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2017 Coastal Master Plan

Attachment C3-11: Blue Crab, *Callinectes sapidus*, Habitat Suitability Model

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Report: Version II

Date: July 2016

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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). The 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 the CPRA and charged the new Authority to develop and implement a comprehensive coastal protection plan, consisting of a Master Plan (revised every 5 years) and annual plans. The CPRA's mandate is to develop, implement and enforce a comprehensive coastal protection and restoration Master Plan.

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Suggested Citation:

O'Connell, A. M., Hijuelos, A. C., Sable, S. E., and Geaghan, J. P. (2016). *2017 Coastal Master Plan Modeling: C3-12 – Blue Crab, Callinectes sapidus, Habitat Suitability Index Model.* Version II. (pp. 1-26). 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 (LDWF) 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
- Bobby Reed
- Brian Lezina
- Dawn Davis
- Jason Adriance
- Glenn Thomas
- Patrick Banks

This effort was funded by the CPRA of Louisiana under Cooperative Endeavor Agreement Number 2503-12-58, Task Order No. 03.

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Executive Summary

The 2012 Coastal Master Plan utilized Habitat Suitability Indices (HSIs) to evaluate potential project effects on wildlife, 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 5-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 blue crab, *Callinectes sapidus*, for use in the 2017 Coastal Master Plan modeling effort.

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List of Abbreviations

CPRA	Coastal Protection and Restoration Authority
CPUE	Catch per unit effort
CW	Carapace width
DO	Dissolved oxygen
ICM	Integrated Compartment Model
LDWF	Louisiana Department of Wildlife and Fisheries
ppt	parts per thousand
SAV	Submerged aquatic vegetation
SAS	Statistical Analysis Software
YOY	Young-of-year

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1.0 Species Profile

The blue crab, a benthic omnivore, is a cosmopolitan species found in coastal waters, primarily in bays and brackish estuaries. It has an extensive range from Nova Scotia to northern Argentina, Bermuda and the Caribbean, and has also been introduced into coastal waters of Europe and Japan. Within the northern Gulf of Mexico, it is abundant throughout the near-shore and estuarine areas (Millikin & Williams, 1984; Williams, 1974, 1984). Juveniles and adults are found on muddy and sandy bottoms while juveniles use both seagrass and marsh habitats as nursery areas (Pattillo et al., 1997). Since blue crabs spend most of their life in the estuary, its habitats are susceptible to anthropogenic influences and thus warrant protection as coastal restoration efforts are planned and implemented.

The high demand for blue crab supports an important commercial and recreational fishery in the Gulf of Mexico, as well as the rest of the United States. In 2009, in Louisiana the blue crab fishery was worth over $36,000,000 and was considered to be at a sustainable level based on biomass (LCTF, 2011). However, destruction of wetland habitat due to dredging, filling, impoundment, flow alteration, and pollution has previously been suggested to cause a decrease in blue crab fishery production (Steele & Perry, 1990). Also, although blue crab recruitment has been adequate, recent declines in numbers of late stage juveniles in the north-central Gulf of Mexico are thought to be associated with drought, habitat alterations due to catastrophic storms, and results of anthropogenic changes to wetlands (Riedel et al., 2010).

Blue crab has important ecological roles as prey for several other commercially important species (e.g., red drum, *Sciaenops ocellatus*, larger blue crabs, and Atlantic croaker, *Micropogonias undulatus*; Gandy et al., 2011; Overstreet & Heard, 1978; Pattillo et al., 1997) and predator of plankton, small invertebrates (including smaller blue crabs), fish, and generally whatever is in the area (Pattillo et al., 1997).

Blue crabs are considered euryhaline and eurythermal but will react to extreme cold and sudden drops in temperature. Blue crab move into deeper waters to escape cold winter temperatures, but return to rivers, tidal creeks, salt marshes and sounds when conditions become more favorable. For juveniles and adults, there are minimum and maximum thermal limits (3 and 37ºC) but these are dependent on acclimation to temperature and salinity. Studies that found maximum abundance of juvenile blue crabs in salinities below 5 ppt suggest that these areas are valuable nursery areas providing protection from predators and enhanced food availability. However, other research found highest average juvenile catches associated with salinities above 14.9 ppt or no relationship between catch and salinity (Guillory et al., 2001). Blue crabs also move out of waters with low dissolved oxygen (DO) levels, and in some cases will actually leave the water to escape anoxic conditions (Killam et al., 1992; Lowery, 1987). In Mobile Bay, large concentrations of migrating blue crabs and other animals occasionally occur during attempts to avoid hypoxic conditions (1-30% saturation), and such events are referred to as "jubilees" (Pattillo et al., 1997). Blue crabs experience mortality when exposed to low DO coupled with high temperatures that are common during the summer (May, 1973; Tagatz, 1969). Abiotic factors, such as salinity, affect the distribution of their prey which can indirectly influence blue crab populations. For example, salinity can influence which bivalve species are available to adults as prey, while relative abundance of prey types in different salinity zones (detritus and gastropods in inland areas vs. fishes and shrimp in more saline areas) can affect what younger crabs consume (Laughlin, 1982; Pattillo et al., 1997).

The blue crab can be infected by several diseases caused by viral, bacterial and fungal agents (Messick & Sinderman, 1992; Steele & Perry, 1990) as well as symbionts and parasites that impact

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metabolism or growth, or increase their vulnerability to predation (Hochberg et al., 1992; Overstreet et al., 1983; Overstreet, 1978). The blue crab is also susceptible to predation and cannibalism (Adkins, 1972a; Heck & Coen, 1995).

