provide more accurate relative distance estimates than Euclidian methods (Froeschke et al. 2010).

Boosted Regression Trees

Relationships between both juvenile bay whiff and southern flounder density and biological, physical, spatial, and temporal variables were determined using a forward fit, stage-wise, binomial boosted regression tree model (De'ath 2007). Boosted regression trees (1) accept different types of predictor variables, (2) accommodate missing values through the use of surrogates, (3) resist the effects of outliers, and (4) automatically fit interactions between predictors (Elith et al. 2006; Leathwick et al. 2006; Elith et al. 2008; Leathwick et al. 2008). Unlike traditional regression techniques, BRT combines the strength of two algorithms, regression trees and boosting, to combine large numbers of relatively simple tree models instead of a single "best" model (Elith et al. 2006; Leathwick et al. 2006; Elith et al. 2008; Leathwick et al. 2008). Each individual model consists of a simple regression tree assembled by a rule-based classifier that partitions observations into groups having similar values for the response variable based on a series of binary splits constructed from predictor variables (Friedman 2001; Leathwick et al. 2006; Elith et al. 2008). The BRT often has a higher predictive performance than single tree methods due to the inherent strengths of regression trees and the robustness of model averaging that improves predictive performance. Overfitting is minimized by incorporating tenfold cross-validation into the model fitting process (Elith et al. 2006; Leathwick et al. 2006; Elith et al. 2008; Leathwick et al. 2008). The fitting of a BRT model is a stochastic process. To examine within model variability, the BRT model was refit using (n=1,000) randomized variations of the original dataset. Mean predicted probability of occurrence and 95 % confidence limits were determined in the study area.

Analyses were conducted in R (version 2.15, R Development Core Team 2009) using the "gbm" library supplemented with functions from Elith et al. (2008). Initially, ten predictors were included in the model: habitat type, dry weight, depth (m), dissolved oxygen (mg O_2/l), temperature (°C), turbidity (cm), salinity, pH, distance to the inlet, and month (treated as a categorical variable; Fig. 2).

Table 1 Mean (± standard error) parameter ranges by habitat from 160 sites (seagrass n=40, oyster reef n=40, and non-vegetated n=80) sampled from February to May 2010 within the Aransas Bay Complex

	Non-vegetation	Oyster	Seagrass
Temperature (°C)	21.55±2.41	21.97±3.47	22.99±3.64
Salinity (psu)	14.74±1.65	13.13±2.08	18.93±2.99
Turbidity (cm)	81.12±9.07	73.10±11.56	56±8.85
Depth (m)	3.59±0.40	2.78±0.44	2.15±0.34
Dissolved Oxygen (mg O2/l)	7.26±0.81	7.89±1.25	9.03±1.43
pH	8.14±0.91	8.22±1.30	8.44±1.33
Dry Weight (%)	47.83±5.49	N/A	29.06 ±4.59

The adjustable model parameters for BRT are tree complexity (tc), learning rate (lr), and bag fraction, where tc controls whether interactions are fitted, lr determines the contribution of each tree to the growing model, and bf specifies the proportion of data to be selected at each step (Elith et al. 2008). Model selection was based on two performance metrics: (1) area under the receiver operating characteristic (ROC) curve and (2) explained deviance on cross-validated data. Selection of predictor variables was done using the gbm.simplify function from Elith et al. (2008), while the tuning parameters

