Evaluating light attenuation and low salinity in the lower Caloosahatchee Estuary with the River, Estuary, and Coastal Observing Network (RECON)

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Abstract The southern portion of the Charlotte Harbor region, which includes Pine Island Sound, San Carlos Bay, and the lower Caloosahatchee Estuary, has over 11,700 ha of submerged aquatic vegetation (SAV). The SAV species in the region have been used as environmental indicators because they are affected by nutrient loading, algae blooms, and freshwater discharges. Management approaches to reduce nutrient loading, phytoplankton concentrations, and high freshwater discharges in the region have also been applied to meet water clarity targets (light attenuation). In an effort to understand the duration and effect of low salinity periods in the lower estuary on water clarity, salinity data at several River, Estuary, and Coastal Observing Network (RECON) sites were analyzed. Optical parameters associated with increased light attenuation (fluorescent dissolved organic matter, chlorophyll, turbidity) were significantly higher during lower salinity periods (less than 25). In addition, discrete light attenuation coefficients, collected as part of RECON monthly maintenance, were analyzed. A synthesis and evaluation of the conditions in the lower Caloosahatchee during the study period (2008-2014) suggest that flow and load reductions would result in increased water clarity.

Keywords FDOM, freshwater discharge, *in situ* chlorophyll, seagrass extent, water clarity, RECON

Introduction

The management of freshwater flows to an estuary can have profound effects on conditions and ecosystem function (Alber 2002, Kimmel 2002). Increasing worldwide demands for freshwater and the loss of critical habitats in coastal areas (Lotze et al. 2006) are contributing to the need for prioritization, allocation, and delivery of freshwater to coastal systems (Montagna et al. 2002). One approach using optimal flow criteria provides a mechanism by which freshwater is allocated to preserve estuarine characteristics (e.g., estuarine gradients, turbidity maximum) and to protect sessile oligohaline (e.g., *Vallisneria americana*), euryhaline (e.g., *Crassostrea virginica, Callinectes sapidus*), and euryhaline species (e.g. *Cynoscion nebulosus, Thalassia testudinum*) that are found in bays and estuaries. However, oscillations in climatic conditions, such as increased hurricanes, can also lead to variable flows,

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nutrient loading (Doering and Chamberlain 1999), and periods of hypoxia (Vaquer-Sunyer and Duarte 2008). Similarly, droughts and floods can lead to the absence of critical spring phytoplankton blooms (Nichols et al. 1986) or reductions in nursery habitats, such as seagrasses or oysters. Consequently, there is a growing need for monitoring of inshore, nearshore, and oceanic conditions over relatively large distances (e.g. 100–200 km) and in "real-time" (Johnson and Needoba 2008) to understand both natural and anthropogenic sources of environmental variability. Estuarine systems have many gradients that change rapidly over short time-scales (hours to days). This requires frequent and simultaneous measurements at multiple locations (Malone 2003) to understand how complex systems are organized and to provide recommendations for how to improve the management of natural resources and maximize ecosystem services (Costanza et al. 1997).

The Caloosahatchee is a channelized and highly managed estuary where freshwater flows are determined by a series of dams and locks which are connected to Lake Okeechobee. At any time the freshwater flows can be any combination water from the Caloosahatchee watershed and from Lake Okeechobee. The Caloosahatchee River is used as a conveyance to release water when levels in the lake are too high. During drought periods, the Caloosahatchee Estuary often does not have sufficient freshwater from the tidal watershed and the oligohaline zone is highly compressed. This problem is exacerbated by the S79 lock and dam, which presents a barrier to upstream movement of the oligohaline zone. Furthermore, the rapid urbanization of the southwest Florida coast has replaced wetlands and riparian areas that once stored and treated stormwater within the Caloosahatchee watershed. The result is an estuary with frequent extreme fluctuations in salinity and dissolved nutrients. Flows reported at S79 are generally indicative of the regional climate conditions, but also reflect water management actions based on evolving protocols for budgeting water to control Lake Okeechobee levels, regulating estuarine salinities, etc. Target minimum flows to the Caloosahatchee Estuary are 300 cubic feet per second (CFS) (8.5 $m^3 s^{-1}$) and operational flexibility has allowed 450 CFS. The optimal minimal flows supportive of valued ecosystem components is 300-800 CFS (SFWMD 2000). Maximum flows that exceed 2,800 CFS (79.3 $m^3 s^{-1}$) can affect oyster spat settlement (*Crassostrea virginica*) and other euhaline species such as *Thalassia testudinum* (CERP RECOVER 2007, Milbrandt et al. in press). The proportion of flow from the watershed versus Lake Okeechobee changes from year-to-year depending on several factors including; rainfall, water storage, the level of Lake Okechobee, climatological predictions, and water use in the Caloosahatchee basin.

