



Water clarity criteria for seagrass protection in Sarasota Bay: An optical model and assessment tool

Final Report

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EXECUTIVE SUMMARY

Seagrasses are a key indicator of estuarine health and the protection of seagrass beds are a cornerstone of the Sarasota Bay Estuary Program's Comprehensive Conservation and Management Plan (SBEP, 2014). Throughout southwest Florida, estuarine water quality criteria have been developed to provide sufficient light penetration to allow for the proliferation of seagrass beds which has proven to be a successful mechanism by which to protect estuarine health. The management paradigm relates water column light attenuation to the depth of penetration of light, which in turn controls the acreage and depth distribution of seagrasses in estuaries. While attenuating substances, color, chlorophyll and turbidity, are easily and routinely measured as part of existing estuarine water quality monitoring programs, direct measurements of light attenuation (i.e. "water clarity") are difficult and complicated by wave action, cloud cover, shading from the sampling vessel, bottom reflectance, and mineralized turbidity that exponentially increases the scattering of light through the water column in unpredictable ways.

Numerical modeling of the diffuse light attenuation coefficients (K_{dPAR}) from laboratory-determined parameters has been shown to be a reliable supplemental method to evaluate water clarity and derive criteria where field light attenuation has been highly variable. Accordingly, a spectrally explicit optical model was constructed and parameterized as a function color, chlorophyll and turbidity. The optical model was calibrated with data from Sarasota Bay where data density and ranges in parameter values were greatest, and applied to all segments. The modeled diffuse attenuation coefficients (K_{dPAR}) agreed well with observed data with a slope of the relationship of 0.97.

Seagrass depth distributions were updated using the most recent available data through the 2014 mapping event. Segment-specific target depths for seagrass were selected by a process similar to that used for previously determined target acreages, using the maxima of either the 1950's or the average of 2004 and 2006 95th percentile of depth distribution. The largest seagrass mapping segment, Sarasota Bay, was shown to be heterogeneous both for seagrass depth distributions and water quality parameters and was therefore sub-segmented based on a prior water quality segmentation scheme. Target seagrass depths ranged between 1.5 and 3.1 m. A water clarity reference period of 2003-2005 was designated to associate with seagrass depths determined in early 2004 and 2006. Mapping indicated that both coverage and maximum depths have increased in several segments from the target reference period.

Quantile regression was used to relate the distribution of modeled K_{dPAR} , between aerial seagrass mapping events to the seagrass depth distribution at the closest subsequent event. Benchmark values in the cumulative distribution of K_{dPAR} , specifically the 20th to the 40th percentiles, were significantly related to variation in seagrass depths indicating that the duration of high clarity conditions over two or more successive growing seasons may be the most critical for seagrass depth changes in most segments. A Water Clarity Reporting Tool was then developed using the benchmark values of modeled K_{dPAR} , and a reference period (2003-2005) reflective of the distribution of water clarity prior to the seagrass target mapping event. A water clarity "score" was computed using the binomial test to evaluate the distribution of modeled K_{dPAR} relative to the benchmark values (i.e. the 20th and 40th percentile values). When water clarity was significantly greater than expected for each benchmark, a score of 1 was applied while if the water clarity was significantly less than expected, a score of negative 1 was applied. If conditions were stable, a zero was applied. The annual scores were summed and the scores were color coded as "Stable", "Caution" or "Declining" conditions, using Green, Yellow and Red, respectively. There were very few instances of "Declining" scores which corroborated the aerial mapping events indicating

that seagrass acreage and depth distributions have been increasing in most segments. . Illustrations of trends in scores, averaged over 2 or three years, were generally consistent with changes in seagrass depths and support the utility of the method; however, there were periods of predicted decreases in water clarity that were independent of higher rainfall events, suggesting additional influences on seagrass cover beyond water clarity.

The optical model and Water Clarity Reporting Tool provide an important and straightforward method of disseminating complex light attenuation processes to both natural resource managers and the lay public to accurately report on estuarine light attenuation conditions affecting a key indicator of estuarine health. While the increase in seagrass cover experienced since 2006 may lead to a re-evaluation of seagrass area and depth targets and water clarity reference periods, the techniques of the optical model and Reporting Tool remain valid and can be readily updated to any future desired reference periods.

ACKNOWLEDGMENTS

This project and the management and protection of critical seagrass habitat would not be possible without the long term and continued mapping efforts of the Southwest Florida Water Management District. We also wish to express our appreciation for the long term and continuing efforts of the samplers, analytical staff, funding agencies, and all participants in the Regional Ambient Monitoring Program of Sarasota and Manatee Counties, whose data made this project possible. We also recognize Ms. Bridgette Froeschke for assistance with earlier R-coding, Mr. Jon Perry for GIS analyses, and Mr. David Gordon for data retrieval and review.

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1.0 INTRODUCTION

The objective of this project was to develop a spectral optical model for the Sarasota Bay Estuary Program (Program) to evaluate variation in estuarine water clarity in relation to seagrass, a key indicator of estuarine health, and provide a technique to conduct an annual assessment of water clarity to support the management and protection of seagrasses within the system. Seagrass have long been recognized as a critical habitat indicative of overall estuarine health (Moore et al., 2004) and maintaining seagrass extent at or near historically pristine conditions has been a continuing goal of the Program (SBEP, 2014). Central to the investigations of changes in seagrass cover over time have been aerial photography and the digitization of those photographs to provide estimates of seagrass areal extents. Early aerial photos during the 1950's have been used to represent historical conditions. More recently, the Southwest Florida Water Management Agency began mapping in 1988, and since 1994, flights and digitized products have been made available roughly biannually.

Early efforts to identify dominant factors contributing to water column light attenuation affecting seagrass within Sarasota Bay (Dixon and Kirkpatrick, 1995) highlighted the attenuation due to epiphytic cover on seagrass blades, and established annualized photosynthetically active radiation (PAR) targets of between 28-50% of surface values at the deep edges of seagrass beds. Nutrient regimes were also demonstrated to play a role in seagrass health (Tomasko et al., 1996). In 2003 (Dixon and Perry, 2003), a detailed change analysis of several time periods identified an inverse correlation between seagrass depths and light attenuation coefficients, varying depth distributions of seagrass categories (patchy, continuous) consistent with light limitation at the deep edges of grasses, and seagrass loss associated with time periods of reduced light availability.

Subsequently, management level seagrass areal targets (JEI, 2008) were developed based on the maximum of either coverage in the 1950's, or the mean of 2004-2006 seagrass areas for each of the five major Bay segments, Palma Sola Bay, Sarasota Bay, Roberts Bay, Little Sarasota Bay, and Blackburn Bay (Figure 1). Seagrass area targets were linked to bathymetric data in 2012 (JEI, 2012) as a necessary step to evaluate the linkages between water quality and seagrass depth limits resulting from the mapped seagrass estimates.



Figure 1. Sarasota Bay Estuary Program seagrass study segments.

Despite these efforts, understanding the specific light requirements for seagrass success has remained elusive. In a number of locales throughout Southwest Florida (Dixon and Kirkpatrick, 1999; Johansson, 2007; 2012; Johansson et al., 2009; Biber et al., 2008; Dixon et al., 2010; Dixon, 2014; Dixon and Wessel, 2016), the measurement of water clarity as an attenuation coefficient of PAR has been shown to be difficult and subject to external influences beyond the presence of attenuating materials in the water column. In contrast, an empirical optical model, with model coefficients parameterized for typical local water quality parameters, can reproducibly compute diffuse attenuation coefficients of photosynthetically active radiation or PAR (K_{dPAR}) from the routinely monitored water quality parameters of color (or colored dissolved organic matter, CDOM), chlorophyll *a*, and turbidity. Accurately modeled K_{dPAR} may permit a more robust assessment of water column clarity and trends over time relative to poorly measured empirical data.

Therefore, the objective of this project was to develop a spectrally-explicit optical model for the Sarasota Bay study area to predict water clarity from all available water quality data (color, chlorophyll *a* and turbidity) and to estimate annual water clarity conditions for each of the estuary segments over the period of record of available data. Target or reference periods for water clarity were identified based on target periods for seagrass acreages, benchmark critical values in the water clarity distributions were established and a Reporting Tool was developed to score annual water clarity conditions relevant to seagrass requirements. The Reporting Tool generates annual water clarity scores for each estuary segment based on the percentage of water clarity measurements that were better or worse than the target percentiles. The Water Clarity Reporting Tool and scoring method can then identify improving, stable, or declining water clarity which provides a readily understood format for sharing progress towards meeting water clarity and seagrass targets, and will allow management efforts to be directed as needed.

2.0 METHODS

2.1 Additional Seagrass Mapping

Southwest Florida Water Management District seagrass surveys from 1988-2014 are based on aerial photography at a 1:24,000 true color scale and are generally obtained during late fall/early winter (November-February) when water clarity in west-central Florida estuaries is greatest. The source data for these surveys were USGS 7.5' topographic quadrangles and the end products are GIS polygon shapefiles of seagrasses along the coastal estuarine waters of southwest Florida. The final estuary characterization included multiple habitat codes. Two types of seagrass codes, patchy (FLUCSCODE 9113) and continuous (FLUCSCODE 9116) were distinguished and recorded; however, for the purposes of this report, the acreages of both classes were combined to yield total seagrass acreage. The minimum mapping unit for determining seagrass coverage was 0.5 acres. This determines the smallest area which was identified as patchy or continuous seagrass with certainty. Earlier seagrass surveys from 1982, 1990, and 1992 were completed for only parts of Sarasota Bay and the 1996 survey was conducted during the summer. These four survey years were not considered in the previous development of seagrass acreage targets (JEI, 2008). Additional years of seagrass GIS coverage (2012, 2014), available since the last analysis of seagrass depth distribution (JEI, 2012) were obtained and incorporated into this analysis.

2.2 Bathymetric Distribution of Seagrass

To correlate seagrass data from the aerial surveys with depth, bathymetry data were obtained from the United States Geological Survey's Florida Shelf Habitat (FLaSH) point dataset to characterize the bathymetry of the Sarasota Bay estuaries (Robbins et al., 2007). These data were referenced to the mean lower low water (MLLW) local vertical datum with a reported vertical accuracy of 0.5 m in waters 0 – 20 m deep and an accuracy of 1.0 m in waters deeper than 20 m. For analysis purposes, the vertical accuracy was assumed to be unbiased and the data are reported as provided without accounting for this uncertainty. The depth data were converted to mean sea level using a correction factor of 0.323 meters as supplied by NOAA for the Sarasota station 8726083.

http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=8726083%20Sarasota,%20FL&type=Datums

To assign a depth to seagrass coverages, it was necessary to develop a grid network such that the bathymetry and seagrass coverages could be joined. A grid with 45m x 45m cells was chosen to join these data based on earlier work in Sarasota Bay (JEI, 2012). The grid cell size was determined by calculating the smallest possible square that was greater than the seagrass survey minimum mapping unit. The grid network was joined with the bathymetry coverage and then with the seagrass coverages for each survey year. The grid overlay was used to assign seagrass presence or absence to each 45mX45m cell in the grid. If greater than 50% of the grid cell contained seagrass, the cell was considered a seagrass cell for that survey year. A depth was then assigned to each cell and the depth distribution calculated of those cells that were

recorded as containing seagrass. The cumulative distribution of seagrass as a function of depth was calculated for each bay segment and survey year.

2.3 Segmentation

Seagrass coverages have typically been evaluated by the broad Bay boundaries listed in Figure 1, above. The original Sarasota Bay Estuary Program water quality segmentation scheme (Estevez and Palmer, 1990), however, employed divisions based on local knowledge. The most significant difference was that Sarasota Bay seagrass segment was subdivided into Sub-segments 1A (Anna Maria Sound), 5, 6, 7, 8, 10, and 11 (representing Sarasota Bay proper in roughly NW, NE, a western and eastern midregion, and SW and SE sections). Initial examination of water quality and clarity data from 1998 to present appeared to support these divisions. Accordingly seagrass coverages and depth distributions were evaluated by these more detailed sub-segments (Figure 2) in addition to seagrass segmentation scheme. Seagrass and water quality segments from Roberts Bay and to the south were similar. Regions which included passes and openings to the Gulf of Mexico were excluded from this project's water quality and seagrass evaluations as these are areas of high uncertainty for bathymetric data, high variability in water quality, and frequent visibility problems that can lessen mapping accuracy. As a result, total areas of seagrass presented in this report may have slight variations from reported acreages of the larger seagrass segments of Figure 1.



Figure 2. Sarasota Bay Estuary Program water quality segmentation of Sarasota Bay.

2.4 Target Depths

Seagrass acreage targets developed from aerial mapping were previously selected as the maximum of either the 1950's coverage or the mean of the 2004 and 2006 coverage (JEI, 2008). At the time acreage targets were established, 2006 was the most current mapping product available. Of the five segments typically used for seagrass assessment, Palma Sola Bay and Sarasota Bay used targets based on 1950's data. In these regions, means of 2004 and 2006 were 98.4% and 96.9%, respectively of the 1950's values. For this project, an analogous technique was employed for establishing depth targets. Segment-specific target depths, using the sub-segments of the Sarasota Bay segment, were defined as the 95th percentile of seagrass depths, the maximum of either the 1950's 95th percentile or the average of 2004 and 2006 95th percentiles.

2.5 Water Quality Data

For calibration of the optical model, a database of concurrently collected date, time, color, chlorophyll, turbidity, and field measurements of K_{dPAR} are required. For the ongoing application of the Annual Water Clarity Reporting Tool, a time series of color, chlorophyll, and turbidity data are required at spatially and temporally representative stations, with a sampling design similar to that employed during the selected reference period.

Both Manatee and Sarasota County conduct ambient monitoring programs within their respective portions of the SBEP study area with a water quality sample generally collected from a single depth at each station. Manatee County's designation for data retrieval from FDEP and EPA databases is 21FLMANA. The Sarasota County program has been conducted since 1998 by Mote Marine Laboratory and data can be retrieved under either 21FLSARA or 21FLMML. Stations within Manatee County are randomly selected as a subset from a suite of predefined grid locations within each segment, with the result that segments are sampled roughly every 50 days on average. Sarasota County station locations were originally randomized by month within the grids of a given segment, and each grid is sampled in each month, approximately every 30 days on average. Stations are considered random for both programs. Data for the period of record (Manatee County, 1995; Sarasota County, 1998) through the end of 2015 were obtained through https://ofmpub.epa.gov/storpubl/dw_pages.querycriteria or directly from the contractor. Parameters in addition to color, chlorophyll, turbidity, light measurements, and attenuation coefficients were also obtained to perform quality reviews and identify outliers. Field blanks and replicates were discarded and overall data were censored to those with only complete records of color, chlorophyll, and turbidity (n=6997). There were additional observations of measured K_{dPAR} with incomplete water quality data. Maximum water quality values recorded were 57 $\mu\text{g L}^{-1}$ chlorophyll *a*, 39 NTU of turbidity, 30 PCU of spectrophotometric true color, and 250 PCU of visually determined apparent color. Water quality data used for modeling and as observations of K_{dPAR} appear in Appendix A.

Differences in the analytical methods and comparison of data from Segments 7 and 8 where the two sampling entities roughly overlap were investigated. Chlorophyll methods were corrected

for pheophytin (prior to 1998) for Manatee County and free of pheophytin afterwards. Sarasota data were chlorophyll corrected for pheophytin prior to 2001 and free of pheophytin afterwards. The two methods for chlorophyll are generally considered comparable. Turbidity methods were identical. Time series of these two parameters in the overlap region near the County line (Figure 3) displayed excellent agreement (Figures 4 and 5). The apparent color method used by Sarasota County was a visual determination on unfiltered samples for the entire period of record. Manatee County color methods and reporting precisions have varied over the years and have been apparent color (visual determination on unfiltered samples; 1995-July 2005), apparent color (spectrophotometric determination at 465 nm on unfiltered samples (September 2005-September 2012), and true color (spectrophotometric determination at 465 nm on filtered samples; September 2012-present). All color data were referenced to platinum cobalt standards and reported in units of PCU.



Figure 3. Region within Segments 7 and 8 (red dashed box) where Manatee County and Sarasota County regional ambient monitoring programs provide data for methods comparisons.

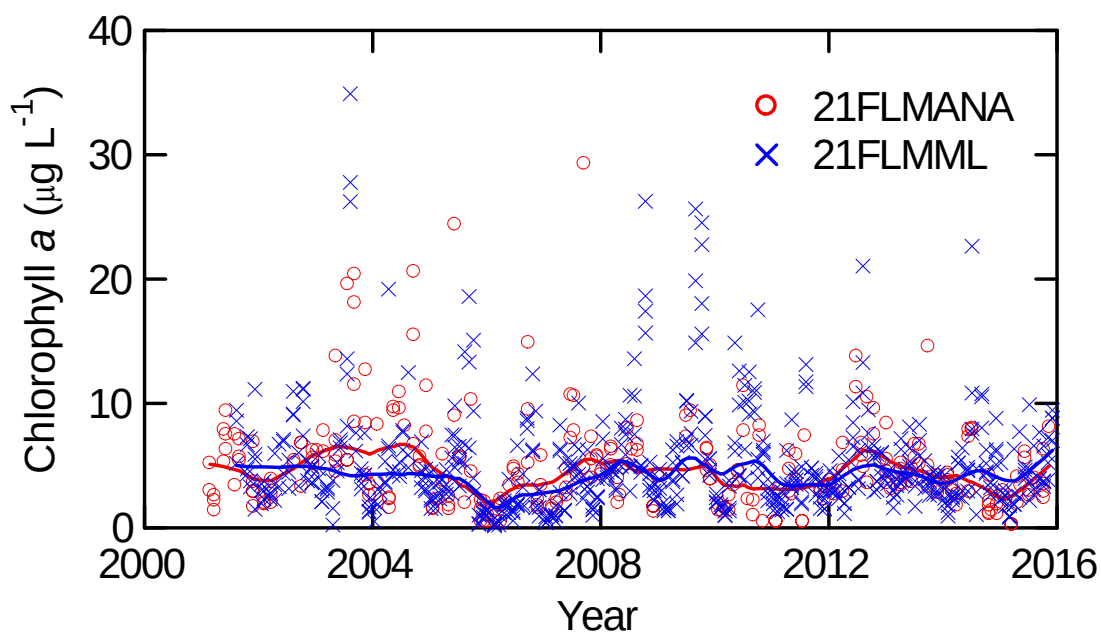


Figure 4. Chlorophyll data reported for Manatee and Sarasota County sampling programs from the Segment 7 and 8 comparison region.

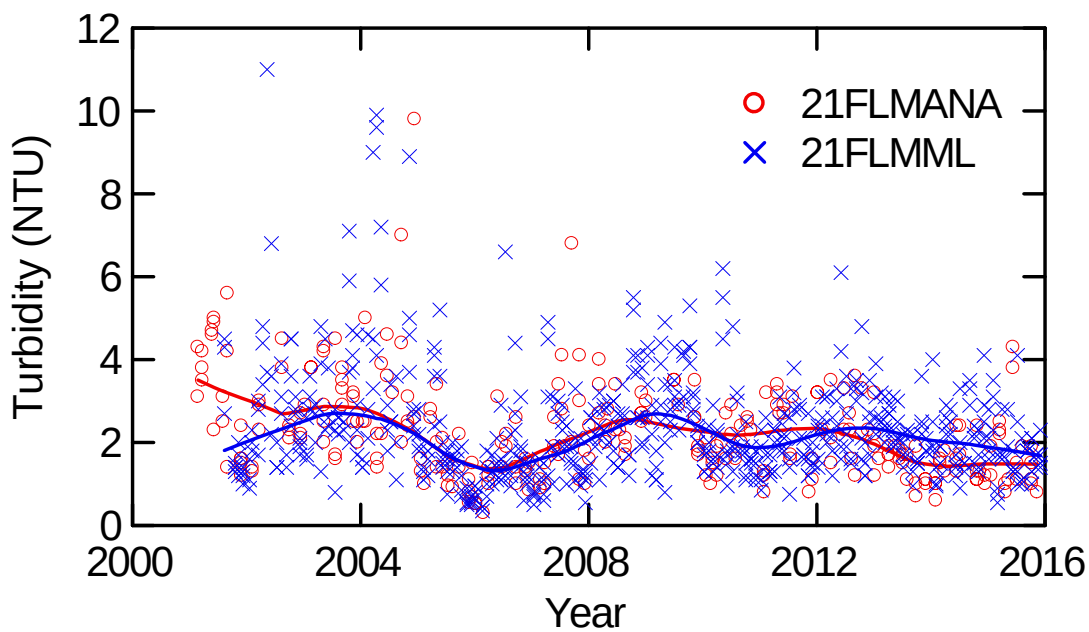


Figure 5. Turbidity data reported for Manatee and Sarasota County sampling programs from the Segment 7 and 8 comparison region.

Spectrophotometric methods measure not only the absorption from dissolved organic matter, but also measure as absorption the scattering caused by particulate matter in unfiltered samples. The resulting spectrophotometric absorbance and calculated PCU values are therefore greater than the absorption due to dissolved organic matter alone and are not consistent with visual apparent color or with true color data measured in other time periods. Attempts to model absorption from spectrophotometric apparent color using turbidity data and a small amount of co-occurring true color data for validation were unsuccessful even though segments other than the study area were retrieved and investigated. As a result, for the purposes of modeling attenuation coefficients, color data were missing between July 2005 and June 2012 for Segments 1A, PS, 5, 6, and the northern portion of Segments 7 and 8. Apparent color (PCU) and spectrophotometric true color (PCU) are not directly comparable, but agreement of the color-derived absorption at 550 nm (a_{550} ; see text below) was acceptable (Figure 6) for true color post-2012 and for visual color pre-2006 given the precision of reported color values to intervals of 10 PCU.

