WATER QUALITY TARGET DEVELOPMENT IN THE SOUTHERN INDIAN RIVER LAGOON

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Abstract: *Water quality and seagrass data collected from 1990 to 1999 for the Southern Indian River Lagoon (SIRL) were evaluated for a correlative link between water quality and the deep edge of seagrass bed depth and to use water quality at sites with the deepest edge of bed depths to establish water quality targets for protecting and restoring seagrass. Spearman's rank correlation revealed significant relationships between several water quality parameters and deep edge of seagrass bed depth. Color, turbidity, and light attenuation (K) were inversely correlated with edge of bed depth; while salinity and pH were directly correlated. Additionally, light attenuation (K) was significantly ($p < 0.001$) correlated with turbidity and color. The 25th and 75th percentiles for water quality parameters (associated with seagrass sites supporting the deepest edge of bed depths) were used to establish water quality targets for the SIRL: salinity ($\geq$28.3 ppt), turbidity ($\leq$4.6 NTU), color ($\leq$13 PCU), and K (≥ -1.0 m^{-1}).*

Key Words: Indian River Lagoon, seagrass, water quality targets

Seagrasses are a prominent component of the Indian River Lagoon (IRL) ecosystem and may be the basis of detrital food chains (Zieman and Zieman, 1989). Seagrass meadows provide habitat for many benthic and pelagic organisms (Thayer et al., 1984), as well as acting to stabilize sediments (Fonseca and Fisher, 1986; Madsen et al., 2001). Seagrasses are sensitive to changes in water quality (Kemp et al., 1983; Twilley et al., 1985), are often included in monitoring programs as indicators of estuarine health (Tomasko et al., 1996), and are being used to set resource-based management targets (Virnstein and Morris 2000; Steward et al. 2005; Corbett and Hale 2006).

Restoration and protection of seagrasses is a primary goal of the IRL Surface Water Improvement and Management (SWIM) Plan (Steward et al., 2003) and the Restoration Coordination and Verification (RECOVER) Monitoring and Assessment Plan (MAP) of the Comprehensive Everglades Restoration Plan (CERP, United States Army Corps of Engineers and South Florida Water Management District, 2004). These plans direct the South Florida Water Management District (SFWMD) to restore and protect seagrasses by improving water quality in the lagoon. This direction is based on the observation that water quality parameters, especially those that effect light affect seagrass.

Several water quality parameters are especially relevant to achieving CERP and SWIM goals. These are total suspended solids, turbidity, color,

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chlorophyll *a*, total phosphorus, and total nitrogen. Total suspended solids, turbidity, and color have all been shown to be negatively related to light availability (Dennison et al., 1993; Gallegos, 1994; Gallegos and Kenworthy, 1996); thus an increase in any or all these factors results in a decrease in the ability of seagrass to photosynthesize. Similarly, increased concentrations of nutrients can indirectly reduce the amount of light penetrating through the water column by promoting the growth of phytoplankton, epiphytic algae, and/or macroalgae each of which may be detrimental to seagrass.

The objectives of this study were to: 1) establish a correlative link between water quality and the deep edge of seagrass bed depth in the southern IRL (SIRL); and 2) use water quality at the sites with the deepest edge of bed depth to establish water quality targets for protecting and restoring seagrass in the SIRL. The "performance" metric used in this study was the depth of the seagrass bed's deep edge. This metric has been shown to reflect the relationship between seagrass and water quality because light availability often determines the depth to which seagrass grows (Dennison, 1991). In addition, water quality significantly influences the depth to which light can penetrate through the water column (Gallegos et al., 1991).

Setting management targets based on seagrass parameters is an important first step toward seagrass restoration and protection (Virnstein and Morris 2000, Steward et al. 2005, Corbett and Hale 2006). The water quality targets developed through this study will be used in conjunction with watershed and estuary modeling to estimate the pollutant load reductions from the watershed needed to meet the SIRL seagrass targets. These targets may be revised as additional water quality/seagrass data become available and based on the feasibility of implementing watershed strategies needed to meet the targets.

