FINAL REPORT
FOR
MOBILE BAY NATIONAL ESTUARY PROGRAM PROJECTS

Prepared by
Dauphin Island Sea Lab

Project Title:
Continued Monitoring for D'Olive Bay

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Executive Summary

The D'Olive watershed comprises three major tributaries, Joe's Branch, D'Olive Creek, and Tiawasee Creek, with over 23 miles of streams. D'Olive Creek and Tiawasee Creek deposit into Lake Forest Lake, which is only flushed into D'Olive Bay during large rain events, and Joe's Branch drains directly into D'Olive Bay. Restoration efforts in Joe's Branch to reduce stream bank erosion and sedimentation, as well as recent restoration activities along D'Olive and Tiawasee Creeks recommended in the D'Olive Watershed Management Plan, were complemented with long-term monitoring at the project sites and downstream in the receiving sub-basin. This report provides summary data for water quality parameters (water-column chlorophyll *a* concentration, color dissolved organic material, total suspended solids, and photosynthetically active radiation) measured in D'Olive Bay over a 4.5-year study period funded in part by Baldwin County Coastal Impact Assistance Program (2014-2015) and the Mobile Bay National Estuary Program (2015-2018) and the influence of those parameters on habitat suitability for submerged aquatic vegetation (SAV).

During this study, light reaching the bottom was only sufficient to support SAV growth at the North D'Olive Bay site (>10% surface irradiance). This site was the shallowest site, at approximately 0.7m depth, and consistently supported a large SAV bed dominated by *Myriophyllum spicatum* (Eurasian watermilfoil). The Mid site (at 1m depth) fluctuated around the lower irradiance threshold, but in 2018 the amount of light reaching the bottom had increased to support SAV with patches of *Ruppia maritima* seen in the area (per. obs.). The South site, the deepest of the three at 1.3m, was always below the minimum light threshold and SAV was only seen on the shallow flats to the west of the sampling location.

We found few significant changes in any of the water quality parameters measured over the study period, likely due to the high variability across seasons. While individual parameters fluctuated substantially, the light attenuation coefficient, K_d, was similar at all sites and was typically higher, thus light availability was reduced, during spring when growth of SAV begins to ramp up. In our best performing regression model, colored dissolved organic matter (CDOM) and chlorophyll *a* concentrations were both significant predictors of K_d. Thus, improving upstream watershed management practices that would reduce CDOM and/or chlorophyll *a* in D'Olive Bay would likely increase the area suitable for the growth of SAV.

Introduction

The D’Olive watershed comprises over 7,700 acres in Baldwin County, Alabama, draining into Mobile Bay through D’Olive Bay. The watershed has three major tributaries, Joe’s Branch, D’Olive Creek, and Tiawasee Creek, with over 23 miles of streams. D’Olive Creek and Tiawasee Creek deposit into Lake Forest Lake, which is only flushed into D’Olive Bay during large rain events, while Joe’s Branch drains directly into D’Olive Bay. Recent restoration efforts along Joe’s Branch, D’Olive Creek and Tiawasee Creek, as recommended in the D’Olive Watershed Management Plan, have been completed to reduce stream bank erosion and sedimentation. To help determine trends and changes in water quality as a result of restoration activities, these projects were complemented with long-term monitoring, not only at the project sites, but also in the receiving sub-basin, D’Olive Bay.

A vital component of the Mobile Bay system is the submerged aquatic vegetation (SAV) beds found in the shallow waters throughout the Mobile-Tensaw Delta and coastal Alabama. Healthy SAV habitats play a critical role in the ecological and environmental health of shallow coastal waters by providing food, shelter, and nursery habitat for a variety of ecologically and commercially important invertebrates (e.g., brown shrimp and blue crabs), fishes (e.g., red drum, spotted sea trout, and largemouth bass), and waterfowl (e.g. the canvasback duck). They play an active role in maintaining good water clarity and reduce turbidity by slowing water flow causing suspended sediments to fall out of suspension. Subsequently, SAV roots and rhizomes hold these sediments in place. Additionally, healthy SAV beds decrease wave action, reducing shoreline erosion. Despite its provision of many valuable ecosystem services, SAV is declining nationally and internationally, with areal declines in states bordering the Gulf of Mexico ranging from 20-100% (Handley et al. 2007). In Alabama coastal waters, historical records are sparse, with the majority of records occurring within the past 20 years (see Vittor 2002, 2009, 2015). And while there has been an increase in spatial extent of SAV in recent years (Vittor 2015), tremendous losses have also occurred, with more than 50% of SAV lost from Mobile Bay since 1981 (USGS 2004). Many factors, both natural and anthropogenic, contribute to SAV decline, including tropical storms, abnormal rainfall patterns, direct damage caused by poor boating practices, dredging and coastal construction, and the addition of wastewater and excess nutrients to coastal waters (Orth et al. 2006). Plant communities at the receiving end of riverine systems may experience the greatest loss, as poor land management practices that increase runoff degrade water quality by increasing deposition of nutrients, sediments, and dissolved organic matter (Moore et al. 2010).

Adequate light is critically important for ensuring SAV health, and significant progress has been made in developing simple optical models that can predict with good success where SAV will prosper. This study examined SAV habitat suitability within D’Olive Bay over a 4.5 year period, documenting the quantity of light reaching SAV in D’Olive Bay and the water quality parameters that impact it.

Methods

Three sites were established along the length of D'Olive Bay in June 2014 during a project funded by the Baldwin County Coastal Impact Assistance Program (2014- 2015) to develop and calibrate a habitat suitability model for tapegrass, *Vallisneria americana* (Table 1, Figure 1). Water quality and clarity were estimated from the following parameters: phytoplankton abundance measured as water-column chlorophyll *a* concentration (CHLA), color dissolved organic material (CDOM), and total suspended solids (TSS), and photosynthetically active radiation (PAR; μmol $m^{-2}s^{-1}$). Depth (m), salinity, temperature (°C), and dissolved oxygen (mg/L) were also measured to describe the physical characteristics of each site. Specific methods for each parameter are described below.

TABLE 1: GENERAL SITE COORDINATES

Site	Latitude	Longitude
North	30.65005	-87.91732
Mid	30.64153	-87.91928
South	30.63323	-87.92029

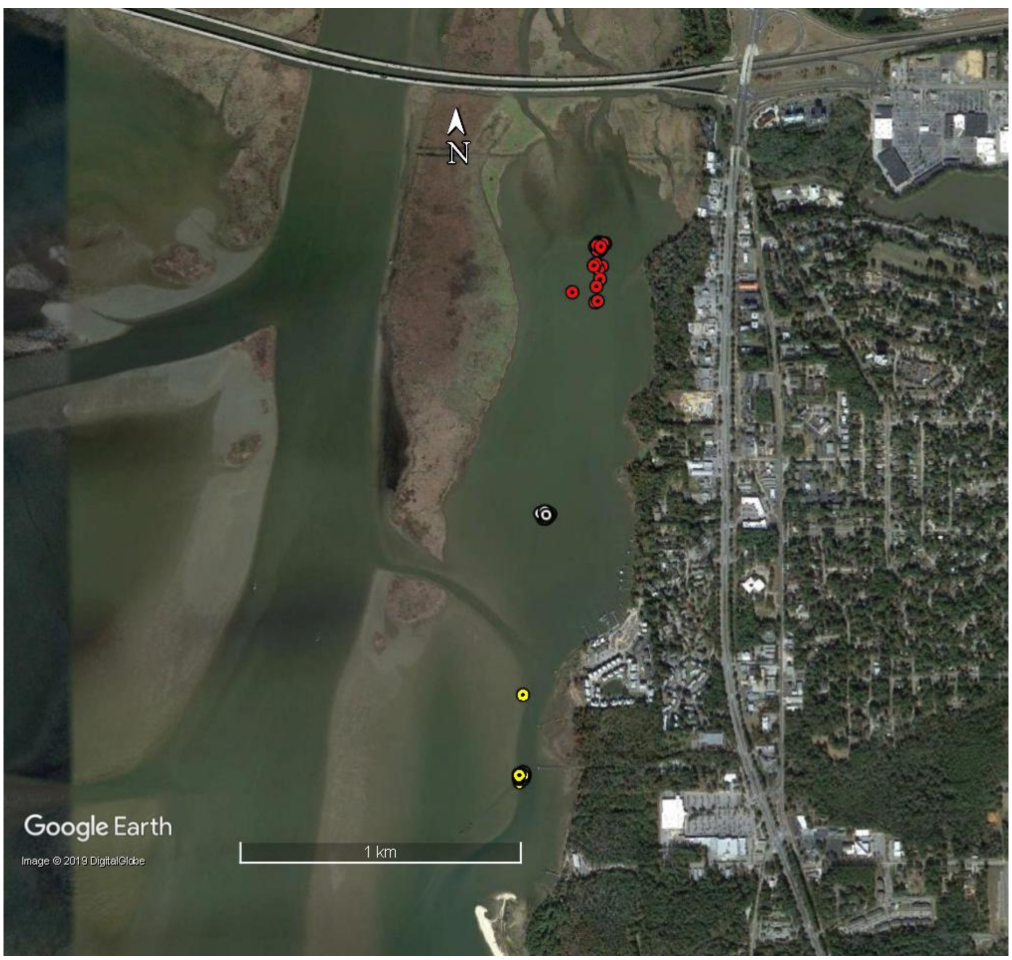

FIGURE 1: MAP OF SAMPLING STATIONS WITHIN D'OLIVE BAY. EACH DOT CORRESPONDS WITH A SAMPLING EVENT AT THE THREE SITES: NORTH BAY (RED DOTS), MID BAY (WHITE DOTS), AND SOUTH BAY (YELLOW DOTS).

Sampling occurred approximately monthly during the main growing season (April-November) and bi-monthly from December to March during 2014-2015, on neap tide to reduce variability due to tidal cycle (incoming versus outgoing and high versus low tide), and when cloud cover was relatively low (i.e. mostly sunny conditions). This sampling regime was continued for an additional three years (July 2015 – October 2018) with funding provided by the Mobile Bay National Estuary Program (2015- 2018) to investigate how water quality and SAV habitat suitability in D'Olive Bay responded as restoration activities were completed within the watershed.

Depth (m) was determined using a weighted line marked in 0.1m increments. Salinity, temperature (^{o}C), and dissolved oxygen (mg L^{-1}) were collected just below the water surface and at the at the bottom using a YSI Pro2030 handheld meter. Turbidity (NTU) was measured from a 25mL water sample collected approximately mid-water column using a LaMotte 2020we handheld turbidity meter.

Photosynthetically active radiation (PAR) was measured using a pair of LI-COR Biosciences spherical quantum sensors, one which served as a reference deck sensor and one that was lowered into the water with measurements taken just below the water surface and every 0.25m through the water column to the bottom. These values were then used to calculate light attenuation through the water column. Light attenuation was expressed as K_d (m^{-1}), the water-column light attenuation coefficient, and calculated using the Lambert-Beer law:

$$I_z = I_0 e^{(-Kd*z)}$$

where I_0 and I_z are PAR measured just the below the water surface and at depth z, respectively. Kd was then calculated as the slope of a regression of ln (I_z/I_0) against z.