The blue crab spends most of its life in estuaries and near-shore Gulf waters. Eggs (273 x 263 µm to 320 x 278 µm at hatching) are carried externally by the female, which are known as sponge or berry crabs, for approximately two weeks. They hatch near the mouths of estuaries and the zoeal larvae are carried off-shore. Zoeae (0.25 -1 mm carapace width [CW]) are planktonic, and remain in off-shore waters for up to one month. Consequently, larvae can be transported ≥300 km or more in the northeastern Gulf (Oesterling & Evink, 1977), suggesting that larvae produced by spawning females in one estuary could recruit into others. Water flow can influence larvae by causing a flushing effect (i.e., pushing them seaward) and preventing larval settlement (Mazzotti et al., 2006). Re-entry to estuarine waters occurs during the megalopal stage (1 – 2.2 -3.0 mm CW) after which they molt to the first crab stage in near-shore waters (Perry et al., 1995; Thomas et al., 1990). Post-settlement survival (Guillory et al., 1998), high predation rates of juveniles (after post settlement; Heck et al., 2001), and incidental harvest rate are also important. Juveniles (2.0 -150 mm CW) and adults tend to be demersal and estuarine. The size at maturity has a wide range; 50% of males mature by 110-115 mm CW, and 50% of females mature by 210-230 (smallest 113) mm CW. Adult males are 117-181 (147 average) mm CW while adult females are 128-182 (148 average) mm CW. Adult males spend most of their time in low salinity waters; females move into these lower salinities as they approach their terminal molt to mate (during the spring in the Gulf of Mexico). After mating, females move to higher salinity areas of estuaries (during June and July in the Gulf of Mexico) and near-shore environments for spawning (Adkins, 1972b; Dudley & Judy, 1971; Millikin & Williams, 1984; Van Den Avyle & Fowler, 1984; Williams, 1984). Movement of mated females from Lakes Pontchartrain and Borgne into Mississippi waters occurs in the fall and early winter months (Perry, 1975; Figure 1).

The spatial and temporal distribution of blue crab life stages within the estuary is summarized by a space-time plot (Figure 2), which indicates the relative abundance of each life stage throughout the year for each region: upper, mid, and lower estuary, and inner and outer shelf. These regions 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. The inner and outer shelf regions are defined as the open marine waters divided by the 20 meter isobath.

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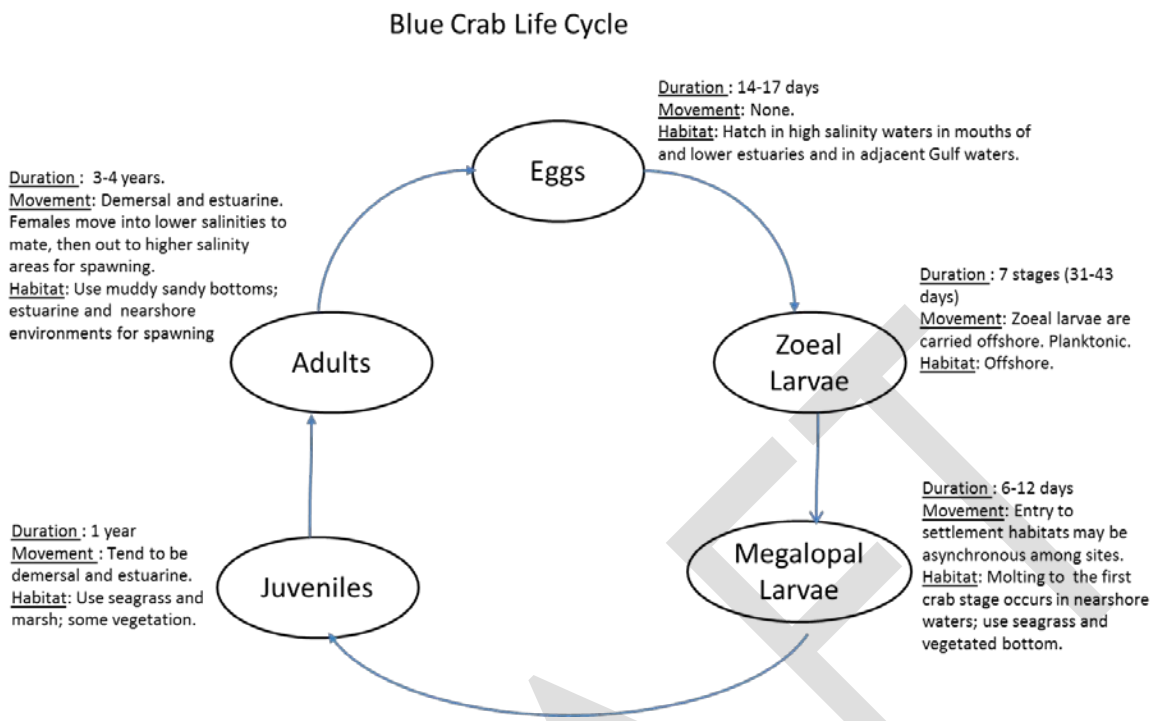

Figure 1: Blue Crab Life Cycle Diagram.

