Fowl River Marsh Study – Hydrology and Hydrography

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Introduction

The objective of this component of the study was to characterize estuarine surface water and marsh porewater variables that may be related to observed changes in marsh spit shorelines and vegetation. For example, estuarine water surface elevation, salinity, and temperature play major roles in structuring the species composition and zonation of marsh plant communities (Eleuterius and Eleuterius 1979; Bertness 1991). Suspended sediment, organic matter, and nutrient inputs to a marsh are necessary to maintain sediment accrual rates at a pace equal to or greater than sea level rise (Stevenson 1986; Craft 2007). Thus, we conducted a study to observe the temporal and spatial patterns and variation in these variables in Fowl River. Quantifying these patterns is key to understanding how changes in hydrology and hydrography may be impacting the marshes in Fowl River. In the following sections we describe our methods, results, and conclusions. An overall conclusion is that the marsh spits are being impacted by several stressors, including sea level rise, salinity intrusion, and nutrient enrichment. We also measured widespread hypoxia ($[O_2] < 2$ mg L^{-1}) in the Fowl River estuary that may warrant separate management and restoration actions.

Methods

The Fowl River estuary has three distinct regions we used to facilitate comparisons along the river. Region 1 is the upstream region characterized by freshwater inputs from the watershed. Region 2 is a transition area between freshwater and more marine influence where the priority marsh spits are located. Region 3 is the most marine area connected to Mobile Bay and Mississippi Sound. The connection to Mississippi Sound is through an artificial canal that enters Fowl River where stations 13 and 14 are located (Figure 1). The borders of the regions are shown in Figure 1.

Sampling of the estuary was conducted from February 2018 to December 2018 with ten monthly surveys of the estuary. On these surveys, estuarine ranges and dynamics of salinity, temperature, oxygen, suspended sediments, organic matter, and nutrients were measured. Per survey, there were 18 hydrographic stations (Figure 1) for quantifying horizontal and vertical gradients of salinity, temperature, and oxygen across the three regions. At eight of 18 stations (Figure 2), we collected discrete surface and bottom water samples that were analyzed for salinity, temperature, and concentrations of suspended sediments, organic matter, and nutrients. At three of the marsh spits (Figure 2), porewater salinity, temperature, and oxygen were collected continuously from April to December 2018 at 15-minute intervals using in situ field sensors in porewater wells. Further details for each of the sampling programs is provided below.

Hydrographic Profiles

During 10 surveys, a vertical profile of salinity, temperature, and O_2 was collected at the 18 stations with a conductivity, temperature, and depth (CTD) sensor. Variables measured on the CTD instruments (Seabird Instruments Inc.) included water salinity, temperature, and oxygen concentration. For each cast, the CTD was first submerged at one-meter depth for one minute

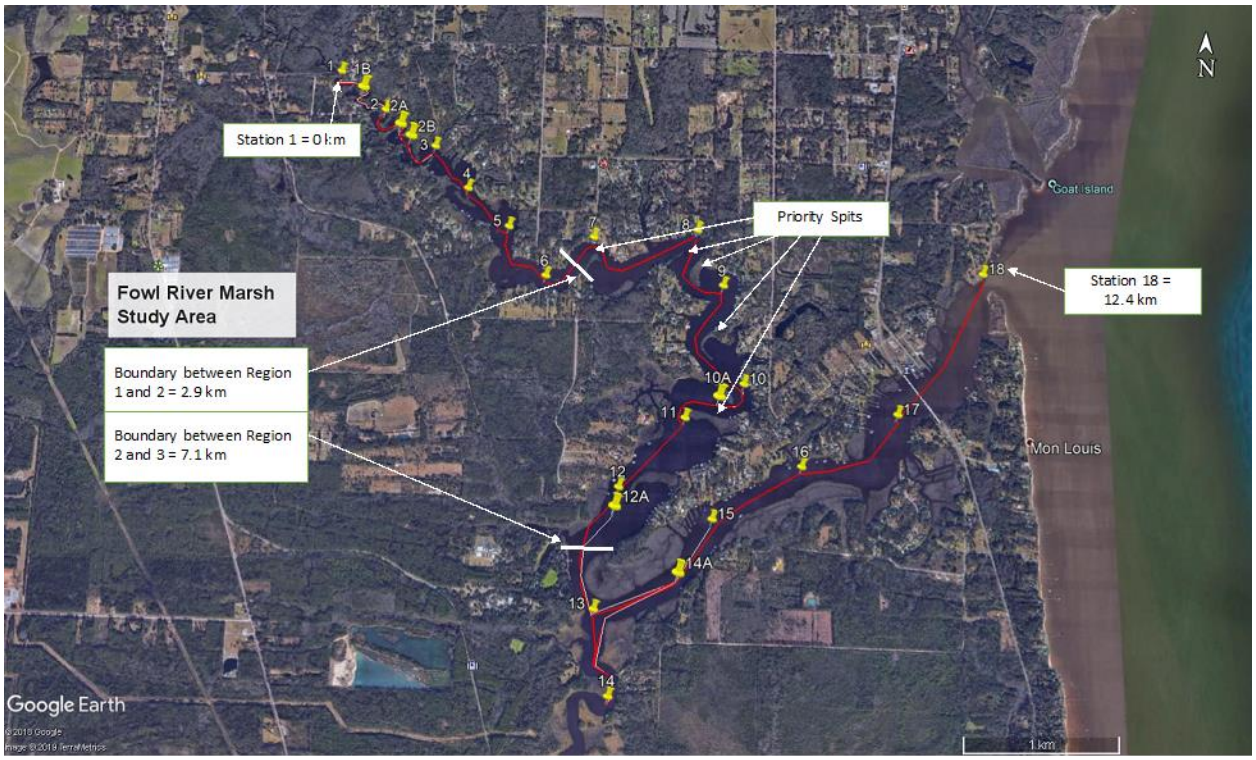

Figure 1. Map of Fowl River study area. The hydrographic stations (yellow pins) are overlaid on a Google Earth image. The red line was used to measure the along channel distances between stations and across the transect (total distance = 12.4 km) using station 1 as the reference location for the beginning of the estuary (0 km) and station 18 as the end of the estuary. White boundary lines for the study regions are shown between stations 6 and 7 and between 12 and 13. Region 1 stations included stations 1-6, Region 2 stations were stations 7-12, and Region 3 stations were 13-18.

to purge the system of bubbles. After purging. the instrument was brought back to the surface and then slowly lowered with a hand winch through the water column to the bottom to obtain a vertical profile. While best efforts were made to sample the exact same locations over the course of the study, bottom depths were not consistent at some of the stations due to the heterogeneity of the bathymetry in the river and to currents.

Discrete Water Column Measurements

Surface and bottom water samples were collected at eight stations during each monthly hydrographic survey (Figure 2). Surface water samples were collected via grab sample and bottom water samples were collected with a 2L Niskin bottle lowered to within one meter of the bottom. Salinity, temperature, and oxygen were measured in surface and bottom water samples using a YSI 2030Pro meter. Sample bottles for collection of water that was later analyzed at the lab were triple-rinsed with site water before collecting samples. Samples were stored in the dark on ice until processed at the lab within four to six hours of collection. Samples were processed and prepared for analysis of chlorophyll-*a* (chl*a*), total suspended solids (TSS), volatile suspended solids (VSS), dissolved nutrients, particulate carbon and nitrogen (PCN), and dissolved organic nitrogen (DON) and organic carbon (DOC). Sample analyses were conducted using established procedures, briefly described below.