Total Suspended Solids (TSS) were measured from 1 L water samples collected at approximately mid-water column, of which a 200-300 mL aliquot was filtered through a muffled, pre-weighed 47 mm GF/F grade filter pad. Each filter pad was placed in a labeled aluminum cup and dried at 70° C for a minimum of 48 hours. The filter pads were reweighed to calculate the mass of total suspended solids in a known volume of water (mg L^{-1}). The filter pads were then burned in a furnace at 500^{o}C for 4 hours to remove the organic constituents and reweighed to determine the Mineral Suspended Solids (MSS, mg L^{-1}).

Particulate organic matter (POM, mg L^{-1}) was calculated as Loss on Ignition (LOI) using the following formula, where DW is dry weight in milligrams:

$$LOI_{POM} = \frac{(DW_{70} - DW_{500})}{Volume\ filtered\ (L)}$$

Color dissolved organic material (CDOM), the color in the water leached from decaying detritus and organic matter, was measured from an aliquot of water filtered through a GF/F filter (0.7µm nominal pore size) for TSS analysis. Absorbance at 440nm was measured using an Ocean Optics

UV/Vis modular spectrometer (USB2000) with a 10cm path length cylindrical quartz cuvette. Absorbance was reported as the absorption coefficient (a_{440nm}, m^{-1}) calculated from the equation

$$a_{\lambda} = \frac{2.303\ A_{\lambda}}{l}$$

where A_{λ} is the measured absorbance at a specific wavelength, here 440nm, and *l* is the path length in meters.

Phytoplankton abundance was measured as water-column chlorophyll *a* concentration (µg L^{-1}) Duplicate 30 mL aliquots of water collected mid-water column were filtered onto a Whatman® 25-mm glass microfiber filter (GF/F). Chlorophyll *a* was extracted from filters using 5 mL of a 2:3 mixture of dimethyl sulfoxide (DMSO):90% acetone, and chlorophyll *a* content (µg L^{-1}) was determined fluorometrically (Turner Designs® TD-700) using the Welschmeyer method (Welschmeyer 1994). Due to a contamination problem with the solvent matrix that occurred during the last year of sampling, data is only reported through January 2017.

To examine significant changes over time, annual means for all parameters were examined for each site using Analysis of Variance (ANOVA). However, data collected during the winter months (December – February) were excluded, as these months fall outside of the SAV growing season. The water quality parameters that influence light attenuation (TSS, CDOM, CHLA) were also analyzed using best subset regression algorithms to determine which parameters best fit into the optical model. Significant variables ($p < 0.05$) were then used to fit the regression model.

Results

Physical site characteristics

The average depths at the three sites were 0.71 m at the North site, 0.93 m at the Mid site, and 1.36 m at the South site. All three sites followed expected seasonal patterns in both temperature and salinity. Temperature was similar for both surface and bottom measurements and ranged between 10.1^{o}C in the winter to 32.9^{o}C in the summer (Figure 2).

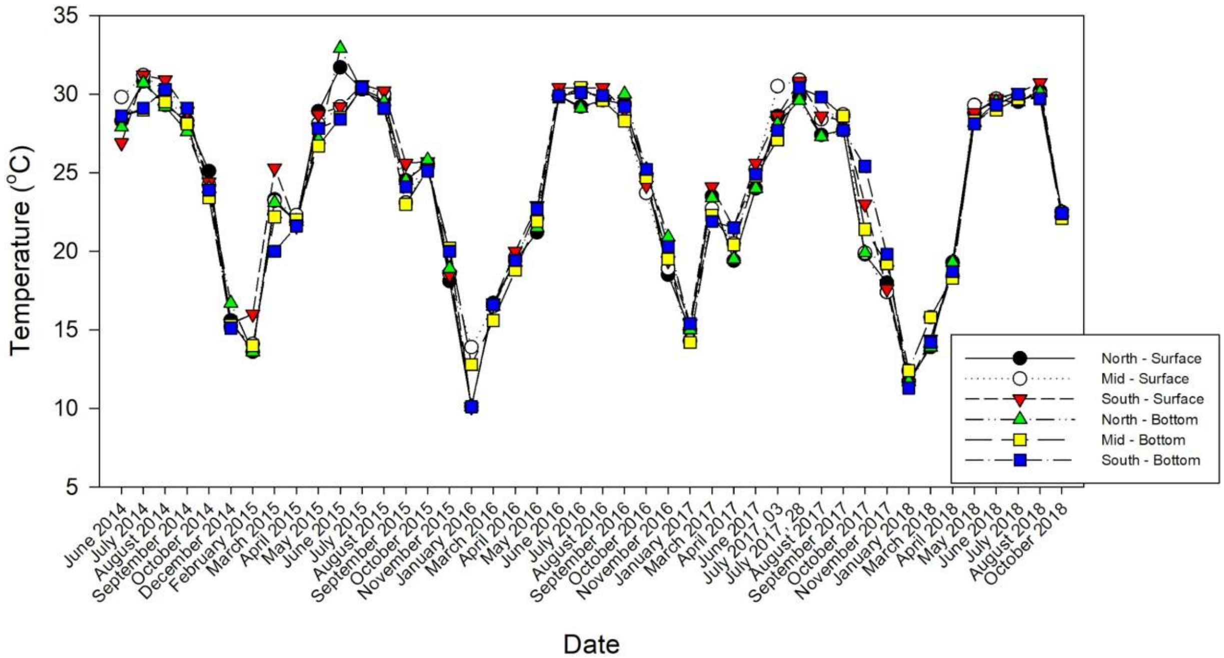

FIGURE 2: SURFACE AND BOTTOM TEMPERATURE (^{O}C) AT THE NORTH, MID AND SOUTH SITES.

Salinity also followed a seasonal pattern with salinities around 0 during the spring and summer months when rainfall is typically high. Higher salinities occurred during the late summer and fall and were stratified with bottom salinities often greater than surface water salinities. Surface salinities ranged from 0 – 17.10, 0.1 – 16.60, and 0.1– 17.60 for the North, Mid, and South sites, respectively, and bottom salinities ranged from 0 – 20.80, 0.1 -20.90, and 0.1 – 23.30 (Figure 3). Seasonal average surface and bottom salinity for each site are reported in Table 2.

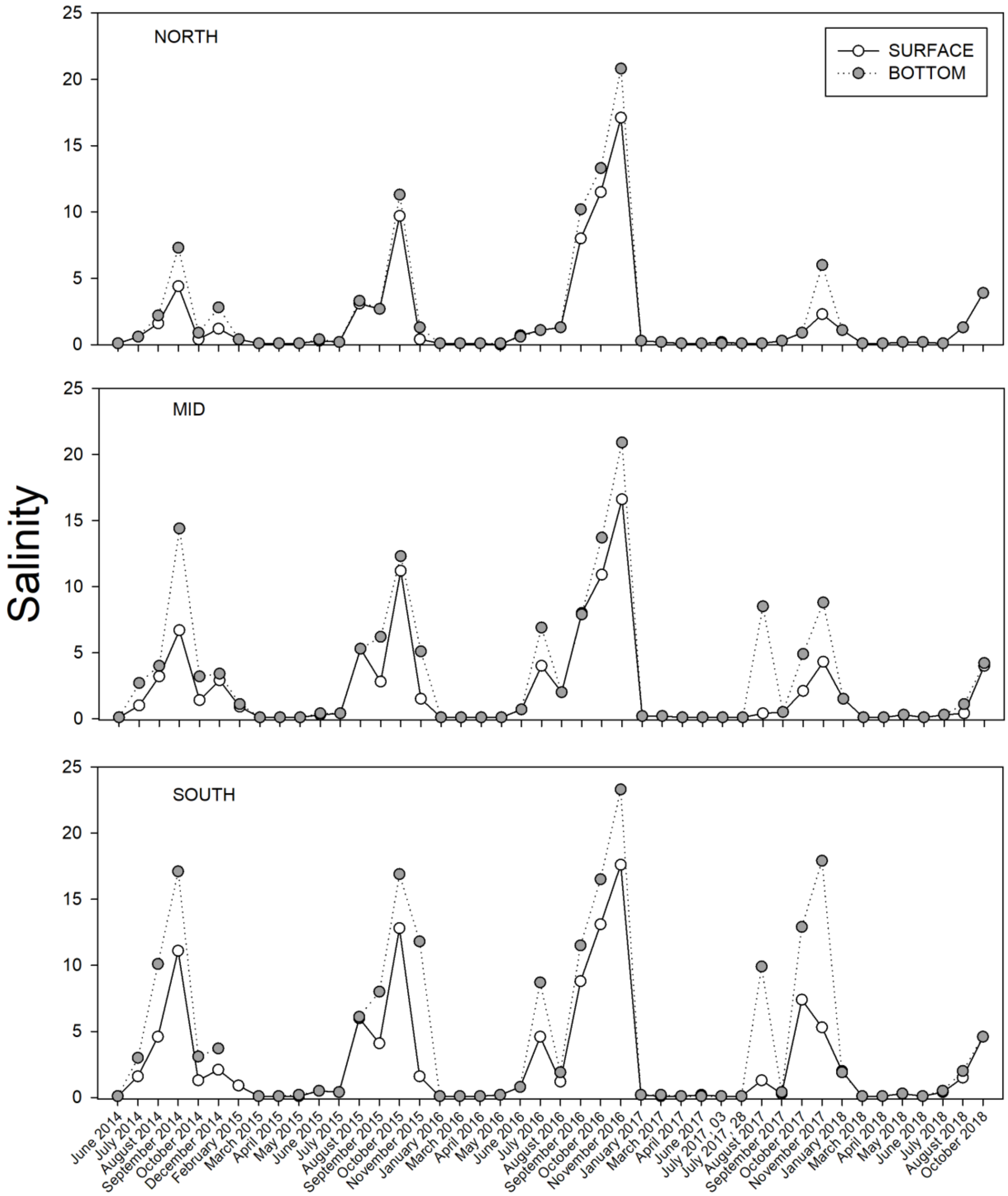

Figure 3: Surface and bottom salinity at the North, Mid and South Sites.

TABLE 2: AVERAGE SURFACE AND BOTTOM SALINITY AT EACH SITE.

Site	**Winter** (Dec, Jan, Feb)		**Spring** (Mar, Apr, May)		**Summer** (Jun, Jul, Aug)		**Fall** (Sept, Oct, Nov)	
	Surface	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*
North	0.62	0.94	0.11	0.12	0.69	0.74	5.13	6.58
Mid	1.12	1.26	0.13	0.13	1.16	2.05	5.83	8.51
South	1.06	1.48	0.13	0.15	1.47	2.78	7.33	12.00

Dissolved oxygen concentrations varied depending on sampling date but was relatively similar across the three sites for both surface and bottom measurements. Values ranged between 1.80 – 12.27 mg/L for surface waters and 1.69 – 12.40 mg/L for bottom waters across all sites (Figure 4).