Study Area—The IRL extends approximately 250 km along the east coast of Florida (Fig. 1 inset) from the Ponce de Leon Inlet in Volusia County to the Jupiter Inlet in Palm Beach County. This study was conducted within the SIRL between the northern St. Lucie County line and Jupiter Inlet, an area encompassing 127 km^2 (Fig. 1). This section of the lagoon is flushed by three inlets (Ft. Pierce, St. Lucie, and Jupiter) and supplied with freshwater by sources which include the C-25 Canal (Taylor Creek) and the St. Lucie River.

The IRL SWIM Plan identifies 26 seagrass management units or "segments" throughout the IRL (Steward et al., 2003) with five, Segments 22 through 26, lying within the SIRL (Fig. 1). The SIRL seagrass segment boundaries were developed through the IRL SWIM planning process and were based on the results of water quality evaluations, as well as, factors such as physical configuration and surrounding land use.

MATERIALS AND METHODS—*Seagrass Monitoring*—The data analyzed herein represent a subset ($n=18$) of seagrass transects ($n>70$) monitored by the St. Johns River Water Management District (SJRWMD) and SFWMD that were initially established in 1994. Although both winter and summer data are collected, only summer data are included in this study. This decision was based on

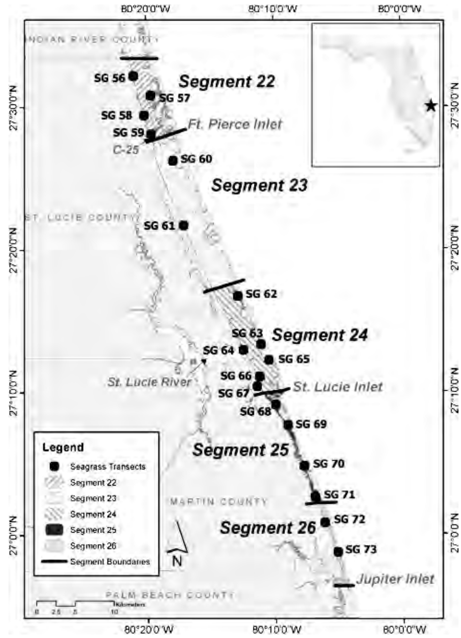

FIG. 1. Map of the Southern Indian River Lagoon, showing segments, seagrass transect locations, major freshwater sources, inlets, and landmarks.

the observation that maximum biomass (Dawes et al., 1995) and highest shoot density (Morris et al., 2000) occur during this season.

Transects are located at fixed sites with permanent stakes marking the ends and extend from the shore to the deep edge of the seagrass bed. Monitoring is conducted by placing 1 m^2 quadrats at regular intervals (5–10 m intervals) along the transect line to determine seagrass parameters as described by Morris et al. 2000. The variables measured and used for this study include: species composition and depth distribution. Water depths along each transect were referenced to Mean Sea Level (MSL) using data from a bathymetric survey conducted for the SFWMD in 1997.

Halodule wrightii and *Syringodium filiforme* are the most abundant seagrass species in the IRL (Thompson, 1978; Dawes et al., 1995; Morris et al., 2000) and have similar light requirements (Kenworthy and Fonseca 1996). For this study, the deep edge of a seagrass bed was defined as the last occurrence along a transect of *H. wrightii* and/or *S. filiforme*. Other seagrass species present in the SIRL include *Thalassia testudinum*, *Halophila decipiens*, *H. johnsonii*, and *H. engelmannii*. Minimal light requirements for *Thalassia testudinum* and *Halophila engelmannii* appear to be similar to light requirements for the two dominant species, while light requirements for *Halophila johnsonii* and *H. decipiens* appear to be less (Dawes et al. 1989, Dennison et al. 1993; Kenworthy and Fonseca 1996). Accordingly, the optical water quality targets developed through this study for protecting and restoring *H. wrightii* and *S. filiforme* should also be appropriate for the other SIRL seagrass species.

