Coastal Protection and Restoration Authority

150 Terrace Avenue, Baton Rouge, LA 70802 | coastal@la.gov | www.coastal.la.gov

2017 Coastal Master Plan

Attachment C3-14: White Shrimp, *Litopenaeus setiferus*, Habitat Suitability Index Model

Report: Final

Date: April 2017

Prepared By: Ann M. O’Connell (University of New Orleans), Ann C. Hijuelos (The Water Institute of the Gulf), Shaye E. Sable (Dynamic Solutions), and James P. Geaghan (Louisiana State University)

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:

O'Connell, A. M., Hijuelos, A. C., Sable, S. E., and Geaghan, J. P. (2017). *2017 Coastal Master Plan: Attachment C3-14: White Shrimp, Litopenaeus setiferus, Habitat Suitability Index Model*. Version Final. (pp. 1-32). 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

The following experts were responsible for the preparation of this document:

- Buddy "Ellis" Clairain - Moffatt and Nichol

The following people assisted with access and summaries of data used in this report:

- Louisiana Department of Wildlife and Fisheries (LDWF) – Harry Blanchet, Michael Harden, Rob Bourgeois, Lisa Landry, Bobby Reed, Dawn Davis, Jason Adriance, Glenn Thomas and Patrick Banks

- The Water Institute of the Gulf – Leland Moss, Amanda Richey, and Camille Stelly

- Coastal Protection and Restoration Authority (CPRA) of Louisiana – Brian Lezina

This effort was funded by the 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 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 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 white shrimp, *Litopenaeus setiferus,* 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
DO	Dissolved oxygen
HSI	Habitat Suitability Index
ICM	Integrated Compartment Model
LDWF	Louisiana Department of Wildlife and Fisheries
SAS	Statistical Analysis Software
SAV	Submerged aquatic vegetation
SI	Suitability Index
TL	Total length

1.0 Species Profile

White shrimp are demersal omnivores that range from Fire Island, New York to the St. Lucie Inlet, Florida, on the Atlantic coast and from Apalachee Bay, Florida to Campeche Bay, Mexico in the Gulf of Mexico (Pattillo et al., 1997). The species is most abundant in Louisiana and Texas (Klima, 1987; Williams, 1984), with the greatest densities occurring off the coast of Louisiana (Klima et al., 1982). The white shrimp commercial fishery in Louisiana has supported more than 60% of the nation's annual landings from 2000-2013 (http://www.st.nmfs.noaa.gov), and the annual white shrimp numbers sampled by the Louisiana Department of Wildlife and Fisheries (LDWF) fisheries-independent monitoring program have continued to rise in the coastal basins since the early 2000s (LDWF, unpublished data).

As with brown shrimp, predation and episodic catastrophes such as hurricanes and hard freezes play important roles in reducing white shrimp populations. Suitable estuarine habitat is critical to survival and recruitment of juveniles (Nance et al., 1989; Turner, 1977) and habitat loss may eventually result in declines in recruitment and harvest (Christmas & Etzold, 1977; Nance et al., 1989). Other factors that affect penaeid shrimp population dynamics are nursery area productivity, prey availability, refuge from predation, amount of freshwater inflow, light intensity, tides, and rainfall (Christmas & Etzold, 1977; Gracia, 1991; Pattillo et al., 1997).

White shrimp also are important to estuarine food webs. White shrimp postlarvae in the estuaries prey upon zooplankton and phytoplankton. Predators of postlarvae include juvenile spotted seatrout, southern flounder, crab megalopae, spot, and killifish (Zein-Eldin & Renaud, 1986). Juveniles and sub-adults in the estuaries are benthic consumers that eat organic-inorganic detritus, fecal pellets, diatoms, polychaetes, and zoobenthos (Rozas & Minello, 2011). They are preyed upon by juvenile and adult spotted seatrout, sea catfish, red drum, southern flounder, ladyfish, sea birds, pinfish, Atlantic sharpnose shark, blue crab, Atlantic croaker, black drum, silver perch, and sand seatrout.

Eggs (0.28 mm diameter and demersal) are spawned from spring through fall in offshore waters, where they hatch and develop into larvae (Christmas & Etzold, 1977; Klima et al., 1982; Figure 1). Larval stages (0.3-7 mm) consist of 5 naupliar stages, 3 protozoeal stages, and 3 mysis stages (Perez-Farfante, 1969). All larval stages are planktonic (Klima et al., 1982; Perez-Farfante, 1969). White shrimp postlarvae (7 mm – 25 mm total length (TL)) recruit into the estuarine nurseries through tidal passes from May to November. One peak is in June and a second peak occurs in September in the northern Gulf of Mexico (Baxter & Renfro, 1968; Klima et al., 1982). After they reach the nursery areas, metamorphosis to the juvenile stage occurs (Cook & Lindner, 1970; Perez-Farfante, 1969; McKenzie, 1981; Muncy, 1984; Williams, 1984). Juveniles (25-120 mm) migrate to less saline waters than brown or pink shrimp. They use mud flats to deep channels and are less dependent on vegetated habitats than brown shrimp. They then leave the shallow marsh habitat for deeper, higher salinity regions of the estuary as they near size at maturation and leave the estuary to spawn in the offshore waters (Cook & Lindner, 1970). After leaving the estuaries, the adult white shrimp (119 mm TL for males at maturity; 165 mm TL for females) generally move westward and deeper in offshore waters (Hollaway & Baxter, 1981; Hollaway & Sullivan, 1982; Lyon & Boudreaux, 1983). In April to mid-May, adult white shrimp move back to near-shore and inshore shelf waters (Hollaway & Sullivan, 1982; Pattillo et al., 1997).

The spatial and temporal distribution of white shrimp 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 (SAV). 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.

