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**2017 Coastal Master Plan**

# Attachment C3-12: Eastern Oyster, *Crassostrea virginica*, Habitat Suitability Index Model

Report: Final

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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 the 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 the eastern oyster, *Crassostrea virginica,* for use in the 2017 Coastal Master Plan modeling effort.

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# List of Abbreviations

| | |
|---|---|
| CPRA | Coastal Protection and Restoration Authority |
| ICM | Integrated Compartment Model |
| LDWF | Louisiana Department of Wildlife and Fisheries |
| PC | Percent cultch |
| ppt | parts per thousand |
| SAS | Statistical Analysis Software |

# 1.0 Species Profile

The eastern oyster's range extends from the Gulf of St. Lawrence to the Gulf of Mexico and has been introduced in other locations worldwide. Genetic data suggest the populations that extend up the western Atlantic Ocean are separate from those in the Gulf of Mexico, with a transition zone occurring along the eastern coast of Florida (Banks et al., 2007). Oysters reside in shallow, well-mixed estuaries, sounds, bays, and behind barrier islands in brackish to saline waters. Their preferred habitats include intertidal areas, shallow bays, other oyster shells, mud flats and offshore sand bars (Pattillo et al., 1997). Although common in Calcasieu Lake, Sabine Lake, Lake Borgne, and Lake Pontchartrain, oysters are most abundant along the southeastern and south central portions of Louisiana's coast from Breton and Chandeleur Sound to the Atchafalaya and Vermilion bays (Nelson et al., 1992). Their latitudinal distribution within an estuary is largely a function of salinity, freshwater input, depth, and substrate, as shown by Melancon et al. (1998) delineation of "oyster resource zones" in the Barataria and Terrebonne estuaries. Field data indicated that oysters were consistently found from the interface of brackish and salt marsh extending seaward, but when favorable salinities occurred may also extend up-estuary (Melancon et al., 1998).

Oysters are considered relatively tolerant to fluctuating water temperatures, salinities, and concentrations of suspended solids (Stanley & Sellers, 1986); however, sedimentation, physical disturbances (e.g., dredging, altered hydrological regimes), coastal development, and overharvesting have resulted in long-term population losses throughout their distribution (Oyster Technical Task Force, 2012). A recent comparison of historic (1885-1915) and current (2000-2010) oyster abundance showed a decline in both oyster biomass and extent in the northern Gulf of Mexico (Figure 1; Ermgassen et al., 2012). Interannual population declines may also occur due to storm surge and wave action that results in the destruction of oyster reefs, killing of spat and juvenile oysters, or displacement of oysters onto habitats that cannot support them (Banks et al., 2007).

The life stages of oysters are found within different regions or salinity zones of the estuary. Figure 2 summarizes the life stage size, duration, and general movement/habitats to provide an understanding of the timing and general locations of the life stages within the estuary. The relative abundance of each life stage in the upper, middle, and lower regions of the estuary are described by the space-time plot in Figure 3. Regions in Figure 3 are generally defined according to habitat and environmental conditions. The upper region of the 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 middle estuary is comprised of more fragmented intermediate and brackish marsh vegetation with deeper and larger ponds and channels and 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.

