**Model Name:** Crawfish Habitat Suitability Index

**Functional Area:** Ecosystem Services / Upper Trophic Level

**Model Proponents:** Coastal Protection and Restoration Authority

**Model Developer(s):** Robert P. Romaire, Aquaculture Research Station and School of Renewable Natural Resources, LSU AgCenter, Baton Rouge, Louisiana

**Please note this is a working-draft document currently undergoing review and revision. The final version will be posted in March 2012 along with the final version of the 2012 Coastal Master Plan.**

# Table of Contents

## 1. *Background*

### a. Purpose of Model

The purpose of this model is to compare the effects of various coastal protection and wetland restoration projects on habitat quality for Louisiana red swamp and white river crawfishes in coastal Louisiana. It was created to provide information to be considered by the State of Louisiana as the 2012 Coastal Master Plan is prepared.

### b. Model Description and Depiction

This crawfish model, prepared for Louisiana's 2012 Coastal Master Plan, is a Habitat Suitability Index (HSI). Habitat suitability indices are used to assess the suitability (potential quality) of habitat for a species but it does not predict either numbers or biomass of the species within the area that is modeled. Habitat suitability indices have a history of development and use in the management of aquatic resources in the USA. Heretofore, an HSI model has not been developed to assess the suitability of wetlands habitat for the Louisiana red swamp and white river crawfishes, two species of significant economic and cultural importance in Louisiana. This crawfish HSI model is the first to assess the suitability of extant and future habitats for red swamp and white river crawfishes. A limitation of the HSI model is that predicted changes in habitat area may or may not translate into actual changes in numbers or biomass of crawfishes because factors other than habitat quality can potentially affect production of crawfishes. The only other published crawfish HSI model that the author is aware of was developed by aquatic ecologists in England to rank stream habitat refugia sites for relocating populations of white-clawed crawfish (crayfish) *Austropotamobius pallipes* from endangered stream habitats (Watson and Rogers, 2003).

The Crawfish Habitat Suitability Index Model (Crawfish HSI) assumes that the habitat quality for red swamp crawfish (*Procambarus clarkii*) and southern white river crawfish (*Procambarus zonangulus*) is affected by five variables: salinity, water temperature, water depth, vegetative habitat type and water level fluctuations during summer-early fall and late fall-winter-spring. Crawfish can physiologically tolerate reasonably high concentrations of salt (dissolved mineral concentration or total dissolved solids) but salinity restricts crawfish habitat suitability by affecting food quality and food supply. Water temperature affects growth rate and reproductive capacity, and extremes in high water temperature can potentially decrease survival by reducing water dissolved oxygen content. Procambarid crawfishes are usually found in highest abundance in relatively shallow waters of less than 1 meter in depth. Deeper waters, particularly during summer and early fall, can adversely affect crawfish abundance by increasing fish predation and reducing the area of edge-substrate (water-land interface area) required for crawfish burrowing, an essential requirement for reproduction. Wetland vegetative habitats are important to crawfish distribution with crawfish most widely found in swamp and freshwater marsh habitats that exhibit significant annual fluctuations in water depth in summer-early fall and late fall-winter-spring. Water level (depth) fluctuation is an important hydrological variable that affects crawfish reproduction and habitat quality. Shallow water in summer-early fall increases the area of reproductive burrowing habitat and mitigates fish predation on reproductively-active female crawfishes. Deeper waters in late-fall-winter-spring expands aquatic habitat for crawfish, particularly in overflow lowland floodplains. Rising river and stream water levels in late winter and spring, from regional rainfall and from winter snowmelt in the middle- and upper-Mississippi River Valley, and its subsequent movement into overflow floodplains generally improves water quality for crawfishes by displacement and dilution of stagnant, hypoxic (low oxygen) waters (Kaller et al. 2011). Hypoxic waters are detrimental to crawfish and other aquatic life in Louisiana's riverine habitats (Bonvillain et al. 2009; Bonvillain et al. 2011).

Each of the five Eco-Hydrology or vegetative habitat variables used in the development of the crawfish HSI model is assigned a dimensionless suitability index (SI) value which varies from 0 (unsuitable) to 1.0 (optimal). The crawfish HSI, which also varies from 0 to 1.0, is calculated as a geometric mean of the SI values; thus, if any component SI is 0 (unsuitable) then the HSI is 0 (poor or unsuitable quality habitat). The crawfish HSI is comprised of three component equations which impact crawfish production: water quality, habitat quality, and reproduction. The component equation for water quality is driven by the SI values for water salinity and water temperature. The component equation for habitat quality (food supply, protective cover, etc.) is driven by SI values for water depth, vegetative habitat type, and water level fluctuation. The component equation for crawfish reproduction is driven by water depth and water level fluctuation in (1) summer-early fall and (2) late fall, winter, spring.

**c. Contribution to Planning Effort**

The State of Louisiana, through the CPRA, is updating the 2007 Master Plan for hurricane protection and ecosystem restoration. The 2012 Coastal Master Plan includes development of modeling tools to predict the effects of long-term protection and restoration projects on habitat for various upper trophic level species of commercial and recreational importance, which includes freshwater procambarid crawfishes. Although the crawfish HSI model developed in this project does not incorporate all environmental variables that potentially impact crawfish habitat, it does have potential application to assess the potential long-term impacts of coastal restoration projects on either improving or degrading crawfish wetland habitats. For example, projects that modify river and stream hydrology (depth, water level fluctuation) in the Louisiana coastal zone with the goal to introduce sediments into subsiding coastal wetlands can potentially degrade crawfish habitat in some areas while expanding crawfish habitat in others. Modification of salinity regimes in Louisiana coastal wetlands from long-term protection and restoration projects can likewise negatively or positively affect procambarid crawfish habitat as changes in salinity alter vegetative habitats that are important food and cover resources for crawfish. The crawfish HSI model can assist coastal planners in determining both potential biological and economic impact of coastal projects on Louisiana wild crawfish fishery.