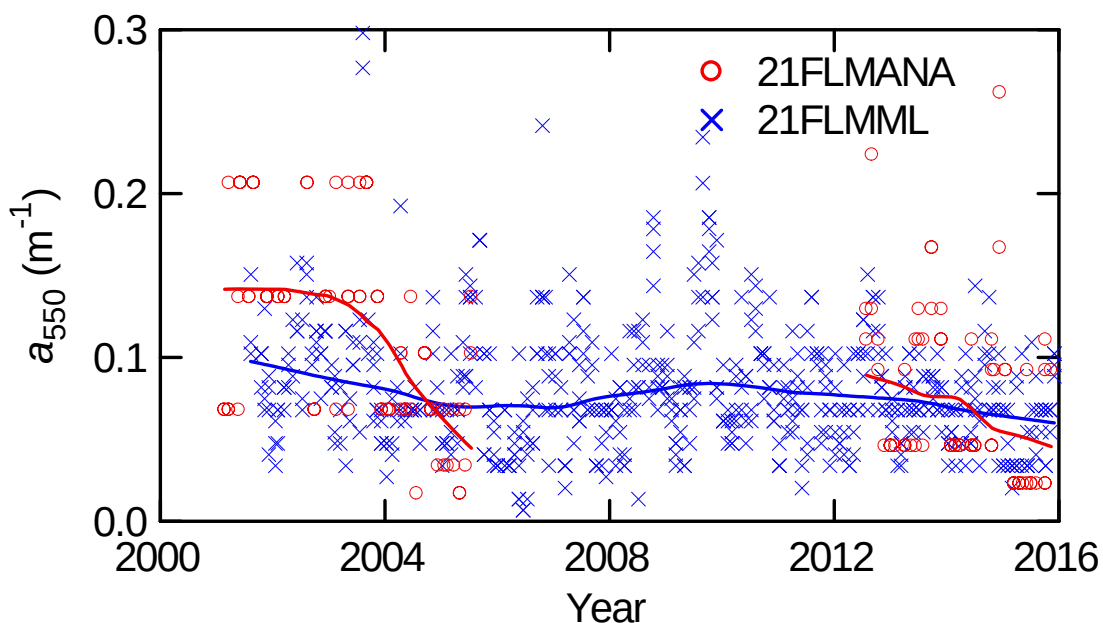


Figure 6. Absorption at 550 nm (a_{550}) computed from apparent and true color reported for Manatee and Sarasota County sampling programs from the Segment 7 and 8 comparison region.

For field collected K_{dPAR} data, instrumentation is consistent between programs and uses two flat, cosine-corrected (2π) sensors, separated by a fixed distance, and making a series of pairs of simultaneous measurements at given depth(s). Most data were available as computed attenuation coefficients, but where only raw light data were available, attenuation coefficients were computed as the negative slope of the $\ln$ -transformed light readings as a function of depth. Values of K_{dPAR} less than 0.2 m^{-1} (the attenuation coefficient of pure water) or greater

than 3 m^{-1} in Manatee County waters and greater than 4 m^{-1} in Sarasota segments were considered suspect and not used for model calibration. Similarly, outliers to the broad relationship of color as a function of salinity were also not used for model calibration.

Comparison of observed K_{dPAR} between sampling programs when water quality parameters agreed well indicated persistently elevated K_{dPAR} in the northern portion of the comparison region of Segments 7 and 8 (Figure 7) by a factor of 1.3. The difference was persistent through out the period of record (Figure 8). As the attenuating water quality parameters agreed well, the lack of agreement in measured K_{dPAR} was attributed to subtle methodological differences in light measurements that could not be readily identified. For trend evaluations, modeled K_{dPAR} were supplemented with measured field attenuation coefficients during the period of missing color after adjustment for the difference in sunangle and effective pathlength between the time of observation and local noon and the factor of 1.3.

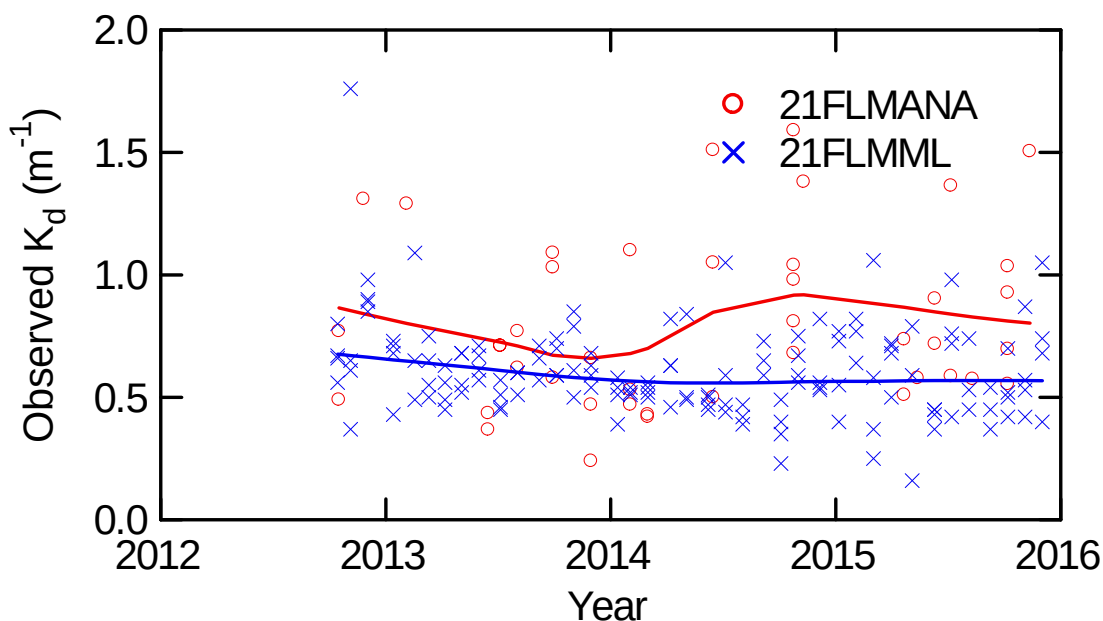


Figure 7. Observed attenuation coefficients (K_{dPAR}) reported for Manatee and Sarasota County sampling programs from the Segment 7 and 8 comparison region during the period when true color data were available.

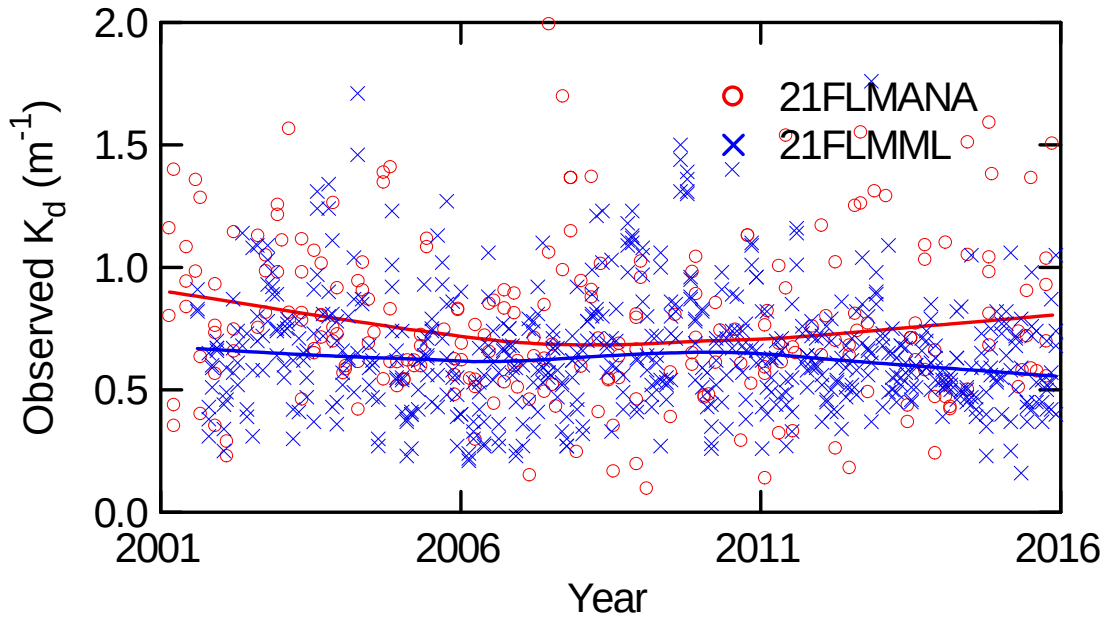


Figure 8. Observed attenuation coefficients (K_{dPAR}) reported for Manatee and Sarasota County sampling programs from the Segment 7 and 8 comparison region.

2.6 Empirical Optical Model

The empirical optical model originated with equations presented in Kirk (1981, 1984, 1991, 1994) and Gallegos (1993) in which the vertical diffuse attenuation coefficient for a given wavelength ($K_{d\lambda}$) is a function of solar zenith angle (the cosine of the angle of the sun from vertical or μ_0), and wavelength-specific scattering (b) and total absorption (a_t) coefficients.

$$K_{d\lambda} = \frac{1}{\mu_0} [a_t^2 + (g_1 * \mu_0 - g_2) * a_t * b]^{\frac{1}{2}} \quad (1)$$

The coefficients g_1 and g_2 are numeric constants, empirically determined for the midpoint of the euphotic zone (Kirk, 1994). Models are regionally calibrated to obtain the inherent optical properties (IOP) of a_t and b numerically described in terms of monitoring water quality data. The resultant model incorporates the characteristic spectral properties of local colored dissolved organic matter (CDOM) or *gelbstoff*, the pigments of typical phytoplankton communities, and the absorption and scattering properties of typical suspended material. The model returns a wavelength-specific (2 nm increments) vertical diffuse attenuation coefficient of an optically deep water column, under standardized conditions, and for the specified water quality conditions of color, chlorophyll, and turbidity.

Empirical model outputs retain the assumptions under which they were formulated and calibrated. The model simulates $K_{d\lambda}$ under optically deep conditions (i.e. no bottom

reflectance) and under direct sunlight only (i.e. direct radiance from the solar disk and not including irradiance due to scattered light or skylight from the remaining portion of the hemisphere). Light from bottom reflectance which “contaminates” the PAR readings of a lower sensor (particularly spherical or 4π sensors) would tend to decrease observed K_{dPAR} measurements relative to modeled values. Larger proportions of diffuse light (as during low sun angles or under overcast conditions) by entering the water column at larger zenith angles and having a longer path length for absorption before reaching a specified depth, would result in increases in observed values of K_{dPAR} relative to modeled values.

Literature values of the spectral distribution of incident irradiance, adjusted for seasonal earth-sun distance and time-of-day atmospheric attenuation, and modeled $K_{d\lambda}$ are then used to compute spectral irradiance at a selected depth (z). Irradiance values are integrated over the spectra (400-700 nm) to obtain total PAR just below the surface (I_0) and at depth z (I_z), and used to compute the %PAR at depth and the K_{dPAR} as:

$$\%PAR = (I_z / I_0) * 100\% \quad (2)$$

$$K_{dPAR} = - \ln (I_z / I_0) / z \quad (3)$$

Modeled K_{dPAR} can then be compared with K_{dPAR} field measurements made with a PAR quantum meter which responds similarly to all wavelengths of light (LiCOR or equivalent) for calibration. Due to the variation in K_d with wavelength, and the differential attenuation of various wavelengths, the modeled K_{dPAR} is strictly applicable only to the depths between which it was derived. Modeled K_{dPAR} can decrease by 10-20% between 0.5 and 2.0 m, requiring model calibration at the same depths as field observations were made. (Similarly, the use of modeled K_{dPAR} values as management criteria should be computed at the relevant depths established for seagrass targets.)

The actual time of field measurements and resulting sun angle are used when calibrating the model, but modeling for trend assessment was conducted using simulations at local noon on the date of the water quality sample collection. The use of the standardized conditions and local noon produce light values at depth that can be considered a daily maxima for the given water quality parameters and direct sunlight assumptions. Modeled data are consequently unaffected by time of day, cloud cover, and bottom type, and respond only to water column attenuators.

The empirical model approach has been repeatedly validated and used under a wide range of water quality conditions (Kirk, 1981; 1984; 1991; 1994b; Gallegos, 1993; 1994; 2001; 2005; Gallegos et al., 1990; 2006; Johansson, 2007; 2012; Johansson et al., 2009; Dixon and Kirkpatrick, 1999; Biber et al., 2008; Dixon et al., 2010; Dixon, 2014; Dixon and Wessel, 2016). Models based on the solution of radiative transfer equations (Mobley, 1994) have also been used to validate the spectral empirical models (Gallegos, 2001), resulting in very high and unbiased correlations between the two approaches in optically deep areas. The agreement between empirical and radiative transfer models results further implies that the source of scatter between observed and empirically model K_{dPAR} values should generally be attributed to

conditions not modeled (optically shallow systems, skylight) or the difficulty of making K_{dPAR} measurements rather than to any bias in the empirical modeling approach. It should be emphasized that the modeled results have the distinct advantage of providing K_d values that are a function of attenuating substances in the water column alone and do not vary based on cloud cover or time of sampling.

2.7 Model Coefficients

Absorption

To initially formulate the optical model in terms of water quality monitoring parameters, total absorption (a_t) was partitioned into that attributable to water (a_w), chlorophyll or phytoplankton (a_{ph}), detritus (a_d), and dissolved color or gelbstoff (a_g) with an implicit non-linear wavelength dependence of each term:

$$a_t = a_w + a_{ph} + a_d + a_g \quad (4)$$

Literature values or specialized data sets were used to permit the calculation of spectral partial attenuation coefficients as a function of typical water quality monitoring parameters. Water absorption profiles (a_w) were drawn from literature values (Pope and Fry, 1997). Values, supplied every 2.5 nm, were splined (Matlab 6.R12) to the 2 nm increments desired (Appendix B, Table B-1).

Specialized data of concurrent chlorophyll, color, and turbidity, together with spectral absorption scans of dissolved, particulate and de-pigmented particulates were collected and analyzed. Absorption due to chlorophyll pigment and detritus was determined through the filter pad method of Kishino (1985), Butler (1962), and Cleveland and Weidemann (1993). Samples were collected bimonthly in conjunction with the Sarasota County ambient monitoring program at a subset of the 40 regularly sampled stations, between April 2012 and February 2013, producing 96 discrete samples. Stations ranged from upper Sarasota Bay through Lemon Bay and were allocated to sample the widest salinity gradient possible.

Measured volumes of water were filtered through glass fiber filters, scanned for absorbance relative to a clean filter, extracted with methanol to remove phytoplankton pigments, and rescanned. The difference between pre- and post-solvent absorbance was that due to pigments alone and was subsequently corrected for filter diameter, volume filtered, and theoretical path amplification ($Beta$ or β ; Bricaud and Stramski 1990; Nelson and Robertson 1993). Absorption coefficients of both chlorophyll and detritus can be enhanced by path amplification factors ($Beta$) as result of the increased scatter and additional opportunities for absorption as light transits through the filter pad. Factors can be either a fixed or absorption dependent quantity, vary by particle size or phytoplankton species, and can vary by a factor of 6 or more (Mueller et al., 2003). As no path amplification data were available specific to

Charlotte Harbor particulates, path amplification factors were adjusted to optimize modeled K_{dPAR} results with field observations.

The spectral absorption profiles of chlorophyll are typically normalized to the near maximum absorption at 440 nm, a mean absorption spectra computed from all normalized spectra, and then chlorophyll-specific absorption at 440 nm (a_{ph440}^*) computed via regression as a function of chlorophyll content determined spectrophotometrically or fluorometrically (APHA, 2005; Arar and Collins, 1997). Normalized spectra, however, displayed considerable coherent seasonal variation, with poor agreement in the 550 nm region (not shown). However, examination of a spectral K_d produced with typical values for color, chlorophyll and turbidity indicated that minimum $K_{d\lambda}$ values and maximum resulting %PAR would be mid spectra, in the 500-600 nm region. A residual of $\pm 0.1 \text{ m}^{-1}$ between modeled and observed K_d at high K_d may represent only ± 0.2 %PAR while the same residual can represent ± 5 %PAR at low K_d . An optimized fit for modeled a_{ph} in the 500-600 nm region is desirable.

Accordingly chlorophyll absorption for each wavelength was directly modeled as a series of power relationships of chlorophyll (Figure 9). Coefficient of determinations, r^2 , were generally 0.8 or above. The modeled chlorophyll absorption, although less variable than that of the original data, did maintain some portion of the seasonal variation in normalized absorption profiles with fits substantially improved in the low absorption region of >500 nm. The formulae for a_{ph} were developed with chlorophyll values as high as $24 \mu\text{g L}^{-1}$, relative to a maximum of $57 \mu\text{g L}^{-1}$ in the data to be modeled. The absorption due to chlorophyll represented a relatively minor portion of the attenuation substances and *Beta* factor for the adjustment of path amplification was not required. Derived coefficients appear in Appendix B, Table B-2, and were formulated as:

$$a_{ph} = C * [\text{Chl } a]^B \quad (5)$$

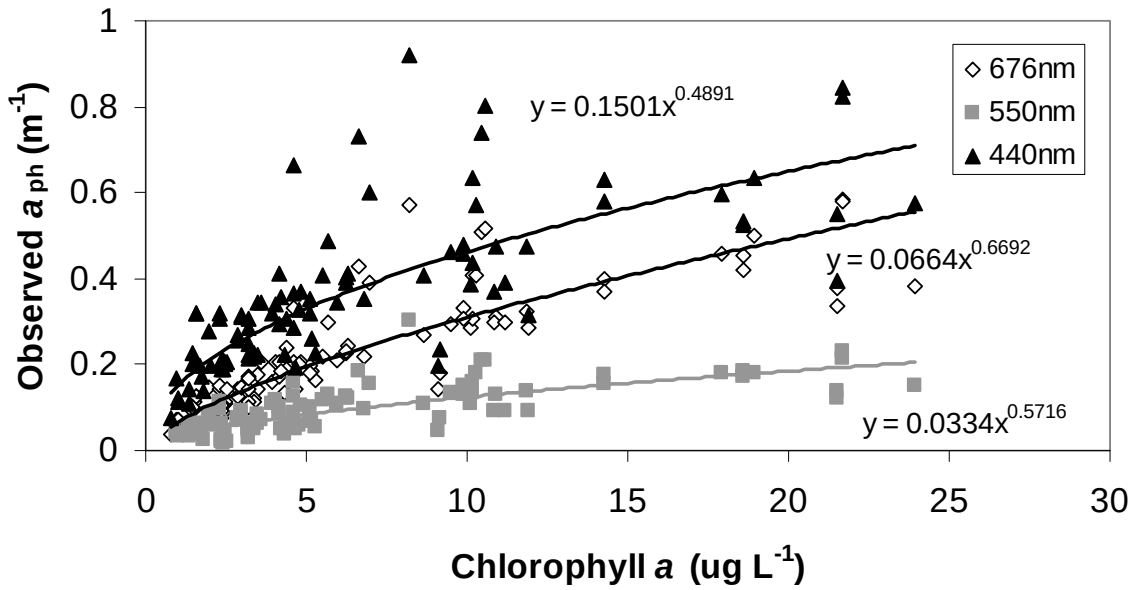


Figure 9. Example of the direct model of chlorophyll absorption, a_{ph} , as derived for wavelengths of 440, 550, and 676.

Absorption coefficients due to detritus (a_d) were obtained from the post-solvent extraction scans described above ($n=96$). Detrital absorption includes not only that due to suspended mineral and organic detrital particles, but also that due to the remaining structural components of de-pigmented phytoplankton. A negative exponential function (Figure 10) very similar to that of CDOM, a_d is generally computed using a reference value at low wavelengths where absorption is maximized. Similar to chlorophyll absorption spectra, however, the optimal fit is desired in the 500-600 nm range. Accordingly, the wavelength of the reference a_d (550 nm) and the spectral range of derived slopes (S_d , 500-600 nm) was selected to maximize the fit between modeled and observed a_d in the mid-spectral region.

Minimum values of a_{d550} were established at 0.0 m^{-1} . Spectral slopes, S_d , exhibited a shallow linear slope with turbidity (Figure 11). The value of a_{d550} had a dependence on both turbidity and a_{g550} of CDOM indicating that precipitated humic and fulvic acids (components of CDOM) likely form the basis of much of the turbidity in the Sarasota Bay system. A *Beta* path amplification factor of 0.8 was derived by optimizing modeled residuals with respect to turbidity. Maximum turbidity data and a_{g550} data used to develop the empirical formula of a_d were 10 NTU and 0.8 m^{-1} (apparent color of 110 PCU), respectively, relative to 39 NTU and 1.93 m^{-1} (apparent color of 250 PCU, true color of 30 PCU) in the data set to be modeled.

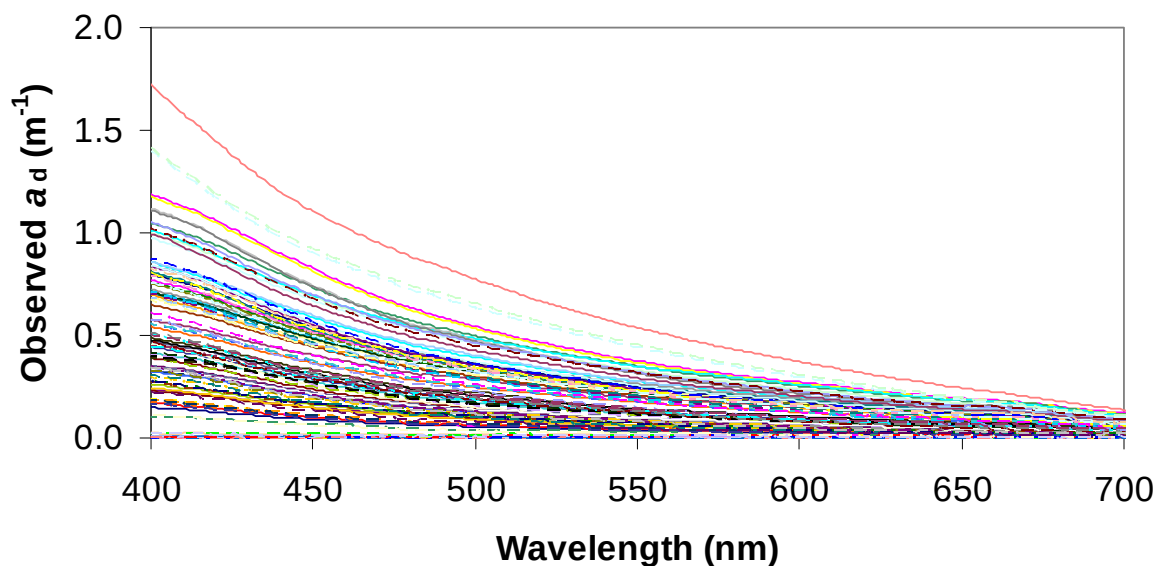


Figure 10. Absorption profiles of de-pigmented phytoplankton, detrital, and mineral particulates, a_d .

