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## 2017 Coastal Master Plan

# Attachment C3-16: Spotted Seatrout, *Cynoscion nebulosus,* Habitat Suitability Index Model

Report: Final

Date: April 2017

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# Coastal Protection and Restoration Authority

This document was prepared in support of the 2017 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every five years) and annual plans. CPRA's mandate is to develop, implement and enforce a comprehensive coastal protection and restoration master plan.

**Suggested Citation:**

Sable, S. E., Hijuelos, A. C., O'Connell, A. M., and Geaghan, J. P. (2017). *2017 Coastal Master Plan: Attachment C3-16: Spotted Seatrout, Cynoscion nebulosus, Habitat Suitability Index Model*. Version Final. (pp. 1-29). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

# Acknowledgements

This document was developed as part of a broader Model Improvement Plan in support of the 2017 Coastal Master Plan under the guidance of the Modeling Decision Team (MDT):

- The Water Institute of the Gulf - Ehab Meselhe, Alaina Grace, and Denise Reed
- Coastal Protection and Restoration Authority (CPRA) of Louisiana – Mandy Green, Angelina Freeman, and David Lindquist.

Buddy "Ellis" Clairain, Moffatt and Nichol, served as subtask leader on the effort, participated in coordination meetings, and provided comments on earlier versions of this report.

Leland Moss, Amanda Richey, and Camille Stelly assisted with preparing graphics and summaries of literature used in this report.

The Louisiana Department of Wildlife and Fisheries provided the data used in the analysis as well as input throughout the project. The following individuals from LDWF participated in coordination meetings, provided comments, and helped answer questions regarding the datasets used in the analysis:

- Harry Blanchet
- Michael Harden
- Rob Bourgeois
- Lisa Landry
- Brian Lezina
- Bobby Reed
- Dawn Davis
- Jason Adriance
- Glenn Thomas
- Patrick Banks

This effort was funded by the Coastal Protection and Restoration Authority (CPRA) of Louisiana under Cooperative Endeavor Agreement Number 2503-12-58, Task Order No. 03.

# Executive Summary

The 2012 Coastal Master Plan utilized Habitat Suitability Indices (HSIs) to evaluate potential project effects on fish and shellfish species. Even though HSIs quantify habitat condition, which may not directly correlate to species abundance, they remain a practical and tractable way to assess changes in habitat quality from various restoration actions. As part of the legislatively mandated five year update to the 2012 plan, the fish and shellfish habitat suitability indices were revised using existing field data, where available, to develop statistical models that relate fish and shellfish abundance to key environmental variables. The outcome of the analysis resulted in improved, or in some cases entirely new suitability indices containing both data-derived and theoretically-derived relationships. This report describes the development of the habitat suitability indices for juvenile and adult spotted seatrout, *Cynoscion nebulosus,* for use in the 2017 Coastal Master Plan modeling effort.

# Table of Contents

## List of Tables



## List of Figures

# List of Abbreviations

| | |
|---|---|
| CPRA | Coastal Protection and Restoration Authority |
| CPUE | Catch per unit effort |
| DO | Dissolved oxygen |
| HSI | Habitat Suitability Index |
| ICM | Integrated Compartment Model |
| LDWF | Louisiana Department of Wildlife and Fisheries |
| SAS | Statistical Analysis Software |
| SI | Suitability Index |
| SL | Standard length |
| TL | Total length |
| YOY | Young-of-year |

# 1.0 Species Profile

Spotted seatrout range from Massachusetts to the Bay of Campeche in Mexico and are most abundant in the northern Gulf of Mexico (Pattillo et al., 1997). The large recreational fisheries for spotted seatrout in the northern Gulf of Mexico supersede the commercial fisheries. Louisiana seatrout catch has steadily increased since the 1980's and has supported the highest annual recreational catch in the United States since the mid-1990s with total annual numbers around 16 to 21 million over the past 10 years (www.st.nmfs.noaa.gov). Florida is usually close behind Louisiana in total annual recreational catch of around 12 to 16 million for the Gulf of Mexico and Atlantic coast (www.st.nmfs.noaa.gov).

Spotted seatrout generally spend their entire life cycle (Figure 1) in inshore waters within and near their natal estuary (Wagner, 1973; Saucier & Baltz, 1993; Ditty & Shaw, 1994; Comyns et al., 2008) showing less than 30% of the adult population moving between estuaries (Killam et al., 1992; Callihan, 2011; Hendon et al., 2002). Adult spotted seatrout, however, have been observed around the inshore oil platforms and reef structures on the continental shelf (Stanley & Wilson, 1990).

Spotted seatrout are opportunistic carnivores whose prey items change with their size. Late juveniles and adults are top level carnivores in estuaries that have very few predators (e.g., sharks, mackerel, tarpon, barracuda) and many preferred prey (shrimps, crabs, forage fish such as bay anchovy and Gulf menhaden, smaller juvenile spotted seatrout and red drum).

Population declines have been related to losses in seagrass beds and other key habitat areas (Ault et al., 1998). Mass mortalities occur with extreme winter cold snaps (North Carolina Spotted Seatrout Fishery Management Plan, 2012), hurricanes, excessive turbidity and fresh water, and super-saturated dissolved oxygen (DO) conditions (Pattillo et al., 1997). In Louisiana, use of weirs in canals or shoreline protection structures may impede the movement of young-of-year (YOY) fish into and out of marsh areas (Herke et al., 1984).

The life stages of spotted seatrout are found within different regions or salinity zones of the estuary (Helser et al., 1993; Shepard, 1986). Figure 1 illustrates the life cycle for the spotted seatrout with the life stage size, duration, and general movement/habitats listed to provide an understanding of the timing and general locations of the life stages within the estuary. Yolk-sac larvae and feeding larvae are separated in the life cycle diagram but are combined as a single larval stage for further description in Table 1 and Figure 2. Early and late juveniles are separated both in the life cycle diagram and in further description because their movement and habitat preferences differ. The adult life stage is comprised of mature age-1+ spawners. Male spotted seatrout grow slower and mature earlier in their second year than females, although nearly all age-1 spotted seatrout are reproductively mature by their second summer (Nieland et al., 2002).

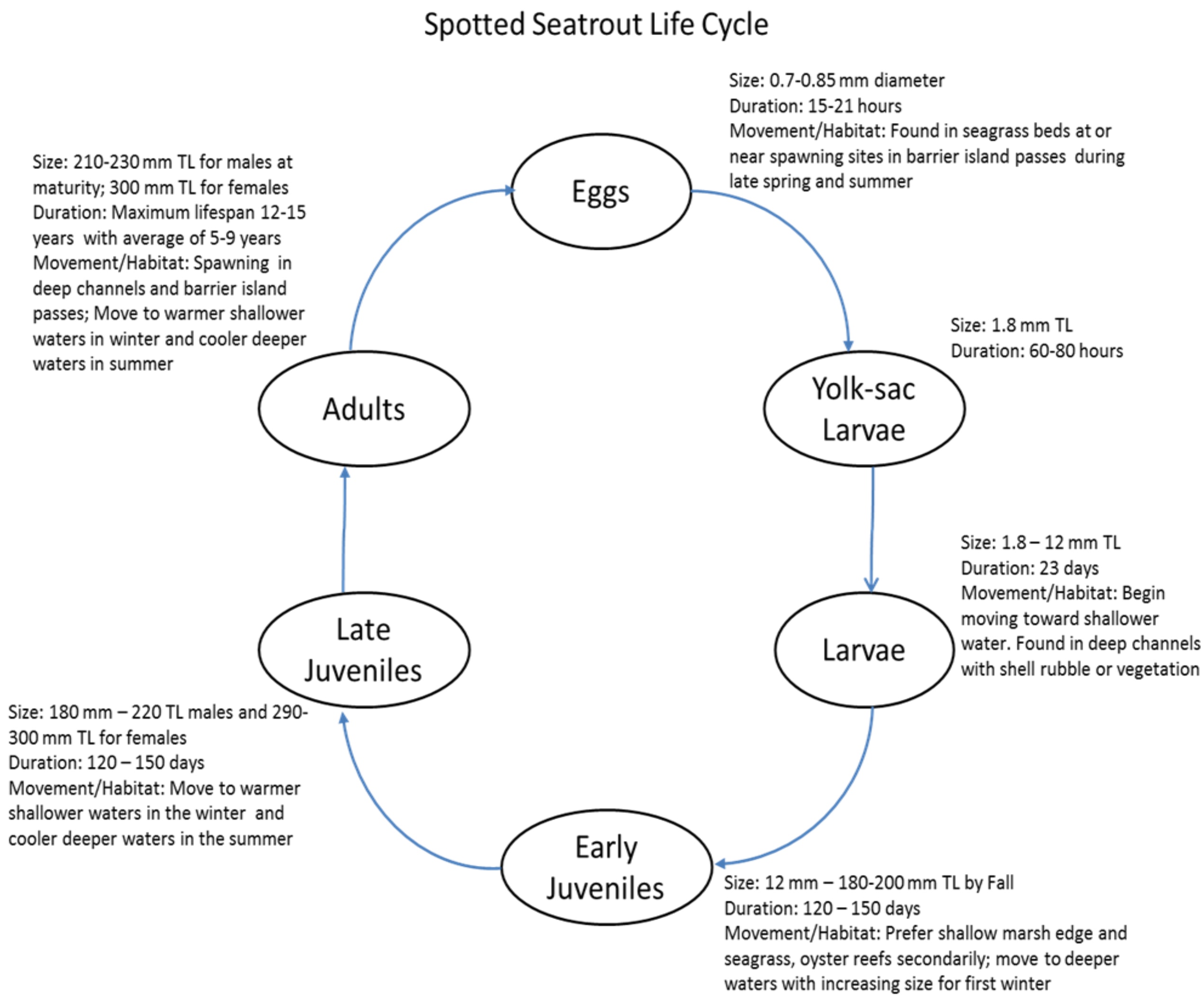



**Figure 1: Spotted Seatrout Life Cycle Diagram.**

The spatial and temporal distribution of spotted seatrout life stages within the estuary is summarized by a space-time plot (Figure 2). The space-time plot indicates the relative abundance of each life stage throughout the year in each region of the estuary: upper, mid, and lower. These regions of the estuary are characterized by similar habitats and environmental conditions (Table 1). Generally, the upper estuary is primarily comprised of shallow creeks and ponds with the greatest freshwater input, lowest average salinities, and densest fresh and intermediate marsh and submerged aquatic vegetation. The mid estuary is comprised of more fragmented intermediate and brackish marsh vegetation with salinities usually between 5 and 20 ppt. The lower estuary is comprised mainly of open water habitats with very little marsh, deeper channels and canals and barrier islands with salinities generally above 20 ppt.