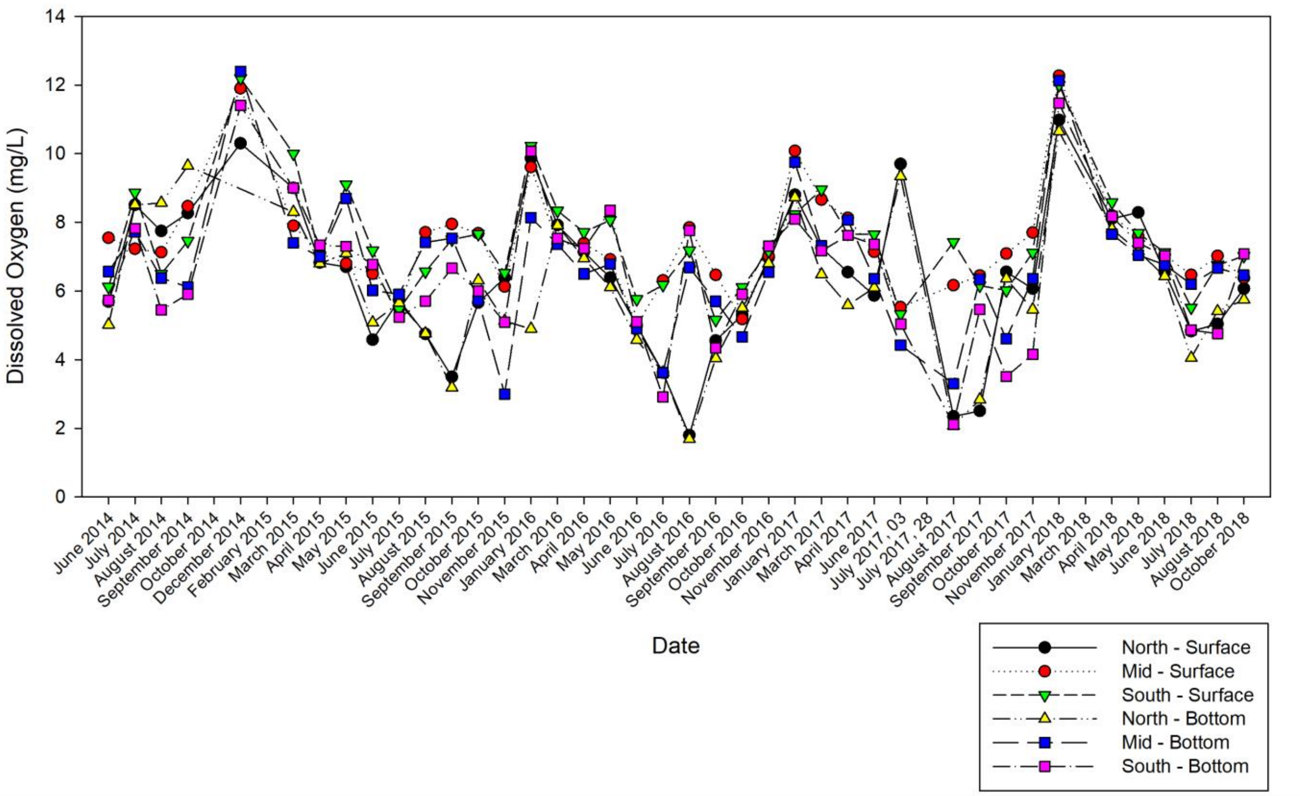

FIGURE 4: SURFACE AND BOTTOM DISSOLVED OXYGEN (MG/L) AT THE NORTH, MID AND SOUTH SITES.

Water clarity and water quality characteristics

Photosynthetically active radiation reaching the benthos (% Surface Irradiance) was highly correlated with depth and not significantly different at the three sites over the 4.5 years of monitoring. Over the project period %SI averaged 4.51% (± 0.72% standard error) at the deepest South site, 9.46% (± 0.86% standard error) at the Mid site and 15.75% (± 1.35% standard error) at the shallowest, North site (Figure; 5, Appendices A and B).

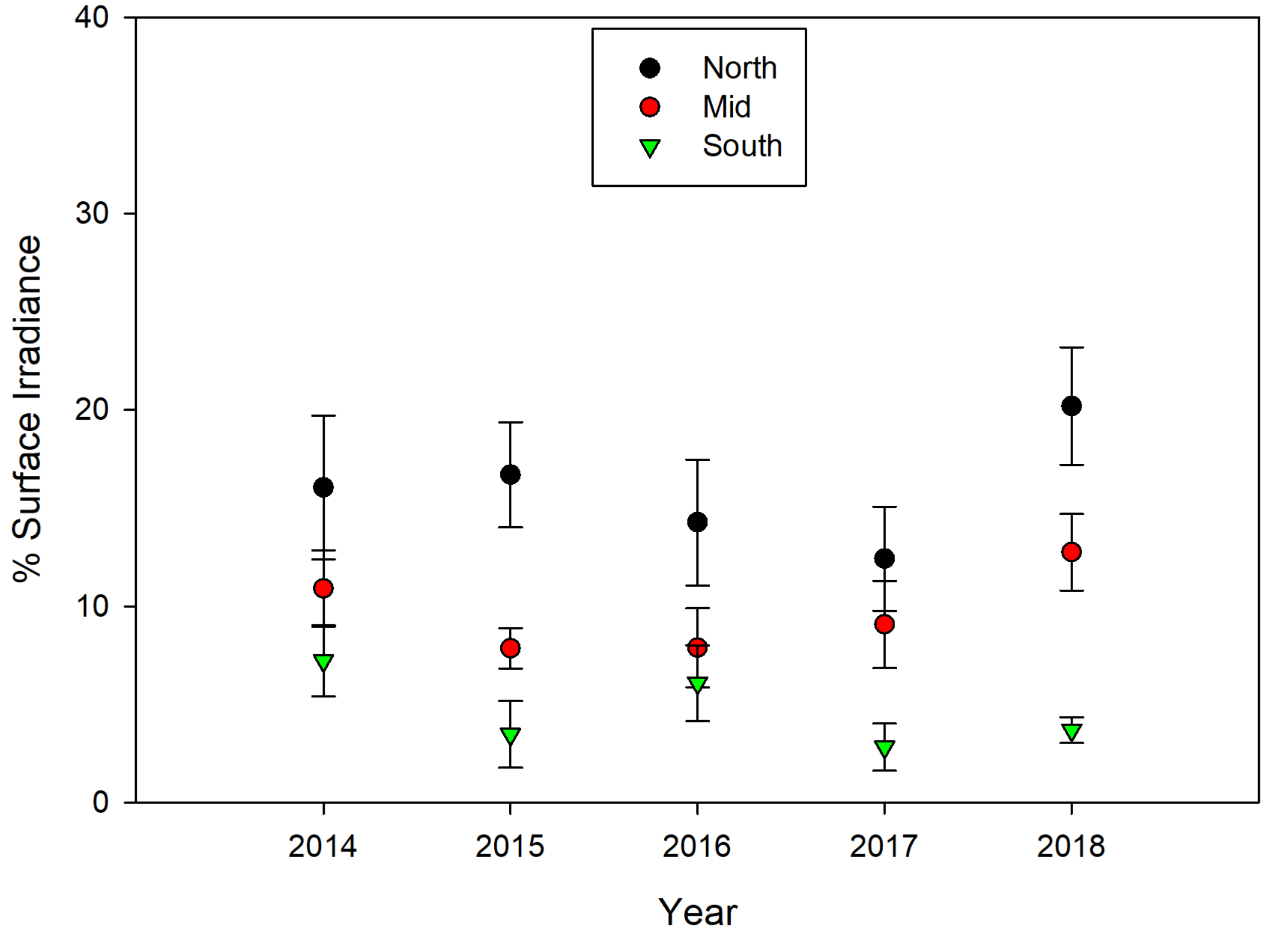

FIGURE 5: MEAN PERCENT IRRADIANCE REACHING THE BOTTOM AT EACH STUDY SITE, AVERAGED PER YEAR (±SE)

Seasonally % SI was lowest in the spring and increased each fall; however, these slight differences were not significant (Figure 6).

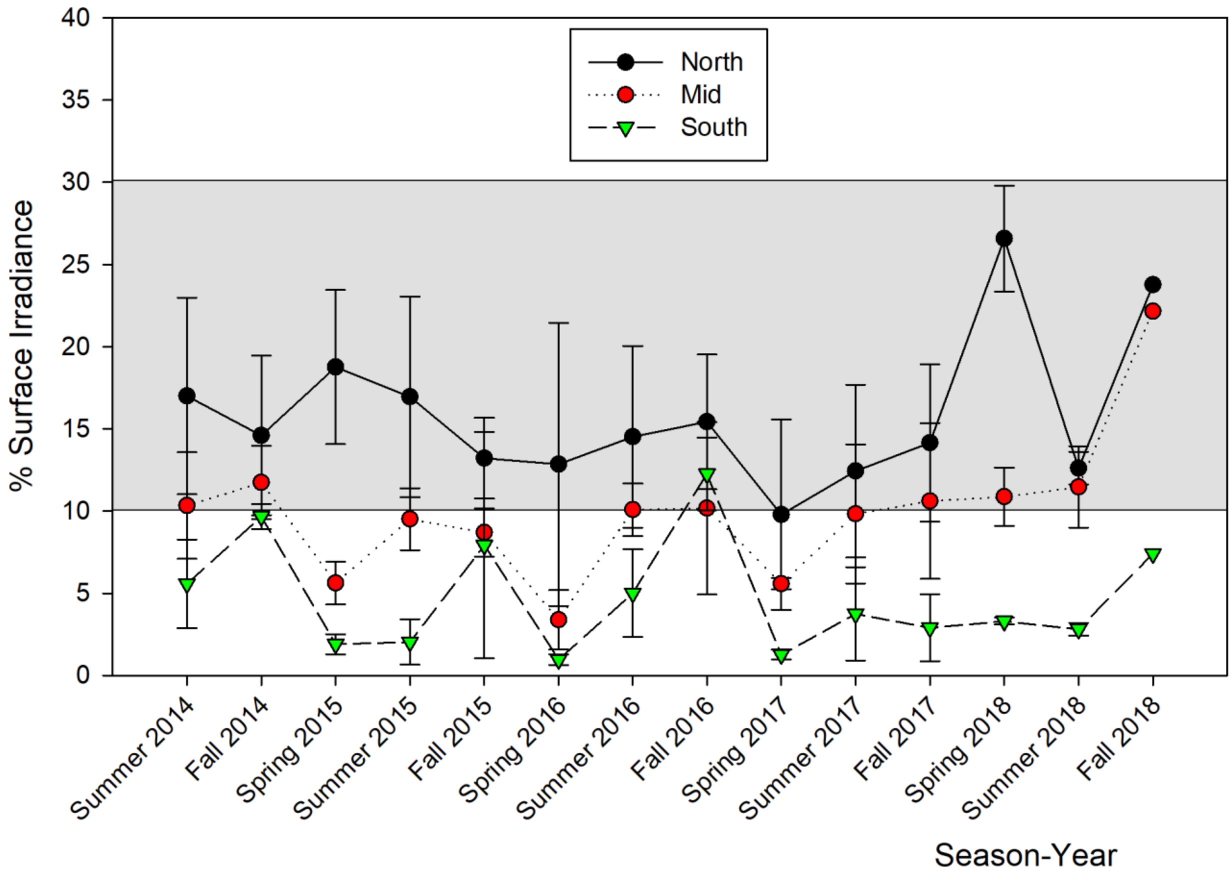

FIGURE 6: MEAN PERCENT IRRADIANCE (±SE) REACHING THE BENTHOS AT EACH STUDY SITE, AVERAGED BY SEASON DURING SAV GROWING PERIOD. SPRING IS MARCH, APRIL, MAY; SUMMER IS JUNE, JULY, AUGUST; AND FALL IS SEPTEMBER, OCTOBER, NOVEMBER. THE GRAY BAR INDICATES THE GENERAL RANGE OF LIGHT REQUIRED BY SAV.

