

## HABITAT EVALUATION IN COASTAL SOUTHWESTERN FLORIDA: A POLICY DECISION MODEL FOR THE BLUE CRAB, *CALLINECTES SAPIDUS*

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**ABSTRACT:** *A stressor response model in the form of a habitat suitability index was created for blue crab to quantify impacts of alternative management actions and to assist managers in policy decisions. The model simulates system response by examining impact of freshwater input into southwest Florida estuaries and is being used to help bring together research and monitoring components within southwest Florida ecosystems as part of the Comprehensive Everglades Restoration Plan. The model uses both a larval-component index and spawning female component index and has been incorporated into a geographic information system to portray responses spatially and temporally to facilitate policy decisions. This habitat suitability stressor response model can be applied at other locations using information from the literature, expert knowledge and available local field data and can be easily modified or refined as additional data becomes available. This study examines four hydrological scenarios: a target flow, 2000 base, and 2050 with and without Comprehensive Everglades Restoration, on the habitat suitability of the estuary for blue crabs. The model indicates that preferred flow frequency distribution and the future conditions with Comprehensive Everglades Restoration Plan have higher habitat suitability values than existing or future without Comprehensive Everglades Restoration Plan conditions.*

**Key Words:** Alternative assessment, blue crab, *Callinectes sapidus*, forecasting model, habitat suitability index, stressor response, Comprehensive Everglades Restoration Plan

HUMAN activity has altered function of natural ecosystems throughout the world (Rapport et al., 1985; Maltby and Dugan, 1994). In areas where impacts are minimal or reversible, natural recovery may be possible. In more heavily-impacted regions, ecological restoration is required. The historic Florida's Everglades, once an expansive and ecologically productive system (Davis and Ogden, 1994), was often described as a free-flowing river of grass (Douglas, 1947). Today, it is fragmented and hydrologically altered (Light and Dineen, 1994; Ogden et al., 2005a; Ogden et al., 2005b), which has led to loss of sheet-flow across the system (Science Coordination Team, 2003) and into estuaries (McIvor et al., 1994), loss of spatial extent (Gunderson and Loftus, 1993), and deteriorated water quality (Ogden et al., 2005a; Ogden et al., 2005b).

The Comprehensive Everglades Restoration Plan (CERP) developed by the U.S. Army Corps of Engineers (USACE) and the South Florida Water Management District (SFWMD) includes a series of restoration projects that focus on the quality, quantity, timing, and distribution of water in the Everglades ecosystem (U.S. Army Corps of Engineers and South Florida Water Management District, 1999). Everglades restoration is a large effort and is being implemented through a series of eight expedited projects, together called Acceler8. The C-43 West Reservoir (an Acceler8 project and a component of a larger restoration effort for the Caloosahatchee River and estuary) focuses on storing regulatory releases from Lake Okeechobee and stormwater runoff. Removing surplus water will reduce excess water flow to the estuary during the wet season and provide essential flows during the dry season. The project will consist of an above-ground reservoir located along the Caloosahatchee River with a maximum storage capacity of 197 million cubic meters (160,000 acre-feet).

The pre-construction effort for such a project involves attaining a series of sequential objectives necessary to arrive at a selected restoration plan (Yoe and Orth, 1996). Two critical objectives of this process are evaluation of alternative restoration plans and comparison of the effects of each alternative. In the evaluation step, each individual restoration alternative is assessed and its effects are quantified and judged. For the C-43 West Reservoir Project, the evaluation protocol chosen here is a forecasting model.

Forecasting models bring together data resulting from research and monitoring studies within ecosystems and place them into an adaptive management framework for evaluation of alternative plans. In an integrated approach that includes both passive and active adaptive management a forecasting model is used to simulate system response for alternative plan evaluation and is validated by monitoring programs to measure actual system response (Barnes and Mazzotti, 2005). Monitoring can then feed back as a passive adaptive management tool for calibration of the forecasting model. Directed research driven by model uncertainties is an active adaptive management strategy for reducing uncertainties in the model (Ogden et al., 2003; Barnes and Mazzotti, 2005).

For the C-43 West Reservoir Project, the forecasting model is a set of habitat suitability models for individual species, which relate stressors to the habitat of each organism. Each forecasting model component is being applied to multiple restoration alternatives with the assumption that, as stress level on the ecosystem changes for each alternative, so will extent and quality of suitable habitat. Another assumption is that habitat suitability is related to distribution and abundance of the species (or life stage) modeled (Klopatak and Kitchens, 1985). This assumption should be tested and models modified as appropriate (Flather et al., 1992).