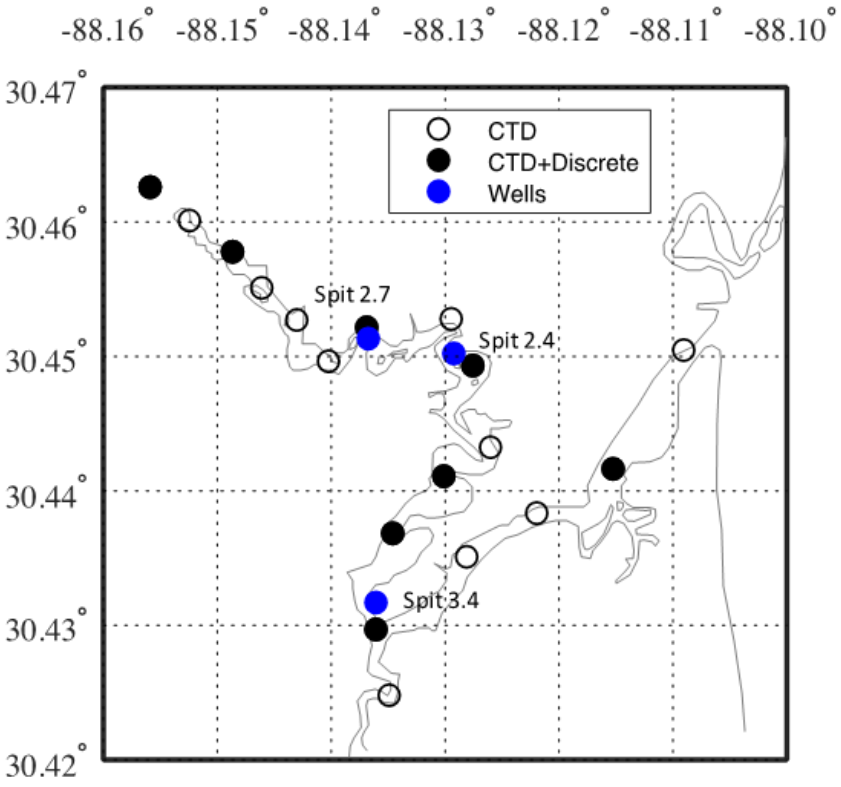

Figure 2. Sampling locations for synoptic surveys (open and closed black circles) and for marsh water surface elevation and porewater hydrography (blue circles). X-axis represents latitude, and Y axis represents longitude.

Chlorophyll *a*

Samples for chlorophyll were filtered onto 25 mm Whatman GF/F filters (nominal pore size of 0.7 µm) and stored frozen at -20°C or colder in a 50 ml polypropylene centrifuge tube or an aluminum foil packet. Prior to analysis, the chlorophyll was extracted in 10 mL of methanol buffered with ammonia acetate and centrifuged at 4000 rpm for 10 minutes. The supernatant was assayed for raw fluorescence measurement on a Turner Trilogy fluorometer calibrated with a known chl*a* standard.

Dissolved Nutrients

Samples were collected by filtration through a combusted GF/F filter and stored frozen at -20°C in a high-density polyethylene (HDPE) bottle. Dissolved nutrients (nitrate, nitrite, ammonium, phosphate, and silicate) were assayed colorimetrically on an automated nutrient auto-analyzer. Dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) were analyzed following high temperature combustion on a Shimadzu TOC/TDN analyzer.

Particulate C, N (PCN)

Samples for PCN were collected onto combusted (90 min at 500°C) 25 mm Whatman GF/F filters. Filters were stored dry in a desiccator or frozen at -20°C, typically in 47 mm polystyrene petri dishes. PCN samples were combusted and analyzed on an elemental analyzer.

Total and Volatile Suspended Solids (TSS/VSS)

Samples for TSS/VSS were filtered onto combusted 47mm GF/F filters of known weight, and stored in a desiccator or frozen at -20°C. Upon analysis, samples were dried in a drying oven at 70-80°C and weighed to obtain TSS. Samples were then combusted at 490°C for 90 minutes and final combusted weight of the filter was used to calculate VSS.

High Frequency Marsh Porewater Time-Series Measurements

HOBO logger instruments were deployed from April 2018 to present to collect time-series data on three spits (2.4, 2.7, and 3.4). Within each spit, five-inch PVC wells were installed at three locations across the spit (upstream, middle, and downstream). Within each well, loggers were deployed to observe water surface elevation, salinity, dissolved oxygen concentration and temperature. Well locations were surveyed with an RTK GPS to obtain horizontal and vertical positions within each marsh spit.

Data Management and Analysis

Data were recorded and stored in Microsoft Excel files. Data processing, analysis, and visualization were conducted in Matlab (Mathworks, Inc). Excel files and Matlab scripts used to generate the figures in this report are available upon request to the authors.

Results

Water Column Hydrographic Profiles

Water-column salinity in Fowl River ranged from 0-13 ppt (Figure 3). Temperature ranged from 14-31 °C (Figure 4). Dissolved oxygen concentrations ranged from 0.1 to 12.8 mg L^{-1}, and oxygen concentrations were commonly below the hypoxic threshold of 2 mg L^{-1} during summer and fall of 2018 (Figure 5).

Monthly, synoptic sampling revealed the expected salinity gradient with freshwater at the upper river and increasing salinity down river towards the mouth of the estuary (Figure 6). From March to April, the water-column was well-mixed with surface and bottom salinity being nearly equal. From May through November, salinity begins to intrude up the estuary mainly in the bottom waters with maximum salinity (> 12) occurring in the bottom water during fall. The salinity characteristics of Region 2 tend to mirror those of Region 1.

Temperatures were at their minimum of (~14 °C) in March and increased to their maximum (>31 °C) in September (Figure 7). On average, temperatures were 4-6 °C cooler at the upstream sites than at the mouth of the estuary.

Oxygen concentrations were highest in March and April, when [O_2] exceeded 10 mg L^{-1}, and lowest at stations in Region 2 where bottom waters were hypoxic ([O_2] < 2 mg L^{-1}) on six of the 10 surveys (Figure 5). Hypoxia also occurred at the border of Region 1 and 2 and in the upstream area of Region 3 (Figure 8).