The **Light attenuation coefficient** (K_d) was similar across all sites, averaging 2.59m^{-1} (± 0.09 standard error) at the South site, 2.75m^{-1} (± 0.14 standard error) at the Mid site, and 2.82m^{-1} (± 0.21 standard error) at the North site (Figure 7), across the study period (see Appendices for yearly and season means). While K_d was not significantly different at any site over the monitoring period, 2016 had the highest K_d values with the largest variance.

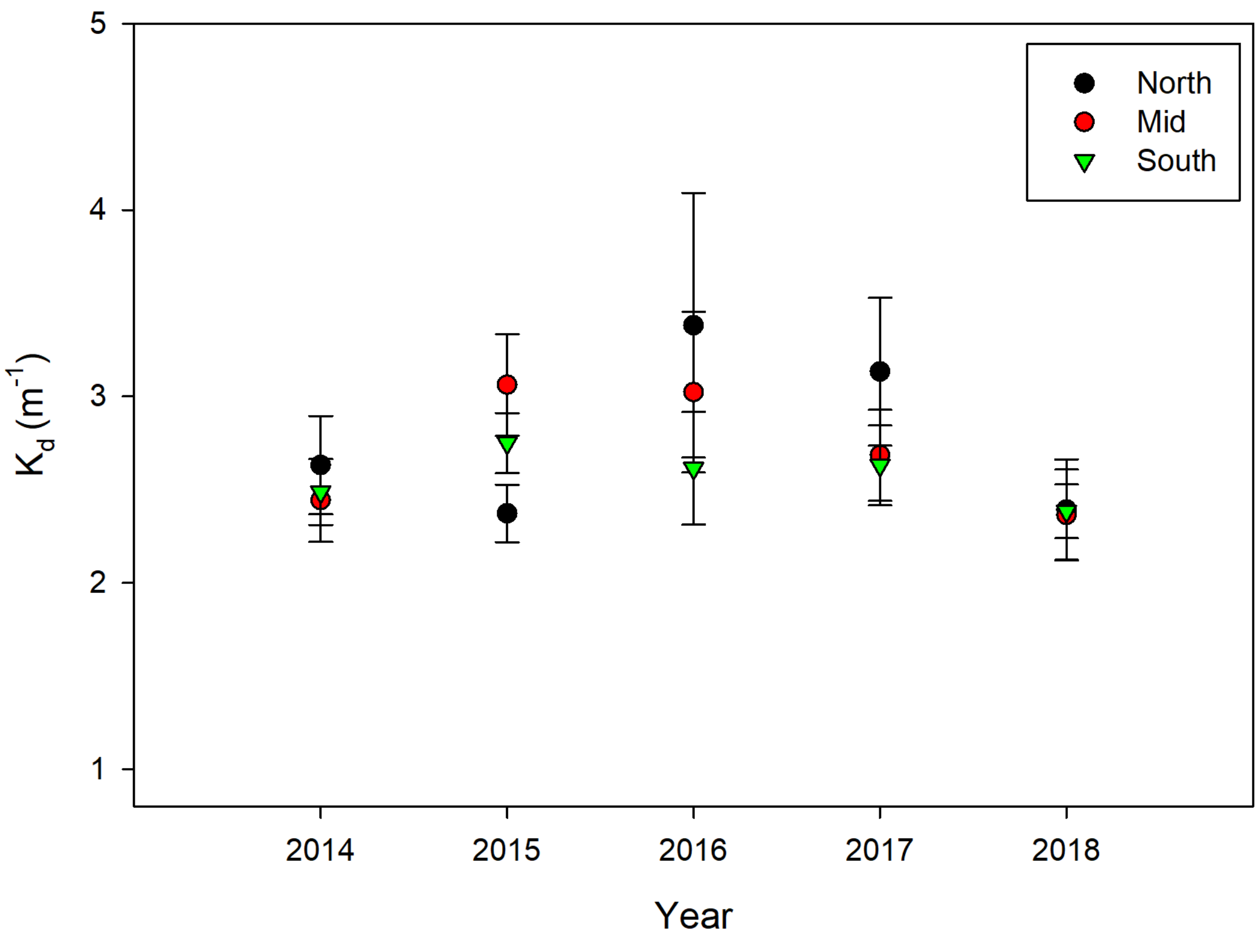

FIGURE 7: MEAN ANNUAL LIGHT ATTENUATION COEFFICIENT (KD) (±SE) AT EACH STUDY SITE

All three sites typically had larger K_d values during spring, but then declined during the summer and fall months (Figure 8). This trend was most pronounced during 2016 and 2017 and may be related to heavy rains in the spring and then clearer water from the Gulf of Mexico pushing up into Mobile and D'Olive Bays during the fall, as indicated by the higher salinities seen in the surface and bottom waters at these sites (Figure 3).

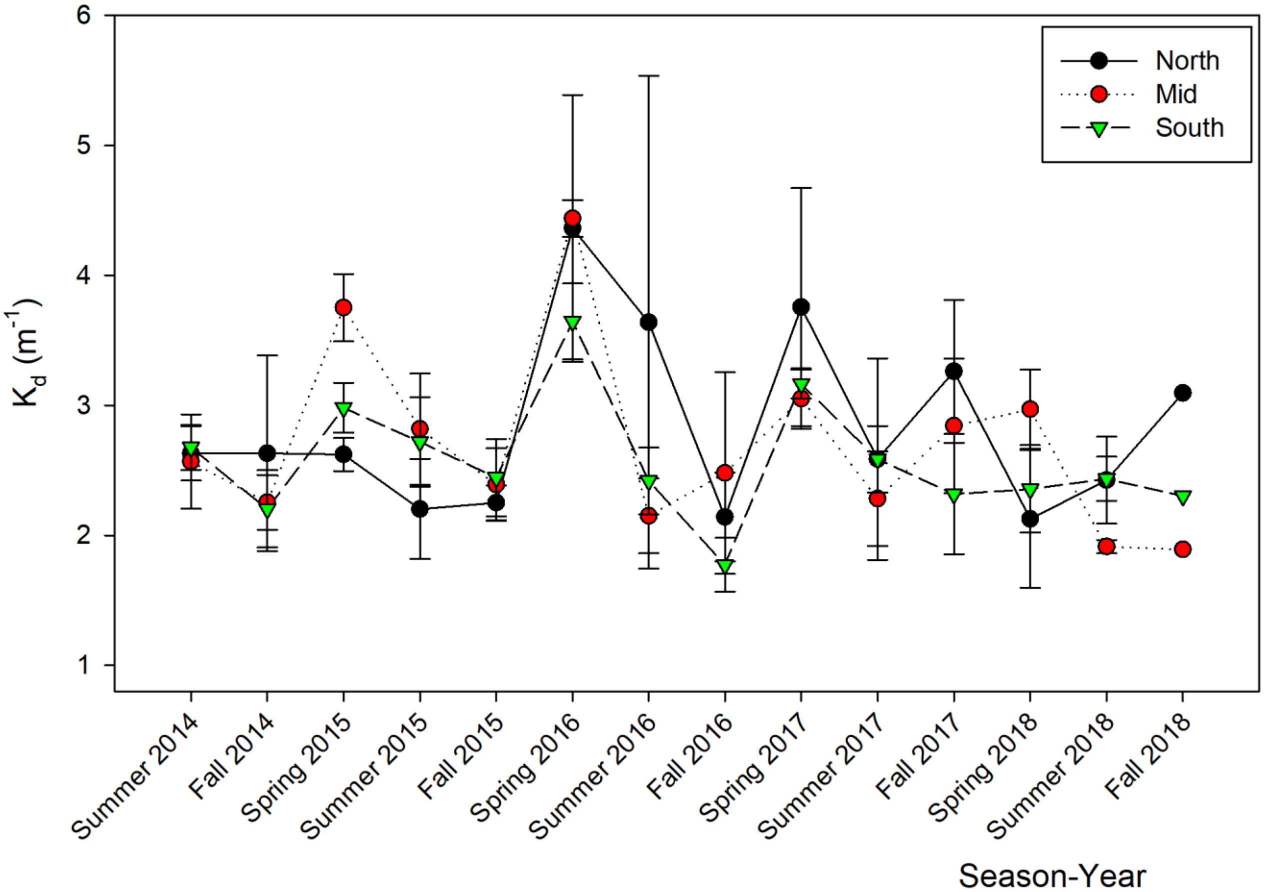

FIGURE 8: MEAN LIGHT ATTENUATION COEFFICIENT (KD) *(±SE)* AT EACH STUDY SITE, AVERAGED BY SEASON DURING SAV GROWING PERIOD. SPRING IS MARCH, APRIL, MAY; SUMMER IS JUNE, JULY, AUGUST; AND FALL IS SEPTEMBER, OCTOBER, NOVEMBER

Mean **Total Suspended Solids** decreased from North to South along the Bay with the North sites ranging between 4-80 with a mean value of 21.94 mg L^{-1}, the Mid site ranging between 3.6 and 60.5, with a mean value of 19.39 mg L^{-1}, and the South site ranging from 5.5 to 48.5, and a mean value of 18.16 mg L^{-1}. TSS was highest in 2015 and 2106 but declined in 2017 and 2018.