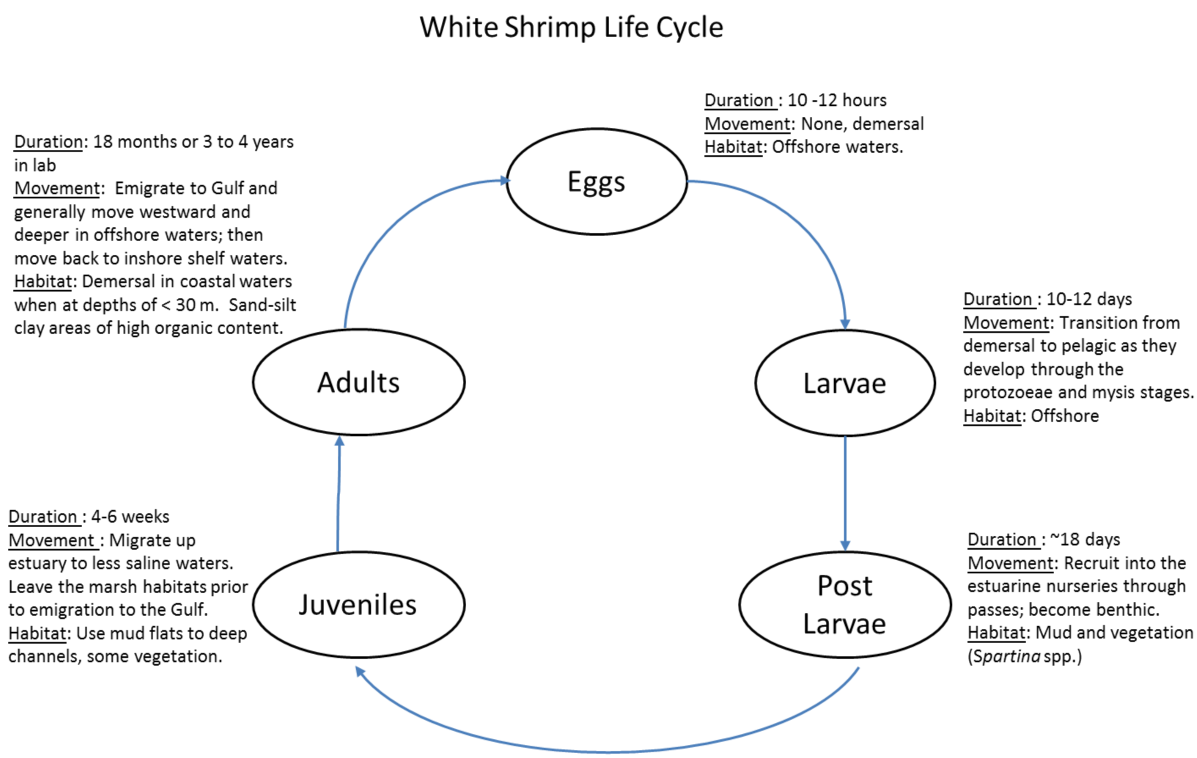


Figure 1: White Shrimp Life Cycle (Pattillo et al., 1997 and references therein).

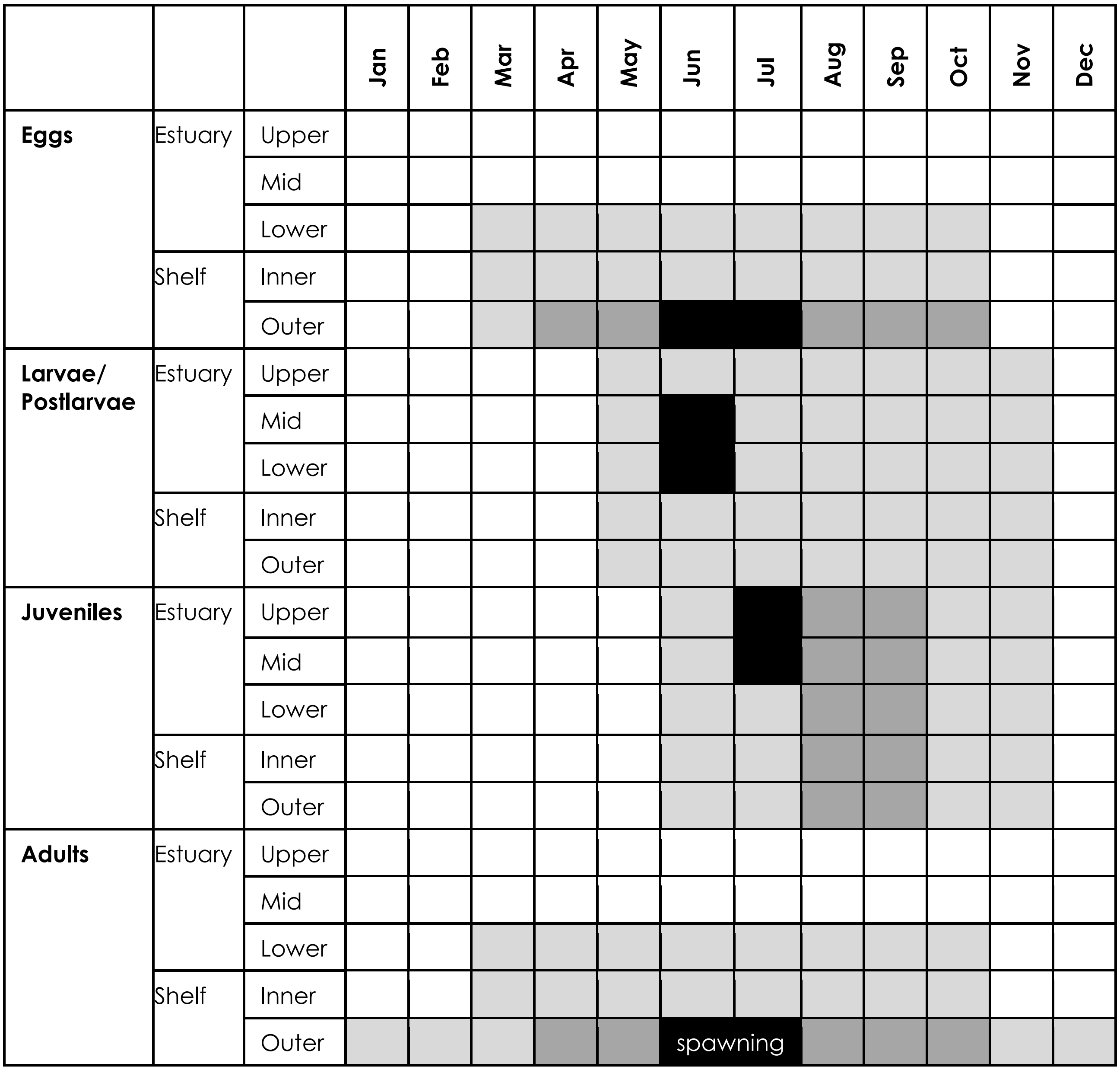


Figure 2: Space-Time Plot by Life Stage for White Shrimp Showing Relative Abundance in the Upper, Mid, and Lower Region of the Estuary, and Inshore and Offshore Shelf Regions by Month. White cells indicate the life stage is not present, light grey cells indicate the life stage is at moderate abundance,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

Table 1: Habitat Requirements for White Shrimp Life Stages. Pattillo et al. (1997), Pattillo et al. (1995), and Zein-Eldin and Renaud (1986) were the primary sources used to construct the table and most of the references are therein.

Life Stage: Process	Salinity (ppt) Optimum (Range)	Temperature (°C) Optimum (Range)	Depth (m)	Preferred Substrate	Turbidity	DO (mg/L)
Egg	(27-35)	-	-	-	-	-
Larvae/ Post-larvae	(0.4-37.4; 27-35)	18-32.5 (12.6-32.5)	-	Mud habitat with marsh vegetation	-	-
Juvenile	<10 (5-26, LA)	15-33 (9-33, LA)	Positively related to depth[a] Flooded marsh[b,c]	Found in shallow mud flats to deep channels; Prefer sandy-mud Prefer 25-80% of area covered by marsh[d]	Negatively related to turbidity[a]	Avoids 1.0-1.5
Adults: Spawning	27-40 (0.1-45.3) (27-35)	(10-37, if acclimated; <18, growth slow)	-	Prefer sand-silt areas high in organic content	-	< 2.0 causes stress Avoid hypoxia, forces shrimp inshore and offshore is blocked by hypoxia in LA[e]

[a] Minello and Webb, 1997; [b] Rozas and Reed, 1993; [c] Minello et al., 2011; [d] Minello and Rozas, 2002; [e] Zimmerman et al., 1997

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 key species was estimated as total catch per sample event for each gear type separately. 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 6 and 16 ft trawl were evaluated for statistical relationships among the associated environmental data and white shrimp CPUE. The 6 ft trawls were historically sampled weekly during April through the closing of the spring shrimp season at fixed stations to sample juvenile penaeid shrimp populations in shallow edge habitats in the interior marshes (LDWF, 2002). The current sampling program limits 6 ft trawl sampling to April and June (LDWF, personal communication). The body of the 6 ft trawl is constructed of 3/8 in bar mesh No. 6 nylon mesh while the tail is constructed of 1/4 in bar mesh knotted 35 lb tensile strength nylon and is 40 in long. The 16 ft trawls historically were 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 (bottom fish) in the larger inshore 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. 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. 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.

