Final Report for Technical Assistance for an Ecological Evaluation of the Southwest Florida Feasibility Study

STRESSOR RESPONSE MODEL FOR THE BLUE CRAB, *CALLINECTES SAPIDUS*

By Frank J. Mazzotti, Leonard G. Pearlstine, Tomma Barnes, Aswani Volety , Kevin Chartier, Alicia M. Weinstein, and Donald DeAngelis

Joint Ecosystem Modeling Laboratory

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FINAL REPORT
for

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Introduction

A key component in adaptive management of Comprehensive Everglades Restoration Plan (CERP) projects is evaluating alternative management plans. Regional hydrological and ecological models will be applied to evaluate restoration alternatives and the results will be applied to modify management actions.

Objective

The purpose of this habitat suitability model for the C-43 West Basin Reservoir and Southwest Florida Feasibility Study projects is to portray species responses to changes in environmental variables resulting from restoration activities spatially and temporally to facilitate policy decisions. The intention of the habitat suitability model is not to simulate the life-cycles of the species. Rather, the intent is to estimate numbers of habitat units to serve as a relative basis for comparing management alternatives.

Southwest Florida Feasibility Study

The Southwest Florida Feasibility Study (SWFFS) is a component of the Comprehensive Everglades Restoration Plan (CERP). The SWFFS is an independent but integrated implementation plan for CERP projects and was initiated in recognition that there were additional water resource issues (needs, problems, and opportunities) within Southwest Florida that was not being addressed directly by CERP. The SWFFS identifies, evaluates, and compares alternatives that address those additional water resource issues in Southwest Florida. An adaptive assessment strategy is being developed that will create a system-wide monitoring program to measure and interpret ecosystem responses. The SWFFS provides an essential framework to address the health and sustainability of aquatic systems. This includes a focus on water quantity and quality, flood protection, and ecological integrity.

C43 West Reservoir

The purpose of the C43 Basin Storage Reservoir project is to improve the timing, quantity, and quality of freshwater flows to the Caloosahatchee River estuary. The project includes an above ground reservoir with a total storage capacity of approximately 197 million cubic meters (160,000 acre-feet) and will be located in the C-43 Basin in Hendry, Glades, or Lee Counties. The initial design of the reservoir assumed 8094 hectares (20,000 acres) with water levels fluctuating up to 2.4

meters (8 feet) above grade. The final size, depth and configuration of this facility will be determined through more detailed planning and design.

Forecasting Models

Forecasting models bring together research and monitoring to ecosystems of Southwest Florida and place them into an adaptive management framework for the evaluation of alternative plans. There are two principle ways to structure adaptive management: (1) *passive* by which policy decisions are made based on a forecasting model and the model is revised as monitoring data become available, and (2) *active* by which management activities are implemented through statistically valid experimental design to better understand how and why natural systems respond to management (Wilhere 2002).

In an integrated approach that includes both passive and active-adaptive management, a forecasting model simulates system response to changes in hydrology and other physical and chemical properties of the estuary and watershed expected to occur with restoration. Forecasting models are validated by monitoring programs to measure actual system response. Monitoring can then provide information for passive-adaptive management for recalibration of the forecasting model. Directed research, driven by model uncertainties, is an active-adaptive management strategy for learning and the reduction of uncertainties in the model.

The forecasting models for the C-43 West Reservoir Project and the Southwest Florida Feasibility Study consist of a set of stressor response (habitat suitability) models for individual species. These stressor response models have been developed principally with literature, expert knowledge, and currently available field data.

Habitat Suitability Indices

Habitat Suitability Indices (HSI) models were developed with each stressor variable portrayed spatially and temporally across systems of the study area at scales appropriate to the organism or community being portrayed. The HSI models have been incorporated into a GIS to portray responses spatially and temporally to facilitate policy decisions and the selection of restoration alternatives for each project. That is, the model describes a response surface of habitat suitability values between 0 (unsuitable) and 1 (most suitability) that vary spatially according to stressor levels throughout the estuary and temporally according to temporal patterns in stressor variables. Much of the temporal variation is a result of temporal cycling of important stressor inputs, such as water temperature and salinity. Temporal change for other important variables may not be cyclical, such as rising sea level and increasing land use and fresh water demands in the region. Areas predicted to be suitable and those predicted to be less suitable or disturbed should be targeted for additional sampling as part of the model validation and adaptive management process.