**d. Description of Input Data**

A 500 $m^2$ grid overlay of the Louisiana coast was created and populated with monthly Eco-Hydrology and habitat class input data. Data from the Eco-Hydrology model needed to drive the Crawfish HSI include: water temperature, water salinity, water depth, and water level fluctuation. Water level fluctuation was defined for two specific periods in an annual cycle: June 1 through November 30 (summer-early fall) and December 1 through May 31 (late fall-winter-spring). Habitat class input data included "bare ground", "fresh", "intermediate", "brackish", "saline", and "swamp" habitats. Habitat classification data were provided by the Vegetation model.

**e. Description of Output Data**

The crawfish model provides an HSI value for each 500 $m^2$ grid for each monthly step-interval over 50 years. A 500 $m^2$ area with an HSI value greater than 0.8 is considered optimal habitat for procambarid crawfishes, and an area with a HSI value of 0.5 to 0.8 is considered suitable to slightly marginal habitat. An HSI value of 0.0 indicates that the habitat is unsuitable.

**f. Statement on the capabilities and limitations of the model**

The HSI value describes the ability of each spatial unit (500 $m^2$ grid) to provide suitable crawfish habiat. In the present model, HSI is calculated in a one-month time step for each spatial unit using modeled input on specific water quality and vegetative variables that were available from the Eco-Hydrology and Vegetation models. The Crawfish HSI in its present form does not consider other potentially important ecological variables that affect habitat suitability, such as dissolved oxygen and sediment substrate, because input data were not available for these two variables. Low oxygen (hypoxic and anoxic) conditions affect survivability of crawfish populations (McClain, 1999) and loosely consolidated sediments high in organic matter can negatively affect reproduction by compromising burrow construction, and subsequent water retention within the burrow (Burras et al., 1995; Burras et al., 1999).

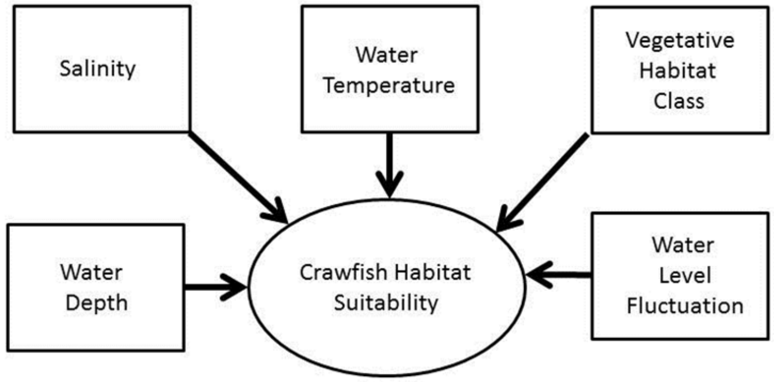
Additionally, the model is potentially limited by the quality of the modeled input data. For example, errors in the model used to predict salinity or water level fluctuation will be transmitted through this model and influence the predicted habitat quality for crawfish. However, these limitations should not influence ranking the effects of various coastal protection and restoration projects according to their effects on habitat quality because the effects of the model limitations would be present and consistent in all model runs.

**g. Description of model development process including documentation on testing conducted (Alpha and Beta tests)**

A habitat suitability index provides a methodology for estimating how various protection and restoration scenarios may affect habitat capacity for key life stages of representative species of fish, shellfish, and wildlife. Habitat suitability is determined by first rating individual suitability indices of environmental or ecological factors (for example, salinity) from zero (0) to one (1) in spatial cells, and then the ratings of multiple suitability indices in each spatial cell are combined to obtain a single value for each cell. The combined values in each cell are then summed over spatial cells to obtain an overall quality-weighted habitat index for the area being studied.

The focus on crawfish model development was for both the juvenile and adult life stages for recreationally and commercially important procambarid crawfishes. The habitat needs and preferences of juveniles are considered because juveniles are usually more sensitive to changes in environmental perturbations. Although this is thought to be the first HSI model developed for procambarid crawfishes, other published HSI models for other shellfish (for example, shrimp and oysters) developed by the US Fish and Wildlife Service were reviewed and served as a starting point for development of the crawfish HSI model.

Personnel with the CPRA provided the modeling team with a list of input variables that would be available for use in model construction. From knowledge of the life history and ecology of procambarid crawfishes in Louisiana and the list of environmental and ecological input factors that were available to construct the model, the following conceptual model for the crawfish HSI was developed.




Conceptual Crawfish Habitat Suitability Model

Details on the how each input factor affects crawfish habitat suitability is discussed in the Section 2a.

## 2. *Technical Quality*

### a. Theory

The red swamp crawfish (*Procambarus clarkii*) and southern white river crawfish (*Procambarus zonangulus)* are the dominant species of commercially and recreationally important crawfishes in Louisiana, comprising nearly all of the commercial harvest (Huner, 2002; Walls, 2009). Numerous biological, environmental, and economic factors affect the amount and value of Louisiana's wild crawfish harvest. Commercial harvest of procambarid crawfishes have averaged nearly 17 million pounds annually over the past 20 years, ranging from a low of nearly 400,000 pounds in 2000 to about 50 million pounds in 1993 (Issacs and Lavergne, 2010). The dockside value of commercial wild crawfish landings (expressed in constant, inflation adjusted 2005 dollars) have averaged $12 million over the same period. Most of the commercial harvest of crawfish occurs in Louisiana's coastal zone south of Interstate-10 (I-10), primarily in the Atchafalaya River Basin.