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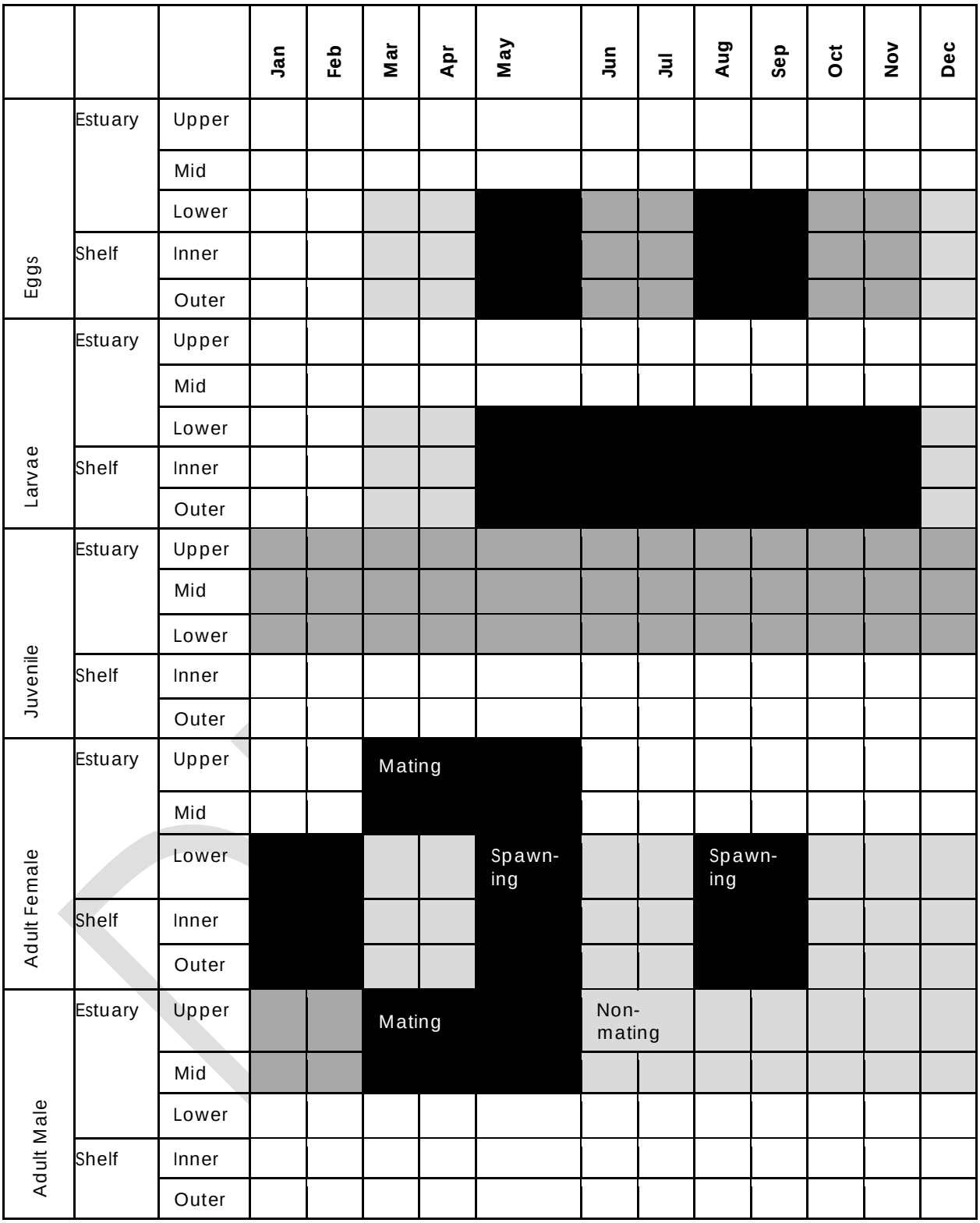

Figure 2: Space-Time Plot by Life Stage for Blue Crab Showing Relative Abundance in the Upper, Mid, and Lower Region of the Estuary, and In-Shore and Off-Shore Shelf Regions by Month. ***White cells indicate the life stage is not present, light grey cells indicate the life stage is at moderate abundance,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

Table 1: Habitat Requirements for Blue Crab Life Stages. Pattillo et al. (1997) and Pattillo et al. (1995) were 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)	Depth (m)	Preferred Substrate	Turbidity	DO (mg/L)
Egg	22-28 (23-32.6)	19-29	Off-shore	-	-	-
Larvae	20-31.1 (5-40)	24-31; larvae develops fastest	-	Megalopae-seagrass or vegetated bottom; Near-shore marsh	-	-
Juvenile	(0-60)	3-35	Demersal estuarine; selected marsh with flood and use areas with high tide	Prefer sea grass but also use saltmarshes; muddy and sandy bottoms	Negatively related to turbidity	Sensitive to hypoxia
Adults	24-37 (0-37)	3- 35°C Mortalities related to extreme and sudden cold	Demersal estuarine	Muddy and sandy bottoms	-	Low DO (<1 ppm) results in mass mortalities

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 blue crab 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-foot seine and the 16 ft trawl were evaluated for statistical relationships among the associated environmental data and blue crab 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

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bag in the middle of the net and a mesh size of 1/4 in bar. The 16 ft trawls have historically been sampled bi-weekly during November through February and weekly from March through October at fixed stations to provide abundance indices and size distributions for penaeid shrimps, crabs and finfish in the larger in-shore bays and Louisiana's territorial waters. The body of the trawl is constructed of 3/4 in bar mesh No. 9 nylon mesh while the tail is constructed of 1/4 in bar mesh knotted 35 lb tensile strength nylon and is 54-60 in long (LDWF, 2002).