Extensive mangrove-lined shorelines in Pine Island Sound and San Carlos Bay are closely associated with oyster reefs and large areas of mixed seagrass species. The biodiversity in seagrass areas is high (Heck 1979, Poulakis et al. 2003) and supportive of a variety of recreational fishery activities with significant economic value (Beever and Walker 2013). The extensive seagrass areas are threatened by shifts in water quantity and quality from the

Caloosahatchee Estuary, and variation in salinity has been identified as a major stressor (Orlando and Douglass 2014). However, exactly how the frequency and duration of lower salinity periods and subsequent reductions in water clarity affect surrounding seagrass areas is poorly understood. The Technical Advisory Committee (TAC) of the Charlotte Harbor National Estuary Program (Janicki et al. 2010, Dixon and Wessel 2014) has established optical targets for protection of existing seagrass, estimated from the data of a large, multi-agency water quality monitoring network (http://www.chnep.wateratlas.usf.edu). The optical targets are based on light attenuation coefficients (Kirk 1983), both measured and derived from optical properties (fluorescent dissolved organic matter, chlorophyll *a*, turbidity). Fluorescent dissolved organic matter (FDOM) is strongly negatively correlated with salinity and positively correlated with total nitrogen (TN) in the Caloosahatchee Estuary (Bailey et al. 2009). This suggests that exceeding the upper threshold of 2,800 CFS (79.3 m^3 s^{-1}) not only lowers salinities below thresholds of harm for certain seagrass species (Irlandi 2006), but also introduces higher nutrient loading and increased phytoplankton productivity, or macroalgal overgrowth (Milbrandt unpublished data, Douglass 2013). While light attenuation observations and targets have provided some initial guidance about water and resource management in this system, an evaluation was needed of the frequency and duration of low salinity events in Pine Island Sound and San Carlos Bay, and their relationship to optical water quality and seagrass health.

Materials and Methods

Monitoring region and sites. Barrier islands, including southern Pine Island, Sanibel, and Captiva Islands, form the border of a large, protected system of bays and sounds in lower Charlotte Harbor. Pine Island Sound and San Carlos Bay are shallow, mangrove-lined estuaries that are affected by freshwater from the Caloosahatchee River (including the tidal watershed, the watershed of the Caloosahatchee upstream of S79, and Lake Okeechobee).

The River, Estuary, and Coastal Observing Network (RECON) is composed of real-time sensor platforms at fixed sites in the Caloosahatchee Estuary, San Carlos Bay, Pine Island Sound, and the Gulf of Mexico (Figure 1). The Shell Point RECON fixed site, established in November 2007, is at the confluence of the Caloosahatchee Estuary and San Carlos Bay and experiences strong tidally-driven mixing with a large range of salinities with each tidal cycle. Shell Point is near several oyster reef and seagrass indicator sites targeted for northern Everglades restoration monitoring (Douglass 2013, Volety and Haynes 2013). McIntyre Creek and Tarpon Bay are fixed RECON locations at the confluence of lower Pine Island Sound and J.N. “Ding” Darling National Wildlife Refuge. McIntyre Creek was established by the U.S. Geological Survey (USGS) in January 2008 and was added to RECON in 2013. Tarpon Bay was established in 2007 but data were not collected from 2008-2010. These sites are moderately influenced by freshwater inputs from the Caloosahatchee River but also have local sources of freshwater from Sanibel Island. They are typically euryhaline (30-35) during dry periods (November-June), and occasionally experience lower salinities during tropical storms or high rainfall and freshwater flow periods (July-October). McIntyre Creek and Tarpon Bay are in well-protected areas close to shore. Blind Pass was a fixed site from 2007-2012 located on the Intracoastal Waterway (ICW) in open water in the middle of the south end of Pine Island Sound. The site was discontinued in 2012 due to a boat strike and the instrumentation was moved to McIntyre Creek. Redfish Pass and Gulf of Mexico are

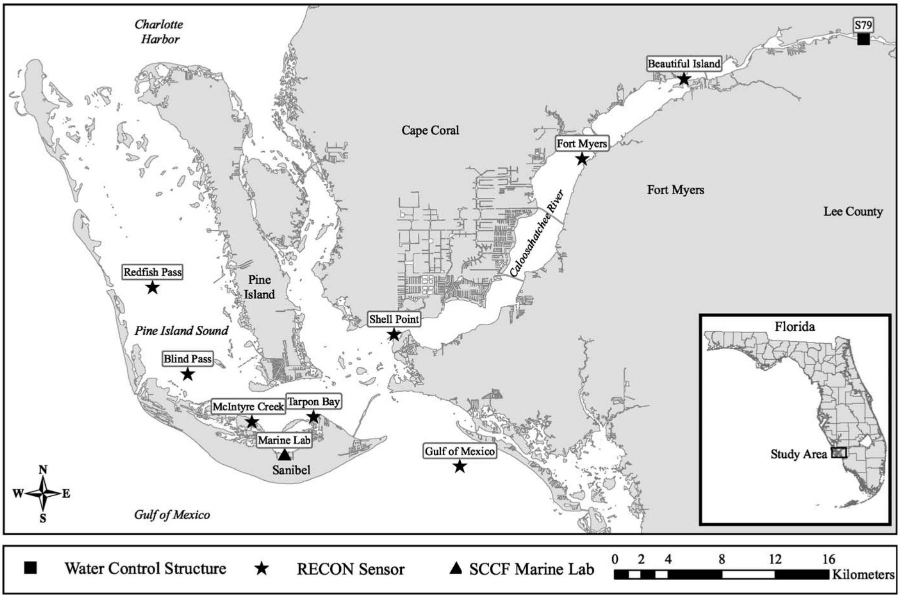

Figure 1. Map of the study area. The map shows the locations of the River, Estuary and Coastal Observing Network (RECON) and the location of the Sanibel-Captiva Conservation Foundation (SCCF) in Southwest Florida.

geographically distant from the Caloosahatchee Estuary and are euryhaline. Redfish Pass and the Gulf of Mexico RECON sites are in open water secured to U.S. Coast Guard channel markers.

