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Sedimentary Conditions at a Tidal Creek that Exhibits Seasonal Pelagic-Benthic Variations

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Honors Thesis
Sedimentary Conditions at a Tidal Creek that Exhibits Seasonal Pelagic-Benthic Variations

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Submitted in Partial Fulfillment of the
Requirements for the Degree of Bachelor of Science
In the HTC Honors College at
Coastal Carolina University

Spring 2024

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Abstract

Tidal creeks in the Grand Strand of South Carolina are small but numerous connectors between land and ocean. One of these creeks, White Point Swash, exhibits a seasonal switch between planktonic and benthic photosynthesizers. As plankton become less abundant in fall, benthic macroalgae bloom, aided by lower water levels due to fall-winter dredging of the main channel, until late Spring. This study builds on previous findings and examines sedimentary conditions at this site further. Sedimentary chlorophyll *a* (in microphytobenthos) and pore water nutrient concentrations are confirmed to be higher than water-column concentrations. Sedimentary nutrient fluxes to the sediment-water interface, calculated using Fick's First Law, are high and are presumed to drive the observed abundant microphytobenthos and benthic macroalgae. Considering the eutrophication risks posed by blooms of phytoplankton and macroalgae, this study provides further insight into the ecological function of this and other urbanized tidal creeks in the region.

Introduction

Nutrient levels are rising in almost all areas along the US coast. This is a serious environmental issue as it increases the threat of eutrophication and harmful algal blooms, leading to hypoxic water conditions, fish kills, coral reef destruction, and many other environmental problems (National Research Council 2000). Nutrient monitoring is vital in determining the risk that coastal waters face. As these problems become more prevalent, nutrient monitoring will be essential to combat these issues.

Our study site is one that is under the threat of eutrophication as there are high nutrient inputs, likely due to the use of fertilizers in residential spaces and golf courses in the area. Previously, this topic (especially, its sedimentary aspects) was researched in a study conducted by Easterling (2023), whose study provided the foundation for the work I have done, as I used many of his methods for analysis and sampling. My research extends the time-series study of Easterling (2023) and complements it by:

(a) defining seasons by month groupings used to compare water column Chlorophyll *a* concentrations (planktonic photosynthesizers) in those seasons,

(b) using Fick's First Law to determine the direction and magnitude of nutrient fluxes across the sediment water interface.

The study conducted in Singleton Swash, another Grand Strand swash (Legut et al. 2020) used concepts similar to the studies mentioned for the analysis of nutrients in sediments and the water column.

Hypotheses

Overarching Hypothesis: Benthic and planktonic photosynthesizer abundances are impacted by varying light availability due to changes in the seasons, nutrient availability and water depth.

Hypothesis 1: Abundances of planktonic photosynthesizers are greater during the spring and summer (March-August) than fall and winter (September-February).

Hypothesis 2: Abundances of benthic photosynthesizers are greater due to lower average water depths and increased light availability.

Hypothesis 3: Nutrient concentrations are greater in sedimentary pore water than in the water column. Consequently, the direction of nutrient flux is from the sediment to the water column.