LDWF also measures temperature, conductivity, salinity, turbidity, 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. Turbidity measurements collected with the trawl samples were not used because trawling disturbs the sediment and thus greatly affects turbidity and species catchability. For the analyses, the associated turbidity (seine only), salinity and temperature measurements were evaluated with the CPUE from the seine and trawl 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 and substrate type are not available from the LDWF datasets. However, a comparison of HSI's developed from those gears that are associated with non-vegetated habitat (i.e., trawls) with those that are associated with vegetation (i.e., seine) was made to see if optimum values for variables were similar between habitats and if they roughly supported previous findings (Pattillo et al., 1997). Thus, the primary focus of the statistical analysis was on the water quality data collected by LDWF, 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 blue crab caught in the seine samples indicated that nearly all were juveniles (i.e., young-of-year [YOY]) less than 117 mm CW (median CW=13 mm; Figure 3). Blue crabs typically mature by 110 mm CW (Pattillo et al., 1997). Sizes above 110 mm CW constituted less than 5% of the total blue crab catch. Therefore, it was assumed that the estimated CPUE from the seine samples were representative of small juvenile blue crab.

The plot of mean CPUE by month for each year indicated the catch of juvenile blue crab in the 50 ft seines was highest during January through March and August through December (Figure 4). These months coincide with the highest numbers of small juvenile blue crab which would have entered the estuaries in late summer/early fall and then overwinter in the estuaries (Millikin &

Williams, 1984; Van Den Avyle & Fowler, 1984). Two different year classes of blue crab are accounted for within the same year, but using these months still captures habitat conditions for the YOY juvenile blue crabs residing in shallow shoreline and marsh habitats. Therefore, the seine data from January through March and August through December were used for the statistical evaluation of the juvenile blue crab CPUE-environment relationships.

The seine data collected in January through March and August through December 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 blue crab CPUE. The environmental variables along with their squared terms and their interactions were examined. Day of year (i.e., 1 to 365) and its squared term were also included in the model to explain any seasonal variation in blue crab within the estuaries.

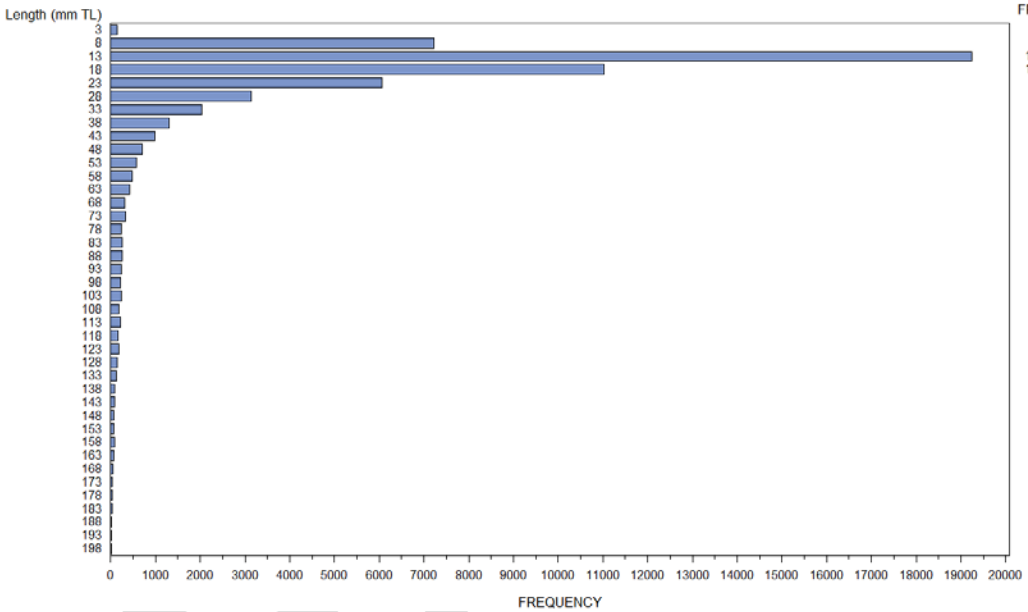

Figure 3: Length-Frequency Distribution of Blue Crab Caught in the 50 ft Seine Samples for Louisiana.