Water Quality Monitoring—To detect long-term water quality trends in the SIRL the SFWMD established 40 water quality stations that were monitored quarterly (January, April, July, and October) from October 1990–July 1999. All water quality samples were collected in accordance with the Florida Department of Environmental Protection (FDEP) approved SFWMD Comprehensive Quality Assurance Plan (# 870166G). *In situ* physical parameters were measured with a Hydrolab Surveyor III at three depths (surface, mid, and bottom) when the total depth at a site was >2 m; if <2 m, measurements were taken at mid depth only. Physical measurements collected at each monitoring station consisted of: temperature, dissolved oxygen, pH, conductivity, salinity, and Secchi disk depth.

Water samples collected at mid depth using a Wildco 2.2-L Van Dorn PVC horizontal sampling bottle, were analyzed for: total Kjeldahl nitrogen, total phosphorus, nitrite + nitrate, orthophosphate, total suspended solids, volatile suspended solids, turbidity, and color. Samples for chlorophyll *a* determination were also collected with the Wildco 2.2-L Van Dorn PVC horizontal sampling bottle at half the Secchi disk depth.

Photosynthetically active radiation (PAR) was measured using a LiCor datalogger and three 4-pi quantum sensors: one located on the deck of the boat (deck cell), one lowered to a depth of 10 cm (10 cm cell), and the third lowered through the water column at 4–6 predetermined intervals to a depth not to exceed 170 cm. In January 1996, the PAR methodology was modified to ensure consistency throughout the entire IRL. The modifications included the 10 cm cell being moved to 20 cm, and third sensor lowered through the water column at 20 cm intervals until reaching 100 cm (i.e. 20, 40, 60, 80, 100); the next reading was taken at 170 cm and thereafter at one meter intervals (170, 270 cm…).

To compare light attenuation values from water quality stations throughout the SIRL, light attenuation values from each depth (K_d) were regressed against depth to calculate one light attenuation coefficient (K) for each water quality station per sampling event. Light attenuation coefficients (K_d) for each depth in a profile were calculated *sensu* Kenworthy (1991) as follows:

$$K_d = \frac{\ln(I_z) - \ln(I_o)}{Z}$$

Where;

I_z = underwater quantum irradiance at depth z in umol/m^2/sec
I_o = underwater quantum irradiance at 10 cm (or 20 cm) depth in umol/m^2/sec
Z = depth at $I_z - 0.1$ (or 0.2) in meters
K_d = diffuse light attenuation coefficient per meter

The I_o value includes an immersion factor which was calculated by subtracting the light reading at the 10 cm or 20 cm depth from the deck cell reading. The immersion factor was then subtracted from all subsequent deck cell readings in a profile and an I_o value computed for each submarine reading, I_z.

Water Quality and Seagrass—Of the 40 water quality stations, 13 were selected for this study based on proximity to a seagrass transect (Fig. 2). All water quality stations were located within 3.5 km of a seagrass transect. Two of the water quality stations were used to represent more than one seagrass transect (IRL 17 was used to represent five seagrass transects and IRL 36 was used to represent two seagrass transects).

Spearman's rank correlation coefficient was used to investigate the relationship between water quality and the deep edge of bed depth. Correlation coefficients for all parameters were calculated using data from all seagrass transects and associated water quality stations for wet season (July and October) samples collected between 1994 and 1999. Although both wet and dry season data were collected, only wet season data were used to best reflect water quality conditions during the time of maximum seagrass biomass and highest shoot density.

Seagrass and Water Quality Targets—From transect data, a mean for the deep edge of bed depth was calculated for each of the five SIRL segments. The segment with the greatest mean edge of bed depth was identified. The average deep edge of bed depth and the 95% Confidence Interval (CI) for this segment were calculated. The lower bound of the CI served as the benchmark depth for this project. All SIRL seagrass transects with mean deep edge depths equal to or greater than this benchmark were identified. Water quality data associated with these transects was used to derive

