CIR1523

Stressor-Response Model for the Spotted Sea Trout (*Cynoscion nebulosus*)[1]

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Introduction

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

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 that was initiated in recognition that some water resource issues (needs, problems, and opportunities) in Southwest Florida were 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.

C-43 West Basin Storage Reservoir Project

The Caloosahatchee River (C-43) West Basin Storage Reservoir project is an expedited CERP project and a component of a larger restoration effort for the Caloosahatchee River and estuary. The purpose of the 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 County. The initial design of the reservoir assumed 8,094 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.

Objective

The purpose of this stressor-response model for the C-43 West Basin Storage Reservoir project and the Southwest

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Florida Feasibility Study is to portray species responses—both spatially and temporally—to changes in environmental variables resulting from restoration activities. The intent of the model is not to simulate the life cycle of the species, but rather to estimate numbers of habitat units to serve as a relative basis for comparing management alternatives. Four hydrologic scenarios are compared: current conditions, 2050-without-CERP, 2050-with-CERP, and target-flow conditions. Each scenario is modeled for wet, dry, and normal rainfall years. The spotted seatrout model is one of a suite of Caloosahatchee estuary models, including tape grass (*Vallisneria*), Seagrass (*Halodule/Thalassia*), blue crab, and eastern oyster, which are being considered together for restoration plan evaluation. The other models are being documented in other reports.

Forecasting Models

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. 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 understand better 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 and is validated by monitoring programs to measure actual system response (Barnes and Mazzotti 2005). Monitoring can then provide information as a passive adaptive management tool for recalibration of the forecasting model. Directed research, driven by model uncertainties, is an active adaptive management strategy for learning and reducing uncertainties in the model (Ogden et al. 2003; Barnes and Mazzotti 2005).

The forecasting models for the C-43 West Basin Storage Reservoir project and the Southwest Florida Feasibility Study consist of a set of stressor-response models (specifically, habitat suitability index models) for individual species. Each model is applied to restoration alternatives with the assumption that as stress levels on the ecosystem change for each alternative, so will extent and quality of suitable habitat.

Habitat Suitability Index Model

Habitat suitability index (HSI) models relate specific environmental requirements of an organism to the actual and/or simulated ecological properties of a study area. Parameters for environmental requirements were defined based on existing literature, expert knowledge, and currently available field data. Values were adjusted for local conditions and then used to create individual suitability indices that drive the model. Suitability values for the individual parameters and for the calculated HSI are represented from zero (unfit habitat) to one (ideal habitat), and are presented in line graphs below (Figure 1, Figure 2, Figure 3, Figure 4b). The HSI model uses a formula (see HSI Formula section below) to calculate habitat suitability monthly as the weighted geometric mean of the specific environmental variables. Because the geometric mean is derived from the product of the variables rather than the sum (as in the arithmetic mean), it has the 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.

The HSI model is incorporated into a geographic information system (GIS) to portray habitat suitability values spatially and temporally across systems of the study area. The values vary spatially according to stressor levels throughout the estuary and temporally as a result of cycling of important stressor inputs, such as water temperature and salinity. 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 HSI models were developed by choosing specific life stages of each species with the most limited or restricted range of suitable conditions, to capture the highest sensitivities of the organisms to the environmental changes associated with planned restoration activities. Environmental parameters used in the model, and their sources, are listed in Table 1.

Ecology of the Spotted Seatrout

The spotted seatrout, *Cynoscion nebulosus*, is a member of the Sciaenidae family of croakers and drums. It is an important species because it is one of the few species that spends its entire life within the confines of a single estuarine system, and therefore can serve as a long-term indicator of estuarine conditions. The spotted seatrout occurs in all estuaries from North Carolina to Mexico along the Atlantic and Gulf of Mexico coasts. An added feature of this species is that it is highly prized by both commercial and recreational fishers, and thus commands attention among the general public. These features of its biology and public importance make it an ideal indicator of estuarine conditions.