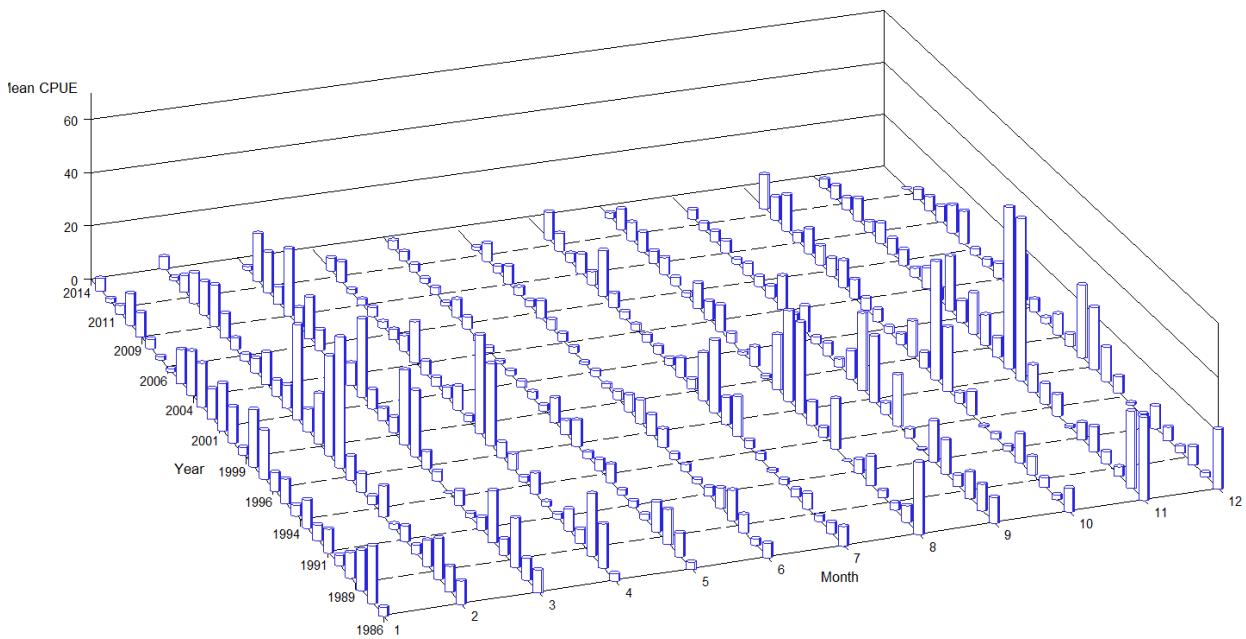

Figure 4: Mean CPUE of Blue Crab by Month for Each Year in the 50 ft Seine Samples.

2.2 16 Foot Trawls

The length distribution of blue crab caught in the 16 ft trawl samples indicated that nearly all were larger juveniles (median CW =62.5 mm; Figure 5) than those caught by the seine. Sizes above 100 mm CW constituted less than 12% of the total blue crab catch. Therefore, it was assumed that the estimated CPUE from the 16 ft trawl samples were representative of large juvenile blue crab.

The plot of mean CPUE by month for each year indicated juvenile blue crab catch in 16 ft trawls are abundant year-round (Figure 6). Therefore, the 16 ft trawl data from all months within a year were used for the statistical evaluation of the juvenile blue crab CPUE-environment relationships.

The 16 ft trawl data collected in January through December over all available years of record (1966-2013) across the Louisiana coastline were evaluated to determine if the averaged salinity and averaged water temperature was related to the juvenile blue crab CPUE. Each sample was kept as an independent observation even though collections were taken biweekly during certain months. Environmental variables along with their squared terms and their interactions were examined. Day of year and its squared term were also included in the model to explain seasonal variation in blue crab abundance within the estuaries.

Results from the analysis of the trawl data indicated that only salinity was significant in predicting blue crab juvenile CPUE. However, given that minimum and maximum thermal limits have been found for this life stage, it is not biologically defensible to exclude temperature from an HSI. Since both the seine and trawl samples juveniles, the remainder of this report focuses on the use of the seine data to develop a juvenile blue crab HSI.

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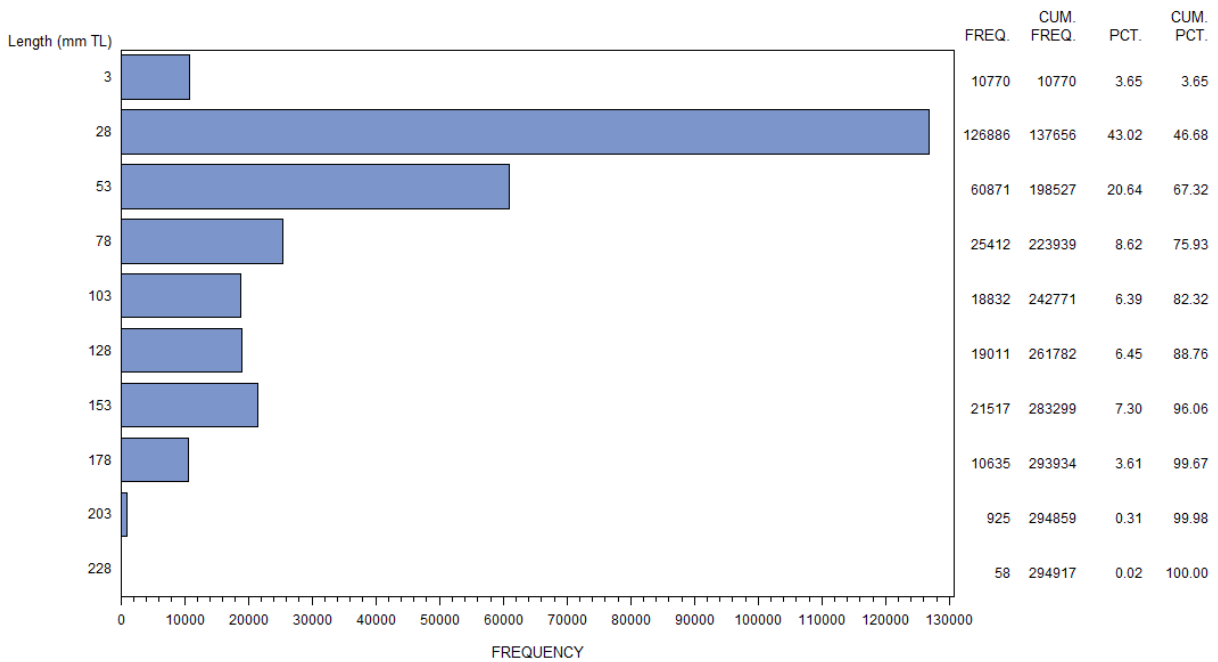

Figure 5: Length-Frequency Distribution of Blue Crab Caught in the 16 ft Trawl Samples for Louisiana.