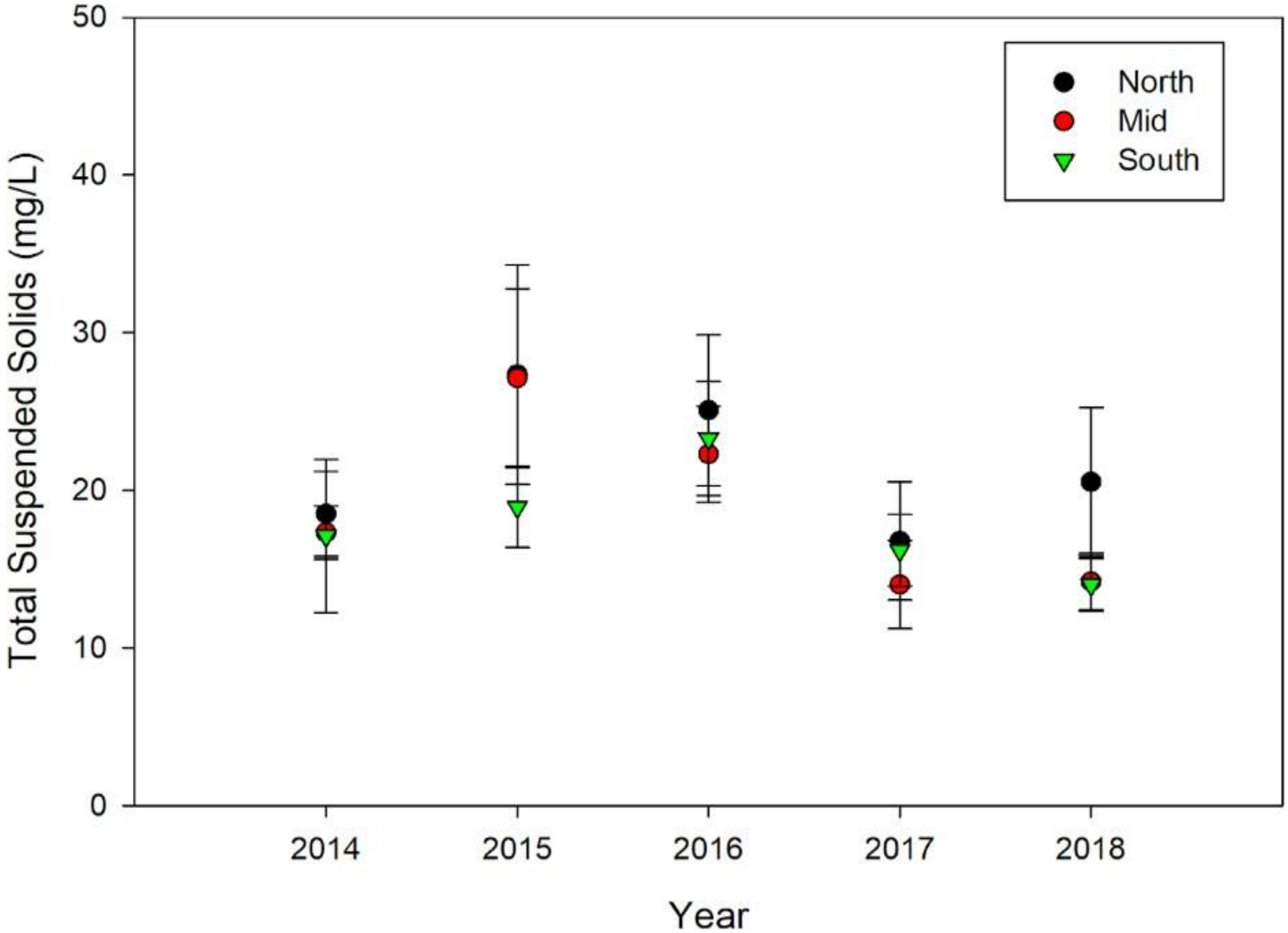

FIGURE 9: MEAN ANNUAL TOTAL SUSPENDED SOLIDS (MG $_{L-1}$) (±SE) AT EACH STUDY SITE

Typically, TSS was high in the spring and fall over most of the years monitored, except 2018 where there was a decreasing trend from spring to fall at all sites. Fall 2015 had the highest TSS values at the North and Mid sites (42.50 mg L^{-1} and 39.00 mg L^{-1}, respectively). Mineral Suspended Solids (MSS) accounted for approximately 60% of the TSS over the study period (Figure 10).

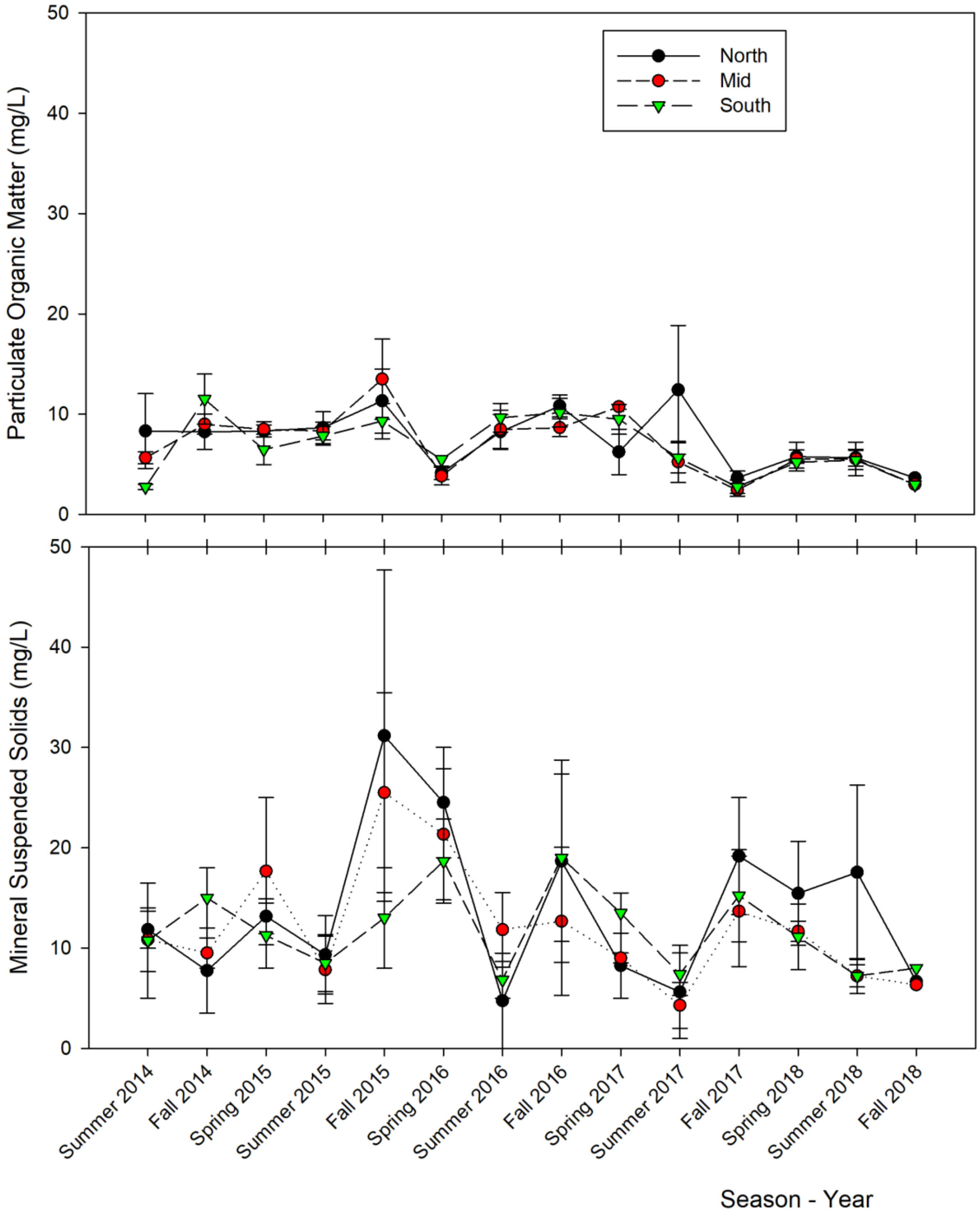

FIGURE 10: MEAN POM AND MSS AT EACH STUDY SITE (±SE), AVERAGED BY SEASON DURING SAV GROWING PERIOD. SPRING IS MARCH, APRIL, MAY; SUMMER IS JUNE, JULY, AUGUST; AND FALL IS SEPTEMBER, OCTOBER, NOVEMBER

Annual mean **Color Dissolved Organic Material (CDOM)** ranged between 2.10 $m^{-1}$and 3.41 m^{-1} at the North site, between 1.73 $m^{-1}$and 3.03 m^{-1} at the Mid site, and between 1.88 m^{-1} and 2.78 m^{-1} at the South site. While not significantly different across years, CDOM values were highest in 2016 and 2017 (Figure 11).

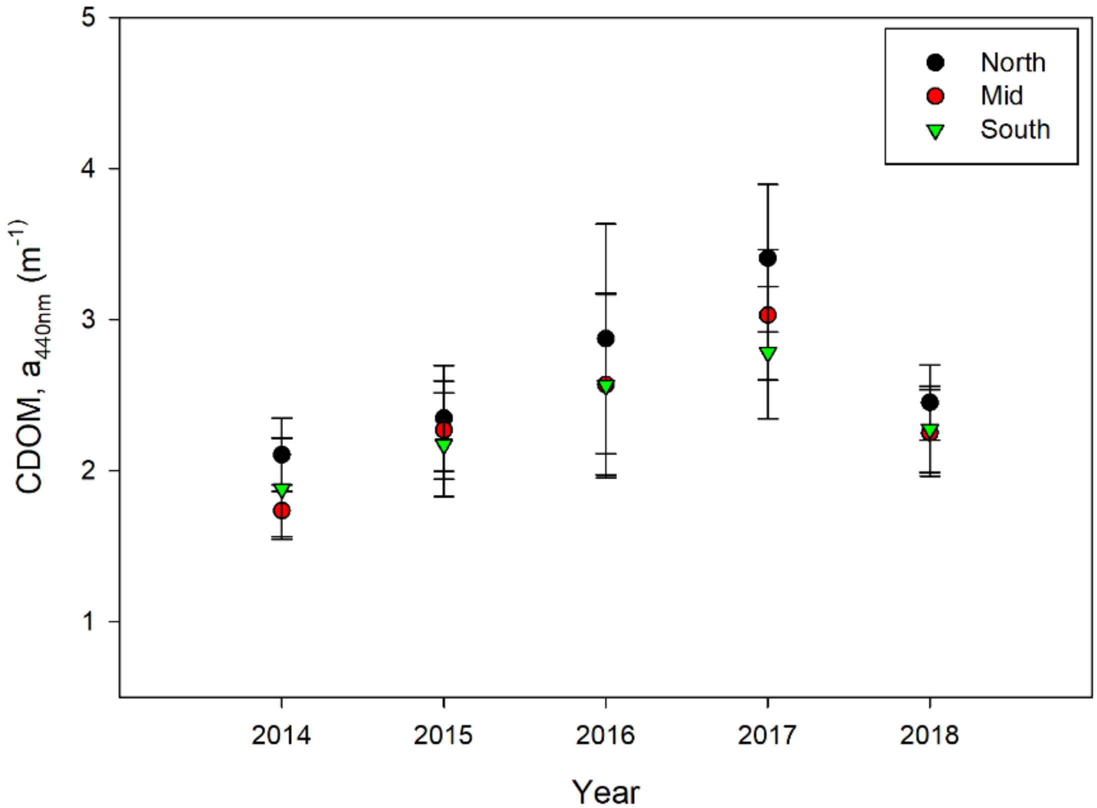

FIGURE 11: MEAN ANNUAL ABSORPTION COEFFICIENT FOR COLOR DISSOLVED ORGANIC MATERIAL, CDOM (± SE) AT EACH STUDY SITE.

Seasonally, CDOM increased in the spring and declined to a low in the fall (Figure 12), likely driven by high terrestrial inputs during the spring rains.