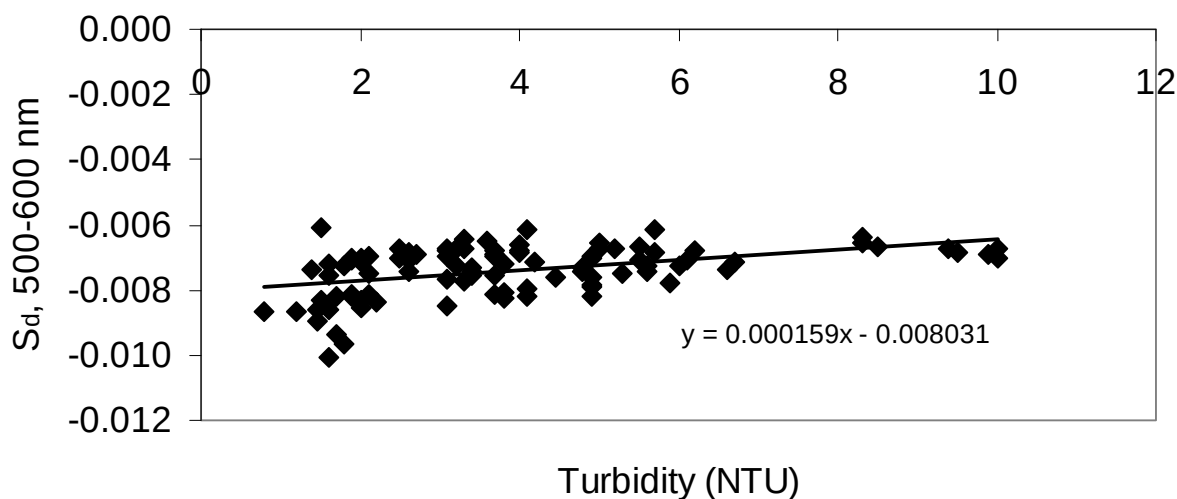


Figure 11. Spectral slope of a_d , S_d , 500-600nm, as a function of turbidity.

$$a_{d550} = \text{MAX}(0, 0.6325 * a_{g550} + 0.03078 * \text{Turbidity} - 0.02634) \quad (6)$$

$$S_d = 0.000159 * \text{Turbidity} - 0.008031 \quad (7)$$

$$a_d = a_{d550} * e^{[S_d * (\lambda - 550)]} \quad (8)$$

Spectral scans for CDOM or a_g were performed on 58 samples collected in 2011 from Sarasota Bay. Samples were filtered through 0.2 micron filters and absorption scans were zeroed at 700 nm where thermal artifacts are minimal and CDOM absorption expected to be absent.

Continuing to maximize model accuracy in the region of low overall attenuation, modeled a_g was formulated as a negative exponential function (Bricaud et al., 1981) of reference a_{g500} as:

$$a_g = a_{g550} * e^{[S_g * (\lambda - 550)]} \quad (9)$$

Computing a_{g550} from reported color (PCU) values was dependent on the method of color analysis. True color, based on spectrophotometric absorption at 465 nm, was back transformed from PCU to the a_{g465} of platinum cobalt standards as:

$$a_{g465} = \text{True Color}_{\text{PCU-465}} * 0.063874 \quad (10)$$

The resulting a_{g465} of samples was converted to a_{g550} based on the relationship of a_{g465} and a_{g550} (Figure 12) in the 2011 samples as:

$$a_{g550} = 0.007025 * a_{g465}^2 + 0.286425 * a_{g465} \quad (11)$$

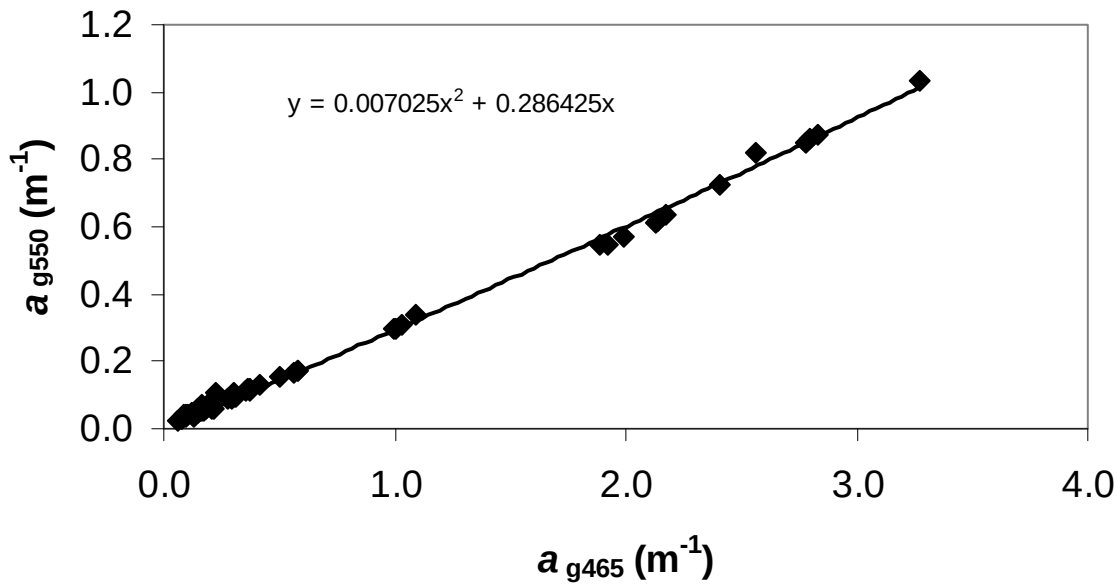


Figure 12. Observed a_{g550} as a function of observed a_{g465} .

Apparent color determined visually was converted to a_{g550} based on the visual color determinations of the 2011 samples and the measured a_{g550} (Figure 13).

$$a_{g550} = 0.00000395 * (\text{App. Color}_{\text{PCU-Vis}})^2 + 0.00676149 * \text{App. Color}_{\text{PCU-Vis}} \quad (12)$$

Spectral slopes, S_g , of CDOM were determined on $\ln$ -transformed a_g data between 500-600 nm and modeled as a function of a_{g550} . The function (Figure 14) was fit as a two part equation to mimic observed slopes and to reasonably account for slopes at a_{g550} higher than observed in the calibration data.

$$S_g = \quad (13)$$

$$\text{If } a_{g550} < 0.9, \\ 0.032782 * a_{g550}^3 + 0.060759 * a_{g550}^2 - 0.03248 * a_{g550} - 0.009507$$

$$\text{If } a_{g440} \geq 0.9 \\ -0.01350$$

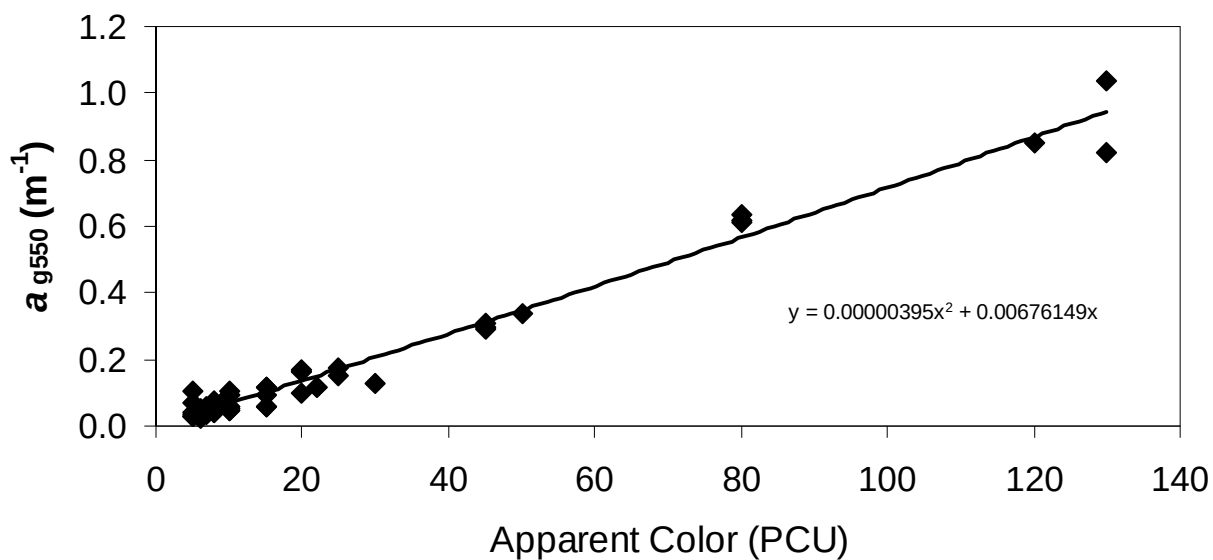


Figure 13. Observed a_{g440} as a function of apparent color, visually determined.

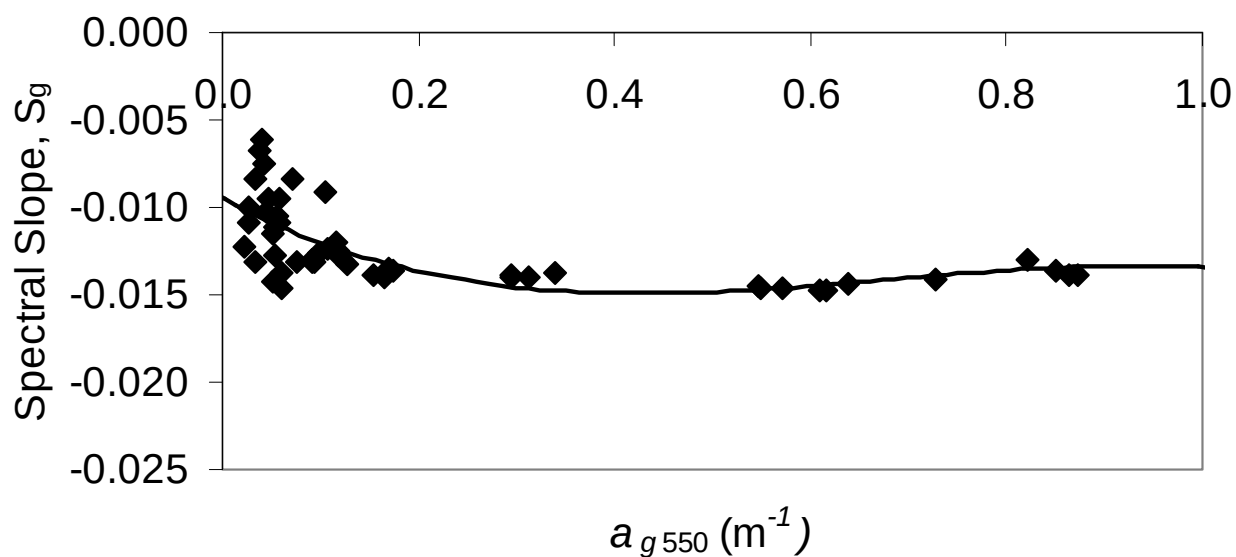


Figure 14. Spectral slope, S_g , 500-600 nm, as a function of observed a_{g550} .

Slopes were smaller than other literature references due to the longer wavelengths used for slope determination. Relationships between a_{g550} and S_g were determined from samples with a maximum a_{g550} of 0.9 m^{-1} (130 PCU for Color_{PCU-Vis}), while samples to be modeled for status evaluations were as high as 1.9 m^{-1} (250 PCU for Apaprent Color_{PCU-Vis}; 30 PCU for True Color_{PCU-465}). A color-dependent amplification factor of $(a_{g550}/0.15)^{0.25}$ was used to minimize residuals across the range of a_{g550} observed.

Scattering

Scattering is strictly partitioned into that due to water and particulates as:

$$b = b_w + b_p \quad (14)$$

Scattering due to water alone varies roughly as λ^{-4} (Buitveld et al., 1994), but was a factor of 300-7000 times smaller than that due to particulates and was subsequently ignored for computational efficiency. Particulate scattering is less spectrally dependent than that due to water, and is primarily affected by particle size and refractive index. Scattering is reported to be best described as a direct function of turbidity (Morel and Gentili, 1991; Gallegos et al., 2008) with an inverse wavelength dependent term and scattering at a reference wavelength approximately equal to 0.92 to 1.1 times turbidity (Kirk, 1994). Other work has found varying exponents to the normalized wavelength term (Morel, 1973; Gallegos *et al.* 2009) ranging between 0.8 and 1.1, and occasionally dependent on color. The model was relatively insensitive to the precise scattering formula, but gave marginally better agreements of modeled K_{dPAR} with field measured K_{dPAR} using the formula as:

$$b(\lambda) = 0.72 * \text{Turbidity} * (555 / \lambda)^{0.8} \quad (15)$$

Insolation

Solar elevations were derived from the day of the year, solar declination, station latitude, and recorded time, and were adjusted for the time constant, the offset in minutes between the longitude of the station and the longitude of the eastern boundary of the start of the local time zone. Air masses, in Standard Atmospheres (SA; the path distance that sunlight travels for a given solar elevation relative to when the sun is directly overhead with SA=1.0), were computed from solar elevation, using an empirical adjustment for a curved rather than a plane-parallel atmosphere (Kasten and Young, 1989). Similar computations were used to calculate the maximum solar elevation (solar noon) for the sampling day.

Extraterrestrial spectral radiation (ASTM, 2003) was adjusted for the Earth-Sun distance for the day of the year (Kirk, 1994). "Global Tilt" values (spectral radiation from solar disk plus sky diffuse and diffuse reflected from ground on south facing surface tilted 37° from horizontal, under 1.5 Standard Atmospheres, SA; ASTM, 2003) were geometrically adjusted to normal values, and using Beer's Law, approximate atmospheric extinction coefficients (in units of SA^{-1})

were computed between adjusted global tilt and solar spectrum at top of atmosphere at the mean Earth-Sun distance (ASTM, 2003). Relevant spectra appear in Appendix B, Table B-3. Solar elevation, resulting SA, and derived atmospheric extinction coefficients were used to compute incident irradiance above the water surface. From the solar elevation or zenith angle (Θ_a , 90° - solar elevation) in air, Snell's Law and the relative index of refraction between air and water was used to compute the zenith angle in water (Θ_w).

Modeled K_{dPAR}

For modeling, irradiance at depth, $I_{z\lambda}$, was computed for each wavelength from the individual spectral attenuation coefficients, $K_{d\lambda}$ as:

$$I_{z\lambda} = I_{0\lambda} * e^{(-K_{d\lambda} * z)} \quad (16)$$

Spectral irradiances were transformed to PAR measurements by integration of $I_{z\lambda}$ and $I_{0\lambda}$ over 400 to 700 nm. Modeled K_{dPAR} and %PAR were computed as:

$$\text{Modeled } K_{dPAR} = -\ln (\Sigma [I_{z\lambda}] / \Sigma [I_{0\lambda}]) / z \quad (17)$$

$$\%PAR = (\Sigma [I_{z\lambda}] / \Sigma [I_{0\lambda}]) * 100\% \quad (18)$$

As K_{dPAR} decreases with increasing depth interval due to differential absorption of selected wavelengths, when comparing modeled K_d with field observations made at selected depths, $I_{z\lambda}$ was computed at both the shallowest (z_1) and deepest (z_2) observation depths and the K_{dPAR} to compare to field observations was computed as:

$$\text{Modeled } K_{dPAR} = -\ln (\Sigma [I_{z2\lambda}] / \Sigma [I_{z1\lambda}]) / (z_2 - z_1) \quad (19)$$

2.8 Model Calibration

Diffuse attenuation coefficients such as K_d are considered an apparent optical property (AOP) and are influenced by the local angular distribution of radiance in addition to the inherent optical properties of absorption and scattering. A number of discrepancies between measured and modeled results may be attributed to the model simulating optically deep conditions and not accounting for changes in the subsurface angular distributions (Θ_w) in light due to interactions with the bottom. Bottom reflectance of direct sunlight can increase the mean subsurface sunangle as direct sunlight reflects off of the sediments, which are typically considered to be lambertian reflectors radiating reflected light equally in all directions. An increase in measured K_{dPAR} relative to modeled values would result, but the bias between modeled and observed values K_d can be lessened by excluding measurements made at shallow stations.

Other factors which effect the angular distribution of subsurface light are the result of varying proportions of direct sunlight and the remaining diffuse skylight from a blue or cloudy sky. The empirical model simulates the attenuation of direct sunlight only, or a sun in a “black” sky, while field measurements are influenced by the actual average angular distribution. During early morning measurements, when the sun is low on the horizon, a large proportion of illumination can be from the remaining hemisphere of the sky as diffuse light. The model will simulate the attenuation of direct sunlight with large θ_w and a subsequently much larger K_{dPAR} than will be measured in the field. Conversely, for midday observations under a completely cloudy sky, the model will simulate a low K_{dPAR} for a nearly vertical direct beam, while field measurements will be of a greater K_{dPAR} from a higher mean θ_w due to the predominance of diffuse illumination. Partially cloudy observations will have an intermediate influence. While field measurements of angular distribution can be made, these data are not typically available and cannot be directly incorporated in the optical model. Restricting the use of early morning data or data with very low irradiance values might limit the influence of these effects, but it should be kept in mind that together, the effects result in both positive and negative residuals, and represent conditions that the model was not designed to incorporate.

Another contribution to variance between modeled and measured K_{dPAR} may be attributed to the character of turbidity. Water quality data (Figure 15) indicate that in addition to turbidity produced by phytoplankton, there can be mineral or detrital turbidity events where chlorophyll is negligible. The optical properties of both absorption and scattering undoubtedly differ for these various particle types. There are also variations in absorptive and scattering properties among phytoplankton species that cannot be retrieved from chlorophyll concentrations alone. Optical modeling calibrations have been formulated to fit a median type of particle, and variance between modeled and measured K_{dPAR} may also result if particle types deviate substantially from the calibration data.

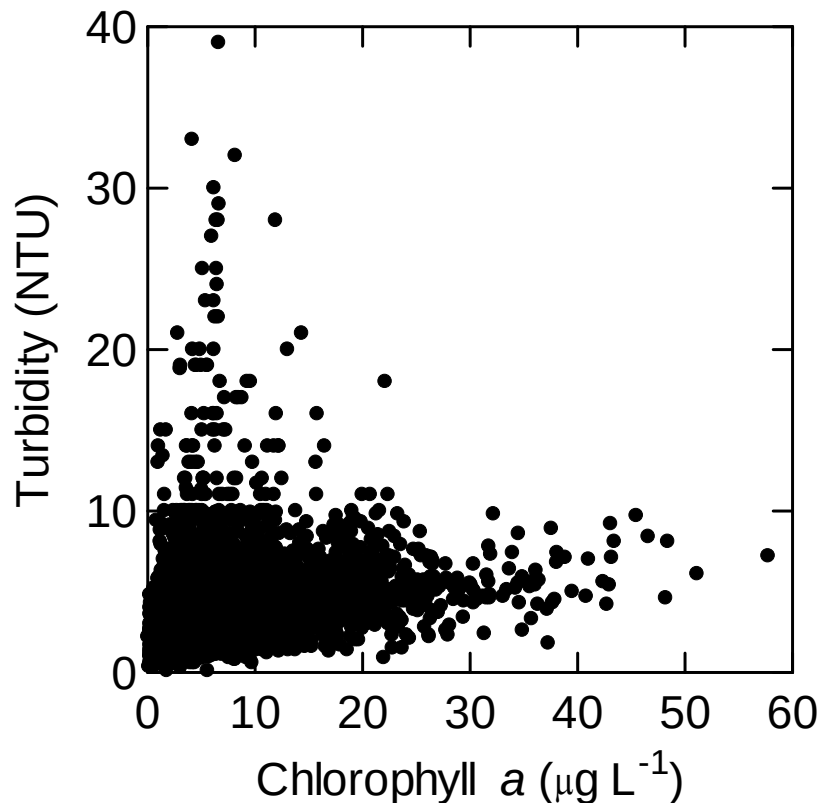


Figure 15. Relationship of chlorophyll and turbidity data for all study segments.

In addition to the sources of variation discussed above, there are numerous subtleties in technique that effect field data quality; making measurements at too shallow a depth for stable readings, allowing reflecting surfaces such as the boat hull to enhance upper sensor PAR readings, allowing boat shadow to reduce readings, measuring over too short an integration time, or allowing reflection of light from sediments to enhance lower sensor readings. For optimal model calibrations, the highest quality field data are desired, i.e. excluding those field K_{dPAR} values with obvious bias.

In order to select data for model calibration, input data were removed if:

- Observed $K_{dPAR} < 0.2 \text{ m}^{-1}$ (attenuation of pure water)
- Observed $K_{dPAR} > 3.0 \text{ m}^{-1}$ (Manatee County data)
- Observed $K_{dPAR} > 4.0 \text{ m}^{-1}$ (Sarasota County data)
- Outliers to the generalized relationship of a_{g550} : Salinity
- Solar elevation $< 25^\circ$
- Station depth $< 2.0 \text{ m}$

2.9 Water Clarity Reporting Tool

While mechanistic relationships between water quality conditions and the living resource requirements of seagrass are not fully understood, the preponderance of evidence suggests that water quality, explicitly water clarity, is a limiting factor in determining the depth distribution, and areal extent, of seagrass. The most recent management efforts explicit for seagrasses in southwest Florida estuaries (JEI, 2010; JEI, 2011; Dixon and Wessel, 2016) proposed water clarity targets based on this assumption, with the understanding that improving water clarity would result in an increase in the areal extent of seagrasses given that other factors are not limiting.

As a result, water clarity targets were identified that were relevant to the observed conditions affecting seagrass within each Bay segment without explicitly identifying the light requirements of seagrass. A reference period was identified based the seagrass target identification process described above and the distribution of water clarity within the identified reference period was used to establish benchmarks of clarity by selecting percentiles which bracket water clarity conditions thought to be most representative of the light requirements of seagrass in each segment at the established target depths. Clarity data from individual years were then evaluated and scored relative to the distribution during the reference period as described below.

Selected Percentiles for Scoring

Quantile regression (QUANTREG Procedure: SAS Institute Inc. 2015) was used as an exploratory data analysis tool to identify the specific quantiles of the distribution of modeled light attenuation values deterministically related to changes in the depth of the seagrass deep edge (i.e. the 95th percentile). Quantile regression was introduced by Koenker and Bassett (1978) as an extension of ordinary least squares (OLS) regression, which models the relationship between one or more covariates X and the conditional mean of the response variable Y , such as the median or the 90th percentile.