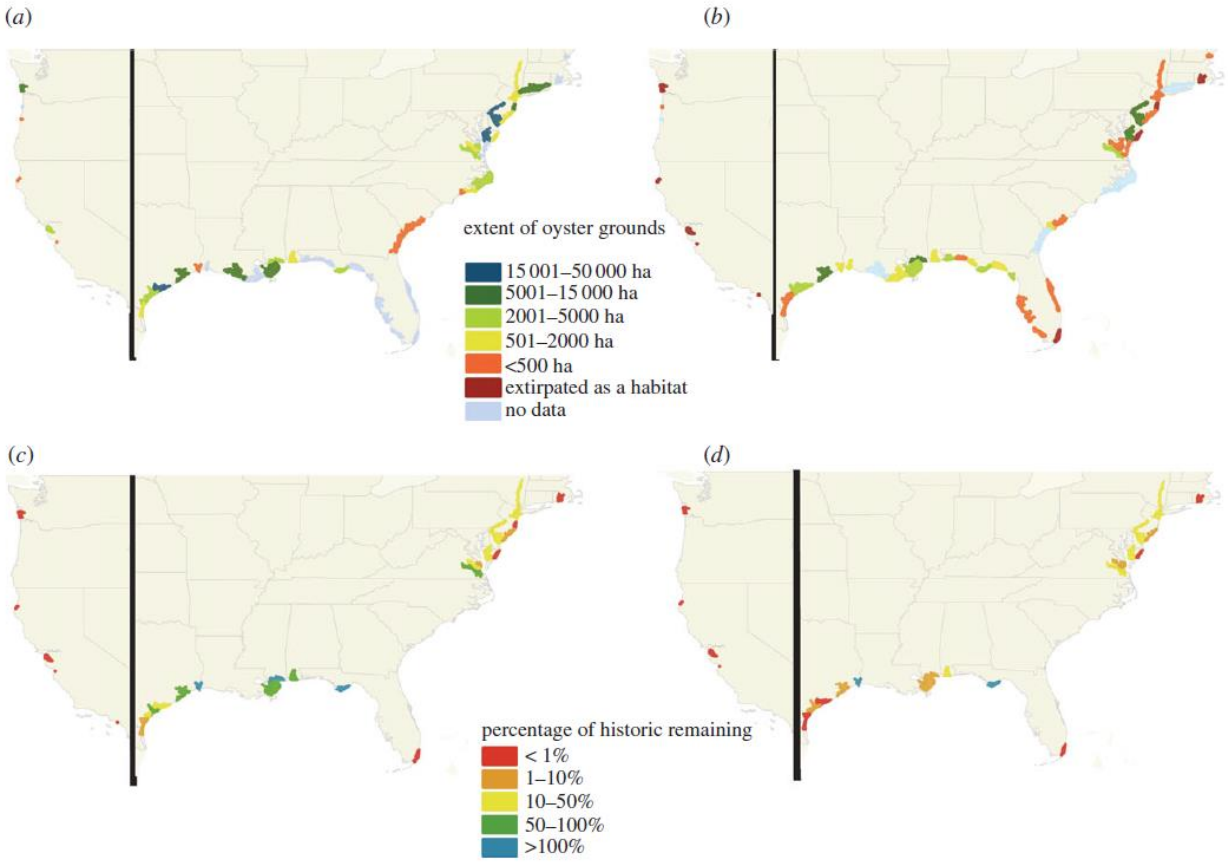


**Figure 1: Maps Illustrating: Oyster Ground Areal Extent (a) Historically and (b) Presently in Estuaries in the U.S. and the Percentage Change in (c) Oyster Ground Extent and (d) Oyster Biomass in Estuaries for which Comparable Historic and Modern Data were Available (from Ermgassen et al., 2012).** Percent change in oyster ground extent or biomass in Louisiana west of the Mississippi River is not indicated because of lack of historical or present-day data for the areas.

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Spawning Adults** | Upper | | | | | | | | | | | | |
| | Mid | | | | | | | | | | | | |
| | Lower | | | | | | | | | | | | |
| **Egg Hatching** | Upper | | | | | | | | | | | | |
| | Mid | | | | | | | | | | | | |
| | Lower | | | | | | | | | | | | |
| **Larvae** | Upper | | | | | | | | | | | | |
| | Mid | | | | | | | | | | | | |
| | Lower | | | | | | | | | | | | |
| **Spat Settling** | Upper | | | | | | | | | | | | |
| | Mid | | | | | | | | | | | | |
| | Lower | | | | | | | | | | | | |
| **Adults** | Upper | | | | | | | | | | | | |
| | Mid | | | | | | | | | | | | |
| | Lower | | | | | | | | | | | | |

**Figure 2: Space-Time Plot by Life Stage for Oysters Showing Relative Abundance in the Upper, Mid, and Lower Region of the Estuary by Month.** White cells indicate the life stage is typically not present, light grey cells indicate the life stage is present but in low abundance, dark grey cells indicate the life stage is present at high abundance (Kilgen et al., 1989; Nelson et al., 1992).