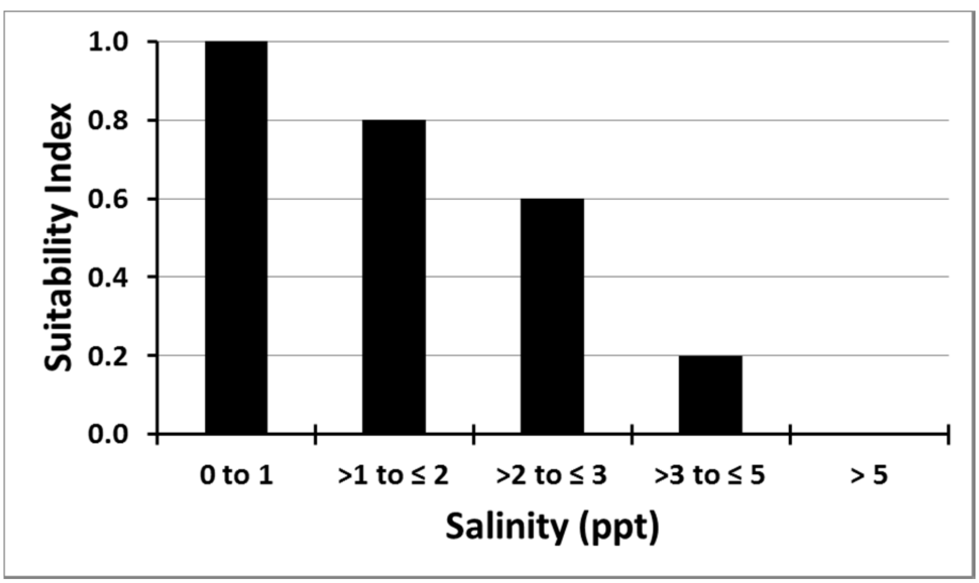
Red swamp and white river crawfishes are tertiary burrowers, and construct simple burrows 1 to 6 feet deep when surface waters recede and/or when females mature and burrow to lay and incubate eggs (Huner, 1995). Females construct burrows at the surface-water interface when preparing to spawn. Burrows must be constructed in water-saturated soils with a sufficient amount of clay to maintain burrow integrity and to prevent desiccation during the period of time that crawfish are confined to the burrow (Huner and Barr 1991). Juvenile and adult crawfish can survive in burrows for as much as 6 months without food. Hatchlings seem to be able to survive 1 to 3 months in burrows depending on temperature. Survival is longer at lower (cooler) temperatures than at higher (warmer) temperatures. As long as a burrow is humid, crawfish can survive in it without free water but crawfish cannot lay and incubate eggs without free water being present. Crawfish close their burrow openings and manipulate the interior surfaces of their burrows to retain water, especially if ground water falls below the bottom of the burrow (Jaspers and Avault, 1969). Newly hatched crawfish remain attached to the females' swimmerets from hatching for about 30-35 days. Juveniles remain with the female until rains or flooded habitats induce their emergence from burrows.

Procambarid crawfishes are adapted to natural cycles of flooding and drought, but are also commonly found in lesser abundance in permanently flooded habitats (McClain and Romaire, 2007; Huner and Konikoff, 2009). Ideal crawfish habitats in natural (non-aquaculture) systems include backwater, slow-moving, cypress-tupelo gum, hyacinth swamps, or natural bayous (Konikoff, 1977; O'Brien, 1977 as cited by Shenoi, 1996). Crawfish production in the Atchafalaya River Basin from fall through spring is positively correlated with elevated (high water) river stages (Shenoi, 1996; Huner and Konikoff, 2009).

<u>Salinity</u>

Variable 1 ($V_1$) is mean monthly water salinity. The value applied is the mean of the monthly water salinity for each 500 $m^2$ grid where water is present. Crawfish are freshwater aquatic invertebrates that have a relatively high tolerance to dissolved mineral content (salinity) in water (Loyacano, 1967a; Loyacano, 1967b; Perry and LaCaze, 1969; Chaney, 1971; Sharfstein and Chafin, 1979; Newson and Davis, 1994; Green et al., 2011). Tolerance to salinity is directly proportional to the size of crawfish. Newly hatched young die at 15 parts per thousand (ppt), and juveniles die at 30 ppt after 1 week of exposure. Salinity affects crawfish reproduction at much lower concentrations (Perry and LaCaze, 1969), but the effect of continuous exposure to low salinity on crawfish reproduction is not fully known. Although crawfish can physiologically tolerate modest concentrations of saline water, areas subject to saltwater intrusion are not conducive to production. Coastal areas with low salinity water usually have highly organic soils that are marginal for burrow construction. In addition, the vegetative food resources on which crawfish depend likely have a much lower tolerance to saline water. Thus, optimal crawfish production is best determined by vegetative habitats in which the long-term tolerance of vegetation is less than or equal to 2 ppt according to the function below.