Seatrout are nonmigratory fish (Tabb 1966) that are found in shallow bays, estuaries, bayous, canals, and along Gulf Coast beaches. Spotted seatrout usually live between 7 and 10 years, completing their entire life cycle in inshore waters and using different estuarine zones and habitats during different life stages (Helser et al. 1993). Adults can tolerate a wide range of salinities and temperatures (Tabb 1958; Simmons 1957; Vetter 1982; Killam et al. 1992) and in South Florida are not commonly exposed to extremes that may be lethal (e.g., temperature <4°C (Tabb 1958)). Spawning is thought to occur throughout the summer (Brown-Peterson 2003; Brown-Peterson et al. 2002; McMichael and Peters 1989) in South Florida estuaries in meso and polyhaline portions of the estuary and near passes (5–30 ppt) but not in oligohaline areas (<5 ppt) (Holt and Holt 2003; Lassuy 1983). A depth requirement for spawning has been suggested as less than 5 m (Brown-Peterson 2003), in areas next to steep drop-offs near seagrass beds (Bortone pers. com) (Figure 4a). Eggs hatch in more saline marine to estuarine environments (25–40 ppt), which enables eggs to stay buoyant (Holt and Holt 2003; Alshuth and Gilmore, 1994).

Juveniles and adult spotted seatrout are frequently associated with seagrass beds, a critical habitat for the species (Chester and Thayer 1990; Tolan et al. 1997, Rooker et al. 1998; Thayer et al. 1999; Baltz et al. 2003). In colder months, they may move into deeper holes within the estuary (Tabb 1958).

The spotted seatrout is an opportunistic carnivore. Its diet changes with size/life stage and with seasonal abundance of food items (Perret et al. 1980). Larvae feed primarily on zooplankton; post-larvae on larval shrimp, copepods, small fishes, and crabs (Lorio and Perret 1980). Juveniles feed predominately on fishes, shrimp (penaeids, mysids, and cardeans), copepods, and other benthic invertebrates (McMichael and Peters 1989; Hettler 1989). Young adults prey on a variety of invertebrates; as mature adults they shift almost entirely to smaller fish when available (McMichael and Peters 1989; Hettler 1989;, Tabb 1958).

Spotted seatrout have growth rings or annuli on the otolith or ear stone; these rings reflect the growth conditions to which the fish have been subjected (Bedee et al. 2003). Therefore, the growth rate of each fish is essentially a permanent historical record that reflects the environmental conditions of a specific estuary.

Habitat Suitability Index for the Spotted Seatrout

The HSI for the adult spotted seatrout consists of two components: a forage habitat component and a spawning habitat component. Environmental variables used to determine suitability of forage habitat include salinity, temperature, and seagrass cover. The variables used for spawning habitat suitability include salinity and proximity to seagrasses and drop-offs. Parameters for each variable were obtained from local scientific data and peer-reviewed scientific literature adjusted for local conditions, and are listed with their sources in Table 1. These parameters were used to create individual suitability indices for each environmental variable (see graphs).

Salinity, temperature, and seagrass coverage were data inputs for the model. Component suitability indices were calculated from the input data according to the parameters described above. Seagrass distribution is derived from the annual output of a suitability model for seagrasses following Mazzotti et al. (2006). Salinity data are derived from conductivity measurements provided by the South Florida Water Management District. Temperature values used in the model are average monthly water temperatures and do not change with hydrologic alternatives. A user interface for running coastal southwestern Florida HSI models is documented in Mazzotti et al. (2006).

HSI Formula

Forage Component Index = ($\text{Habitat}^{w}_{\text{Seagrass\%Cover}}$ * Salinity^{w} * Temperature^{w})

Spawn Component Index = ($\text{Habitat}^{w}_{\text{Drop-off\&SeagrassProximity}}$ * Salinity^{w}) Spawning is May - October

HSI = MAX (ForageComponent, SpawnComponent)

The HSI for any particular grid-cell is selected as the maximum of the forage component or the spawning component. The component values are not multiplied together because they occupy different places in the landscape.