LDWF also measures temperature, conductivity, salinity, turbidity, dissolved oxygen (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 averages of their measurements were 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 LDWF datasets. However, a comparison of HSIs developed from those gears that are associated with non-vegetated habitat (trawls) with those that are associated with vegetation (seine) was made to see if optimum values for variables were similar between habitats and if they roughly supported previous findings (CPRA, 2012; Minello & Rozas, 2002). Thus, 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 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

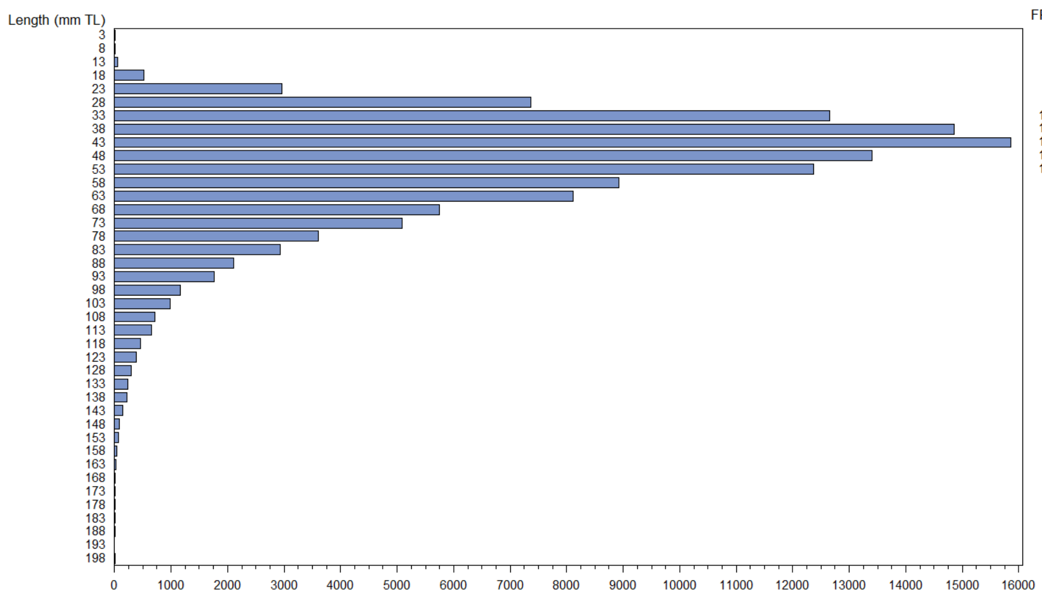
catch in order to reduce the amount of zeroes in the dataset. In this way, the analysis was not focused on describing environmental effects on species catch when the species typically are not in the estuaries or else at very low numbers.

2.1 Seines

The length distribution of white shrimp caught in the seine samples indicated that nearly all were small juveniles (median TL=43 mm; Figure 3). White shrimp typically mature at around 119-165 mm TL (Baltz et al., 1993; Rozas & Reed, 1993). Sizes above 119 mm TL constituted less than 2% of the total white shrimp catch. Therefore, it was assumed that the estimated CPUE from the 50 ft seines samples were representative of small juvenile white shrimp.

The plot of mean CPUE by month for each year indicated the catch of juvenile white shrimp in the 50 ft seines was consistently highest during June through November (Figure 4). This seasonality of juvenile white shrimp catch in the seine samples coincides with their life history information of peak spawning on the shelf from June through July with juveniles occurring in the estuaries from June through November then gradually emigrating to the offshore spawning ground (Baxter & Renfro, 1968; Cook & Lindner, 1970; Klima et al., 1982). Therefore, the seine data from June through November were used for the statistical evaluation of the juvenile white shrimp CPUE-environment relationships, and the remaining months were dropped from the analysis as those months showed low and inconsistent catch of white shrimp in the seines (Figure 4).

The seine data collected in June 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 white shrimp CPUE. The environmental variables were examined along with their squared terms and their interactions. Day of year and its squared term were also included in the model to explain any seasonal variation in white shrimp within the estuaries.



Length (mm TL)	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
3	6	6	0.00	0.00
8	10	16	0.01	0.01
13	61	77	0.05	0.06
18	516	593	0.42	0.48
23	2958	3551	2.39	2.87
28	7368	10919	5.95	8.82
33	12652	23571	10.22	19.03
38	14862	38433	12.00	31.03
43	15865	54298	12.81	43.84
48	13402	67700	10.82	54.67
53	12376	80076	9.99	64.66
58	8923	88999	7.21	71.87
63	8110	97109	6.55	78.41
68	5749	102858	4.64	83.06
73	5088	107946	4.11	87.16
78	3604	111550	2.91	90.08
83	2931	114481	2.37	92.44
88	2101	116582	1.70	94.14
93	1758	118340	1.42	95.56
98	1164	119504	0.94	96.50
103	990	120494	0.80	97.30
108	711	121205	0.57	97.87
113	648	121853	0.52	98.39
118	454	122307	0.37	98.76
123	383	122690	0.31	99.07
128	301	122991	0.24	99.31
133	240	123231	0.19	99.51
138	213	123444	0.17	99.68
143	137	123581	0.11	99.79
148	91	123672	0.07	99.86
153	70	123742	0.06	99.92
158	42	123784	0.03	99.95
163	27	123811	0.02	99.98
168	6	123817	0.00	99.98
173	7	123824	0.01	99.99
178	3	123827	0.00	99.99
183	3	123830	0.00	99.99
188	3	123833	0.00	99.99
193	1	123834	0.00	99.99
198	7	123841	0.01	100.00

Figure 3: Length-Frequency Distribution of White Shrimp caught in the 50 Foot Seine Samples for Louisiana.

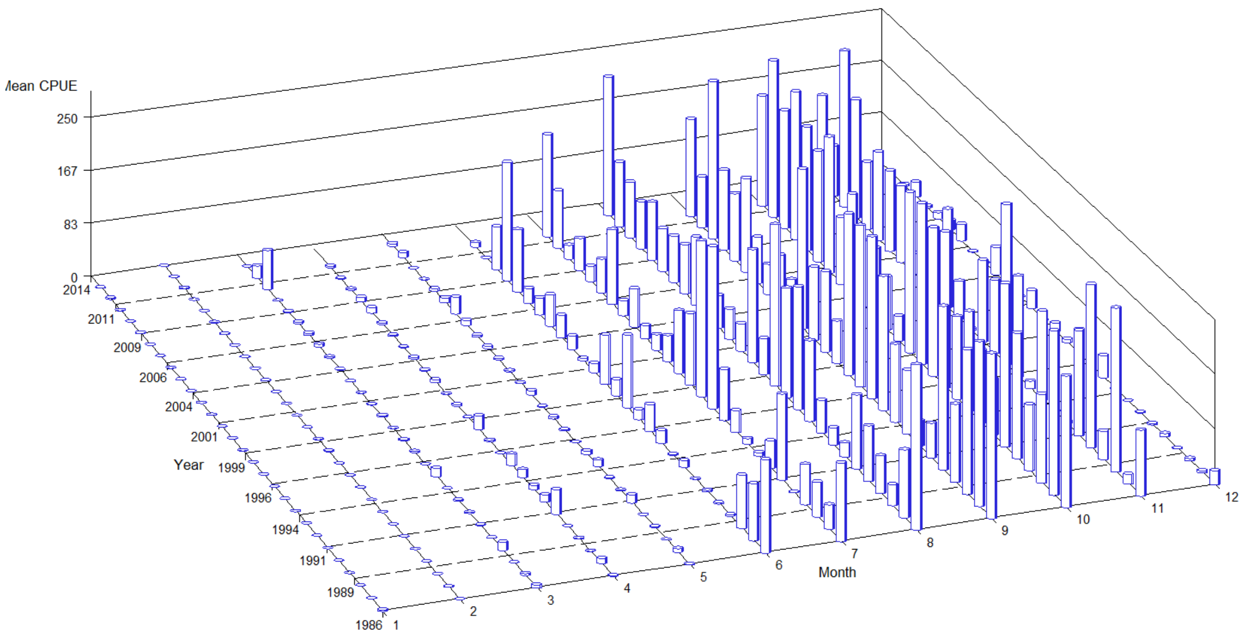


Figure 4: Mean CPUE of White Shrimp by Month for Each Year in the 50 Foot Seine Samples.