RECON monitoring methods. Several biological, chemical, and physical parameters are measured hourly at each RECON station and all data are autonomously sent back to shore and made web-accessible in near real time with Seabird Coastal LOBO instruments (Table 1) Instruments are deployed and maintained from small boats with a maximum service interval of 1-2 months. The Seabird Coastal LOBO instrument packages are each attached to pilings at depths of at least 1.5 m below MLLW (Mean Lower Low Water). Configurations, tolerances, sensitivity, and variability specifications of the sensors are available from the sensor manufacturers (Seabird Coastal) and on the RECON website (http://recon.sccf.org). Each instrument package was scheduled to record and transmit data to the shore at 1-hour intervals. Data were downloaded into AQUARIUS, a software program for water data management, for analyses.

Kd PAR. During monthly service and maintenance visits to RECON sites, a data logger and sensor (Biospherical) were deployed to simultaneously measure surface and subsurface flux of photosynthetically active radiation (PAR, µmol m^{-2} s^{-1}). The data were collected for 60 s at 1 hz intervals at 0.70 m offset depths. The Biospherical BICs are multi-channel radiometers (PAR, 400-700 nm) and are deployed from the boat at a fixed width (0.6 m) using a steel lowering frame. For each sampling event at each station, a light attenuation coefficient (Kd) was calculated as:

$$Kd = \ln(I_1/I_2)/(Z_2\text{-}Z_1), \tag{1}$$

where Kd is light attenuation coefficient, I_1 and I_2 are downwelling irradiances at depths at Z_1 and Z_2 (Kirk 1983). The data were entered into a Microsoft Access database along with other RECON field Quality Assurance/Quality Control discrete data. Light sensors were calibrated by Biospherical in 2007, 2008, 2009, and 2012.

Table 1. Parameters measured at RECON locations.

Parameter	Instrument	Manufacturer
Temperature	WQM	Seabird Coastal
Salinity	WQM	Seabird Coastal
FDOM	ECO FLS	Seabird Coastal
Chlorophyll *a*	WQM	Seabird Coastal
Turbidity	WQM	Seabird Coastal
Dissolved Oxygen	WQM	Seabird Coastal
Nitrate	ISUS V3	Seabird Coastal

S79 flow. The proportion of flow from the watershed versus Lake Okeechobee varies from year-to-year depending on a large number of factors, including climatic factors and lake management. For the purposes of this article, the water conditions in the lower estuary are influenced directly by S79 flows. The flow from S79 is the cumulative flow from Lake Okeechobee and the Caloosahatchee watershed (Figure 2). While inexact, the proportion of flow from Lake Okeechobee can be derived by subtracting flows coming out of the Lake (S77) and dividing by the total flow from S79. Daily flows from S77 and S79 were downloaded from DBHydro and were provided by the South Florida Water Management District (SFWMD).

Seagrass transects. Ten transects are sampled at the end of the dry period (May) as part of an annual evaluation of seagrass within and near the Ding Darling National Wildlife Refuge. For each transect, a quadrat is placed at the shallow edge, a quadrat is placed at the deep edge, and quadrats are taken at two randomly selected positions along the transect. Shoot density, percent cover, and canopy height are determined for each seagrass species present and for macroalgae (Thompson et al. 2013).

Statistical analysis. The frequency and duration of low salinity events, defined by salinities lower than 25, was analyzed using AQUARIUS data parsing tools. A monthly summary by site of the number of days, average salinity, and sample size was calculated. A monthly summary of flow from S77 and S79 was also tabulated along with the proportion of flow from S77 as a percentage. Kendall seasonal trend analysis (WQStatPlus, Sanitas Technologies) was performed on light attenuation, salinity and optical properties for all RECON sites (Hirsch et al. 1982). A General Linear Model (GLM) analysis tested whether chlorophyll *a* (chl *a*), turbidity and FDOM were significantly different between salinities above or below 25. Seasons were defined as wet from June 15 to October 15 and dry from Oct 16 to June 14 based on rainfall data from 2004-2014. Pearson correlation analysis (MINITAB) was used to relate salinity with optical properties. Descriptive statistics (MINITAB) were used on seagrass shoot density data.

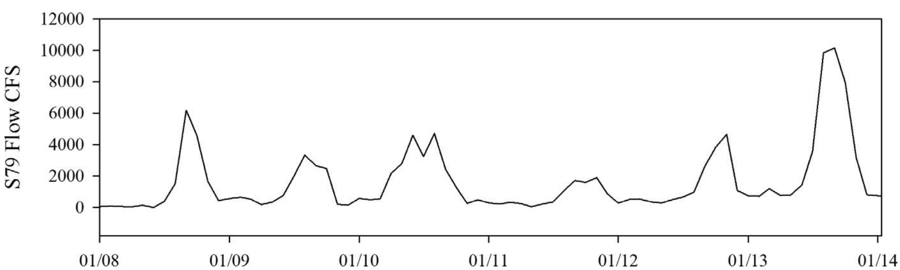

Figure 2. Monthly mean flow from S79 during the study period. The landfall of TS Faye in 2008 and the high flows in 2013 resulted in low salinity periods in the lower estuary, as measured by RECON. Daily flow data were provided by DBHYDRO and the SFWMD.