Since the seagrass aerial estimates occurred every two or three years, modeled light attenuation between those years were pooled to provide a distribution of values to associate to the observed seagrass depths. The K_{dPAR} distribution was modeled as the dependent variable and the mapped seagrass deep edge was modeled as the independent variable. All quantiles between the 5th and 95th percentile were estimated and confidence intervals were developed using resampling. An example of the model output for a single segment is provided in Figure 16 where the slope of the regression for each percentile is plotted as the dark blue solid line. The blue band represents the confidence intervals and when the band doesn't include zero, the particular quantile has a significant relationship with depth. In this case, quantiles between the 10th and 45th percentiles were significant while the remaining quantiles were not. Results for all segments appear in Appendix C.

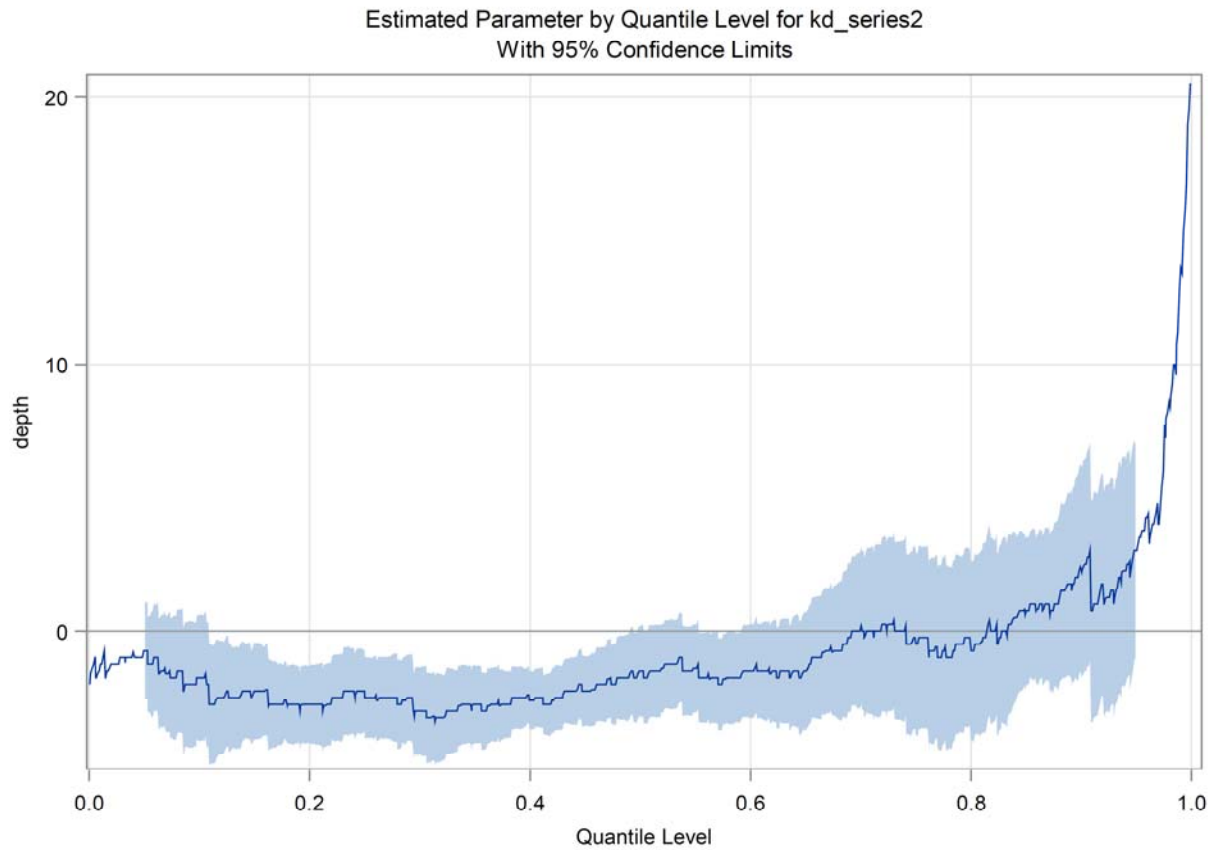


Figure 16. Results of quantile regression evaluating seagrass depth and light attenuation.

Scoring Method

The scoring method provides annual, segment-specific water clarity scores based on the frequency distribution of modeled K_{dPAR} data relative to that of a reference period (JEI, 2010, 2011; Dixon and Wessel, 2016). The binomial test (Wackerly et. al., 1996) was used to identify significant differences between each year's water clarity data and the benchmark points, that is, the selected percentile values from the reference period. As an example, using the 30th and 70th percentiles:

- If more than 30% of the K_{dPAR} measurements were below the benchmark with statistical significance ($\alpha=0.05$), then the water clarity was considered to be improving and was assigned a value of positive 1.
- If less than 30% of the values were below the benchmark with statistical significance ($\alpha=0.05$), then the water clarity was considered to be degrading and was assigned a value of -1.
- Otherwise the value was 0.

This scoring is performed on both benchmarks (i.e. the 30th and 70th percentiles). The sum of the scores is used to assess the annual water clarity for each Bay segment. The distribution of potential scores ranges from -2 to 2. To create the scores, all that needs to be known is the number of samples and the number of samples less than or equal to the criterion values for the benchmarks.

Analogous to the techniques employed for the protection of the Charlotte Harbor system (Dixon and Wessel, 2016), resulting scores are graded as follows:

Green = score greater than -1	Stable
Yellow = score of -1 or less	Caution
Red = score of less than -1 for consecutive years	Declining

Stability in scores relative to the benchmark period is considered sufficient for the protection of water clarity and seagrass extent and the scores can be related to changes in seagrass depth over time. It should be noted that the binomial test used to score the water clarity data relies on the assumption that samples are independent and that the design of the sampling program network conforms to this assumption. The test is also sensitive to changes in temporal sampling frequency that may bias the seasonal weighting of samples. The percentiles selected and used for the reference period of this project were developed with and applied to the current sampling scheme which is monthly and with consistent numbers of samples per segment among the Manatee and Sarasota County programs. Future application of the tool should include the review of data density from individual years relative to the reference period to avoid bias from changing number of stations or missed sampling periods.

3.0 RESULTS

3.1 Segmentation

Results of analysis for the sub-segments of the “Sarasota Bay” seagrass segment suggested that the seagrass areal extents varied significantly from one another over time supporting the need for subdividing the larger segment. In addition, the results indicate that present acres (2014) exceed the targets established based on either 1950’s or 2004-2006 averages and that 2008, 2010, 2012, and 2014 appeared to be a period of very stable coverage. The four most recent mapping were selected to compare regions.

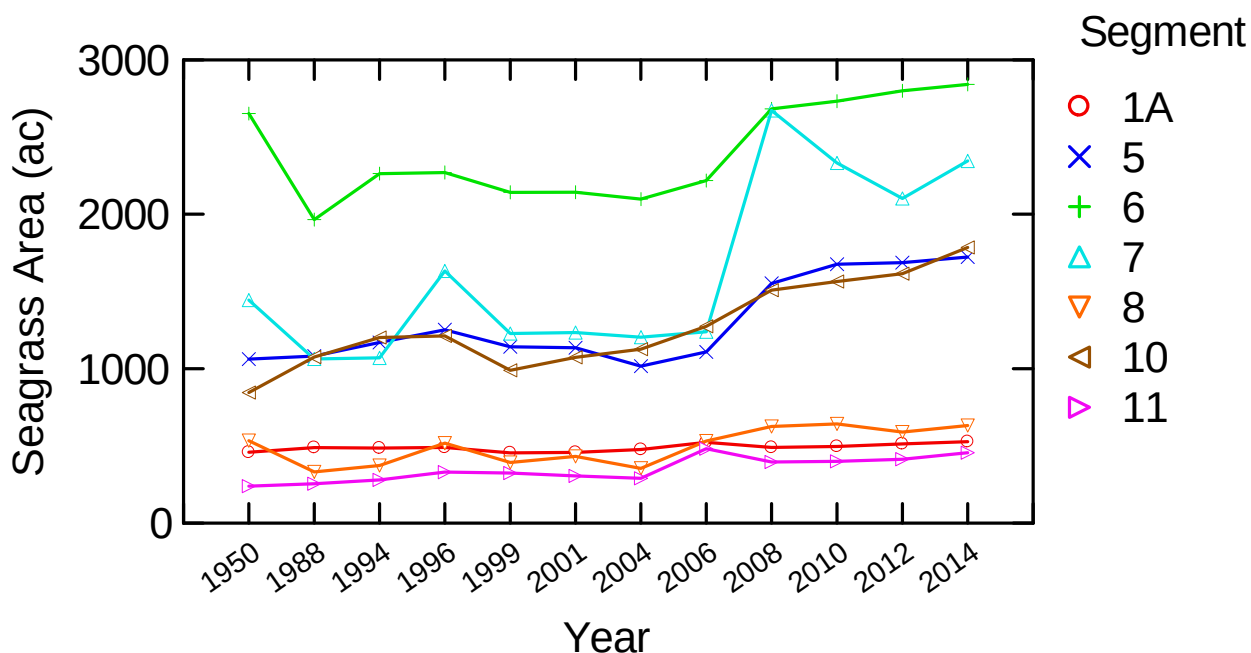


Figure 17. Time series of seagrass areal extent for the Sarasota Bay segment, 1950 to present, subdivided by water quality segments.

Depth distributions within the stable period of 2008-2014 differ widely among sub-segments (Figure 18). An Analysis of Variance on the ranked 95th percentile of the depth distribution for each mapping period indicated significant differences by sub-segment and that all sub-segments differed from one another (Tukey’s HSD) with the exception of Sub-segments 7 and 10 and Sub-segments 8 and 11 (Figure 19; Table 1). Similar significant differences by sub-segments appear in the attenuating water quality parameters (Figure 20). Even between Sub-segments 7 and 10 where depths are not significantly different, trends in depth over time differed and argued for analysis of water clarity data by the smaller regions. Sub-segments are subsequently referred to in this report as segments and analyses performed accordingly.

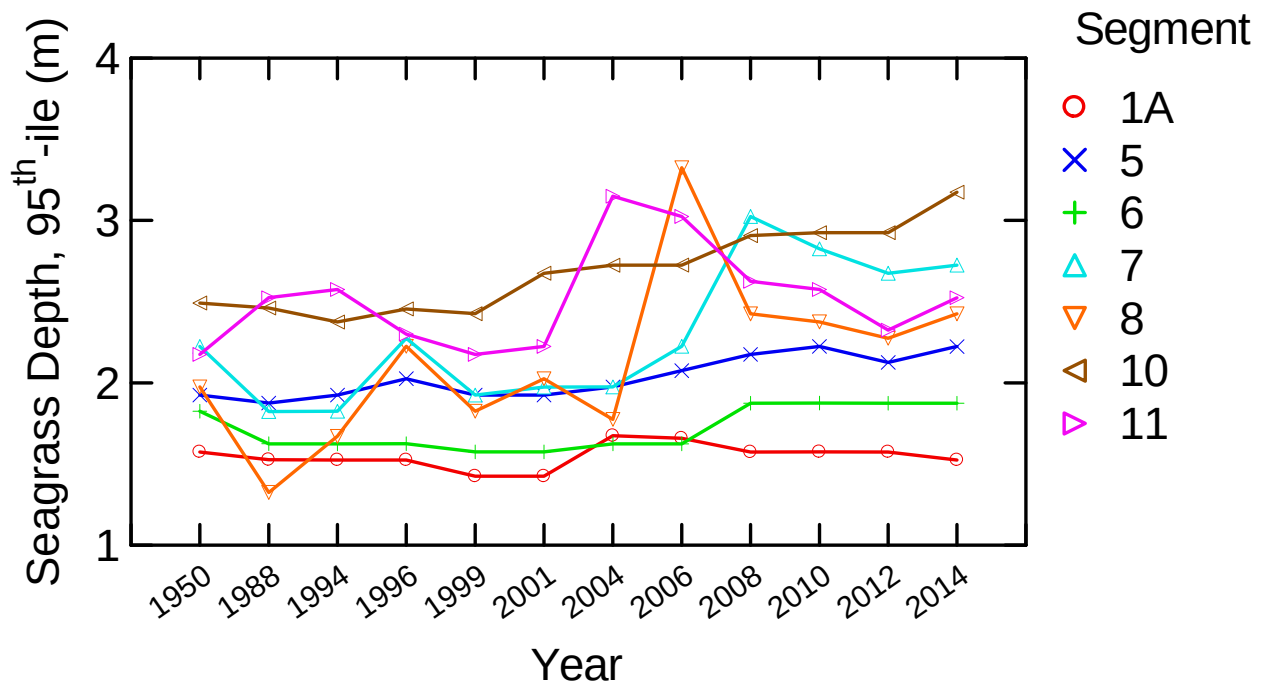


Figure 18. Time series of the 95th percentiles of the depth distribution of seagrass within the Sarasota Bay segment, 1950 to present, subdivided by water quality segments.

Table 1. Tukey's HSD of 95 th percentile of cumulative depth distribution, p-values.							
	10	11	1A	5	6	7	8
10	1.000						
11	0.000	1.000					
1A	0.000	0.000	1.000				
5	0.000	0.000	0.000	1.000			
6	0.000	0.000	0.000	0.000	1.000		
7	0.703	0.003	0.000	0.000	0.000	1.000	
8	0.000	0.142	0.000	0.001	0.000	0.000	1.000

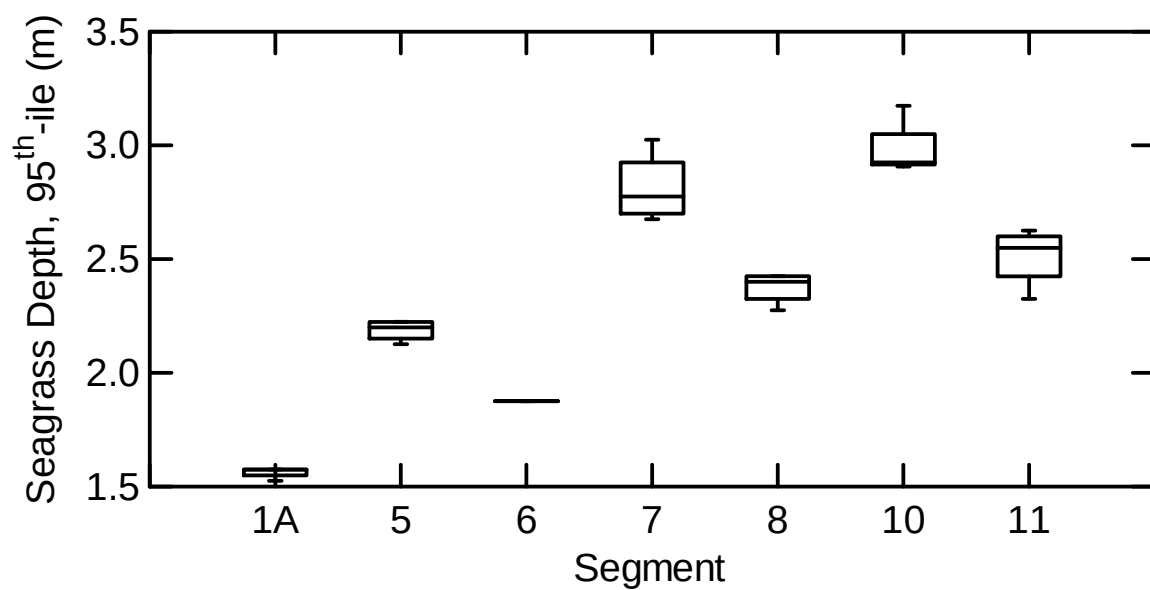


Figure 19. Distribution of the 95th percentiles of seagrass depth distribution within the Sarasota Bay segment, 2008-2014, subdivided by water quality segments.

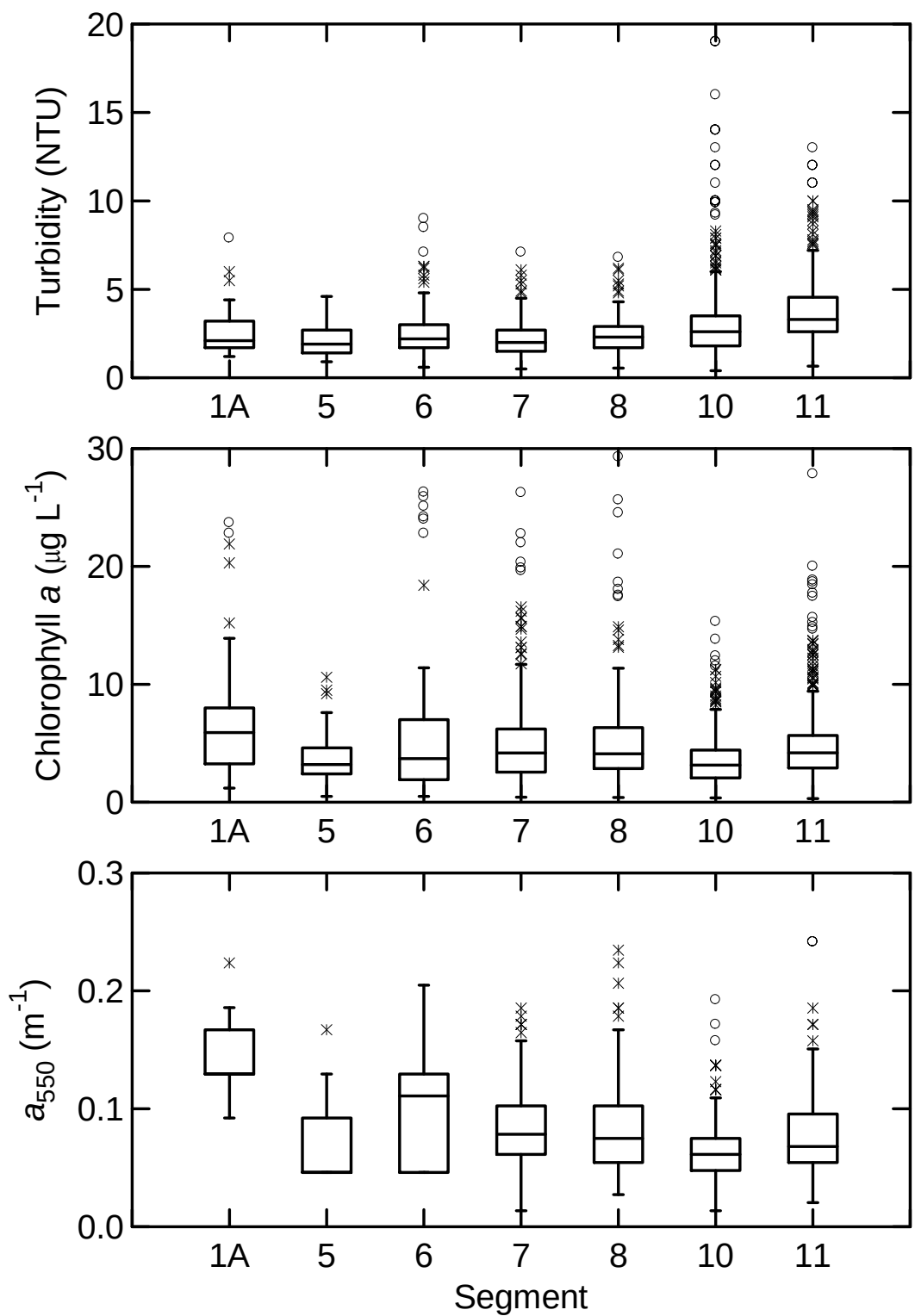


Figure 20. Distribution of the attenuating water quality parameters within the Sarasota Bay segment, 2008-2014, subdivided by water quality segments.

3.2 Target Depths

Target depths for seagrasses by segment (Table 2) were selected as the deeper of the 95th percentile of the depth distribution between 1950 or the average of 2004-2006 delineations. More recent areal extents are provided for reference in the right hand column. Target depths range between 1.52 and 3.09 m over all segments. Five of the eleven segments have targets based on 1950's coverage and four segments (green) have depths that have exceeded target depths in recent years (2008-2014). Depths of all segments and mapping years appear in Figure 21 and Appendix D.

Table 2. Seagrass target depths, selected as the deeper of the 95 th percentile in either 1950 or 2004-2006 (averaged), and compared to the most recent period of stable depths, 2008-2014.				
Segment	1950	2004-2006	Target Depth	2008-2014
1A	1.57	1.67	1.67	1.56
PSB	1.52	1.32	1.52	1.45
5	1.93	2.02	2.02	2.19
6	1.83	1.62	1.83	1.87
7	2.22	2.10	2.22	2.81
8	1.98	2.55	2.55	2.38
10	2.49	2.72	2.72	2.98
11	2.18	3.09	3.09	2.51
RB	1.98	1.95	1.98	1.97
LSB	1.67	1.62	1.67	1.62
BB	1.42	1.75	1.75	1.62

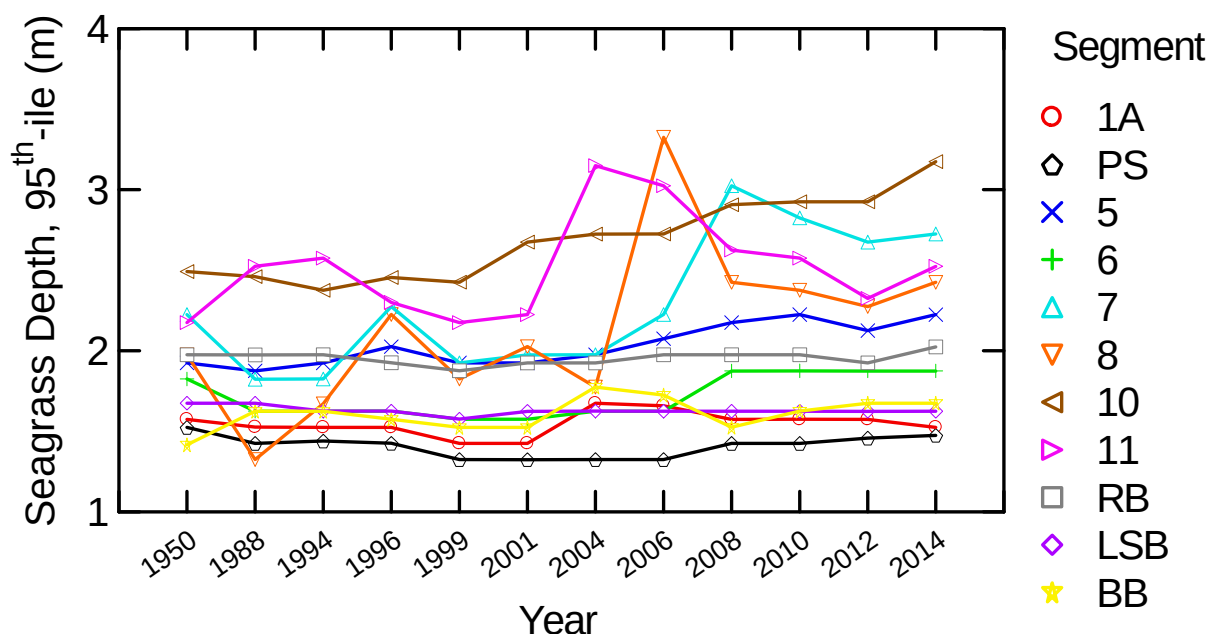


Figure 21. Time series of the 95th percentiles of seagrass depth distribution within all Sarasota Bay segments.