2.2 6 Foot Trawls

The length distribution of white shrimp caught in the 6 ft trawl samples indicated that nearly all were larger juveniles (median TL=72.5 mm; Figure 5) than those caught by the seine. Sizes above 119 mm TL constituted less than 4% of the total white shrimp catch. Therefore, it was assumed that the estimated CPUE from the 6 ft trawl samples were representative of large juvenile white shrimp.

The plot of mean CPUE by month for each year indicated the catch of juvenile white shrimp in the 6 ft trawls was consistently highest during June through October (Figure 6). Note that sampling effort of the 6 ft trawls has been reduced in recent years (Figure 6). The 6 ft trawl data from June through October were used for the statistical evaluation of the juvenile white shrimp CPUE-environment relationships, and the remaining months were dropped from the analysis as those months showed low and inconsistent catch of white shrimp in the 6 ft trawls (Figure 6).

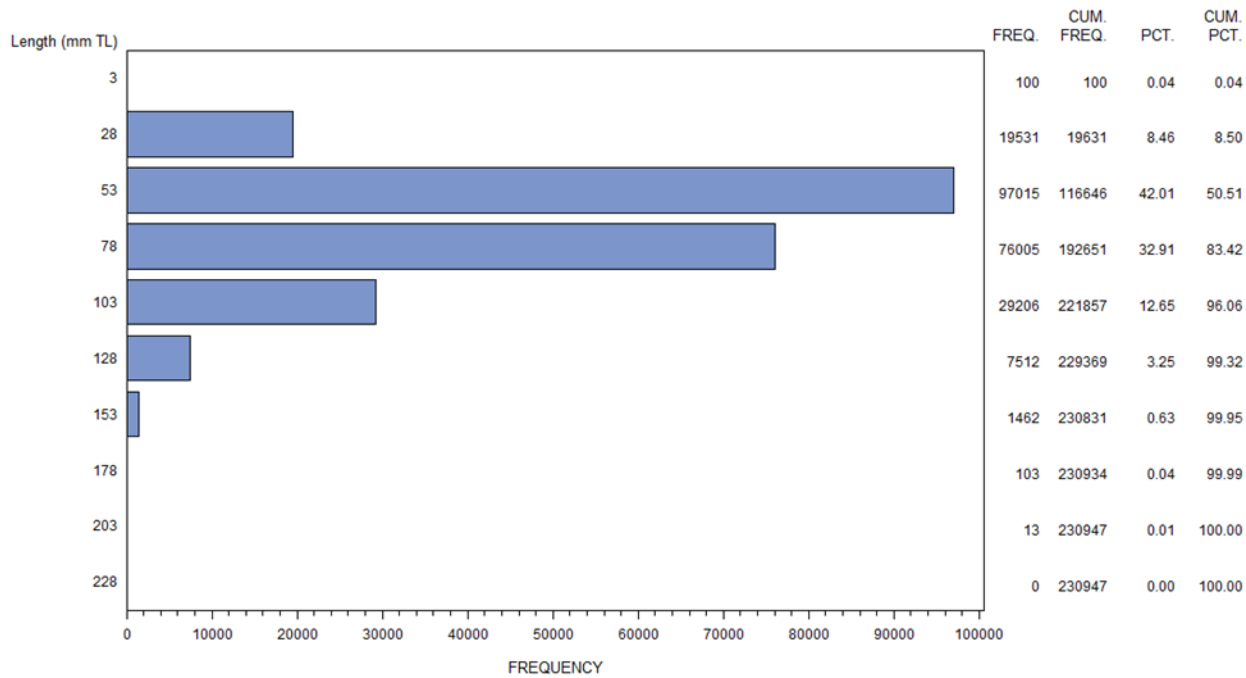


Figure 5: Length-Frequency Distribution of White Shrimp Caught in the 6 Foot Trawl Samples for Louisiana.