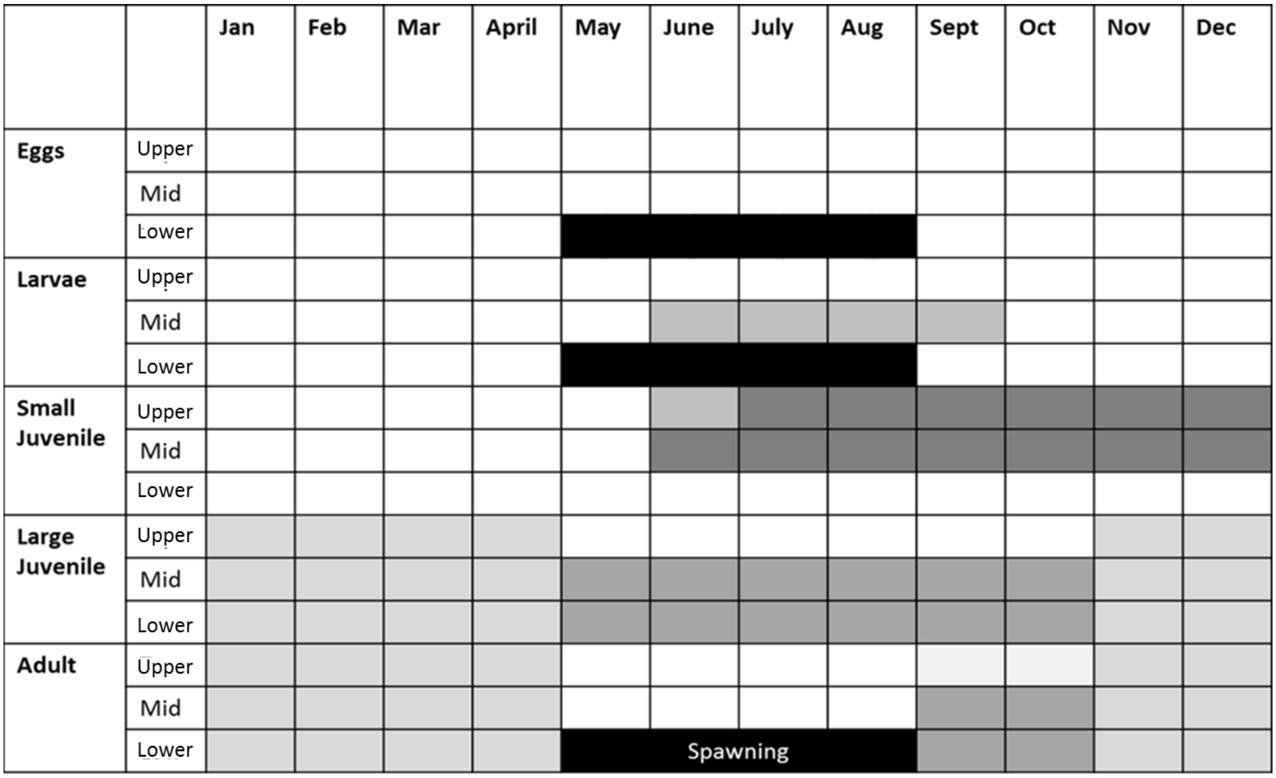



**Figure 2: Space-Time Plot by Life Stage for Spotted Seatrout Showing Relative Abundance in the Upper, Mid, and Lower Region of the Estuary by Month.** White cells indicate the life stage is not present, light grey cells indicate the life stage is at moderate abundance, dark grey cells indicate abundant, and black indicates highly abundant.

**Table 1: Habitat Requirements for Spotted Seatrout Life Stages.** Pattillo et al. (1997) was the primary source used to construct the table and the reader should refer to references therein.

| Life Stage: Process | Salinity (ppt) Optimum (Range) | Temperature (°C) Optimum (Range) | Depth (m) | Preferred Substrate | Turbidity | DO (mg/L) |
|---|---|---|---|---|---|---|
| Egg | 15-35 (5-45) | 23-32.7 | - | Grass beds at or near barrier island passes | - | Optimum at 5-6 with mass mortality below 2 |
| Larvae | 20-35 (8-40) | 20-30 (5-36) | - | Deep channels with shell rubble or vegetation | - | Optimum at 5-6 with mass mortality below 2 |
| Juvenile | 8-25 (0-48) | 20-30 (5-36) | 0.2-2.2 | Shallow seagrass, marsh edge | Prefer lower turbidity | Optimum at 5-6 with mass mortality below 2 |

| Life Stage: Process | Salinity (ppt) Optimum (Range) | Temperature (°C) Optimum (Range) | Depth (m) | Preferred Substrate | Turbidity | DO (mg/L) |
|---|---|---|---|---|---|---|
| Adults: Foraging | 18-32 (0.2-75) | 20-24 15-27 (4-33) | - | Seagrass beds, channels and canals, surf zones of barrier islands, near-shore platforms, shell reefs | Prefer lower turbidity | Optimum at 5-6 with mass mortality under sustained periods between 0-2 |
| Spawning | | 21-34 | 3-50 | Deep channels and barrier island passes | | |

# 2.0 Approach

The statistical analyses used the data collected by the Louisiana Department of Wildlife and Fisheries' (LDWF) long-term Fisheries-Independent Monitoring program conducted for coastal marine fish and shellfish species. The program employs a variety of gear types intended to target particular groups of fish and shellfish; although all species caught, regardless if they are targeted, are recorded in the database. Due to the variable catch efficiency of the gear types, catch per unit effort (CPUE) for spotted seatrout was estimated as total catch per sample event for each gear type separately. The LDWF gears that caught consistent and relatively high abundances of the species of interest over time were used for the statistical analysis.

Data from the 50 ft seine and the 750 ft experimental gill net were evaluated for statistical relationships among the associated environmental data and spotted seatrout CPUE. The 50 ft seines have historically been sampled once or twice per month at fixed stations within each coastal basin by LDWF to provide abundance indices and size distributions of the small fishes and invertebrates using the shallow shoreline habitats of the estuaries (LDWF, 2002). The seine is 6 ft in depth and has a 6 ft by 6 ft bag in the middle of the net and a mesh size of 1/4 in bar. The 750 ft experimental gill nets have historically been sampled once per month at fixed stations from October through March and twice per month from April through September to provide abundance indices and sizes for adult finfish such as spotted seatrout, Gulf menhaden and red drum. The experimental gill nets are 750 ft long, 8 ft deep, and comprised of five 150 ft panels of 1 in, 1-1/4 in, 1-1/2 in, 1-3/4 in, and 2 in bar mesh (LDWF, 2002). The experimental gill nets consistently collect relatively high numbers of adult spotted seatrout and the data are used specifically for obtaining an index of adult spotted seatrout abundance and size distribution within the estuaries.

LDWF also measures temperature, conductivity, salinity, turbidity (i.e., secchi depth), DO, and station depth in concurrence with the biological (catch) samples. Conductivity and salinity were highly correlated, so for this analysis only salinity was used. Station depth was not used in the analysis as it characterizes the station and is not measured to serve as an independent variable for CPUE. DO has only been measured consistently since 2010, so DO was not included in the analyses since the minimal sample size greatly limits the ability to statistically test for significant species-environment relationships. For the analyses, the associated turbidity, salinity, and temperature measurements were evaluated with the juvenile and adult CPUE from the seine and gill net station samples. Salinity and temperature are measured at top and bottom of the water column and an average of their measurements was used for the analyses. Examination of the top and bottom measurements usually showed no or little difference between the two, and often only top or bottom salinity was collected such that the mean value was the result from the single measurement.

Other important variables such as vegetated/non-vegetated habitat are not available from the LDWF datasets. However, a cursory examination of the catch and length data from the seines and gill nets was made to support the premise that smaller juveniles would be caught near the shallow vegetated habitats (Baltz et al., 2003). The primary focus of the statistical analysis was on the water quality data collected by LDWF, and then a theoretical, literature-based relationship for wetland vegetation was incorporated.

Length distributions of the species were plotted by each gear type to determine if the catch was comprised of primarily juveniles, adults, or a combination of the life stages. Mean monthly CPUE by year for the species in each gear was also estimated and then plotted to determine which months had the highest consistent catch over time and which months had variable and low or no catch over time. These plots allowed for subsetting the data by the months of highest species catch in order to reduce the amount of zeroes in the dataset. In this way, the analysis was not focused on describing environmental effects on species catch when the species typically are not in the estuaries or else at very low numbers.

## 2.1 Seines

The length distribution of spotted seatrout caught in the 50 ft seine samples indicated that nearly all were less than 180-200 mm total length (TL; Figure 3), indicative of the early juvenile life stage (Nieland et al., 2002; Figure 1). Sizes above 200 mm TL (i.e., late juvenile and adults) constituted 1% of the total catch. As a result, discussion of juvenile spotted seatrout herein will be in reference to the early juvenile life stage.

