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2017 Coastal Master Plan

Attachment C3-18: Largemouth Bass, *Micropterus salmoides,* Habitat Suitability Index Model

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Coastal Protection and Restoration Authority

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

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Executive Summary

The 2012 Coastal Master Plan utilized Habitat Suitability Indices (HSIs) to evaluate potential project effects on fish and shellfish species. Even though HSIs quantify habitat condition, which may not directly correlate to species abundance, they remain a practical and tractable way to assess changes in habitat quality from various restoration actions. As part of the legislatively mandated five year update to the 2012 plan, the fish and shellfish habitat suitability indices were revised using existing field data, where available, to develop statistical models that relate fish and shellfish abundance to key environmental variables. The outcome of the analysis resulted in improved, or in some cases entirely new, suitability indices containing both data-derived and theoretically-derived relationships. This report describes the development of the habitat suitability index for juvenile and adult largemouth bass, *Micropterus salmoides,* 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
NTU	Nephelometric Turbidity Units
SAS	Statistical Analysis Software
SAV	Submerged aquatic vegetation
SI	Suitability Index
TL	Total length
YOY	Young-of-year

1.0 Species Profile

Largemouth bass are the most popular sport fish in the United States (Lasenby & Kerr, 2000). The fishery is a large economic driver for local residents (Chen et al., 2003) and has led to a great deal of stocking both as a way to supplement wild populations and to alter the genetics (i.e., to increase size and growth rate) of the current population (Diana & Wahl, 2008). Native to North America, their range extends from the coastal plain of North Carolina to Texas and northeast Mexico, through the Mississippi River System, Great Lakes, and southern Ontario. Within the United States, there are two genetic strains of the largemouth bass: the northern strain (*Micropterus salmoides salmoides*) and the Florida strain (*Micropterus salmoides floridanus*) with viable hybrids (Philipp et al., 1983).

Adult largemouth bass are piscivores with a broad diet breadth (Hodgson et al., 2008) that can cause them to become catastrophically invasive when introduced into non-native areas (Kazumi & Keita, 2003). They exhibit aggressive behaviors allowing them to out-compete other predators for prey, which can indirectly affect their prey's resources (e.g., phytoplankton and zooplankton populations; Brown et al., 2009). Adult largemouth bass have few predators, namely humans, since they grow too large to be prey to most species. The juveniles, on the other hand, have a wide spectrum of fish and avian predators including perch, pike, heron and kingfishers (Scott & Crossman, 1973).

The life cycle of largemouth bass, with general habitat preferences and diet of each of the life stages, is presented in Figure 1. Spawning occurs in the spring typically around dawn and dusk (McPhail & McPhail, 2007) on sandy or gravel substrate or soft mud adjacent to vegetative cover (Brown et al., 2009; Davis & Lock, 1997). Larger adults tend to spawn earlier in the season, which may help their progeny survive (Goodgame & Miranda, 1993; Ludsin & DeVries, 1997; Peer et al., 2006; Post, 2003). After a spawning event, the eggs hatch in three to five days (Scott & Crossman, 1973). The number of eggs spawned is dependent largely on the size of the female and can range from 2,000 – 94,000 (Scott & Crossman, 1973). As largemouth bass grow from fry to juveniles their diet transitions from insects and larvae to piscivorous feeding (Stein, 1970; Brown et al., 2009), which allows individuals to build up enough lipid reserves to survive the winter months (Ludsin & DeVries, 1997). Adult largemouth bass are highly adapted to variable salinities and temperatures, but generally prefer low salinity (< 5 ppt) and warm temperature (~28°C) environments. Recent work has suggested juvenile largemouth bass (< age-3) can experience higher growth rates in brackish environments relative to freshwater habitats as a result of the availability of estuarine and marine prey with high caloric densities (Glover et al., 2013). In Louisiana, largemouth bass have a diverse diet with a large portion made up of invertebrates, shrimp and fish in addition to crawfish and crabs (Boudreaux, 2013). As visual foragers, they require consistently low turbidity to increase foraging opportunities (Buck, 1956; Stuber et al., 1982), although they can sense vibrations and may depend on olfactory cues (Scott & Crossman, 1973). It is generally reported that intermediate levels of submerged aquatic vegetation (~30% coverage) are considered optimal for largemouth bass populations (Maceina, 1996; Miranda & Pugh, 1997).

The spatial and temporal distribution of largemouth bass life stages within Louisiana's estuaries is summarized by a space-time plot (Figure 2), which indicates the relative abundance of each life stage throughout the year for each estuarine region: upper, mid, and lower. 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.