Criteria for selecting focal species were based on their ecological, recreational, and/or economical importance, as well as their well-established linkage to stressors of management interest (Barnes, 2005). An additional criterion for focal species selection was the relevance of a species to engage the public concern as to the outcomes of restoration projects. The habitat suitability models created for the C-43 West Basin Reservoir Project include the blue crab (*Callinectes*

*sapidus* Rathbun), spotted seatrout (*Cynoscion nebulosus* Cuvier), eastern oyster (*Crassostrea virginica* Gmelin), seagrass (*Thalassia testudinum* Banks & Soland. ex Koenig and *Halodule wrightii* Aschers.), and wild celery (*Vallisneria americana* Michx.). This paper presents the process that was used to develop a habitat suitability model for the blue crab and demonstrates its use for the assessment of restoration alternatives in the Caloosahatchee estuary, Florida.

The blue crab is an estuarine-dependent crustacean that supports a crab-trap fishery in the Caloosahatchee River and estuary (FWC, 1997). Its life history involves a complex cycle of planktonic, nektonic, and benthic stages which occur throughout the estuarine-near-shore marine environment in a variety of habitats. The blue crab is one of the more abundant estuarine macro-invertebrates and supports valuable commercial and recreational fisheries along the Atlantic and Gulf coasts where it plays a crucial role in estuarine food webs, providing prey for many species and is in turn a voracious predator on other species (Laughlin, 1982; Van Den Avyle and Fowler, 1984; Van Engel, 1987; Mansour, 1992).

Blue crabs are a highly prized commodity to consumers. In the state of Florida, fishing effort increased significantly in the 1980's and 1990's while landings have fluctuated (Guillory et al., 2001; Murphy et al., 2001). During 1998–2000, the highest reported landings on Florida's Gulf coast were in Lee County (Murphy et al., 2001). In 2004–05 the number of licensed crabbers in Lee County, Florida was 118 (FWC, 2005a) and in 2004 over 70,300 kg (155,000 pounds) of blue crab were harvested (FWC, 2005b). This fishery expends a large effort and yields large numbers of crabs for local and distant consumers while providing a valuable local economic employment opportunity (Wasno, 2006).

**METHODS—Model development and application—**Habitat Suitability Indices (HSI) used here were developed by choosing specific life stages with the most limited, restricted, or tightest range of suitable conditions, to capture the highest sensitivities of organisms to environmental changes associated with planned restoration activities. Each stressor metric was portrayed spatially and temporally across aquatic systems of the study area at a scale appropriate to blue crabs. The blue crab HSI model was incorporated into a geographic information system (GIS) to portray responses spatially and temporally. As a result, the model was capable of describing a response surface of habitat suitability values that vary spatially according to stressor levels throughout the estuary and temporally according to temporal patterns in stressor variables. Much of the temporal variation observed was caused by the temporal pattern of important stressor inputs, such as water salinity and temperature.

Adult blue crabs tolerate a very wide range of estuarine conditions (Perry and McIlwain, 1986). Therefore, it was determined that limiting variables for successful blue crab habitat are the more restricted conditions necessary for blue crab recruitment. As a result, two components (i.e., larval settlement (megalopae) and spawning females) were chosen to determine habitat suitability of blue crabs recruitment in the Caloosahatchee Estuary. Variables used to estimate habitat suitability for larval settlement were salinity, temperature, and flow. To estimate habitat suitability for spawning females, salinity and temperature were included in the model. Each variable can be weighted ( $w$ ) with regard to importance; however, the sum of the weights must be equal to one.

$$\text{Blue Crab Larval Component Index} = (\text{Salinity}^w * \text{Temperature}^w * \text{Flow}^w) \quad (1)$$

$$\text{Blue Crab Spawning Female Component Index} = (\text{Salinity}^w * \text{Temperature}^w) \quad (2)$$

$$\text{HSI}_{\text{June–October}} = (\text{Larvae Component Index}^w + \text{Spawning Female Component Index}^w) \quad (3)$$

$$\text{HSI}_{\text{March–May, Nov, Dec}} = (\text{Spawning Female Component Index}^w) \quad (4)$$

TABLE 1. Environmental requirements taken principally from peer reviewed scientific literature and used to create HSI curves.