The plot of mean CPUE by month for each year indicated juvenile spotted seatrout were primarily collected by 50 ft seines during September through November (Figure 4). This seasonality of juvenile spotted seatrout catch in the seine samples coincides with their life history information. Spawning takes place in the deeper, lower estuaries around tidal passes and barrier islands from May through September, and the juveniles move into the shallow vegetated reaches of the estuaries about a month after hatching and remain there for their first year (Helser et al., 1993; Pattillo et al., 1997; Saucier & Baltz, 1993). Therefore, the seine data from September through November were used for the statistical evaluation of the juvenile spotted seatrout CPUE-environment relationships.

The seine data collected in September through November over all available years of record (1986-2013) across the Louisiana coastline were evaluated to determine if the averaged salinity, averaged water temperature, and/or turbidity data were related to the juvenile spotted seatrout CPUE. All three environmental variables were examined along with their squared terms and their interactions. Day of year (i.e., 1 to 365) and its squared term were also included in the model to help explain any seasonal variation in juvenile spotted seatrout within the estuaries.

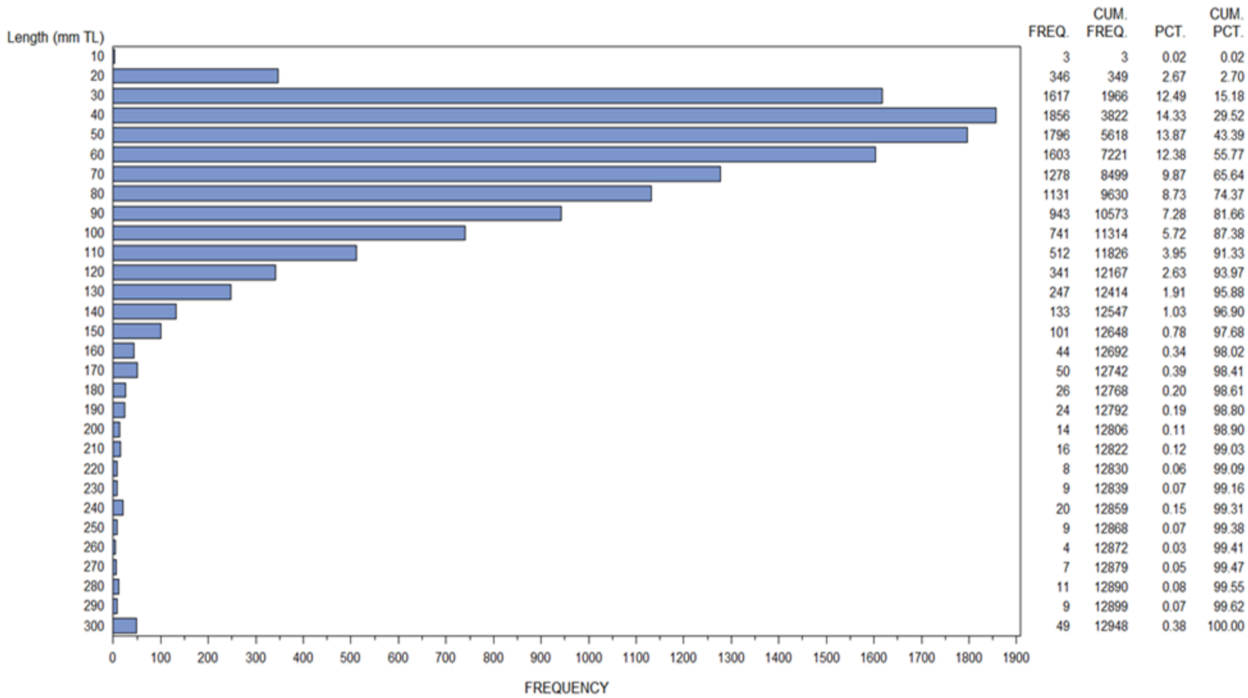



**Figure 3: Length-Frequency Distribution of Spotted Seatrout Caught in the 50 Foot Seine Samples for Louisiana.**

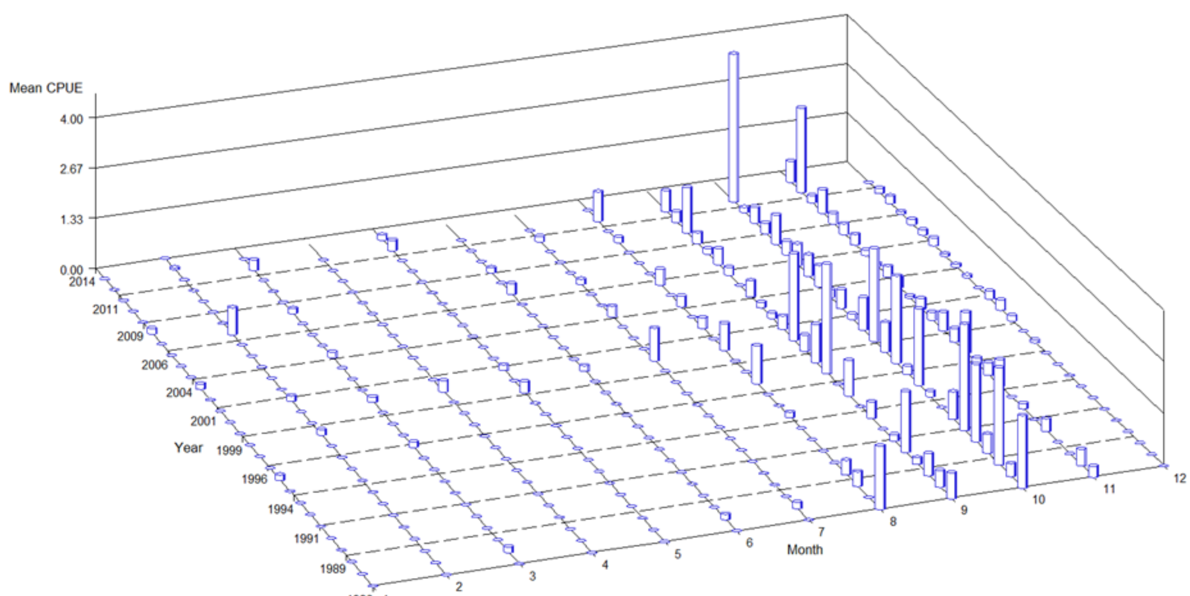


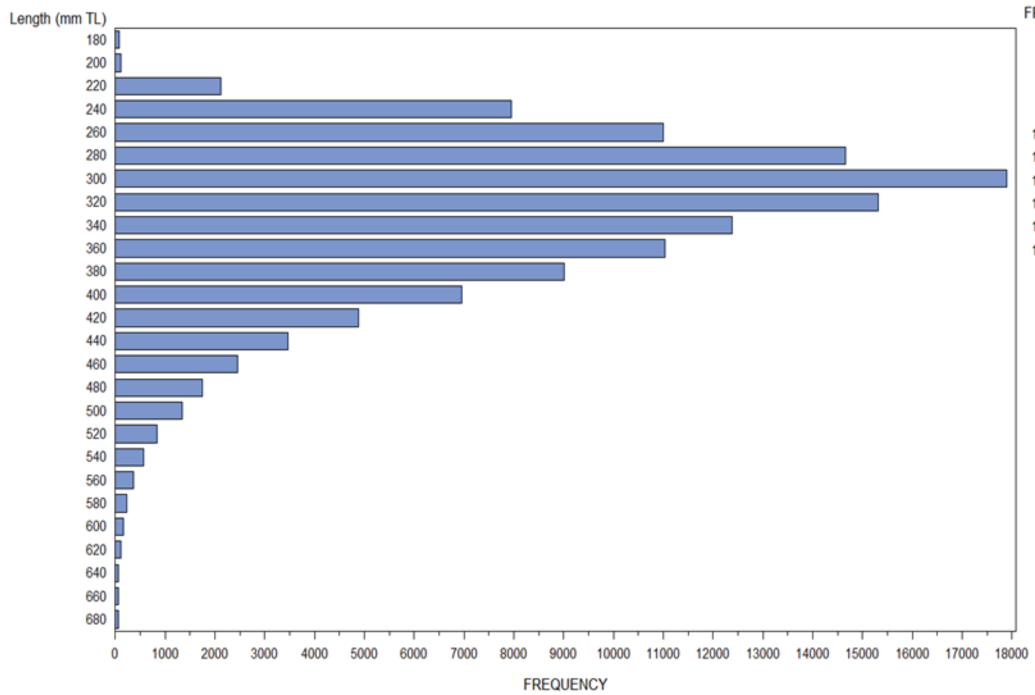

**Figure 4: Mean CPUE of Spotted Seatrout by Month for Each Year in the 50 Foot Seine Samples.**

## 2.2 Experimental Gill Nets

The length distribution of spotted seatrout caught in the experimental gill net samples indicated that nearly all were adults (i.e., past their first year) greater than 200 mm TL (Figure 5). Spotted seatrout typically mature around 230 mm TL (males) and 300 mm TL (females; Nieland et al., 2002), so about 28% of the catch is comprised of immature or subadult spotted seatrout under 280 mm TL (Figure 5).

The plot of mean CPUE by month for each year indicated adult spotted seatrout catch in gill nets is year-round (Figure 6). Therefore, the gill net data from all months were used for the statistical evaluation of the adult spotted seatrout CPUE-environment relationships.