Discrete Water Column Measurements

There was a clear positive correlation between TSS and salinity, with TSS peaking at approximately 50 mg m^{-3} at the mouth of Fowl River (Figure 9). This relation with salinity resulted in lowest salinity in Region 1 and Region 2 and highest in Region 3. Also, bottom waters generally

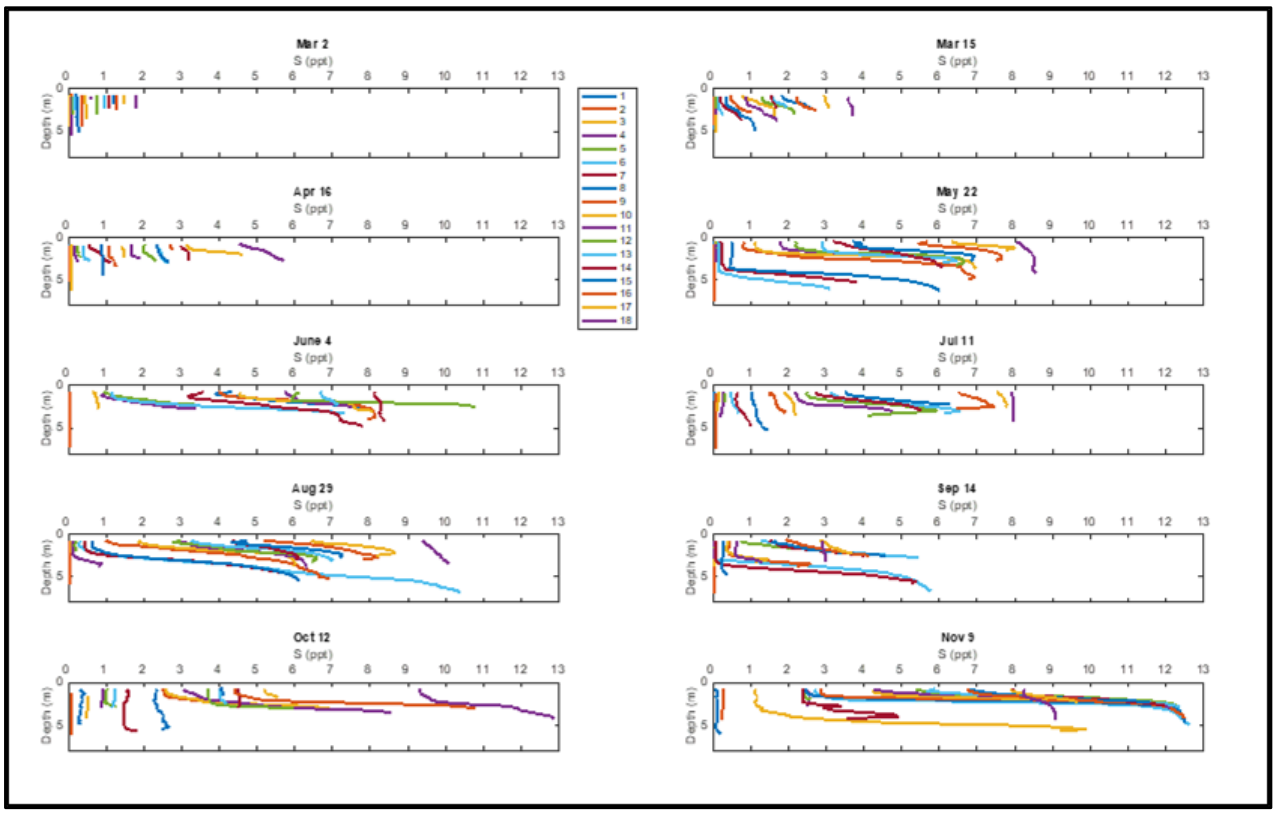

Figure 3. Salinity (S) profiles at 18 stations per monthly survey.

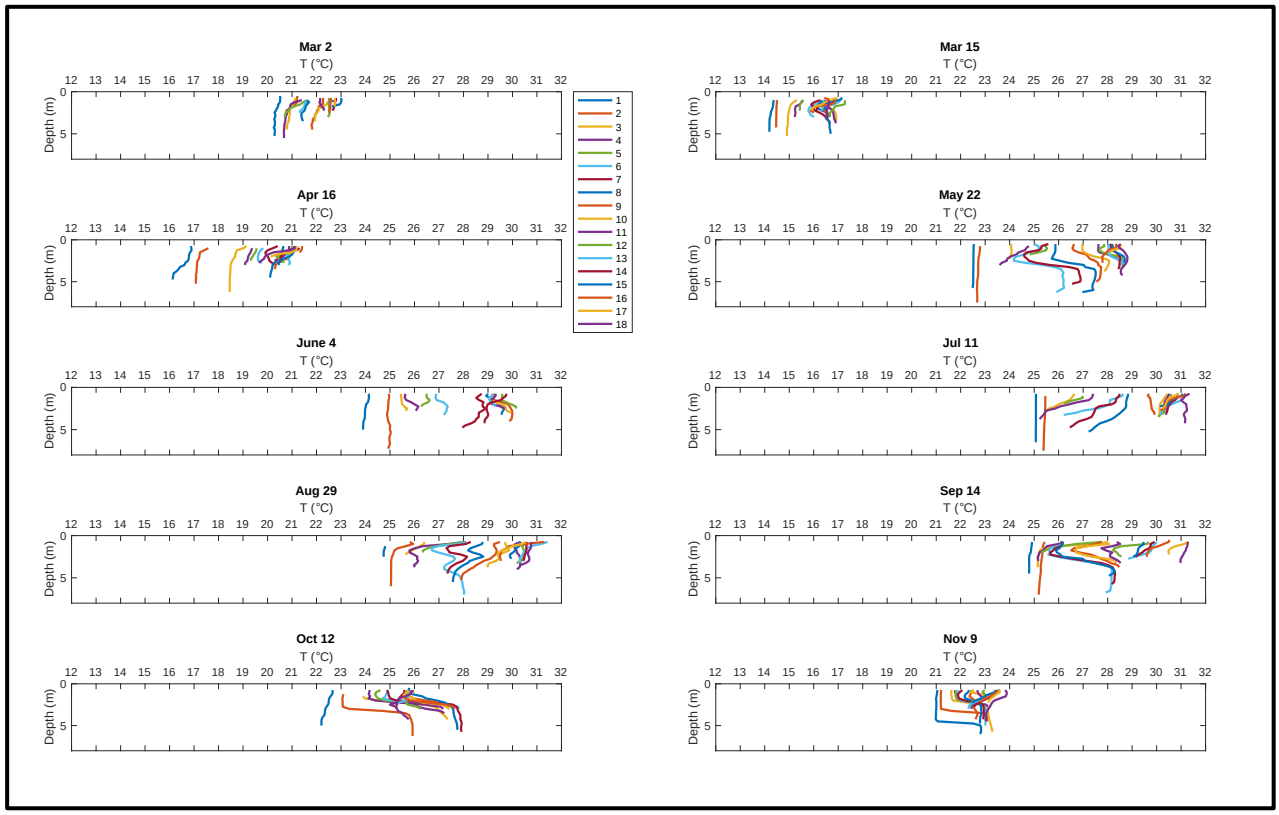

Figure 4. Temperature (T) profiles at 18 stations per monthly survey.