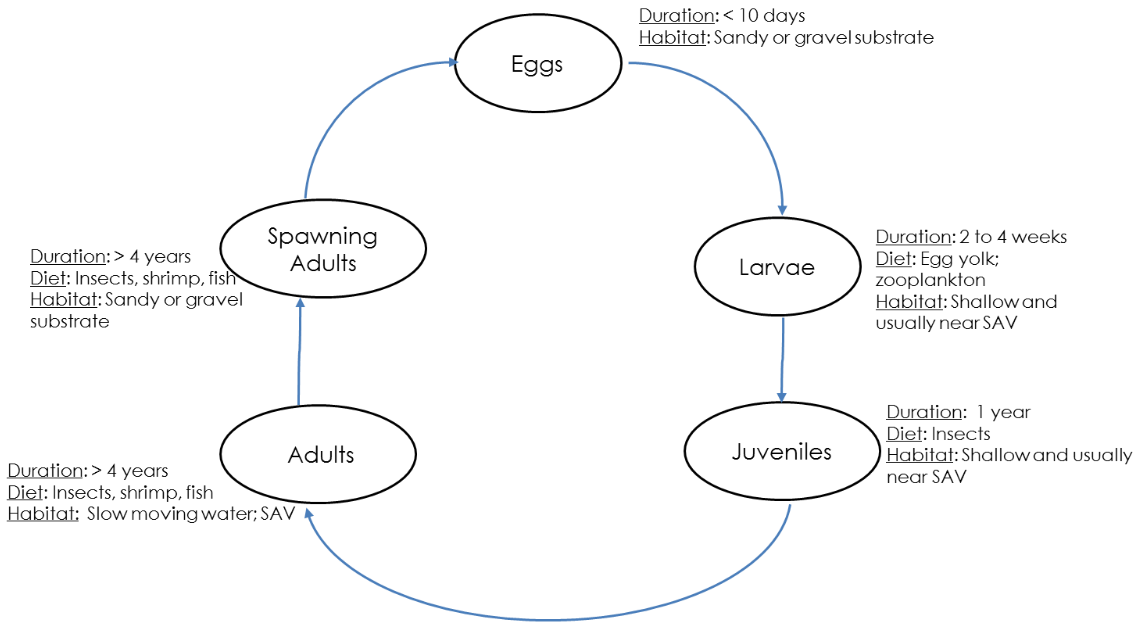


Figure 1: Largemouth Bass Life Cycle Diagram.

		Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Egg Hatching	Upper												
	Mid												
	Lower												
Larvae	Upper												
	Mid												
	Lower												
Juvenile	Upper												
	Mid												
	Lower												
Adult	Upper												
	Mid												
	Lower												
Spawning Adult	Upper												
	Mid												
	Lower												

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

Table 1: Habitat Requirements for Largemouth Bass Life Stages.

Life Stage	Salinity (ppt) Optimum (Range)	Temperature (°C) Optimum (Range)	Depth (m)	Substrate	Flows (cm/s)
Spawning	-	15.6-21 (13-26)[1,2]	0.15-7.5 m [3]	Hard substrate (sand or gravel)[4]	-
Egg Hatching	-	15.6-21 (13-26)[5,6]	-	Muck or silt is unsuitable[7]	<10[8]
Young-of-Year (fry)/ Juvenile	0-1.6 (0-6)[9]	27-30 (15-32)[10]	-	-	4-27[11]
Adults	0.5-5.0 (0.5-24)[12,13]	24-30 (15-36)[14,15]	1-6 [summer] ; > 6 [winter] [16,17]	-	-

[1](Carr, 1942; Kelley, 1968); [2](Allen & Romero, 1975; Clugston, 1964); [3](Stuber et al., 1982); [4](Davis & Lock, 1997); [5](Carr, 1942; Kelley, 1968); [6](Allen & Romero, 1975; Clugston, 1964); [7](Robinson, 1961); [8](Stuber et al., 1982); [9](Tebo & McCoy, 1964); [10](Strawn, 1961); [11](Laurence, 1972; MacLeod, 2011; Stuber et al., 1982); [12](Bailey et al., 1954); [13](Peer et al., 2006); [14](Mohler, 1966; Stuber et al., 1982); [15](Brungs & Jones, 1977; Coutant, 1975; Mohler, 1966; Venables et al., 1978); [16](Robbins & MacCrimmon, 1974; Winter, 1977); [17](Robbins & MacCrimmon, 1974; Winter, 1977)

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 inland freshwater and 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) was estimated for each gear type separately and the gears that caught the most largemouth bass were used in the analysis. The inland freshwater electrofishing gear employed state wide in freshwater rivers, lakes, and bayous served as the best gear type for examining trends in largemouth bass CPUE on a coast wide scale. CPUE represents number of fish collected per 15 minute electrofishing period. Electrofishing sampling is typically conducted one to four times a year with some instances of more frequent sampling. Electrofishing can result in high variability in species composition and abundance among years (Meador & McIntyre, 2003) so variation among years and among months within years was included as random components in the statistical analysis.