Methods

Study Site

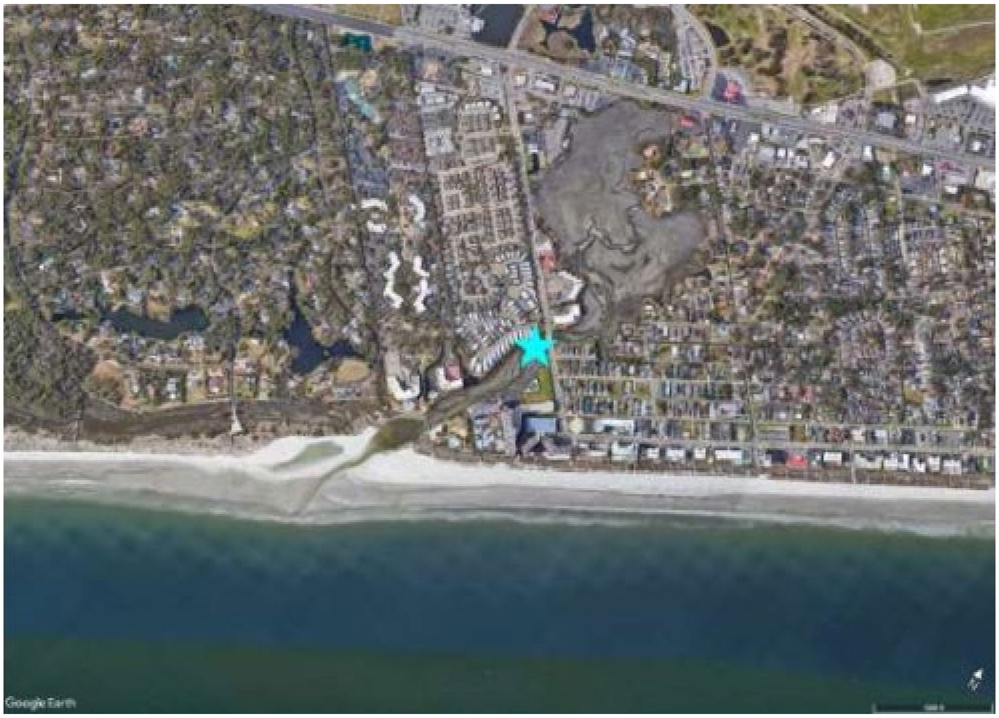

Figure 1. Study site of White Point Swash in Myrtle Beach, South Carolina. Photos were obtained with Google Earth.

White Point Swash is located in Horry County, South Carolina, between North Myrtle Beach and Briarcliffe Acres. This site has been studied by CCU's Coastal Biogeochemistry group since 2018, in part with funding by local municipalities, who regularly dredge the main channel at the beach. Part of this work took place at a station (blue star on station map; satellite photo courtesy of Google Earth) where sensor measurements for water level, temperature, salinity and oxygen are continuously taken. In addition, monthly water-column samples for nutrients, turbidity and chlorophyll have been collected since November 2019, along with creek floor images for benthic macroalgal coverage quantification (Hannides et al., unpublished data). Samples for pore water nutrients and sedimentary chlorophyll were collected at this station from September 2022 to April 2023 (Easterling 2023), and formed the foundation of this study.

Sampling

Sediment samples were collected down to 2.5 cm from the sediment surface using plastic syringe cut-off cores. Pore water samples were drawn from a depth of 2.5 cm using sampling needles and filtered through 0.2-μm syringe filters. All of these samples were taken monthly.

Laboratory Analysis

Pore water was analyzed for nitrate (Schnetger and Lehners 2014), nitrite (Bendschneider and Robinson 1952), ammonium (Holmes et al. 1999), and phosphate (Murphy and Riley 1962). Dissolved inorganic nitrogen (DIN) is defined as the sum of nitrate, nitrite, and ammonium. The concentration of sedimentary chlorophyll a was determined fluorometrically (Hannides et al. 2014, Arar and Collins 1997).

Image Analysis

Monthly analyses were conducted by photography of the creek bottom in White Point Swash. The purpose of this was to determine macroalgal cover on the creek bottom. Grids of the creek bottoms were analyzed in Microsoft PowerPoint. Each box of the grid had a percentage of algal cover, and these boxes were added together for a total sum of algal cover.

Data Analysis

All data was analyzed visually and statistically in Microsoft Excel.