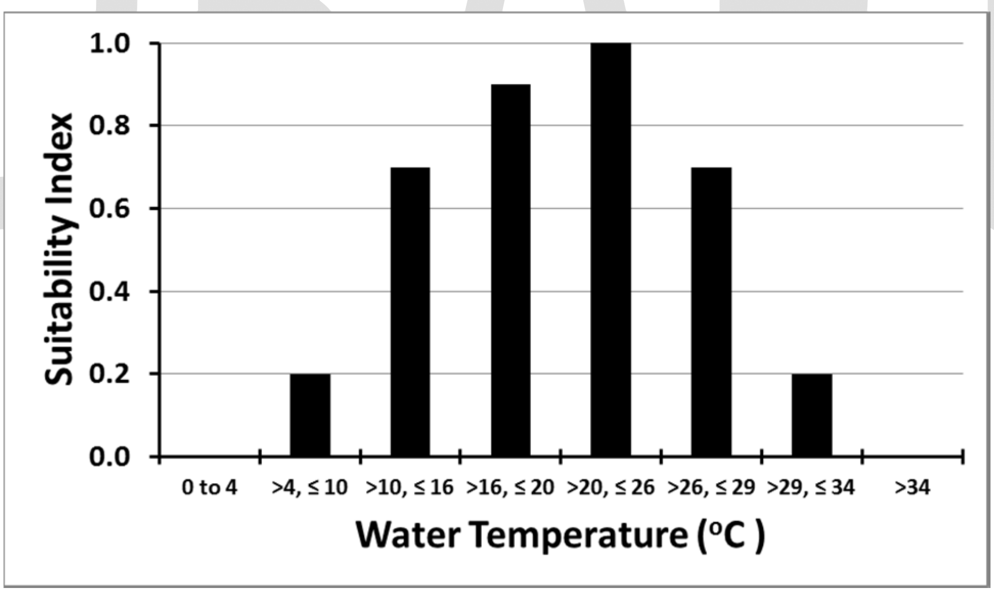
| | | |
|---|---|---|
| $SI_1$ = | 1.0 | for $V_1$ = 0 to 1 |
| | 0.8 | for $V_1$ = > 1 to ≤ 2 |
| | 0.6 | for $V_1$ = > 2 to ≤ 3 |
| | 0.2 | for $V_1$ = > 3 to ≤ 5 |
| | 0 | for $V_1$ = >5 |



Water Temperature

Variable 2 ($V_2$) is mean monthly water temperature. The value applied is the mean of the monthly water temperature for each 500 $m^2$ grid where water is present. The general effects of water temperature on *P. clarkii* and *P. zonangulus* growth and mortality are generally well known (Huner, 1987; Newsom and Davis, 1994; Chen et al., 1995; McClain 2010). Crawfish grow by molting, and molting intervals increase as the crawfish age. Duration of a molting interval is temperature dependent. Molt intervals for crawfish range from around 6 days to 30 days depending on temperature and age. After approximately 11 molts, the crawfish mature and are capable of reproduction. At water temperatures of 75 to 80$^o$F, crawfish can mature in 3 months, but under the normal temperature regime in southern Louisiana, assuming emergence of young crawfish in the fall, it takes 5 to 6 months for crawfish to mature. SI values for water temperature for red swamp and white river crawfish are as follow:

| | | |
|---|---|---|
| $SI_2$ = | 0.0 | for $V_1$ = 0 to 4 |
| | 0.2 | for $V_2$ = > 4 and ≤ 10 |
| | 0.7 | for $V_2$ = > 10 and ≤16 |
| | 0.9 | for $V_2$ = > 16 and ≤ 20 |
| | 1.0 | for $V_2$ = > 20 and ≤ 26 |
| | 0.7 | for $V_2$ = > 26 and ≤29 |
| | 0.2 | for $V_2$ = > 29 and ≤34 |
| | 0.0 | for $V_2$ = > 34 |