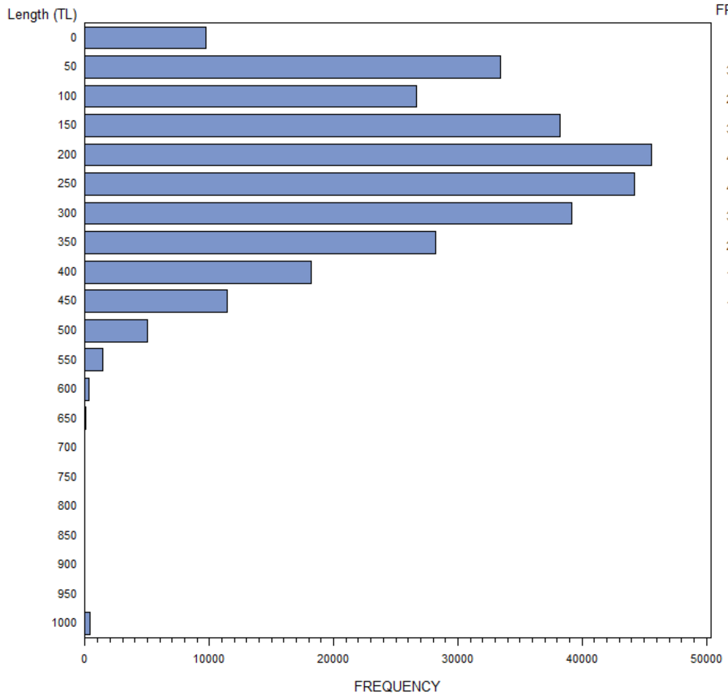
Associated with each electrofishing sample, LDWF also samples the top, middle and bottom of the water column at each site for water temperature, salinity, dissolved oxygen (DO), pH, redox, and turbidity. Of these variables, water temperature, salinity, turbidity and DO are the most important determinants of largemouth bass abundance at all life stages (Boudreaux, 2013; Buck, 1956; Peer et al., 2006; Stuber et al., 1982). Although DO is measured at time of sample, it is a highly variable parameter and a single point measurement is not necessarily representative of

the DO conditions experienced by the fish sampled. As a result, average salinity, temperature, and turbidity were used for the analysis. The period of record for the LDWF water quality data at electrofishing sites dates back to 1990 for a few sites but is readily available from hundreds of sites state wide starting in the late 1990s/early 2000s. Thus, the analysis was conducted for those time periods in which environmental data records were available, although biological records (i.e., CPUE) may date back a decade earlier.

Additional parameters expected to influence largemouth bass include prey concentration and emergent and aquatic vegetation. Suitability curves for these parameters were developed based on literature and professional judgment. Thus, the statistical analysis presented here focused on the development of quantitative relationships between largemouth bass and water temperature, salinity, and turbidity. The resulting equations will be standardized to a 0 to 1 scale in order to combine with the prey concentration and vegetation suitability index curves (described in 'Habitat Suitability Index Model').

Within the electrofishing gear type, the length-frequency distributions were examined to determine the life stages represented in the catch (Figure 3). Mature adults are > 260 mm total length (TL; Boudreaux, 2013; Ludsin & DeVries, 1997). Approximately 65% of the individuals were less than < 250 mm suggesting the samples comprised both juveniles/young-of-year (YOY) and adults. The habitat requirements for these life stages are not markedly different, although adults have higher salinity tolerances than YOY (Table 1). However, given the interest in developing a habitat suitability index model that is applicable to both adults and juveniles, the dataset was not subset by size distribution.

Mean monthly CPUE by year for the species in the 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 present or else at very low numbers. Although largemouth bass are present year round, they are most abundant March – November (Figure 4). Therefore, the electrofishing data from March through November were used for the statistical evaluation of the adult/juvenile largemouth bass CPUE-environment relationships.



Length (TL)	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
0	9738	9738	3.22	3.22
50	33471	43209	11.08	14.30
100	26682	69891	8.83	23.14
150	38185	108076	12.64	35.78
200	45558	153634	15.08	50.86
250	44255	197889	14.65	65.51
300	39179	237068	12.97	78.48
350	28206	265274	9.34	87.82
400	18201	283475	6.03	93.85
450	11406	294881	3.78	97.62
500	5000	299881	1.66	99.28
550	1419	301300	0.47	99.75
600	310	301610	0.10	99.85
650	45	301655	0.01	99.86
700	3	301658	0.00	99.86
750	0	301658	0.00	99.86
800	1	301659	0.00	99.86
850	0	301659	0.00	99.86
900	1	301660	0.00	99.87
950	0	301660	0.00	99.87
1000	407	302067	0.13	100.00

Figure 3: Length-Frequency Distribution (mm TL) of Largemouth Bass in Electrofishing Samples.