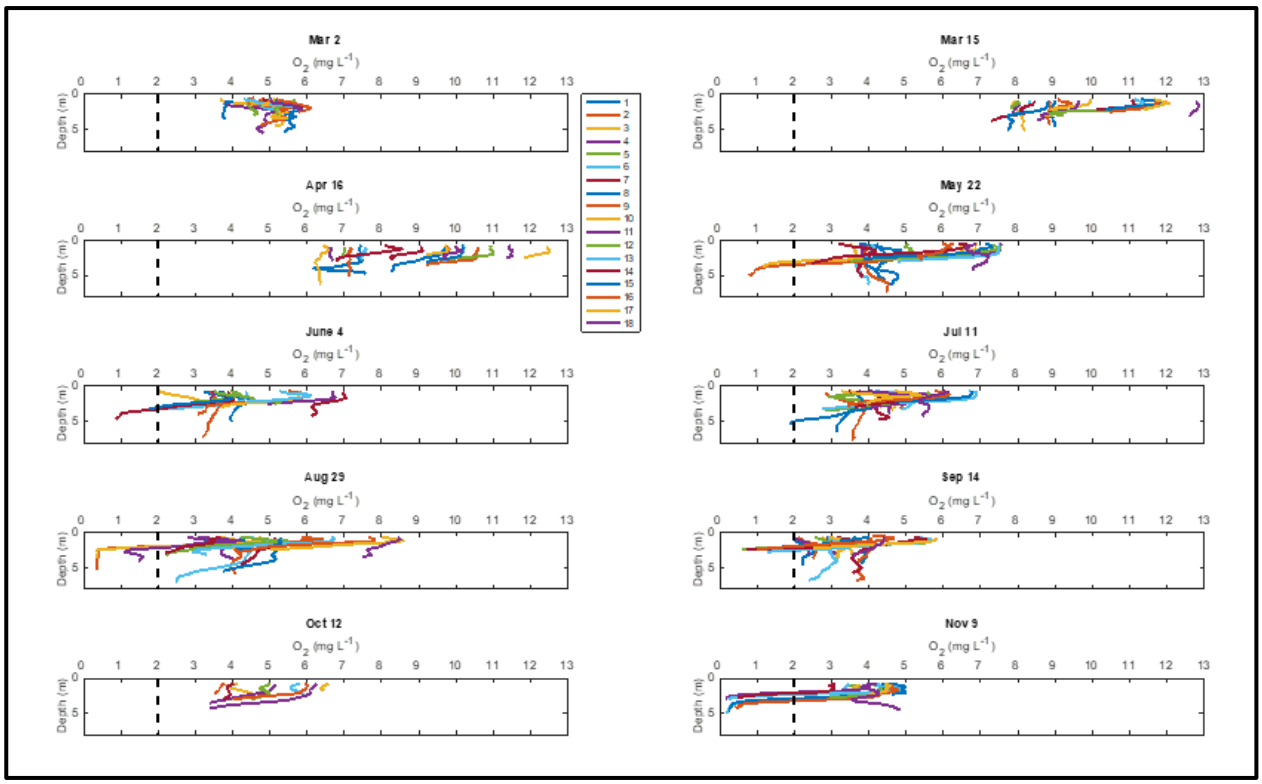

Figure 5. Oxygen (O2) profiles at 18 stations per monthly survey. The dashed vertical line indicates the commonly defined hypoxic threshold concentration of 2 mg L-1.

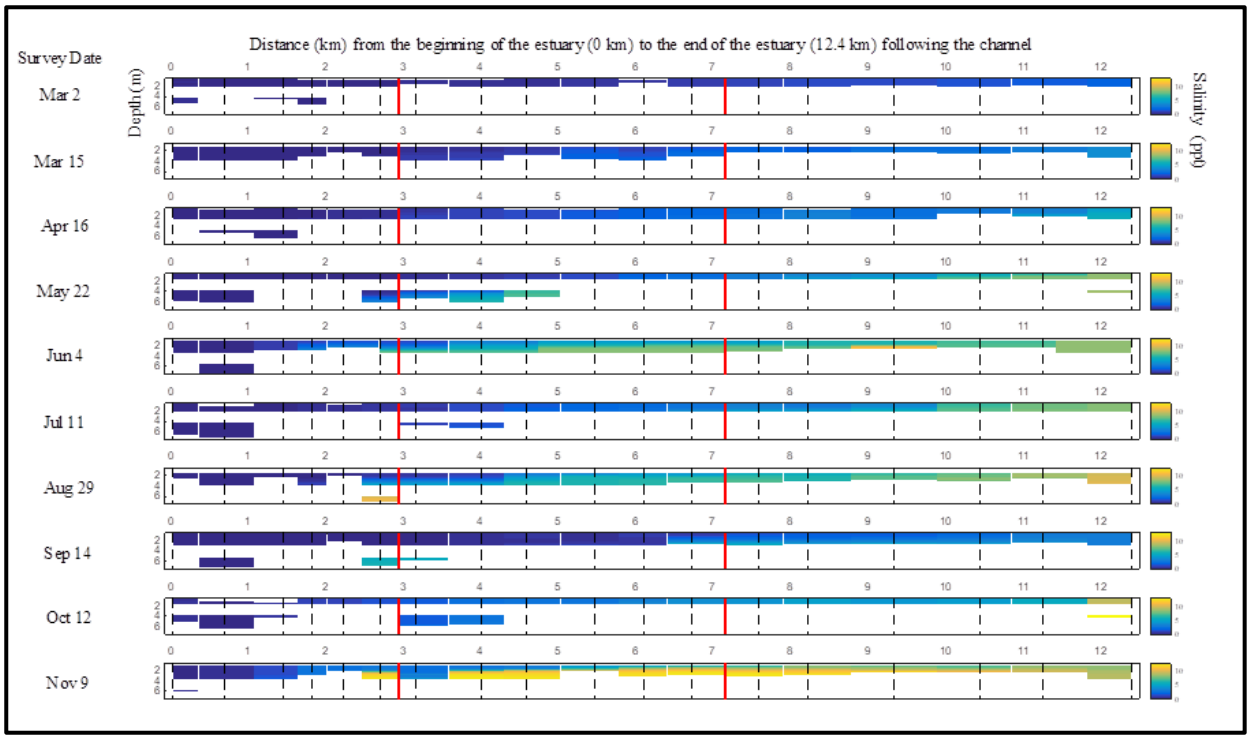

Figure 6. Survey side views of salinity plotted along the transect in Figure 1. Salinity variation is shown by color (see the color bar) and varies by depth (0.25 to 7.75 m) on the y-axis and distance (km) along the estuary on the x-axis. Vertical dashed lines show the location of CTD profile stations. Solid red lines mark the boundaries for the study regions: from the left, the first red line separates Regions 1 and 2 and the second red line separates Regions 2 and 3.