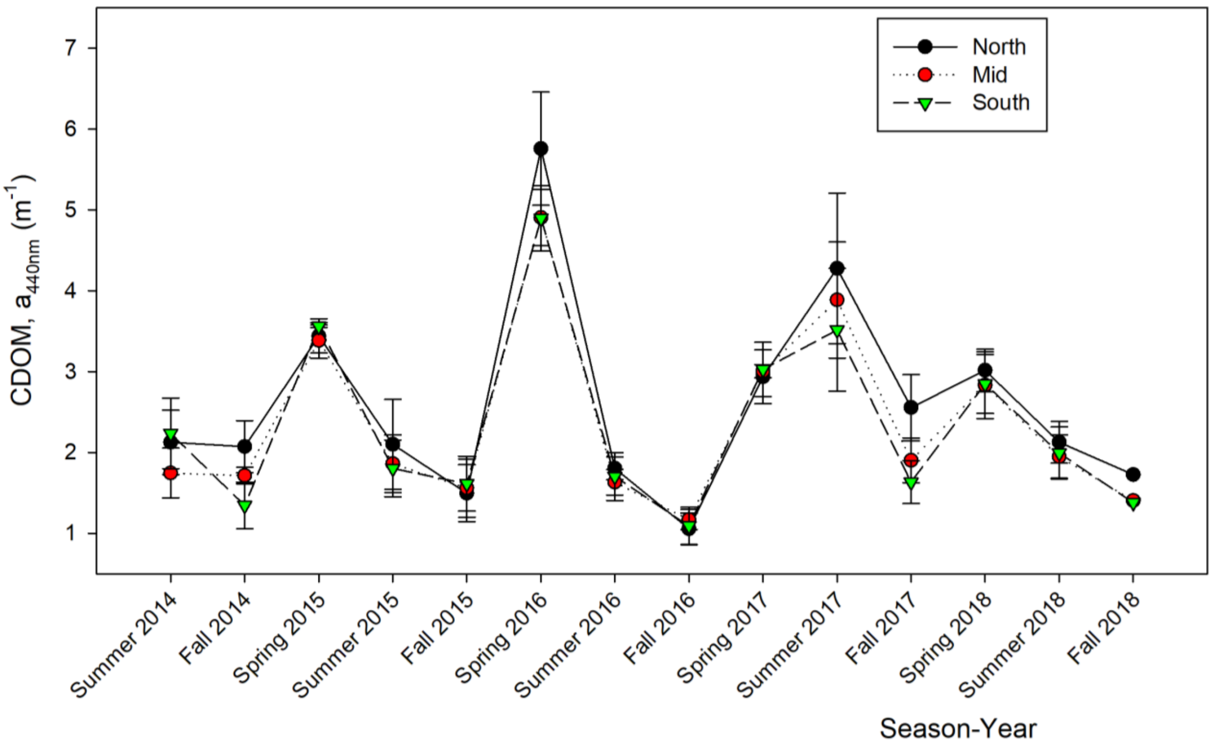

FIGURE 12: MEAN ABSORPTION COEFFICIENT FOR COLOR DISSOLVED ORGANIC MATERIAL, CDOM (±SE), AVERAGED BY SEASON DURING SAV GROWING PERIOD. SPRING IS MARCH, APRIL, MAY; SUMMER IS JUNE, JULY, AUGUST; AND FALL IS SEPTEMBER, OCTOBER, NOVEMBER

Mean **phytoplankton abundance** measured by water column **chlorophyll *a* concentration (CHLA)** at the North sites was 13.54 µg L^{-1} (± 1.67 standard error) ranging between 3.84 and 32.32 µg L^{-1}, was 14.14 µg L^{-1} (± 1.57 standard error) ranging between 3.94 and 33.40 µg L^{-1} at the Mid site, and was 12.46 µg L^{-1} (± 1.38 standard error) ranging between 3.70 and 28.82 µg L^{-1} at the South site (Figure 13).

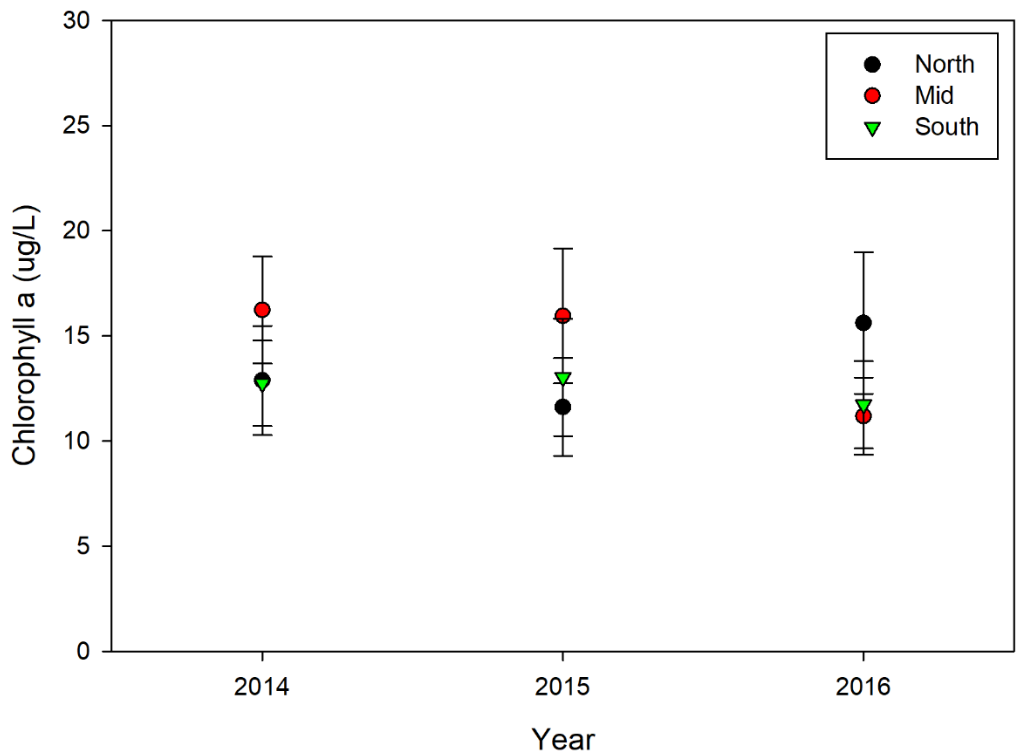

FIGURE 13: MEAN ANNUAL CHLOROPHYLL A CONCENTRATION (± SE) AT EACH STUDY SITE.

Highest values of CHLA were seen during the fall at all sites in 2015 and 2016 (Figure 14).

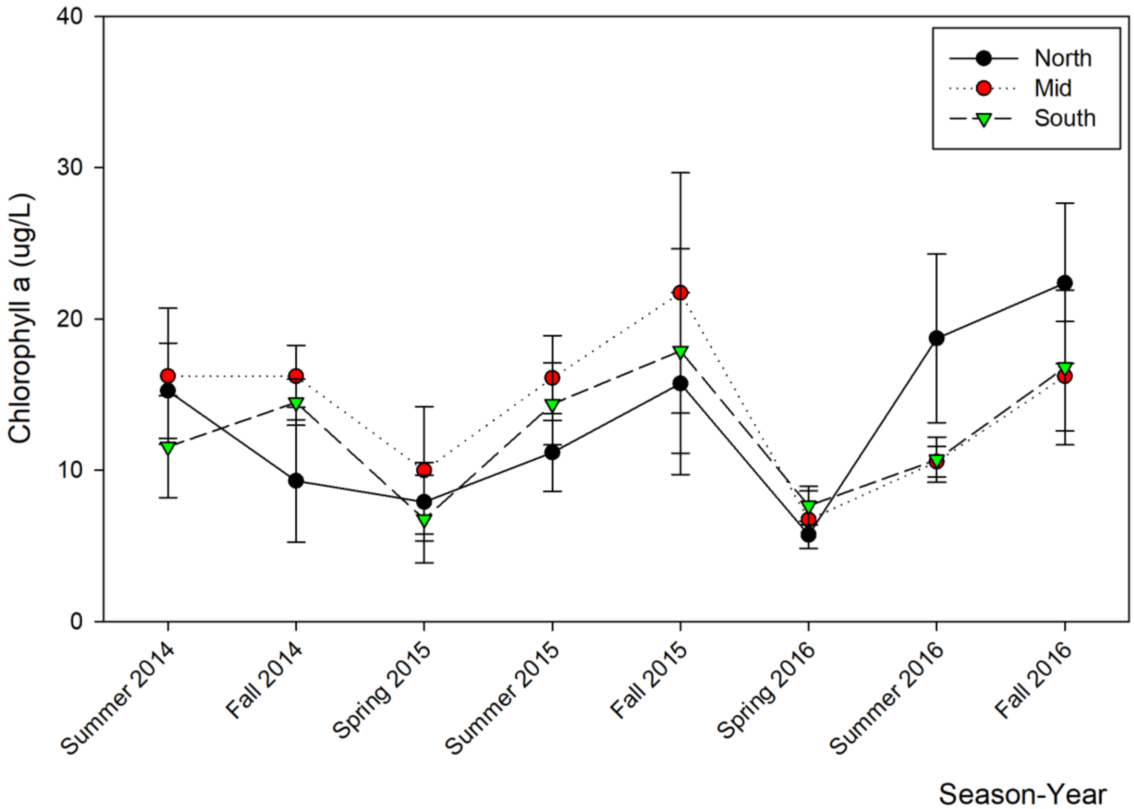

FIGURE 14: MEAN CHLOROPHYLL A CONCENTRATION (± SE) AT EACH SITE, AVERAGED BY SEASON DURING SAV GROWING PERIOD. SPRING IS MARCH, APRIL, MAY; SUMMER IS JUNE, JULY, AUGUST; AND FALL IS SEPTEMBER, OCTOBER, NOVEMBER

To examine how the above water quality parameters influenced the light attenuation coefficient, we use regression analysis, pooling data during the SAV growing season (spring, summer and fall) from all three sites for the 3 years (2014-2016) in which all parameters of interest (TSS [MSS & POM], CDOM, and CHLA) were measured. Best subset regression algorithms indicated that CDOM and CHLA were significant variables for the model ($p < 0.001$ and $p = 0.007$, respectively), with these parameters accounting for 44% of the variability in K_d. The best equation was:

$$K_d = 0.735 + (0.597 * CDOM) + (0.0486 * CHLA)$$

Discussion and Conclusions

D'Olive Bay is a shallow embayment that supports an abundant SAV community consisting of *Vallisneria americana* (wild celery), *Myriophyllum spicatum* (Eurasian watermilfoil), *Najas guadelupensis* (southern naiad), *Heteranthera dubia* (water stargrass), *Ceratophyllum demersum* (coontail), *Stuckenia pectinata* (sago pondweed), *Potamogeton crispus* (curly pondweed), and *Ruppia maritima* (widgeon grass) (Byron, pers. obs.; Vittor 2015). While species have different light requirements related to their growth forms (canopy-forming versus meadow-forming), generally between 10-30% of the surface PAR must reach the benthos for an area to sustain healthy SAV beds (Kemp et al. 2004). Studies targeting *Vallisneria americana*, a species of interest in this study, have found lower light threshold values ranging between 5 and 28% of surface irradiance (Dobberfuhl, 2007; French and Moore, 2003; Batiuk et al. 2000) with the amount of light required related to other environmental stresses, e.g. salinity stress (French and Moore, 2003).