The gill net data collected over all available years of record (1986-2013) across the Louisiana coastline were evaluated to determine if the averaged salinity, averaged water temperature, and/or turbidity data were related to the adult spotted seatrout CPUE. Day of year and its squared term were also included in the model to help account for any seasonal variation in the adult spotted seatrout abundance within the estuaries.




| Length (mm TL) | FREQ. | CUM. FREQ. | PCT. | CUM. PCT. |
|---|---|---|---|---|
| 180 | 72 | 72 | 0.06 | 0.06 |
| 200 | 116 | 188 | 0.09 | 0.15 |
| 220 | 2110 | 2298 | 1.69 | 1.84 |
| 240 | 7951 | 10249 | 6.37 | 8.21 |
| 260 | 10993 | 21242 | 8.80 | 17.01 |
| 280 | 14660 | 35902 | 11.74 | 28.75 |
| 300 | 17894 | 53796 | 14.33 | 43.09 |
| 320 | 15308 | 69104 | 12.26 | 55.35 |
| 340 | 12388 | 81492 | 9.92 | 65.27 |
| 360 | 11041 | 92533 | 8.84 | 74.11 |
| 380 | 9009 | 101542 | 7.22 | 81.33 |
| 400 | 6956 | 108498 | 5.57 | 86.90 |
| 420 | 4885 | 113383 | 3.91 | 90.81 |
| 440 | 3466 | 116849 | 2.78 | 93.59 |
| 460 | 2448 | 119297 | 1.96 | 95.55 |
| 480 | 1751 | 121048 | 1.40 | 96.95 |
| 500 | 1337 | 122385 | 1.07 | 98.02 |
| 520 | 843 | 123228 | 0.68 | 98.69 |
| 540 | 565 | 123793 | 0.45 | 99.15 |
| 560 | 365 | 124158 | 0.29 | 99.44 |
| 580 | 235 | 124393 | 0.19 | 99.63 |
| 600 | 164 | 124557 | 0.13 | 99.76 |
| 620 | 114 | 124671 | 0.09 | 99.85 |
| 640 | 66 | 124737 | 0.05 | 99.90 |
| 660 | 54 | 124791 | 0.04 | 99.95 |
| 680 | 67 | 124858 | 0.05 | 100.00 |

**Figure 5: Length-Frequency Distribution of Spotted Seatrout Caught in the Gill Net Samples for Louisiana.**

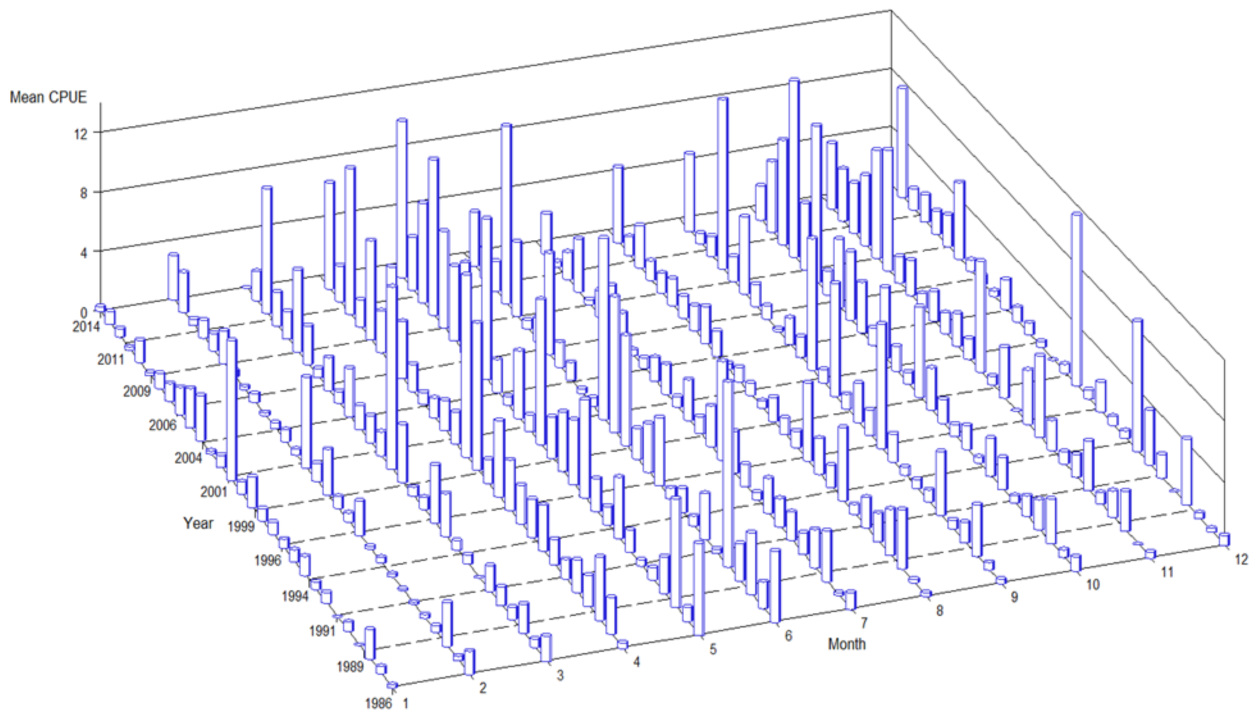



**Figure 6: Mean CPUE of Spotted Seatrout by Month for Each Year in the Gill Net Samples.**

## 2.3 Statistical Analysis

The statistical approach was developed to predict mean CPUE in response to environmental variables for multiple species of interest and was designed for systematic application across the coast. The methods described in detail below rely on the use of polynomial regressions and commonly-used Statistical Analysis Software (SAS) procedures that can be consistently and efficiently applied to fishery-independent count data for species with different life histories and environmental tolerances. As a result, the same statistical approach was used for each of the fish and shellfish species that are being modeled with habitat suitability indices (HSIs) in the 2017 Coastal Master Plan.

The species CPUE data were transformed using ln(CPUE+1). Given that the sampling is standardized and CPUE represent discrete values (total catch per sample event), ln(CPUE+1) transformation was appropriate for the analysis. Distributions that are reasonably symmetric often give satisfactory results in parametric analyses, due in part to the effectiveness of the Central Limit Theorem and in part to the robustness of regression analysis. Nevertheless, it is expedient to approximate normality as closely as possible prior to conducting statistical analyses. The negative binomial distribution is common for discrete distributions for samples consisting of counts of organisms when the variance is greater than the mean. In these cases, the natural logarithmic transformation is advantageous in de-emphasizing large values in the upper tail of the distribution. As a result, the data were natural log-transformed for the analysis. The transformation worked generally well in meeting the assumptions of the regression analysis.

Predictive models can often be improved by fitting some curvature to the variables by including polynomial terms. This allows the rate of a linear trend to diminish as the variable increases or decreases. Scientists have previously described relationships of estuarine species to factors like salinity and temperature as nonlinear, and it can be expected that the spotted seatrout can respond nonlinearly to environmental variables as well (i.e., they have optimal values for biological processes; Kostecki, 1984). Thus, polynomial regression was chosen for the analyses. Another consideration in modeling the abundance of biota is the consistency of the effect of individual variables across the level of other variables. The effect of temperature, for example, may not be consistent across all levels of salinity. These changes can be modeled by considering interaction terms among the independent variables in the polynomial regression equation.

Given the large number of potential variables and their interactions, it is prudent to use an objective approach, such as stepwise procedures (Murtaugh, 2009), to select the variables for inclusion in the development of the model. The SAS programming language has a relatively new procedure called PROC GLMSelect, which is capable of performing stepwise selection where at each step all variables are rechecked for significance and may be removed if no longer significant. However, there are a number of limitations to PROC GLMSelect. GLMSelect is intended primarily for parametric analysis where the assumption of a normal distribution is made. It does not differentially handle random variables, so modern statistical techniques involving random components, non-homogeneous variance and covariance structure cannot be used with this technique. As a result, PROC GLMSelect was used as a 'screening tool' to identify the key variables (linear, polynomial, and interactions), while the SAS procedure PROC MIXED was used to calculate parameter estimates and ultimately develop the model. PROC MIXED is intended primarily for parametric analyses, and can be used for regression analysis. Although it is capable of fitting analyses with non-homogenous variances and other covariance structures, the ultimate goal of the analysis was to predict mean CPUE, not for hypothesis testing or for placing confidence intervals on the model estimates. The statistical significance levels for the resulting parameters were used to evaluate whether the parameters of the polynomial regression model adequately described the predicted mean ($p<0.05$).

# 3.0 Results

## 3.1 Seines

The regression analyses for the seines were initially run with salinity, temperature and turbidity (i.e., secchi depth) as independent variables, but the range in turbidity values turned out to be very small with nearly all secchi depth measurements at the sampling stations being less than 2 ft. Including turbidity (secchi depth in feet) within the polynomial regression equation caused much more flipping (i.e., quickly changing direction) of the function at extreme turbidity values outside the range of the data and unrealistic predicted CPUE values. Therefore, turbidity was dropped as an independent variable and the statistical analysis of the seines was re-run with temperature, salinity, and day.

The resulting polynomial regression model from the seine analysis describes juvenile spotted seatrout CPUE (natural log transformed) in terms of all significant effects from salinity and temperature, the squared terms and the interactions, and day of year (Equation 1; Table 2). Surface response plots are used to visually depict the relationships for the two interacting independent variables (x,y) and CPUE (z) with the day variable set to its mean value (Figure 7). The scatter plot overlaid on the surface response shows the LDWF data used to develop the polynomial regression (Figure 7).