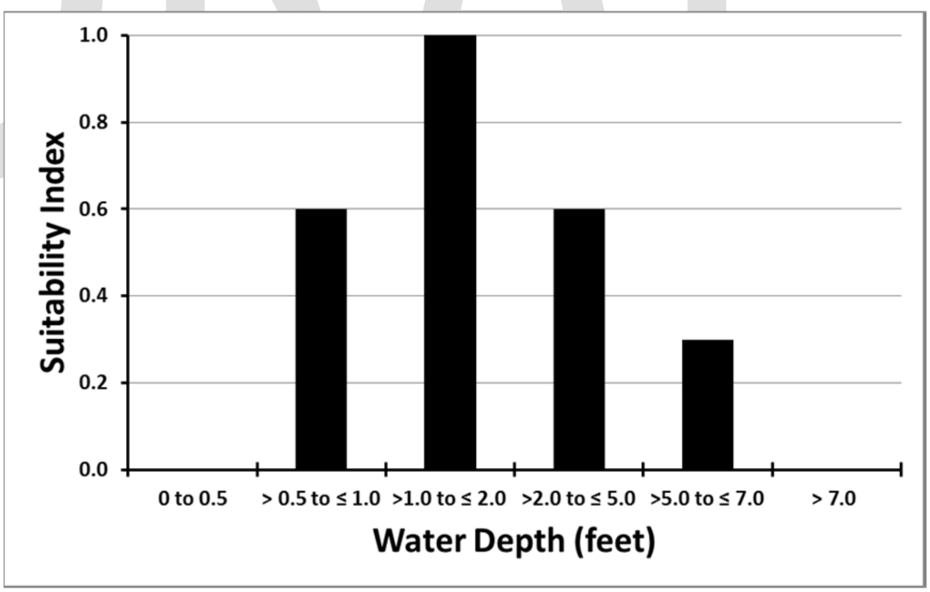



Water Depth

Variable 3 ($V_3$) is mean monthly water depth (feet). The value applied is the mean of the monthly water depth for each 500 $m^2$ grid where water is present. Red swamp and southern white river crawfishes thrive in areas that are periodically flooded and dry (bare ground, no water). Pollard et al. (1983) reported procambarid crawfishes were most abundant in areas of the Atchafalaya Basin where water depth was less than 1 meter (~ 3 feet). Shallow water (less than 1 foot in depth) can reduce crawfish growth in winter because shallow water cools more rapidly than deeper water. Crawfish growth in early summer can be reduced from excessively high water temperature as water levels recede (become very shallow) in riverine floodplains. High water temperatures associated with receding waters are an important environmental cue that stimulates burrowing of crawfish. Crawfish predation from wading birds and mammals are likely higher when water is shallow (Huner and Barr, 1991; Huner and Konikoff, 2009). Because crawfish are benthic animals that reside mostly on sediment substrates, deeper water is also not conducive to optimal crawfish production. In deep water, crawfish are potentially more likely to be subjected to chronic hypoxic and anoxic conditions during warmer months when hydrological conditions do not favor water flow (flushing action) through wetland habitats (Konikoff, 1977; Shenoi, 1996; Kaller et al. 2011). Furthermore, in deeper waters, juvenile and adult crawfishes are more vulnerable to predation by numerous species of freshwater fishes that prey on crawfish (Perret et al., 2009; Huner and Konikoff, 2009). Nearly 40 years of observations by LSU AgCenter biologists show that optimal crawfish production occurs at water depths typically ranging from 1 to 2 feet in depth (Hill and Cancienne, 1975; McClain et al. 2007). Based on review of literature and experience of the crawfish model developer (Romaire) the following suitability index function was derived for water depth (feet).



| | | | |
|---|---|---|---|
| $SI_3$ = | 0.0 | for $V_3$ | = 0 to 0.5 |
| | 0.6 | for $V_3$ | = > 0.5 to ≤ 1.0 |
| | 1.0 | for $V_3$ | = > 1.0 to ≤ 2.0 |
| | 0.6 | for $V_3$ | = > 2.0 to ≤ 5.0 |
| | 0.3 | for $V_3$ | = > 5.0 to ≤ 7.0 |
| | 0.0 | for $V_3$ | = > 7.0 |




<u>Vegetative Habitat Class</u>

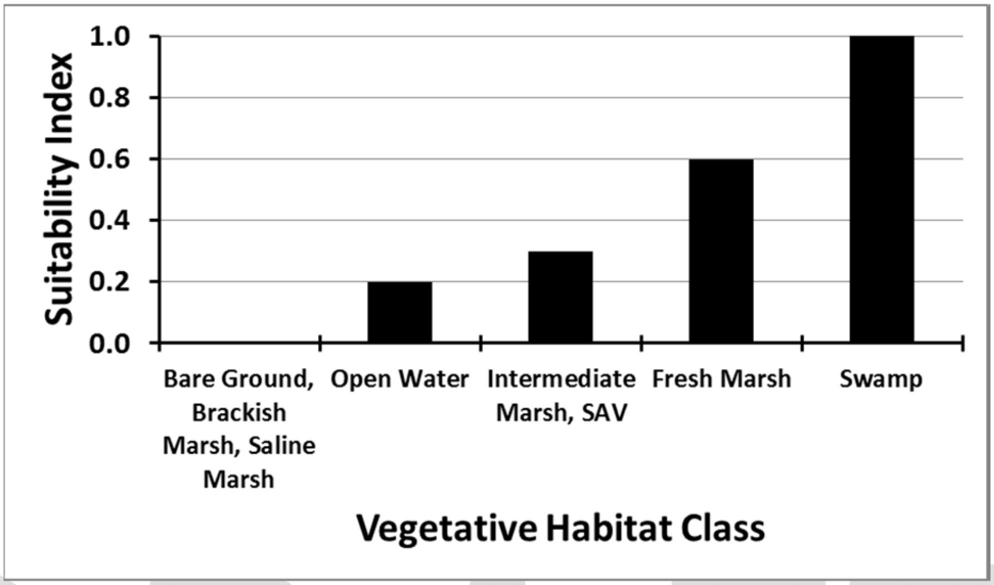
Variable 4 ($V_4$) is vegetative habitat class. The value for $V_4$ is the vegetative habitat class for each 500 $m^2$ grid. Red swamp crawfishes are most widely associated with lentic, swamp /marsh-type habitats (Penn 1943) and southern white river crawfishes are largely associated with more permanent, flowing (lotic) aquatic habitats (Huner 1995). Habitat preference types for red swamp crawfish and southern white river crawfish, as defined by Huner and Konikoff (2009), are summarized as follows in Table 1:

Table 1. Frequency of occurrence (%) for red swamp and white river crawfishes in various wetland habitat types (source: Huner and Konikoff, 2009).

| Habitat Type | Red Swamp Crawfish (% frequency of occurrence) | White River Crawfish (% frequency of occurrence) |
|---|---|---|
| Marshes and Marsh Pools | 35 | 0 |
| Swamps and Swamp Forests | 30 | 9 |
| Ponds and Borrow Pits | 14 | 27 |
| Ditches (mostly roadside) | 12 | 27 |
| Bayous | 8 | 0 |
| Pineland Sloughs and Springs | 1 | 10 |
| Creeks and Rivers | 0 | 25 |
| Other | 0 | 2 |