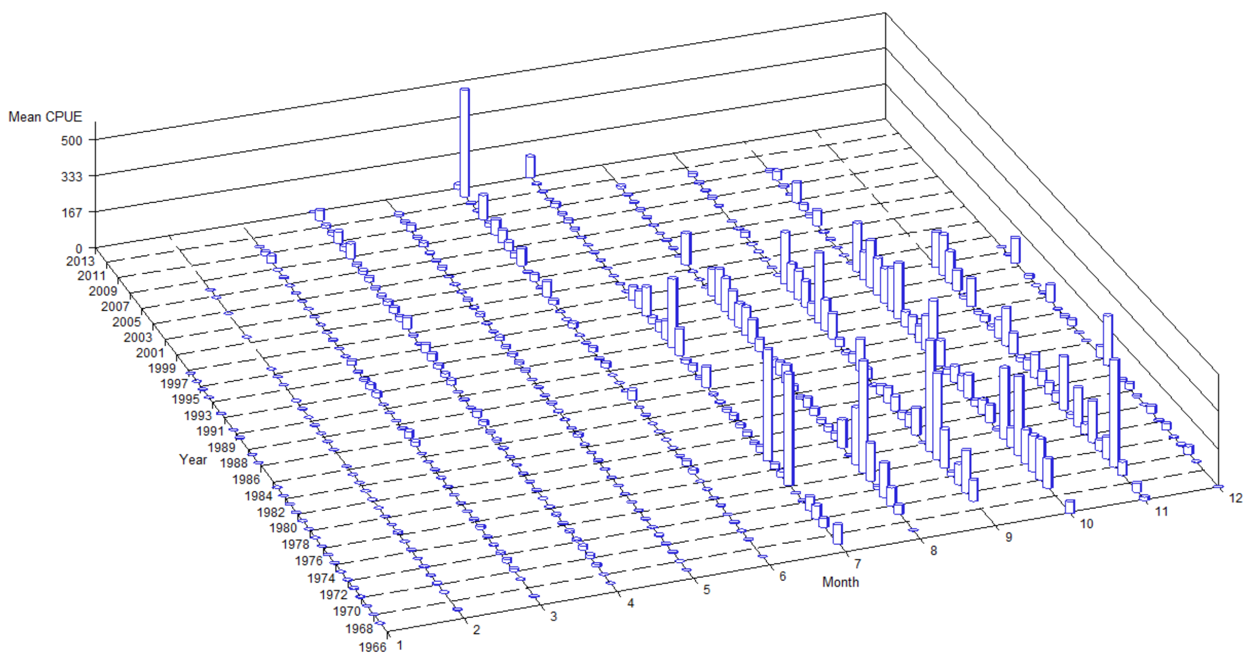


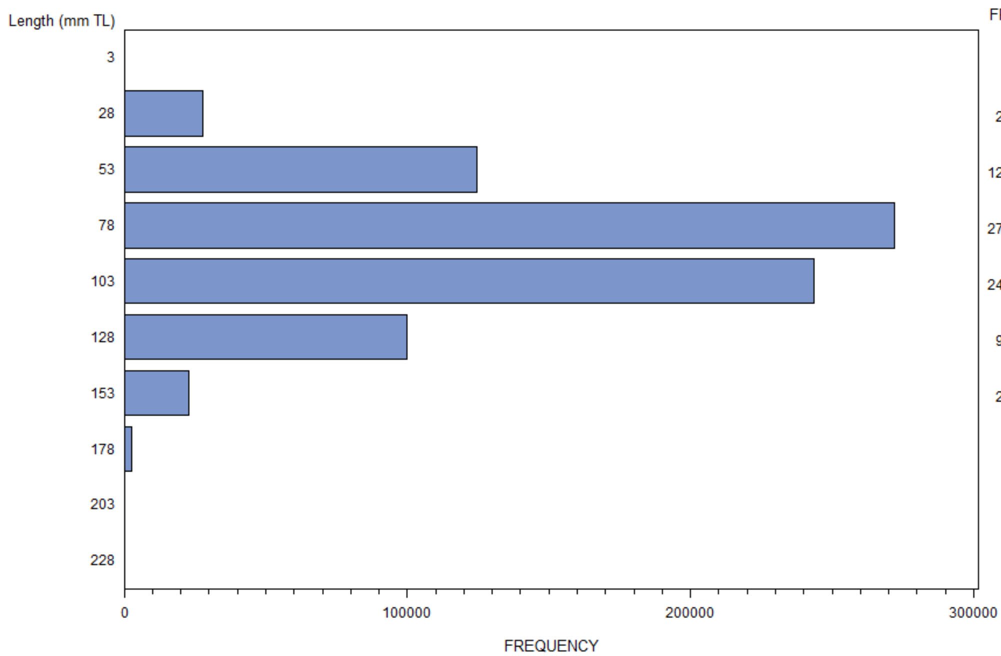
Figure 6: Mean CPUE of White Shrimp by Month for Each Year in the 6 Foot Trawl Samples.

2.3 16 Foot Trawls

The length distribution of white shrimp caught in the 16 ft trawl samples indicated that nearly all were large juveniles (median TL = 92.5 mm; Figure 7). Sizes above 119 mm TL constituted less than 10% of the total white shrimp catch. Therefore, it was assumed that the estimated CPUE from the 16 ft trawl samples were representative of large juvenile white shrimp.

The plot of mean CPUE by month for each year indicated the catch of juvenile white shrimp in the 16 ft trawls was consistently highest during July through December (Figure 8). Therefore, the 16 ft trawl data from July through December were used for the statistical evaluation of the juvenile white shrimp CPUE-environment relationships, and the remaining months were dropped from the analysis as those months showed low and inconsistent catch of white shrimp in the 16 ft trawls (Figure 8).

The 6 ft and 16 ft trawl data collected in June through October and July through December, respectively, over all available years of record (1966-2013) were evaluated separately to determine if the averaged salinity and averaged water temperature were related to the juvenile white shrimp CPUE. Each 16 ft trawl sample was kept as an independent observation even though collections were taken bi-weekly during certain months. Both environmental variables along with their squared terms and their interactions were examined. Day of year and its squared term were also included in the models to explain any seasonal variation in white shrimp within the estuaries.



Length (mm TL)	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
3	178	178	0.02	0.02
28	27831	28009	3.51	3.53
53	124673	152682	15.71	19.24
78	271841	424523	34.25	53.49
103	243690	668213	30.70	84.19
128	99787	768000	12.57	96.77
153	22780	790780	2.87	99.64
178	2520	793300	0.32	99.95
203	319	793619	0.04	99.99
228	55	793674	0.01	100.00

Figure 7: Length-Frequency Distribution of White Shrimp Caught in the 16 Foot Trawl Samples for Louisiana.

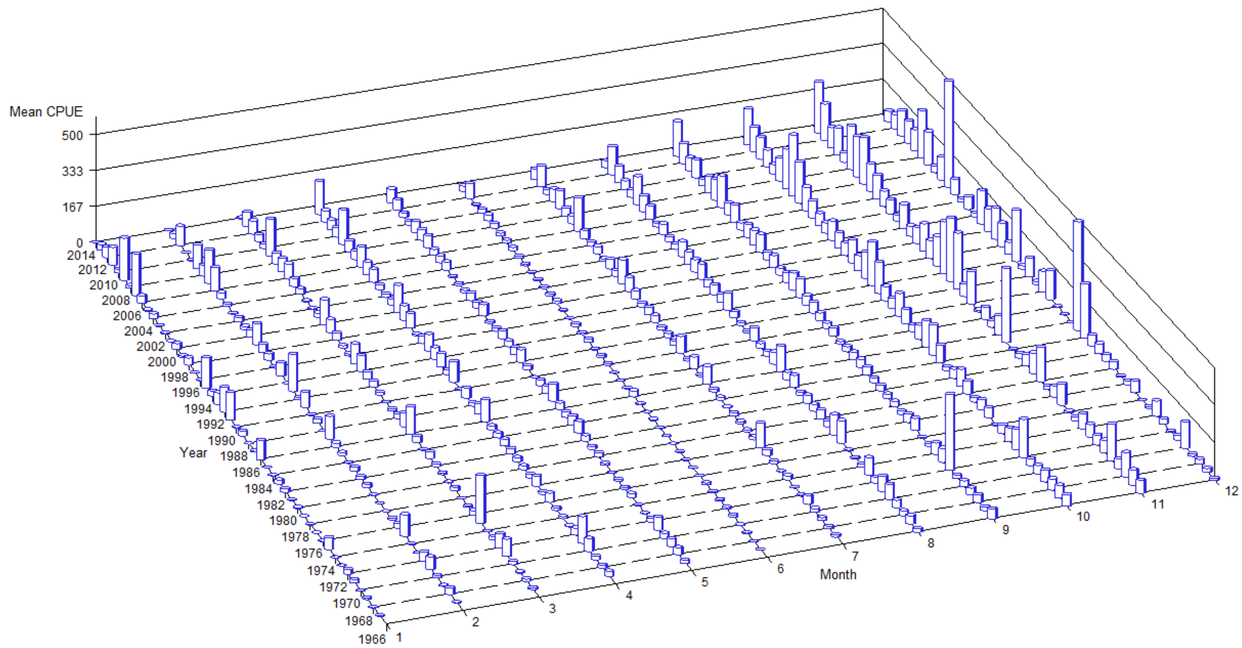


Figure 8: Mean CPUE of White Shrimp by Month for Each Year in the 16 Foot Trawl Samples.

2.4 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 white shrimp 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, 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 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 white shrimp CPUE (natural log transformed) in terms of all significant effects from salinity and 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 9) 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 9).