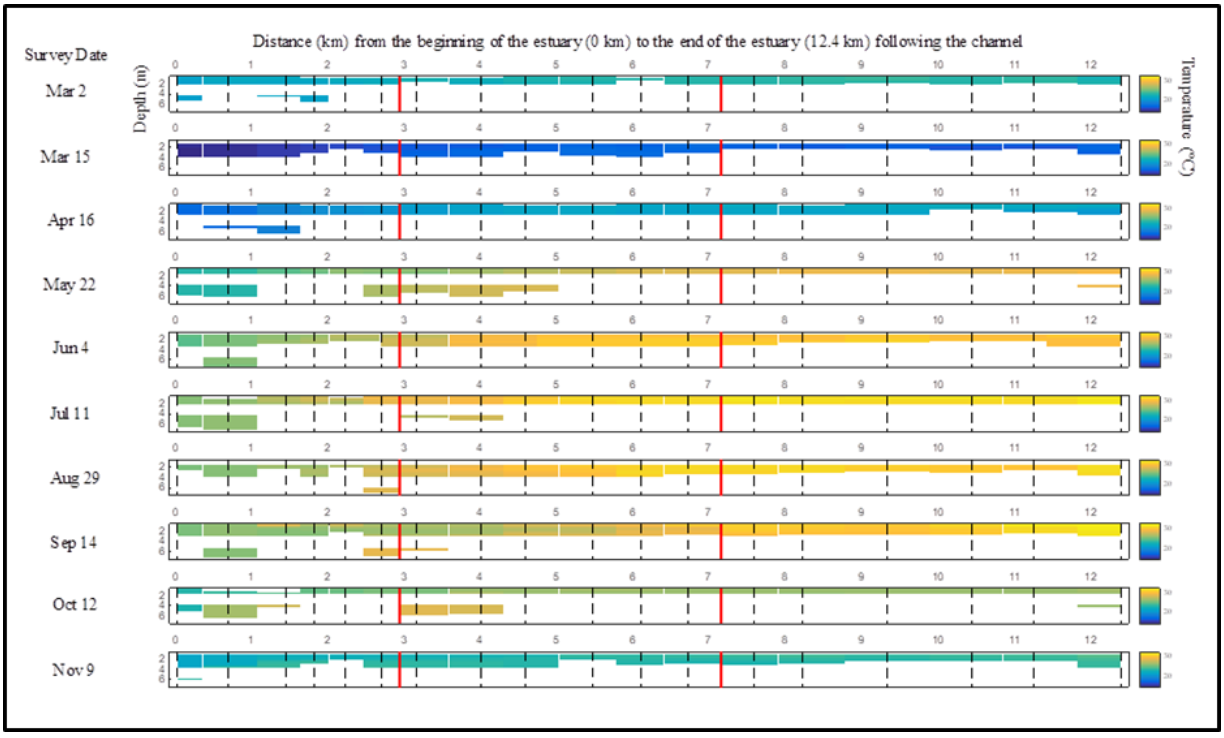

Figure 7. Survey side views of temperature plotted along the transect in Figure 1. Temperature variation is shown by color (see the color bar) and varies by depth (0.25 to 7.75 m) on the y-axis and distance (km) along the estuary on the x-axis. Vertical dashed lines show the location of CTD profile stations. Solid red lines mark the boundaries for the study regions: from the left, the first red line separates Regions 1 and 2 and the second red line separates Regions 2 and 3.

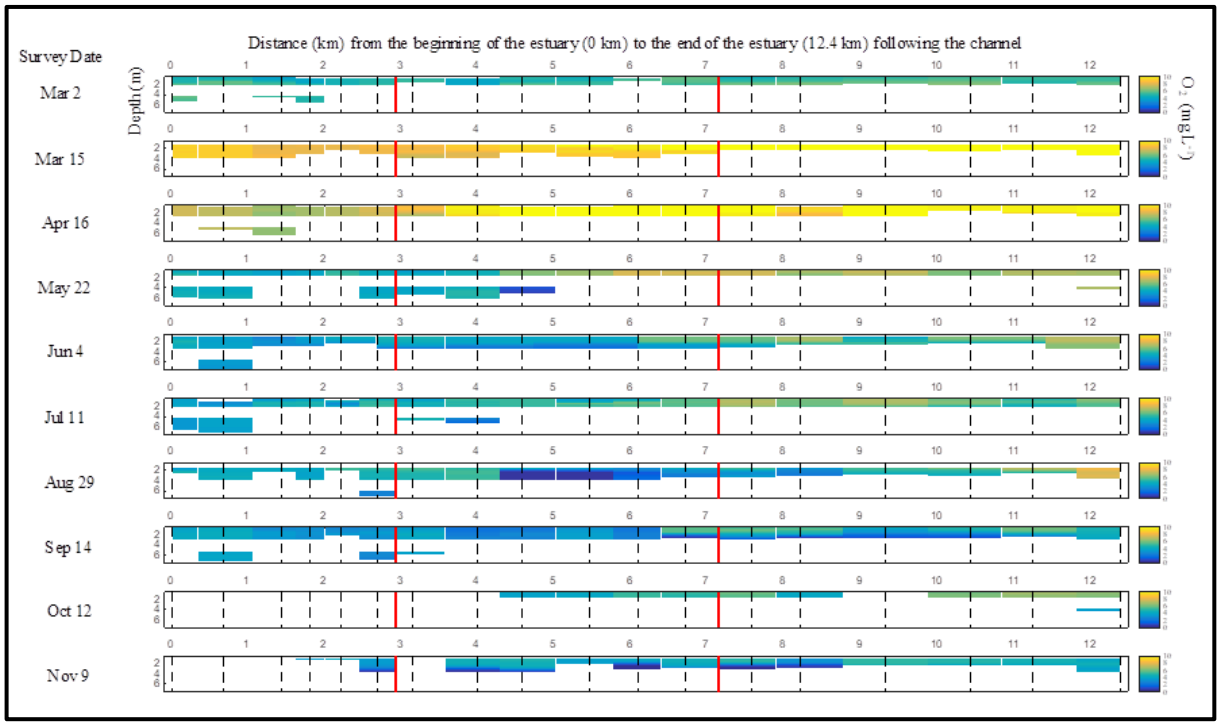

Figure 8. Survey side views of dissolved oxygen plotted along the transect in Figure 1. Oxygen variation is shown by color (see the color bar) and varies by depth (0.25 to 7.75 m) on the y-axis and distance (km) along the estuary on the x-axis. Vertical dashed lines show the location of CTD profile stations. Solid red lines mark the boundaries for the study regions: from the left, the first red line separates Regions 1 and 2 and the second red line separates Regions 2 and 3.