Results

Shell Point. Salinities were routinely below 25 at Shell Point during the study period (Figure 3), especially during the summer wet period each year. There were 4 years where average monthly salinities during the dry period did not go below 25 (2008, 2009, 2011, 2012). In the remaining 3 years (2010, 2013, 2014), monthly salinities were below 25 during the dry period for an average of 10.77 days. Wet period monthly salinities were lowest in 2013 (10 days) and highest in 2012 (27 days), when comparing wet periods in all years. The duration of low salinity periods during the wet period was between 7-9 days per month for most years. The exception was in 2013 where salinities were below 25 for an average of 20 days per month and ranged from 9 days in June 2013 to 30 days in September 2013. Light attenuation (Kd PAR) ranged from 0.48-2.57 m^{-1} with a mean of 1.13 ($n = 41$) during the study period (Figure 4). There were no significant differences in the optical properties between salinities < 25 and > 25. Photosynthetically active light attenuation (Kd PAR) did exhibit a positive trend (Seasonal Kendall, WQ Stats) from 2007 to 2012, but was not significant.

Tarpon Bay and McIntyre Creek. These two sites were grouped together because of their similarity in salinity responses to S79 flows. Salinities at these two sites did not go below 25 from January through June from the start of monitoring until 2014 (Figure 3). However, Tarpon Bay salinities were not collected from 2008-2010. During 2008-2009, salinities at McIntyre Creek (USGS 2014) were above 25 during both the wet and dry seasons. Salinities were below 25 for moderate periods (10-20 days) at the end of the wet period and beginning of the dry period (August-December) at McIntyre Creek and Tarpon Bay. In 2010, salinities at McIntyre Creek were below 25 in both August and October (13 days) with average monthly salinities from 27-31. In 2011, salinities at McIntyre Creek were below 25 for 10 days. In 2012, mean monthly salinities at McIntyre Creek were 24.5-31.3 for 2 months (October-November) and salinities were below 25 for 16 and 18 days, respectively. In 2012 in Tarpon Bay, salinities were below 25 for the same months and for slightly longer duration. Salinities at both McIntyre Creek and Tarpon Bay sites were lower and lasted for longer duration in 2013 because of high flows from S79. At McIntyre Creek, salinities were below 20 for all of September and October 2013 and most of August and November. Similarly, salinities at Tarpon Bay were below 20 for extended periods in September (29 days) and October (24 days) during the high flows from S79 in 2013. There was not sufficient light attenuation data at either site to conduct the seasonal trend analysis.

Blind Pass. In 2008, salinities at Blind Pass (Figure 3) were below 25 in August 2008 for only 3 days (mean salinity 21.24) and in September for 5 days (23.59). From August 27 to September 3, 123 of 193 observations (64%) were below 25. Significantly higher FDOM ($F = 20.42$, $p < 0.01$) and chl *a* ($F = 9.10$, $p < 0.01$) were found in the water where salinity was below 2. Salinities at Blind Pass were below 25 for brief periods from May-June 2008. Relatively short periods (3-7 days) of salinities less than 25 occurred again in July-September 2010. Periods of salinity below 25 were very short, lasting less than 1 day in 2011. The periods below 25 in 2012 occurred from August through October and were short (September, 6 days) duration events. In all observations where salinity was below 25, FDOM and chl *a* were significantly higher in low salinity water than FDOM and chl *a* in water where salinity was > 25 during the same month. Light attenuation at Blind Pass (Figure 4) from 2007-2012 ranged from 0.28-2.00 m^{-1} with a mean of 0.96 m^{-1} (MINITAB, n = 47). There was a significant increasing trend (95% confidence) in light attenuation during the study period (Kendall, WQStat Plus). Trend analysis indicated a 0.01 m^{-1} increase annually in Kd PAR. There is no data from Blind Pass after 2012 because the piling it was attached to was struck by a large vessel and the instrument was moved to McIntyre Creek.

Redfish Pass and Gulf of Mexico. In 2008, salinity at Redfish Pass was below 25 a day in September after Tropical Storm Fay (Figure 3). Salinities at the Gulf of Mexico were also below 25 for 1 day (1 d) in August 2008 related to the same high flow event. During periods of salinity below 25 at the Gulf of Mexico site (n = 13) compared to periods above 25 (n = 191), there were significantly higher FDOM (MINITAB, GLM, $F = 180$, $p < 0.01$), and significantly higher chl *a* ($F = 41.37$, $p < 0.01$). However, turbidity was not significantly different. At Redfish Pass, optical properties were similarly compared during this event. There were significantly higher FDOM (GLM, Minitab, $F = 59.68$, $p < 0.01$), significantly higher chl *a* ($F = 28.36$, $p < 0.01$) and significantly higher turbidity ($F = 4.27$, $p < 0.05$) in the lower salinity periods. Another short period below 25 occurred at Redfish Pass in October 2008.

The other notable period where salinities were below 25 at the most marine sites (Redfish and Gulf) occurred from August-October, 2013. Salinities at the Gulf of Mexico in 2013 were frequently below 25 for several consecutive months (August-December, 2013), but only for short periods, usually at low tide for 2-5 hours. During those periods, significant differences in optical properties were found when salinities below 25 were observed. From July 21-27, 2013 there were 6 occurrences of salinity below 25 at the Gulf of Mexico site. Significantly higher FDOM (GLM, Minitab, $F = 73.24$, $p < 0.01$) and chl *a* ($F = 47.57$, $p < 0.01$) were associated with salinities less than 25, while differences in turbidity were not significant. At Redfish Pass, 150 of 2183 observations (7%) were below 25 from July 7, 2013 to October 5, 2013. Most of the below 25 observations occurred for short periods at low tide. During these observations where salinity was below 25, FDOM was significantly higher (GLM, Minitab, $F = 236.42$, $p < 0.01$), along with chl *a* ($F = 267.49$, $p < 0.01$) and turbidity ($F = 4.26$, $p < 0.05$). Light attenuation (Kd PAR) at the Gulf