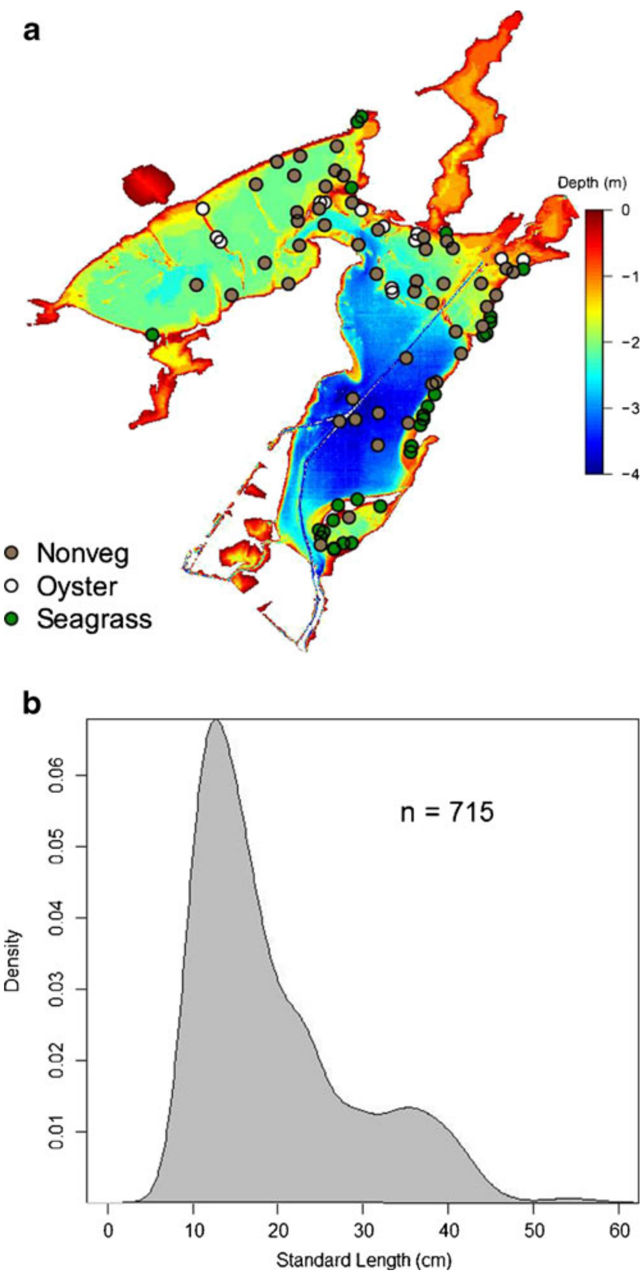

Fig. 3 **a** Sampling sites by habitat and depth within the Aransas Bay Complex where juvenile bay whiff were captured from February to May 2010. Non-vegetated bottom sites are indicated with *brown circles*, oyster sites are indicated with *white circles*, and seagrass sites are indicated with *green circles*. **b** Density graph of standard length for juvenile bay whiff captured in the Aransas Bay Complex from February to May 2010. Mean length=19.68±0.35 mm SL

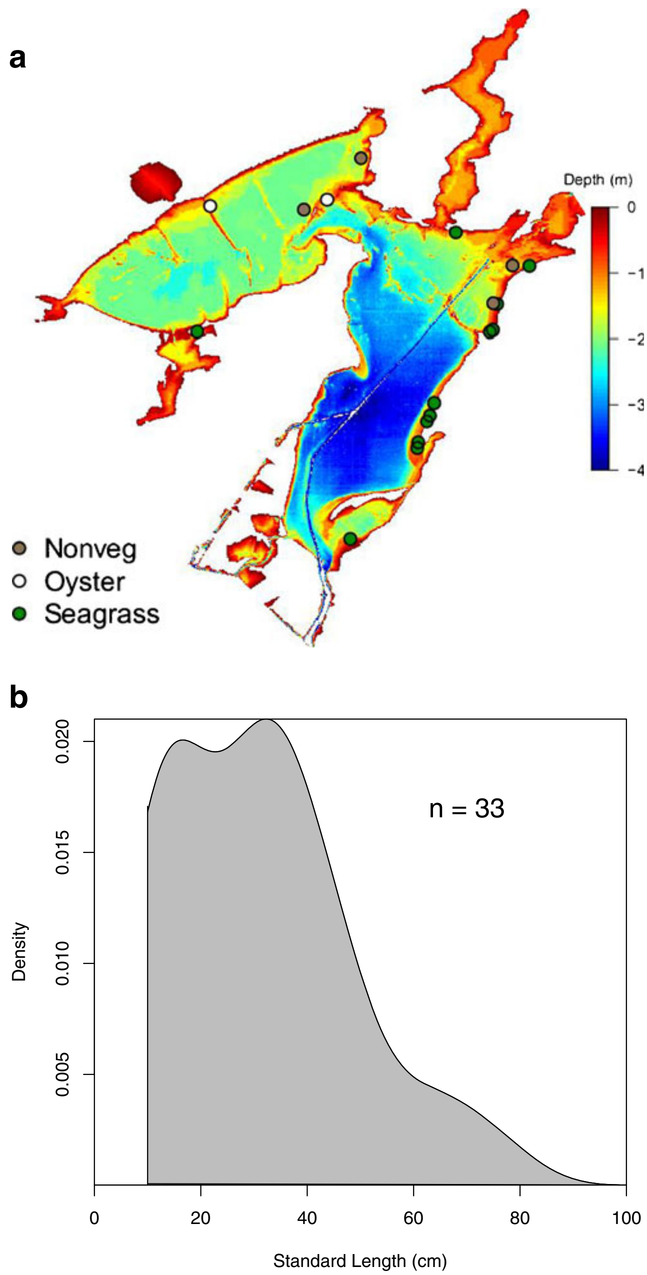

Fig. 4 **a** Sampling sites by habitat and depth within the Aransas Bay Complex where juvenile southern flounder were captured from February to May 2010. Non-vegetated bottom sites were indicated with *brown circles*, oyster sites were indicated with *white circles*, and seagrass sites were indicated with *green circles*. **b** Density graph of standard length for juvenile southern flounder captured in the MANERR from February to May 2011. Mean length=30.90± 2.98 mm SL

Table 2 Predictive performance of boosted regression trees (BRT) models for juvenile bay whiff and southern flounder. *tc* = tree complexity, *lr* = learning rate, and *bf* = bag fraction

Percentage Deviance Explained								
Species	*tc*	*lr*	*bf*	Cross-Validation	Training	Total Deviance	Mean ROC Cross-Validation	Mean ROC Cross-Validation SE
Bay whiff	2	0.001	0.65	21.70 %	46.80 %	1.374	0.797	0.013
Southern flounder	5	0.0005	0.6	15.07 %	45.50 %	0.703	0.802	0.023

were optimized by cross-validation selecting a final model larger than 1,000 trees with maximum explained deviance on cross-validated data.

