



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

**STRESSOR RESPONSE MODEL FOR THE  
SEAGRASSES, *Halodule wrightii* and  
*Thalassia testudinum***

By Frank J. Mazzotti, Leonard G. Pearlstine, Robert Chamberlain, Tomma Barnes,  
Kevin Chartier, and Donald DeAngelis

Joint Ecosystem Modeling Laboratory  
Technical Report

FINAL REPORT  
for

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## Contents

Introduction.....	1
Southwest Florida Feasibility Study.....	1
C43 West Reservoir.....	1
Forecasting Models.....	1
Habitat Suitability Indices .....	2
Ecology of the Seagrass .....	2
HSI for Seagrass .....	9
References Cited.....	17

## Figures

Figure 1. Caloosahatchee Estuary SAV monitoring stations.....	4
Figure 2. Time series density of seagrass .....	5
Figure 3. Seagrass coverage at two locations in San Carlos Bay .....	6
Figure 4. HSI value for seagrass response to salinity .....	10
Figure 5. HSI value for seagrass response to light. ....	11
Figure 6. Average Monthly Photosynthetic Active Radiation (PAR). ....	12
Figure 7. Light attenuation vs. Salinity in seagrass areas.....	13
Figure 8. Light attenuation regions.....	18
Figure 9. HSI value for Seagrass response to temperature.....	14
Figure10. Estimated water temperature in the Caloosahatchee Estuary .....	15

## Tables

Table 1. Habitat requirements for the seagrass, <i>Halodule</i> and <i>Thalassia</i> . ....	7
Table 2. Changes to the HSI model's spatial boundaries and post-processing routines.....	9

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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.

## **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 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.

## **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 (170,000 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 and is 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. That is, the model describes 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 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 Seagrasses**

Beds of submerged aquatic vegetation (SAV) are important to the ecology of shallow estuarine and marine environments. These beds provide habitat for many benthic and pelagic organisms,

function as nurseries for juveniles and other early life stages, stabilize sediments, improve water quality, and can form the basis of a detrital food web (Kemp et al. 1984; Fonseca and Fisher 1986; Carter et al. 1988; Killgore et al. 1989; Lubber et al. 1990). Because of the importance of these beds, estuarine restoration initiatives often focus on SAV (Batiuk et al. 1992; Johansson and Greening 2000; Virnstein and Morris 2000). SAV are commonly monitored to gauge the health of estuarine systems, (Tomasko et al. 1996) and their environmental requirements can form the basis for water quality goals (Dennison et al. 1993; Stevenson et al. 1993).

In the Caloosahatchee Estuary, field and laboratory research has been conducted by the South Florida Water Management District (SFWMD, associated contractors, and non-government organizations over a wide range of flows and salinities. This information, along with the results from researchers in other systems, is used to estimate maximum freshwater inflow limits and associated water quality requirements to protect and restore *Halodule wrightii* (shoal grass) and *Thalassia testudinum* (turtle grass).

McNulty et al. (1972) and Harris et al. (1983) mapped SAV in the lower estuary upstream of Shell Point, as well as throughout the outer embayments. *Halodule* is the only seagrass species consistently located upstream of Shell Point (Figure 1: Stations 5 and 6) until it mixes downstream with *Thalassia* and other less common species in San Carlos Bay (Stations 7 and 8) and Pine Island Sound (Stations 9 and 10). *Halodule* has a wide salinity tolerance (McMahan 1968). It does not survive below 3.5 ppt and prefers salinity as high as 44 ppt (Zieman and Zieman 1989). This wide tolerance is probably why it is the only true seagrass species encountered upstream of Shell Point. Monitoring results (Figure 2a) indicate that, of all areas where *Halodule* is present, the lowest biomass is found upstream, where salinity is more diluted and most variable (Chamberlain et al 1995, Chamberlain and Doering 1998b, Doering et al. 2002). The greatest biomass occurs when salinity is above 20 ppt. Figure 2a also depicts seasonal growth patterns that can be influenced by high freshwater inflow that cause decreasing salinity (as occurred in the Water Year 2006) due to tropical storms during 2004 and 2005.

Literature summarized by Zieman and Zieman (1989) indicates that the optimum salinity range for *Thalassia* is 24-35 ppt. The maximum photosynthetic activity of *Thalassia* occurs in euhaline seawater and decreases proportionately with decreasing salinity. *Thalassia* does not grow in areas with salinity normally below 17 ppt and will suffer significant leaf loss when exposed to lower salinity. *Thalassia* does not exist upstream of Shell Point where salinity during the SFWMD study was more variable. Recent monitoring results (Figure 2b) also depict a declining density below normal at the end of WY 2006 from discharge related to tropical storms during 2004 and 2005.