Despite the similarities of the two species and the overlapping use of habitats, red swamp crawfishes are typically associated with "swamp" habitats and the southern white river crawfishes are associated with "riverine" habitats (Sheppard, 1974; Konikoff, 1977; O'Brien, 1977; Paille, 1980; Pollard et al., 1983; Shenoi, 1996). Both species thrive in areas that are periodically flooded and dry (bare ground) as in the overflow swamp habitats of the Atchafalaya River Basin. The majority of wild crawfish commercially harvested in Louisiana are from the swamp habitats of the Atchafalaya River Basin with lesser quantities captured in freshwater marsh habitats. Open water habitats, which are not subject to annual flooding and drying episodes and which have resident populations of fishes, usually support only small amounts of crawfish because of potentially heavy fish predation. Brackish water and saltwater marsh habitats are not suitable habitats for procambarid crawfishes, and crawfish are excluded from terrestrial (bare ground) habitats. The suitability index function for vegetative habitat class is assigned as follows:

$SI_4$ = 0.0 for $V_4$ = Bare Ground or Brackish Marsh or Saline Marsh
0.2 for $V_4$ = Open Water
0.3 for $V_4$ = Intermediate Marsh or Submerged Aquatic Vegetation (SAV)
0.6 for $V_4$ = Fresh Marsh
1.0 for $V_4$ = Swamp




Because each full 500 $m^2$ grid cell can potentially contain more than a single vegetative habitat class, the following equation weights the vegetative habitat suitability for a mixture of habitat types within an individual cell.

$$SI_{veg} = [0*(\%Bare\ Ground + \%Brackish\ Marsh + \%Saline\ Marsh) + 0.2*\%Open\ Water + 0.3*(\%Intermediate\ Marsh + \%SAV) + 0.6*\%Fresh\ Marsh + 1.0*\%Swamp\ Forest]$$

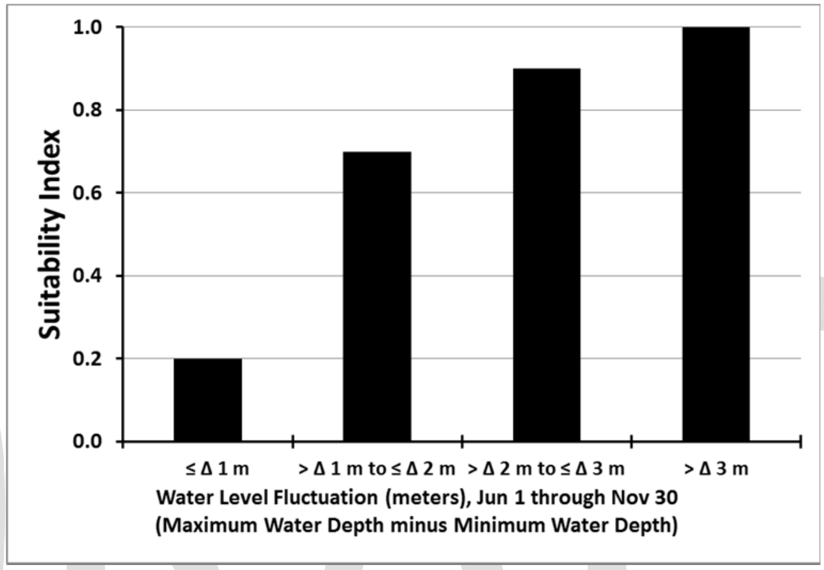
Water Level (Depth) Fluctuation

Variable 5 ($V_{5max}$-$V_{5min}$) is water level (depth) fluctuation. The value is the water level (depth) difference (delta, Δ) between the mean monthly maximum water depth minus the mean monthly minimum water depth for each 500 $m^2$ grid for two distinct periods over an annual cycle: June 1 through November 30 (summer and early fall water level fluctuation); and December 1 through May 31 (late fall through late spring water level fluctuation).

The hydrologic cycle in southern Louisiana that is optimal for production of red swamp and southern white river crawfishes consists of a low water depth or dry (bare ground) conditions during a 3 to 4 month period during the summer and early fall, followed by deeper water conditions during fall, winter and spring (Konikoff, 1977; Pollard et al., 1983; Dellenbarger and Luzar, 1988; Huner and Konikoff, 2009). Low (shallow) water depth, as reflected in part by a higher water level (depth) fluctuations during summer and early fall: (1) significantly increases the amount of reproductive burrowing habitat, (2) permits the growth of vegetation that serves as the base of the food web for the crawfishes when the area floods in late fall/winter, and (3) reduces the predatory pressure of fishes on crawfish populations (Penn, 1943; Konikoff, 1977; Huner and Barr, 1991). As water levels (depth) increase in overflow habitats in late fall and winter in response to rising river levels in the lower Mississippi River watershed, female crawfish are flushed from burrows with their young and the adults and juveniles are dispersed into habitats replete with forage, protective vegetative cover and generally oxygen-rich water. High (deeper) water conditions, as reflected in part by reduced water level (depth) fluctuation during late fall through spring, are generally conducive to good crawfish production (Konikoff, 1977; Huner and Barr, 1991; Huner and Konikoff, 2009).

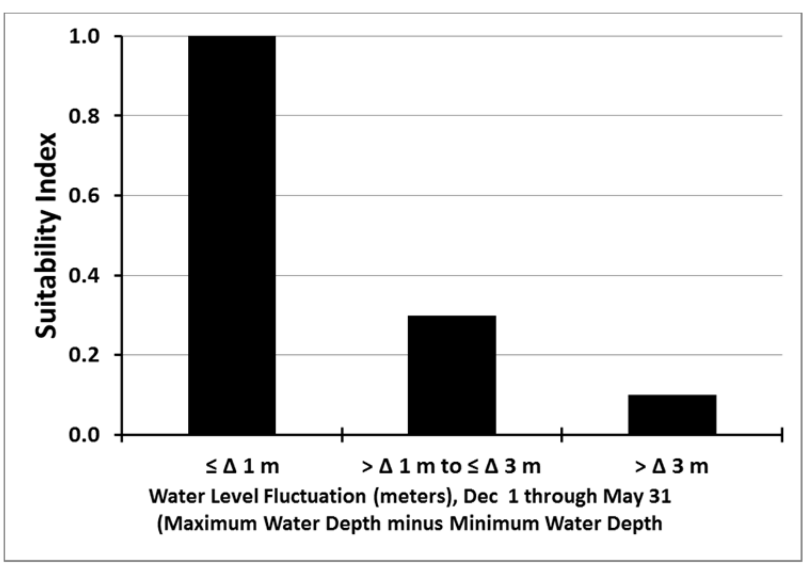
The suitability index function for water level fluctuation (in meters) for summer through early fall (June 1 through November 30) is assigned as follows:

$SI_{5\ (Jun\ through\ Nov)}$ = 0.2 for $V_{5max}$-$V_{5min}$ = ≤ Δ 1 meter
0.7 for $V_{5max}$-$V_{5min}$ = > Δ 1 meter to ≤ Δ 2 meter
0.9 for $V_{5max}$-$V_{5min}$ = > Δ 2 meter to ≤ Δ 3 meter
1.0 for $V_{5max}$-$V_{5min}$ = > Δ 3 meter




The suitability index for water level fluctuation (in meters) for late fall through the following spring (December 1 through May 31) is assigned as follows:

$SI_{5\ (Dec\ through\ May)}$ = 1.0 for $V_{5max}$-$V_{5min}$ = ≤ Δ 1 meter
0.3 for $V_{5max}$-$V_{5min}$ = > Δ 1 meter to ≤ Δ 3 meter
0.1 for $V_{5max}$-$V_{5min}$ = > Δ 3 meter



Component Equations for Crawfish HSI

A monthly crawfish HSI value is calculated for each 500 $m^2$ grid. The HSI is determined as the un-weighted geometric mean of three component index (CI) equations that influence water quality, habitat, and reproduction, all which collectively affect the suitability of an aquatic habitat to support freshwater procambarid crawfishes.

$$\text{Crawfish HSI} = (CI_{\text{water quality}} * CI_{\text{habitat}} * CI_{\text{reproduction}})^{1/3}$$

The HSI determines potential quality habitat if water quality, vegetative, hydrology variables are favorable. A HSI of 1 equals optimal habitat and 0 equals unsuitable habitat.

The component index equation for water quality is driven by the suitability index (SI) values for monthly mean water salinity ($SI_1$) and water temperature ($SI_2$)

$$CI_{\text{water quality}} = (SI_1 * SI_2)^{1/2}$$

The component index equation for habitat, which represents suitability of food resources and potential protective cover from predators, is driven by the suitability index (SI) values for monthly mean water depth ($SI_3$), vegetative habitat class ($SI_4$), and water level fluctuations ($SI_5$).

$$CI_{\text{habitat}} = (SI_3 * SI_4 * SI_5)^{1/3}$$

The component index equation for crawfish reproduction is largely driven by suitability index (SI) values for water depth ($SI_3$) and water level fluctuation ($SI_5$) during:
(1) summer-early fall (June 1 through November 30) and (2) late fall-winter-spring (December 1 through May 31).

Summer-Early Fall $CI_{\text{reproduction}} = (SI_3 * SI_{5\text{ Jun through Nov}})^{1/2}$

Late Fall-Winter-Spring $CI_{\text{reproduction}} = (SI_3 * SI_{5\text{ Dec through May}})^{1/2}$

**b. Description of system being represented by the model**

This model simulates the effects of water salinity, water temperature, water depth, vegetative habitat class and water level fluctuations on habitat suitability for red swamp and white river crawfishes Louisiana over a 50 year time scale within 500 x 500 m cells per year and with and without implementation of different protection and restoration projects.

**c. Analytical requirements**

The Crawfish HSI has the following analytical requirements: water salinity, water temperature, water depth, vegetative habitat class and water level fluctuations within each 500 x 500 m cell per year. The geometric mean of the water quality, habitat, and reproduction components provides the HSI for each cell.

**d. Assumptions**

All suitability index (SI) variables are given equal weight in the calculation of the crawfish HSI.

**e. Identification of formulas used in the model and proof that the computations are appropriate and done correctly**

The model decision rules that were coded are provided in section 2.a. above. Quality review was performed by both the model coders and CPRA to ensure formulas and computations were correct.

### *3. System Quality*

**a. Description and rationale for selection of supporting software tool/programming language and hardware platform**

Building on the ecological modeling application development performed for the Everglades modeling community, Java was used as the programming language inside the Eclipse RCP environment which supports plug-in software development. This approach facilitated the construction of software suites which execute the specific decision rules provided by subject matter experts allowing an end-user to choose which of the ecosystem services models to run.

**b. Proof that the programming was done correctly**

All software products are the result of multiple programmers working in concert. As part of the code development process, code classes are either team developed which ensures multiple individuals real-time code review or when individually coded are spot checked prior to production builds and exports. After final model coding was performed, an independent review was performed to ensure that the model code exactly matched the decision rules contained in the documentation provided to the model coder.

**c. Availability of software and hardware required by model**

The choice of Java as the development platform ensures the broadest execution platform. These software suites can run on desktops with the following operating systems: Windows XP, 7 (32 and 64 bit), Apple OSX (32 and 64 bit), Linux. Furthermore, these Java executables could be easily re-compiled to run on Windows or Linux Application Servers.

**d. Description of process used to test and validate model**

The model was tested prior to production release with fabricated data built according to the data descriptions provided by the various teams. The absence of "real" data made pre-production testing less effective than it could have been had there been high quality test data.