Habitat Suitability Models

We used ordinary kriging with a spherical semivariogram of predicted probability of occurrence of bay whiff and southern flounder (Froeschke et al. 2010) to develop spatially explicit predictions. Kriging is a spatial interpolation algorithm that was used to predict values at unsampled sites in the study area (Saveliev et al. 2007). This routine was carried out for each iteration of the fitted BRT model (n=1,000) to determine the mean (and 95 % confidence limits) of predicted probability of occurrence across the study area. Kriging was carried out using the automap (Hiemstra et. al. 2008) and raster (Hijmans and van Etten 2012) libraries in R (version 2.15, R Development Core Team).

Results

Abiotic and Biotic Parameters

During this study, temperature ranged from 12.88 °C (February) to 30.48 °C (May), and the depth across sites ranged from 0.08 m (seagrass) to 3.54 m (non-vegetated bottom; Table 1). The lowest salinity (6.22) occurred in an oyster reef in Copano Bay sampled in February, and the highest salinity (33.50) occurred in seagrass in Aransas Bay sampled in March (Table 1). The lowest dissolved oxygen (2.72 mg O_2/l) occurred in April in seagrass in Copano Bay, and the highest dissolved oxygen (14.49 mg O_2/l) also occurred in April but in non-vegetated bottom in Aransas Bay (Table 1). Percent dry weight was lowest (10.09 %) in March in Copano Bay at a non-vegetated site and highest (75.58 %) in May in Aransas Bay at a non-vegetated site (Table 1). Turbidity ranged from 20 to 200 cm, with the

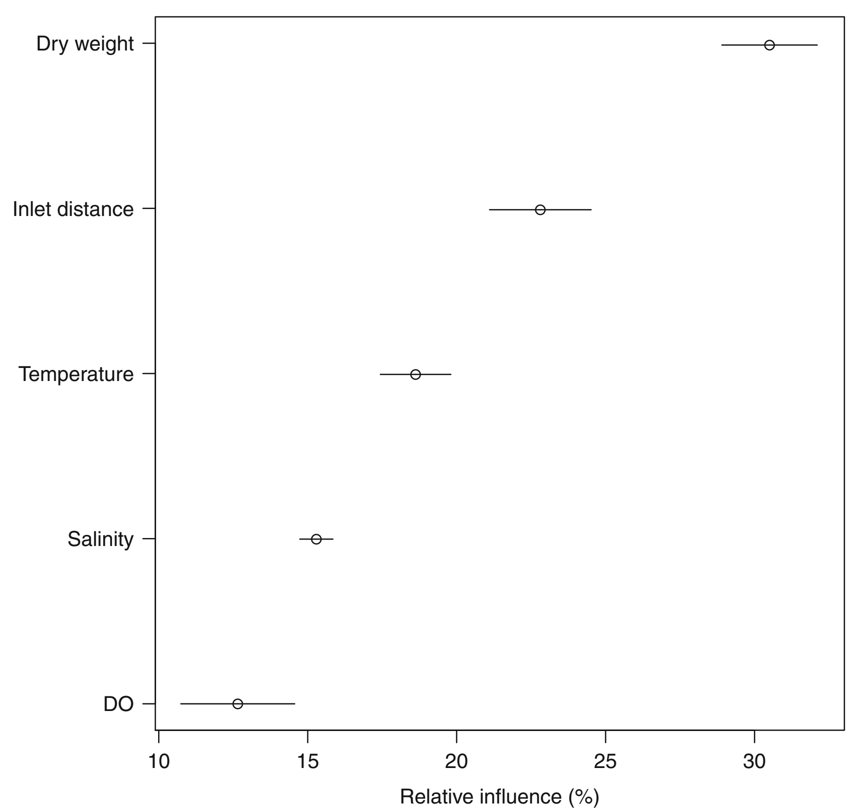

Fig. 5 Relative influence (%) with 95 % confidence intervals of the five important predicator variables by a boosted regression trees model relating the probability of capture of juvenile bay whiff to the environment in order to identify essential fish habitat within the Aransas Bay Complex. *Y-axis* parameters: % dry weight, inlet distance, temperature (°C), salinity (psu), and dissolved oxygen (*DO*; mg O_2/l)