Comparison of map coverage by Harris et al. (1983) determined substantial loss in seagrass during the mid-later 20<sup>th</sup> century. This loss was in part due to changes in freshwater flow patterns (salinity variability), physical alteration in the estuary and watershed, as well as changes in water management practices (Chamberlain and Doering 1998a). Harris et al. (1983) reported that the greatest loss appeared to be from deeper beds, which indicates that a change in water clarity has occurred, in part probably due to the increased freshwater inflow reaching the downstream beds and associated decreased water quality (i.e., increased water color).

In general, as flows increase, the water quality constituents (primarily color) that inhibit light penetration also increase. Therefore, as light attenuation increases, the depth at which the seagrass can survive decreases. SFWMD monitoring data indicates that average monthly flows

from S-79 that exceed 4,000 cfs are associated with light penetration below that necessary to support plants at 1 m depth in San Carlos Bay. Lower mean monthly discharges that approach 3,000 cfs are associated with the same problem for *Halodule* upstream of Shell Point. At deeper depths (e.g., 1.5m) plant coverage is considerably more sensitive to the freshwater inflow (Figure 3).

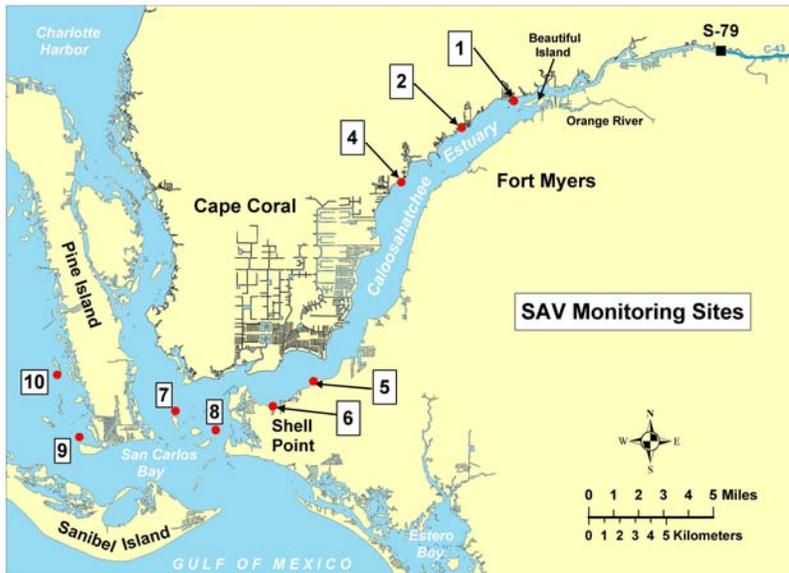


Figure 1. Caloosahatchee Estuary SAV monitoring stations for *Vallisneria americana* is found at stations 1-3, *Halodule wrightii* at stations 5-10, *Thalassia testudinum* at stations 8-10.

Based on the literature identified in Table 1, along with SFWMD laboratory and field research, the HSI curve in Figure 4 was formulated to represent relative *Halodule* and *Thalassia* response to salinity values generated during model runs.

Although there are species-specific variations, generally speaking, SAV distributions are limited by four environmental factors: light, salinity, temperature, and nutrients (Dennison et al. 1993, Kemp et al. 2004). In the Caloosahatchee, as indicated above, studies have documented that SAV distribution and subsequently its functionality, is strongly related to limits on their physiological response to salinity and light. Except at the distribution margins, plant location in the estuary generally depends on salinity, while growth characteristics controlling plant height and depth strongly relates to light attenuation within salinity tolerant zones.

The average daily bottom light (ADBL) required by SAV, which helps determine the depth to which plants exist, is measured in the photosynthetic active radiation (PAR) spectrum of 400-700 nanometers during the entire 24 hour day (not just daylight or peak light periods). ADBL for shoal grass can be divided into stressed environments like in Iona Cove, and more desirable areas as in San Carlos Bay (as evidenced in the results of Dunton 1994 and 1996 from Texas). Dunton and Tomasko (1991) and Dunton (1996) also determined light requirements during winter and summer seasons. Based primarily on their results, the minimum range of ADBL in Iona Cove is estimated to be about 50-60 micro-Einsteins ( $\mu E = \text{micromoles}/\text{m}^2/\text{sec}$ ) and saturation is 220-

300uE, depending on the season . In San Carlos Bay, the minimum and saturation levels of ADBL equates to about, 75-100uE, and 225-325uE, respectively.