3.3 Model Calibration

Model calibration consisted of exploration of the effects of the empirical parameters of g_1 and g_2 , adjustments to the coefficients drawn from the literature to compute scattering from turbidity, and absorption-dependent adjustment of path amplification factors for the partial absorption coefficients due to CDOM, chlorophyll and turbidity. As a result of the larger data set and the larger range in color, chlorophyll and turbidity for the southern segments, and the larger uncertainty in measured K_{dPAR} for the northern segments, model calibration was conducted with the southern segment data and then applied to all water quality data.

The slope of the calibration relationship (plotted as modeled K_{dPAR} as a function of observed K_{dPAR}) was determined with a line of organic correlation (LOC), as errors were possible in both the x and y dimensions. For validating model calibration, the slope should ideally fall between 0.8 – 1.2. In addition, it was desirable that the intercept of the LOC would be within $\pm 0.2 \text{ m}^{-1}$, the attenuation coefficient of pure water at the sampling depths. The final LOC slope was 0.9672 ($n=3579$) with an intercept of 0.0429 (Figure 22). Consistent with the LOC slope near 1.00, the median residual was 0.04 m^{-1} , and the median root mean square error was 0.13 m^{-1} . Examination of residuals by segment (Figure 23) indicated that median residuals ranged between -0.06 to 0.01 m^{-1} with the 25th and 75th percentiles inside an envelope of $\pm 0.2 \text{ m}^{-1}$, the attenuation of pure water. For the northern segments, comparison of the modeled K_{dPAR} with the independent observed K_{dPAR} (after adjustment of sunangle and factor of 1.3) resulted in a median difference of -0.11 m^{-1} , or modeled K_{dPAR} slightly larger than the adjusted data.

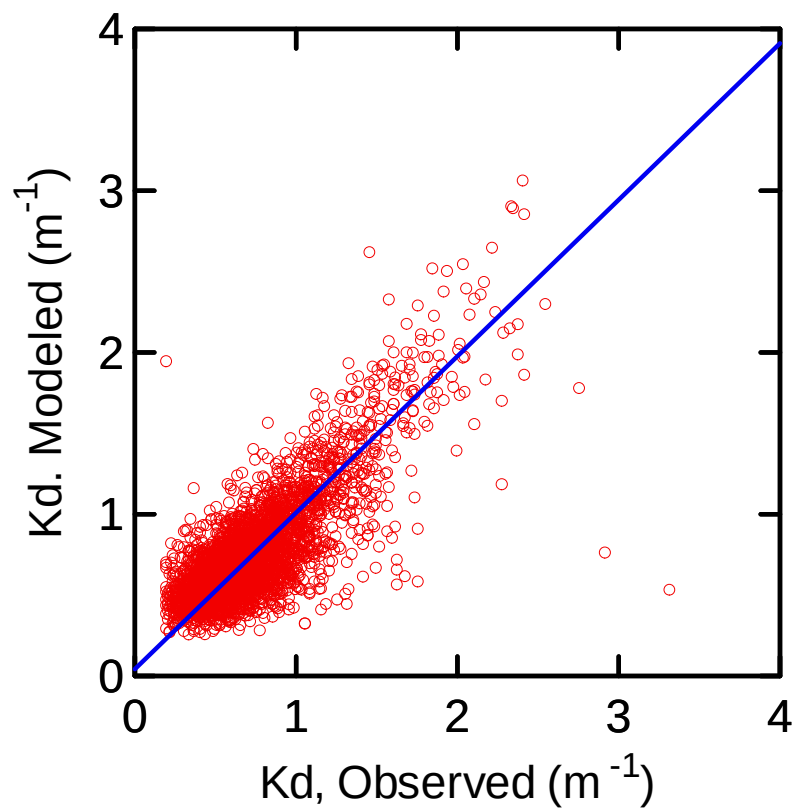


Figure 22. Agreement between modeled and observed K_{dPAR} . Line of organic correlation indicated in blue.

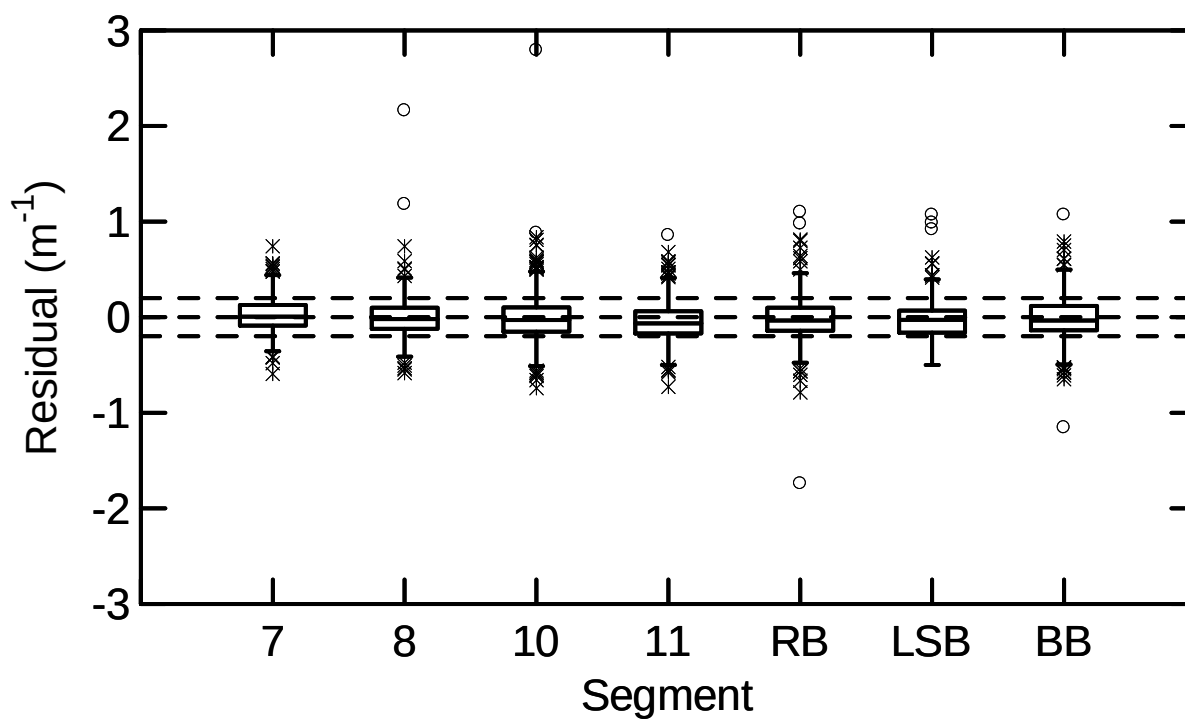


Figure 23. Residuals of observed less modeled K_{dPAR} for Sarasota segments.

3.4 Reference Period

As the reference (“target”) period for seagrass coverage was based on mapping from the 1950’s, 2004, and 2006, and as water quality data were not available from the 1950’s, the reference period for water clarity was necessarily limited to that relevant to the 2004 and 2006 seagrass delineations. The 2004 and 2006 aerial photography was captured in January 2004 and February 2006, respectively (SWFWMD, 2017). Under the assumption that winter seagrass coverage reflected light conditions during at least the prior growing season, the water clarity reference period was therefore identified as 2003-2005, inclusive. Cumulative frequency distributions were computed by segment from modeled K_{dPAR} (supplemented by measured adjusted coefficients when K_{dPAR} could not be modeled), from 2003 through 2005, to represent the water clarity conditions relevant to the target seagrass values.. Adjusted, observed K_{dPAR} contribute to reference distributions for portions of Segments 7 and 8 and for the remaining northern segments (1A, PS, 5, and 6) from July through December 2005, or approximately 9% of the reference data for northern segments.

3.5 Selected reference percentiles

Each date of seagrass mapping and the segment-specific 95th percentile of seagrass depth distribution was associated with individual quantiles of the distributions of modeled K_{dPAR} of the appropriate segments and calendar years of the prior interval. Successive regressions of the individual quantiles of K_{dPAR} (Appendix C) as a function of depth were significant for a portion of the K_{dPAR} distributions from all segments with the exception of Segment 1A, Segment 7, and Blackburn Bay. Of the remaining segments, the interval of the 20th to the 40th percentile of K_{dPAR} distribution provided the largest interval of significant results over the most segments. Slopes are negative as expected; that is, deeper depths are associated with smaller K_{dPAR} values (higher clarity). In addition, the significance of the low percentiles, the 20th and 40th, imply that median water clarity conditions may not be the most relevant indicator of seagrass depth extension suggesting the spring growing season before freshwater runoff and seasonal phytoplankton growth increase K_{dPAR} values may be critical to seagrass success. For those segments without significant relationships between the 20th-40th interval and the seagrass deep edge, the percentile values were still considered to represent benchmark values indicative to relative changes in water clarity that would affect the overall acreage of seagrass for that sub-segment.

For Segment 1A, reference to seagrass mapping (JEI, 2008) indicates that seagrass acreage and depth distributions have been extremely stable over time. There is substantial bay bottom shallower than the 95th percentile depths of grasses which have apparently never supported seagrass (Figure 24). The region without seagrass also includes the ICW channel. The region is dynamic, experiencing strong tidal currents, and the deeper waters of the channel also tend to concentrate highly colored flows from the Manatee River to the north, or high turbidity flows from Longboat Pass to the south during storm events (personal observation). Periodic but

localized and extreme high K_{dPAR} events are likely not well captured by the spatially distributed monthly sampling program which has comparatively few stations and observations in this segment. Tidal velocities can also exert a mechanical disruption that prevents seagrass presence. The combined effects of velocity and periodic high attenuation events apparently supersede or obscure typical light and seagrass depth relationships.

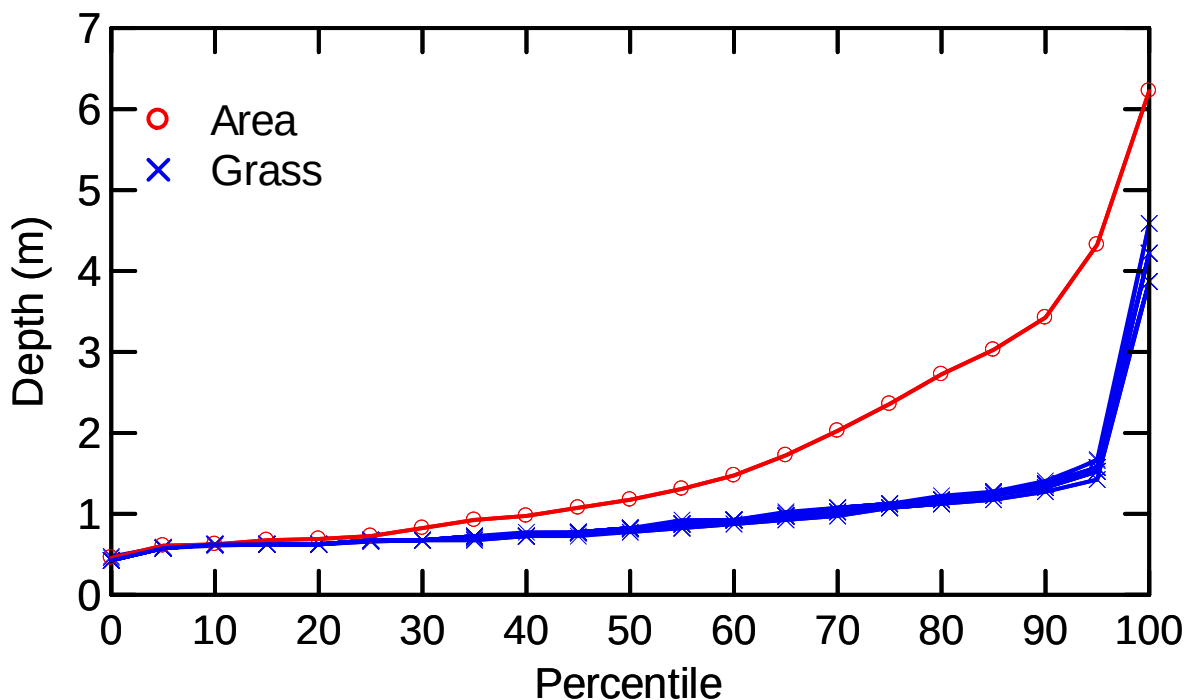


Figure 24. Depth distribution of seagrass (blue; 1950-2014) and total area (red) of Segment 1A, Anna Maria Sound.

For Segment 7, with the ICW along the eastern boundary, seagrass depth distribution has varied over the years (Figure 25). Tidal currents in the segment area are more moderate than Segment 1A as the segment encloses near the null zone between Longboat and New Passes. The K_d percentiles significantly associated with the 95th percentile of depths range from the 5th to the 20th and appear to indicate that high clarity events are even more critical in this segment.

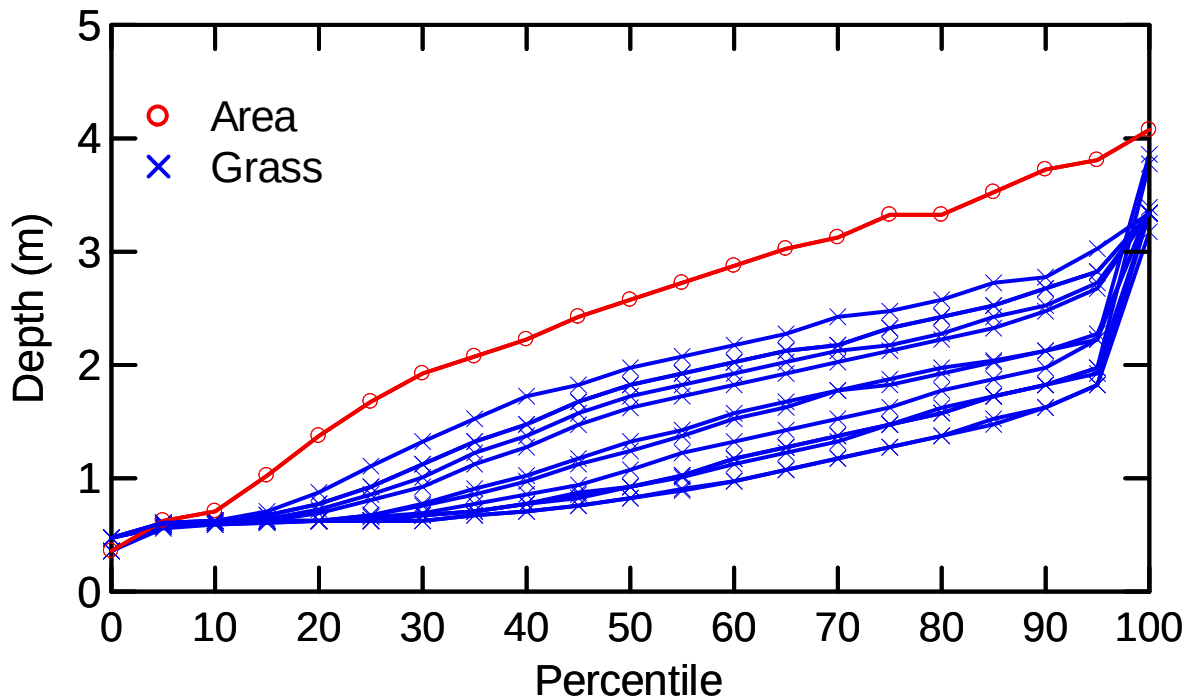


Figure 25. Depth distribution of seagrass (blue; 1950-2014) and total area (red) of Segment 7, middle, western Sarasota Bay.

For Blackburn Bay, nearly the entirety of the segment has seagrass coverage with the exception of the ICW channel (Figure 26). Localized water clarity elevations and mechanical disturbance from passing vessels, in addition to periodic influxes of high turbidity coastal waters through the Venice Inlet, likely restrict seagrass expansion into the channel regardless of the overall distribution of K_{dPAR} . Similar to Segment 1A, the channel also directs high turbidity inflows from coastal storm events. High attenuation events may not be representatively captured by the spatially distributed sampling program which is also generally prohibited from anchoring and sampling in the channel. Water clarity improvements are unlikely to increase seagrass coverages or depths materially in this segment, although declining water clarity, worse than observed during the mapping periods, could still result in a decline in coverage for the shallower depths.

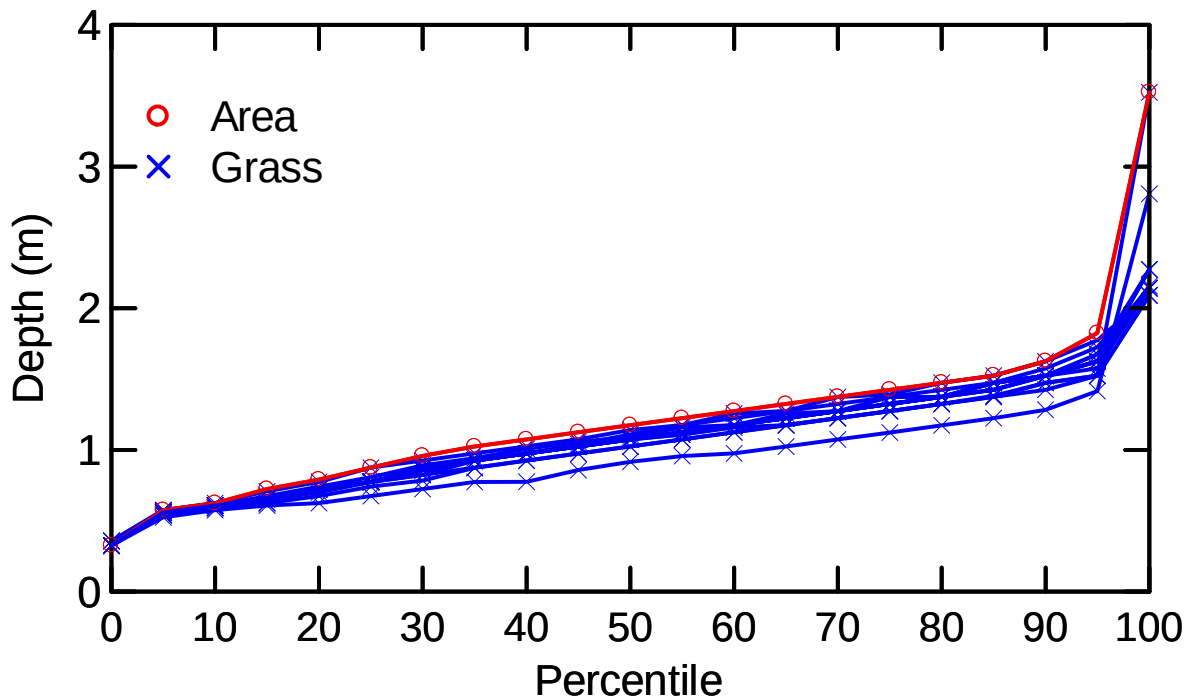


Figure 26. Depth distribution of seagrass (blue; 1950-2014) and total area (red) of Segment BB, Blackburn Bay.

The depth and the K_{dPAR} relationships in the remaining segments were significant for the region between the 20th and 40th quantiles. Other relatively constricted segments with the ICW as a prominent feature apparently have sufficient bay bottom at appropriate depth intervals outside of the channel to allow seagrass coverage to respond to changes in water clarity. Percentiles used by the Water Clarity Reporting Tool to evaluate annual distributions of K_{dPAR} relative to the designated reference period were set at 20th and 40th percentiles (Table 3; Figure 27) and computed from the modeled K_{dPAR} of 2003-2005, augmented as necessary by the adjusted measured K_{dPAR} . It should be noted that Segment 1A and 5 have comparatively few observations during the reference period. The 20th and 40th quantiles of modeled K_{dPAR} are equivalent to the 80th and 60th quantiles of %PAR computed at target depths (Figure 28). Combined, these results can be viewed as maximum seagrass depths are being function of the duration of K_{dPAR} between approximately 0.4 and 0.8 m⁻¹, or the duration of %PAR at target depths of between 15-40%.