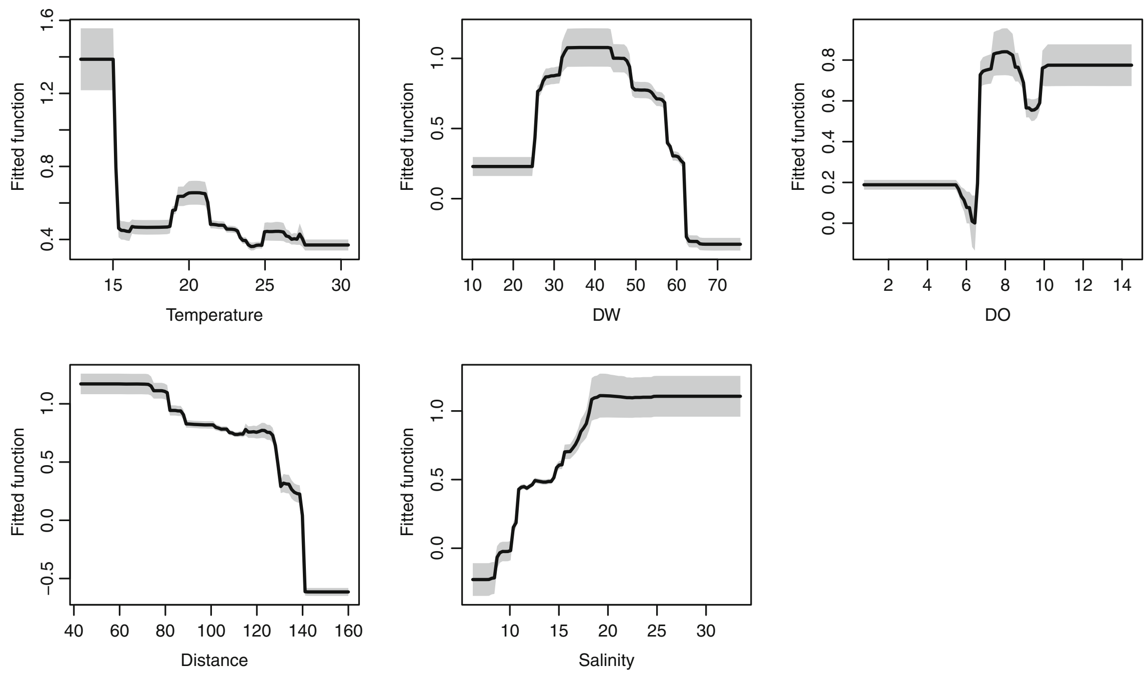

Fig. 6 Functions fitted with 95 % confidence intervals for the five important predictor variables by a boosted regression trees model relating the probability of capture of juvenile bay whiff to the environment in order to identify essential fish habitat within the Aransas Bay Complex. *Y-axes* are on the logit scale with mean zero. *X-axes* parameters: % dry weight (*DW*), distance to the nearest inlet, temperature (temperature, °C), salinity (psu), and dissolved oxygen (*DO*; mg O_2/l)

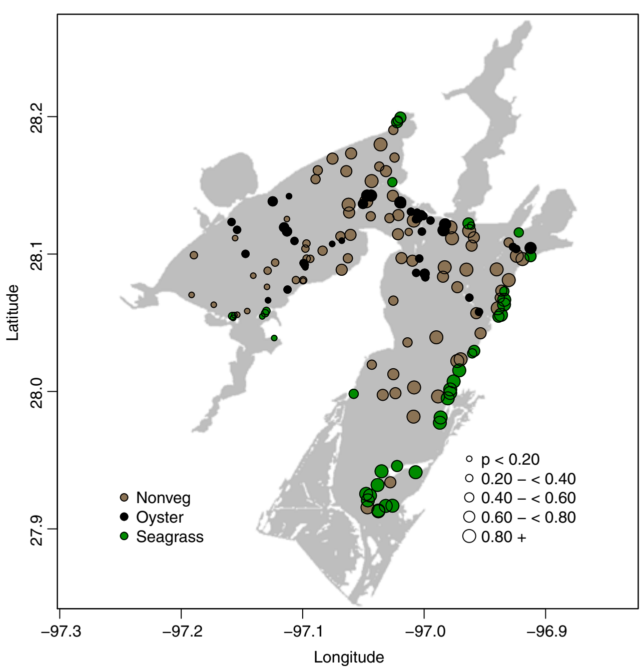

Fig. 7 Prediction of juvenile bay whiff from the boosted regression trees model indicating that the highest probability of collection would occur among habitats located along the east and north areas of Aransas Bay and the northwest corner of Copano Bay. Moderate probability of occurrence for bay whiff occurred along the very west side along Aransas Bay and the northeast corner of Copano Bay. The lowest probability of occurrence for bay whiff occurred along the middle and south areas of Copano Bay

lowest turbidity occurring in seagrass in February in Copano Bay and the highest turbidity occurring in non-vegetation in May in Aransas Bay (Table 1).