We found few significant differences in any water quality parameters over the 4.5 years of study, which reflects the high seasonal variability of these parameters. Generally, K_d values were highest in the spring, especially during 2016, corresponding with reduced light available for SAV at the beginning of the growing season. CDOM values were also generally higher in the spring, especially during 2016, and CDOM was determined to be an important predictor of K_d from the regression model analysis. Because CDOM is typically prevalent where terrestrial inputs are high (Branco and Kremer 2005), it likely reflects runoff received by D'Olive Bay.

Phytoplankton abundance, as indicated by chlorophyll *a* concentration, is often used as a proxy for nutrient loading (Greening and Janicki, 2006). Our regression analysis found that chlorophyll *a* was also a significant predictor of K_d, and based on a previous study of habitat requirements and depth limits for SAV in the Mobile-Tensaw Delta, areas where chlorophyll *a* values were $\leq$10 ugL^{-1} supported SAV beds (Heck and Byron, unpublished data). Over the 2.5 years which chlorophyll *a* data was available for this study, values rarely measured below 10ugL^{-1} and reductions in chlorophyll *a* levels to below this threshold could decrease K_d, increasing the maximum depth and thus the area suitable for SAV growth, especially at the deeper Mid and South sites in D'Olive Bay. Tampa Bay, Florida is a good example of how reductions in nutrient loading, primarily total nitrogen loading, resulted in a decrease in chlorophyll *a* concentration (i.e. phytoplankton abundance) and an increase in water quality and clarity which resulted in an increase in total seagrass cover (Greening et al. 2014). These reductions were possible despite a large growth of human population in the watershed due to a concerted effort between management efforts to establish numeric water quality targets, implementation of state and federal regulatory programs, and citizen involvement (Greening et al. 2014).

During the 4.5 years of this study, North D'Olive Bay consistently supported a large SAV bed, primarily dominated by *Myriophyllum spicatum* (Eurasian watermilfoil). While water quality at this site was often not different than the Mid or South sites, the shallow nature of this site (mean depth of 0.7m) allowed more light to reach the bottom with light availability typically above the lower threshold for SAV growth. The Mid site fluctuated around the lower light threshold, but in

2018 the amount of light reaching the bottom had increased enough to support SAV and patches of *Ruppia maritima* were seen in the area (per. obs.). The South site located on the edge of natural channel, and the deepest of the three sites, was always below the minimum light threshold and SAV was only seen in shallower water nearshore or on the flats to the west of the sampling location. Overall, improved management practices implemented upstream will likely reduce CDOM, the supply of nutrients and thus amount of chlorophyll *a*, and would decrease light attenuation through the water column in D'Olive Bay with the result being an increase in the area suitable for the growth of SAV.

Literature Cited

Batiuk, R. A., P. Bergstrom, M. Kemp, E. Koch, L. Murray, J.C. Stevenson, R. Bartleson, V. Carter, N. B. Rybicki, C. Gallegos, L. Karrh, M. Naylor, D. Wilcox, K. Moore, S. Ailstock, And M. Teichberg. 2000. Chesapeake Bay submerged aquatic vegetation water quality and habitat-based requirements and restoration targets: A second technical synthesis. U.S. Environmental Protection Agency, Chesapeake Bay Program, Annapolis, Maryland.

Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V.Carter, S. Kollar, P. Bergstrom, and R. Batiuk. 1993. Assessing water quality with submersed aquatic vegetation. Habitat requirements as barometers of Chesapeake Bay health.Bioscience 43:86–94.

Dobberfuhl, D.R. 2007. Light limiting thresholds for submerged aquatic vegetation in a blackwater river. Aquatic Botany, 86: 346 – 352.

French, G.T. and K.A. Moore. 2003. Interactive effects of light and salinity stress on the growth, reproduction, and photosynthetic capabilities of *Vallisneria americana* (wild celery). Estuaries, 26(5): 1255-1268.

Greening, H., Janicki, A., 2006. Toward reversal of eutrophic conditions in a subtropical estuary: water quality and seagrass response to nitrogen loading reductions in Tampa Bay, Florida, USA. Environmental Management, 38, 163e178.

Greening, H., A. Janicki, E.T. Sherwood, R. Pribble, J.O.R. Johansson. 2014. Ecosystem responses to long-term nutrient management in an urban estuary: Tampa Bay, Florida, USA. Estuarine, Coastal and Shelf Science, 151: A1-A16.

Kemp, W.M., R. Batiuk, R. Bartleson, P.Bergstrom, V. Carter, C.L.Gallegos, W. Hunley, L.Karrh, E.W. Koch, J.M. Landwehr, K.A. Moore, L. Murray, M. Naylor, N.B. Rybicki, J.C. Stevenson, and D.J. Wilcox. 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: Water Quality, Light Regime, and Phyio-Chemical Factors. Estuariues, 27: 363-377.

Kenworthy, W.J. and M.S. Fonseca. 1996. Light requirements of seagrasses *Halodule wirghtii* and *Syringodium filiforme* derived from the relationshoip between diffuse light attenuation and maximum depth distribution. Estuaries, 19: 740-750.

Steward, J.S., R.W. Virnstien, L.J. Morris and E.F. Lowe. 2005. Setting seagrass depth, coverage, and light targets for the Indian River Lagoon System, Florida. Estuaries, 28: 923-935.

Appendix

Appendix A: Annual means and standard errors for all parameters measured.

Yearly averages of water quality parameters

NORTH D'Olive	TSS	POM	MSS	CHLA	Turbidity	Secchi depth	CDOM	%SI	Kd
2014 COUNT	5	5	5	5	5	5	5	5	5
2014 MEAN	18.50	8.30	10.20	12.88	13.73	0.34	2.10	16.04	2.63
2014 STDERR	2.71	2.11	1.96	2.60	1.32	0.04	0.24	3.66	0.26
2015 COUNT	9	9	9	9	7	9	9	8	8
2015 MEAN	27.33	9.44	17.89	11.61	17.28	0.34	2.35	16.69	2.37
2015 STDERR	6.97	1.15	5.97	2.32	4.23	0.04	0.35	2.69	0.15
2016 COUNT	8	8	8	9	9	9	9	9	9
2016 MEAN	25.06	7.69	17.38	15.61	14.99	0.49	2.87	14.27	3.38
2016 STDERR	4.79	1.22	4.84	3.37	4.83	0.06	0.76	3.21	0.71
2017 COUNT	9	8	8	NA	9	9	9	8	8
2017 MEAN	16.77	8.70	9.67		13.76	0.44	3.41	12.42	3.13
2017 STDERR	3.75	3.34	3.27		3.65	0.07	0.49	2.65	0.40
2018 COUNT	7	7	7	NA	7	7	7	7	7
2018 MEAN	20.52	5.43	15.10		14.23	0.41	2.45	20.19	2.39
2018 STDERR	4.71	0.70	4.10		2.32	0.06	0.25	2.99	0.27

MID D'Olive	TSS	POM	MSS	CHLA	Turbidity	Secchi depth	CDOM	%SI	Kd
2014 COUNT	5	5	5	5	5	5	5	5	5
2014 MEAN	17.30	7.00	10.30	16.23	11.70	0.36	1.73	10.90	2.44
2014 STDERR	1.70	0.94	1.83	2.54	1.86	0.02	0.17	1.94	0.22
2015 COUNT	9	9	9	9	7	9	9	8	8
2015 MEAN	27.11	10.11	17.00	15.95	13.96	0.40	2.27	7.85	3.06
2015 STDERR	5.68	1.47	4.50	3.20	2.01	0.03	0.32	1.04	0.27
2016 COUNT	9	9	9	9	9	9	9	9	9
2016 MEAN	22.28	7.00	15.28	11.18	14.81	0.51	2.57	7.88	3.02
2016 STDERR	3.04	1.03	3.40	1.83	4.02	0.06	0.60	2.01	0.43
2017 COUNT	9	9	9		9	9	9	8	8
2017 MEAN	14.00	5.54	8.46		13.35	0.44	3.03	9.06	2.68
2017 STDERR	2.79	1.37	2.35		1.68	0.04	0.43	2.22	0.24
2018 COUNT	7	7	7		7	7	7	7	7
2018 MEAN	14.19	5.19	9.00		11.98	0.44	2.25	12.74	2.36
2018 STDERR	1.79	0.81	1.22		1.39	0.02	0.29	1.95	0.24

SOUTH D'Olive	TSS	POM	MSS	CHLA	Turbidity	Secchi depth	CDOM	%SI	Kd
2014 COUNT	5	4	4	5	5	5	5	5	5
2014 MEAN	17.10	7.13	12.88	12.74	11.43	0.38	1.88	7.22	2.49
2014 STDERR	4.85	2.73	2.92	2.03	1.75	0.04	0.34	1.80	0.18
2015 COUNT	8	8	8	9	7	9	8	8	8
2015 MEAN	18.94	8.06	10.88	13.03	12.85	0.41	2.17	3.47	2.75
2015 STDERR	2.57	0.83	2.12	2.79	1.46	0.05	0.34	1.70	0.16
2016 COUNT	9	9	9	9	9	9	9	9	9
2016 MEAN	23.28	8.44	14.83	11.73	14.29	0.47	2.56	6.08	2.61
2016 STDERR	3.61	0.94	3.40	2.08	3.52	0.06	0.61	1.93	0.30
2017 COUNT	9	8	8		9	9	9	8	8
2017 MEAN	16.19	5.54	11.85		13.13	0.42	2.78	2.82	2.63
2017 STDERR	2.28	1.16	2.15		1.68	0.04	0.44	1.20	0.21
2018 COUNT	7	7	7		7	7	7	7	7
2018 MEAN	14.00	5.00	9.00		11.95	0.46	2.27	3.69	2.38
2018 STDERR	1.68	0.50	1.51		1.95	0.03	0.29	0.65	0.14

Appendix B: Seasonal means and standard errors for all parameters measured.