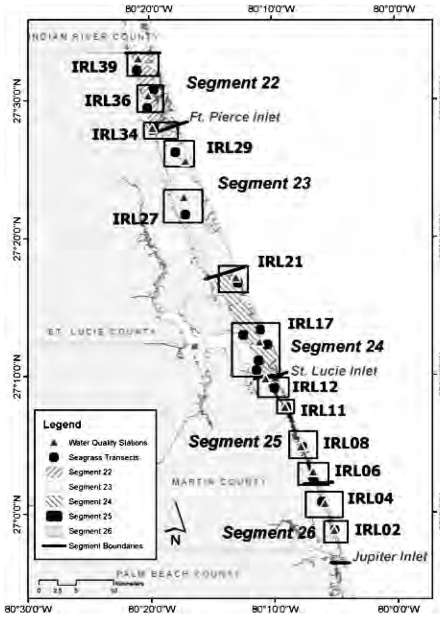

FIG. 2. Map showing water quality stations and associated seagrass transects used to assess the relationship between water quality and seagrass performance. Boxes include one water quality station and associated seagrass transect(s).

the water quality concentration targets. The 25th and 75th percentiles for water quality parameters were used to establish the targets.

RESULTS—*Seagrass Transects: Deep Edge of Bed*—The mean deep edge of bed depths per transect varied (Fig. 3). The second transect north of Jupiter Inlet (SG 72) had the deepest mean edge of bed depth. The shallowest edge of bed depths were found at transects near the mouth of the St. Lucie River (St. Lucie Inlet area). As distance increased from the mouth of the St. Lucie River, so did the edge of bed depth.

Water Quality – Seagrass Correlations—The Spearman's rank correlation revealed that five parameters (K, color, turbidity, salinity, and pH) showed significant correlation with seagrass edge of bed depth (Table 1), however, none explained more than 33% of the observed variance. Color and turbidity were inversely correlated with the seagrass edge of bed depth. Conversely, as salinity increased, so did the seagrass edge of bed depth. K and deep edge of bed depth showed a significant correlation (Figure 4; Spearman's rs $= -0.32$, $p < 0.05$, $n = 78$). As light attenuation in the water column increased, the seagrass edge of bed depth decreased. The light attenuation coefficient itself was correlated with turbidity (Spearman's rs $= -0.33$, $p < 0.001$, $n = 102$) and color (Spearman's rs $= -0.30$, $p < 0.001$, $n = 102$).

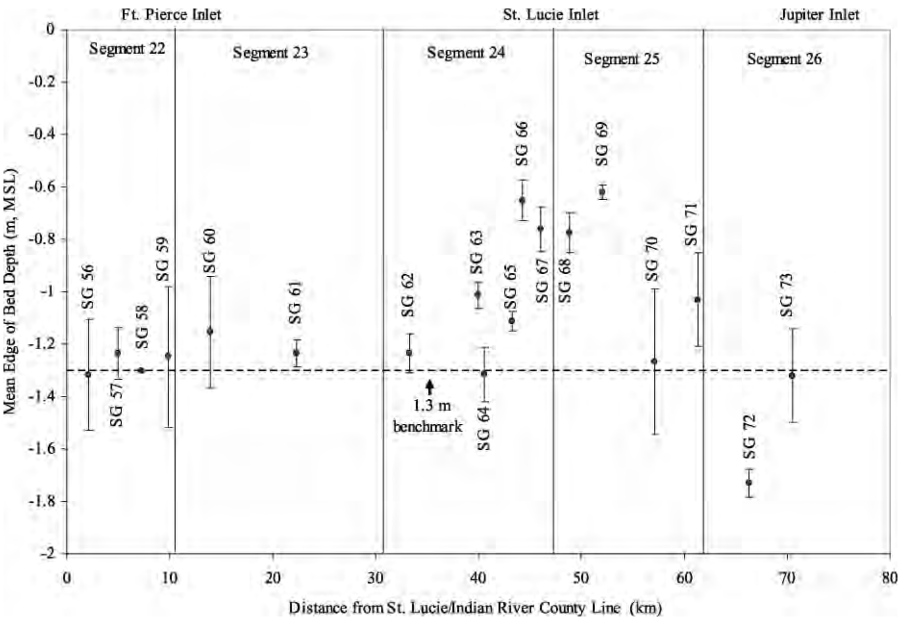

FIG. 3. Depth at the edge of seagrass bed. Transect means (± standard deviation) are shown with filled circles (•) and segment means with filled squares (■). Means were derived from 1994–1999 summer transect data. Transect numbers are prefaced with "SG".