Bay whiff was the most abundant flatfish species collected. In 160 samples, bay whiff comprised 95.7 % (n=715) of flatfishes collected (Fig. 3a) and ranged in size from 8.1 to 56.7 mm SL (mean 19.68±0.35 mm SL; Fig. 3b). Southern flounder comprised 4.3 % (n=33) of flatfishes collected (Fig. 4a) and ranged in size from 10.4 to 75.8 mm SL (mean=30.9±2.98 mm; Fig. 4b).

Habitat Model for Bay Whiff and Southern Flounder

The simplified habitat BRT model for bay whiff incorporated five out of the ten variables and was determined as the "best" fit model (mean CV ROC=0.797±0.013; Table 2). Dry weight of the sediment explained the most deviance in the model (30.56 %±1.60) followed by distance to inlet (22.84 %±1.71), temperature (18.64 %±1.19), salinity (15.3 %±0.56), and dissolved oxygen (12.66 %±1.92; Fig. 5). The fitted functions from the "best" fit BRT habitat model indicated that juvenile bay whiff occur in areas with sediment containing 25– 45 % dry weight, with the highest distribution occurring between 30 and 45 % and the probability of occurrence rapidly declining with greater than 45 % dry weight (Fig. 6). Moreover, probability of occurrence of bay whiff was greatest in areas ≤ 120 cost distance units

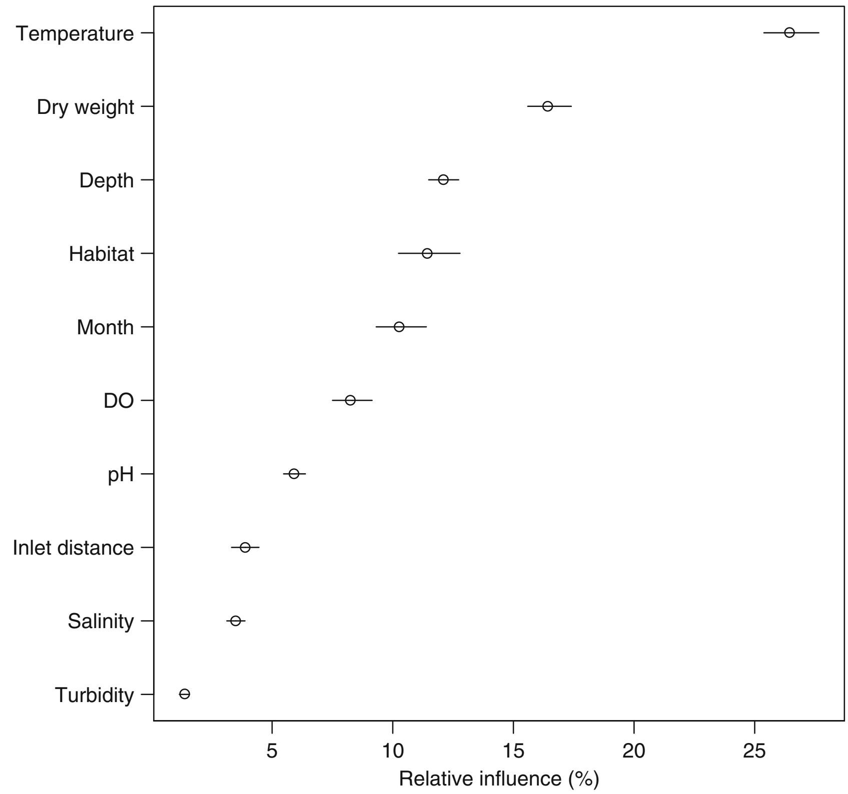

Fig. 8 Relative influence (%) with 95 % confidence intervals for the ten predictor variables by a boosted regression trees model relating the probability of capture of juvenile southern flounder to the environment in order to identify essential fish habitat within the Aransas Bay Complex. *Y-axis* parameters: temperature (°C), % dry weight, habitat, month, depth (m), dissolved oxygen (*DO*; mg O_2/l), pH, inlet distance, salinity (psu), and turbidity (cm)

from the Aransas tidal inlet, with temperatures less than 15 °C, with salinities greater than 10, and dissolved oxygen levels greater than 6 mg O_2/l (Fig. 6).

Spatial prediction of juvenile bay whiff from the BRT model indicated that the highest probability (> 0.8) of collection would occur among all habitats (seagrass and non-vegetation) along the east and north areas of Aransas Bay and the northeast corner of Copano Bay (Fig. 7). Moderate probability of occurrence (0.5–0.8) for bay whiff occurred on the very west side along Aransas Bay and the northeast corner of Copano Bay. The lowest probability (< 0.05) of occurrence for bay whiff occurred along the middle open water areas and south areas of Copano Bay (Fig. 7).