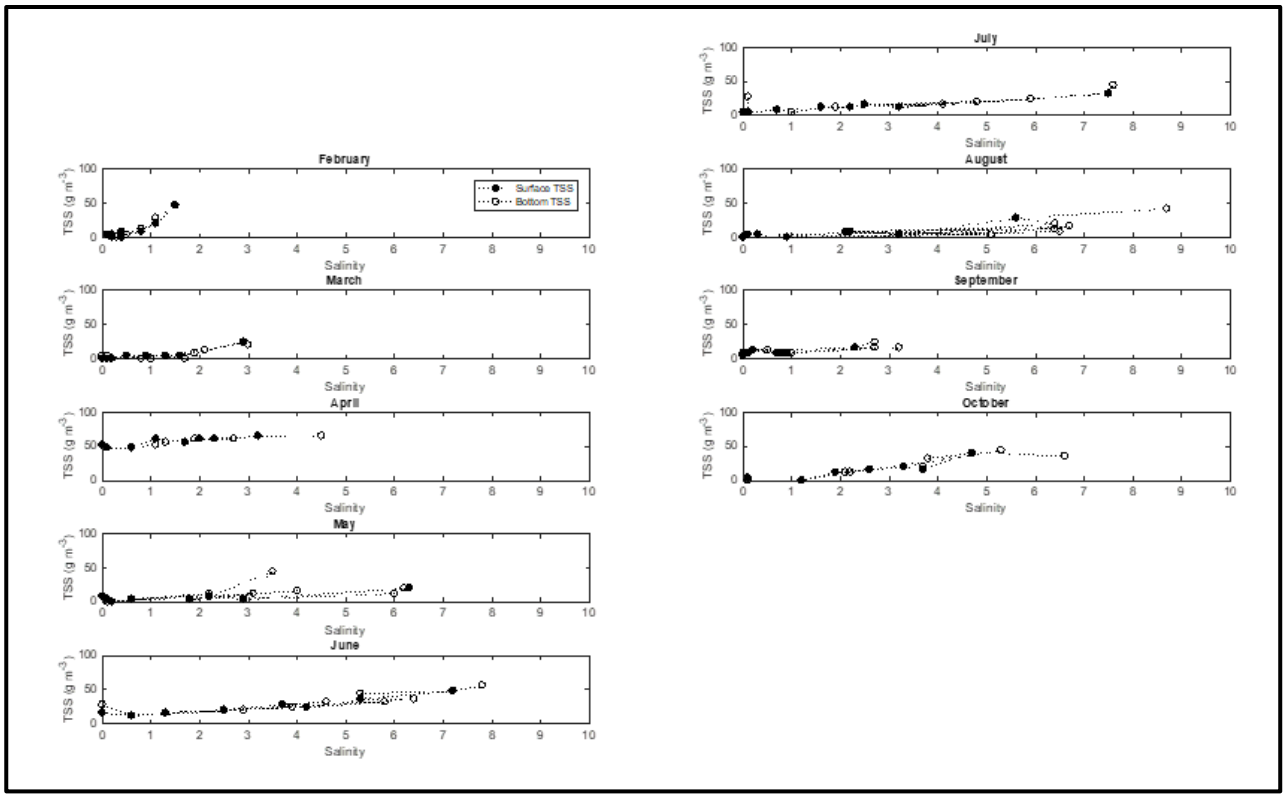

Figure 9. Monthly Water column suspended sediment concentrations as a function of salinity.

had higher TSS than surface water. Overall, this pattern indicated that the primary source of suspended sediments to this system was Mobile Bay rather than the Fowl River Watershed.

NO_3^- concentrations of approximately 40 mmol m^{-3} were common in the upper estuary and decreased down estuary (Figure 10). High NO_3^-, NH_4^+ (not shown) and PO_4^{3-} (not shown) concentrations translated to high chl*a* concentrations (Figure 11), which often exceed 40 mg m^{-3}. Eutrophication and associated poor water quality condition is generally indicated at chl*a* > 20 mg m^{-3} (Bricker et al. 2003; US EPA 2015)

High Frequency Marsh Porewater Time-Series Measurements

Surface water elevation data obtained from the wells indicated that the marshes were flooded from April-October 2018 (Figure 12). The instruments were still in the field collecting data at the time of this report. The instruments will be brought back to the lab in April 2019, which will terminate the time-series measurements in the marsh.

Porewater salinities (Figure 13) were lower at spits 2.4 and 2.7 and highest at spit 3.4, which was located across from Bellingrath Gardens and closest in proximity to Mobile Bay. Within a spit, there was a noticeable gradient in salinity with the upstream portion of the spit having lower salinity than the downstream portion, with salinity values generally highest in the middle of the spits.

Conclusions

Results suggest the observed marsh spit degradation is likely due to a combination of factors. First, the marsh surface was inundated for nearly the entire period from April-October (Figure 12). Sea-level rise is occurring in Mobile Bay at a rate of ~3.6 mm y^{-1} (calculated from surface elevation data at Dauphin Island and Mobile State Docks). During this study, the current sea level is greater than the mean elevation of the surface marsh. Further, suspended sediment concentrations were mainly driven by inputs from Mobile Bay (Figure 9). Thus, the spits in the middle and upper river are removed