Variable	Value
Blue Crab: Larvae (Megalopae) Salinity	Optimal – $>30\%$ (Costlow 1967) Range – $10\%$ to $40\%$ (Costlow 1967) Most at $>20\%$ (Perry 1975)
Blue Crab: Larvae (Megalopae) Temperature	Optimal – $25^{\circ}\text{C}$ Range – $21.5^{\circ}\text{C}$ – $34.5^{\circ}\text{C}$ (Costlow 1967)
Blue Crab: Spawning Female Salinity	Range $21\%$ – $35\%$ (Costlow and Bookhout 1959; Sulkin and Epifanop 1975; Bookhout et al., 1976; Sulkin et al., 1976; Steele and Bert 1994)
Blue Crab: Spawning Female Temperature	Range $16^{\circ}\text{C}$ – $25^{\circ}\text{C}$ (Steele and Bert 1994)

Values for these environmental requirements were taken principally from peer reviewed scientific literature (Table 1) and adjusted for local conditions using expert knowledge and local data. Adjusted values were then used to create the individual suitability indices (FIG. 1) that drive the model. The suitability indices are represented as line graphs, where the Y axis is in a scale of 0–1 to represent the suitability of each variable value and the X axis is the range of values for the variable being modeled. The values range from 0 to 1 indicates unfit to ideal habitat, respectively.

In the blue crab model, habitat suitability was calculated monthly as the weighted geometric mean of the individual suitability indices for each of the environmental variables. Because the geometric mean is derived from the product of variables rather than the sum (as in the arithmetic mean) and has the property that if any individual variable was unsuitable for species success (i.e., the value of the variable is zero) then the entire index went to zero. An annual index was then calculated as the average (arithmetic mean) of monthly indices. For blue crab recruitment indices, the annual mean was obtained by averaging monthly index values calculated from June through October, corresponding with local spawning and settlement activity in southwest Florida estuaries. Suitable habitat was then aggregated for purposes of reporting into four categories as “poor”, “good”, “better” and “best”. Habitat units are reported both monthly and annually as area of suitable habitat in each habitat category.

Model output was designed to provide information through numerical values as well as visual aids that allow users to rapidly explore and compare mapped results. The user interface was created with flexibility to adjust input and their weighted importance. Versatility allows, for instance, variable weighting for the impact that monthly water temperatures can have on a species habitat. This is valuable because the same temperature may have a different effect on a species habitat affinity during different seasons. The flow component is also capable of change by the user just by entering the total number of maximum flow days per month. Flow is important during the months when larval growth occurs. For example, if there are more than five consecutive days of high flow, then there is an increased likelihood of reduced survivability. Each component can be weighted to give it more or less importance in the calculation of the HSI. With each change in the maximum flow days per month and/or component weight a new simulation is performed, creating a new display. The total HSI value for any location is displayed in chart form and numerically for each individual component by clicking on the displayed map at any location. Users may also view each individual month’s results by selecting the particular month.

Input data for the model came from multiple sources. Salinity data for the HSI models were obtained using an estuary-salinity regression model and a spatial interpolator post processor (Story, 2005). The regression model uses daily flows at the Franklin Lock and Dam structure (S-79), the boundary between freshwater and estuarine portions of the Caloosahatchee River. The regression model is based on 19 fixed sampling stations within the estuary and is post processed into a grid using inverse distance weighting with barriers (Story, pers comm., 2005). This produces a grid of salinity values for different flow