Table 3. Selected percentiles of the frequency distribution of modeled K_{dPAR} from 2003-2005, by segment.					
Segment	Designation	n=	20th	40th	Median
1A	Anna Maria Sound	22	0.510	0.683	0.705
PS	Palma Sola Bay	47	0.630	0.783	0.860
5	Sarasota Bay NW	23	0.542	0.814	0.830
6	Sarasota Bay NE	54	0.530	0.651	0.720
7	Sarasota Bay MW	105	0.500	0.580	0.620
8	Sarasota Bay ME	102	0.479	0.610	0.635
10	Sarasota Bay SW	170	0.430	0.505	0.570
11	Sarasota Bay SE	170	0.485	0.590	0.620
RB	Roberts Bay	175	0.630	0.770	0.820
LSB	Little Sarasota Bay	170	0.670	0.800	0.860
BB	Blackburn Bay	175	0.560	0.680	0.740

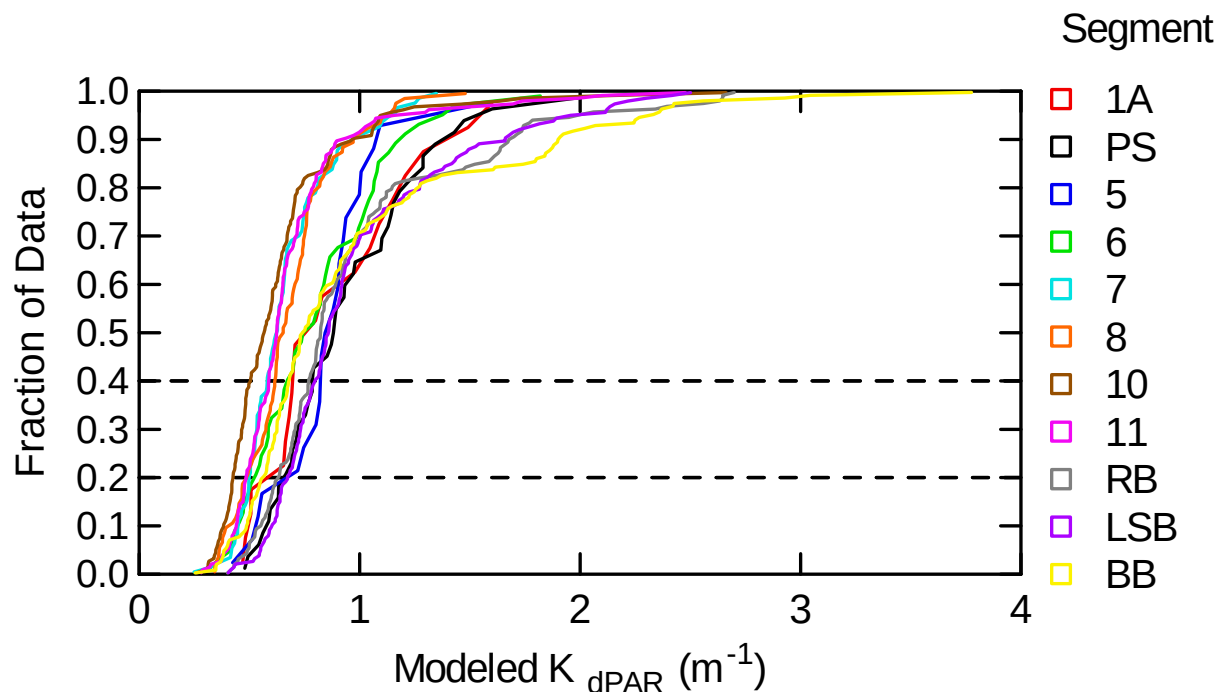


Figure 27. Cumulative distribution by segment of modeled K_{dPAR} during the reference period of 2003-2005, inclusive. Limit lines indicate select percentiles for score assessment.

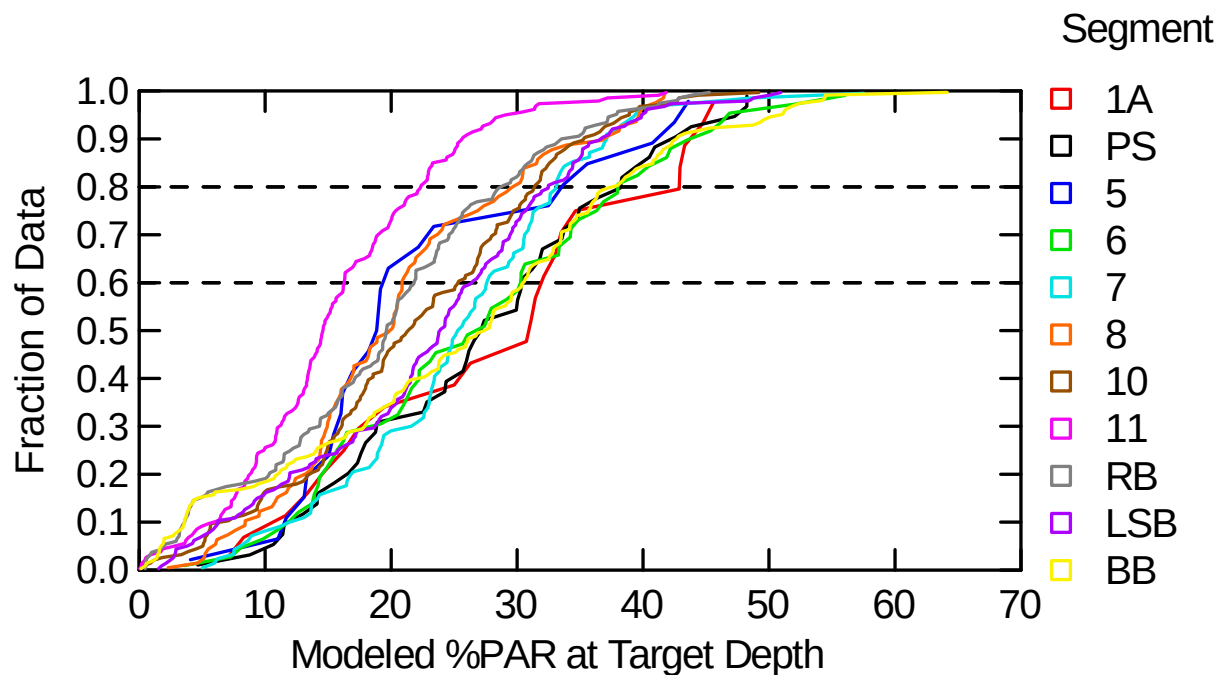


Figure 28. Cumulative distribution by segment of modeled %PAR at target depths during the reference period of 2003-2005, inclusive. Limit lines indicate the %PAR associated with the selected reference K_{dPAR} percentiles.

3.6 Annual Scores

The cumulative distribution of modeled K_{dPAR} at target depths was generated for each segment and year. The 20th and 40th percentile values from the reference distribution (2003-2005) were chosen as benchmark points from which to evaluate data from other years. The scores obtained from the binomial test of each annual percentile against the critical reference percentiles were summed and coded according to the decision rules described above. The fact that depth distributions were significant with water clarity of the preceding 2-3 year period lends support to the scoring practice of marking a year as declining only if two successive years were scored as -2. Annual scores were computed provided data were available in approximately nine of twelve months, but it should be kept in mind that the initial scores of each segment may be slightly biased by an incomplete year of water quality data. In the case of Segments 7 and 8, Manatee County sampling began in 1995, while Sarasota County sampling of the southern portion of those segments did not begin until 2001. Table 4 illustrates the resulting scores and decision rule categories.

Reference to regional rainfall totals (SWFWMD, 2017b; Figure 29) indicate that the target water clarity period of 2003-2005 experienced a relatively wet dry season in 2003, and a wet season with relatively high rainfall in 2004, while 2005 values recorded near median rainfall totals for

both wet and dry season. The higher rainfalls and resulting freshwater inflow would be expected to increase water color and attenuation coefficients. It appears likely that the seagrass coverages and depths of 2004 and 2006, significantly correlated against distributions of 2-3 year periods of K_{dPAR} , operate at a long lag times, and may also include the cumulative influences of the extended dry season droughts of 1999-2002 and moderate wet season rainfall of 1998-2003 in addition to the water clarity of 2003-2005 alone.

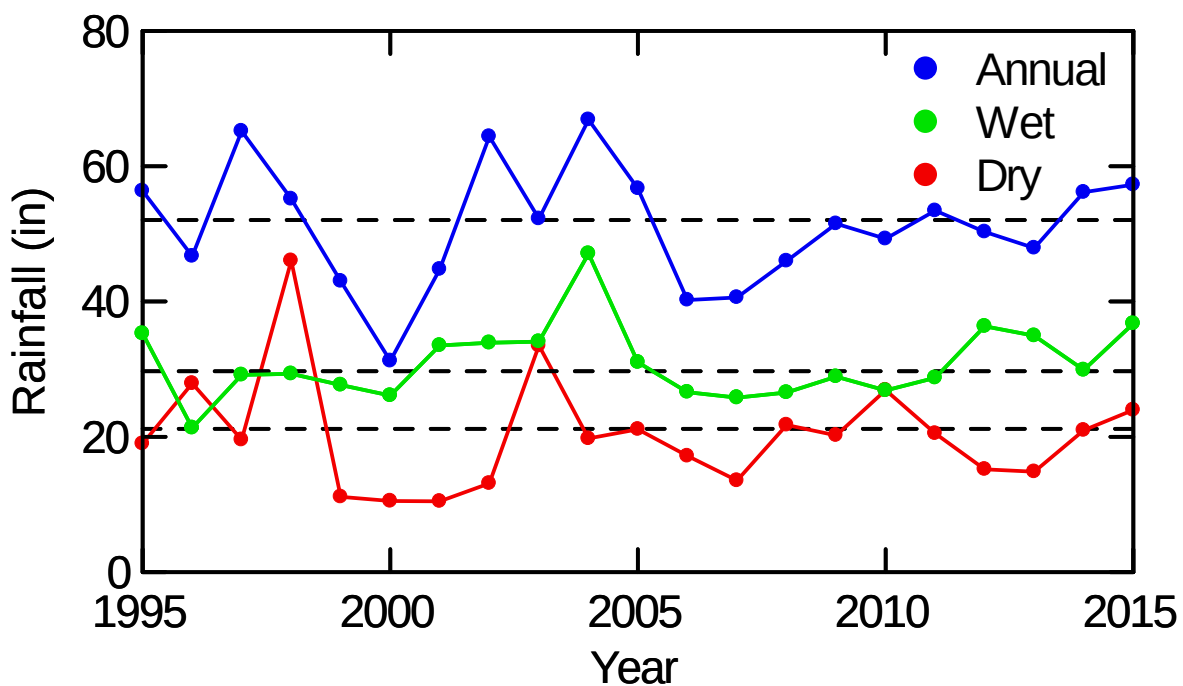


Figure 29. Rainfall amounts by calendar year (blue), wet season (June-September; green) and dry season (October-May; red). Limit lines are median rainfall from 1915 to present, for annual, wet and dry seasons (top to bottom).

There were relatively few instances of successive years with scores of “-2”, red coding (Table 4). In addition to segment-specific performance, a number of region-wide trends were evident in the time series of scores. The years of 1998-2001 experienced decreased clarity in a number of segments (Segments 10, 11, RB, LSB, and BB). The wet season of 1998 was particularly wet, and higher color and decreased water clarity may be expected in the portion of the study area which experiences the proportionally larger freshwater inflows. In contrast, the dry seasons and annual rainfall for 1999-2001 were extremely dry and so do not account for the period of reduced clarity experienced by Segment 10. As Segment 11 was not similarly affected, coastal influences or high turbidity events may explain the decreased water clarity in Segment 10 and are supported by the highest annual median turbidity, but not chlorophyll, for this particular year and segment.

The declining water clarity in Segment 11 in 2009-2010 was accompanied by reductions in many segments in 2010. The slightly wetter dry season in 2010 was not as wet as that experienced in 2003. In Segment 11, turbidity and chlorophyll were particularly high in 2010 indicating that a phytoplankton bloom, although not a *Karenia brevis* bloom or “red tide”, contributed to reduced water clarity at this time together with elevated color from rainfall. Water clarity scores from Segment 10 and 11 and to the south remained somewhat variable from 2010, onward. In contrast, the northern segments experienced continued high clarity conditions from 2004 onwards, including several years, 2006-2007 and 2012-2015, where scores were stable or improving for several consecutive years. It should be emphasized that attenuation coefficients, while strongly linked to rainfall, inflow and water color, also respond to turbidity and chlorophyll from storm-induced resuspension, beach nourishment activities, and phytoplankton blooms, and so do not simply mirror salinity variations alone.

Table 4. Results of Water Clarity Reporting Tool applied to modeled water clarity data from the Sarasota Bay Estuary Program study area for each estuarine segment.											
Year	1A	PS	5	6	7	8	10	11	RB	LSB	BB
1995	1	2	1	1	1	1					
1996	0	0	1	2	1	0					
1997	1	0	1	2	0	0					
1998	1	0	0	1	1	0	-2	-1	-2	-2	-2
1999	1	0	1	-1	-1	0	-2	-2	0	-1	-1
2000	2	0	0	2	1	2	-2	0	0	0	0
2001	0	0	2	0	0	-1	-2	-1	0	0	-1
2002	1	1	1	0	0	0	0	0	0	0	0
2003	2	0	2	-2	-1	-1	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0
2005	2	2	2	2	2	2	0	1	0	0	0
2006	0	1	1	2	2	2	1	2	0	1	2
2007	0	0	2	0	2	2	2	2	2	0	2
2008	0	2	2	2	0	0	-1	-2	1	2	2
2009	1	0	2	0	-1	0	-1	-2	0	0	1
2010	0	0	1	2	0	1	-2	-2	-1	-1	-2
2011	0	2	2	1	2	1	-1	-1	-1	0	1
2012	0	0	2	0	0	-1	0	-2	-2	-2	1
2013	1	1	2	0	0	0	-2	0	-1	0	-1
2014	1	0	2	1	2	2	0	-1	1	2	2
2015	0	0	2	2	2	2	-1	-1	0	0	0

The critical percentiles of K_{dPAR} (20th and 40th) against which seagrass depths were significant were based on a 2-3 year distribution, or the K_{dPAR} between seagrass mapping events. The K_{dPAR} used for a reference or target period was similarly that measured over the 3 year period of 2003-2005. The scoring of Table 4, however, represents an annual assessment. For illustration of the time series of seagrass depths and Water Clarity Reporting Scores, a 2 or 3 year moving average of scores was computed and compared to the deep edge distribution of seagrass. An example for Segment 5 is provided in Figure 30. The figure illustrates the direct relationship between increasing depth distribution with increasing water clarity scores over the last five mappings. Segment 7 (Figure 31) is another example where extended periods of high water clarity were experienced before seagrass depths increased. Other segments such as Segment 11 (Figure 32) display more complex behavior in that shallowing of seagrass depths was noted in 2006-2008 despite high water clarity scores across the time period. Subsequent declining water clarity scores are consistent with shallower depths. Remaining segments are illustrated in Appendix E.

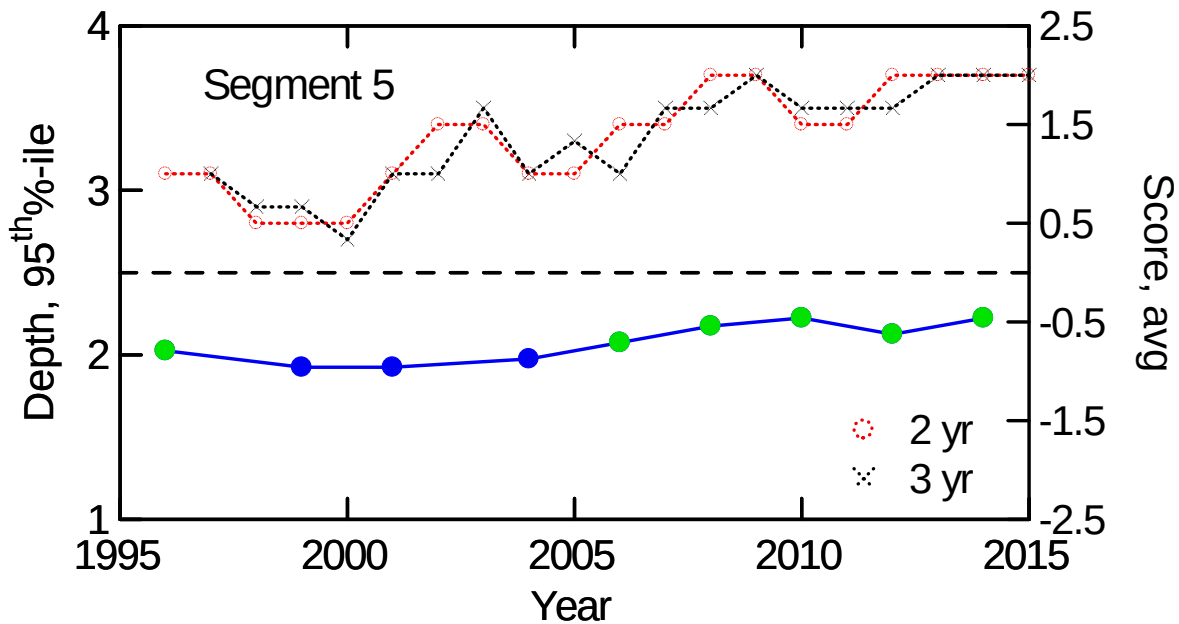


Figure 30. The 95th percentile of seagrass depth (blue) for Segment 5, when greater than or equal to target depth (green), and the 2 and 3 year moving average of Water Clarity Reporting Scores.

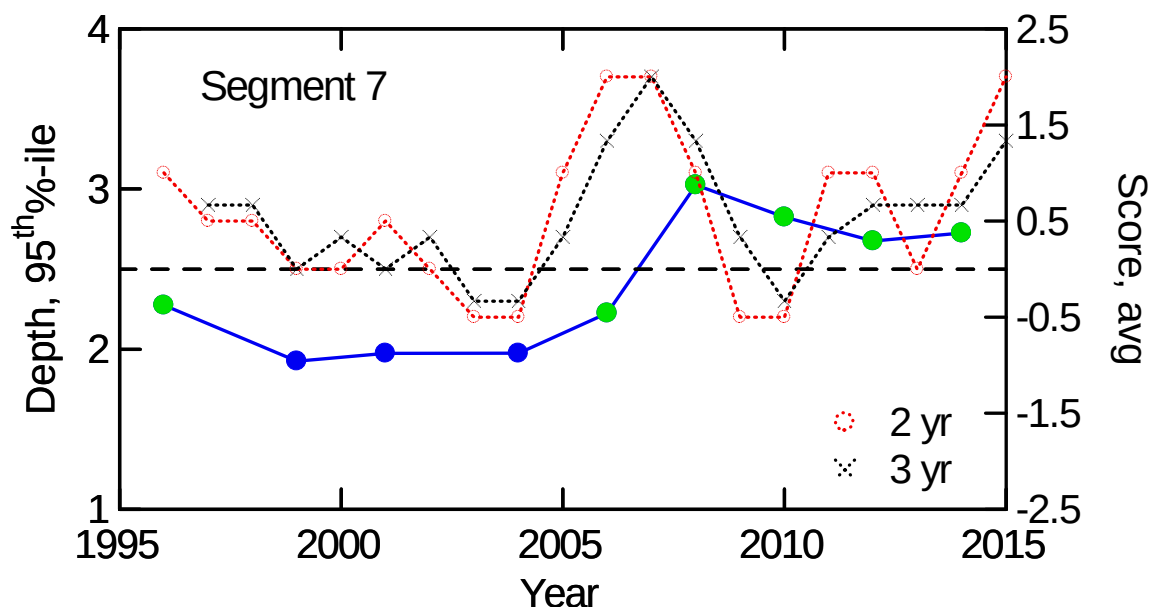


Figure 31. The 95th percentile of seagrass depth (blue) for Segment 7, when greater than or equal to target depth (green), and the 2 and 3 year moving average of Water Clarity Reporting Scores.

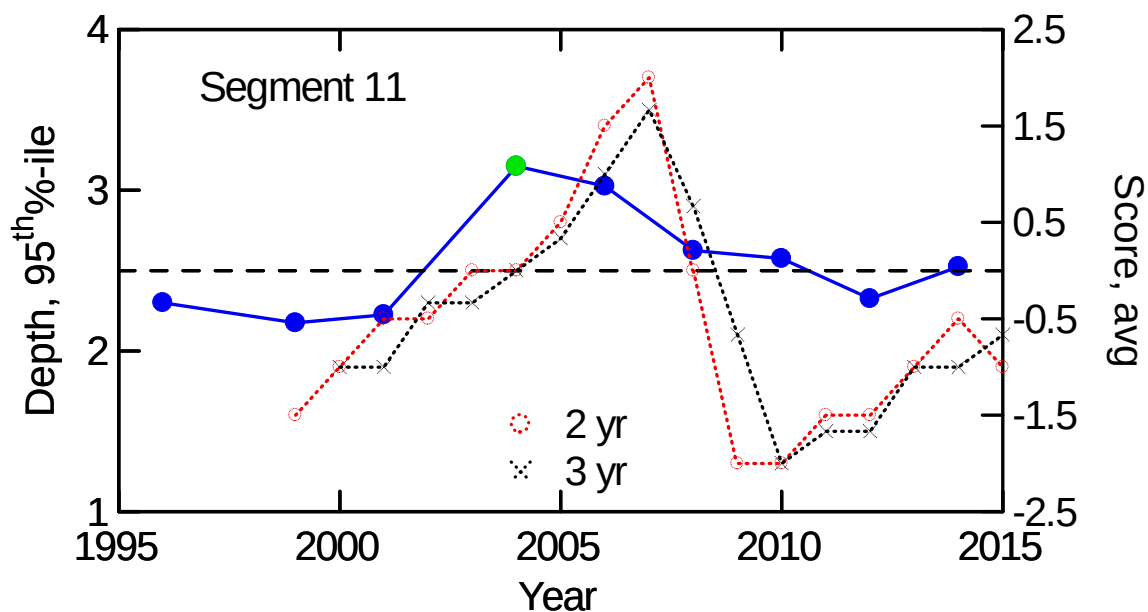


Figure 32. The 95th percentile of seagrass depth (blue) for Segment 11, when greater than or equal to target depth (green), and the 2 and 3 year moving average of Water Clarity Reporting Scores.

Although not used for scoring and trend detection in this project, and not the most indicative of the depth limits of seagrass over time, measures of the central tendency of K_{dPAR} and %PAR received at target depths remain useful quantities to place this work in context with existing

literature and common practices of seagrass management. Segment-specific median K_{dPAR} values were provided in Table 3 above. Given the demonstrated significance of the 2 to 3 year light history to seagrass depths, annual median K_{dPAR} values are illustrated as a moving three year average (Figure 33). Application of the individual modeled K_{dPAR} values at target depths for each segment produce estimates of %PAR received by depth-limited seagrass. Annual medians are again illustrated as a time series of 3 year moving averages (Figure 34). During the reference period, median %PAR ranged between 15-31%PAR for individual segments. During a period of higher attenuation (2000-2005) target depths received 10-25%PAR, while the most recent period of higher clarity in many segments, target depths received ~12-38%PAR.