Suitability Index Graphs

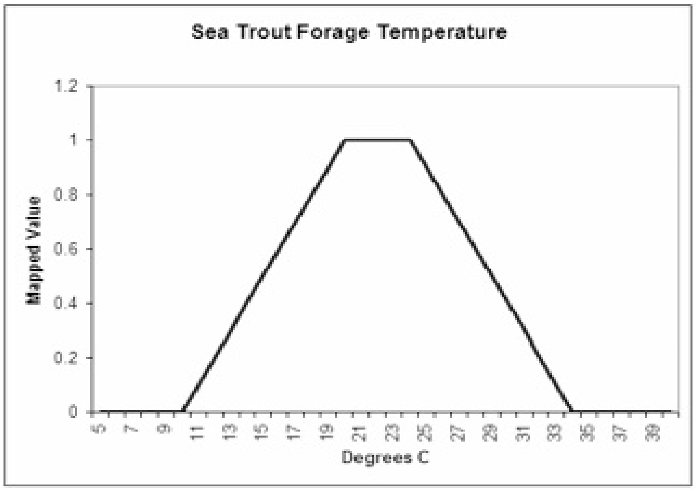

Figure 1. Suitability index for spotted seatrout adult foraging response to temperature.
Credits: Leonard Pearlstine, University of Florida/IFAS, 2006

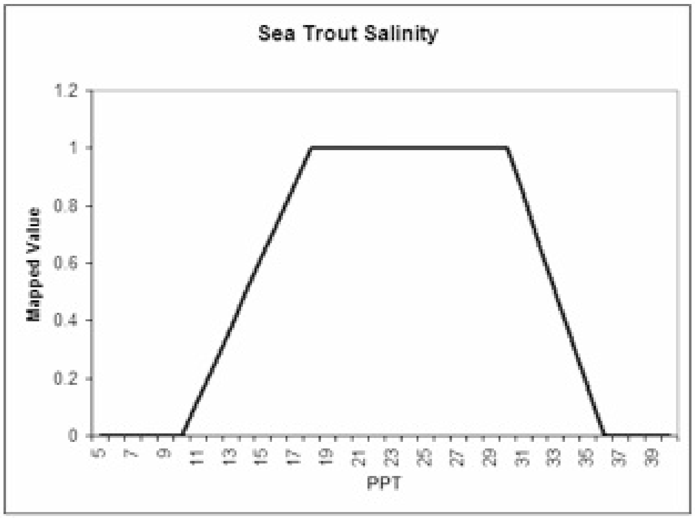

Figure 2. Suitability index for spotted seatrout adult foraging response to salinity.
Credits: Leonard Pearlstine, University of Florida/IFAS, 2006

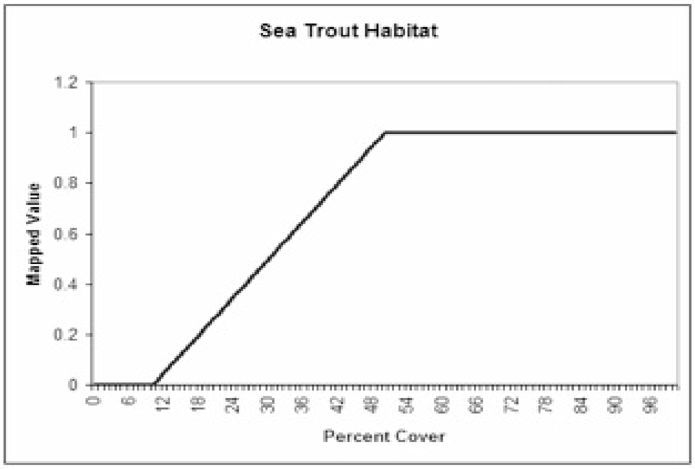

Figure 3. Suitability index for spotted seatrout adult foraging response to seagrass cover.
Credits: Leonard Pearlstine, University of Florida/IFAS, 2006