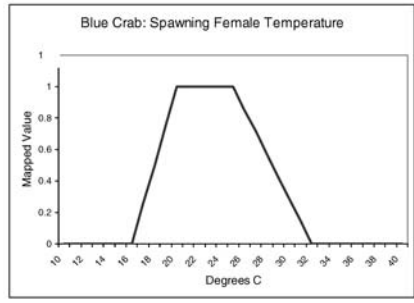
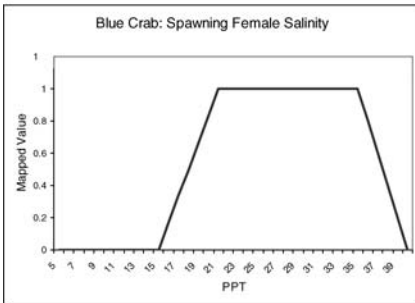
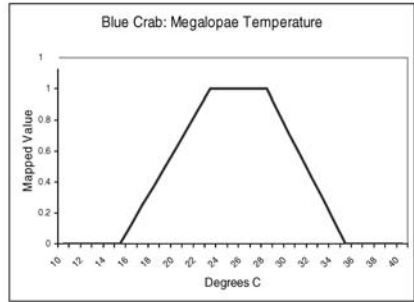
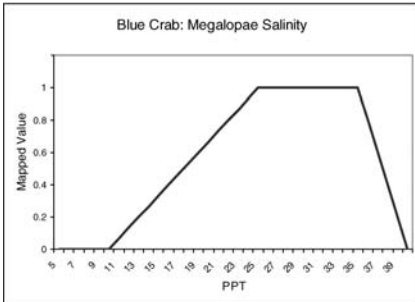
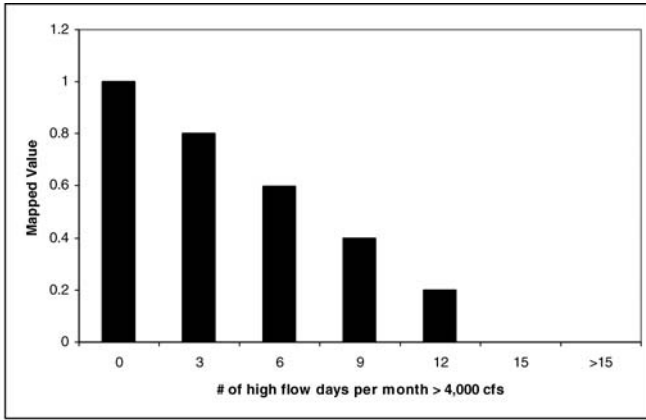


FIG. 1. Suitability index diagrams created for the blue crab using data from Table 1 (adjusted for local conditions).

alternatives. Flow values at S-79 can be obtained from several different regional-scale hydrodynamic models. Substrate, bathymetry, and temperature data were obtained through previous projects (Avineon, 2003; Hansen and Perry, 2003; Tetra Tech, 2004).

Four initial hydrologic scenarios have been evaluated for the C-43 West Reservoir Project. Flow at S-79 was obtained using the South Florida Water Management Model (SFWMM) (MacVicar et al., 1984; SFWMD, 1997), a landscape scale computer model that simulates regional hydrology on a daily basis at a scale of 10.36 km<sup>2</sup> (four square miles; i.e., 2 × 2 model). The SFWMM uses climatic data for the 1965–2000 period of hydrologic conditions which includes drought and wet periods. SFWMM model output was then run through the Caloosahatchee Estuary Salinity Regression Model and Spatial Interpolator Post

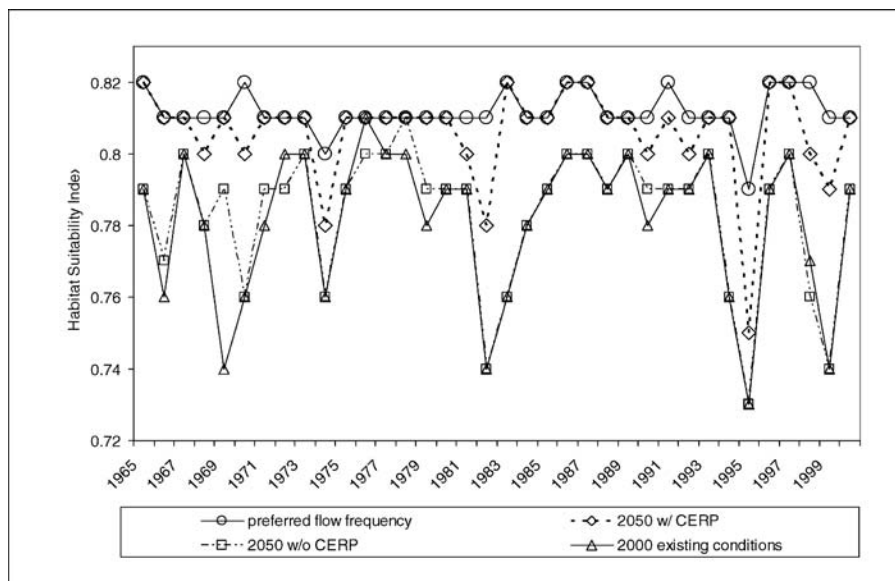


FIG. 2. Modeling results for yearly average blue crab settlement habitat suitability for 20 years comparing the preferred flow frequency for the Caloosahatchee Estuary, the 2000 existing conditions, 2050 condition without the Comprehensive Everglades Restoration Plan projects and 2050 conditions with Comprehensive Everglades Restoration Plan as defined by the Comprehensive Everglades Restoration Plan Final Integrated Feasibility Report (USACE and SFWMD, 1999).