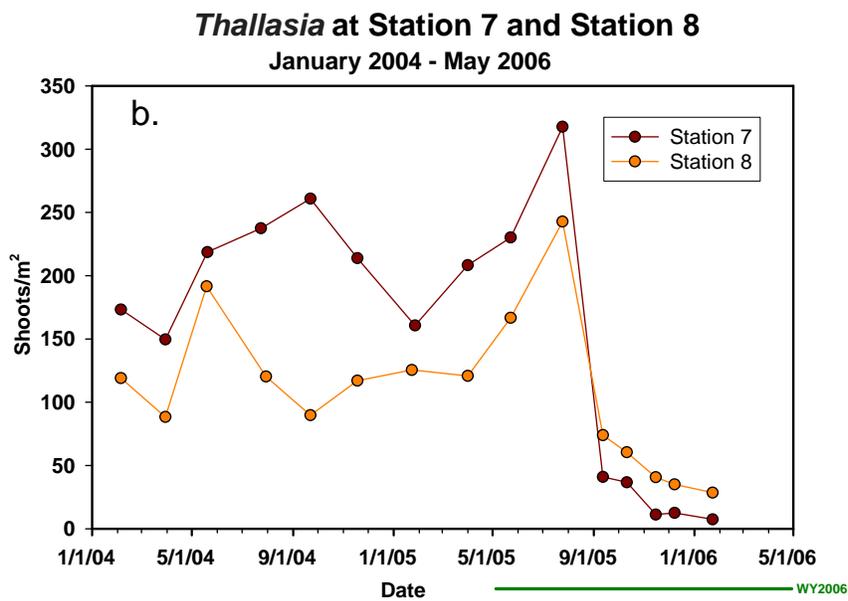
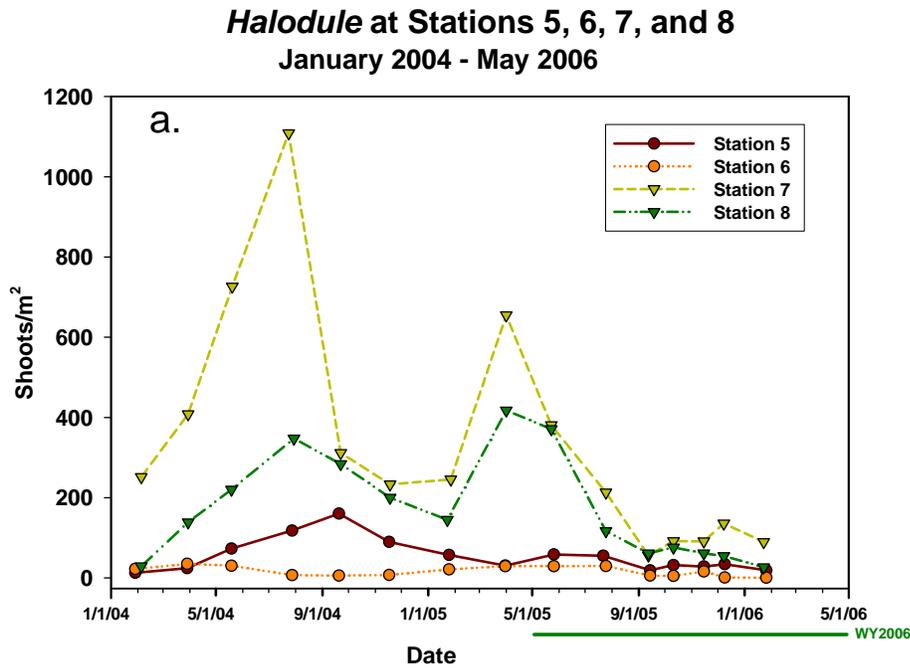


Figure 2. Time series density of seagrass: (a.) *Halodule wrightii*; and (b) *Thalassia testudinum* (turtle grass) in the Caloosahatchee Estuary and San Carlos Bay, with the time period of a Water Year indicated (WY: May 1 –April 30). Data collected by the Sanibel-Captiva Conservation Foundation.