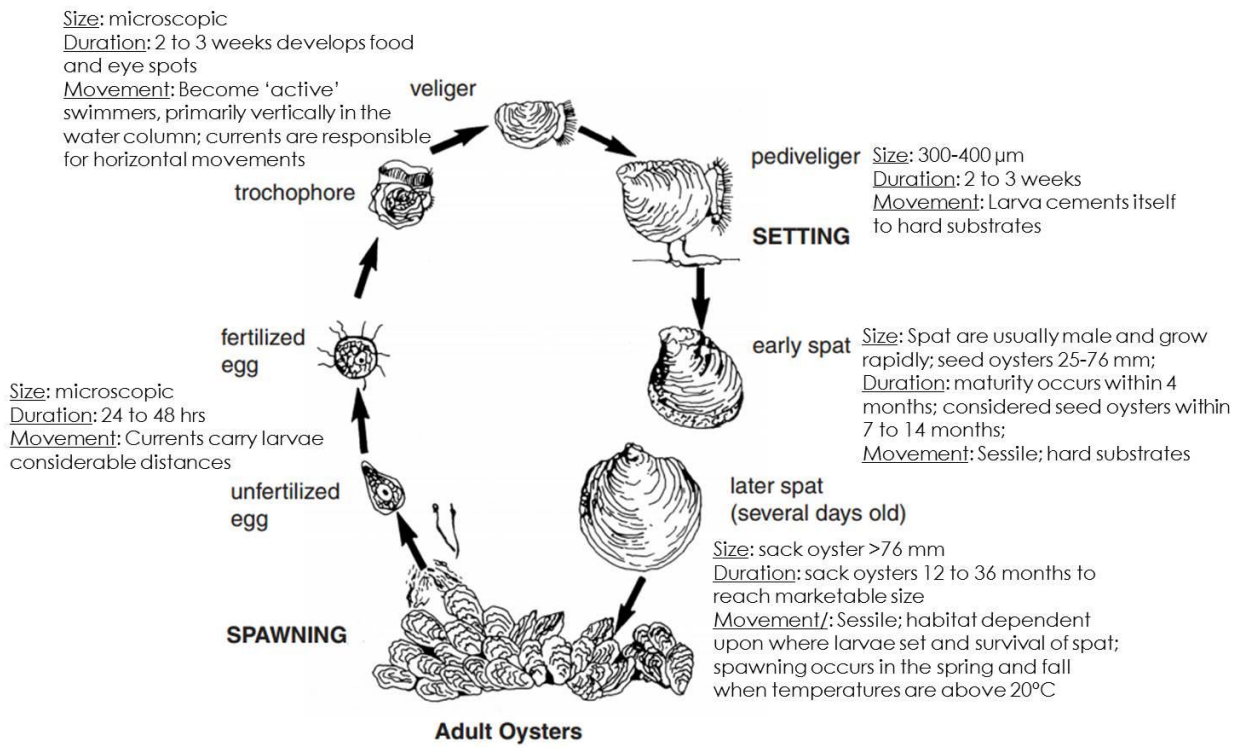


**Figure 3: Eastern Oyster Lifecycle Diagram (diagram modified from Wallace, 2001).**

The life history of the eastern oyster is closely tied to seasonal environmental conditions and availability of food resources. Oysters allocate considerable energetic resources towards reproduction and as a result, experience slower growth rates during spawning (Kennedy et al., 1996). Growth generally increases in August and September after spawning, but temperature, salinity, intertidal exposure, turbidity and availability of food (i.e., phytoplankton density) all play an important role in oyster growth rates.

Temperature and salinity are two key environmental variables affecting every aspect of oyster biology: gonadal development, time of spawning, feeding, growth, respiration, parasite-disease interactions, predation rates, and subsequently their distribution (Shumway, 1996). As a result, most scientific studies of oyster life history focus on relative tolerance and the interactions between temperature, salinity, and oyster biology. In the Gulf of Mexico, spawning occurs when salinities are higher than 10 ppt and water temperatures exceed 20°C, or for mass spawning, above 25°C (Banks et al., 2007; Stanley & Sellers, 1986). Spawning is initiated by males and peaks occur in late May, early June, and September (Stanley & Sellers, 1986).

Oysters undergo several larval stages before becoming sessile. During the larval stages, they are active swimmers (more so vertically than horizontally) and become planktotrophic feeders, feeding on small plants and animals. Prior to settling, the larvae undergo morphological changes and develop a foot used for locomotion and selecting a substrate (Kennedy et al., 1996). Larval distribution and retention is generally believed to be a function of both passive processes resulting from prevailing currents and active processes in which larvae exhibit behavioral responses (i.e., swimming) in response to environmental conditions, such as salinity and temperature (Dekshenieks et al., 1996). Shells or other firm substrates are preferred as attachment sites. Spatfall generally peaks from May through August, with the rise in water temperatures (Kilgen et al., 1989). Spat mortality is density-dependent but it is also influenced by tidal zonation and salinity regimes (Oyster Technical Task Force, 2012).