1. Water column [Chl a] data was grouped by season (spring and summer = March-August; fall and winter = September-February) to test Hypothesis 1.
2. Correlations of water level against benthic macroalgal coverage, sedimentary and water-column [Chl a] were used to test Hypothesis 2.
3. Nutrient concentrations in the sediment and the water column were compared to test Hypothesis 3. Fick's First Law was used to calculate flux direction and magnitude across the sediment-water interface:

$$Flux = -\phi^2 D^o \frac{[C]_z - [C]_0}{dz}$$

Results

Examination of the time-series data (Figures 2 and 3) shows the following:

1. Average water level, sedimentary chlorophyll *a*, and benthic macroalgal coverage dropped during dredging events.
2. Microphytobenthos (sedimentary chlorophyll *a*) and benthic macroalgae (% coverage) showed increases in concentrations as the system stabilized with a lower water level.
3. A gap in data is seen in Figure 3 as no sampling was conducted over summer break.
4. Dissolved phosphate and inorganic nitrogen followed similar trends in both the water column and sediment, except in two instances: Winter/Spring of 2022-23 and Winter/Spring of 2024, where water column concentrations decreased as sedimentary concentrations increased.

While no significant statistical differences were seen in water column chlorophyll *a* concentrations between seasonal groupings, in part due to large deviations, it is clear that average concentrations were higher during the Spring and Summer (Figure 4).

Regression relationships between average water level and percent benthic macroalgal coverage and sedimentary chlorophyll *a* concentrations were negative, while the water-level relationship with chlorophyll *a* concentrations in the water column was non-existent (Figure 5). While none of these regressions were strong for this study period, the benthic macroalgal photosynthesizers' relationship is more visible than the others.

Chlorophyll *a* concentrations were much higher in the sediment than in the water column, with all values plotting well below the 1:1 ratio line (Figure 6).

Dissolved inorganic nitrogen (DIN) concentrations were also much higher in the sediment than in the water column, as seen again with all values being plotted below the 1:1 ratio line (Figure 7). The DIN flux, as calculated using Fick's First Law, showed a flux of 24.1 ± 5.3 μmol m^{-2} d^{-1} from the sediment to the water column (Figure 7).

Dissolved phosphate (PO_4^{3-}) concentrations showed the same relationship as DIN, with phosphate concentrations were much higher in the sediment than in the water column (Figure 8), with all values plotting below the 1:1 ratio line. The phosphate flux, calculated using Fick's First Law, showing a flux of 3.4 ± 2.1 μmol m^{-2} d^{-1} from the sediment to the water column (Figure 8).

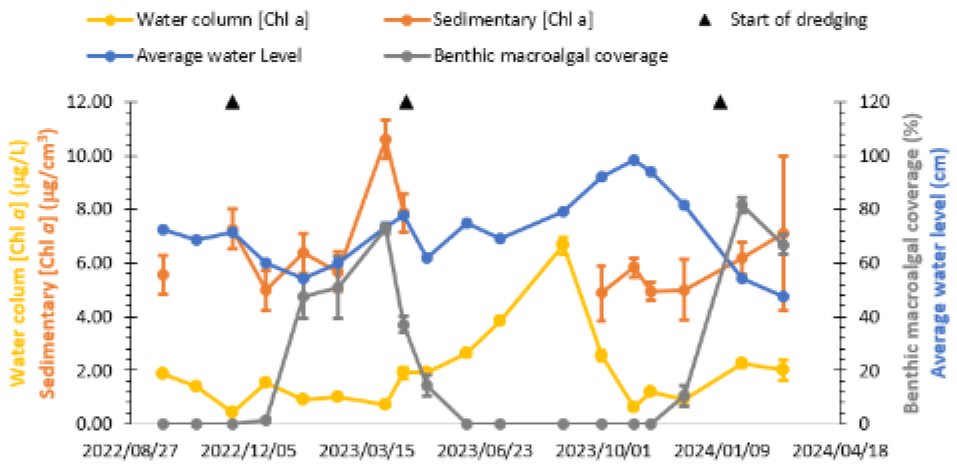

Figure 2. Time series plot showing Chlorophyll *a* concentrations in both the sediment and water column (primary y-axis), average water level (cm) and percent benthic macroalgal coverage (secondary y-axis), and dredging events (triangles at top of plot) from August 2022 to April 2024. Error bars represent one standard deviation; if error bars are not visible, standard deviation is smaller than the symbols.