For distribution patterns of juvenile southern flounder, the full model was selected (mean CV ROC=0.802±0.023; Table 2). Temperature explained the most deviance in the model (26.52 %±1.14) followed by percent dry weight of sediment (16.5 %±0.90), depth (12.11 %±0.62), habitat (11.51 %±1.27), month (10.35 %±1.04) , dissolved oxygen (8.32 %±0.82), pH (5.92 %±0.45), salinity (3.5 %±0.38), distance to inlet (3.89 %±0.62) , and turbidity (1.37 %± 0.21; Fig. 8). The fitted functions from the BRT model indicated that the highest occurrence rates of juvenile southern flounder were in water temperatures less than 15 °C, dry weight of the sediment less than 30 %, water depth less than 1.2 m, and dissolved oxygen greater than 8 mg O_2/l (Fig. 9). Moreover, the fitted functions indicated that there was a higher probability of occurrence of juvenile southern flounder in seagrass as compared to non-vegetated or oyster reefs. With respect to pH, distance to inlet, salinity, and turbidity, the fitted functions from the BRT indicated no relationship with the occurrence of juvenile southern flounder (Fig. 9).

Spatial prediction of juvenile southern flounder from the BRT model indicated that the highest probability (> 0.25) of collection was in seagrass beds along the eastern edge of Aransas Bay (Fig. 8). Moderate probability of collection (0.15–0.25) was in seagrass located in the southern and northern regions of Aransas Bay and Copano Bay (Fig. 10). The lowest prediction for probability of occurrence (< 0.15) was in non-vegetated and oyster habitats throughout Copano Bay and in open water non-vegetated sites in Aransas Bay (Fig. 10).

Discussion

This study demonstrates the importance of incorporating biological, physical, and spatial variables in species habitat models to identify the frequency of occurrence patterns of estuarine organisms. The occurrence of juvenile bay whiff and southern flounder demonstrated strong relationships with biological (habitat type, dry weight of sediments), physical (depth, dissolved oxygen, temperature, turbidity, and pH), and spatial (distance to inlet) variables. The occurrence of bay whiff was most strongly influenced by % dry