The surface response plot (Figure 7) shows that juvenile spotted seatrout abundance [ln(CPUE+1)] is a peak function of both temperature and salinity. Catch in the seines increases from low temperatures of about 5°C to gradually peak from about 20°C through 30°C and then decrease again at higher temperatures. Likewise, catch in seines peaks at salinities from about 15-25 ppt and decreases on both sides with the decrease in catch a little steeper at higher salinities (Figure 7). The surface response equation (Figure 7) is truncated to predict zero catch at salinity and temperature values at the extremes because there were very little data and the polynomial model predicts unreasonable values beyond the available data.

$$\ln(CPUE+1) = -8.6532 + 6.2748(Day) - 1.1591(Day^2) + 0.0251(Salinity) + 0.07216(\text{Temperature}) - 0.00077(Salinity^2) - 0.00000085(Salinity^2 * Temperature^2) - 0.00168(Temperature^2) \quad (1)$$

**Table 2: List of Selected Effects with Parameter Estimates and their Level of Significance for the Resulting Polynomial Regression in Equation 1.** Interactions between variables are denoted by *.

| Selected Effects | Parameter Estimate[1] | p value |
|---|---|---|
| Intercept | -8.6532 | <.0001 |
| Day | 6.2748 | <0.0001 |
| $Day^2$ | -1.1591 | <.0001 |
| Salinity | 0.0251 | <.0001 |
| Temperature | 0.07216 | 0.0002 |
| $Salinity^2$ | 0.00077 | <.0001 |
| $Salinity^2 * Temperature^2$ | -0.00000085 | <.0001 |
| $Temperature^2$ | -0.00168 | 0.0002 |

[1] Significant figures may vary among parameters due to rounding or accuracy of higher order terms.

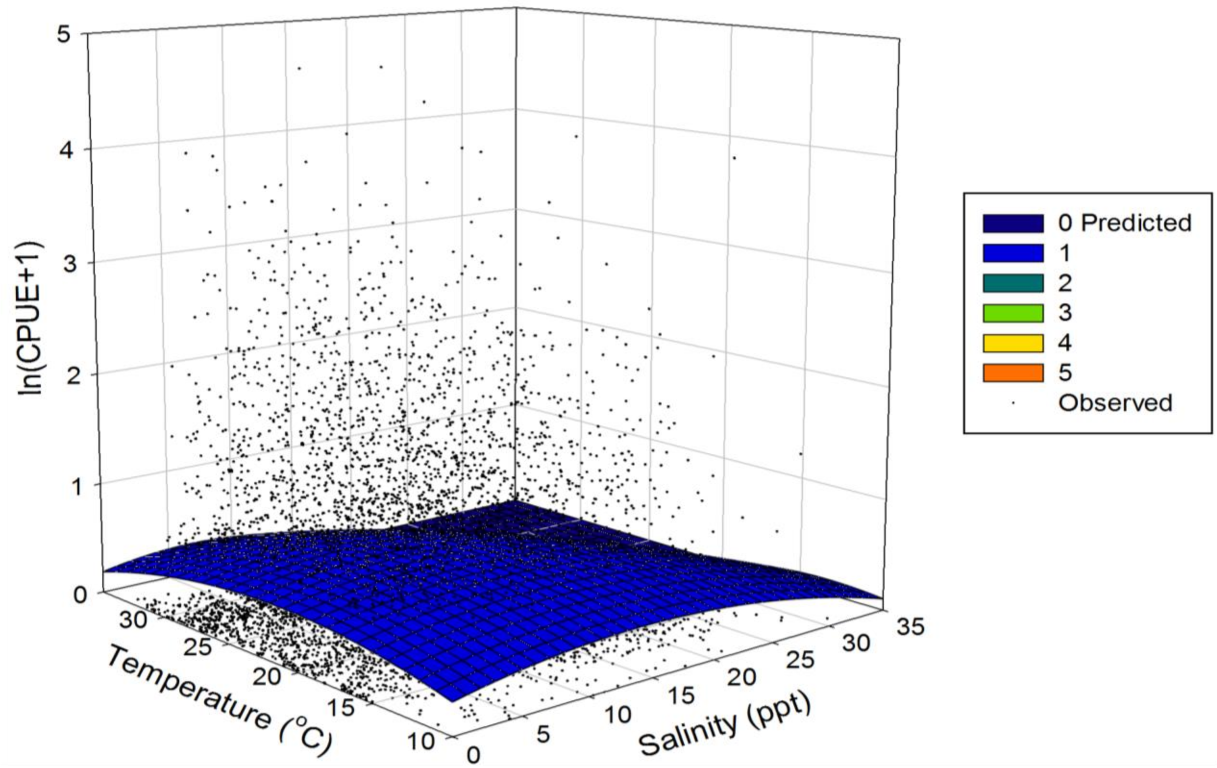



**Figure 7: Surface Plot for the Polynomial Regression in Equation 1 over the Range of Salinity and Temperature Values and using a Mean Day of October 17 (Day 290) in the Equation.** The scatter plot of salinity, temperature and juvenile spotted seatrout CPUE data from the 50 ft seine station samples are overlaid on the plot.

## 3.2 Experimental Gill Nets

The regression analyses for the gill nets were also initially run with salinity, temperature and turbidity as independent variables. However, turbidity was dropped as an independent variable for the reasons previously stated in Section 3.1.

The resulting polynomial regression model (Equation 2) from the gill net analysis describes adult spotted seatrout CPUE (natural log transformed) in terms of all significant effects from salinity and temperature, the squared terms and the interactions, and day of year. Table 3 lists the selected effects with the parameter estimates and their resulting level of significance for the polynomial regression. The surface response plot demonstrates the relationships for the two interacting independent variables (x,y) and CPUE (z) with the day variable set to its mean value (Figure 8). The scatter plot overlaid on the surface response shows the LDWF data used to develop the polynomial regression (Figure 8).

The surface response plot in Figure 8 indicates that adult spotted seatrout abundance [ln(CPUE+1)] increases in the gill nets from zero at a temperature of about 5°C to peak around 20°C and then decrease again at higher temperatures when salinities range from 0-15 ppt. When salinities are greater than about 15 ppt, CPUE for adult spotted seatrout increases with increasing temperatures. This result agrees with previous findings that adult spotted seatrout distribution in the estuaries is determined by temperature gradients (Helser et al., 1993; Pattillo et al., 1997; Saucier & Baltz, 1993). Adult spotted seatrout move throughout the estuary year-round in search of optimum temperatures to support feeding and growth, and concentrate in the deeper, more saline waters of the lower estuary during spawning season.

$$\ln(CPUE+1) = -0.2433 - 0.00983(Day) - 0.0109(Day^2) - 0.02731(Salinity) + 0.0904(Temperature) + 0.00357(Salinity * Temperature) + 0.00144(Salinity^2) + 0.000007(Salinity^2 * Temperature^2) - 0.00027(\text{Temperature} * \text{Salinity}^2) - 0.00233(\text{Temperature}^2) \quad (2)$$

**Table 3: List of Selected Effects with Parameter Estimates and their Level of Significance for the Resulting Polynomial Regression in Equation 2.** Interactions between variables are denoted by *.

| Selected Effects | Parameter Estimate | p value |
|---|---|---|
| Intercept | -0.2433 | 0.0426 |
| Day | -0.000983 | 0.8945 |
| $Day^2$ | -0.0109 | 0.5743 |
| Salinity | -0.02731 | 0.0043 |
| Temperature | 0.0904 | <.0001 |
| Salinity*Temperature | 0.00357 | <.0001 |
| $Salinity^2$ | 0.00144 | 0.0014 |
| $Salinity^2$*$Temperature^2$ | 0.000007 | <.0001 |
| Temperature*$Salinity^2$ | -0.00027 | <.0001 |
| $Temperature^2$ | 0.00233 | <.0001 |

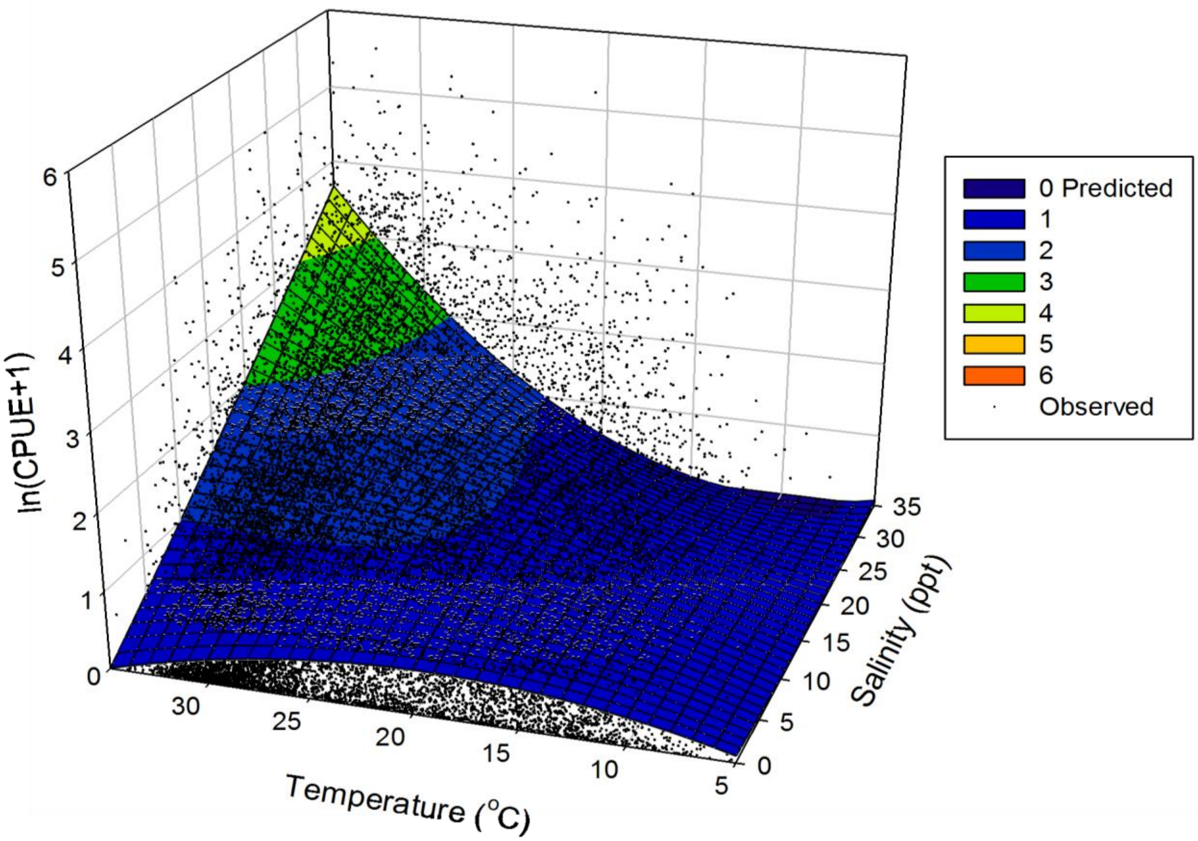



**Figure 8: Plot for the Polynomial Regression in Equation 2 over the Range of Salinity and Temperature Values and using a Mean Day of June 29 (Day 180) in the Equation.** The scatter plot of salinity, temperature and adult spotted seatrout CPUE data from the gill net station samples are overlaid on the plot.