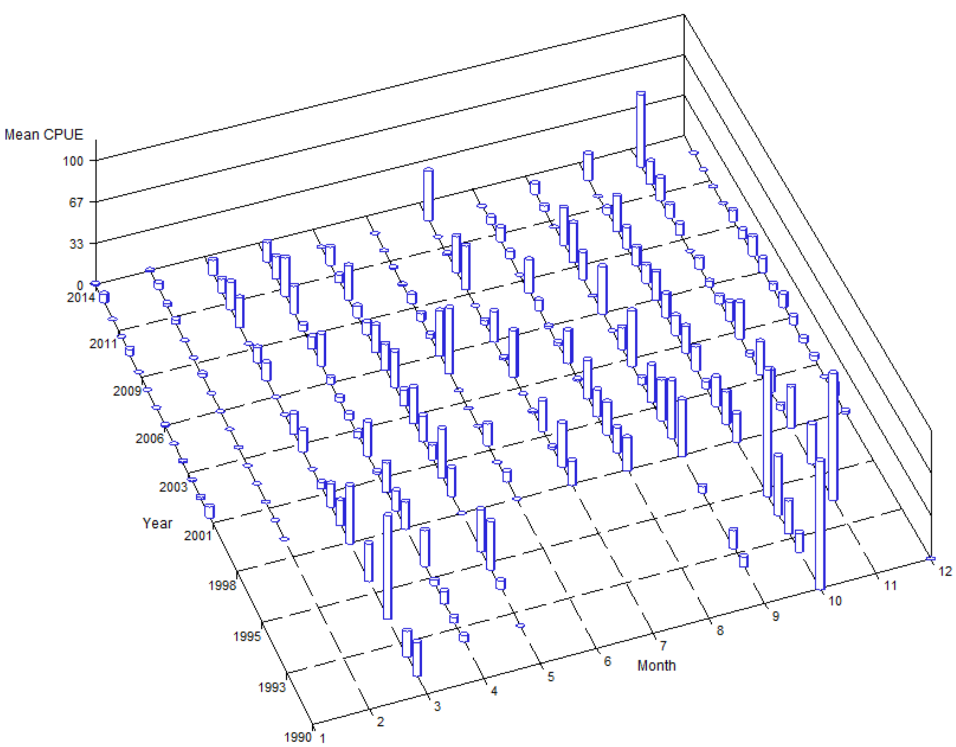


Figure 4: Mean Catch per Unit Effort (CPUE) of Largemouth Bass in Electrofishing Samples.

2.1 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. This was necessary due to time and resource constraints on the overall model improvement effort. It is possible that an analysis focused solely on largemouth bass would have identified an alternative approach.

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

Predictive models can often be improved by fitting some curvature to the variables by including polynomial terms. This allows the rate of a linear trend to diminish as the variable increases or decreases. It is expected that the largemouth bass may respond nonlinearly to salinity and temperature (i.e., they have optimal values for biological processes; Glover et al., 2013). 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

The resulting polynomial regression model from the analysis describes largemouth bass CPUE (natural log transformed) in terms of all significant effects from salinity, temperature, turbidity, day of year, and their squared terms (Equation 1; Table 2). The model produces a dome-shape relationship between CPUE and temperature, with highest CPUE occurring between 20-24°C (Figure 5). Largemouth bass CPUE was also highest at lowest salinities and turbidities (Figure 6 and Figure 7). These responses agree with the ranges and optimums presented in Table 1.

$$\ln(\mathrm{CPUE}+1) = 0.8752 - 1.7125(Day) + 0.3768(Day^2) - 0.2759(Salinity) + 0.007203(Salinity^2) + 0.3328(Temperature) - 0.0406(Turbidity) - 0.00764(Temperature^2) + 0.000632(Turbidity^2) \quad (1)$$

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

Selected Effects	Parameter Estimate[1]	p value
Intercept	0.8752	0.4897
Day	-1.7125	0.0683
Day^2	0.3768	0.1029
Turbidity	-0.04060	0.0002
$Turbidity^2$	0.000632	0.0043
Salinity	-0.2759	<.0001
$Salinity^2$	0.007203	<.0001
Temperature	0.3328	0.0003
$Temperature^2$	-0.00764	0.0001

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

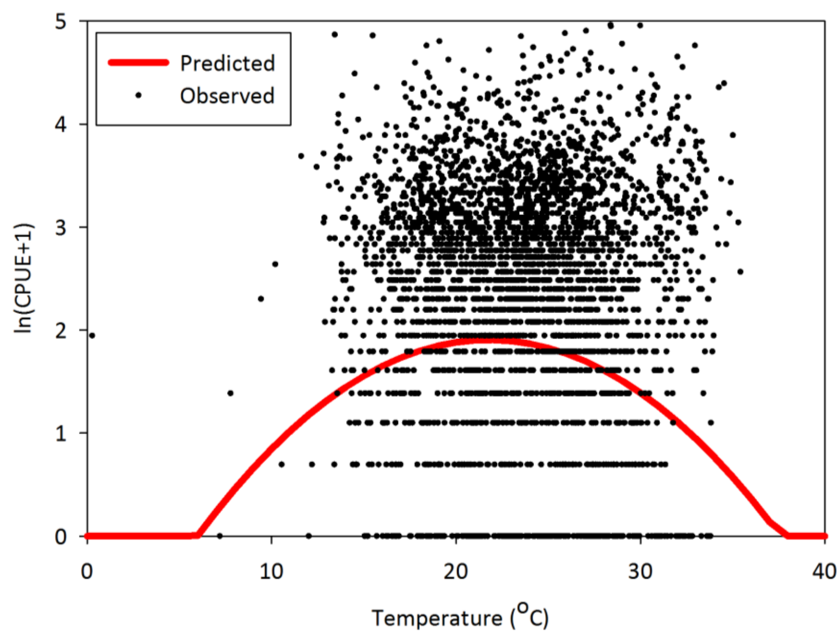


Figure 5: Predicted Output from Polynomial Regression in Equation 1 over the Range of Temperatures Values. Observed values of temperature and ln(CPUE+1) are overlaid.