Species selected for modeling (focal species) are ecologically, recreationally or economically important and have a well established linkage to stressors of management interest. They may also make good focal species because they engage the public in caring about the outcome of restoration projects. The habitat suitability models (HSI) were developed by choosing specific life stages of each species with the most limited, restricted, or tightest range of suitable conditions, to capture the highest sensitivities of the organisms to the environmental changes associated with the planned restoration activities. Values used in the models are listed in Table 1.

The models calculate habitat suitability monthly as the weighted geometric mean of the environmental variables identified as important for each model. Because the geometric mean is derived from the product of the variables rather than the sum (as in the arithmetic mean) and has the appropriate property that if any of the individual variables are unsuitable for species success (i.e., the value of the variable is zero) then the entire index goes to zero.

Ecology of the Blue Crab

The blue crab (*Callinectes sapidus*) has a native range from Nova Scotia to northern Argentina. In the Gulf of Mexico, the blue crab's life history is typical of other estuarine-dependent species. Mating may take place year-round (Guillory et al. 2001), but peaks from May through October in Florida when temperatures exceed 22°C (Steele 1979). Mating occurs in brackish areas of the upper estuary. In a study by Steele and Bert (1994) most ovigerous females were captured in water with temperatures between 16°C and 25°C and salinities between 21‰ and 35‰. Sex recognition in blue crabs occurs by visual, chemical, and tactile stimuli. Females mate only once during their lifetime, during her last molt when she is soft. The female crab couples with a male, and is carried beneath him. The male crab stays with the fertilized female to protect her from harm until her shell is hardened. Sperm transferred to the female are used for repeated spawns (Guillory et al. 2001). Males may mate several times during the last three or four growth stages (Truitt 1939).

Female blue crabs are catadromous and after mating, the female blue crab begins a migration back to high-salinity waters to spawn. Fertilized eggs begin development internally, then are extruded out and attached to fine setae under the apron, producing a spongy, lemon-colored egg mass. As the embryonic crabs develop, the color of the egg mass darkens to orange, then brown, and finally black. Eggs hatch in about two weeks.

Spawning occurs when water temperatures begin to rise in the spring and summer (Perry and McIlwain 1986), usually March through September, with peaks in March-April and September (Steele and Bert 1994), and in salinities ≥ 21‰ (Costlow and Bookhout 1959, Sulkin and Epifanoi 1975, Bookhout et al 1976, Sulkin et al 1976). Most female blue crabs spawn at least twice and may produce several million eggs. Females generally return to brackish waters to develop their second sponge (Targatz 1968, Adkins 1972) but after the second spawn female crabs will usually return to higher salinity water for the remained of their life (Tagatz and Frymire 1963, More 1969).

Salinity is a dominant factor affecting hatching, larval development, and survival (Costlow and Bookhout 1959). Optimal salinities for hatching have been recorded at 23 – 30 ‰ (Sandoz and Rogers 1944) and lab studies have shown that hatching is unsuccessful at ≤15 ‰ and ≥ 33° (Sandoz and Rogers 1944, Costlow and Bookout 1959). Temperature may also be an important factor in hatching success and have been reported to be between 19° C and 29°C (Sandoz and Rogers 1944) and 20°C and 35°C (Costlow 1967).

Newly hatched larvae, or zoeae, are barely visible. Larvae are pelagic and exported from the estuaries to adjacent high salinity self waters where they remain planktonic during the first seven stages (zoeal) of larval development. Although early stage crab zoeae are good osmoregulators, they lose this ability as they progress through later zoeal stages (Kalber 1970). Sandow and Rogers (1944) reported optimum salinities and temperatures for metamorphosis during these first three stages ranged from 21‰ to 28‰ and 20°C to 29°C. The optimal salinity and temperature combination for zoeal development is 25°C and 30 ‰ (Costlow and Bookhout 1959, Sulkin and

Epifanio 1975, Bookhout et al. 1976), although a range of salinities between 20.1‰ to 30.1‰ are conducive to larval development (Costlow and Bookhout 1959)

At the eighth larval stage, the megalopae stage which occurs at about 31 to 49 days (Costlow and Bookhout 1959), larvae re-enter the estuaries where they settle and molt to the first crab stage (More 1969, King 1917, Perry 1975, Perry and Stuck 1982). The survival and rate of megalopal development is highly variable under different temperatures and salinities. Costlow (1967) found megalopal growth was most pronounced at 30˚C in salinities of 10‰ to 40‰ and that salinities greater than 30‰ is optimal. He also concluded that water temperatures between 21.5°C and 34.5°C are good and that 25°C is optimal (Costlow 1967). Perry (1975) reported most megalopae occurred in salinities >20 ‰.