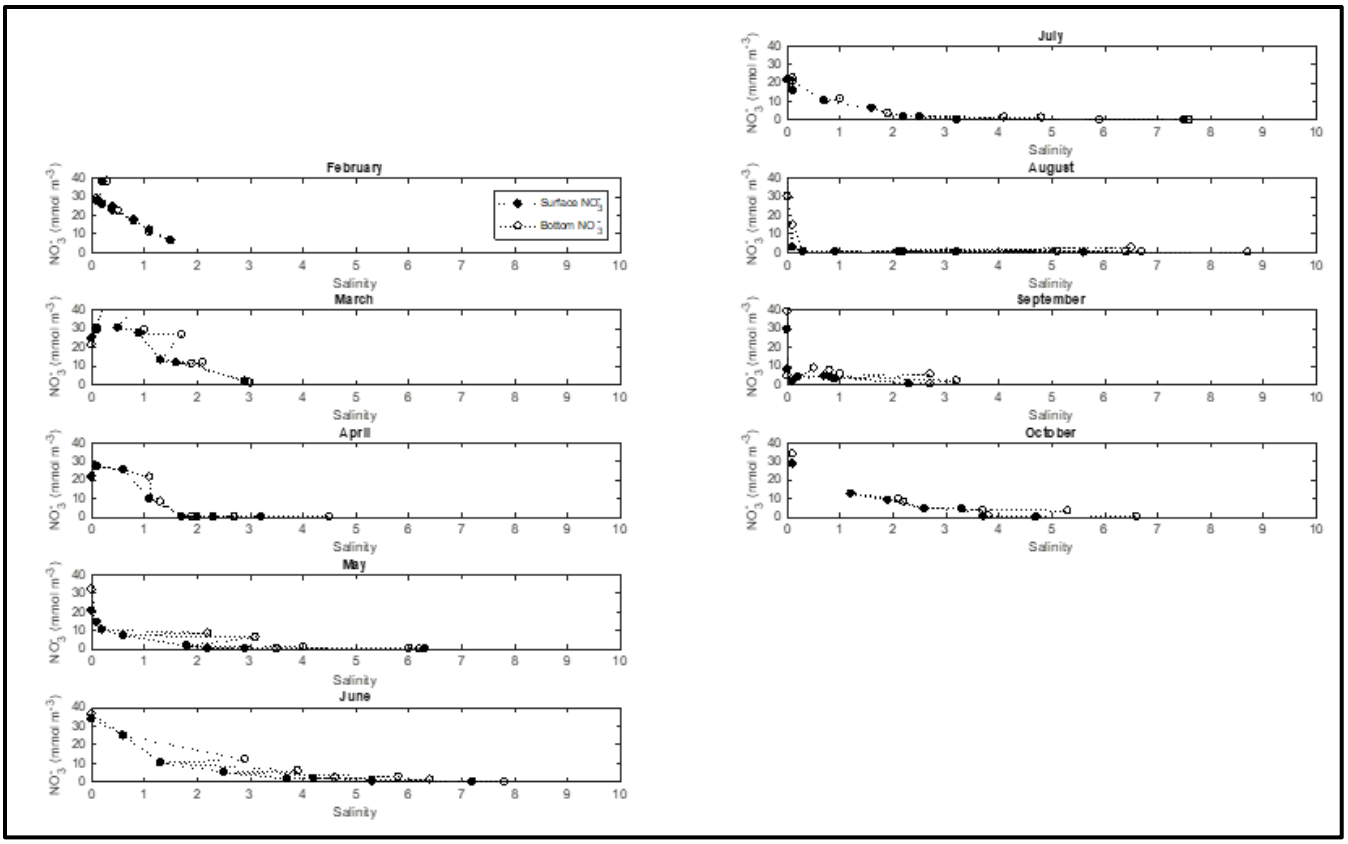

Figure 10. Monthly water column nitrate concentrations as a function of salinity

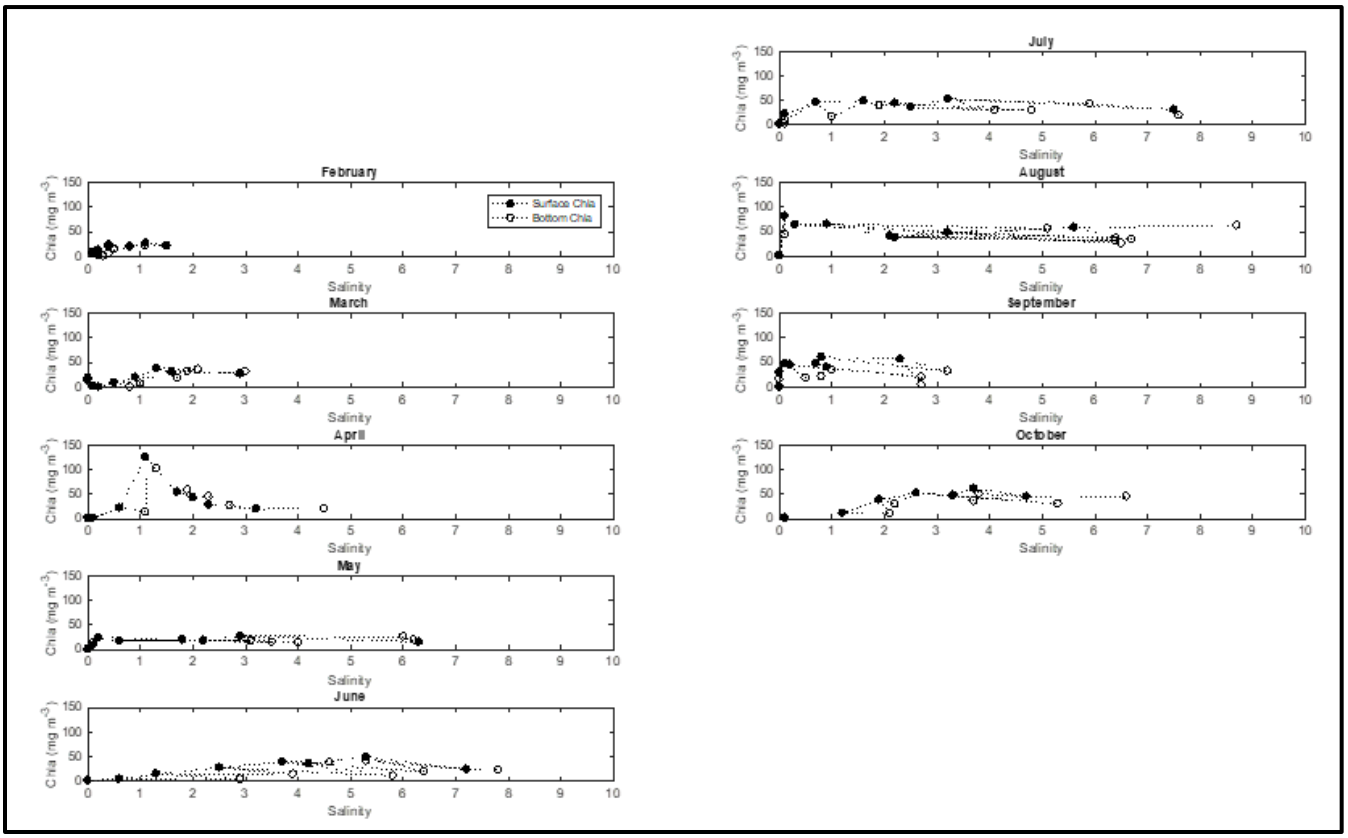

Figure 11. Monthly water column chlorophyll-a concentrations as a function of salinity.

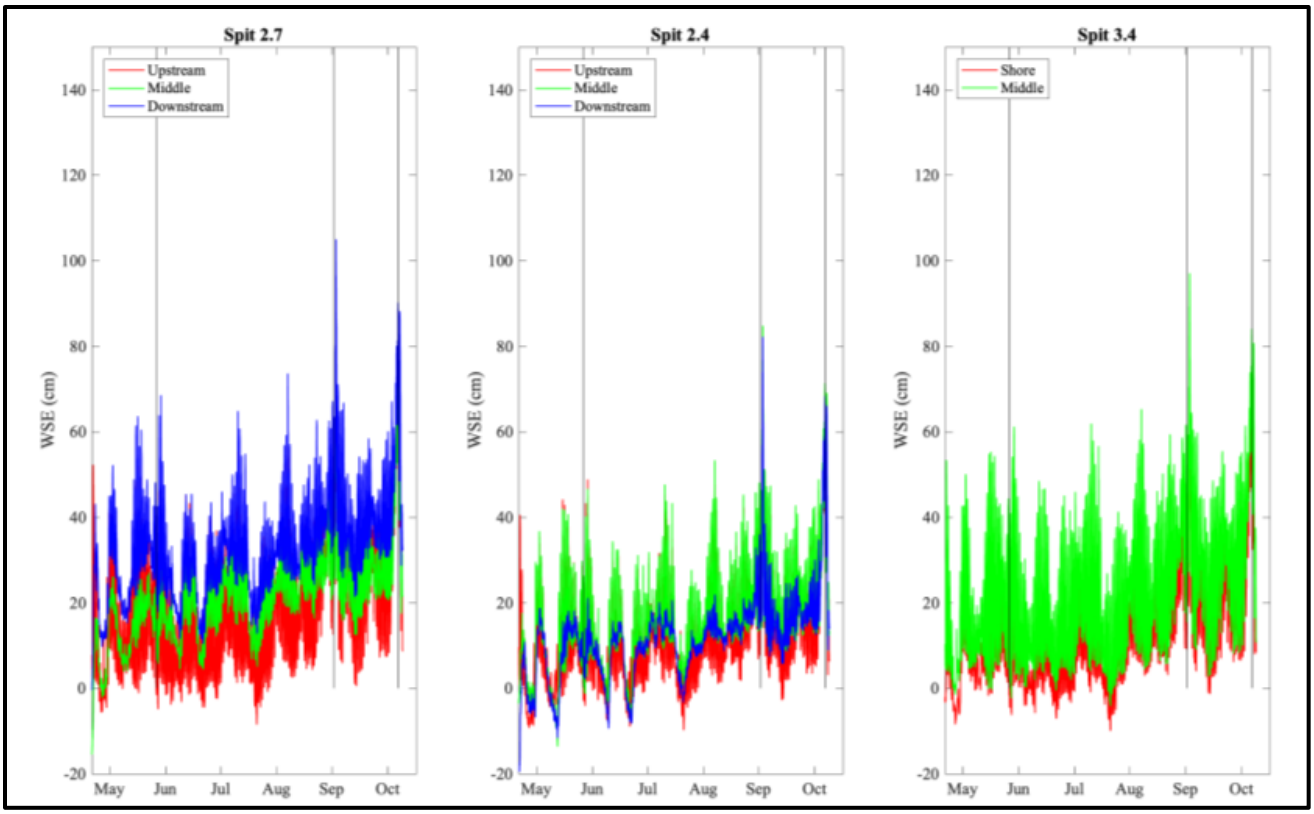

Figure 12. Time-series of water surface elevation from spits 2.7, 2.4, and 3.4.