Juvenile white shrimp were generally abundant between 10-28°C and 6 and 32 ppt; however, peak catches occurred at 14-24°C and 18-24 ppt (Figure 9). The peak water temperatures are

slightly lower than those reported in the recent white shrimp HSI models (20-30°C; CPRA, 2012), whereas the peak salinities are higher than was previously determined (5-15 ppt).

$$\ln(\text{CPUE}+1) = -7.9150 + 8.1556(Day) - 1.6101(Day^2) - .03471(Salinity) + .009624(Temperature) + .01385(Salinity * Temperature) - .00264(Salinity^2) - .00115(Temperature^2) - .00034(Salinity * Temperature^2) \quad (1)$$

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	-7.9150	<0.0001
Day	8.1556	<0.0001
Day^2	-1.6101	<0.0001
Salinity	-0.03471	0.4771
Temperature	0.009624	0.8770
Salinity*Temperature	0.01385	0.0010
$Salinity^2$	-0.00264	<0.0001
$Temperature^2$	-0.00115	0.3669
$Salinity*Temperature^2$	-0.00034	<.0001

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

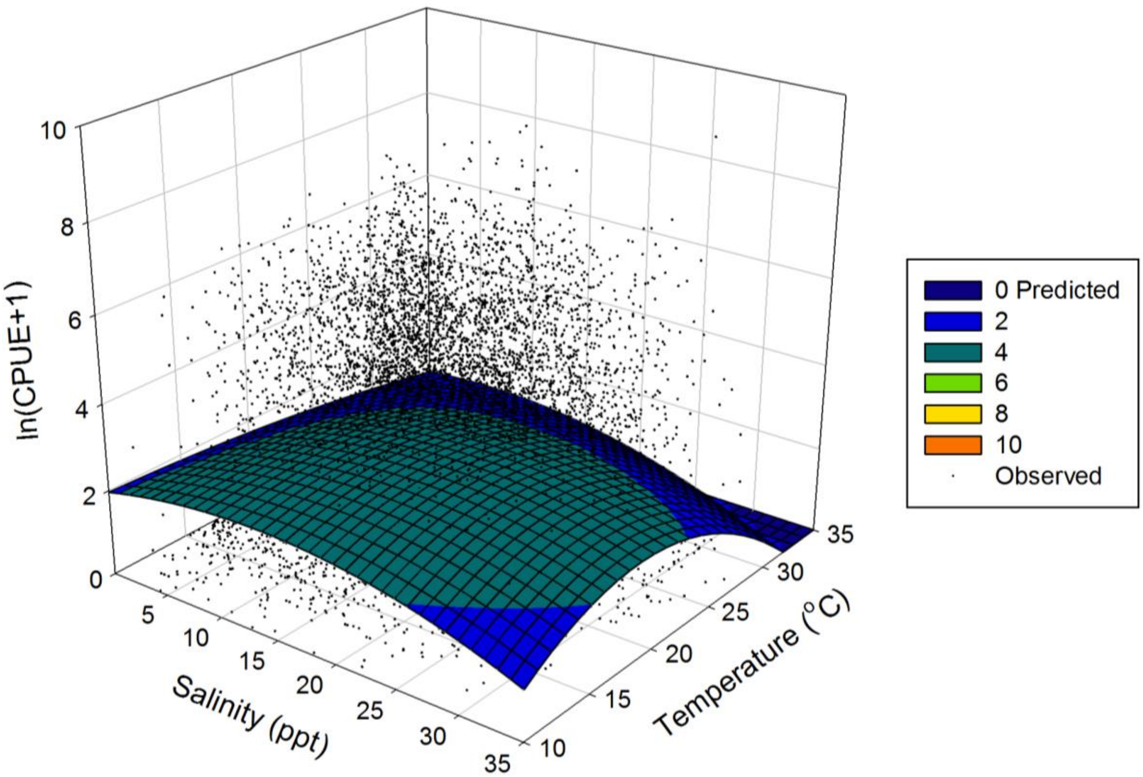


Figure 9: Surface Plot for the Polynomial Regression in Equation 1 over the Range of Salinity and Temperature Values and Substituting Mean Day of September 11 into the Equation. The scatter plot of salinity, temperature and juvenile white shrimp CPUE data from the 50-foot seine station samples are overlaid on the plot.

3.2 Trawls

Preliminary analysis indicated the two trawl gear types had similar predictions of white shrimp CPUE in response to salinity and temperature. As a result, the data for both trawls were combined using the dates in common between the two gears (July – October). The resulting polynomial regression model (Equation 2) from the analysis describes white shrimp CPUE in terms of all significant effects from salinity, temperature, their squared terms and their interactions, and day of year (Table 3).

A dummy variable, "gear", was used to control for the effect of the different gears on model predictions: when its value is "1" the prediction represents the 6 ft trawl; when its value is "0" the results are adjusted for the 16 ft trawl.

The surface response for the resulting polynomial regression model (Equation 2) is plotted for the range of salinities and temperatures for mean day of August 27 (Figure 10). There is a strong effect of salinity on CPUE with a substantial peak occurring at the combination of lower temperatures and salinities between 5-20 ppt, with peaks between 12-17 ppt. These peaks occur at slightly lower salinity values than those from the analysis of the seine data and are closer to the ranges presented in Table 1, although still higher than the reported optimum of 5-15 ppt. With regards to temperature, there are few data points below 15°C and the results at those combinations may not be biologically meaningful because the polynomial model "flips" to

predict unreasonable values beyond the available data. As a result, truncating the model to the range of available data provides a better snapshot of the relationship (Figure 10). The coefficient for the ‘gear’ variable indicates there is a decrease in white shrimp catch when gear is set to 1 (6 ft trawl) rather than 0 (16 ft trawl). However, these differences have no effect on the overall shape of the responses to salinity and temperature. As a result, gear was held constant at 0 for the development of the suitability index, as described below.

$$\ln(CPUE+1) = -8.2435 + 1.248(Salinity) + 0.3732(Temperature) - 0.03476(Salinity^2) \\ -0.00751(Temperature^2) - 0.08411(Salinity * Temperature) - 0.00004(Salinity^2 * Temperature^2) \\ +0.00141(Salinity * Temperature^2) + 0.002221(Temperature * Salinity^2) \\ +4.6448(Day) - 0.8693(Day^2) - 0.545(Gear) \qquad (2)$$

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	-8.2435	<0.0001
Salinity	1.248	<0.0001
Temperature	0.3732	<0.0001
$Salinity^2$	-0.03476	<0.0001
$Temperature^2$	-0.00751	<0.0001
Salinity*Temperature	-0.08411	<0.0001
$Salinity^2$*$Temperature^2$	-4.00E-05	<0.0001
Salinity*$Temperature^2$	0.00141	<0.0001
Temperature*$Salinity^2$	0.002221	<0.0001
Day	4.6448	<0.0001
Day^2	-0.8693	<0.0001
Gear	-0.545	<0.0001

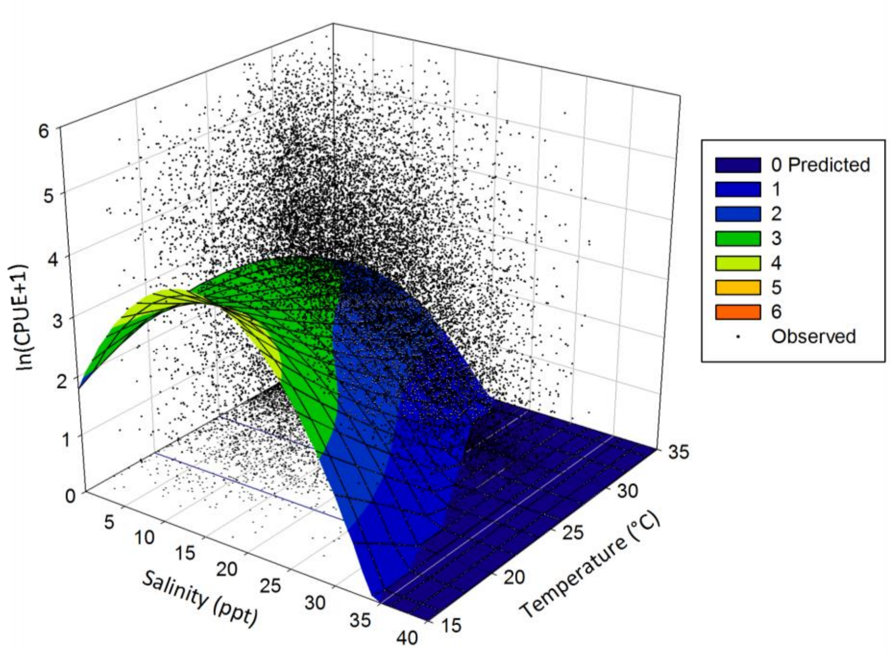


Figure 10: Surface Response Plot for Juvenile White Shrimp in 6 Foot and 16 Foot Trawls in Relation to Temperature and Salinity and with the Response Surface Truncated at the Temperature Extremes (<15 and > 35°C) to Remove the Extreme Values from the Polynomial Regression.