Juvenile blue crabs show wide seasonal distribution in Gulf estuaries (Guillory et al 2001). Orth and Van Montfrans (1990) found a significant positive relationship between blue crab production and total vegetated area and Zimmerman and Minello (1984) found that in Texas, juvenile blue crabs were significantly more abundant in flooded salt-marshes that in subtidal areas without vegetation. Daud (1979) found that at the 5-10 mm stage, juvenile blue crabs were more abundant in the brackish to saline areas of the estuary and Guillory (2001) noted that larger juvenile blue crabs seem to prefer low to intermediate salinities characteristic of middle and upper estuarine waters.

Adult blue crabs, in general, are widely distributed and occur on a variety of bottom types in fresh, estuarine, and shallow oceanic waters, although they are distributed seasonally with respect to salinity and sex (Steele and Bert 1993). Female crabs migrate from hyposaline waters (<35‰) to higher salinity water to spawn and hatch their eggs. The male blue crab usually remains within the estuary during its entire post larval life and move into lower salinity waters to molt (Murphy et al 2001, Tagatz 1968).

HSI for the Blue Crab

The blue crab (*Callinectes sapidus*) is an estuarine-dependent crustacean that is common in the crab-trap fishery in the Caloosahatchee River. Its life history involves a complex cycle of planktonic, nektonic, and benthic stages which occur throughout the estuarine-nearshore marine environment in a variety of habitats. The blue crab is one of the more abundant estuarine macroinvertebrates and supports valuable commercial and recreational fisheries along the Atlantic and Gulf coasts where it plays a crucial role in the estuarine food web, providing prey for many species and in turn a ravenous predator on other species.

Blue crabs are highly prized commodity to consumers. The species supports a rather large fishery that historically has had large and consistent landings within the estuary. The estimated number of licensed crab fishers in Lee County is 183 and the number of licensed crab traps is over 63,000 (FMRI, 2003). This fishery expends a large effort and yields large numbers of crabs for local and distant consumers while supporting a valuable local economic employment opportunity.

Two components, larvae settlement and spawning females have been chosen for determining habitat suitability for the Blue Crab in the Caloosahatchee Estuary. Variables to be used to estimate larvae settlement suitability are: salinity, temperature, and flow. To estimate spawning adult suitability, salinity and temperature will be used. Specific requirements have been pulled from scientific literature are listed, along with their source, in the table below for both adult female blue crabs and larval settlement.

A user interface for running coastal southwestern Florida HSI models is documented in Mazzotti *et al.* (2006).

Table 1. Habitat Requirements for the Blue crab.