# 4.0 Habitat Suitability Index Model for Juvenile Spotted Seatrout

Although the polynomial regression function in Equation 1 appears long and complex, the regression model is simply describing the relationship among juvenile spotted seatrout catch in the seines and the salinity and temperature taken with the samples. In order to use the polynomial regression (Equation 1) as an HSI model, the equation was standardized to a 0-1 scale. Standardization of the equation was performed by first back-transforming the predicted CPUE [ln(CPUE+1)] to untransformed CPUE values. The predicted untransformed CPUE values were then standardized by the maximum predicted (untransformed) CPUE value from the response function. Maximum CPUE was calculated by running the polynomial model through salinity and temperature combinations that fall within plausible ranges.

A predicted maximum juvenile seatrout ln(CPUE+1) value of 0.7078 was generated from the seine polynomial regression at a temperature of 20°C and salinity of 11 ppt. The back-transformed CPUE value (1.029) was used to standardize the other predicted untransformed CPUE values from the regression. The resulting standardized water quality suitability index (SI) was combined with a standardized (0-1) index for emergent vegetation to produce the juvenile spotted seatrout HSI model. Both components of the model are equally weighted and the geometric mean is used as all variables are considered essential to juvenile spotted seatrout:

$$HSI = (SI_1 * SI_2)^{1/2}$$

Where:

$SI_1$ – Suitability index for juvenile spotted seatrout in relation to salinity and temperature during the months of September through November ($V_1$)

$SI_2$ – Suitability index for juvenile spotted seatrout in relation to the percent of cell that is emergent vegetation ($V_2$)

## 4.1 Applicability of the Model

This model is applicable for calculating the habitat suitability index for YOY juvenile spotted seatrout (median size about 60 mm TL from Figure 3) from September through November in coastal Louisiana marsh edge and shallow shoreline habitats.

## 4.2 Response and Input Variables

**$V_1$: Salinity and temperature during the months of September through November**

Calculate monthly averages of salinity (ppt) and temperature (°C) from September through November:

$$\begin{aligned} V_1 = & -8.6532 + 6.2748(2.9006) - 1.1591(2.9006^2) + 0.0251(Salinity) + 0.07216(\text{Temperature}) \\ & - 0.00077(Salinity^2) - 0.00000085(Salinity^2 * Temperature^2) \\ & - 0.00168(Temperature^2) \end{aligned}$$

The resulting suitability index ($SI_1$) should then be calculated as:

$$SI_1 = \frac{e^{V_1} - 1}{1.029}$$

which includes the steps for back-transforming the predicted CPUE from Equation 1 and standardizing by the maximum predicted (untransformed) CPUE value equal to 1.029. The surface response for $SI_1$ is demonstrated in Figure 9.

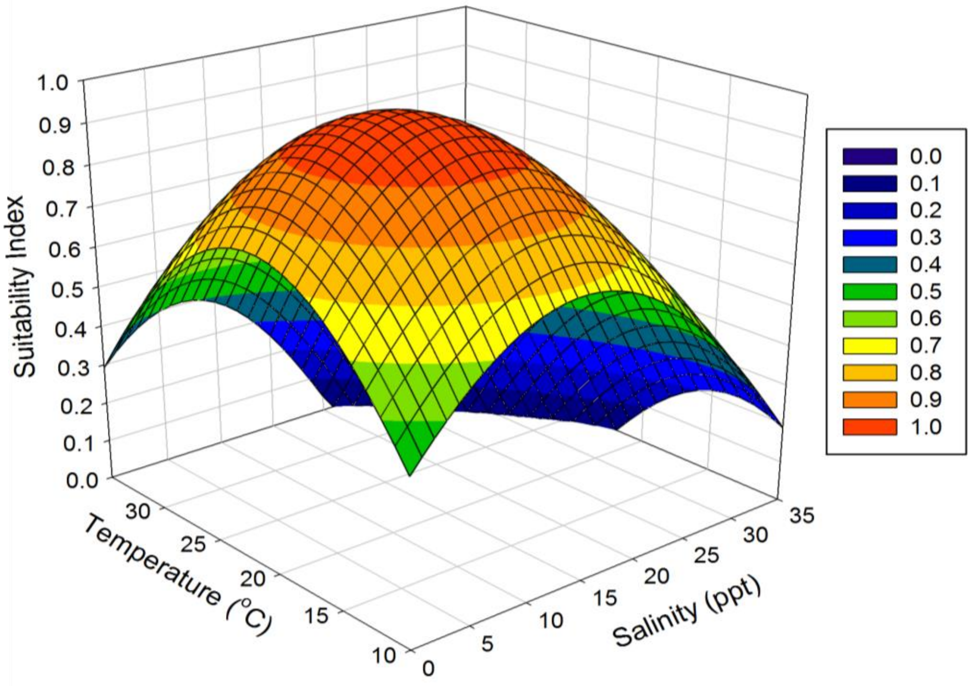



**Figure 9: Surface Plot Demonstrating the Predicted Suitability Index (0-1) for Juvenile Spotted Seatrout in Relation to Salinity and Temperature and Resulting from the Back-Transformation and Standardization of the Polynomial Regression in Equation 1.**

Rationale: Salinity and temperature are important abiotic factors that can influence the spatial and temporal distribution of juvenile spotted seatrout in the estuaries within a year. The suitability index for juvenile spotted seatrout resulted from the polynomial regression model that described the fit to the observed seine catch data in relation to the salinity and temperature measurements taken concurrent with the LDWF seine samples. The resulting suitability index predicts salinity and temperature ranges and optimums that agree well with the ranges and optimums previously described in the literature for juvenile spotted seatrout (Table 1) and with the ranges reported by Alford (2012) who analyzed the same dataset as was used in this analysis.

Limitations: The variable 'day' in Equation 1 has been replaced by a constant value equal to the mean day from the analysis (October 17).[2] Holding 'day' constant prevents the variable from contributing to the within- or among-year variation, so that only salinity and temperature can vary within and among years. Further, the optimal salinities and temperatures should not be interpreted as optimums for specific biological processes, such as growth or reproduction. Instead, the optimums represent the conditions in which juvenile spotted seatrout most commonly occur, as dictated by physiological tolerances, prey availability, mortality, seasonal movements, and other factors.

[2] Day of the year is scaled between 1 and 3.65 (i.e., 365/100) because the coefficients for higher power terms get exceedingly small and often do not have many significant digits. For example, a coefficient of 0.00004 may actually be 0.0000351 and that can make a big difference when multiplied by 365 raised to the power of 2. By using a smaller value, decimal precision is improved.

**$V_2$: Percent of cell that is covered by land and including all types of emergent vegetation**

Calculate the percent of the (500 X 500 m) cell that is wetland (covers all emergent wetland vegetation types) and substitute $V_2$ into the suitability index ($SI_2$) for juvenile spotted seatrout. The equation for $SI_2$ is plotted in Figure 10. The index is calculated as:

$SI_2 = 0.02 * V_2 + 0.5$ for $V_2 < 25$

$1.0$ for $25 \leq V_2 \leq 80$

$5.0 – 0.05 * V_2$ for $V_2 > 80$

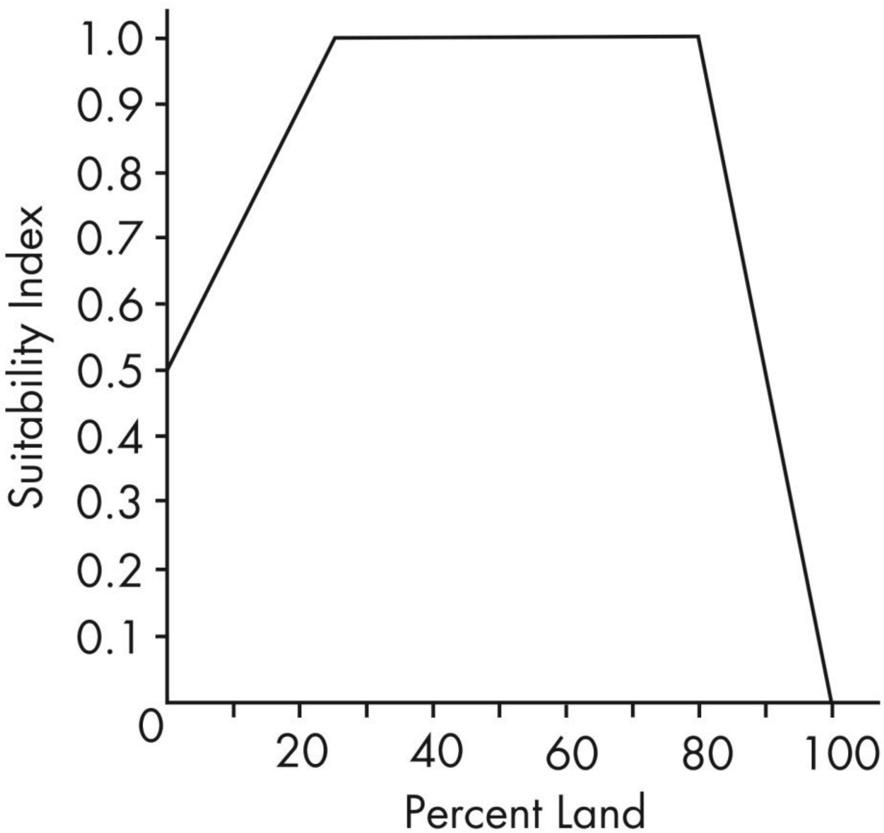



**Figure 10: The Suitability Index for Juvenile Spotted Seatrout in Relation to the Percent Emergent Vegetation (Percent Land = $V_2$).**