Water Quality Targets—Segment 26 had the deepest mean edge of bed depth (−1.5 m, MSL; Figure 3). The lower bound of the 95% CI for Segment 26 was −1.3 m MSL (the benchmark depth for this evaluation). Five transects located throughout the SIRL (Transects 56, 58, 64, 72, and 73) had mean edge of bed depths greater than or equal to the benchmark depth (Figure 3). Wet season water quality data associated with these five transects were used to develop the water quality targets (Table 2).

A comparison of the proposed SIRL water quality target values with the median wet season water quality from all 40 SIRL water quality stations (July and October data from 1990–1999) is provided in Table 3. A high percentage of these values exceed the proposed SIRL water quality targets.

DISCUSSION—Light is a significant controlling factor in the depth distribution of seagrass in the SIRL. Turbidity and color, which attenuate light, significantly affect SIRL seagrass distribution. Most of the increased color and turbidity values in the SIRL are being delivered with high flows of fresh water discharge, which in turn reduce the salinity values in the lagoon. Reducing flows to the SIRL will increase salinity and reduce turbidity, color, and light attenuation values.

The lack of a significant correlation between Chl *a* and seagrass edge of bed depth might suggest that the "eutrophication scenario" (sensu Kemp et al. 1983), in which excess nutrient loading leads to increases in Chl *a* concentra-

TABLE 1. Correlations between water quality parameters and seagrass edge of bed depth (Spearman's Rank Correlation; *significant relationships).

Parameter	n	rs statistic	95% CI	2-tailed p
Color (PCU)	102	−0.30	−0.47 to −0.12	0.002*
Volatile Suspended Solids (mg/L)	102	−0.01	−0.20 to 0.19	0.946
Turbidity (NTU)	102	−0.33	−0.50 to −0.15	0.001*
Total Suspended Solids (mg/L)	102	−0.03	−0.22 to 0.17	0.766
Total Phosphorus (mg/L)	69	−0.08	−0.31 to 0.16	0.536
Orthophosphate (mg/L)	69	−0.07	−0.30 to 0.17	0.573
Total Kjeldahl Nitrogen (mg/L)	79	0.04	−0.18 to 0.26	0.730
Total Nitrogen (mg/L)	84	0.09	−0.13 to 0.30	0.406
Nitrate + Nitrite (mg/L)	102	−0.11	−0.30 to 0.08	0.254
Nitrite (mg/L)	84	0.12	−0.10 to 0.33	0.270
Chlorophyll *a* (mg/m3)	97	−0.16	−0.35 to 0.04	0.125
Secchi Disk (m)	75	0.21	−0.02 to 0.42	0.068
Salinity (ppt)	93	0.30	0.10 to 0.47	0.004*
Dissolved Oxygen (mg/L)	94	0.15	−0.05 to 0.35	0.139
pH units	93	0.23	0.03 to 0.42	0.026*
K (m^{-1})	78	−0.32	−0.50 to −0.10	0.005*