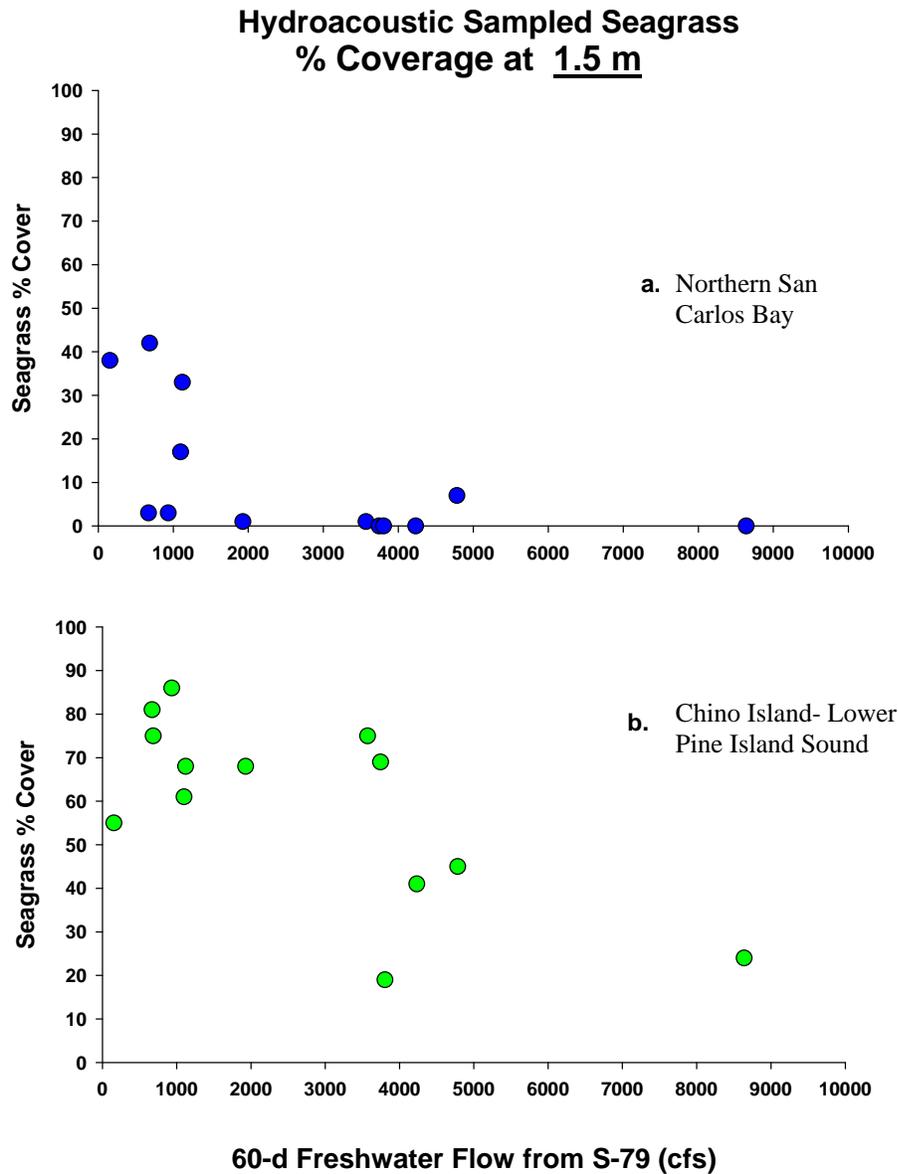


Figure 3. Seagrass coverage at two locations downstream of the Caloosahatchee River (a. Site 7; and b. Site 9-in Figure 1) compared to 60-day average freshwater inflow from S-79 prior to sampling.

These estimates can be put on a relative HSI scale from 0 to 1 as reflected in Figure 5. However, this scale better reflects the quality of habitat (e.g. plant growth potential and health), not the amount of coverage (acres), which is one of the HSI modeling objectives. For example, a HSI =1.0 or 0.5 both represent an area with plant coverage that is sustainable between months. To address this issue, a “50% Approach” was adopted, whereby a single linear line from the minimum ADBL during the winter in Iona Cove to the PAR level of 150uE is used that represents 50% of saturation during the summer growing season in San Carlos Bay (Figure 5).

Table 1. Habitat Requirements for the Seagrasses, *Halodule* and *Thalassia*. The following table summarizes S-79 inflow criteria (mean monthly cubic feet per second), important salinity ranges, and water quality requirements for the protection and support of *Halodule* and *Thalassia* in the Caloosahatchee Estuary.

Variable	Estuary Area	Value	Source
<i>Halodule</i> and <i>Thalassia</i>	Throughout their range	<u>Light to 1m:</u> 1) Min. 20-25% of Subsurface irradiance 2) Minimum attenuation Coef -1.5 3) Most important during warm growing season 4) Recovery goal: Deeper, 2m? 5) Optimal Productivity at 300 mE	Kenworthy and Haurert 1991 Tomasko and Hall 1999 Dixon and Leverone 1995 Herzka and Dunton 1997 Fong et al. 1997
<i>Halodule</i>	Throughout its range	<u>Salinity:</u> 1) 3.5ppt - minimum tolerance; duration of tolerance 1-2 months; Recovery 1 year (following winter and spring) of preferred salinity 2) Prefers > 20ppt, below which productivity declines 3) Optimum, seawater ~ 35ppt 4) Location requirements – long term average salinity >20ppt, std. dev. < 10ppt  <u>Temperature:</u> 1) Greatest productivity during March – September (Possibly a magnitude more biomass in shallow areas of Area 6) 2) Optimum 22-26°C	Ziemann and Ziemann 1989 McMahan 1968 Chamberlain and Doering 1998b Chamberlain (Pers. field/lab obs) 2004  Chamberlain (Pers. field/lab obs/analysis) 2004 Fong et al. 1997
	Area 5	<u>Flow</u> (to achieve above salinity and light limits): 1) Max < 3,000 cfs 2) Preferred < 1000 cfs 3) Optimum < 500 cfs	Chamberlain and Doering 1998b Doering et al. 2002
<i>Thalassia</i>	Throughout its range	<u>Salinity:</u> 1) ~ 6ppt - minimum tolerance; duration tolerance 1-2 months; Recovery 1 year (following winter and spring) of preferred salinity;	Chamberlain and Doering 1998b Doering and Chamberlain 2000 Doering et al. 2002 Ziemann and Ziemann 1989 Ziemann et al 1999 Chamberlain (Pers. field/lab obs/analysis) 2004