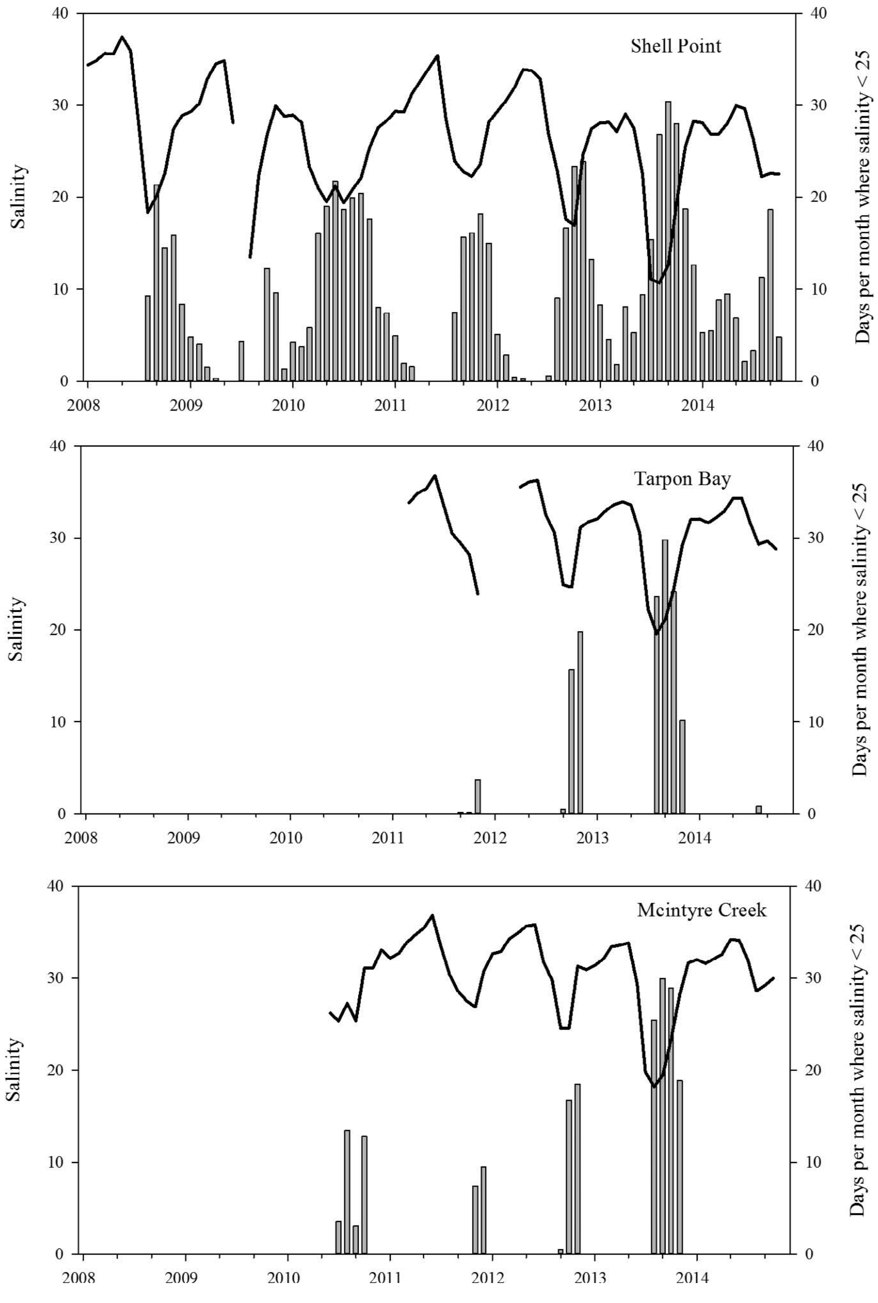

Figure 3. Frequency and duration of low salinity events recorded at RECON locations. Mean monthly salinity (line graph) and the cumulative number of days per month (bars) when salinity below 25 was measured. Sites are listed, generally, from upstream to downstream.