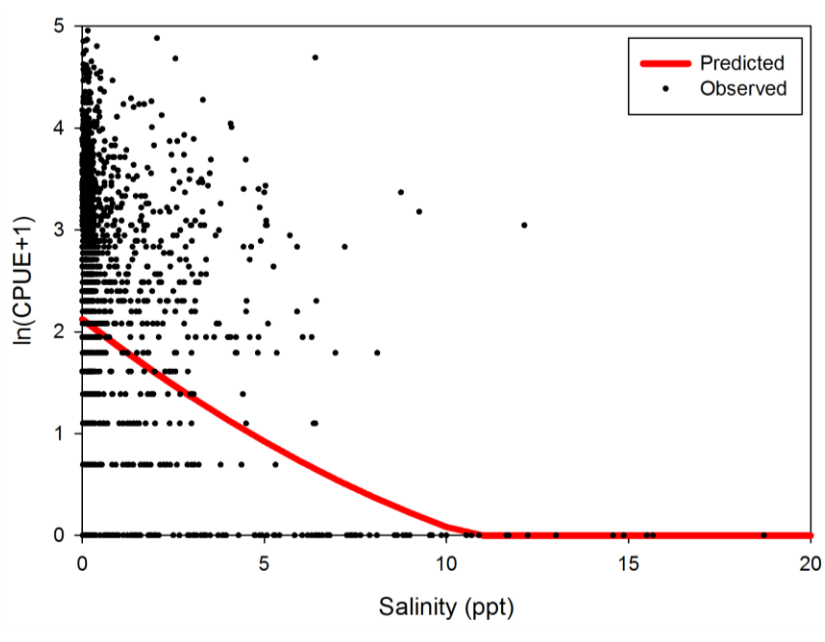


Figure 6: Predicted Output from Polynomial Regression in Equation 1 over the Range of Salinity Values. Observed values of salinity and ln(CPUE+1) are overlaid.

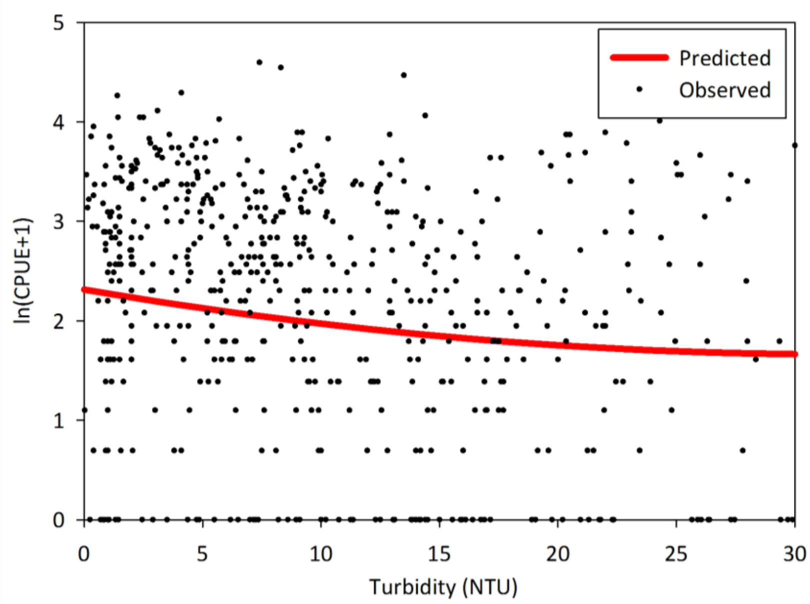


Figure 7: Predicted Output from Polynomial Regression in Equation 1 over the Range of Turbidity Values (in Nephelometric Turbidity Units [NTU]). Observed values of turbidity and ln(CPUE+1) are overlaid.

4.0 Habitat Suitability Index Model for Juvenile and Adult Largemouth Bass

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

A predicted maximum largemouth bass ln(CPUE+1) value of 2.903 was generated from the polynomial regression at a temperature of 22°C, salinity of 0 ppt, and turbidity of 0 NTU. The back-transformed CPUE value (17.225) 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 and submerged aquatic vegetation and a standardized index for Chlorophyll *a* concentration (used as a proxy for prey availability) to produce the HSI model. All three components of the model are equally weighted and the geometric mean is used as all variables are considered essential to juvenile and adult largemouth bass.

$$HSI = (SI_1 * SI_2 * SI_3)^{1/3}$$

Where:

SI_1 – Suitability index for juvenile and adult largemouth bass in relation to salinity, temperature, and turbidity during the months of March through November (V_1)

SI_2 – Suitability index for juvenile and adult largemouth bass in relation to the percent of the cell that is emergent vegetation and submerged aquatic vegetation (V_2)

SI_3 – Suitability index for juvenile and adult largemouth bass in relation to the Chlorophyll *a* concentrations of the cell (V_3)

4.1 Applicability of the Model

The model is applicable for calculating annual habitat suitability index for juvenile and adult largemouth bass (median size about 200 mm TL from Figure 3) from March through November in low-salinity estuarine habitats (e.g., ponds, lakes, bayous) of Louisiana.