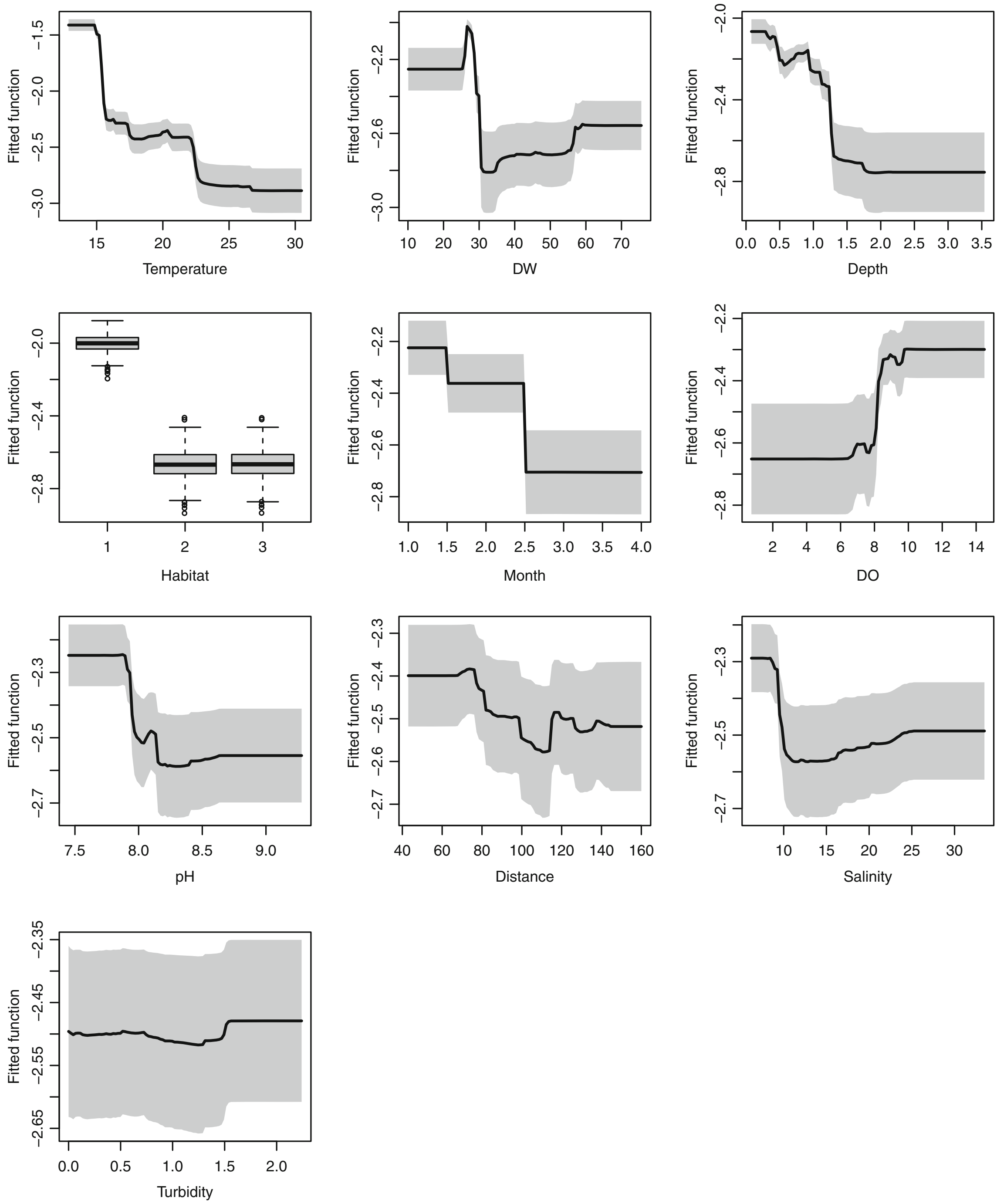

Fig. 9 Functions fitted with 95 % confidence intervals for the ten predictor variables by a boosted regression trees model relating the probability of capture of juvenile southern flounder to the environment in order to identify essential fish habitat within the Aransas Bay Complex. *Y-axes* are on the logit scale with mean zero. *X-axes* parameters: temperature (°C), % dry weight (*DW*), habitat (*1* seagrass, *2 non-vegetated, and 3 oyster reef), month (1.0 February, 2.0 March, 3.0 April, 4.0 May), depth (m), dissolved oxygen (DO; mg O_2/l), pH, distance to the nearest inlet, salinity (psu), and turbidity (cm)*

weight of sediments, distance to inlet, water temperature, salinity, and dissolved oxygen. The occurrence of southern flounder was driven by water temperature, dry weight of sediments, habitat type, month of collection, depth, and dissolved oxygen. Others have shown biological variables such as prey abundance, predators, habitat structure, water depth, and physical factors (temperature, salinity, oxygen, and hydrodynamics) to be major factors affecting the growth, survival, and recruitment of flatfishes (Gibson 1994; Allen and Baltz 1997; Stoner et al. 2001; Glass et al. 2008).

Due to a paucity of information about bay whiff in the Gulf of Mexico, this study is valuable in beginning to

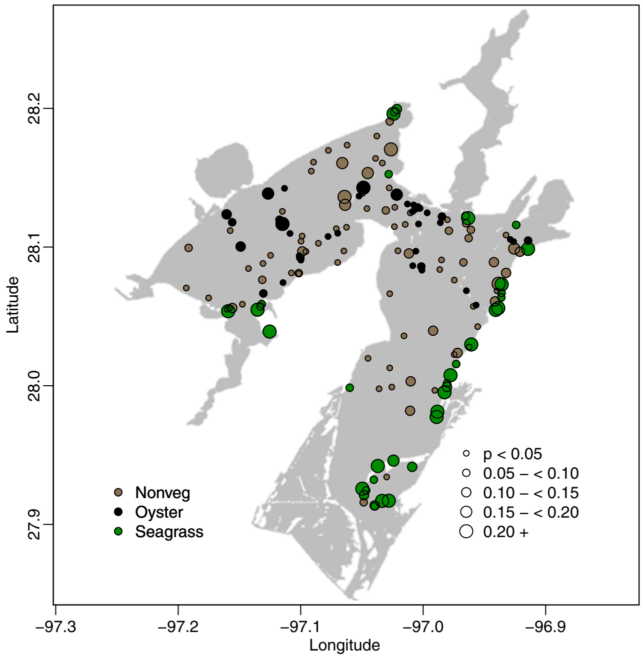

Fig. 10 Prediction of juvenile southern flounder from the BRT model indicated that the highest probability of collection was in seagrass beds along the eastern edge of Aransas Bay. Moderate probability of collection was in seagrass located in the southern region and northern regions of Aransas Bay and Copano Bay. The lowest prediction for probability of occurrence was in non-vegetated and oyster locations throughout Copano Bay and in the middle non-vegetated sites in Aransas Bay

understand environmental constraints for this highly abundant species. Habitat type was not detected as an important variable in predicting the occurrence of bay whiff. The probability of occurrence for juvenile bay whiff was instead associated with low temperatures, moderate percent dry weight of sediments, low salinities, and high dissolved oxygen levels. Results of the BRT model indicated that environmental conditions were more influential than habitat type (e.g., seagrass). Our results suggest that bay whiff are habitat generalists, which is consistent with previous findings (Allen and Baltz; Walsh and Peters 1999). These results suggest that management of bay whiff should focus more on habitat quality rather than structured habitat type and should consider the effect of environmental conditions on fish habitat quality.

Similar to other studies, juvenile southern flounder were relatively rare in our samples, particularly compared to bay whiff (Hoese and Moore 1998; Walsh and Peters 1999; McEachran and Fechhelm 2006; Nañez-James et al. 2009). Results indicate that juvenile southern flounder are most likely to occur in areas with low temperatures, low percent dry weight of sediment, shallow depth, seagrass habitat, and high dissolved oxygen content. The highest occurrence rates of juvenile southern flounder temperatures below 15 °C is consistent with previous studies in Texas (captured between 14.5 and 21.6 °C; Günter 1945). However, previous work has shown that the optimum recruitment temperature of southern flounder is 16–16.2 °C (Stokes 1977). Given the importance of temperature on occurrence patterns, projected sea temperature increases are of potential concern for this species. Seawater temperature is projected to increase by 4 °C in the twenty-first century (Thuiller 2007). Both AppleBaum et al. (2005) and Fodrie et al. (2010) reported rising sea temperatures within the Gulf of Mexico. These predicted increases in temperature could have substantial effects on the temporal and spatial recruitment patterns and, ultimately, population size of southern flounder.