Variable	**Value**	Source
Blue Crab: Larvae Salinity	Optimal – 30‰ for zoea >30‰ for megalopae Range – 20‰-30‰ for zoea 10‰ to 40‰ for megalopae Most at >20‰	Costlow, J.D., Jr. and C.G. Bookhout. 1959. The larval development of Callinectes sapidus Rathbun reared in the laboratory. Biological Bulletin 116(3):373-396. Sulkin, S.D. and C.E. Epifanio. 1975. Comparison of rotifers and other diets for rearing early larva of the blue crab, Callinectes sapidus Rathbun. Estuarine and Coastal Marine Science 3:109-113. Bookhout, C.G., J.D. Costlow, Jr. and R.Monroe. 1976. Effects of methoxchlor on larval development of mud-crab and blue-crab. Water, Air, and Soil Pollution 5:349-365. Sandoz, M.D. and R. Rogers 1944. The effect of environmental factors on hatching, molting and survival of zoea larvae of the blue crab Callinectes sapidus Rathbun. Ecology 25(2):216-228 Perry, H.M. 1975. The blue crab fishery in Mississippi. Gulf Research Reports 5(1):39-57.
Blue Crab: Larvae Temperature	Optimal – 25°C for zoea 25°C for megalopae Range – 20°C-29°C for zoea 21.5˚C-34.5˚C for megalopae	Costlow, J.D., Jr. and C.G. Bookhout. 1959. The larval development of Callinectes sapidus Rathbun reared in the laboratory. Biological Bulletin 116(3):373-396. Sulkin, S.D. and C.E. Epifanio. 1975. Comparison of rotifers and other diets for rearing early larva of the blue crab, Callinectes sapidus Rathbun. Estuarine and Coastal Marine Science 3:109-113. Bookhout, C.G., J.D. Costlow, Jr. and R.Monroe. 1976. Effects of methoxchlor on larval development of mud-crab and blue-crab. Water, Air, and Soil Pollution 5:349-365. Sandoz, M.D. and R. Rogers. 1944. The effect of environmental factors on hatching, molting and survival of zoea larvae of the blue crab Callinectes sapidus Rathbun. Ecology 25(2):216-228
Blue Crab: Spawning Female Salinity	Range 21‰-35‰	Costlow, J.D., Jr. and C.G. Bookhout. 1959. The larval development of Callinectes sapidus Rathbun reared in the laboratory. Biological Bulletin 116(3):373-396. Sulkin, S.D. and C.E. Epifanio. 1975. Comparison of rotifers and other diets for rearing early larva of the blue crab, Callinectes sapidus Rathbun. Estuarine and Coastal Marine Science 3:109-113. Bookhout, C.G., J.D. Costlow, Jr. and R.Monroe. 1976. Effects of methoxchlor on larval development of mud-crab and blue-crab. Water, Air, and Soil Pollution 5:349-365. Sulkin, S.D. E.S. Branscomb, and R.E. Miller. 1976. Induced winter spawning and culture of larvae of the blue crab, Callinectes sapidus Rathbun. Aquaculture 8:103-113. Steele, P. and T. M. Bert. 1994. Population ecology of the blue crab, Callinectes sapidus Rathbun, in a subtropical estuary: Population structure, aspects of reproduction, and habitat partitioning. Florida Marine Research Publication 0(51):1-24.
Blue Crab:	Range 16°C-25°C	Costlow, J.D., Jr. and C.G. Bookhout. 1959. The larval development of Callinectes sapidus Rathbun reared in the laboratory. Biological

Spawning Female Temperature		Bulletin 116(3):373-396. Sulkin, S.D. and C.E. Epifanio. 1975. Comparison of rotifers and other diets for rearing early larva of the blue crab, Callinectes sapidus Rathbun. Estuarine and Coastal Marine Science 3:109-113. Bookhout, C.G., J.D. Costlow, Jr. and R.Monroe. 1976. Effects of methoxchlor on larval development of mud-crab and blue-crab. Water, Air, and Soil Pollution 5:349-365. Sulkin, S.D. E.S. Branscomb, and R.E. Miller. 1976. Induced winter spawning and culture of larvae of the blue crab, Callinectes sapidus Rathbun. Aquaculture 8:103-113. Steele, P. and T. M. Bert. 1994. Population ecology of the blue crab, Callinectes sapidus Rathbun, in a subtropical estuary: Population structure, aspects of reproduction, and habitat partitioning. Florida Marine Research Publication (51):1-24.

HSI for the Blue Crab

HSI Formula

Calculated monthly.

Recruitment Model = Larvae Settlement & Growth (June – December) + Spawning Female (March – September)

Component Indices are the weighted geometric mean of the variables. The final HSI is a minimum score of the larval and adult component indices for months when both spawning and settlement are occurring.

Blue Crab *LarvalComponentIndex* = $(\text{Salinity}^{w} * \text{Temperature}^{w} * \text{Flow}^{w})$

Blue Crab *SpawningFemaleComponentIndex* = $(\text{Salinity}^{w} * \text{Temperature}^{w)}$

$\text{HSI}_{\text{June-September}} = \text{MIN}(\textit{LarvaeComponentIndex}, \textit{SpawningFemaleComponentIndex})$

$\text{HSI}_{\text{March-May}} = \textit{SpawningFemaleComponentIndex}$

$\text{HSI}_{\text{October-December}} = \textit{LarvalComponentIndex}$

The default weight, *w = 1/(number of variables).* The weight can take on different values for the different variables; however, the sum of the weights must be equal to one.

Since all the life stages are not being modeled, suitability indices are only calculated for months when the larvae and spawning female stages are present.