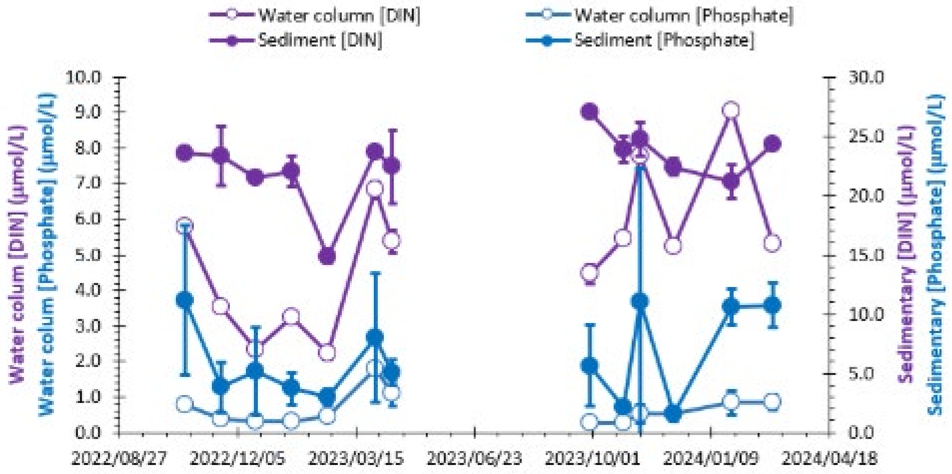

Figure 3. Time series plot showing dissolved inorganic nitrogen (DIN) concentrations in purple and dissolved phosphate concentrations in blue. Water column values are plotted on the primary y-axis. Sedimentary values are plotted on the secondary y-axis. Error bars represent one standard deviation; if error bars are not visible, standard deviation is smaller than the symbols.