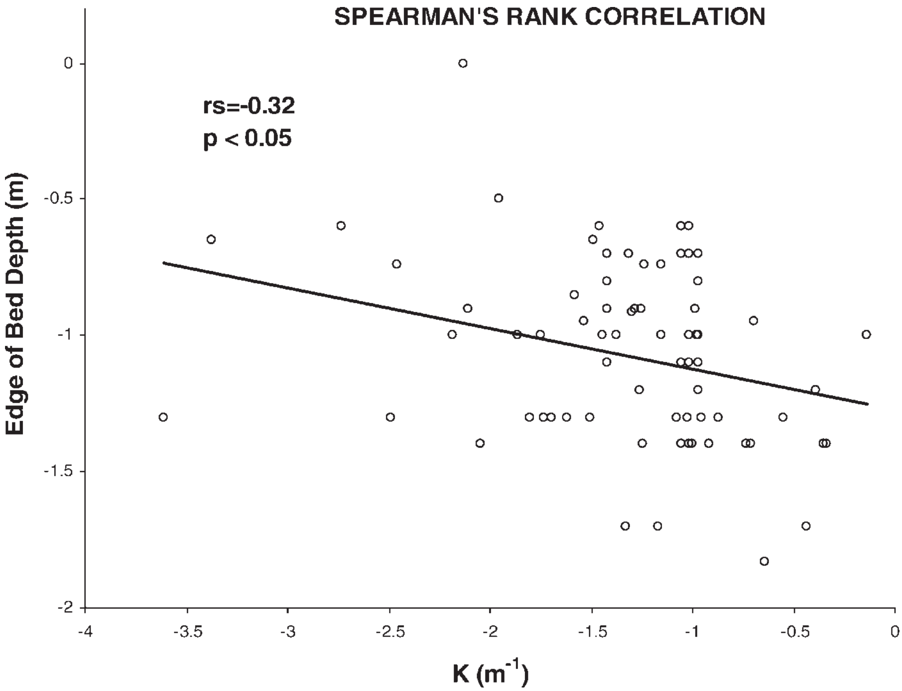

FIG. 4. Correlation between depth at the edge of seagrass beds and K.

TABLE 2. Water Quality Targets for the Southern Indian River Lagoon ([a] limit not an appropriate measure for seagrass growth).

Parameter	25th Percentile	Median Value	75th Percentile
Color (PCU)	[a]	8	≤13
Turbidity (NTU)	[a]	2.84	≤4.6
Total Suspended Solids (mg/L)	[a]	20	≤28
Total Phosphorus (mg/L)	[a]	0.053	≤0.070
Orthophosphate (mg/L)	[a]	0.023	≤0.037
Total Nitrogen (mg/L)	[a]	0.7	≤1.1
Nitrite + Nitrate (mg/L)	[a]	0.004	≤0.008
Chlorophyll a (mg/m^3)	[a]	3.1	≤5.3
Secchi Disk (m)	≥1.0	1.4	[a]
Salinity (ppt)	≥28.3	30.4	[a]
K (m^{-1})	[a]	−1.2	≥−1.0

tions and decreases in light, is not occurring in the SIRL. Kenworthy and Fonseca (1996) reached a similar conclusion for Hobe Sound, located near the southern end of our study area.

Although the Spearman's rank correlation of the deep edge of bed depth with water quality was not significant for all the parameters, targets are being proposed for all of the parameters listed in Table 2. Following the logic of Dennison et al. (1993) and Stevenson et al. (1993), efforts to meet all the water quality targets should help maintain or increase the seagrass edge of bed depth and therefore improve the overall health of the seagrasses in the SIRL.

The proposed water quality target values are the first step in the Pollutant Load Reduction Process for the SIRL. Ultimately, the SIRL water quality target values will be used in conjunction with hydrodynamic/water quality and

TABLE 3. Comparison of Water Quality Targets to Historic Values ([a] indicates significant correlation to seagrass edge of bed depth).

Parameter	Target Values	Number of Samples	Number of Exceedances From Target Values: Dry Season	Number of Exceedances From Target Values: Wet Season	Percent Exceedance from Target Values
Color (PCU)[a]	≤13	1322	206	379	44
Turbidity (NTU)[a]	≤4.6	1350	443	268	53
Total Suspended Solids (mg/L)	≤28	1345	257	224	36
Total Phosphorus (mg/L)	≤0.070	1270	112	193	24
Orthophosphate (mg/L)	≤0.037	1260	75	176	20
Total Nitrogen (mg/L)	≤1.1	1244	75	114	15
Nitrite + Nitrate (mg/L)	≤0.008	1352	293	253	40
Chlorophyll *a* (mg/L)	≤5.3	1179	179	321	42
Salinity (ppt)[a]	≥28.3	1295	180	310	38
K (m^{-1})[a]	≥−1.0	598	79	102	30

watershed modeling to evaluate the pollutant load reductions needed in the watersheds to meet the targets.

To better understand the water quality/seagrass link in the SIRL, modifications have since been made to the SIRL water quality monitoring network. Beginning on January 10, 2000, water quality stations were co-located with 10 of the 18 seagrass transects in the SIRL. The monitoring was increased from quarterly to 7 times a year. These new data collected specifically at the seagrass transects will help validate relationships between WQ and seagrass, and thus refine the targets.

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