Temperature values used in model are average monthly water temperatures and do not change with hydrologic alternatives.

HSI Curves

*Due to the lack of local studies, HSI curves were constructed using data from peer reviewed literature and modified, where appropriate, based on local conditions and local observations.

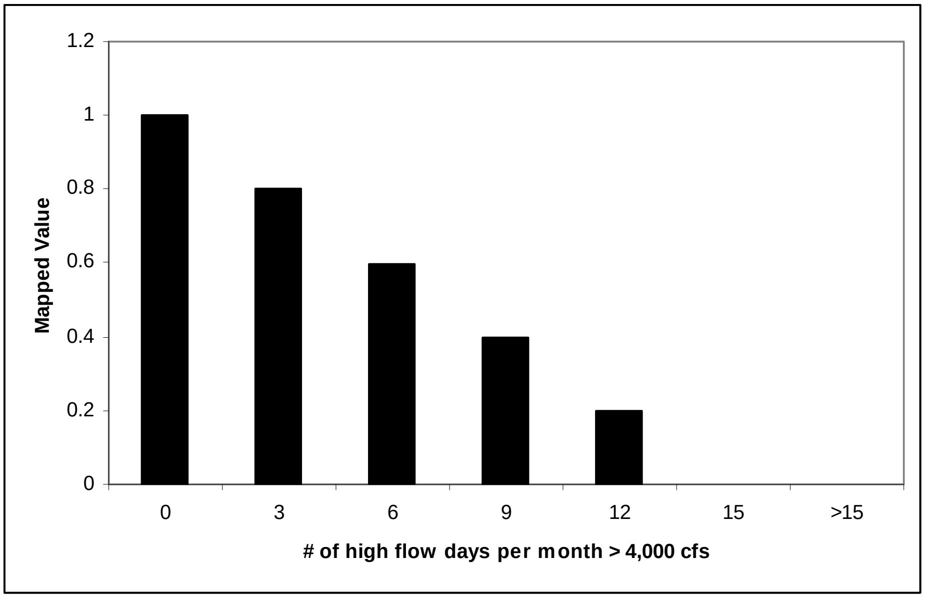

Figure 1. Index value for blue crab larvae response to flow. Flow values were established by local scientists and are general for the flushing effect on zooplankton which prevents larval settlement. These values are specific for the Caloosahatchee estuary.

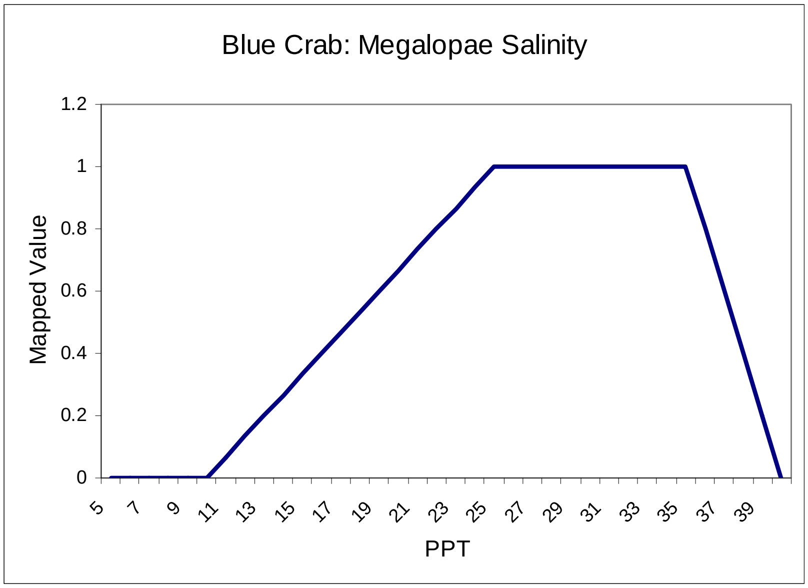

Figure 2. Index value for blue crab megalopae response to salinity.