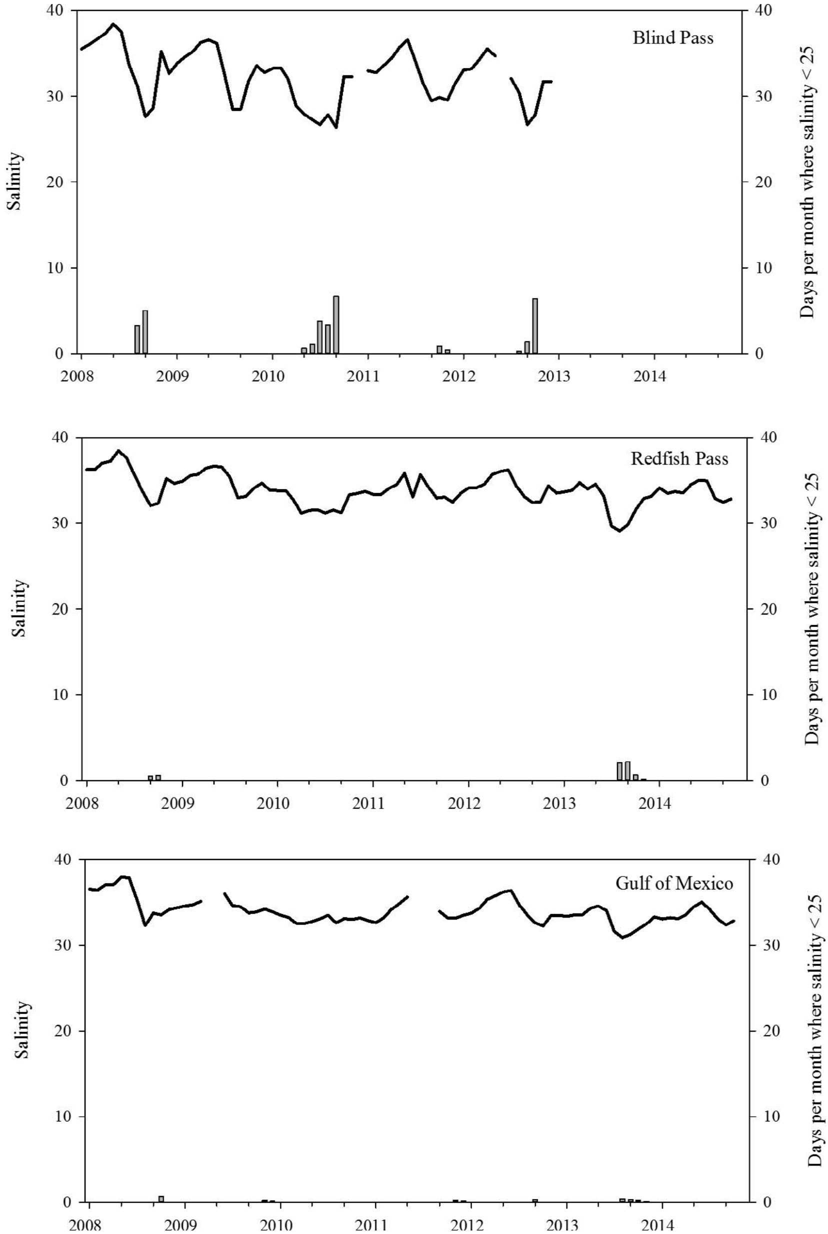

Figure 3. Continued.

of Mexico site ranged from 0.35-1.83 m^{-1} with a mean of 0.82 m^{-1} (Minitab, n = 30). No trends in light attenuation were found when similar seasons were grouped and analyzed at the Gulf of Mexico location (Seasonal Kendall, WQ Plus).

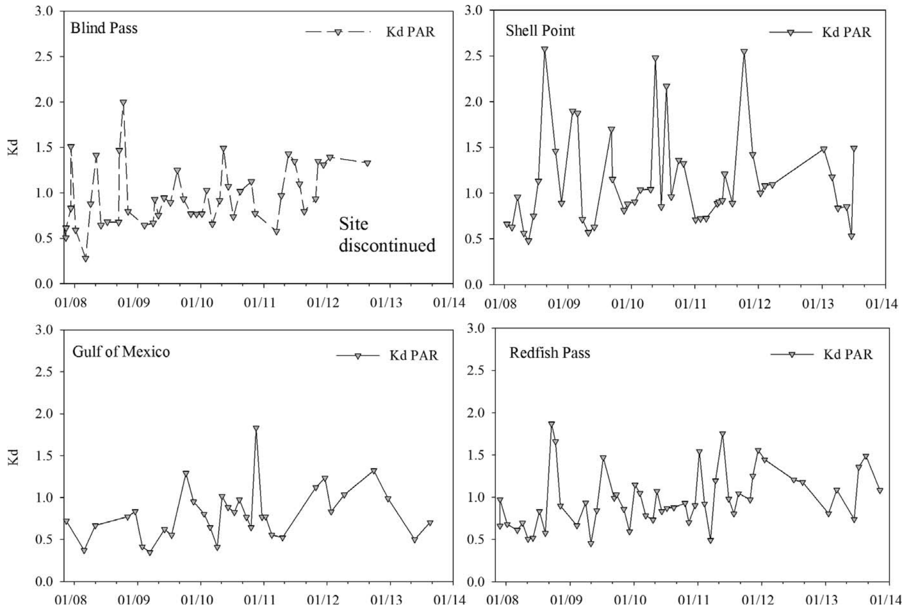

Figure 4. Light attenuation coefficients (KdPAR) recorded during monthly RECON maintenance and calibration service trips. Light attenuation is calculated from 2 underwater sensors on a lowering frame. KdPAR is the photosynthetically active radiation (400 nm-700 nm). Significant increasing trends in Kd were found at 95% confidence at Redfish Pass and Blind Pass but not at the Gulf of Mexico or Shell Point.

Light attenuation at Redfish Pass (Figure 4) ranged from 0.45-1.86 m^{-1} with a mean of 0.97 m^{-1} (Minitab, n = 46). There was a significant increasing trend (Kendall, WQStat Plus) in Kd PAR during the study period (2007-2012, 95% confidence).

Seagrass shoot density. A complete analysis of all nine transects is available in Thompson et al. (2013). The results from one transect in southern Pine Island are shown (Figure 5) and is located near the SCCF Marine Lab and the Tarpon Bay RECON site. Shoot density was variable by year. Shoot densities were highest for *Thalassia testudinum* in 2013 and increased from 2010-2013. There was a clear decrease in *Thalassia* shoot densities 2014. The shoot densities for *Halodule wrightii*, in contrast, were highest in 2010 and decreased to the lowest in 2012.