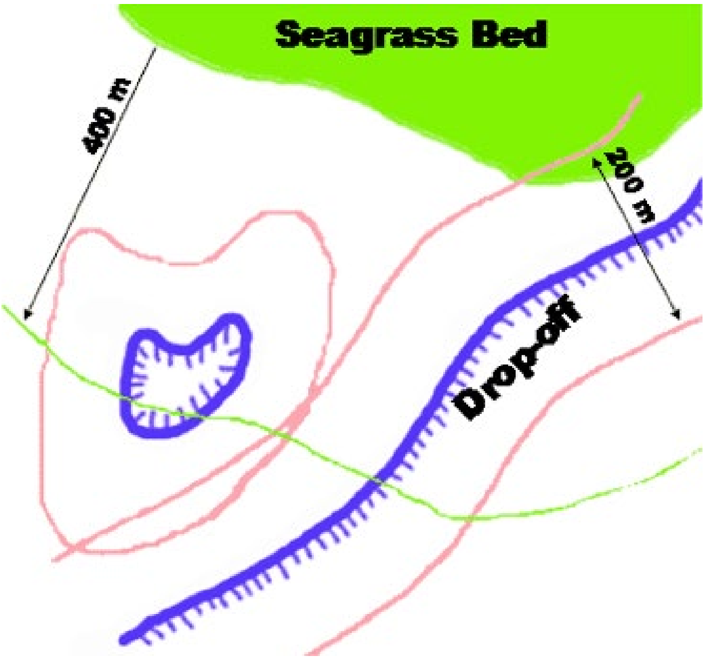

Figure 4a. Spotted seatrout adult spawning requirement for depth. Spawning is within a 100 m proximity to steep drop-offs and a 400 m proximity to seagrass beds.
Credits: Kevin Chartier, University of Florida/IFAS, 2006

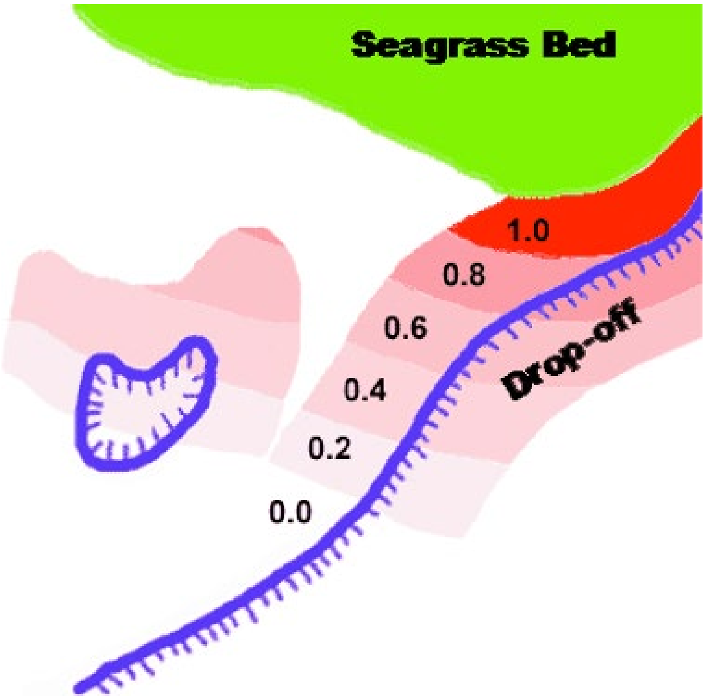

Figure 4b. Suitability index for spotted seatrout adult spawning response to depth. The suitability value of the spawning habitat component decreases linearly as distance increases from a seagrass bed. The habitat suitability is illustrated here as a red gradient with values from 0.0 (white) to 1.0 (darkest red).
Credits: Kevin Chartier, University of Florida/IFAS, 2006

HSI Model Results

Results are displayed in Figure 5 as average yearly HSI values for four hydrologic scenarios: current conditions, 2050-without-CERP, 2050-with-CERP, and target-flow conditions for optimum variation in salinity and estuarine biodiversity. Each scenario was modeled for a wet year (1995), a dry year (2000), and a normal year (1996), based on annual rainfall within the Caloosahatchee Basin. The model for 2050-with-CERP is more similar to target conditions than the other two scenarios. During the wet year (1995), present conditions and 2050-without-CERP HSI values were significantly higher than the target conditions and 2050-with-CERP. For the dry year (2000), HSI values for target conditions and 2050-with-CERP were significantly higher than present conditions and 2050-without-CERP. For a normal rainfall year (1996), the present condition and 2050-without-CERP scenarios show large fluctuations (from 0.19 to 0.49) in HSI values from month to month whereas the target-flow and 2050-with-CERP scenarios show a trend with a decreasing HSI through the dry season (from 0.35 to 0.26) and increasing HSI in the rainy season (from 0.26 to 0.48).