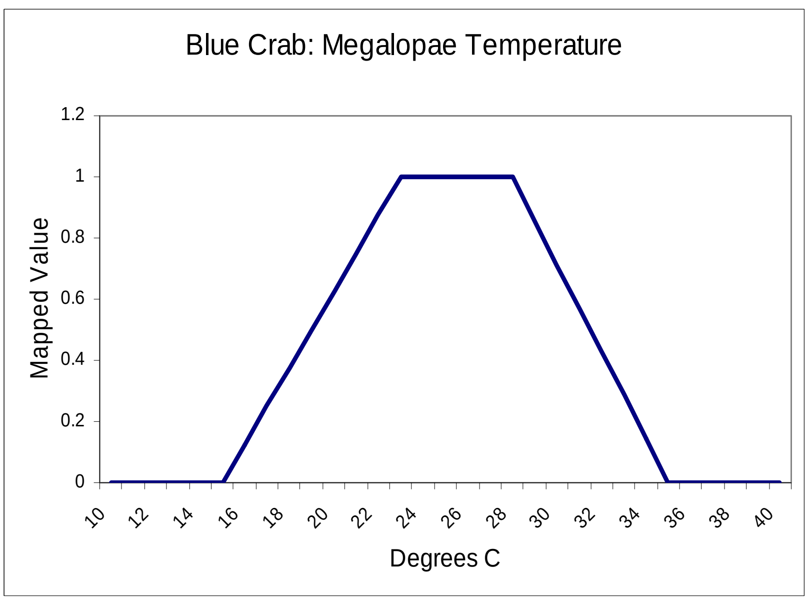

Figure 3. Index value for blue crab megalopae response to temperature.

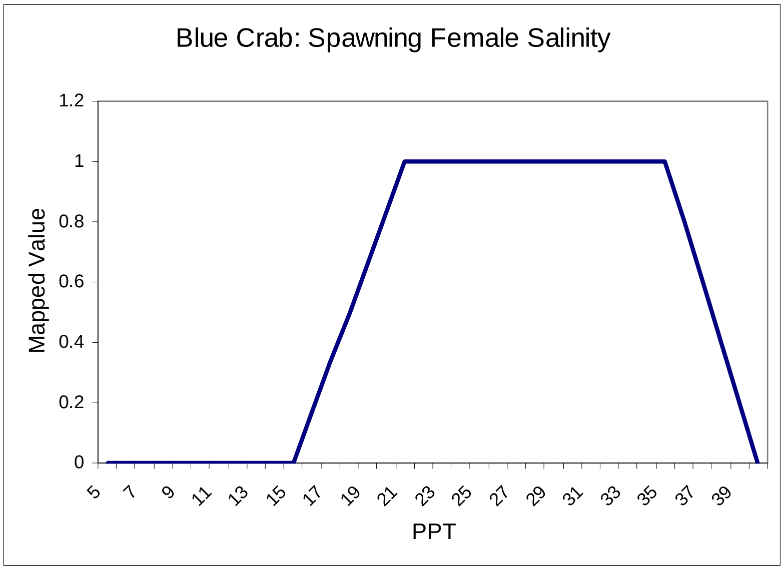

Figure 4. Index value for blue crab spawning female response to salinity.

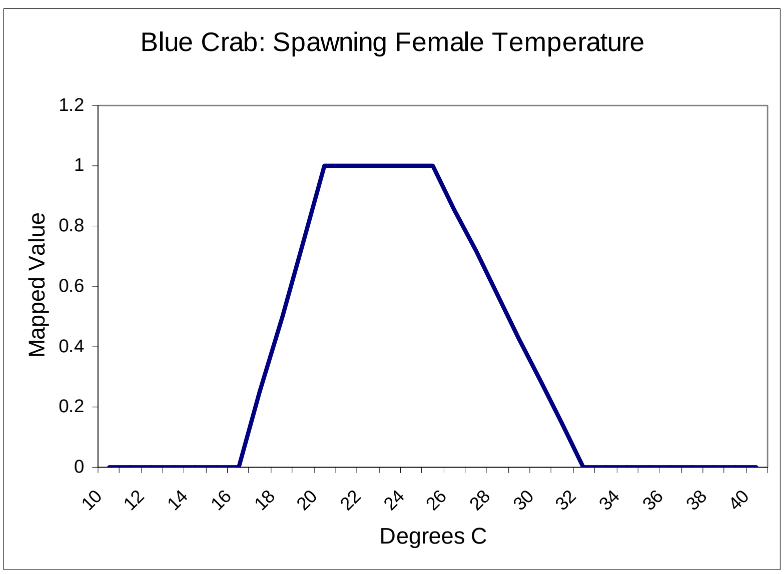

Figure 5. Index value for blue crab spawning female response to temperature.

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