4.2 Response and Input Variables

V_1: Salinity, temperature, and turbidity during the months of March through November

Calculate monthly averages of salinity (ppt), temperature (°C), and turbidity (NTU) from March through November:

$$V_1 = 0.8752 - 1.7125(1.99) + 0.3768(4.808) - 0.2759(Salinity) + 0.007203(Salinity^2) + 0.3328(Temperature) - 0.0406(Turbidity) - 0.00764(Temperature^2) + 0.000632(Turbidity^2)$$

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

$$SI_1 = \frac{e^{V_1} - 1}{12.214}$$

which includes the steps for back-transforming the predicted CPUE from Equation 1 and standardizing by the maximum predicted (untransformed) CPUE value equal to 12.214. The suitability index curves that describe the standardized juvenile and adult largemouth bass response (0-1) to individual effects of salinity, temperature, and turbidity are shown in Figure 8 through Figure 10.

Rationale*:* Salinity, temperature, and turbidity are important abiotic factors that can influence the spatial and temporal distribution of largemouth bass within a year. The suitability index resulted from the polynomial regression model that described the fit to the observed catch data in relation to the salinity, temperature, and turbidity measurements taken by the LDWF electrofishing samples. The resulting suitability index predicts salinity, temperature, and turbidity ranges and optimums (Figure 8 - Figure 10) that agree well with the ranges and optimums previously described in the literature for juvenile and adult largemouth bass (Table 1). Largemouth bass are generally found in low salinity environments < 5 ppt, but have also been shown to be tolerant of salinities up to 12 ppt (Peer et al., 2006). Temperature plays a key role in

the success of spawning adults and ultimately egg survival. Previous studies have shown optimum temperatures between 15°C and 30°C (Table 1). Largemouth bass are visual piscivores; thus, high turbidity may limit growth and reproductive success via reduction in foraging success (McMahon & Holanov, 1995).

Limitations*:* The variable 'day' in Equation 1 has been replaced by a constant value equal to the mean day from the analysis (July 18).[2] Holding 'day' constant prevents the variable from contributing to the within- or among-year variation, so that only salinity, temperature, and turbidity can vary within and among years. The salinity suitability index was adjusted to reflect zero suitability for salinity greater than 20 ppt in order to prevent the model from placing the species in high salinity areas. Similarly, the turbidity suitability index was truncated at 32 NTU, such that all predictions at higher turbidity values are equal to those at turbidity of 32 NTU.

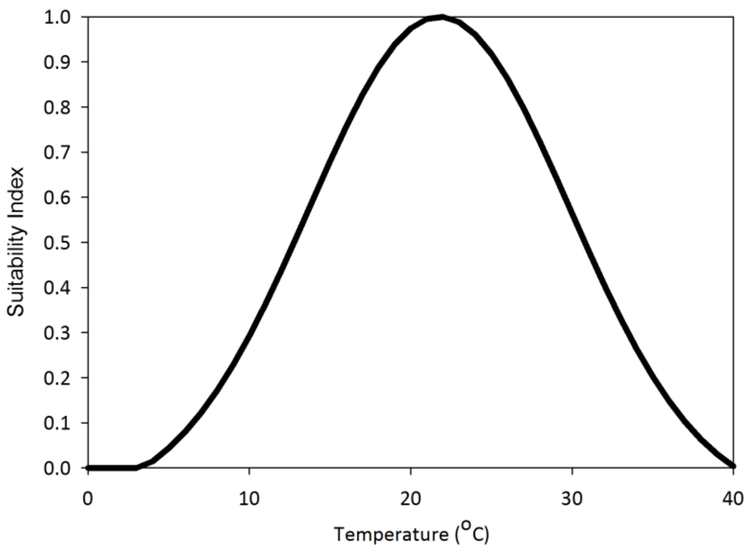


Figure 8: Graph Demonstrating the Predicted Suitability Index (0-1) for Largemouth Bass in Relation to Temperature, with All Other Variables Held Constant at their Optimum Values, and resulting from the Back-Transformation and Standardization of the Polynomial Regression in Equation 1.

[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.