Processor (Story, 2005). Four sets of grids were generated from daily flows at S-79 from the following sources:

- 1) Preferred flow frequency distribution for the Caloosahatchee Estuary (PFF) based on providing a full range of salinity along its longitudinal axis that is supportive of naturally occurring estuarine biota (SFWMD, 2003). This represents a target condition.
- 2) Existing conditions (2000).
- 3) Future conditions (2050) without any Comprehensive Everglades Restoration Plan projects.
- 4) Future conditions (2050) with the Comprehensive Everglades Restoration implemented.

**RESULTS**—The results are displayed in Figure 2. The models have the capability of displaying results as average yearly HSI or average yearly habitat units. For the purpose of this paper, we have used average HSI values. The model indicates that preferred flow frequency distribution and the future conditions with CERP have higher HSI values than existing or future without CERP conditions. Figure 3 is a graphic comparison of the 2050 with CERP and 2050 without CERP, showing average HSI value distribution in the Caloosahatchee Estuary using 1998 hydrology, and with CERP conditions having a higher distribution of “best” HSI values.

**DISCUSSION**—Ultimate selection of restoration alternatives depends on evaluation of a suite of factors including national and regional economic development, cost, real estate, fish and wildlife, cultural resources, and water quality. When

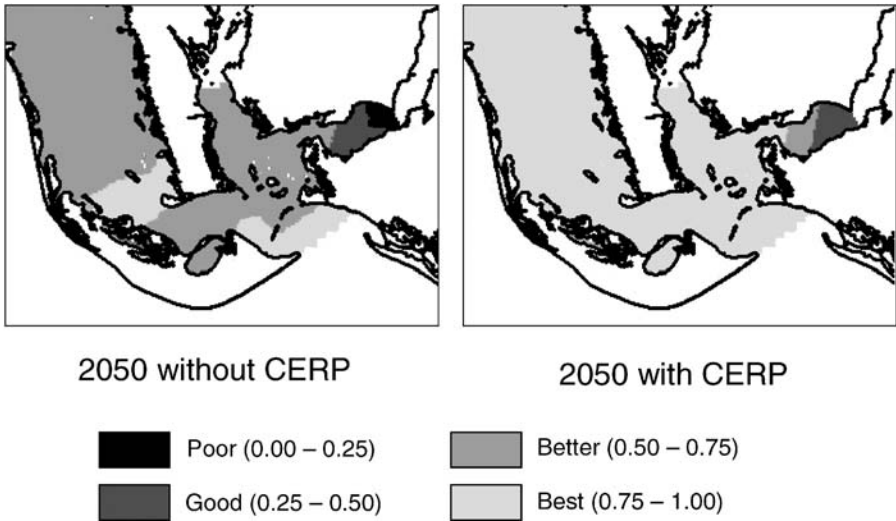


FIG. 3. Comparison of 2050 conditions with the implementation of Comprehensive Everglades Restoration Plan (USACE and SFWMD, 1999) and 2050 condition without the any Comprehensive Everglades Restoration Plan projects. Maps show average habitat suitability in the Caloosahatchee Estuary for hydrology year 1998.

possible, benefits from each alternative should be quantified into appropriate units such as dollars or habitat units (Yoe and Orth, 1996). In many cases, evaluations are made through informal and subjective processes or by using best professional judgment. This can make quantification of benefits difficult. The use of quantifying tools can assist significantly in this process.

HSIs (USFWS, 1981) and other habitat assessment models have become a common methods for environmental evaluations and, in ecosystem restoration projects, are often used as a first approximation toward quantifying relationships between ecosystem changes due to land and water management practices and their effects on specific species (Turner et al., 1995; Mladenoff et al., 1997; Elliot et al., 1999; Curnutt et al., 2000; Larson et al., 2003; Tarboton et al., 2004). More than 150 HSI models were published by the U.S. Fish and Wildlife Service as part of the Habitat Evaluation Procedures; a planning and evaluation technique that focuses on the habitat requirements of fish and wildlife (US Fish and Wildlife Service, 1980).