Adult oysters live in aggregations on reefs or beds and their distribution is a function of where the larvae settle and the survival of spat. Competitors for space on substrate include slipper shells, jingle shells, hooked mussels, barnacles, and other oysters. Oyster reefs are also prone to numerous predators including black drum, sheepshead, skates, drilling snail, flatworm, blue crab, mud crab, and stone crab (Menzel, 1955) and are susceptible to diseases (Vibrio and Pseudomonas; *Perkinsus marinus*) and parasites (*Nematopsis ostrearum*). Predation rates tend to increase in higher salinities (> 15 ppt) by stenohaline organisms such as oyster drills *Thais haemastoma* (Pattillo et al., 1995). Similarly, the prevalence of the protozoan parasite, *Perkinsus marinus* increases with higher temperatures and salinities (Barnes et al., 2007), typically during the summer months (Oyster Technical Task Force, 2012). Using wavelet techniques to analyze a 10-year time series of disease prevalence and intensity, chlorophyll a, suspended sediments, water temperature, and salinity, Soniat et al. (2005) detected a recurring pattern between El Niño Southern Oscillation events and oyster disease in the northern Gulf of Mexico. The authors concluded that outbreaks of *Perkinsus marinus* in oyster populations can be initiated within six months of a La Niña event.

Although relatively tolerant to fluctuations in salinities, optimum salinities for adults occur between 15 and 30 ppt (Table 1). The promyal chamber traps saltwater and allows the eastern oyster to tolerate wider fluctuations in salinity than other oyster families (Stanley & Sellers, 1986). Tolerance of low salinity is mediated at lower temperatures, but as temperatures increase, tolerance diminishes (Pattillo et al., 1995). Maturation rates decrease when salinities drop below the optimum (Pattillo et al., 1995).

**Table 1: Habitat Requirements for Eastern Oyster Life Stages.**

| Life Stage | Salinity[1] (ppt) Optimum (Range) | Temperature[2,3] (°C) Optimum (Range) | Depth[2] (m) Optimum | Substrate[2] Optimum | Flows[2] Optimum |
|---|---|---|---|---|---|
| Spawning | 13-20 (2-40) | 25-30 (20-30) | - | - | - |
| Egg Hatching | 10-22 (7.5-34) | - | - | - | - |
| Larvae/ Pre-Juvenile | 8-15 (5-39) | 25-30 (20-30) | 0.5-3 m | Oyster shells, calcareous remains of other mollusks, wooden material, rocks, gravel, and solid refuse | 500-2,500 cfs (>4,000 cfs will restrict larval settlement) |
| Juvenile | 8-15 (2-43.5) | - | - | | - |
| Adults | 15-30 (2-43.5) | 20-30 (1-49) | 0.5 – 3 m | | - |

[1] Pattillo et al., 1995; [2] Barnes et al., 2007; [3] Stanley and Sellers, 1986)

# 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. LDWF samples oysters using 24 in wide dredges and square-meter quadrat gears. The dredge samples are currently collected on public oyster grounds within the basins once per month in January, February, March, April, August, November, and

December and then twice per month in May, June, September and October, but the samples are not an indicator for relative abundance or density but rather used to non-quantitatively characterize recruitment and size distribution of the oysters (oysters classified as: spat, seed, or sack; LDWF, 2002). The quadrat samples provide a measure of oyster density collected annually typically in July at several sites along the public oyster grounds within each basin. As a result, oyster density collected in the quadrat sampling was determined most appropriate for developing an improved Habitat Suitability Index (HSI).

Associated with quadrat sampling, LDWF also measures water temperature, salinity, dissolved oxygen, pH, redox, and turbidity at a depth of one foot off the bottom. Given that these variables are only collected once per year, they represent site conditions at that point in time and not necessarily representative of the environmental conditions year round. However, LDWF also measures water temperature and salinity at the top and bottom of the water column during the marine finfish and groundfish/trawl sampling throughout the year. This coast wide dataset possesses a period of record of at least as long as the oyster dataset and provides an opportunity to characterize site conditions near oyster grounds throughout the year. The salinity and temperature data from the marine finfish and groundfish/trawl sampling program were restricted to those samples taken within a 5 km radius of the oyster sampling. Samples were initially restricted to those less than 1 km, but this greatly reduced the number of available stations and limited the ability to statistically test for significant species-environment relationships. Although this distance presents a limitation in terms of detecting finer-scaled changes in salinity and temperature, the interest of this analysis was to capture general site conditions on a seasonal and annual scale.

Key factors in determining oyster abundance are the presence of suitable cultch, salinity, and temperature. The presence of oyster drills or the occurrence of parasitism is also a critical factor in oyster survival but may be implicitly characterized by salinity. The HSI used in the 2012 Coastal Master Plan included mean salinity during the spawning season, minimum monthly salinity, mean annual salinity, suitable cultch, and wetland habitats in order to restrict the HSI to open water areas (see Appendix D13 in CPRA, 2012). Temperature was not explicitly included in the previous HSI model, but is a critical variable that triggers spawning and promotes spat settlement. This analysis investigated the derivations of salinity used in the 2012 Coastal Master Plan, as well as temperature.