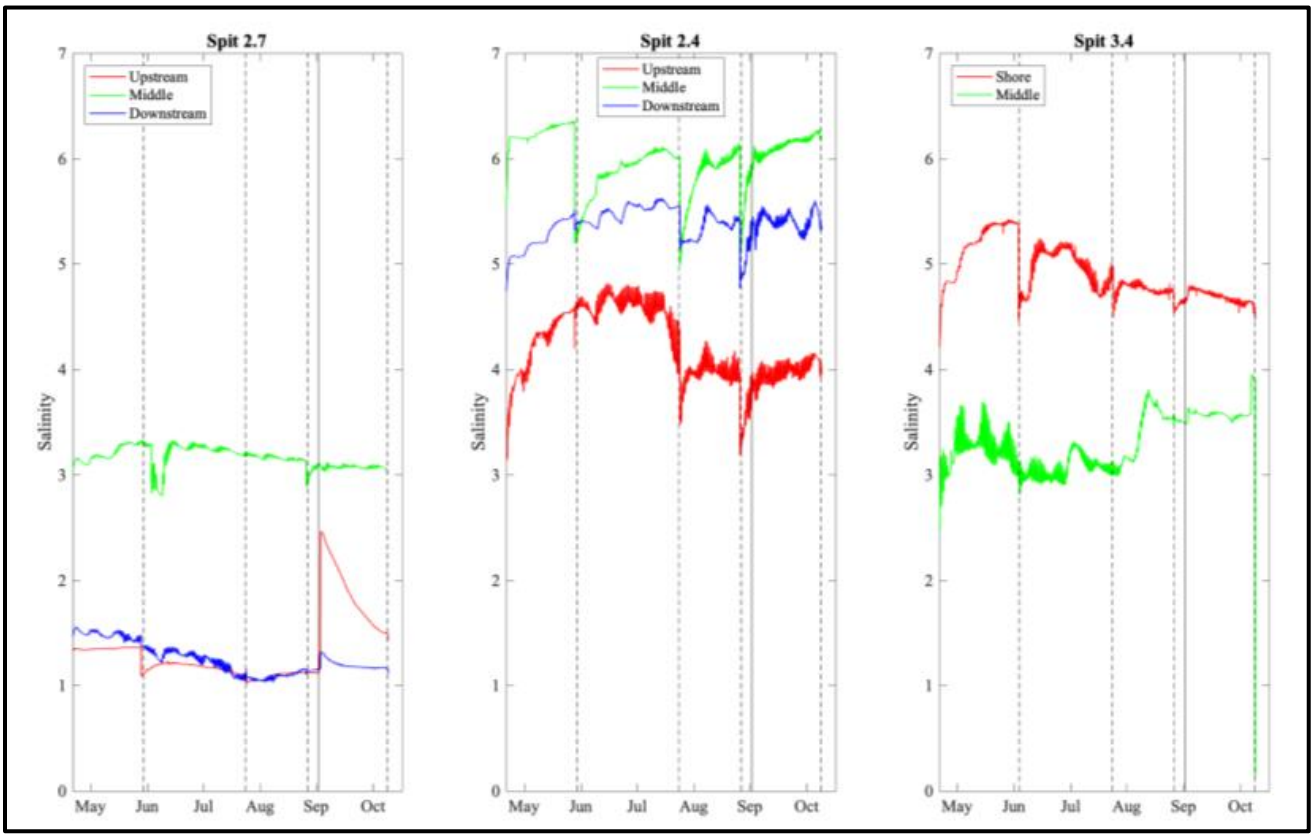

Figure 13. Time-series of porewater salinity from spits 2.7, 2.4, and 3.4.

from the sediment sources and may not be receiving and accreting sediments fast enough to keep up with sea-level rise.

Second, it is likely that salinity is increasing in this system due to observed sea-level rise and decreasing freshwater inflows from the greater Mobile Bay Watershed (USGS data). In this study, salinity in Region 2 was like salinity in Region 3 (Figure 6), indicating salinity changes experienced at the mouth of the Fowl River estuary will affect Region 2. Salinity in Region 1 appears to be mainly controlled by the freshwater inputs from the watershed maintaining nearly fresh conditions. Higher bottom-water salinity was observed to be encroaching into Region 1 in the summer and fall. Our salinity data from the marsh porewaters also confirm these patterns, with salinity from spit 2.4 and spit 3.4 (lower part of Region 2 and upper part of Region 3, respectively) being more similar than with spit 2.7, which was located at the border of Region 1 and 2.

Third, the nutrient, chl*a*, and oxygen observations indicate Fowl River is a eutrophic system. The impacts of eutrophication on marsh health are not well understood in the Gulf of Mexico. However, in other systems, such as New England marshes (Deegan et al. 2012), eutrophication is linked to collapse and loss of the marsh edge. Also, a recent study indicates nutrient enrichment affected a Louisiana marsh plant (*Spartina patens*) by weakening its roots and making it more vulnerable to collapse (Hollis and Turner 2019). In sum, nutrient impacts result in 1) changes in plant root:shoot ratios with plants investing more energy in shoot production under high nutrient conditions, 2) reduction in the strength of the roots, and 3) enhanced remineralization of marsh soil organic matter due to elevated nutrients and labile organic matter from phytoplankton. In combination, these effects may cause slumping and erosion of marsh edges. Though not directly related to marsh health and thus not a focus of this study, hypoxia is prevalent in Fowl River. Hypoxia was observed frequently in Regions 2 and 3 and suggests that large areas of the estuary were impacted. It is likely the hypoxia is related to the surface water eutrophication, but further work is required to confirm this linkage.

References

Bertness, M.D., 1991. Zonation of Spartina patens and Spartina alterniflora in New England salt marsh. Ecology, 72(1), pp.138-148.

Bricker, S.B., Ferreira, J.G. and Simas, T., 2003. An integrated methodology for assessment of estuarine trophic status. Ecological modelling, 169(1), pp.39-60.

Craft, C., 2007. Freshwater input structures soil properties, vertical accretion, and nutrient accumulation of Georgia and US tidal marshes. Limnology and oceanography, 52(3), pp.1220-1230.

Eleuterius, L.N. and Eleuterius, C.K., 1979. Tide levels and salt marsh zonation. Bulletin of Marine science, 29(3), pp.394-400.

Deegan, L.A., Johnson, D.S., Warren, R.S., Peterson, B.J., Fleeger, J.W., Fagherazzi, S. and Wollheim, W.M., 2012. Coastal eutrophication as a driver of salt marsh loss. *Nature*, 490(7420), p.388.

Hollis, L.O. and Turner, R.E., 2019. The Tensile Root Strength of Spartina patens: Response to Atrazine Exposure and Nutrient Addition. *Wetlands*, pp.1-17.

Levine, J.M., Brewer, J.S. and Bertness, M.D., 1998. Nutrients, competition and plant zonation in a New England salt marsh. Journal of Ecology, 86(2), pp.285-292.

U.S. Environmental Protection Agency. Office of Water and Office of Research and Development., 2015. National Coastal Condition Assessment 2010 (EPA 841-R-15-006). Washington, DC. December 2015.