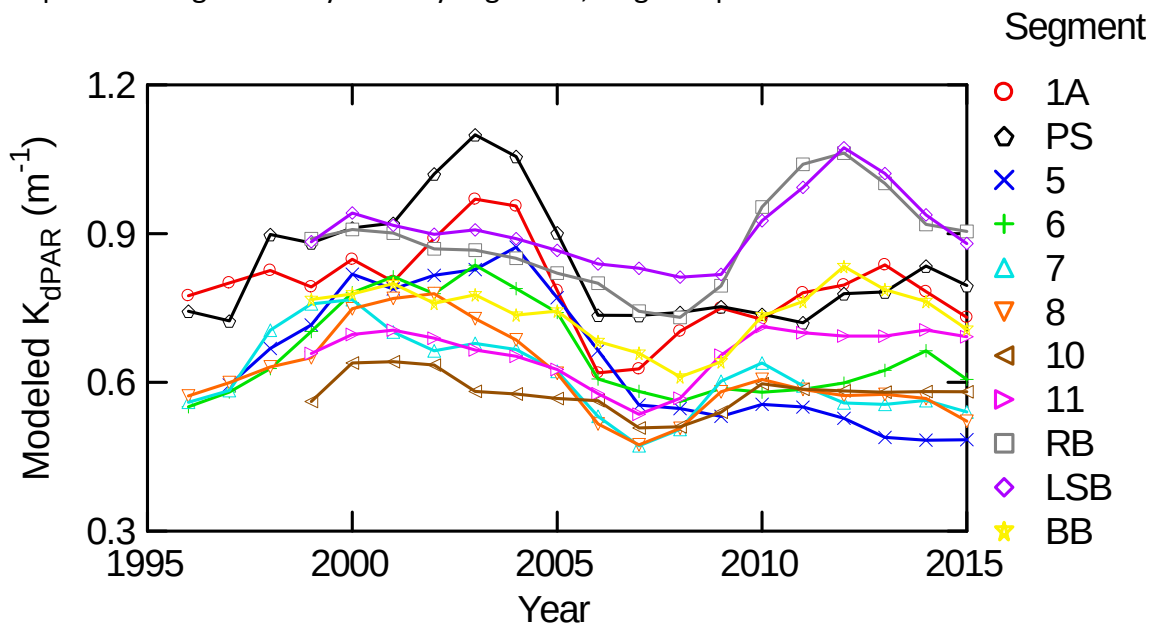


Figure 33. Three year moving averages of annual median K_{dPAR} by segment.

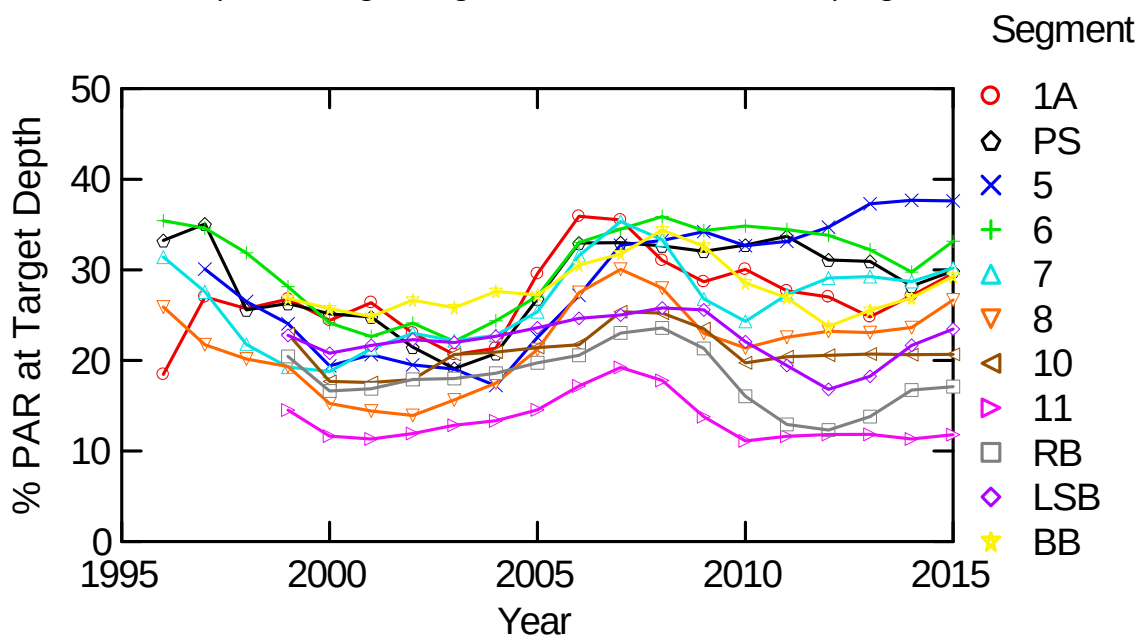


Figure 34. Three year moving averages of annual median %PAR at target depth by segment.

4.0 SUMMARY AND CONCLUSIONS

The most recent seagrass mapping data of the Sarasota Bay study area were joined with a bathymetric grid and the cumulative distributions of seagrass as a function of depth were provided in increments of 5% for each Bay segment and year for all seagrass mapping products from 1950 through 2014. Sub-segments of the larger “Sarasota Bay” seagrass segment were investigated and found to be significantly different for the 95th depth percentiles and for water quality parameters during a period (2008-2014) when seagrass areas and depths were relatively stable. The 95th percentiles of the depth distributions of the smaller sub-segments varied by nearly 1.5 m. The remainder of the analyses were performed using the 11 smaller segments.

Prior work (JEI, 2008) had established seagrass acreage targets as the maximum of either the 1950’s coverage or the mean of the acres in the 2004 and 2006 mapping efforts. At the time, 2006 was the most recent available mapping. For this project, target depths for seagrass were similarly established as the maximum of the 95th percentile of the seagrass depth distribution of either 1950’s or the mean of the 2004 and 2006 values. Target depths ranged from 1.5 to 3.1 m. A number of segments have displayed depth extensions since 2006.

Using specialized data sets which provided regionally-specific partitioning of absorption for chlorophyll pigments, detrital materials, and dissolved organics, a spectrally explicit optical model was calibrated for the Sarasota Bay Estuary Program study area in order to compute diffuse attenuation coefficients (K_{dPAR}) from typical water quality monitoring variables of color, chlorophyll, and turbidity. In the available water quality data, color had been analyzed by a variety of methods that were rectified to a single computed absorption coefficient to the extent possible. In the case of color data collected using spectrophotometric color measurements, measured K_{dPAR} , was applied after adjusting for the difference between observation time and local noon, and empirically rectifying observed K_{dPAR} between sampling programs.

Model calibration was excellent overall and indicated a robust approach to computing water clarity in the ranges most relevant for seagrass growth. In many cases, the modeled values are a more uniformly reliable indicator of water column clarity than when K_{dPAR} is measured in very shallow systems with variations induced by cloud cover, sun angle, wave conditions or bottom reflectance. The optical model provides an analytical approach to computing water clarity, K_{dPAR} , and %PAR, at predetermined depths and as a function of the water quality monitoring parameters, color, chlorophyll and turbidity.

While target depths were selected as the maximum depths between the 1950’s and 2004-2006, there were no water quality data available from the 1950’s with which to model K_{dPAR} . A reference period of target water clarity was therefore selected as that which was associated with the 2004 and 2006 seagrass mapping events. Knowing that seagrass coverage (mapped in the early months of 2004 and 2006) was undoubtedly influenced by the water clarity during the prior growing season, water clarity reference periods were considered to be the calendar years of 2003 and the intervening 2004 and 2005 period, inclusive.

For the majority of segments, the distribution of water clarity was significantly associated with the depth distribution of grasses over time, provided a lengthy period (2-3 years) of modeled K_{dPAR} was assessed. The 20th and 40th percentiles of K_{dPAR} distribution proved the most useful, indicating that the low attenuation coefficient, high clarity conditions over two or more successive growing seasons may be the most critical for seagrass depth changes. The segments where depths and K_{dPAR} were not as clearly linked may have water clarity influences not captured by the spatially distributed sampling, or may have mechanical disturbances from currents or concentrated boat traffic.

Annual scoring of the distributions of K_{dPAR} modeled from the probabilistic water quality sampling of the study area was applied relative to the identified reference period (2003-2005). Examination of individual scores indicated that declines in water clarity resulted not only from climatic variations in rainfall and freshwater inflow, but also from periods with elevated turbidity and chlorophyll. Illustrations of trends in scores, averaged over 2 or three years, were consistent in many instances with changes in 95th percentiles of seagrass depths and support the utility of the method while also indicating that there remain influences on seagrass cover beyond water column clarity. Although not used for scoring, and not always significant with trends in depth over time, median values of %PAR at target depths ranged from 15-31% during the reference period of 2003-2005.

The optical model and the Water Clarity Reporting Tool provide an important and easy to understand method of disseminating complex, non-linear attenuation processes to both public and managers alike. Routinely applied, both the model and the Reporting Tool will measure and accurately report on estuarine conditions with demonstrated links to key natural resources. While the increase in seagrass cover experienced since 2006 may lead to a re-evaluation of seagrass area and depth targets, and water clarity reference periods, the techniques of the optical model and Reporting Tool remain valid and can be readily updated to any future desired reference periods.

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APPENDIX A
Water Quality and Attenuation Coefficient Data
Electronic Only

APPENDIX B
Spectral Coefficients

Table B-1. Spectral absorption coefficients of pure water (Pope and Fry, 1997).

nm	a_w (m^{-1})	nm	a_w (m^{-1})	nm	a_w (m^{-1})
400	0.00660	500	0.02040	600	0.2224
402	0.00590	502	0.02220	602	0.2431
404	0.00550	504	0.02460	604	0.2546
406	0.00520	506	0.02650	606	0.2602
408	0.00500	508	0.02870	608	0.2634
410	0.00470	510	0.03250	610	0.2644
412	0.00460	512	0.03640	612	0.2661
414	0.00450	514	0.03900	614	0.2673
416	0.00440	516	0.03980	616	0.2687
418	0.00440	518	0.04000	618	0.2715
420	0.00450	520	0.04090	620	0.2755
422	0.00470	522	0.04150	622	0.2802
424	0.00480	524	0.04160	624	0.2821
426	0.00480	526	0.04210	626	0.2863
428	0.00480	528	0.04290	628	0.2908
430	0.00490	530	0.04340	630	0.2916
432	0.00500	532	0.04450	632	0.2982
434	0.00520	534	0.04500	634	0.3005
436	0.00550	536	0.04570	636	0.3036
438	0.00590	538	0.04680	638	0.3083
440	0.00630	540	0.04740	640	0.3108
442	0.00680	542	0.04850	642	0.3202
444	0.00730	544	0.05020	644	0.3237
446	0.00780	546	0.05210	646	0.3288
448	0.00850	548	0.05420	648	0.3360
450	0.00920	550	0.05650	650	0.3400
452	0.00960	552	0.05890	652	0.3544
454	0.00970	554	0.05960	654	0.3655
456	0.00960	556	0.05990	656	0.3792
458	0.00960	558	0.06080	658	0.3970
460	0.00980	560	0.06190	660	0.4100
462	0.01000	562	0.06370	662	0.4219
464	0.01010	564	0.06400	664	0.4273
466	0.01010	566	0.06520	666	0.4319
468	0.01030	568	0.06770	668	0.4366
470	0.01060	570	0.06950	670	0.4390
472	0.01080	572	0.07250	672	0.4469
474	0.01120	574	0.07540	674	0.4474
476	0.01170	576	0.07960	676	0.4527
478	0.01220	578	0.08480	678	0.4623
480	0.01270	580	0.08960	680	0.4650
482	0.01300	582	0.09680	682	0.4755
484	0.01340	584	0.10540	684	0.4826
486	0.01390	586	0.11470	686	0.4918
488	0.01450	588	0.12440	688	0.5048
490	0.01500	590	0.13510	690	0.5160
492	0.01600	592	0.14840	692	0.5336
494	0.01680	594	0.16040	694	0.5498
496	0.01800	596	0.17610	696	0.5713
498	0.01940	598	0.19840	698	0.5985
				700	0.6240

Table B-2. Coefficients for spectral modeling of a_{ph} in the form of $a_{ph} = C * Chl^B$.

nm	B	C	nm	B	C	nm	B	C
400	0.4139	0.1286	500	0.5137	0.0860	600	0.6597	0.0185
402	0.4188	0.1295	502	0.5165	0.0828	602	0.6652	0.0185
404	0.4249	0.1306	504	0.5173	0.0799	604	0.6698	0.0186
406	0.4305	0.1323	506	0.5168	0.0773	606	0.6665	0.0193
408	0.4343	0.1347	508	0.5172	0.0746	608	0.6657	0.0199
410	0.4364	0.1374	510	0.5175	0.0720	610	0.6711	0.0203
412	0.4383	0.1401	512	0.5188	0.0693	612	0.6788	0.0207
414	0.4395	0.1426	514	0.5219	0.0665	614	0.6833	0.0213
416	0.4404	0.1448	516	0.5239	0.0641	616	0.6903	0.0216
418	0.4424	0.1461	518	0.5242	0.0619	618	0.6968	0.0218
420	0.4453	0.1469	520	0.5262	0.0596	620	0.7003	0.0221
422	0.4482	0.1474	522	0.5307	0.0571	622	0.7036	0.0223
424	0.4528	0.1473	524	0.5345	0.0549	624	0.7047	0.0225
426	0.4569	0.1478	526	0.5395	0.0525	626	0.7034	0.0228
428	0.4588	0.1497	528	0.5453	0.0502	628	0.6981	0.0233
430	0.4601	0.1520	530	0.5489	0.0483	630	0.6964	0.0236
432	0.4635	0.1534	532	0.5513	0.0466	632	0.6991	0.0236
434	0.4676	0.1544	534	0.5556	0.0448	634	0.6988	0.0237
436	0.4707	0.1550	536	0.5593	0.0431	636	0.6921	0.0242
438	0.4720	0.1553	538	0.5632	0.0416	638	0.6824	0.0247
440	0.4733	0.1544	540	0.5651	0.0401	640	0.6767	0.0248
442	0.4748	0.1522	542	0.5651	0.0389	642	0.6716	0.0250
444	0.4758	0.1492	544	0.5637	0.0379	644	0.6649	0.0254
446	0.4767	0.1455	546	0.5649	0.0366	646	0.6582	0.0257
448	0.4782	0.1411	548	0.5675	0.0350	648	0.6548	0.0261
450	0.4790	0.1371	550	0.5714	0.0334	650	0.6544	0.0267
452	0.4790	0.1340	552	0.5748	0.0319	652	0.6558	0.0276
454	0.4799	0.1315	554	0.5794	0.0304	654	0.6576	0.0291
456	0.4830	0.1289	556	0.5816	0.0290	656	0.6577	0.0314
458	0.4856	0.1268	558	0.5838	0.0278	658	0.6603	0.0343
460	0.4862	0.1256	560	0.5916	0.0264	660	0.6651	0.0378
462	0.4872	0.1244	562	0.5998	0.0252	662	0.6682	0.0421
464	0.4889	0.1228	564	0.6035	0.0245	664	0.6660	0.0475
466	0.4892	0.1214	566	0.6024	0.0241	666	0.6623	0.0533
468	0.4891	0.1198	568	0.6057	0.0234	668	0.6603	0.0587
470	0.4886	0.1180	570	0.6147	0.0225	670	0.6610	0.0628
472	0.4876	0.1163	572	0.6237	0.0217	672	0.6620	0.0654
474	0.4858	0.1147	574	0.6207	0.0216	674	0.6615	0.0669
476	0.4850	0.1129	576	0.6231	0.0213	676	0.6588	0.0673
478	0.4864	0.1111	578	0.6315	0.0207	678	0.6555	0.0662
480	0.4884	0.1093	580	0.6370	0.0203	680	0.6558	0.0631
482	0.4894	0.1076	582	0.6358	0.0204	682	0.6586	0.0583
484	0.4887	0.1062	584	0.6409	0.0201	684	0.6654	0.0518
486	0.4886	0.1049	586	0.6487	0.0196	686	0.6751	0.0442
488	0.4922	0.1026	588	0.6594	0.0190	688	0.6845	0.0366
490	0.4969	0.1000	590	0.6624	0.0187	690	0.6868	0.0301
492	0.4998	0.0975	592	0.6630	0.0187	692	0.6797	0.0249
494	0.5025	0.0951	594	0.6598	0.0187	694	0.6656	0.0209
496	0.5062	0.0923	596	0.6579	0.0187	696	0.6574	0.0171
498	0.5097	0.0893	598	0.6569	0.0187	698	0.6581	0.0136

Table B-3. Atmospheric extinction coefficients and extraterrestrial radiation (solar spectrum at top of atmosphere) at mean Earth-Sun distance.

(nm)	Atmosph. Extinct. Coeff (SA ⁻¹)	I _{ta} ² (W m ⁻² nm ⁻¹)	(nm)	Atmosph. Extinct. Coeff (SA ⁻¹)	I _{ta} ² (W m ⁻² nm ⁻¹)	(nm)	Atmosph. Extinct. Coeff (SA ⁻¹)	I _{ta} ² (W m ⁻² nm ⁻¹)
400	0.45270	1.68850	500	0.22600	1.91600	600	0.17880	1.77000
402	0.44420	1.81400	502	0.22650	1.86000	602	0.17560	1.71500
404	0.43660	1.76300	504	0.23280	1.83300	604	0.17420	1.77900
406	0.42900	1.66600	506	0.22600	2.02500	606	0.17050	1.75800
408	0.42210	1.69900	508	0.22240	1.88000	608	0.16590	1.75100
410	0.41500	1.53700	510	0.21870	1.91000	610	0.16330	1.72400
412	0.40740	1.81600	512	0.21540	1.98900	612	0.16130	1.73600
414	0.40120	1.71440	514	0.21280	1.82400	614	0.15940	1.65500
416	0.39380	1.81500	516	0.21120	1.89100	616	0.15660	1.66400
418	0.38780	1.68500	518	0.20930	1.75900	618	0.15520	1.70200
420	0.38180	1.59900	520	0.20830	1.86000	620	0.15520	1.71100
422	0.37570	1.78200	522	0.20750	1.91500	622	0.16360	1.67840
424	0.37000	1.70800	524	0.20680	1.94100	624	0.16580	1.66700
426	0.36310	1.69900	526	0.20690	1.87400	626	0.16000	1.64000
428	0.35830	1.65100	528	0.20760	1.88000	628	0.19870	1.69300
430	0.35190	1.21200	530	0.20740	1.89200	630	0.17360	1.66500
432	0.34650	1.82200	532	0.20640	1.95800	632	0.15690	1.59010
434	0.34170	1.56000	534	0.20450	1.86900	634	0.14560	1.63700
436	0.33650	1.86800	536	0.20250	1.97400	636	0.14150	1.60930
438	0.33050	1.66300	538	0.20030	1.91300	638	0.13730	1.66500
440	0.32690	1.83000	540	0.19920	1.80000	640	0.13300	1.61300
442	0.32150	1.92200	542	0.20030	1.88800	642	0.12960	1.60900
444	0.31770	1.89410	544	0.19880	1.91900	644	0.12760	1.61400
446	0.31320	1.75570	546	0.19940	1.86090	646	0.13230	1.59100
448	0.30930	2.01400	548	0.19690	1.82600	648	0.14600	1.60200
450	0.30310	2.06900	550	0.19460	1.86300	650	0.13100	1.52600
452	0.29900	2.04700	552	0.19300	1.89600	652	0.14490	1.59100
454	0.29430	2.01800	554	0.19250	1.87800	654	0.12510	1.57500
456	0.29050	2.06300	556	0.19230	1.85700	656	0.12710	1.32330
458	0.28770	2.03200	558	0.19280	1.85300	658	0.12370	1.53900
460	0.28430	1.99730	560	0.19290	1.78600	660	0.12510	1.55800
462	0.28010	2.07800	562	0.19310	1.80100	662	0.13860	1.57100
464	0.27650	2.01500	564	0.19390	1.83600	664	0.12450	1.55400
466	0.27170	2.02100	566	0.19450	1.75000	666	0.11380	1.55500
468	0.26930	2.01200	568	0.19780	1.85900	668	0.10770	1.53480
470	0.26670	1.93900	570	0.20220	1.82800	670	0.10510	1.53400
472	0.26420	2.07000	572	0.20340	1.87200	672	0.10340	1.50600
474	0.26290	2.01200	574	0.20410	1.87300	674	0.10170	1.51300
476	0.26320	2.01200	576	0.20470	1.81800	676	0.10030	1.51500
478	0.26070	2.08600	578	0.20170	1.79900	678	0.09930	1.50700
480	0.25560	2.06800	580	0.19370	1.83400	680	0.09810	1.49400
482	0.25020	2.06230	582	0.18670	1.85200	682	0.09700	1.49300
484	0.24590	1.98900	584	0.18190	1.85400	684	0.09640	1.46600
486	0.24240	1.60100	586	0.18050	1.79200	686	0.09590	1.43300
488	0.23950	1.93500	588	0.19150	1.82100	688	0.23390	1.47600
490	0.23710	2.03200	590	0.21060	1.72180	690	0.20010	1.47900
492	0.23400	1.85600	592	0.20480	1.78800	692	0.14260	1.45400
494	0.23170	1.93390	594	0.19860	1.78900	694	0.15560	1.45700
496	0.22960	1.94900	596	0.18940	1.79600	696	0.13730	1.44200
498	0.22730	1.92400	598	0.18640	1.77200	698	0.10020	1.41700
						700	0.12090	1.42200