4.0 Habitat Suitability Index Model for Juvenile White Shrimp (Seine)

Although the polynomial regression functions appear long and complex, the regression models are simply describing the relationships between white shrimp 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 white shrimp 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 white shrimp ln[(CPUE+1)] value of 3.25 was generated from the seine polynomial regression at a temperature of 18°C and salinity of 20 ppt. The back-transformed CPUE value (24.687) 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 small juvenile white shrimp HSI model. Both components of the model are equally weighted and the geometric mean is used as all variables are considered essential to small juvenile white shrimp:

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

Where:

SI_1 – Salinity and temperature during the months of June through November (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 (median TL=43 mm; Figure 3) juvenile white shrimp from June 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 June through November

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

$$V_1 = -7.9150 + 8.1556(2.543) - 1.6101(2.543^2) - .03471(Salinity) + .009624(Temperature) + .01385(Salinity * Temperature) - .00264(Salinity^2) - .00115(Temperature^2) - .00034(Salinity * Temperature^2)$$

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

$$SI_1 = \frac{e^{V_1} - 1}{24.68}$$

which includes the steps for back-transforming the predicted CPUE from Equation 1 and standardizing by the maximum predicted (untransformed) CPUE value equal to 24.68. The surface response for SI_1 is demonstrated in Figure 11.

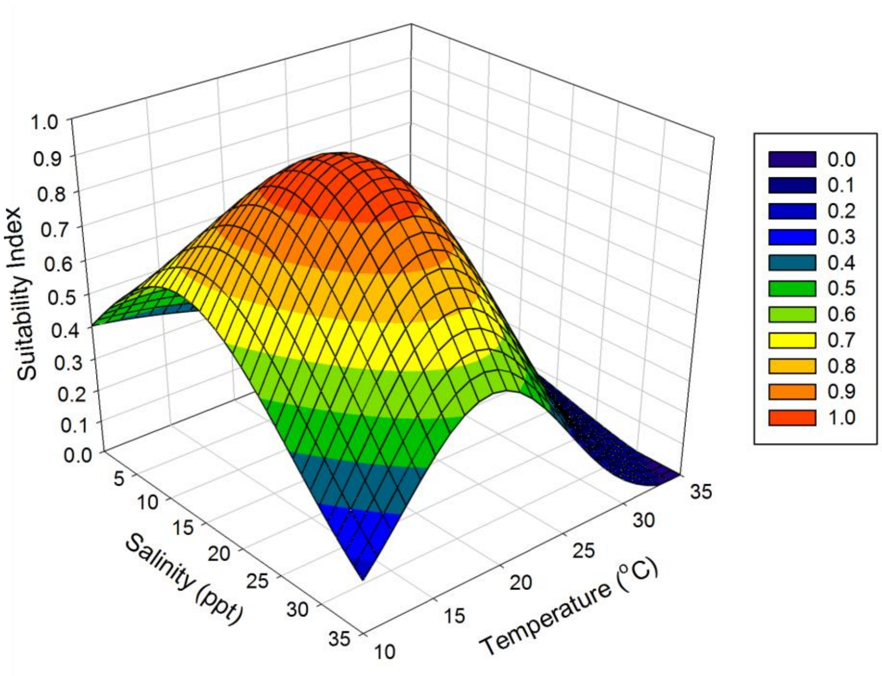


Figure 11: Surface Plot Demonstrating the Predicted Suitability Index (0-1) for Small Juvenile White Shrimp in Relation to Salinity and Temperature and Resulting from the Back-Transformation and Standardization of the Polynomial Regression in Equation 1.

Rationale: Salinity and temperature are important abiotic factors that can influence the spatial and temporal distribution of small juvenile white shrimp in the estuaries within a year. The suitability index for small juvenile white shrimp 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 LDWF seine samples. The resulting suitability index falls within the ranges previously described in the literature for juvenile white shrimp, although the optimum salinity values are higher than the optimum salinity values reported in Table 1. The previous master plan HSI combined seine and trawl gears (CPRA, 2012). Because these gears employ different levels of effort (as previously described) and target different parts of the shrimp life cycle, it was felt that relationships specific to each gear were warranted.

Limitations: The variable 'day' in Equation 1 has been replaced by a constant value equal to the mean day from the analysis (September 11).[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 small juvenile white shrimp 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 land

V_2 is the percent of the cell that is covered by land (emergent wetland vegetation of all types). The equation for SI_2 is plotted in Figure 12.

$SI_2 = 0.028 * V_2 + 0.3$	for $V_2 < 25$
1.0	for $25 \le V_2 \le 80$
$5.0 – 0.05 * V_2$	for $V_2 > 80$

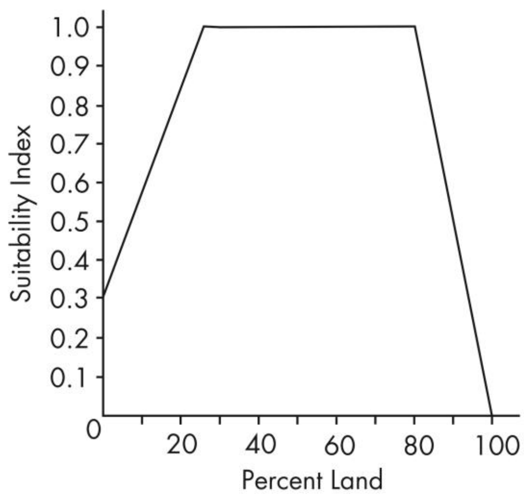


Figure 12: The Suitability Index for Small Juvenile White Shrimp in Relation to the Percent Emergent Vegetation (Percent Land= V_2).

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 juvenile white shrimp. This relationship was developed 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 spotted seatrout in the 2012 Coastal Master Plan. The 2012 white shrimp wetland suitability index was utilized in the 2017 HSI model; however, the SI was increased to 0.3 at 0% wetland as white shrimp juveniles can occur in shallow non-vegetated bottom, and SI was decreased to 0 at 100% land as this configuration is not expected to hold value for this species.