		<p>Mortality when 0 ppt for <math>\geq 3</math> weeks – no recovery</p> <p>2) Prefers &gt; 20ppt, &lt; 17ppt productivity declines</p> <p>3) Optimum, 24-35ppt</p> <p>4) Location requirements – long term average salinity &gt;20-25ppt, std. dev. <math>\leq 5</math>ppt</p>	
		<p><u>Temperature:</u></p> <p>1) Greatest productivity during March – September</p> <p>2) Optimum when <math>\sim 30^{\circ}\text{C}</math></p> <p>3) Decreased productivity @ <math>&lt; 20^{\circ}\text{C}</math></p> <p>4) Stressful when water temp <math>&lt; 15^{\circ}\text{C}</math> (winter)</p> <p>5) Mortality - month <math>&gt; 36^{\circ}\text{C}</math></p>	<p>Chamberlain (Pers. field/lab obs/analysis) 2004</p> <p>Dawes et al. 1997</p> <p>Koch and Erskine 2001</p> <p>Miller 2000</p>
<i>Halodule and Thalassia</i>	Area 6	<p><u>Flow</u> (to achieve above salinity and light limits):</p> <p>1) Max 4,500 cfs</p> <p>2) Preferred <math>&lt; 2,500</math> cfs</p> <p>3) Optimum <math>&lt; 1,000</math> cfs</p>	<p>Chamberlain and Doering 1998b</p> <p>Chamberlain 1995</p> <p>Doering et al. 2002</p>

The formula for calculating ADBL is based on the Lambert-Beer equation, which requires knowing: (1) surface incident light in the PAR spectral range; (2) water column light attenuation (K); and (3) depth. Average monthly incident PAR for the Caloosahatchee is depicted in Figure 6 and was calculated from a daily average PAR dataset, recorded by a continuous sensor during 1998-2004, located in the nearby Estero Bay Watershed. Light attenuation was calculated based on the curvilinear relationships of salinity and simultaneous light attenuations measurements (Figure 7) at stations upstream and downstream of Shell Point (Figure 8). Depth was determined from bathymetry surveys of the Caloosahatchee Estuary and the resulting information supplied in a GIS data file that matched the grid cell points of the model.

Seasonal patterns are an indication of the influence and importance of temperature on seagrass, with the best growth occurring between the 22 and 30°C range. In addition, temperature will affect photosynthesis by altering the rate of biochemical reactions of photosynthesis. Therefore, ecological models of seagrass include temperature as a variable governing seagrass growth predictions (Fong et al. (1887). Based on these literature results and those identified in Table 1, a HSI temperature curve was developed (Figure 9) that indicates the relative importance and input value to the HSI model, as per the estimated daily average (ambient) temperature (Figure 10).

# HSI for the Seagrass, *Halodule wrightii* and *Thalassia testudinum*

## HSI Variables and Summary Formula

Habitat suitability for the combined grasses *Halodule wrightii* and *Thalassia testudinum* is calculated monthly as a geometric mean:

$$\text{HSI} = (\text{Previous}^w * \text{Salinity}^w * \text{Temperature}^w * \text{LightAvailability}^w)$$

Where  $w$  = the weight for each variable and the sum of  $w = 1$ . In the accepted model, each of the variables has been weighed equally, so  $w = 0.25$ .

### Previous

"Previous" variable included because current month's HSI score should depend on the how well the grass was doing last month (previous score). In the model application, Previous = previous\_month\_HSI score + 0.05, (not to exceed 1.0), in order to allow for growth from month to month, if other conditions are suitable.

Table 2. Changes to HSI model's spatial boundaries (A and B) and post-processing routines (C) for adjusting the final HSI ecological model scores to better reflect long-term impacts of severe reduction in seagrass coverage due to low HSI scores of environmental variables (salinity, light and temperature in above model formula).

Routine	Model output criteria	Model score adjustment
A.	Apply new masks for the three areas of the estuary (Pine Island, San Carlos Bay, and Iona Cove)	Consider them separately and evaluate the spread across them
B.	Establish a lower depth threshold of 5 ft and 7ft in San Carlos Bay and Pine Island Sound	Model areas > depth thresholds are not scored
C.	If HSI score $\leq 0.1$ for one month,	Than HSI = 0.1 for remainder of season

Adjustments were agreed to by ecological benefits sub-team (6/14/06)

## HSI Curves and Application (for determining HSI variable input values)

### Salinity

HSI Calculation – Values based on the literature identified in Table 1, along with SFWMD laboratory and field research, which resulted in the curvilinear relationship between HSI values and salinity depicted below in Figure 4.