Discussion

A restoration goal for the Caloosahatchee estuary is to reduce flow events greater than 79.29 CMS (cubic meters per second), to eliminate flow events higher than 127.43 CMS, and to provide no flows less than 12.75 CMS to the estuary (Chamberlain data unpublished, 2005). Throughout the years modeled, the condition of full restoration (2050-with-CERP), as defined by the Comprehensive Everglades Plan (U.S. Army Corps of Engineers and South Florida Water Management District 1999) closely matches the target-flow condition. The C-43 West Basin Reservoir restoration project will capture high flows during the wet season, and store water necessary to maintain minimum flows during the dry season. During extremely wet years, such as 1995, the C-43 reservoir may not be able to provide enough storage to maintain a higher suitability of seatrout habitat in the lower estuary and the low target may not be optimal for adult spotted seatrout spawning and foraging. During an extremely dry year (e.g., 2000), CERP provides enough water to meet the flow of 12.75 CMS, the minimum target for dry-season environmental releases, but HSI scores show that this may still be insufficient flow to provide optimal habitat suitability for spotted seatrout in the lower portions of the estuary. Additional water storage and supply needs will be addressed by the Southwest Florida Feasibility Study.

The HSI model developed here serves as a heuristic model upon which to build for future efforts. The model is simple but allows incorporation of features considered important in describing conditions that are presumed important to sustain viable spotted seatrout populations. As more data become available, additional variables, habitat requirements, or additional life stages can be incorporated. This could strengthen the model and its application to restoration alternative evaluation. Similarly, as relationships between spotted seatrout and the environment become clarified (e.g., curvilinear as opposed to linear), these relationships can be easily modified to make them more realistic and biologically meaningful. As with the evaluation of any model, there is a need for model verification, calibration, and validation. In concert with the model development process, continuous internal examination of the model served as a means for verification. Continued monitoring and research will be necessary to calibrate and validate the model.

In summary, an HSI model for the spotted seatrout integrated with GIS for visual display was developed to enhance decision making and assist in the selection of restoration alternatives for the Caloosahatchee estuary, Lee County, Florida. The model is based on real scientific data and peer–reviewed scientific literature. Although this model is optimized for local use, it can be applied to other estuaries by adjusting variable values to mimic local conditions of those estuaries. The use of such a model reduces uncertainty associated with restoration.

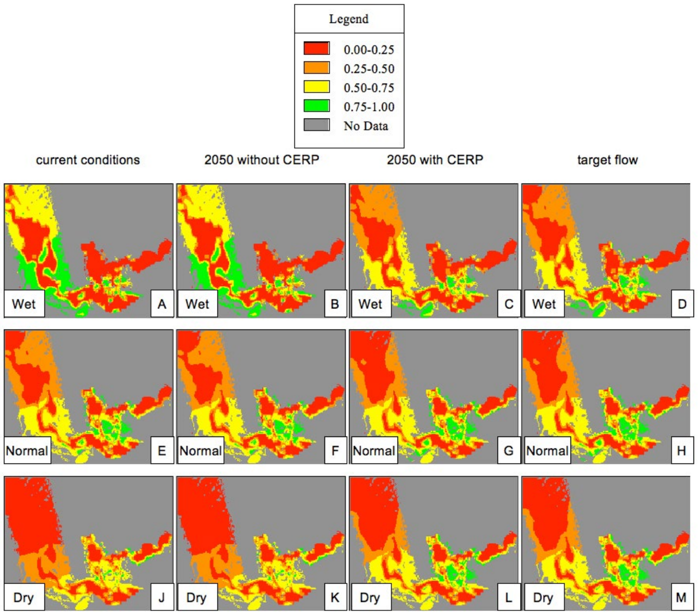

Figure 5. Distribution of HSI values for the four modeled hydrologic scenarios for wet (1995), dry (2000), and normal (1996) rainfall years.
Credits: Kevin Chartier, University of Florida/IFAS, 2006

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Table 1. Habitat requirements for the spotted seatrout.