Limitations: Juvenile white shrimp also use submerged aquatic vegetation (SAV; Rozas & Minello, 2006) and seagrass beds are considered prime habitat due to increased prey as well as for cover from predators. However, white shrimp do not rely as heavily on this vegetation as do other decapods (Laney, 1997) and there are no recent HSIs that include a relationship between SAV and this species. Regardless, the 2017 Coastal Master Plan HSI model does not quantify specific habitats such as SAV or marsh edge, and 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 Juvenile White Shrimp (Trawl)

Although the polynomial regression functions appear long and complex, the regression models are simply describing the relationships between white shrimp catch in the trawl 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 white shrimp 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 white shrimp ln(CPUE+1) value of 4.006 was generated from the trawl polynomial regression at a temperature of 21°C and salinity of 9 ppt. The back-transformed CPUE value (53.93) was used to standardize the other predicted untransformed CPUE values from the regression. The surface response that describes the standardized juvenile white shrimp (0-1) response to salinity and temperature is shown in Figure 13. This predicted response surface is the resulting water quality suitability index to be used for the large juvenile white shrimp. The standardized water quality index was combined with a standardized (0-1) index for emergent vegetation to produce the large juvenile white shrimp HSI model. Both components of the model are equally weighted and the geometric mean is used as all variables are considered essential to large juvenile white shrimp:

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

Where:

SI_1 – Salinity and temperature during the months of July through October (V_1)

SI_2 – Percent of cell that is emergent vegetation (V_2)

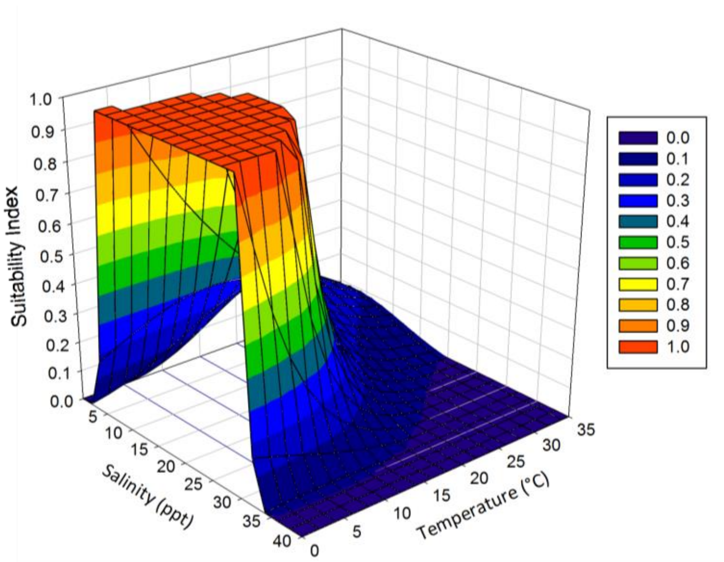


Figure 13: Surface Plot Demonstrating the Predicted Suitability Index (0-1) for Large Juvenile White Shrimp in Relation to Salinity and Temperature and Resulting from the Back-Transformation and Standardization of the Polynomial Regression in Equation 2.

5.1 Applicability of the Model

This model is applicable for calculating the habitat suitability index of large (median = 82.5 mm TL) juvenile white shrimp from July through October in Louisiana's inshore and deeper estuarine waters as they are emigrating from the estuary.

5.2 Response and Input Variables

V_1: Salinity and temperature during the months of July through October

Calculate monthly averages of salinity (ppt) and temperature (°C) from July through October:

$$V_1 = -8.2435 + 1.248(Salinity) + 0.3732(Temperature) - 0.03476(Salinity^2) - 0.00751(Temperature^2) - 0.08411(Salinity * Temperature) - 4.00\text{E} - 05(Salinity^2 * Temperature^2) + 0.00141(Salinity * Temperature^2) + 0.002221(Temperature * Salinity^2) + 4.6448(2.3940) - 0.8693(2.3940^2)$$

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

$$SI_1 = \frac{e^{V_1} - 1}{16.89}$$

which includes the steps for back-transforming the predicted CPUE from Equation 1 and standardizing by the maximum predicted (untransformed) CPUE value equal to 53.93. The surface response for SI_1 is demonstrated in Figure 13.

Rationale*:* Salinity and temperature are important abiotic factors that can influence the spatial and temporal distribution of large juvenile white shrimp in the estuaries within a year. The suitability index for large juvenile white shrimp resulted from the polynomial regression model that

described the fit to the observed trawl catch data in relation to the salinity and temperature measurements taken concurrent with LDWF trawl samples. The resulting suitability index predicts optimums that fall within the ranges previously described in the literature for juvenile white shrimp although salinity optimums are slightly higher than the reported optimums (Table 1). The previous master plan HSI combined seine and trawl gears (CPRA, 2012). Because these gears employ different levels of effort (as previously described) and target different parts of the shrimp life cycle, it was felt that relationships specific to each gear were warranted.

Limitations: The variable 'day' in Equation 1 has been replaced by a constant value equal to the mean day from the analysis (August 27). 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 large juvenile white shrimp most commonly occur, as dictated by physiological tolerances, prey availability, mortality, seasonal movements, and other factors. Finally, V_1 is inaccurate at temperatures less than 15 and greater than 35°C. As a result, a conditional statement should be applied and the model should be adjusted as followed:

If temperature <15 or temperature >35°C then V_1=0

V_2: Percent of cell that is land

V_2 is the percent of the cell that is covered by land (emergent wetland vegetation of all types). The equation for SI_2 is plotted in Figure 14.

SI_2 = 1.0 for $V_2 \leq 30$

1.43-0.0143*V_2 for $V_2 > 30$

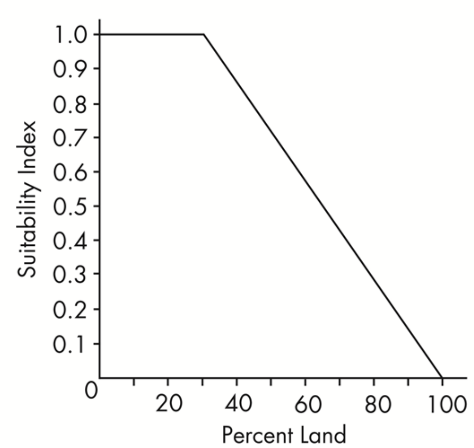


Figure 14: The Suitability Index for Large Juvenile White Shrimp in Relation to the Percent Emergent Vegetation (Percent Land= V_2).

Rationale: This relationship represents large juvenile white shrimp that are moving away from the shoreline into inshore and deeper estuarine waters. Therefore, it is thought that areas with more water (up to 30% wetland) would be appropriate for this life stage. The benefits of edge and

shoreline habitat may be less important during the larger juvenile life stage as the species begins to emigrate offshore.

Limitations: None.

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 white shrimp. 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 small juvenile white shrimp model, high scores were observed around fragmented marsh areas, 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, southern Barataria Bay, and Vermilion Bay. For large juvenile white shrimp, the model did not produce realistic distributions of habitat across the coast. Scores were predominantly low (< 0.5) and the scores at the higher end of the observed range were located in low-salinity lakes and bays (e.g., Lake Maurepas, Atchafalaya Bay), rather than the higher-salinity lower basins and sounds where this life stage would be located. This is most likely attributed to the temperature function in the polynomial regression and the inherent bias in the trawl gear. During warmer months, white shrimp are less likely to be caught by trawls as they are typically found within marsh habitats. As temperatures decrease, white shrimp move out of the marsh and into open waters where they are more easily sampled by trawls. As a result, the model is predicting greater habitat suitability for white shrimp where the waters are cooler. Further, 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 small and large juvenile 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 small juvenile white shrimp habitat distribution and inaccurate representations of large juvenile shrimp habitat distribution in coastal Louisiana. Thus, the results of the large juvenile white shrimp HSI model were not utilized for the 2017 Coastal Master Plan.

Although the polynomial regression model used to fit LDWF seine data produced a function relating white shrimp 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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