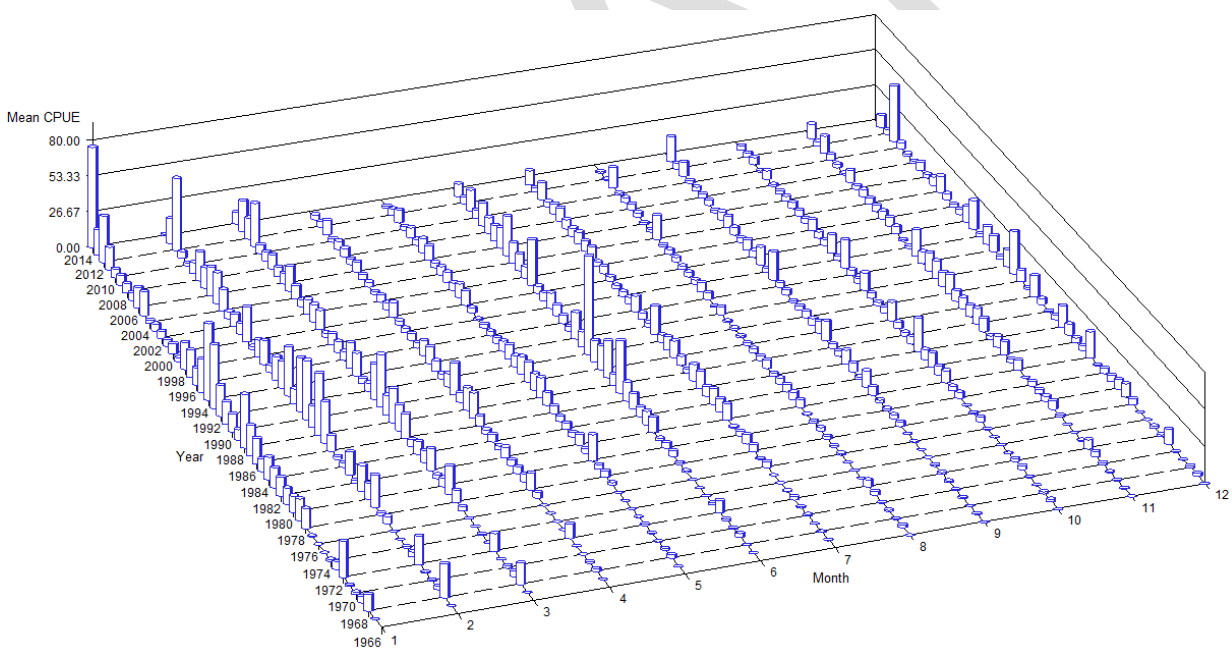

Figure 6: Mean CPUE of Blue Crab by Month for Each Year in the 16 ft Trawl Samples.

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 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. 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 blue crab may respond nonlinearly to environmental variables as well (i.e., they have optimal values for biological processes; Pérez-Castañeda & Defeo, 2005; Villarreal et al., 2003). 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, 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 ($p<0.05$).

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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 two feet. Including turbidity (secchi depth in feet) within the polynomial regression equation caused much more flipping within the function (i.e., quickly changing direction) 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 blue crab CPUE (natural log transformed) in terms of all significant effects from salinity, temperature, their squared terms and their interactions, and day of year (Equation 1; Table 2). Surface response plots are used to visually depict the relationships for any two interacting independent variables (x,y) and CPUE (z) with the remaining independent variables held constant. The surface response for the resulting polynomial regression (Equation 1) is plotted for the range of salinities and temperatures (Figure 7) with day held at its mean. The scatter plot overlaid on the surface response shows the observed data used to develop the polynomial regression (Figure 7).

The parameter estimates in Table 2 and surface response plots (Figure 7) indicate that the effects of temperature on blue crab abundance are relatively uniform up until 12 ppt where there is a negative effect of high salinity. Blue crab catch is high at a wide range of temperatures (10-32 °C) but peaks at 18-22°C (Figure 7). Blue crab catch is also highest at lower salinities (≤ 10 ppt; Figure 7).

$$\begin{aligned}\mathrm{In}(\mathrm{CPUE}+1) = 0.8587 - 0.2451(Day) + 0.07012(Day^2) - 0.03677(Salinity) \\ + 0.06561(Temperature) + 0.000312(Salinity^2) - 0.00182(Temperature^2)\end{aligned} \quad (1)$$

Table 2: List of Selected Effects with Parameter Estimates and their Level of Significance for the Resulting Polynomial Regression in Equation 1.

Selected Effects	Parameter Estimate[1]	p value
Intercept	0.8587	<0.0001
Day	-0.2451	0.0020
Day^2	0.07012	0.0008
Salinity	-0.03677	<0.0001
Temperature	0.06561	<0.0001
$Salinity^2$	0.000312	0.0184
$Temperature^2$	-0.00182	<0.0001