The period of record for LDWF quadrat oyster sampling dates back to as early as 1980 for Barataria and Terrebonne basins. The analysis was limited to collections taken during the summer months (June-August; Figure 4). Salinity and temperature measurements collected at the top and bottom of the water column were averaged for the analysis. If multiple measurements were available within 5 km of the oyster sites, the samples were averaged. Mean salinity during the spawning season was calculated from May – October and lagged such that spawning conditions at year *n* would be used to predict oyster density at year n+1. Similarly, mean annual and minimum monthly temperature and salinity were derived from July of year n to June of year n+1 in order to predict oyster density of year n+1.

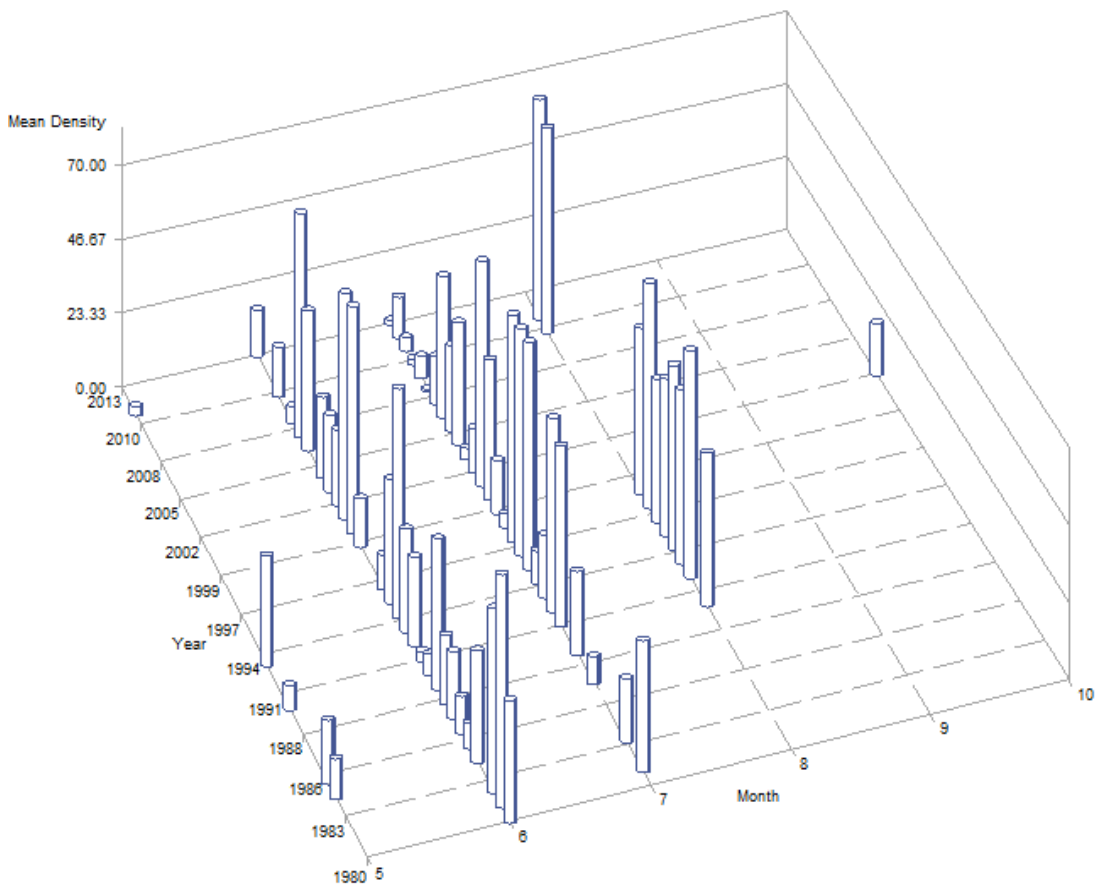


**Figure 4: Mean Density of Oysters by Month for Each Year in the Square-Meter Quadrat Samples.**

# 3.0 Statistical Approach

The statistical approach was developed to predict mean density 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 the eastern oyster would have identified an alternative approach.

The species density data were transformed using ln(density+1). 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 oysters may respond nonlinearly to salinity and temperature. 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 density, 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 ($p<0.05$).