Ideally, model outputs would be validated by comparing the model predictions to observations made in the field but that is not possible with this model. The second best validation is based upon comparison of modeled predictions to what is expected given the known inputs. The latter approach was followed and known spatial patterns and temporal patterns in input were used to predict output patterns for procambarid crawfishes. For example, habitat quality for procambarid crawfishes was projected to be low (ranging from 0 to 0.2) in areas modeled as saline marsh.

**e. Discussion of the ability to import data into other software analysis tools (interoperability issue)**

Being standards compliant with international modeling data standards ensures rather broad interoperability. Unidata actively supports netCDF read/write libraries for C++, Java, C# and Fortran programming languages across multiple operating systems. Additionally, netCDF is natively consumable by commercial software product such as ESRI ArcMAP and MatLab.

Furthermore, the Everglades Joint Ecologic Modeling community has backed a USGS software development effort resulting in EverVIEW which brings an open-source visualization platform solution to the complex realm of binary modeling data.

### 4. *Usability*

**a. Availability of input data necessary to support the model**

All input data are simulated by other master plan models: water salinity, water temperature, water depth, vegetative habitat class, and water level fluctuation. The input files required to run this model are available through the CPRA.

**b. Formatting of output in an understandable manner**

The output data is a suitability index ranging from zero to one that represents the crawfish habitat suitability of a 500 x 500 m model grid cell. The output files are in netCDF format and can be viewed using EverVIEW or ESRI ArcGIS. The output is best comprehended by assigning a color to each grid commensurate with its HSI value.

**c. Usefulness of results to support project analysis**

Coastal zone projects that modify river and stream hydrology (depth and water level fluctuation) in the Louisiana coastal zone with the goal to introduce sediments to re-vitalize habitat lost to coastal land subsidence have the potential to degrade crawfish habitat in some areas while expanding crawfish habitat in others. Modification of salinity regimes in Louisiana coastal wetlands from long-term restoration and protection projects can either negatively or positively affect procambarid crawfish habitat because changes in salinity alter various vegetative habitats that are important food and cover resources for crawfish for commercially and recreationally important crawfishes. The Crawfish HSI can assist coastal planners in determining both potential biological and economic impact on coastal projects on the Louisiana commercial and recreational crawfish fisheries.



**d. Ability to export results into project reports**

The model output is in netCDF format, which provides both a graphical and tabular representation of the model results that can be incorporated into reports. Model outputs can also be imported into ESRI ArcMap.

**e. Training availability**

Training for model usage would be provided through CPRA.

**f. Users documentation availability and whether it is user friendly and complete**

There are currently no user's guides or technical manuals to support the model; however, the model does have a help screen that explains how to convert model inputs into the necessary format as well as which files are necessary to run the model.

**g. Technical support availability**

Access to technical support would be provided through CPRA.

**h. Software/hardware platform availability to all or most users**

The ecosystem services modeling suite, being coded in Java, will run on most operating systems.

i. **Accessibility of the model**
Access to model and associated installation and execution files would be provided through CPRA.

j. **Transparency of model and how it allows for easy verification of calculations and outputs**
Model decision rules are documented in section 2a. Model HSI values must be between zero and one.

## *5. Sources of model uncertainty*

Uncertainty is introduced into model projections by two factors. The first factor is the scientific rigor of the assumptions on how input variables affect habitat quality for procambarid crawfishes. The water quality and general hydrological habitat requirements for red swamp and white river crawfishes in Louisiana are generally well known. However, numerous factors that likely affect crawfish habitat quality have not been thoroughly researched. It is possible that environmental and ecological factors that have a significant impact on overall crawfish habitat quality for procambarid crawfishes were not available as data input to include into in the model, and the research data that was available to use in model development has limitations as to the rigor of the research findings.

Secondly, the highest uncertainty in model output may be associated with modeled input. The water temperature, water salinity, water depth and water stage data used as input to the model were provided by the Eco-Hydrology model, and the inputs are subject to any errors inherent in the modeling process.

An additional area of uncertainly is the inability to determine the relative importance of the various suitability index variables in determining habitat suitability for procambarid crawfishes in coastal Louisiana. Consequently, the current Crawfish HSI gives equal weight to all SI variables in the HSI calculation.

## *6. Suggested model improvements*

The Crawfish HSI could be improved by addition of input variables to account for the effects of hypoxia, fish predation, and substrate sediment type on crawfish habitat suitability. Hypoxia directly affects the growth and survivability of crawfish (McClain 1999) and indirectly affects crawfish production by affecting the survivability of fishes that prey on crawfish. Substrate sediment type can affect the ability of crawfish to construct and maintain moisture in sub-surface burrows constructed during low-water periods. Input data (real or modeled) on dissolved oxygen, substrate-sediment type, and an index of predaceous fish density input data were not available to use in development of the crawfish HSI model.

## *7. Quality review*

Specific QR procedures for the Crawfish HSI to support the 2012 Coastal Master Plan included comparison of modeled predictions with expected outcomes given the known inputs. The modeling team used known spatial and temporal patterns in input to predict habitat quality for each of the species. The spatial pattern of suitable procambarid crawfish habitat in modeled output was compared with commercial procambarid harvest statistics by watershed basin collected via trip-ticket data by the Louisiana Department of Wildlife and Fisheries and results compared favorably. Commercial harvest of crawfish occurred in southern geographic regions of the state showed from modeled HSI output that crawfish habitat was suitable.

## 8. *Uncertainty analysis*

No uncertainty analysis was performed for this model.

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