Seasonal averages of water quality parameters

NORTH D'Olive	TSS	POM	MSS	CHLA	Turbidity	Secchi depth	CDOM	%SI	Kd
Summer 2014 COUNT	3	3	3	3	3	3	3	3	3
Summer 2014 MEAN	20.17	8.33	11.83	15.27	15.37	0.37	2.13	17.00	2.63
Summer 2014 STDERR	3.00	3.72	1.86	3.15	0.54	0.03	0.40	5.98	0.21
Fall 2014 Count	2	2	2	2	2	2	2	2	2
Fall 2014 MEAN	16.00	8.25	7.75	9.31	11.27	0.30	2.07	14.60	2.63
Fall 2014 STDERR	6.00	1.75	4.25	4.05	2.55	0.10	0.32	4.85	0.75
Spring 2015 COUNT	3	3	3	3	3	3	3	3	3
Spring 2015 MEAN	21.50	8.33	13.17	7.92	16.70	0.33	3.44	18.76	2.62
Spring 2015 STDERR	1.76	0.60	1.74	2.59	0.75	0.03	0.21	4.68	0.13
Summer 2015 COUNT	3	3	3	3	1	3	3	3	3
Summer 2015 MEAN	18.00	8.67	9.33	11.18	9.15	0.40	2.10	16.95	2.20
Summer 2015 STDERR	5.35	1.59	3.92	2.56		0.10	0.56	6.10	0.39
Fall 2015 COUNT	3	3	3	3	3	3	3	2	2
Fall 2015 MEAN	42.50	11.33	31.17	15.74	20.56	0.30	1.50	13.22	2.25
Fall 2015 STDERR	19.37	3.19	16.52	6.01	10.41	0.06	0.35	2.46	0.13
Spring 2016 COUNT	3	3	3	3	3	3	3	3	3
Spring 2016 MEAN	28.67	4.17	24.50	5.74	32.09	0.30	5.76	12.85	4.36
Spring 2016 STDERR	4.91	0.67	5.51	0.90	7.27	0.00	0.70	8.61	1.03
Summer 2016 COUNT	2	2	2	3	3	3	3	3	3
Summer 2016 MEAN	13.00	8.25	4.75	18.72	6.64	0.63	1.80	14.52	3.64
Summer 2016 STDERR	3.00	1.75	4.75	5.57	2.48	0.09	0.14	5.54	1.90
Fall 2016 COUNT	3	3	3	3	3	3	3	3	3
Fall 2016 MEAN	29.50	10.83	18.67	22.38	6.25	0.53	1.06	15.44	2.14
Fall 2016 STDERR	11.06	1.09	10.08	5.30	1.14	0.09	0.19	4.09	0.34
Spring 2017 Count	2	2	2		2	2	2	2	2
Spring 2017 MEAN	14.50	6.25	8.25		12.31	0.38	2.94	9.78	3.76
Spring 2017 STDERR	1.00	2.25	3.25		2.89	0.07	0.33	5.78	0.92
Summer 2017 COUNT	4	4	4		4	4	4	3	3
Summer 2017 MEAN	18.06	12.44	5.63		15.88	0.51	4.28	12.44	2.59
Summer 2017 STDERR	7.47	6.41	4.64		7.81	0.12	0.93	5.25	0.78
Fall 2017 COUNT	3	2	2		3	3	3	3	3
Fall 2017 MEAN	16.56	3.67	19.17		11.89	0.40	2.56	14.15	3.26
Fall 2017 STDERR	7.31	0.67	5.83		5.41	0.13	0.41	4.78	0.55
Spring 2018 COUNT	3	3	3		3	3	3	3	3
Spring 2018 MEAN	21.22	5.78	15.44		16.98	0.37	3.02	26.58	2.13
Spring 2018 STDERR	6.60	1.44	5.19		4.78	0.12	0.26	3.22	0.53
Summer 2018 COUNT	3	3	3		3	3	3	3	3
Summer 2018 MEAN	23.22	5.67	17.56		13.01	0.47	2.13	12.62	2.42
Summer 2018 STDERR	9.50	0.84	8.69		2.57	0.07	0.26	0.99	0.33
Fall 2018 COUNT	1	1	1		1	1	1	1	1
Fall 2018 MEAN	10.33	3.67	6.67		9.62	0.40	1.73	23.76	3.10

MID D'Olive	TSS	POM	MSS	CHLA	Turbidity	Secchi depth	CDOM	%SI	Kd
Summer 2014 COUNT	3	3	3	3	3	3	3	3	3
Summer 2014 MEAN	16.50	5.67	10.83	16.24	13.22	0.37	1.75	10.34	2.57
Summer 2014 STDERR	2.60	0.60	3.18	4.49	2.42	0.03	0.31	3.24	0.36
Fall 2014 Count	2	2	2	2	2	2	2	2	2
Fall 2014 MEAN	18.50	9.00	9.50	16.22	9.42	0.35	1.72	11.74	2.25
Fall 2014 STDERR	2.50	1.00	1.50	2.04	2.89	0.05	0.10	2.23	0.21
Spring 2015 COUNT	3	3	3	3	3	3	3	3	3
Spring 2015 MEAN	26.17	8.50	17.67	10.01	17.03	0.37	3.39	5.62	3.75
Spring 2015 STDERR	7.84	0.76	7.34	4.21	3.76	0.03	0.22	1.30	0.26
Summer 2015 COUNT	3	3	3	3	1	3	3	3	3
Summer 2015 MEAN	16.17	8.33	7.83	16.11	10.01	0.40	1.86	9.51	2.82
Summer 2015 STDERR	3.37	0.88	3.35	2.80		0.00	0.36	1.88	0.43
Fall 2015 COUNT	3	3	3	3	3	3	3	2	2
Fall 2015 MEAN	39.00	13.50	25.50	21.73	12.21	0.43	1.56	8.70	2.39
Fall 2015 STDERR	13.54	4.00	9.96	7.95	2.32	0.09	0.36	1.47	0.28
Spring 2016 COUNT	3	3	3	3	3	3	3	3	3
Spring 2016 MEAN	25.17	3.83	21.33	6.75	29.45	0.32	4.91	3.39	4.44
Spring 2016 STDERR	5.80	0.88	6.55	1.89	5.28	0.02	0.35	1.81	0.14
Summer 2016 COUNT	3	3	3	3	3	3	3	3	3
Summer 2016 MEAN	20.33	8.50	11.83	10.58	9.32	0.55	1.63	10.08	2.15
Summer 2016 STDERR	2.09	1.89	3.72	1.01	1.13	0.05	0.16	1.60	0.29
Fall 2016 COUNT	3	3	3	3	3	3	3	3	3
Fall 2016 MEAN	21.33	8.67	12.67	16.22	5.65	0.67	1.17	10.18	2.48
Fall 2016 STDERR	8.17	0.88	7.37	3.61	0.40	0.09	0.13	5.25	0.78
Spring 2017 Count	2	2	2		2	2	2	2	2
Spring 2017 MEAN	19.75	10.75	9.00		15.15	0.33	3.01	5.59	3.05
Spring 2017 STDERR	0.75	0.25	0.50		1.65	0.03	0.08	0.35	0.23
Summer 2017 COUNT	4	4	4		4	4	4	3	3
Summer 2017 MEAN	9.54	5.25	4.29		12.71	0.48	3.89	9.83	2.28
Summer 2017 STDERR	3.82	2.05	2.30		2.51	0.05	0.72	4.23	0.36
Fall 2017 COUNT	3	3	3		3	3	3	3	3
Fall 2017 MEAN	16.11	2.44	13.67		13.00	0.47	1.90	10.62	2.84
Fall 2017 STDERR	6.12	0.62	5.50		4.37	0.09	0.28	4.73	0.52
Spring 2018 COUNT	3	3	3		3	3	3	3	3
Spring 2018 MEAN	17.22	5.56	11.67		14.27	0.38	2.83	10.88	2.97
Spring 2018 STDERR	1.44	0.91	1.02		2.07	0.02	0.41	1.78	0.30
Summer 2018 COUNT	3	3	3		3	3	3	3	3
Summer 2018 MEAN	12.78	5.56	7.22		11.16	0.47	1.95	11.47	1.91
Summer 2018 STDERR	3.28	1.68	1.75		1.76	0.03	0.27	2.47	0.05
Fall 2018 COUNT	1	1	1		1	1	1	1	1
Fall 2018 MEAN	9.33	3.00	6.33		7.54	0.50	1.40	22.15	1.89

SOUTH D'Olive	TSS	POM	MSS	CHLA	Turbidity	Secchi depth	CDOM	%SI	Kd
Summer 2014 COUNT	3	2	2	3	3	3	3	3	3
Summer 2014 MEAN	10.83	2.75	10.75	11.57	12.37	0.37	2.24	5.58	2.68
Summer 2014 STDERR	4.37	0.25	5.75	3.36	1.93	0.03	0.44	2.70	0.17
Fall 2014 Count	2	2	2	2	2	2	2	2	2
Fall 2014 MEAN	26.50	11.50	15.00	14.50	10.02	0.40	1.35	9.67	2.20
Fall 2014 STDERR	5.50	2.50	3.00	1.53	4.00	0.10	0.29	0.77	0.30
Spring 2015 COUNT	2	2	2	3	3	3	2	3	3
Spring 2015 MEAN	17.75	6.50	11.25	6.78	15.10	0.40	3.56	1.91	2.98
Spring 2015 STDERR	4.75	1.50	3.25	2.89	1.78	0.06	0.02	0.62	0.19
Summer 2015 COUNT	3	3	3	3	1	3	3	3	3
Summer 2015 MEAN	16.33	7.83	8.50	14.40	16.70	0.33	1.80	2.04	2.72
Summer 2015 STDERR	1.92	0.93	2.84	2.71		0.03	0.35	1.38	0.34
Fall 2015 COUNT	3	3	3	3	3	3	3	2	2
Fall 2015 MEAN	22.33	9.33	13.00	17.90	9.32	0.50	1.61	7.93	2.44
Fall 2015 STDERR	6.39	1.76	5.01	6.76	0.68	0.12	0.34	6.87	0.30
Spring 2016 COUNT	3	3	3	3	3	3	3	3	3
Spring 2016 MEAN	24.17	5.50	18.67	7.68	27.87	0.32	4.90	0.97	3.65
Spring 2016 STDERR	4.19	0.00	4.19	1.27	2.03	0.02	0.41	0.33	0.29
Summer 2016 COUNT	3	3	3	3	3	3	3	3	3
Summer 2016 MEAN	16.50	9.67	6.83	10.71	9.22	0.50	1.70	5.01	2.42
Summer 2016 STDERR	1.80	1.42	1.83	1.51	1.68	0.06	0.30	2.66	0.26
Fall 2016 COUNT	3	3	3	3	3	3	3	3	3
Fall 2016 MEAN	29.17	10.17	19.00	16.80	5.80	0.60	1.09	12.27	1.77
Fall 2016 STDERR	9.74	1.42	8.35	5.12	0.93	0.12	0.23	2.20	0.21
Spring 2017 Count	2	2	2		2	2	2	2	2
Spring 2017 MEAN	23.00	9.50	13.50		17.85	0.30	3.03	1.28	3.16
Spring 2017 STDERR	0.50	1.50	2.00		3.45	0.00	0.33	0.29	0.11
Summer 2017 COUNT	4	3	3		4	4	4	3	3
Summer 2017 MEAN	11.42	5.67	7.39		12.19	0.44	3.52	3.76	2.59
Summer 2017 STDERR	2.28	1.48	2.12		2.56	0.04	0.76	2.84	0.26
Fall 2017 COUNT	3	3	3		3	3	3	3	3
Fall 2017 MEAN	18.00	2.78	15.22		11.25	0.48	1.64	2.91	2.32
Fall 2017 STDERR	4.44	0.68	4.58		2.68	0.12	0.26	2.03	0.46
Spring 2018 COUNT	3	3	3		3	3	3	3	3
Spring 2018 MEAN	16.33	5.22	11.11		15.35	0.42	2.85	3.31	2.36
Spring 2018 STDERR	3.34	0.11	3.28		3.56	0.06	0.36	0.21	0.34
Summer 2018 COUNT	3	3	3		3	3	3	3	3
Summer 2018 MEAN	12.67	5.44	7.22		10.55	0.48	2.00	2.82	2.44
Summer 2018 STDERR	1.86	0.97	1.09		1.10	0.02	0.32	0.39	0.17
Fall 2018 COUNT	1	1	1		1	1	1	1	1
Fall 2018 MEAN	11.00	3.00	8.00		5.92	0.55	1.38	7.41	2.30