# 4.0 Results

The resulting polynomial regression model from the analysis describes mean summer oyster density only in terms of mean annual salinity (Equation 1; Table 2). No other variables were significant. The general trend of the relationship supports the suitability index curve developed in the 2012 Coastal Master Plan with highest oyster densities occurring near 18 ppt (Figure 5). Oyster densities begin to decline as salinities increase, although at a slower rate than the 2012 HSI. Few data exist beyond 20 ppt so the model should be cautiously applied at salinities greater than 20 ppt.

$$\ln(density + 1) = 1.4086 + 0.3353(Salinity) - 0.0096(Salinity^2) \quad (1)$$

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

| Selected Effects | Parameter Estimate | p value |
|---|---|---|
| Intercept | 1.5245 | < 0.0001 |
| Salinity | 0.1733 | 0.0002 |
| Salinity$^2$ | -0.00490 | 0.0049 |

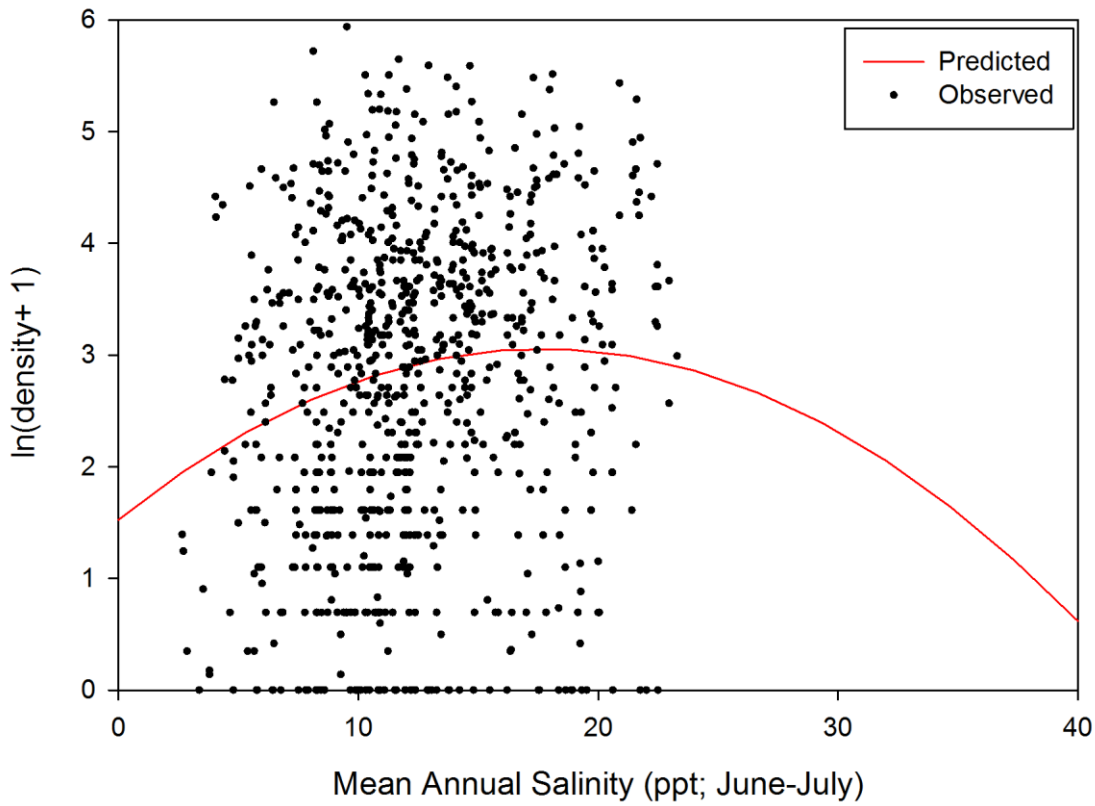


**Figure 5: Relationship of Oyster Density and Mean Annual Salinity.**

# 5.0 Habitat Suitability Index Model for Eastern Oyster

The preceding analytical approach was developed as part of a larger effort to improve the habitat suitability index models for several fish and shellfish species of interest. However, the analysis did not detect a significant effect of spawning season salinity and temperature or annual minimum salinity and temperature on oyster density, due in part to the limitations of the salinity and temperature data previously described and due to the fact that oyster density is only measured once a year. More frequent oyster density measurements along with continuous

measurements of salinity, temperature and other key water quality parameters known to impact oyster survival should be conducted to derive a new HSI for the future. As a result, it is recommended that the model used in 2012 be carried forward to the 2017 Coastal Master Plan given that the model includes additional variables known to influence oyster density in coastal Louisiana. A description of this model follows:

$$HSI = (SI_1 * SI_2 * SI_3 * SI_4 * SI_5)^{\frac{1}{5}}$$

Where:

$SI_1$ = Suitability index for eastern oyster in relation to percent cover of cultch ($V_1$)

$SI_2$ = Suitability index for eastern oyster in relation to mean salinity during the spawning season (mean monthly May through September; $V_2$)

$SI_3$ = Suitability index for eastern oyster in relation to the minimum monthly mean salinity ($V_3$)

$SI_4$ = Suitability index for eastern oyster in relation to mean annual salinity (grand mean of the monthly mean salinities; $V_4$)

$SI_5$ = Suitability index for eastern oyster in relation to percent land ($V_5$)

## 5.1 Applicability of the Model

This model is applicable for calculating an annual habitat suitability index for the eastern oyster in water bottoms of coastal Louisiana.