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

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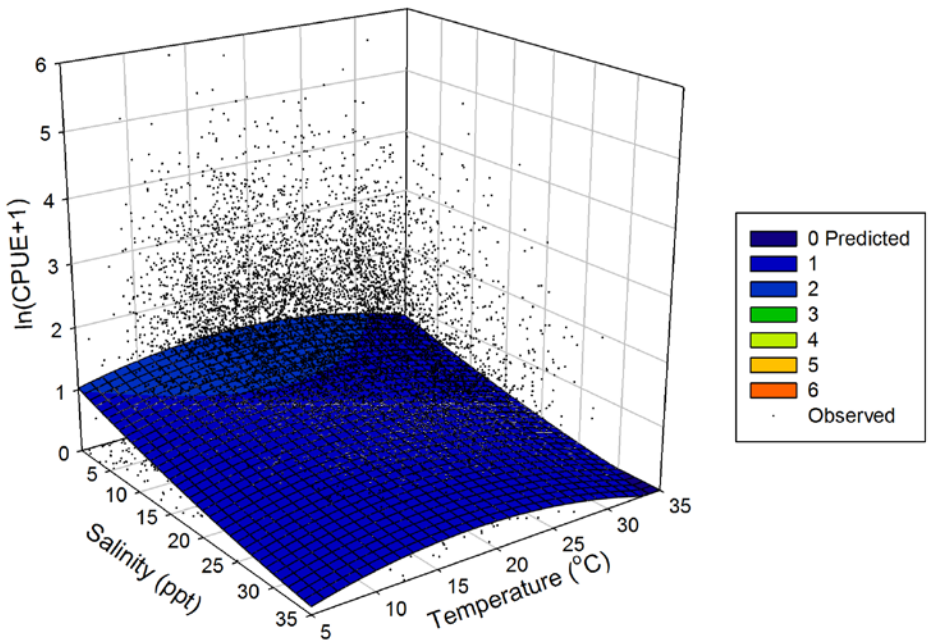

Figure 7: Surface Plot for the Polynomial Regression in Equation 1 Over the Range of Salinity and Temperature Values and Substituting a Mean Day of July 28 into the Equation. The scatter plot of salinity, temperature and juvenile blue crab CPUE data from the 50 ft seine station samples are overlaid on the plot.

4.0 Habitat Suitability Index Model for Juvenile Blue Crab

Although the polynomial regression functions appear long and complex, it is important to remind readers that the regression models are simply describing the relationships between blue crab catch in the seine and the salinity and temperature taken with the samples. The surface plots demonstrate the relationships and interactions between the independent variables that predict the mean blue crab CPUE.

In order to use the polynomial regression functions in an HSI model, the equations were standardized to a 0-1 scale. Standardization of the CPUE data is relatively straightforward and begins with converting the predicted log-transformed CPUE [ln(CPUE+1)] back to raw, untransformed CPUE values. The predicted untransformed CPUE values were then standardized by the maximum CPUE value. Maximum CPUE was calculated by running the model through salinity and temperature combinations that fall within plausible ranges.

A predicted maximum juvenile blue crab ln[(CPUE+1)] value of 1.244 was generated from the seine polynomial regression at a temperature of 18 °C and salinity of 0 ppt. The back-transformed CPUE value (2.47) was used to standardize the other predicted untransformed CPUE values from the regression. The resulting standardized water quality suitability index was combined with a standardized (0-1) index for emergent vegetation to produce the juvenile blue crab HSI model. Both components of the model are equally weighted and the geometric mean is used as all variables are considered essential to juvenile blue crab:

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

Where:

SI_1 – Salinity and temperature during the months of January through March and August through December (V_1)

SI_2 – 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 of small (under 60 mm CW) juvenile blue crabs from January through March and August through December in coastal Louisiana marsh edge and shallow shoreline habitats.

4.2 Response and Input Variables

V_1: Salinity and temperature during the months of January through March and August through December

Calculate monthly averages of salinity (ppt) and temperature (°C) from January through March and August through December**:**

$$V_1 = 0.8587 - 0.2451(2.0880) + 0.07012(2.0880^2) - 0.03677(Salinity) + 0.06561(Temperature) + 0.000312(Salinity^2) - 0.00182(Temperature^2)$$

Suitability index should be calculated as followed:

$$SI_1 = \frac{e^{V_1} - 1}{2.47}$$

which includes the steps for back-transforming the predicted CPUE from Equation 1 and standardizing by the maximum predicted (untransformed) CPUE value equal to 2.47. The surface response for SI_1 is demonstrated in Figure 8.

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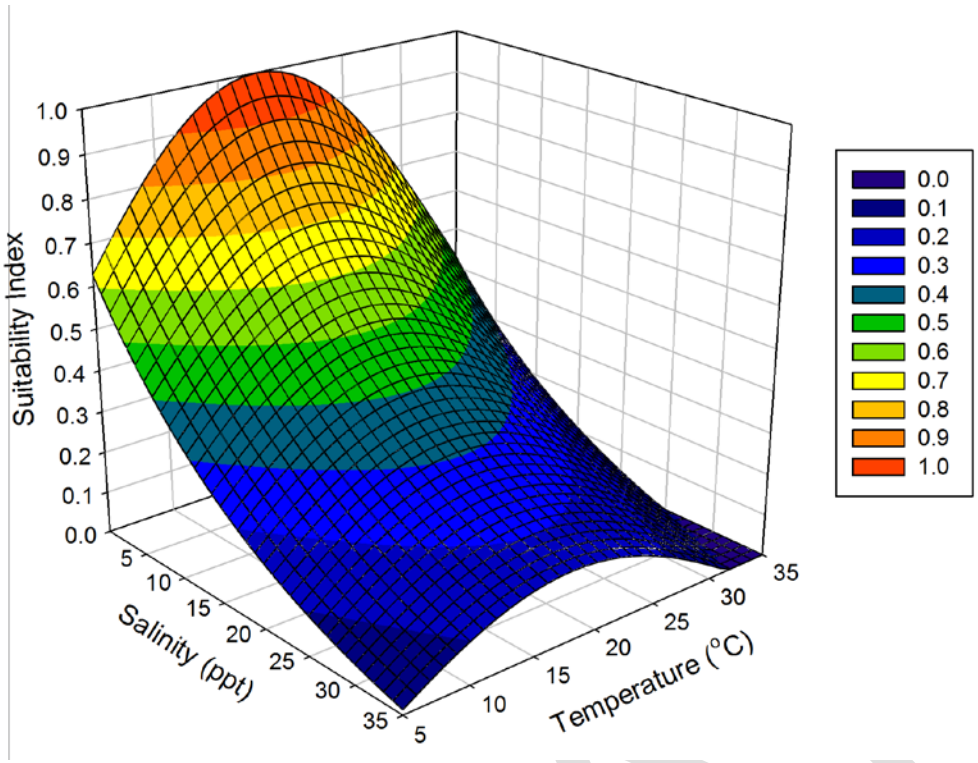