The series of models created for the C-43 West Reservoir Project build on these and other existing models, when available. For the blue crab, no pre-existing model was identified. A GIS based HIS model for blue crab was created for use in the Caloosahatchee estuary by resource managers. This model has several advantages over previous HSI models in the integration of GIS into the model for easy visualization and the adaptation of HSI values to suit local conditions in southwest Florida.

An advantage of this type of forecasting model is that it can be developed in early stages of a project using scientific literature, expert knowledge, and field data. By optimizing the models to local conditions and physiological adaptations to local

environments, the C-43 blue crab HSI can better capture the sensitivities of organisms in the Caloosahatchee Estuary, and allow managers to better distinguish between and quantify benefits of restoration alternatives. In addition, the incorporation of the C-43 HSIs into a GIS interface makes overall interpretation of results easier for managers and allows them to display details for any specific location within the estuary.

Another advantage of the blue crab model is that it can be easily transferred and applied to other estuaries by incorporating local variables or conditions, collected through monitoring or mapping programs. Using this type of local focus can assist in transforming somewhat generic assessments into a more refined site or project specific analyses.

When choosing restoration alternatives, it needs to be kept in mind that HSI models are only simplifications of reality and that there are limitations to using this type of tool such as:

1. Other factors affecting habitat suitability may have been ignored or omitted due to lack of baseline/input data.
2. HSIs do not predict the population dynamics of the organisms modeled only the quality of their habitat.
3. HSIs only give a snapshot in time (monthly or yearly value) and do not incorporate spatial or temporal aspects of species habitat relations (Turner et al., 1995).

As a result, managers should not depend on HSI models alone for selection of restoration or management alternatives, but should incorporate HSIs with monitoring and research plans. Because different ecosystem indicators can respond to management scenarios or restoration alternatives in different ways and at different times, large scale restoration projects such as the C-43 West Reservoir Project should not depend on results of a single model. Instead, multiple models for a suite of species, with different habitat requirements, response times and scales should be used in conjunction with monitoring and research components.

Model verification, calibration, and validation must also be considered and are often misconstrued. Verification is the internal examination of the model and can be done throughout the model development process. Calibration, in the case of HSI models, can be done by addressing scientific uncertainties within the model through research and adjusting the HSI curves accordingly. Research is a key component of active adaptive ecosystem management (Barnes and Mazzotti, 2005). Scientific uncertainties have been reduced by using peer reviewed scientific literature. Spatial uncertainties, such as grid size or resolution of input layers, may also be present. Uncertainties may also be present where we have used regional data to estimate a local response. This occurs in geographic regions where there is a lack of scientific data on the organism being modeled and may increase with distance from the source data. Validation is the process of using the HSI models to make predictions of how restoration will affect the habitat of a specific species or suite of species, and through monitoring, confirm the predictions. This is the passive adaptive process (Barnes and Mazzotti, 2005). Monitoring results can also be used to fine-tune the HSI graphs.

In the case of the blue crab model HSI, the model does not predict if blue crab settlement is actually occurring, it only examines the suitability of the habitat for settlement at any given point in time. Whether or not settlement is actually occurring is beyond the scope of this model. If it is found through monitoring that they are not, settlement failure then becomes a research question.

Results from four model runs for the blue crab not only show that the preferred flow frequency and 2050 with CERP hydrologic conditions produce higher HSIs, but they also show more consistent HSI value from year to year. Actual blue crab populations are dependent on what has happened in the estuary in previous years; if settlement conditions are poor one year, the following year there may be a decrease in the population of spawning females and in turn a decrease in larvae for settlement (Tagatz, 1965). This may not be apparent in the model results, which strictly look at habitat value for average conditions of the year.

**CONCLUSION**—A HSI model for the blue crab integrated with GIS for visual display was developed. This model is optimized for use in the Caloosahatchee estuary but can be applied to other estuaries by adjusting variable values to mimic local conditions of those estuaries. This model will enhance decision making by resource managers by providing a tool that is based on empirical data rather than informal judgments or professional opinion.

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