Discussion

The high resolution salinity and optical properties (chl *a*, FDOM, turbidity) for the Caloosahatchee Estuary and Pine Island Sound provided by RECON were used to determine the frequency, duration, and effects of low salinity periods in the lower estuary. High volume flows from S79 as a result of tropical storms and/or water management in south Florida resulted in large-scale periodic decreases in salinity, increases in FDOM, and increases in chlorophyll *a*. Given

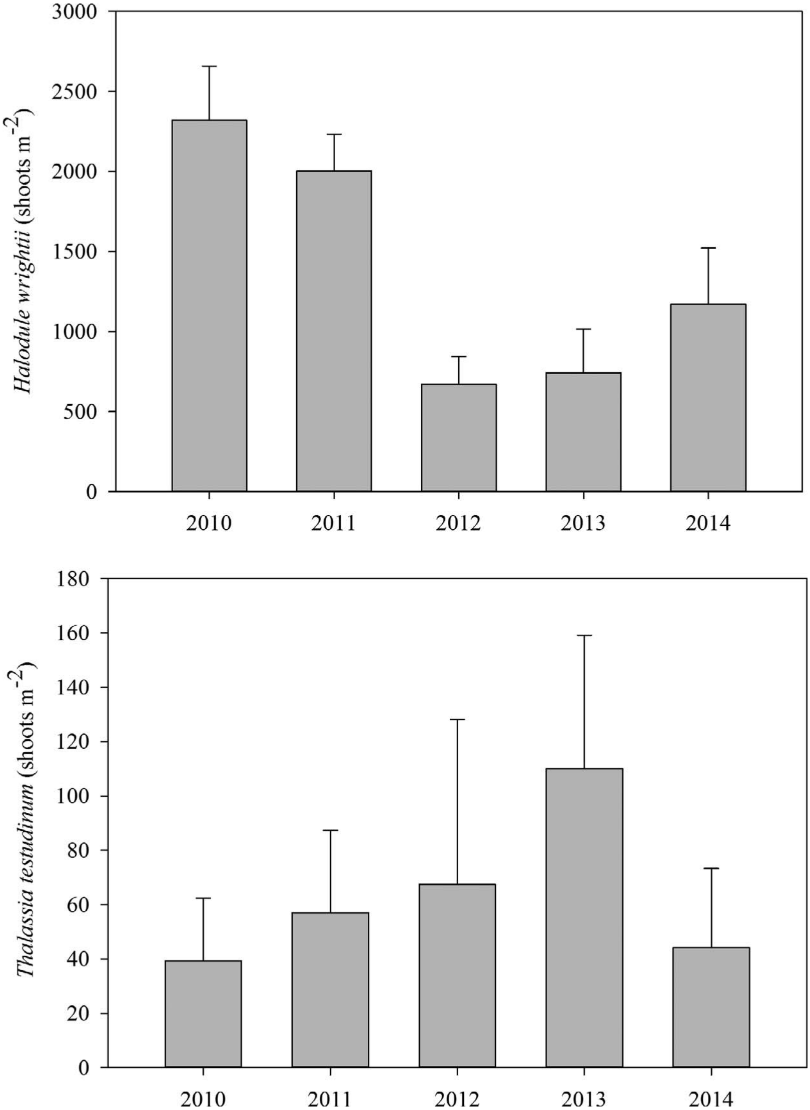

Figure 5. Seagrass shoot density for *Halodule wrightii* and *Thalassia testudinum* at transect NWR2 in southern Pine Island Sound. Annual seagrass monitoring within J.N. "Ding" Darling National Wildlife Refuge occurs at 10 sites (Thompson et al. 2013). These are the results from 1 site near the Tarpon Bay RECON.

that there are likely to be delays in the diversion of water to the Everglades and the creation of water storage projects, an analysis of how often and how long these events occur was needed along with a synthesis of the extent that these events affect water quality indicators (such as chlorophyll *a* and light attenuation) and biological indicators (such as SAV and oysters).

Salinities at Shell Point are often below 25, especially during the wet season because it is near the mouth of the Caloosahatchee which is relatively narrow and conveys water from S79 and the tidal watershed. Shell Point is also surrounded by oyster reefs that require periods of lower salinity (Volety et al. 2008). Typical wet season periods where salinities were below 25 were between 15-20 days per month. An exceptionally wet year with high flows occurred in 2013 where salinities were below 25 for an average of 20-30 days during wet season months. Large releases from S79 during 2013 combined with tidal basin flows likely resulted in slower oyster growth, poor spat production and excessive valve closure as salinities were below 14 (Volety et al. 2003). Monitoring sites near Shell Point (Volety and Haynes 2013) during this period indicated 100 percent mortality of spat.

While low salinity periods are common at Shell Point, it remained unclear whether and how high discharges from S79 and high tidal basin flows affect locations in Pine Island Sound or the Gulf of Mexico. High frequency data collected by RECON allowed for the determination of the frequency and duration of low salinity events. Two events were evident in this analysis; the landfall of Tropical Storm Faye (August 2008) and the wet season of 2013. The S79 average flow during August 2008 was 6,202 CFS with a maximum occurring on August 20, 2008 of 18,139 CFS. By looking at RECON sites and data, the event propagated throughout the lower estuary over the course of August and September, depending on the distance from the Caloosahatchee, with greater distances seeing low salinity events at a later time. At the Gulf of Mexico site, the Tropical Storm Faye event caused salinities to fall below 25 for a total of less than 1 day during September 2008 (Figure 3). The low salinity event was recorded at other RECON locations in 2008. Salinities at Blind Pass were below 25 in August 2008 for 3 days and in September for nearly 5 days. During the last week of August and first week of September of 2008, 64 percent of the salinity observations at Blind Pass were below 25. This large pulse of water from Tropical Strom Faye was widely distributed but fairly short lived. The water associated with the low salinity pulse had significantly higher FDOM and chlorophyll *a* which would affect the light field for seagrass but the short duration likely had little to no effect.