Data Source - Freshwater inflows are estimated for S-79 and from the tidal basin using hydrologic models. Flows are generated for each base-case and proposed alternative.

These flows are input for the CH3D hydrodynamic salinity model and associated regression routine, which calculates salinity at fixed locations in the estuary. Using a spatial interpolation program, salinity is then calculated throughout the estuary at each GIS cell point where a HSI value is determined.

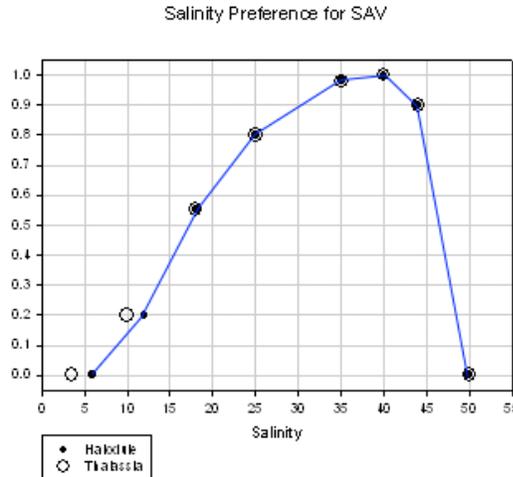


Figure 4. Habitat suitability index value for seagrass response to salinity.

#### Available light at Depth (based on *Halodule wrightii* requirements)

HSI Calculation – Literature provided estimates of the light needed by *Halodule*, ranging from the minimum requirements to the maximum a plant can utilize. Since this project is interested in estimating the area of coverage and not the density, a 50% line was used to estimate HSI related to potential for presence (Figure 5).

#### Data Source

- Depth - Recent bathymetry data provided in GIS format to match HSI cells.
- Available incident light at the surface (surface irradiance = SI) - Daily average value estimated from a continuous sensor (7 year period of record, 1998-2004: Figure 6).
- Light attenuation (K) - Amount of Photosynthetic Active Radiation (PAR) lost with increasing water depth. Field measured values were correlated with simultaneous field measurements of salinity from upstream of Shell Point (Iona Cove area) and downstream (San Carlos Bay and Pine Island Sound) using non-linear regression (Figures 7 and 8).
- Amount of light at depth (ADBL) for each HSI cell – Determined using the Lambert-Beer equation (  $[(0.9*SI)*e^{-K*depth}]$  ), which requires input of the incident light just below the water surface (.90(SI)), the attenuation coefficient (K), and depth of each GIS cell.