Rationale: The percent of wetland or total vegetated area within the cell is directly proportional to the marsh habitat's long-term carrying capacity for the juvenile spotted seatrout. This relationship was initially defined by Minello and Rozas (2002) for juvenile brown shrimp, white shrimp and blue crab and subsequently incorporated into HSIs for the brown shrimp, white shrimp, and juvenile spotted seatrout in the 2012 Coastal Master Plan (CPRA, 2012) to represent these species dependence upon shallow marsh habitats for feeding and growth (Baltz et al., 2003; Peterson, 1986). The 2012 spotted seatrout wetland suitability index was utilized in the 2017 HSI model; however, the SI was decreased from 0.7 to 0.5 at 0% land (or 100% open water) to reduce the habitat capacity of open water for juvenile spotted seatrout and to implicitly account for reduced food and cover from predation.

Limitations: Seagrass beds and other submerged aquatic vegetation (SAV) are also considered important nursery habitat for juvenile spotted seatrout, and have been included in the existing Kostecki (1984) HSI model. The 2017 Coastal Master Plan HSI, however, does not quantify specific nursery habitats, such as SAV or marsh edge, but instead identifies the general landscape configuration (land:water) where optimum levels of these habitats are expected to occur.

# 5.0 Habitat Suitability Index Model for Adult Spotted Seatrout

A predicted maximum adult spotted seatrout ln(CPUE+1) value of 1.353 was generated from the gill net polynomial regression at a temperature of 25°C and salinity of 25 ppt (see Section 4.0 for description of how the maximum value was generated). The back-transformed CPUE value (2.869) was used to standardize the other predicted untransformed CPUE values from the regression. The surface response that describes the standardized adult spotted seatrout response (0-1) to salinity and temperature is shown in Figure 11. The CPUE values above 25°C and salinity of 25 ppt were truncated to predict the maximum suitability of 1.0 for the adults. This predicted response surface is the resulting water quality suitability index to be used for the adult spotted seatrout. The standardized water quality index was combined with a standardized (0-1) index for emergent vegetation to produce the adult spotted seatrout HSI model. Both components of the model are equally weighted and the geometric mean is used as all variables are considered essential to spotted seatrout:

$$HSI = (SI_1 * SI_2)^{1/2}$$

Where:

$SI_1$ – Suitability index for adult spotted seatrout in relation to salinity and temperature ($V_1$)

$SI_2$ – Suitability index for adult spotted seatrout in relation to the percent of cell that is emergent vegetation ($V_2$)

## 5.1 Applicability of the Model

This model is applicable for calculating the habitat suitability index for adult spotted seatrout in the estuary throughout the year. Optimum habitat suitability at higher temperatures and salinities accounts for the spawning aggregations in the deeper, more saline regions of the lower estuary during the summer months (Table 1).

## 5.2 Response and Input Variables

**$V_1$: Salinity and temperature throughout the year**

Calculate monthly averages of salinity (ppt) and temperature (°C) throughout the year:

$$V_1 = -0.2433 - 0.00983(1.805) - 0.0109(1.805^2) - 0.02731(Salinity) + 0.0904(Temperature) + 0.00357(Salinity * Temperature) + 0.00144(Salinity^2) + 0.000007(Salinity^2 * Temperature^2) - 0.00027(\text{Temperature} * \text{Salinity}^2) - 0.00233(\text{Temperature}^2)$$

The resulting suitability index ($SI_1$) should then be calculated as:

$$SI_1 = \frac{e^{V_1} - 1}{2.869}$$

which includes the steps for back-transforming the predicted CPUE from Equation 2 and standardizing by the maximum predicted (untransformed) CPUE value equal to 2.869 (at 25°C and 25 ppt). The surface response for $SI_1$ is demonstrated in Figure 11.

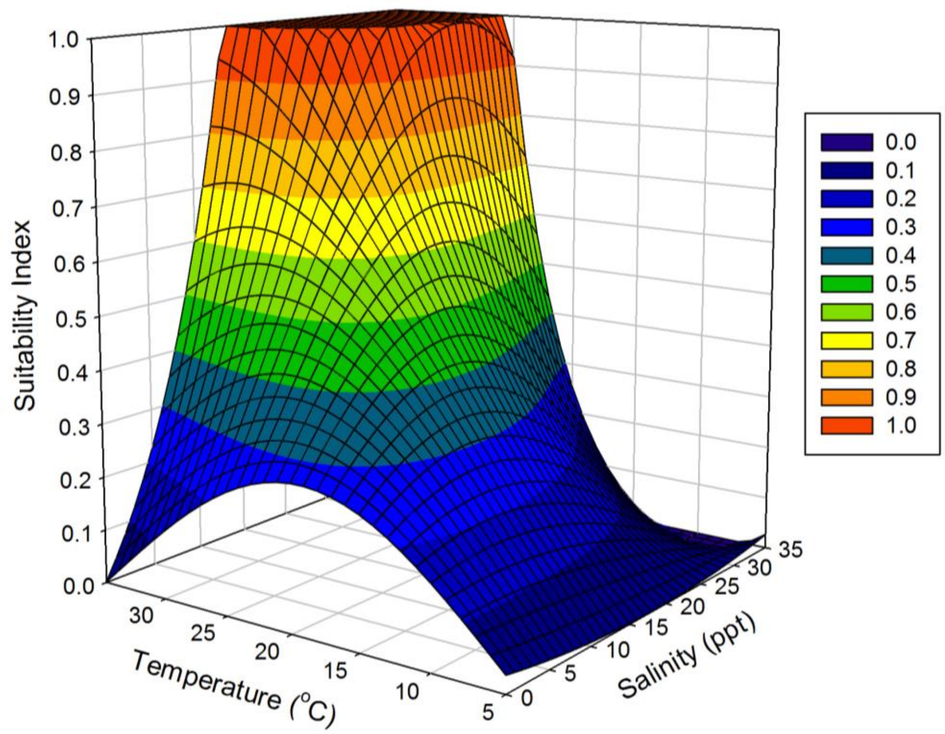



**Figure 11: Surface Plot Demonstrating the Predicted Suitability Index (0-1) for Adult Spotted Seatrout in Relation to Salinity and Temperature and Resulting from the Back-Transformation and Standardization of the Polynomial Regression in Equation 2.**

Rationale*:* Salinity and temperature are important abiotic factors that can influence the spatial and temporal distribution of adult spotted seatrout in the estuaries within a year. The suitability index for adult spotted seatrout resulted from the polynomial regression model that described the fit to the observed gill net catch data in relation to the salinity and temperature measurements taken concurrent with the LDWF gill net samples. The model was biased towards high catch of adults in the higher salinity waters of the lower estuary during the summer spawning aggregations. The polynomial regression model was adjusted to provide optimum suitability from 25°C and 25 ppt in order to increase the range of suitable conditions for the adults outside of the spawning season since they move about the estuary year-round. The resulting suitability index predicts salinity and temperature maximums that still coincide with spawning aggregations concentrated in the lower estuary during the summer (Table 1) while providing reasonably realistic suitability for adults within the estuary for the rest of the year.

Limitations*:* The variable 'day' in Equation 2 has been replaced by a constant value equal to the mean day from the analysis (June 29). Holding 'day' constant prevents the variable from contributing to the within- or among-year variation, so that only salinity and temperature can vary within and among years. Further, the optimal salinities and temperatures should not be interpreted as optimums for specific biological processes, such as growth or reproduction. Instead, the optimums represent the conditions in which the adult spotted seatrout most commonly occur, as dictated by physiological tolerances, prey availability, mortality, seasonal movements, and other factors.