## 5.2 Response and Input Variables

The section below was extracted from Appendix D13 in the 2012 Coastal Master Plan. For additional details on the model, the reader should refer to CPRA (2012).

**$V_1$: Percent of the bottom within the cell that is covered with cultch**

Suitable cultch is expressed as the percentage of the bottom covered (PC) with hard substrate (e.g., oyster shell; Figure 6). A percent land variable restricts oysters to aquatic model grid cells and includes or excludes them from others as land is lost or built. Unlike the salinity values that change with each model run (i.e., each year), grid percent coverage with cultch is typically the same for all model runs (and years). Changes in the static cultch file are, however, allowed in three special conditions. 1) Reef projects that add cultch to the bottom. Grids can be modified to reflect the new conditions. Grids are assigned PC values according to project specifications or outcomes. This exception allows for the inclusion of restoration projects such as reef building to enhance oyster habitat. 2) Manipulations of the cultch grid to allow for identification of potential for oyster habitat if salinity is suitable. Artificially setting a PC value in selected grids (in addition to the static PC file) and calculating the HSI value provides a tool for locating areas for reef projects such as those described in 1) above. 3) Allowances for land loss (newly created open water areas) to become suitable oyster habitat, by implementing model code changes that incorporate percent land. The default PC for newly created open water is 0%, but can be adjusted for scenarios incorporating proposed reef construction (as in special condition 1 above) or for selecting locations for reef construction (as in special condition 2 above).

$SI_1$ =

$0.04*V1$ for $V_1 \leq 10$
$0.02 *V_1+0.2$ for $V_1 \leq 30$
$0.01*V_1+0.5$ for $V_1 \leq 50$
1 for $V_1 > 50$

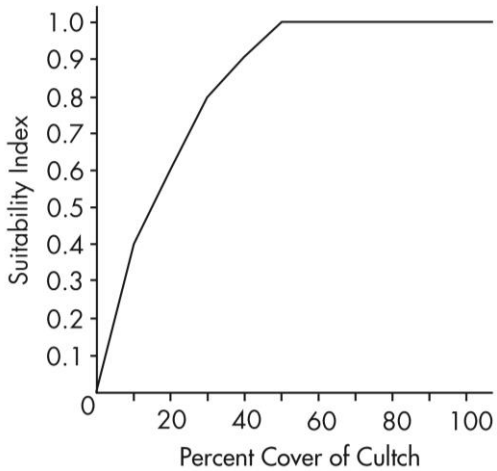


**Figure 6: The Suitability Index for Eastern Oyster in Relation to the Percent Cover of Cultch ($V_1$).**

**$V_2$: Mean salinity during the spawning season May through September**

Calculate the mean salinity May through September ($V_2$) of the 500 x 500 m cell. This variable reflects the higher optimal salinities required for spawning as opposed to the optimum salinity requirements of adults (Figure 7).

$SI_2$ = 0 for $V_2 < 5$
$0.06*V_2 - 0.3$ for $V_2 < 10$
$0.07*V_2 - 0.4$ for $V_2 < 15$
$0.1167*V_2 - 1.1$ for $V_2 < 18$
1.0 for $V_2 < 22$
$-0.0875*V_2 + 2.925$ for $V_2 < 30$
$-0.04*V_2 + 1.5$ for $V_2 < 35$
$-0.02*V_2 + 0.8$ for $V_2 < 40$

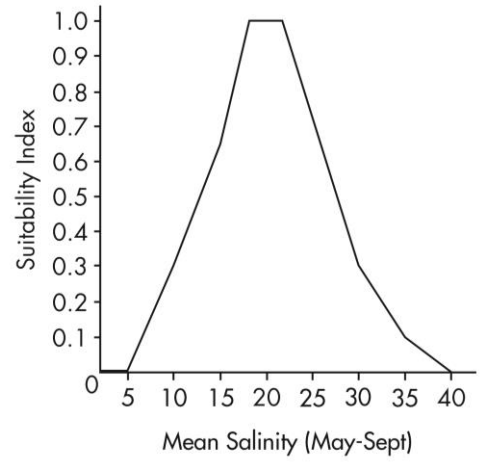


**Figure 7: The Suitability Index for Eastern Oyster in Relation to Mean Salinity May through September ($V_2$).**

**$V_3$: Minimum monthly salinity January through December**

Calculate the mean monthly salinities January through December of the 500 x 500 m cell and use the lowest monthly mean ($V_3$). This variable is a surrogate for frequency of floods in the models of Cake (1983) and Soniat and Brody (1988) and is essential to describe the impacts of freshwater diversions or hydrological alterations (Figure 8).