Figure 8: Surface Plot Demonstrating the Predicted Suitability Index (0-1) for Juvenile Blue Crab in Relation to Salinity and Temperature and Resulting from the Back-Transformation and Standardization of the Polynomial Regression in Equation1.

Rationale: Salinity and temperature are important abiotic factors that can influence the spatial and temporal distribution of juvenile blue crab in the estuaries within a year. The suitability index for juvenile blue crab resulted from the polynomial regression model that described the fit to the observed 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 blue crab (see Table 1). Although temperature and salinity can vary greatly during the juvenile life stage, minimum and maximum thermal limits (3 and 37 °C) have been found and both were found to be significant factors in the seine analysis.

Limitations: The variable 'day' in Equation 1 has been replaced by a constant value equal to the mean day from the analysis (July 28).[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. The surface response equation (Figure 8) is truncated at salinities greater than 35 ppt and temperatures greater than 35 °C because there were no catch data for juvenile blue crab at these temperature and salinity combinations. Further, the optimal salinities and temperatures should not be interpreted as optimums for specific biological

[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.

processes, such as growth or reproduction. Instead, the optimums represent the conditions in which juvenile blue crab 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

V_2 is the percent of the (500 x 500 m) cell that is covered by land (i.e., emergent wetland vegetation of all types). The equation for SI_2 is plotted in Figure 9. The index is calculated as:

$$SI_2 = \begin{cases} 0.028 * V_2 + 0.3 & \text{for } V_2 < 25 \\ 1.0 & \text{for } 25 \leq V_2 \leq 80 \\ 5.0 - 0.05 * V_2 & \text{for } V_2 > 80 \end{cases}$$

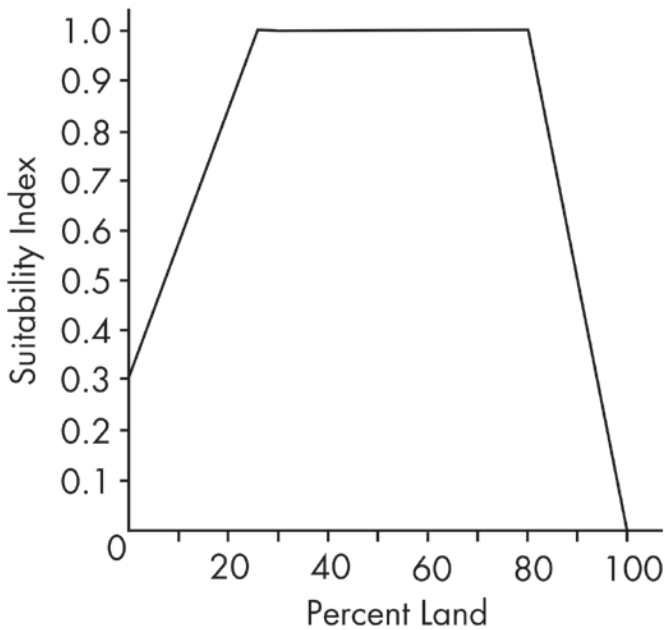

Figure 9: The Suitability Index for Juvenile Blue Crab in Relation to the Percent Emergent Vegetation (Percent Land = V_2).

Rationale: The percent of land or total vegetated area within the cell is directly proportional to the marsh habitat's long-term carrying capacity for the juvenile blue crab. This relationship was developed by Minello and Rozas (2002) for juvenile brown shrimp, white shrimp and blue crab and subsequently incorporated into HSI's for the brown shrimp, white shrimp and juvenile spotted seatrout in the 2012 Coastal Master Plan. The optimum percent wetland SI for juvenile blue crab was set similar to that of the 2012 Coastal Master Plan HSIs (CPRA, 2012) at 25 to 80%; however, the SI was set to 0.3 at 0% wetland to reflect blue crab juveniles utilization of shallow non-vegetated bottom; and SI was set to 0 at 100% land as this configuration is not expected to hold value for this species.

Limitations: Juvenile blue crabs also use submerged aquatic vegetation (SAV) (Rozas & Minello, 2006) and seagrass beds are considered prime habitat for blue crab due to increased prey as well as for cover from predators. However, the 2017 Coastal Master Plan HSI model does not quantify specific 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 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 blue crab. 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 blue crab model, high scores were observed around fragmented marsh areas, especially those with low salinities, such as marshes near Lake Salvador, White Lake, and the lower Atchafalaya. Scores were lowest in open, saline water bodies closest to the Gulf of Mexico such as Barataria Bay, Terrebonne Bay, and Calcasieu Lake. 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 the juvenile blue crab model, HSI scores greater than zero were observed in isolated areas in the upper Atchafalaya Basin where blue crab are not likely 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 juvenile blue crab habitat distribution in coastal Louisiana.

Although the polynomial regression model used to fit the LDWF seine data produced functions relating blue crab 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.

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