**$V_2$: Percent of cell that is covered by land and including all types of emergent vegetation**

Calculate the percent of the (500 X 500 m) cell that is wetland (covers all emergent wetland vegetation types) and substitute $V_2$ into the suitability index ($SI_2$) for adult spotted seatrout. The equation for $SI_2$ is plotted in Figure 12. The index is calculated as:

$$SI_2 = \begin{cases} 0.012 * V_2 + 0.7 & \text{for } V_2 < 25 \\ 1.0 & \text{for } 25 \leq V_2 \leq 70 \\ 3.33 - 0.0333 * V_2 & \text{for } V_2 > 70 \end{cases}$$

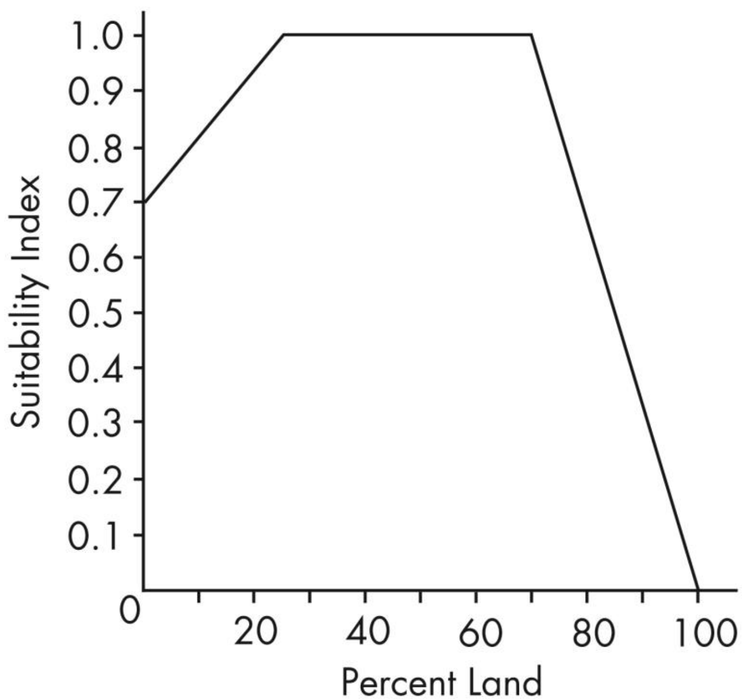



**Figure 12: The Suitability Index for Spotted Seatrout in Relation to the Percent Emergent Vegetation (Percent Land = $V_2$).**

Rationale: The percent of wetland or open water area within the cell is directly proportional to the habitat's long-term carrying capacity for the adult spotted seatrout. This relationship was initially defined by Minello and Rozas (2002) for juvenile brown shrimp, white shrimp and blue crab and subsequently incorporated into HSIs for the brown shrimp, white shrimp, and juvenile spotted seatrout in the 2012 Coastal Master Plan (CPRA, 2012) to represent these species dependence upon shallow marsh habitats for feeding and growth (Baltz et al., 2003; Peterson, 1986). It is also applicable to the adult spotted seatrout HSI in that it represents the species' affinity for marsh habitats where their prey are located. Slight modifications to the original suitability index were needed to better represent the adult life stage. These adjustments included increasing the suitability of open water habitat (0% land) and reducing the suitability when land increases beyond 70% of the cell by assuming that waters within this configuration would be shallow and difficult to access and therefore limit the foraging success of larger predatory fishes.

Limitations: The amount of marsh edge habitat is indirectly taken into account in the increased food/cover estimates using percent land. The open water proportion of the cell that includes submerged aquatic vegetation is not included in the increased food/cover component of the model as previously described in Section 4.2.

# 6.0 Model Verification and Future Improvements

A verification exercise was conducted to ensure the distributions and patterns of HSI scores across the coast were realistic relative to current knowledge of the distribution of spotted seatrout. In order to generate HSI scores across the coast, the HSI models were run using calibrated and validated Integrated Compartment Model (ICM) spin-up data to produce a single value per ICM grid cell. Given the natural interannual variation in salinity patterns across the coast, several years of model output were examined to evaluate the interannual variability in the HSI scores.

For the juvenile spotted seatrout model, high scores were observed around fragmented marsh areas and adjacent bays and lakes, such as those within Barataria, Breton, and Terrebonne basins. Scores were lowest in open water bodies closest to the Gulf of Mexico such as Chandeleur Sound and Terrebonne Bay. For adult spotted seatrout, the reverse was observed. Highest scores were observed in lakes and bays closest to the Gulf, with HSI scores decreasing further inland into fresher areas. A limitation of the HSI models is that there are no geographic constraints that prevent the model from generating HSI scores in areas where the species are not likely to occur. For example, habitat in certain areas may be highly suitable but likely may never be occupied due to accessibility constraints (e.g., impounded wetlands) or perhaps because of the life cycle (e.g., larvae are not carried into the upper basins and therefore these areas may be under-utilized by juveniles). In both the juvenile and adult models, HSI scores greater than 0 were observed in isolated areas in the upper Atchafalaya Basin, where the species are not known to occur. As a result, the areas of the northern Atchafalaya are being excluded from the HSI model domain. Overall, the results of the verification exercise were determined to be accurate representations of both juvenile and adult spotted seatrout habitat distributions in coastal Louisiana.

Although the polynomial regression model used to fit the LDWF seine and gill net data produced functions relating spotted seatrout catch to salinity and temperature that generally agreed with their life history information and distributions (Pattillo et al., 1997), polynomial models can predict unreasonable results outside of the modeled data range. Other statistical methods and modeling techniques exist for fitting nonlinear relationships among species catch and environmental data that could potentially improve the statistical inferences and model behavior outside of the available data. A review of other statistical modeling techniques could be conducted in order to determine their applicability in generating improved HSI models in the future.

# 7.0 References

Alford, J. B. (2012). Salinity levels that optimize nekton community structure in the lower Barataria Estuary, Louisiana. Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA. 65 p.

Ault, J. S., Bohnsack, J. A., and Meester, G. A. (1998). A retrospective (1979–1996) multispecies assessment of coral reef fish stocks in the Florida Keys. *Fisheries Bulletin, 96,* 395–414.

Baltz, D. M., Thomas, R. G., and Chesney, E. J. (2003). Spotted seatrout habitat affinities in Louisiana. In S. A. Bortone (Ed.), *Biology of the Spotted Seatrout* (pp. 145-175). Boca Raton, FL: CRC Press.

Callihan, J. D. (2011). *Spatial ecology of adult spotted seatrout, Cynoscion nebulosus, in Louisiana coastal waters*. Dissertation. Louisiana State University, Department of Oceanography and Coastal Sciences, Baton Rouge, LA. 296 p.

Coastal Protection and Restoration Authority (CPRA). (2012). *Louisiana's Comprehensive Master Plan for a Sustainable Coast*. Baton Rouge, LA: CPRA, p. 186.

Comyns, B. H., Rakocinski, C. F., Peterson, M. S. and Shiller, A. M. (2008). Otolith microchemistry of juvenile spotted seatrout, *Cynoscion nebulosus*, reflects local natal regions across coastal Mississippi. *Marine Ecology Progress Series* 371, 243-252.

Ditty, J. G., and Shaw, R. F. (1994). *Preliminary guide to the identification of the early life history stages of sciaenid fishes from the western central Atlantic*. NOAA Tech. Memo. NMFS-SEFSC-349.

Helser, T. E., Condrey, R. E., and Geaghan, J. P. (1993). Spotted seatrout distribution in four coastal Louisiana estuaries. *Transactions of the American Fisheries Society*, *122*, 99-111.

Hendon, J. R., Warren, J. R., Franks, J. S. and Buchanan, M. V. (2002). Movements of spotted seatrout (*Cynoscion nebulosus*) in Mississippi coastal waters based on tag-recapture. *Gulf of Mexico Science* 2002(2), 91-97.

Herke, W. H., Rogers, B. D., and Knudsen, B. B. (1984). Habits and habitats of young spotted seatrout in Louisiana marshes. *Louisiana Agricultural Experimental Station Research Report, 3*, 1-48.

Killam, K. A., Hochberg, R. J., and Rzemien, E. C. (1992). *Synthesis of basic life histories of Tampa Bay species*. Tampa Bay National Estuary Program, Tech. Pub. No. 10-92.

Kostecki, P.T. (1984). *Habitat suitability index models: spotted seatrout.* U.S. Department of the Interior Fish and Wildlife Service, FWS/OBS-82/10.75, 22 p.

Louisiana Department of Wildlife and Fisheries. (2002). *Marine fisheries division field procedure manual*. Version 02-1.

Minello, T. J., and Rozas, L. P. (2002). Nekton in Gulf coast wetlands: Fine-scale distributions, landscape patterns, and restoration implications. *Ecological Applications*, *12*(2), 441–455.

Murtaugh, P. A. (2009). Performance of several variable-selection methods applied to real ecological data. *Ecology Letters, 12(10), 1061-1068.*

Nieland, D. L., Thomas, R. G., and Wilson, C. A. (2002). Age, growth, and reproduction of spotted seatrout in Barataria Bay, Louisiana. *Transactions of the American Fisheries Society*, *13*, 245-259.

*North Carolina Spotted Seatrout Fishery Management Plan.* (2012). Spotted seatrout fishery management plan advisory committee and the North Carolina Division of Marine Fisheries, Department of Environmental and Natural Resources, Morehead City, NC, 344 p.

Pattillo, M. E., Czapla, T. E., Nelson, D. M., and Monaco, M. E. (1997). *Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Volume II: Species life history summaries.* ELMR Rep. No. 11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. 377 p.

Peterson, G. W. (1986). *Distribution, habitat preferences, and relative abundance of juvenile spotted seatrout and red drum in the Caminada Bay estuary, Louisiana*. M.S. thesis, Louisiana State University, Baton Rouge, LA, 96 p.

Saucier, M. H., and Baltz, D. M. (1993). Spawning site selection by spotted seatrout, *Cynoscion nebulosus*, and black drum, *Pogonias cromis*, in Louisiana. *Environmental Biology of Fishes*, *36*, 257-272.

Shepard, J. A. (1986). Salinity: a factor affecting fluctuation of spotted seatrout, *Cynoscion nebulosus*, stocks. *Louisiana Department of Wildlife and Fisheries Technical Bulletin*, *40*, 49-53.

Stanley, D. R., and Wilson, C. A. (1990). A fishery dependent based study of fish species composition and associated catch rates around oil and gas structures off Louisiana. *Fisheries Bulletin, U.S., 88*, 719-730.

Wagner, P. R. (1973). *Seasonal biomass, abundance and distribution of estuarine dependent fishes in the Caminada Bay system of Lousiana*. Dissertation. Louisiana State University, Baton Rouge, LA, 207 p.