$SI_3$ = 0.0 for $V_3 < 2$
0.025*$V_3$ - 0.05 for $V_3$= 4
0.225* $V_3$ - 0.85 for $V_3$= 6
0.25* $V_3$ - 1.0 for $V_3 < 8$
1.0 for $V_3 \leq 10$

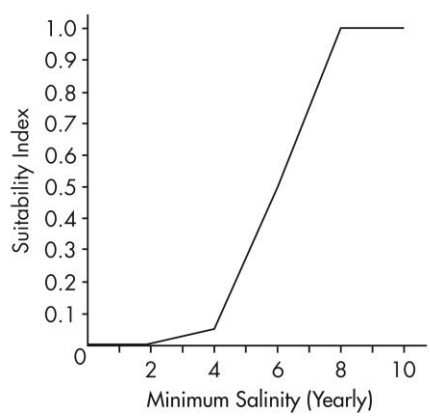


**Figure 8: The Suitability Index for Eastern Oyster in Relation to Minimum Salinity January through December ($V_3$).**

**$V_4$: Mean annual salinity**

Calculate the grand mean of the monthly salinities January through December of the 500 x 500 m cell ($V_4$). Annual mean salinity defines the range over which adult oysters survive (Figure 9).

$SI_4$ = 0.0 for $V_4 < 5$
$0.2*V_4 - 1.0$ for $V_4 < 10$
1.0 for $V_4 < 15$
$-0.08*V_4 + 2.2$ for $V_4 < 20$
$-0.07* V_4 + 2.0$ for $V_4 < 25$
$-0.03* V_4 + 1.0$ for $V_4 < 30$
$-0.01* V_4 + 0.4$ for $V_4 < 35$
$-0.01* V_4 + 0.4$ for $V_4 \leq 40$

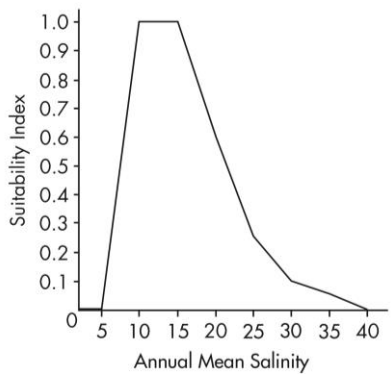


**Figure 9: The Suitability Index for Eastern Oyster in Relation to Annual Mean Salinity ($V_4$).**

**$V_5$: Percent of cell that is covered by land**

Calculate the percent of the 500 x 500 m cell that is covered by land and including all vegetation types ($V_5$). This restricts oysters to aquatic habitats and is used to scale the output (Figure 10).

$SI_5 = (-0.01 * V_5) + 1$

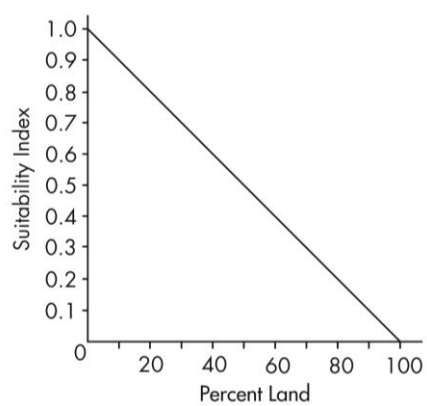


**Figure 10: The Suitability Index for Eastern Oyster as it Relates to Percent Land ($V_5$).**

# 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 oysters. 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.

For the oyster model, high scores were observed around Barataria Bay, west and north of Terrebonne Bay, and southern areas of Calcasieu Lake. Scores were lowest in the northeastern areas of Terrebonne Bay, Vermillion Bay, Little Lake, and southern Breton Sound. Limitations of the model include high uncertainty in cultch cover across the coast, lack of a temperature response curve, and no connections between the previous year's oysters' suitability or long-term salinity trends. Despite these limitations, the model works reasonably well in predicting oyster habitat distribution in coastal Louisiana.

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