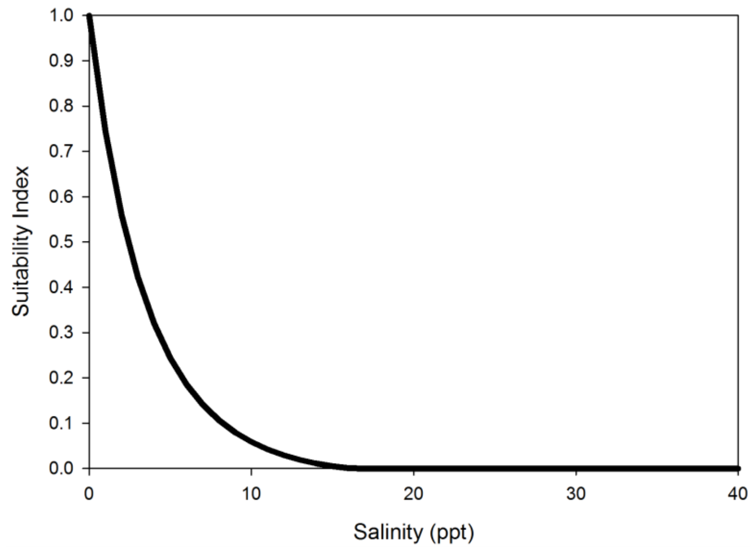


Figure 9: Graph Demonstrating the Predicted Suitability Index (0-1) for Largemouth Bass in Relation to Salinity, with Al Other Variables Held Constant at their Optimum Values, and resulting from the Back-Transformation and Standardization of the Polynomial Regression in Equation 1.

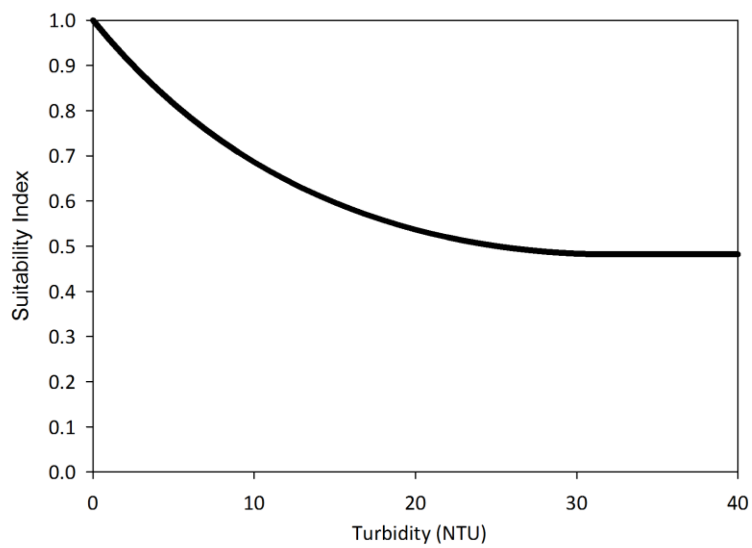


Figure 10: Graph Demonstrating the Predicted Suitability Index (0-1) for Largemouth Bass in Relation to Turbidity, with All Other Variables Held Constant at their Optimum Values, and resulting from the Back-Transformation and Standardization of the Polynomial Regression in Equation 1.

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

Calculate the percent of the (500 X 500 m) cell that is covered by emergent vegetation types and submerged aquatic vegetation combined to derive V_2 for the suitability index (SI_2). The equation for SI_2 is plotted in Figure 11. The index is calculated as:

SI_2 = 0.01	for $V_2 < 20$
0.099 * V1-1.97	for $20 \leq V_2 < 30$
1.0	for $30 \leq V_2 < 50$
-0.0283*V1+2.414	for $50 \leq V_2 < 85$
0.01	for $85 \leq V_2 < 100$
0	for $V_2 = 100$

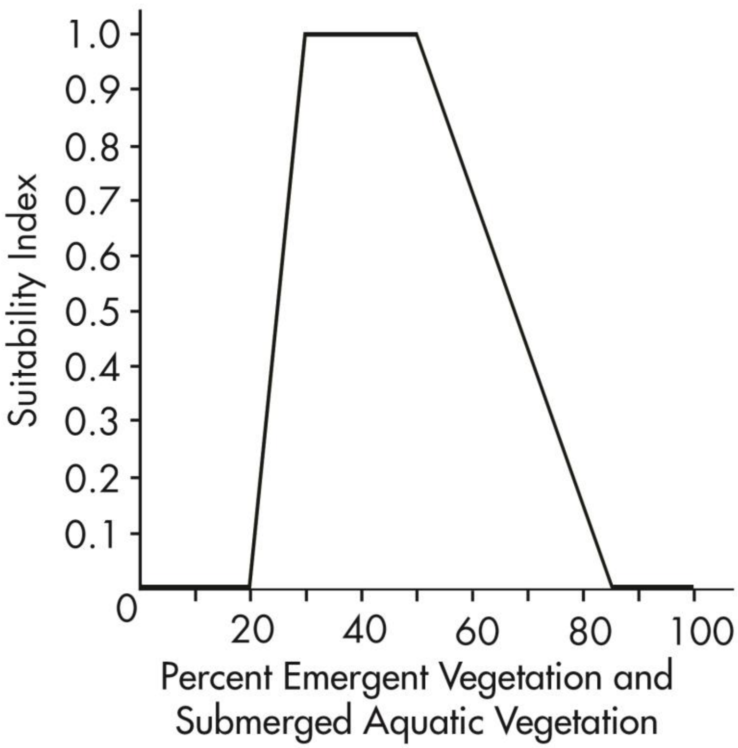


Figure 11: The Suitability Index for Largemouth Bass in Relation to the Percent Emergent Vegetation and Submerged Aquatic Vegetation (V_2).