Biological variables percent dry weight of sediments, depth, and habitat type were the second through fourth most important variables. Previously, EFH for young-of-the-year southern flounder in Aransas Bay and Copano Bay, TX, USA was identified as vegetated habitats (seagrass and marsh edge) that occur closest to the tidal inlet between Aransas Bay and the Gulf of Mexico and in high-salinity areas (Nañez-James et al. 2009), and our models support those results. However, based on the results of this study, we suggest that when incorporating both habitat type and distance to inlet in predictive models, habitat type contributes more to occurrence rates of juvenile southern flounder than distance to inlet. The relationship between habitat type and distance to inlet implies that there is a correlation with habitat type and the distance to inlet that may be caused by increased habitat quality near the inlets (increased water exchange with the Gulf of Mexico). Clearly, identifying EFH for southern flounder is a component of sound management for this species. Additionally, in Newport River and Back Sound estuaries in North Carolina, no size-specific patterns in habitat utilization were found, but the abundance of southern flounder was significantly higher in the spring in the middle and upper estuary on mud substrates with detritus and in the fall in areas near marsh edges with mud substrates and detritus (Walsh and Peters 1999). Glass et al. (2008) concluded that variation seen in density of southern flounder is more influenced at the bay scale than at the habitat scale. These results underscore the value of considering biotic factors (e.g., seagrass) as well as the suite of environmental characteristics (abiotic factors) and how these factors interact to ultimately determine habitat quality for southern flounder.

Dissolved oxygen, pH, salinity, and turbidity were less important predictors of occurrence. While dissolved oxygen levels can influence the distribution, abundance, and diversity of organisms (Breitburg 2002, Vaquer-Sunyer 2008, Montagna and Froeschke 2009), this primarily occurs at low oxygen levels (i.e., < 2 mg O_2/l). In this study, few samples were taken in low DO conditions, but low dissolved oxygen events (e.g., hypoxia) are increasing in frequency and spatial extent in Texas estuaries (Applebaum et al. 2005, Montagna and Froeschke 2009). These data suggest that oxygen levels could influence the distribution and abundance of southern flounder. Southern flounder are euryhaline (Deubler 1960), but survivorship and growth rates increase in lower-salinity waters (Stickney and White 1974, Hickman 1968). This study supports these prior findings as the occurrence of southern flounder was more prevalent in the low-salinity environments. This result illuminates potential ramifications of reduced freshwater inflow into the Aransas Bay Complex as historic inflows are increasingly diverted for human usage.

Abiotic factors were important in predicting the distribution of both bay whiff and southern flounder. Although both dissolved oxygen and % dry weight of sediments were important abiotic variables, their ranges differed between species. We suggest that conservation measures for both flatfish species within the Aransas Bay Complex should prioritize areas that include high probabilities of occurrence for juvenile bay whiff and juvenile southern flounder in the same locations, specifically along the eastern side of Aransas Bay and the north corner of Copano Bay.

Despite the strengths of our modeling approach, there are some inherent limitations. Cross-validated model evaluation indicated good performance of the BRT for both bay whiff and southern flounder. It is possible that other factors affecting their distribution or frequency of occurrence may not have been incorporated into the model, for example, biotic components: spawning location, prey and predator density, using % dry weight as an indicator of organic content. However, we were able to examine several variables simultaneously that were related to habitat suitability, providing timely information for the conservation and management of bay whiff and southern flounder within the Aransas Bay Complex.

This study demonstrated the importance of incorporating environmental and biological variables in species habitat models to identify areas suitable for EFH designation. Habitat is clearly a driving factor for most estuarine-dependent species; however, establishing EFH should also extend beyond the first steps of delineating habitat–density relationships by including interactions among suitable biotic and abiotic constraints within particular areas (Hayes et al. 1996). The complex nature of many marine life history strategies coupled with the lack of research on other ecosystem-level interactions has made progress toward determining EFH problematic (Shutter 1990; and Guisan and Thuiller 2005), and these types of relationships had not been established for flatfish in Texas estuaries. Evidence from this study will lead to more comprehensive management strategies as species habitat models can provide much-needed information to better identify EFH. The modeling approach developed in this study also provides a framework for natural resource managers to identify crucial nursery habitats for various developmental stages of fishery species. Climate changes will certainly alter abiotic factors within all marine environments; therefore, we must understand the importance of these changes to develop a more effective ecosystem-based management system (Chittaro et al. 2009).

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