The wet season of 2013 brought a long duration event where low salinities occurred in consecutive months (July-November). The flows recorded at S79 were well-above recommended maximum flows (2,800 CFS) the maximum monthly average occurring in September (10,160 CFS) with 56 percent coming from S77 (Lake Okeechobee) and 44 percent from the Caloosahatchee watershed upstream of S79. This event was caused by the lack of water storage in South Florida combined with a record-setting rainfall throughout south Florida. The Caloosahatchee and St. Lucie Rivers are 'relief valves' for excess water and high lake stage levels in Lake Okeechobee. This event was most evident in lower Pine Island Sound RECON sites such as McIntyre Creek and Tarpon Bay. At both of these sites, salinities were around 20 for several months. The extended low salinity period is thought to cause seagrass leaf losses in July and August and resulted in unusually large wrack piles on nearby shorelines (Milbrandt, personal observation). The scale of the 2013 wet season low salinity event also was evident at Redfish Pass and the Gulf of Mexico RECON sites, despite the long distances from the mouth of the Caloosahatchee. At Redfish Pass, low salinity periods were up to 2 days, while at the Gulf of Mexico site, low salinity events lasted 2-5 hours. The longer durations likely reflect greater mixing as the saltwater and freshwater mix in route to Redfish Pass. However, there is limited data available on stratification throughout the Charlotte Harbor and lower Caloosahatchee Estuary to completely understand the duration and frequency of low salinity periods from RECON's fixed depth platforms.

All of the low salinity events had significantly higher FDOM and higher chlorophyll *a* than higher salinity events that occurred during the same time. These properties are potential threats to *Thalassia* and *Syringodium* (Irlandi 2006), which comprise a large proportion of the mapped seagrass in the region (Brown and Stafford 2011). Salinities below 25 are known to have harmful effects on seagrasses and they face additional sublethal effects of lower light availability (Dennison et al. 1993).

While the RECON sensors provide high frequency data about salinity and optical properties, the maintenance and calibration activities that occur monthly have generated a monthly dataset that includes the empirical measurement of the light field in the upper 1 m of the water column. Light attenuation showed significant increasing trends at several RECON locations, including Shell Point, Blind Pass, and Redfish Pass. The salinities at Blind Pass and Redfish Pass also showed significant decreasing trends when the data are considered by season (wet, dry). Correlations confirmed that lower salinities were also associated with higher FDOM and chlorophyll *a* and offer a cause for the increasing trends in light attenuation.

An increasing trend in light attenuation should be evaluated carefully by researchers and resource managers. Seagrass aerial extent as determined by photointerpretation has limitations (Robbins 1997) and may not be sensitive enough to detect incremental declines (or increases) in seagrass habitat. The lack of sufficient ground-truthing of the interpreted aerial images for a large area like Pine Island Sound means that any losses of habitat and degradation of habitat function may not be detected. Results from one transect in Tarpon Bay suggest that shoot densities are not following a linear response to either salinity or the light field. Instead, there appears to be a biological interactive effect between species where after periods of low salinity the community shifts from a *Thalassia*-dominated to a *Halodule*-dominated or macroalgal-dominated community. This pattern was also found by Orlando and Douglass (2014). The role of macroalgae as a competitor for space and light and as a false positive in aerial interpretation of SAV cover should be addressed to better interpret seagrass transect data collected by the SCCF, SFWMD, SWFWMD, FDEP and others. While the presence of macroalgae in seagrass ecosystems is not a rare occurrence (Brown and Stafford 2011), others have shown macroalgae to be an indicator of nutrient loading in Buzzards Bay, MA

(Valiela et al. 1997). A manipulative, hypothesis-based approach to understanding these interactions in lower Pine Island Sound is needed. Additional ground-truthing of aerial imagery through hydroacoustic, deep-edge mapping or by drop camera mapping is recommended.

Literature suggests that sustained periods of low salinity and low light threaten seagrasses (Irlandi 2006) but it is unclear how high flow events are affecting seagrasses. It is possible that the decreased shoot densities of *Thalassia* in 2014 represents an eventual response to extended low salinity periods in 2013. The nearest RECON site is Tarpon Bay which had 4 consecutive months in 2013 of 20 or more days of salinities < 25. It is also possible that seagrasses retreated to shallower depths after 2013 but the data shown here do not consider the deep edge. The field experiment was not designed to examine changes in depth distributions during low salinity events. Shoot densities vary due to biological and physical factors and this study demonstrates that further investigation of deep edges and seagrass areas around the RECON sites is needed.

The establishment of optical targets (Corbett and Hale 2006, Janicki et al. 2010) represents a supplemental method to monitoring using aerial images to meet the goal of long term sustainability and maintenance of the seagrass resources. The optical targets are more sensitive to incremental changes in water quality and optical properties. Significant increasing trends in FDOM at Redfish Pass should serve as an indication that water clarity is declining (Dixon and Wessel 2014) and that nitrogen loads are increasing, given the positive linear correlation between FDOM and total nitrogen (Baldwin et al. 2009). Increased storage of storm water and the diversion of water south to Florida Bay through the Everglades as envisioned by the Comprehensive Everglades Restoration Plan (CERP) can stabilize light attenuation trends and potentially result in restoration of SAV habitats and habitat function.

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