Rationale: Emergent and submerged aquatic vegetation: 1) provide foraging opportunities for juveniles and adults that feed on insects, fish, and other invertebrates, 2) provide protection to juveniles from larger predators, and 3) may serve as potential spawning habitat for adults. Given that the functions they provide to juvenile and adult largemouth bass are similar, it is recommended the suitability index developed in the 2012 Coastal Master Plan for emergent vegetation (see Appendix D9 in CPRA, 2012), be used to represent both emergent vegetation and SAV. This assumes that the presence of SAV is equal to that of emergent vegetation and that the presence of either (or both) at intermediate levels (i.e., 30-50%) provide suitable habitat. Given that the absence of vegetation does not lead to direct mortality, the minimum suitability index is 0.01. This prevents the overall HSI model from equaling zero when vegetation is absent.

Limitations: None.

V_3: Chlorophyll *a* concentration of the cell

Calculate the Chlorophyll *a* concentration of the (500 X 500 m) cell and substitute V_3 into the suitability index (SI_3). The equation for SI_3 is plotted in Figure 12. The index is calculated as:

$$SI_3 = 0.24 + \frac{0.85}{1 + e^{-\frac{V_3 - 35.75}{7.8414}}}$$

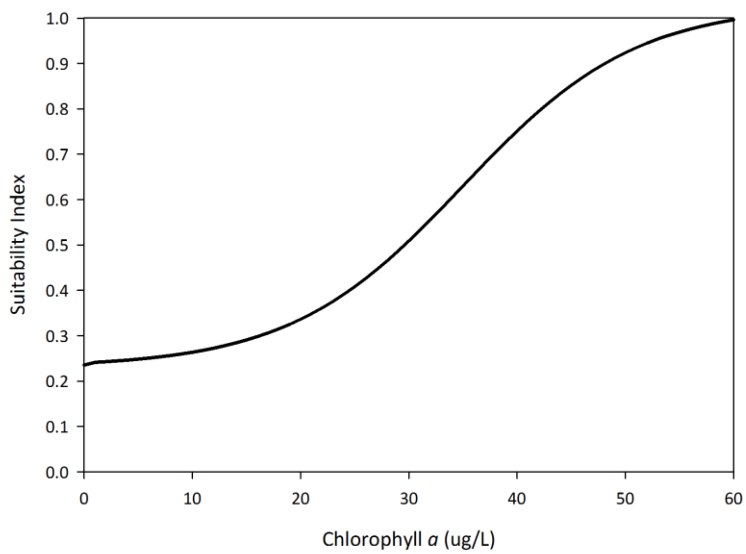


Figure 12: The Suitability Index for Largemouth Bass in Relation to the Chlorophyll a Concentration (Chlorophyll a = V_3).

Rationale*:* The sigmoidal feeding response function best fit the largemouth bass suitability index presented in the 2012 Coastal Master Plan. Increased Chlorophyll *a* concentrations have an indirect effect on juvenile and adult largemouth bass in that it is indicative of high primary productivity and foraging opportunities for largemouth bass prey (e.g., insects, fish, and other invertebrates). As a result, high Chlorophyll *a* concentrations should result in high food availability for largemouth bass. The SI_3 equation was modified from the 2012 Coastal Master Plan to better represent the sigmoidal shape of the curve; however, the overall relationship remains largely unchanged. No additional literature and data for which to make further improvements were available.

Limitations*:* The relationship assumes that largemouth bass habitat suitability is directly related to Chlorophyll *a* concentration.

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 largemouth bass. In order to generate HSI scores across the coast, the HSI model was 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. An accurate representation of algae/phytoplankton in the system was not available as inputs to generate a chlorophyll *a* suitability index (SI) score, and thus SI_3 was held constant at 1 for all model runs. Further, a universal equation applicable to the entire coast could not be generated to convert turbidity (in NTU) to total suspended solids in order to link the HSI model to

the hydrology subroutine. As a result, turbidity was held constant at 0 (i.e., the optimum value in the polynomial equation) for all model runs.

For the largemouth bass model, high scores were observed around low salinity areas with fragmented marsh or SAV, such as those within Barataria, Breton, and the Atchafalaya. Scores were lowest in open water bodies closest to the Gulf of Mexico such as Chandeleur Sound and Terrebonne Bay. 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). Overall, the results of the verification exercise were determined to be accurate representations of largemouth bass habitat distribution in coastal Louisiana.

Although the polynomial regression model used to fit the LDWF electrofishing data produced functions relating largemouth bass catch to salinity, temperature, and turbidity 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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