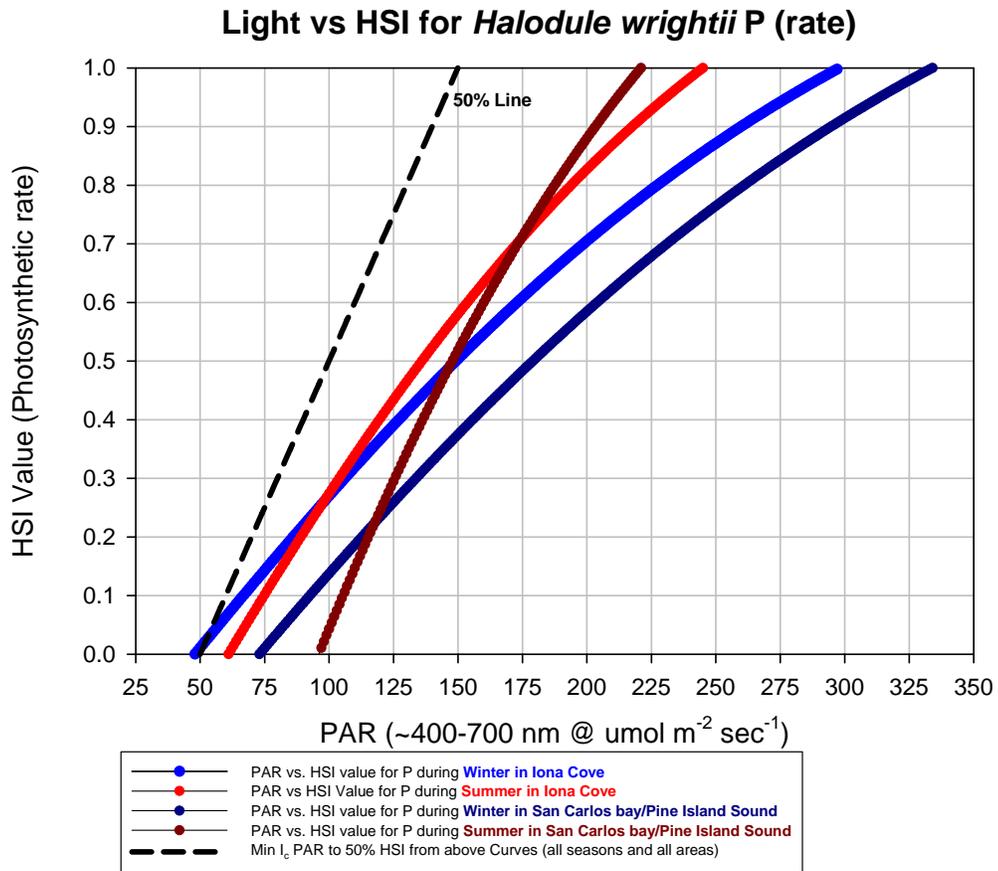


Figure 5. Habitat suitability index value for seagrass response to light. HSI values represent the relative amount of average daily light required by *Halodule wrightii*. The 50% line was used in the model to indicate relative light vs. plant's need to maintain presence

### Available Light at the Surface

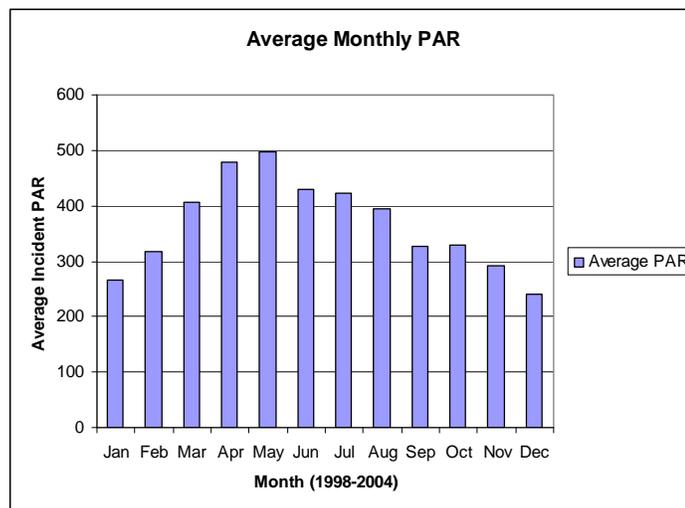


Figure 6. Average Monthly Photosynthetic Active Radiation (PAR)

**San Carlos Bay and Iona Cove**  
Light Attenuation vs Salinity

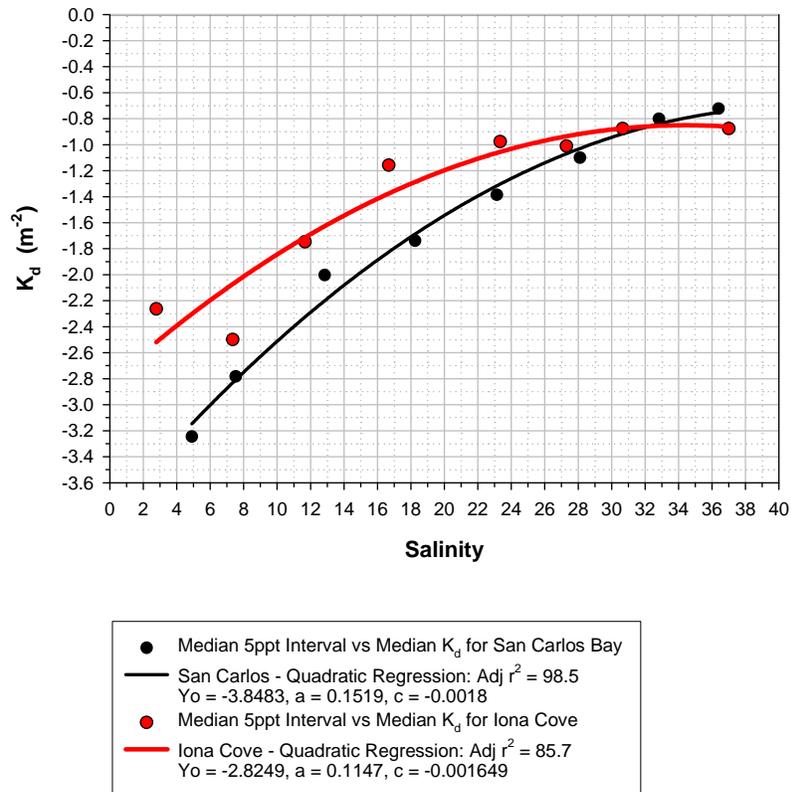


Figure 7. Light attenuation vs. Salinity in seagrass areas.