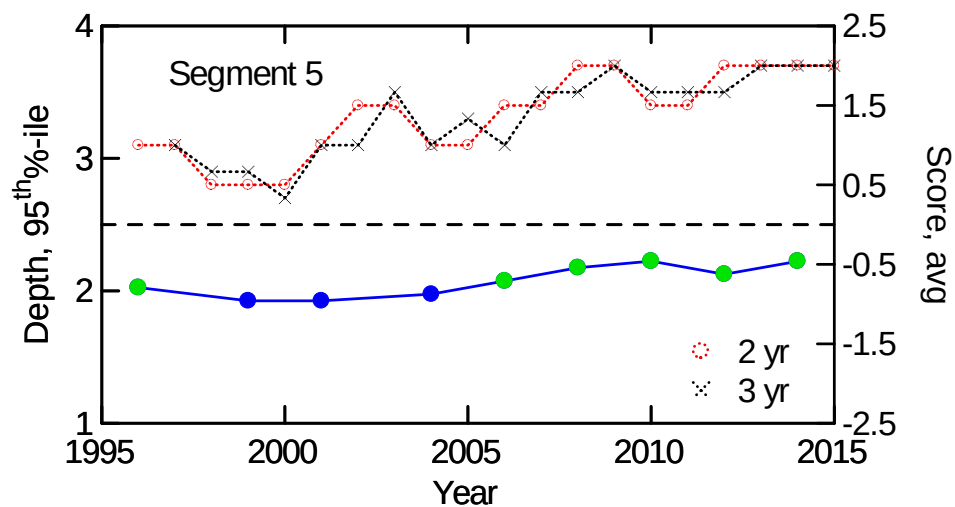
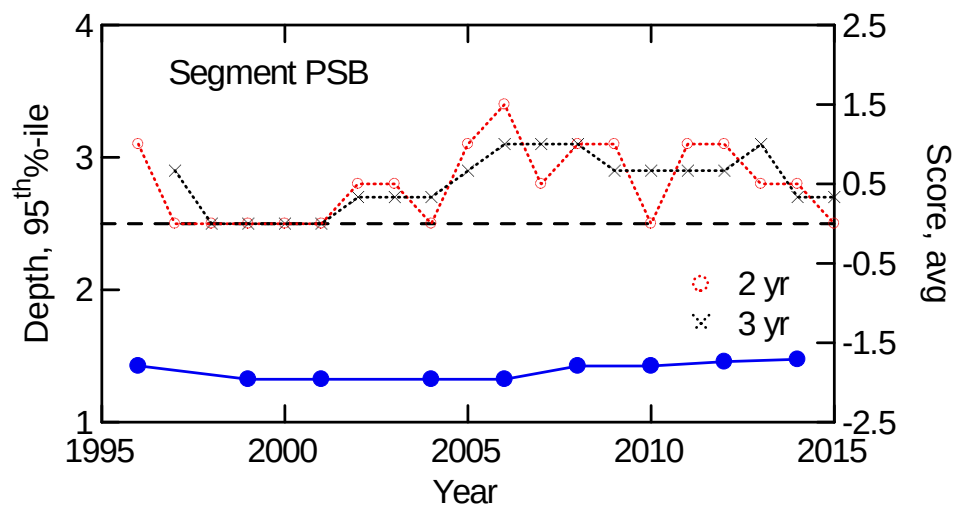
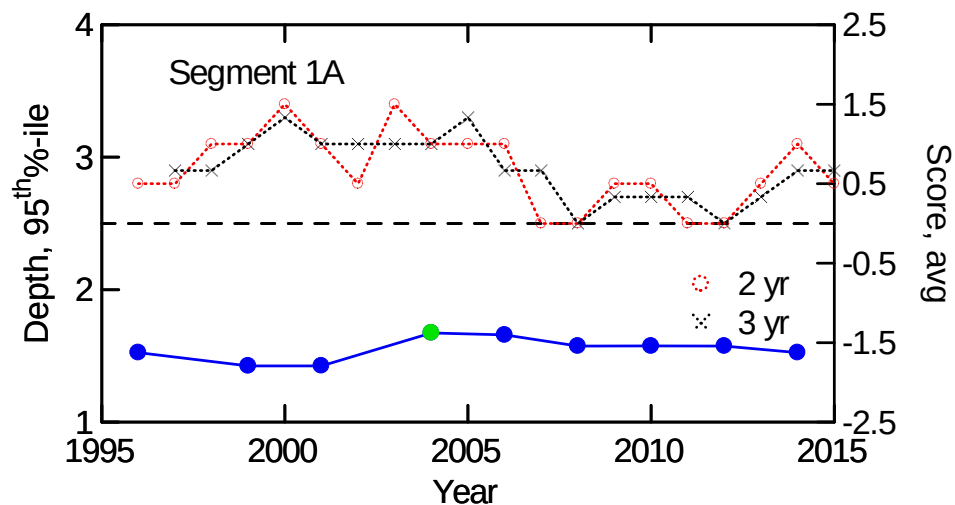
APPENDIX C
Results of Quantile Regressions

APPENDIX D
95TH Depth Percentiles from Seagrass

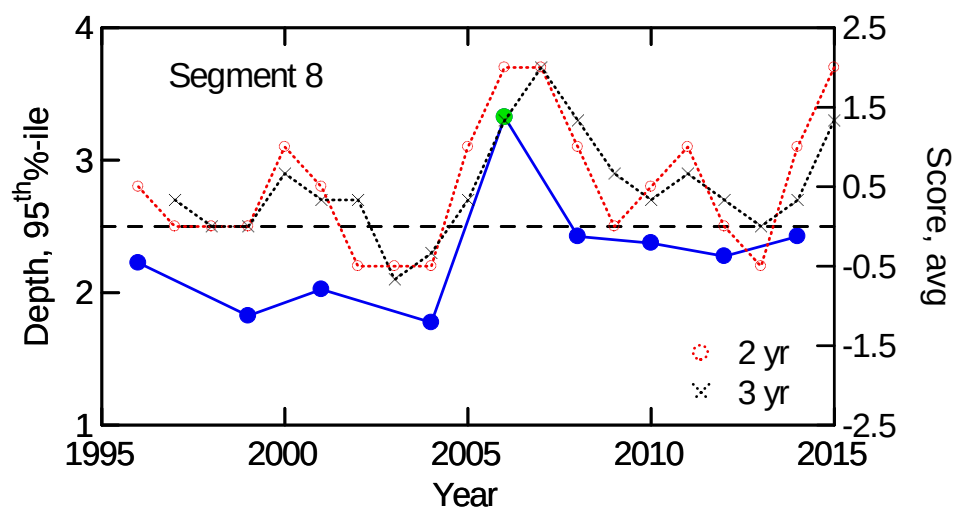
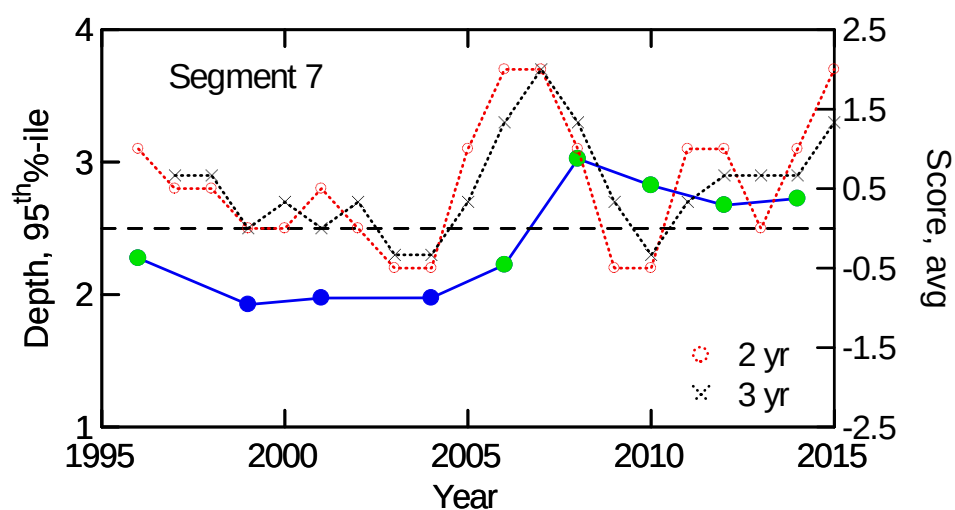
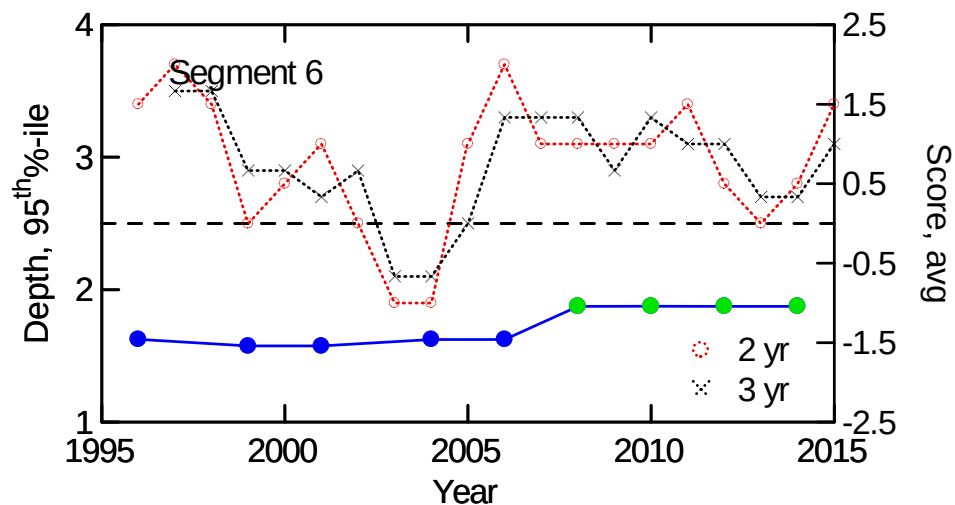
Table D-1. 95TH depth percentiles from seagrass mapping

Segment	Year	Area (ac)	95th %ile (m)	Segment	Year	Area (ac)	95th %ile (m)	Segment	Year	Area (ac)	95th %ile (m)
1A	1950	459	1.57	7	1950	1444	2.22	RB	1950	283	1.98
1A	1988	489	1.53	7	1988	1063	1.82	RB	1988	328	1.97
1A	1994	486	1.52	7	1994	1070	1.82	RB	1994	346	1.97
1A	1996	490	1.52	7	1996	1633	2.27	RB	1996	359	1.93
1A	1999	455	1.42	7	1999	1228	1.93	RB	1999	333	1.88
1A	2001	458	1.42	7	2001	1234	1.97	RB	2001	274	1.93
1A	2004	477	1.67	7	2004	1204	1.98	RB	2004	370	1.93
1A	2006	523	1.66	7	2006	1239	2.22	RB	2006	326	1.98
1A	2008	490	1.57	7	2008	2672	3.03	RB	2008	304	1.98
1A	2010	497	1.57	7	2010	2332	2.83	RB	2010	330	1.98
1A	2012	513	1.57	7	2012	2102	2.68	RB	2012	305	1.93
1A	2014	527	1.52	7	2014	2345	2.73	RB	2014	319	2.02
	Total				Total				Total		
1A	Area	894	4.33	7	Area	5208	3.81	RB	Area	1282	2.47
PSB	1950	1024	1.52	8	1950	534	1.98	LSB	1950	876	1.67
PSB	1988	1109	1.42	8	1988	332	1.32	LSB	1988	529	1.68
PSB	1994	1091	1.44	8	1994	373	1.67	LSB	1994	595	1.63
PSB	1996	1134	1.43	8	1996	518	2.22	LSB	1996	719	1.63
PSB	1999	1027	1.32	8	1999	393	1.83	LSB	1999	765	1.58
PSB	2001	1050	1.32	8	2001	433	2.03	LSB	2001	691	1.62
PSB	2004	1002	1.32	8	2004	355	1.77	LSB	2004	762	1.63
PSB	2006	1025	1.32	8	2006	532	3.33	LSB	2006	648	1.62
PSB	2008	1163	1.43	8	2008	626	2.43	LSB	2008	841	1.62
PSB	2010	1173	1.43	8	2010	643	2.38	LSB	2010	887	1.62
PSB	2012	1180	1.46	8	2012	590	2.28	LSB	2012	908	1.62
PSB	2014	1234	1.47	8	2014	632	2.43	LSB	2014	925	1.62
	Total				Total				Total		
PSB	Area	2877	2.47	8	Area	3581	3.73	LSB	Area	2010	2.08
5	1950	1062	1.93	10	1950	846	2.49	BB	1950	270	1.42
5	1988	1082	1.88	10	1988	1075	2.46	BB	1988	406	1.62
5	1994	1170	1.93	10	1994	1202	2.38	BB	1994	409	1.62
5	1996	1252	2.03	10	1996	1212	2.46	BB	1996	398	1.58
5	1999	1142	1.92	10	1999	990	2.43	BB	1999	370	1.53
5	2001	1136	1.92	10	2001	1073	2.68	BB	2001	300	1.52
5	2004	1017	1.98	10	2004	1126	2.72	BB	2004	468	1.78
5	2006	1109	2.07	10	2006	1275	2.73	BB	2006	417	1.73
5	2008	1553	2.17	10	2008	1508	2.91	BB	2008	340	1.53
5	2010	1677	2.22	10	2010	1565	2.93	BB	2010	378	1.63
5	2012	1687	2.13	10	2012	1615	2.93	BB	2012	396	1.67
5	2014	1723	2.22	10	2014	1785	3.17	BB	2014	417	1.67
	Total				Total				Total		
5	Area	2430	3.06	10	Area	3284	4.01	BB	Area	635	1.83
6	1950	2652	1.83	11	1950	240	2.18				
6	1988	1966	1.62	11	1988	255	2.52				
6	1994	2263	1.62	11	1994	280	2.58				
6	1996	2270	1.63	11	1996	330	2.30				
6	1999	2142	1.58	11	1999	324	2.17				
6	2001	2143	1.57	11	2001	306	2.22				
6	2004	2098	1.62	11	2004	290	3.15				
6	2006	2218	1.62	11	2006	482	3.02				
6	2008	2682	1.87	11	2008	396	2.63				
6	2010	2732	1.88	11	2010	400	2.58				
6	2012	2799	1.87	11	2012	414	2.33				
6	2014	2841	1.87	11	2014	456	2.52				
	Total				Total						
6	Area	4407	3.03	11	Area	2521	3.66				

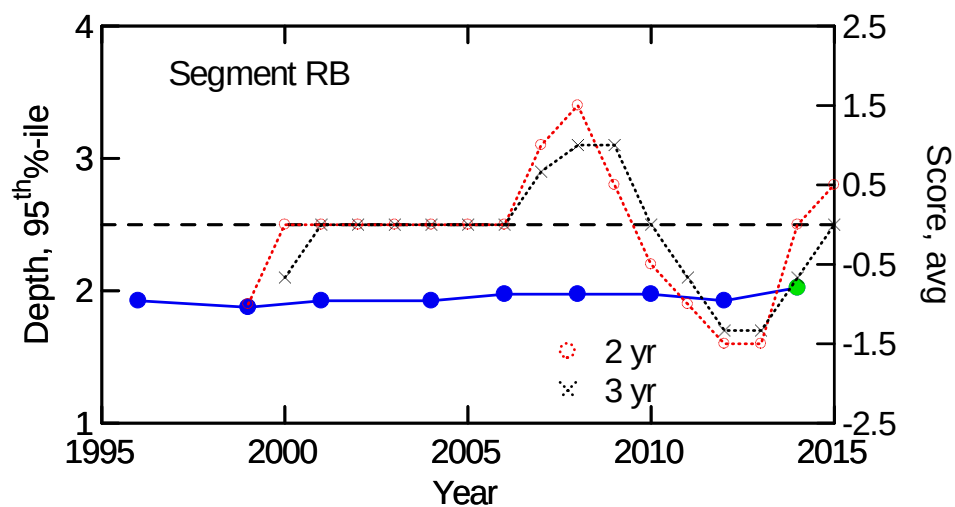
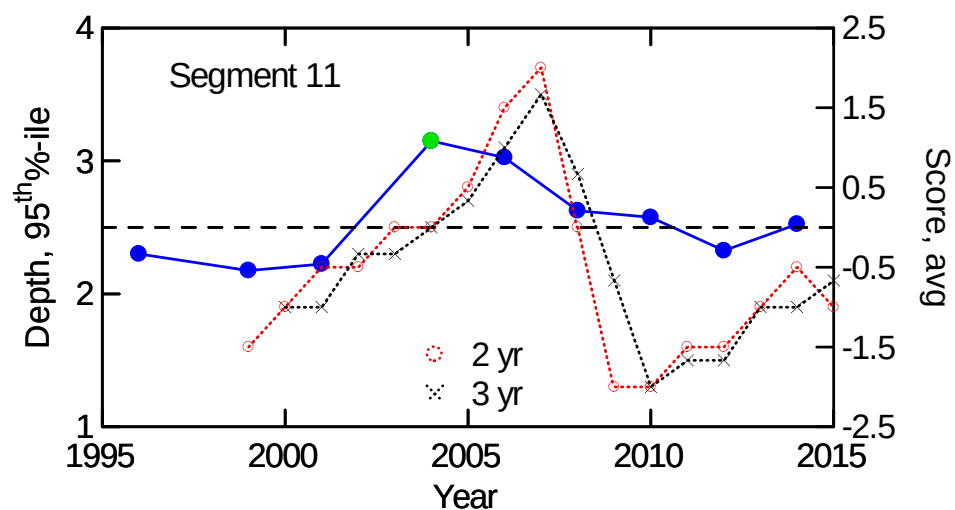
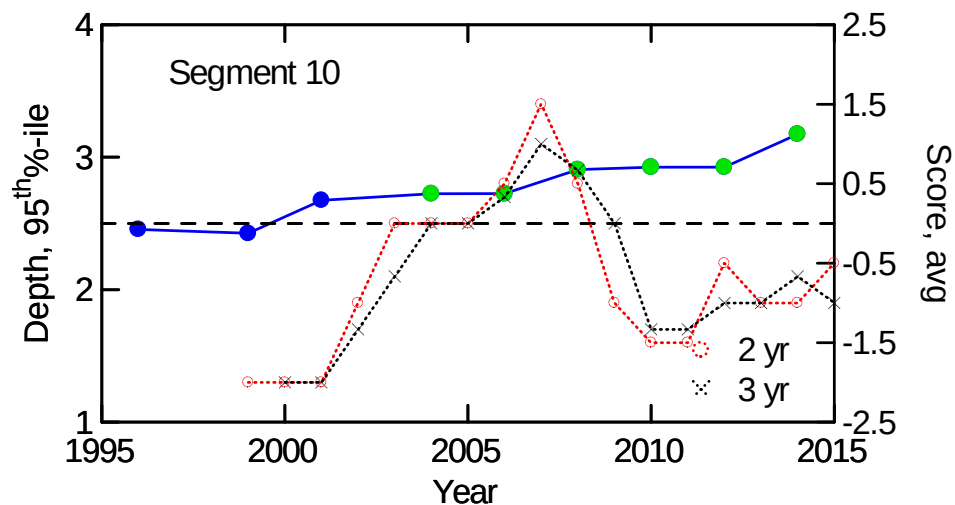
APPENDIX E
Time Series of Seagrass Depths and Water Clarity Reporting Scores



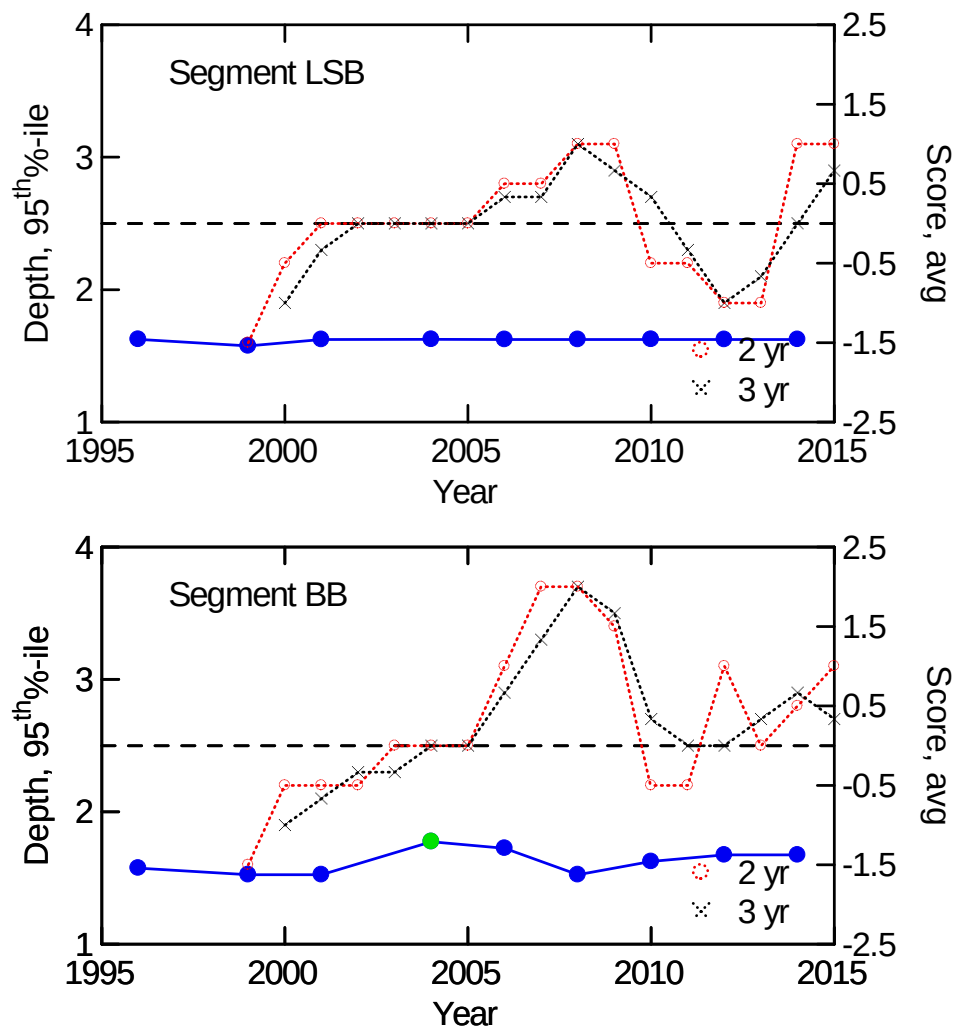
The 95th percentile of seagrass depth (blue), when greater than or equal to target depth (green), and the 2 and 3 year moving average of Water Clarity Reporting Scores.



The 95th percentile of seagrass depth (blue), when greater than or equal to target depth (green), and the 2 and 3 year moving average of Water Clarity Reporting Scores.



The 95th percentile of seagrass depth (blue), when greater than or equal to target depth (green), and the 2 and 3 year moving average of Water Clarity Reporting Scores.



The 95th percentile of seagrass depth (blue), when greater than or equal to target depth (green), and the 2 and 3 year moving average of Water Clarity Reporting Scores.