Variable	**Value**	**Source**
Adult Foraging: Salinity	18–32 ppt in Louisiana	Baltz, D.M., R.G. Thomas, and E.J. Chesney. 2003. Spotted seatrout habitat affinities in Louisiana. In Biology of the Spotted Seatrout, ed. S.A. Bortone, 147-175. Boca Raton, FL: CRC Press.
Adult Foraging: Temperature	20°C–24°C in Louisiana	Baltz, D.M., R.G. Thomas, and E.J. Chesney. 2003. Spotted seatrout habitat affinities in Louisiana. In Biology of the Spotted Seatrout, ed. S.A. Bortone, 147-175. Boca Raton, FL: CRC Press.
	15°C–27°C in Florida	Tabb, D.C. 1958. Differences in the estuarine ecology of Florida waters and their effect on populations of the spotted weakfish, *Cynoscion nebulosus* (Cuvier and Valenciennes). Twenty-third North American Wildlife Conference: 392-401.
	< 4°C lethal in Florida	Story, M. and E.W. Gudger. 1936. Mortality of fishes due to cold at Sanibel Island, Florida, 1886-1936. Ecology 17:640-648.
Adult Foraging: Seagrass cover	Essential	Baltz, D.M., R.G. Thomas, and E.J. Chesney. 2003. Spotted seatrout habitat affinities in Louisiana. In Biology of the Spotted Seatrout, ed. S.A. Bortone, 147-175. Boca Raton, FL: CRC Press. Chester, A.J. and G.W. Thayer. 1990. Distribution of spotted seatrout (*Cynoscion nebulosus*) and gray snapper (*Lutjanus griseus*) juveniles in seagrass habitats of western Florida Bay. Bull. Mar. Sci. 46(2):45-357. Tolan, J.M., S.A. Holt, and C.P. Onuf. 1997. Distribution and community structure of ichthyoplankton in Laguna Madre seagrass meadows: potential impact of seagrass species change. Estuaries 20:450-465. Rooker, J.R., S.A. Holt, M.A. Sota, and G.J. Holt. 1998. Postsettlement patterns of habitat use by sciaenid fishes in subtropical seagrass meadows. Estuaries 21:318-327. Thayer, G.W., A.B. Powell, and D.E. Hoss. 1999. Composition of larval, juvenile, and small adult fishes relative to changes in environmental conditions in Florida Bay. Estuaries 22:518-533. Thomas, P., C.R. Arnold, J.F. Muir, and R.J. Roberts. 1993. Environmental and hormonal control of reproduction in sciaenid fish. Recent Adv. Aquacul. 4:31-42.
Adult Spawning: Salinity	16–32 ppt in Florida & Texas	Holt, G.J. and S.A. Holt. 2003. Effects of variable salinity on reproduction and early life stages of spotted seatrout. In Biology of the Spotted Seatrout, ed. S.A. Bortone, 135-145. Boca Raton, FL: CRC Press.
	18–33 ppt Florida east coast	Alshuth, S. and R.G. Gilmore. 1994. Salinity and temperature tolerance limits for larval spotted seatrout, *Cynoscion nebulosus* C. (Pisces: Sciaenidae). International Journal for the Exploration of the Sea, Council Meeting Papers. ICES-CM-1994/L:17. 19 pp.
Adult Spawning: Temperature	21°C–34°C in Louisiana	Baltz, D.M., R.G. Thomas, and E.J. Chesney. 2003. Spotted seatrout habitat affinities in Louisiana. In Biology of the Spotted Seatrout, ed. S.A. Bortone, 147-175. Boca Raton, FL: CRC Press.
	21°C–34°C in Florida	Brown-Peterson, N.J. 2003. The reproductive biology of spotted seatrout. In Biology of the Spotted Seatrout, ed. S.A. Bortone, 99-133. Boca Raton, FL: CRC Press.
Drop-offs	Essential	Lowerre-Barbieri, S.K. 2006. Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission. Personal Communication.
Seagrass Bed Distance	Proximate	Brown-Peterson, N.J. 2003. The reproductive biology of spotted seatrout. In Biology of the Spotted Seatrout, ed. S.A. Bortone, 99-133. Boca Raton, FL: CRC Press.