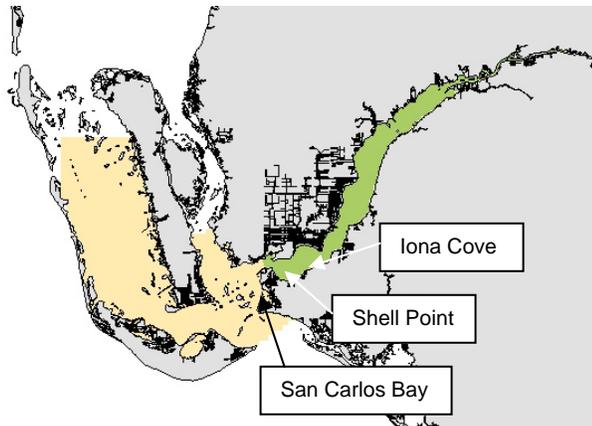


Figure 8. Light attenuation regions. The model uses Iona Cove light attenuation relationships for areas east of Shell Point and San Carlos Bay light attenuation relationships for areas west of Shell Point.

## Temperature

HSI Calculation – Preferred temperature range of seagrass (Figure 9) based on literature values (Dawes et al. 1997, Koch and Erskine 2001, Miller 2000).

Data Source – HSI uses a monthly average estimated water temperature. The single monthly value is estimated by fitting a non-linear regression line to daily temperature vs. day of the year (Period of record beginning in 1993), so each day has about 13 temperature values (Figure 10).

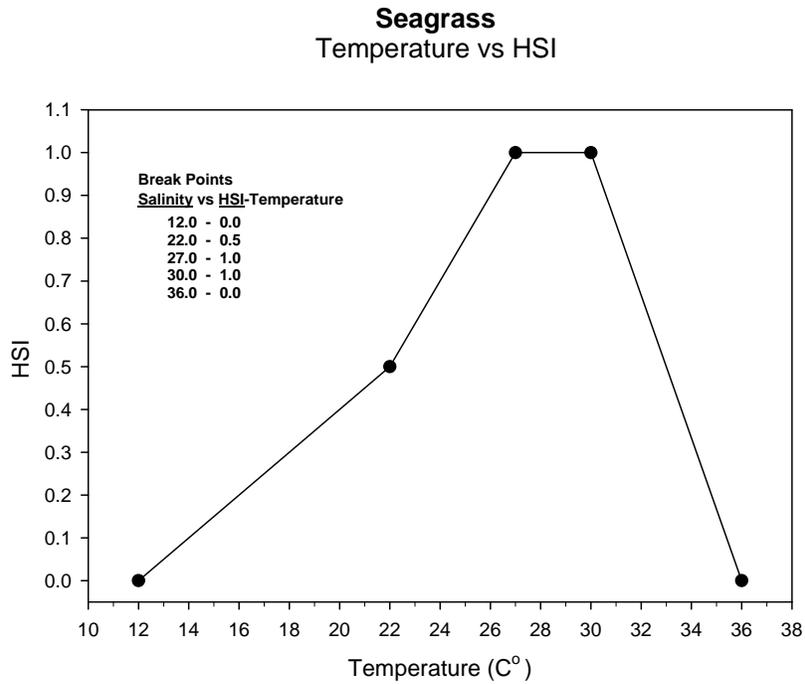


Figure 9. Habitat suitability index value for seagrass response to temperature.

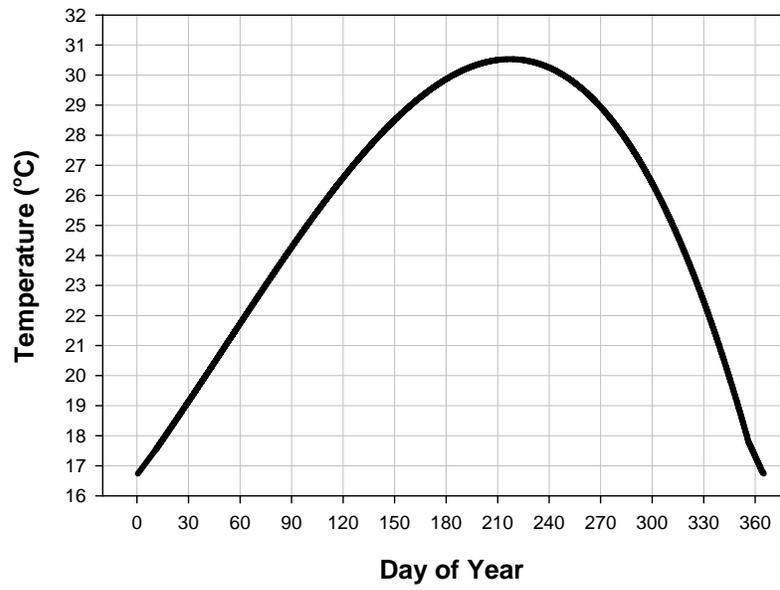


Figure 10. Estimated water temperature in the Caloosahatchee Estuary adjacent to seagrass area.

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