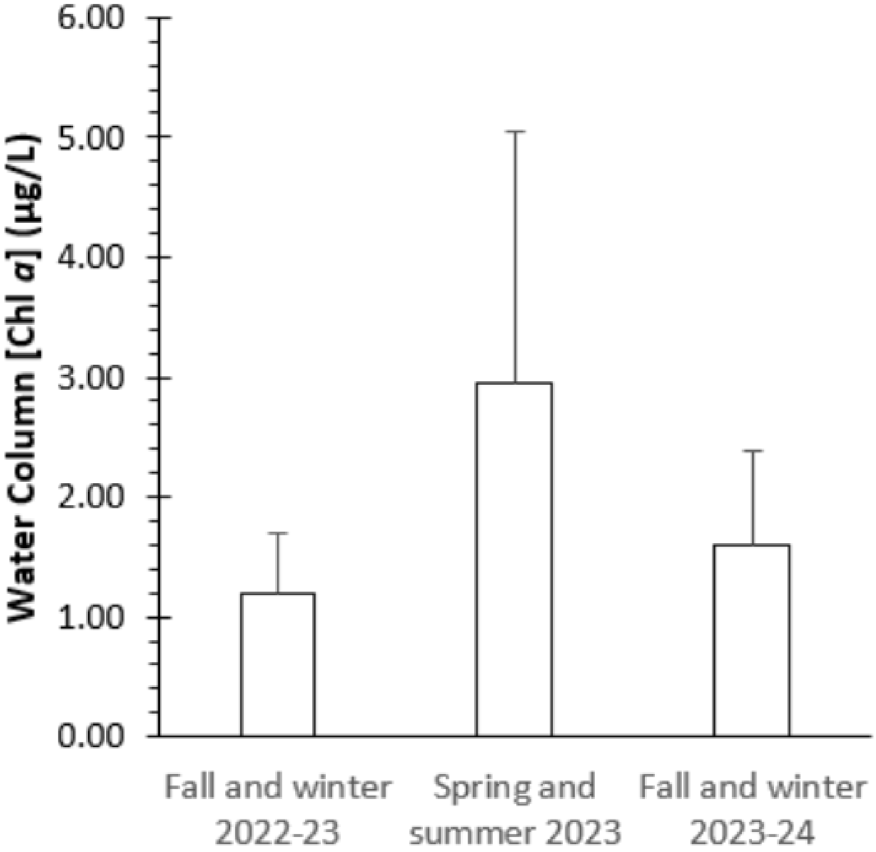

Figure 4. Average water column chlorophyll *a* concentrations are plotted on the y-axis. Seasonal groupings from 2022 to 2024 are plotted on the x-axis. The fall and winter group is defined as September to February, while the spring and summer group is defined as March to August. Error bars represent one standard deviation; if error bars are not visible, standard deviation is smaller than the symbols.

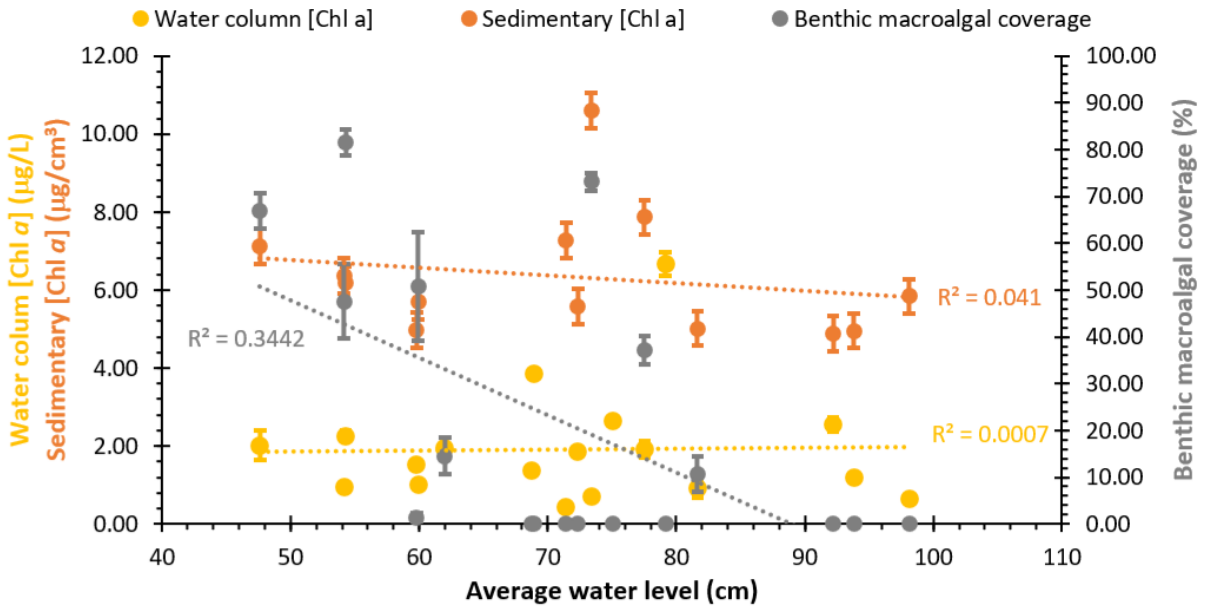

Figure 5. Scatter plot showing Chlorophyll *a* concentrations in both the sediment, shown in orange, and water column, shown in yellow, on the primary y-axis. Percent benthic macroalgal coverage is plotted in gray on the secondary y-axis. Average water level (cm) is plotted on the x-axis. Note that chlorophyll *a* concentrations in the water column are plotted in units of µg/L while concentrations in the sediment are plotted in units of µg/cm^3. Error bars represent one standard deviation; if error bars are not visible, standard deviation is smaller than the symbols.

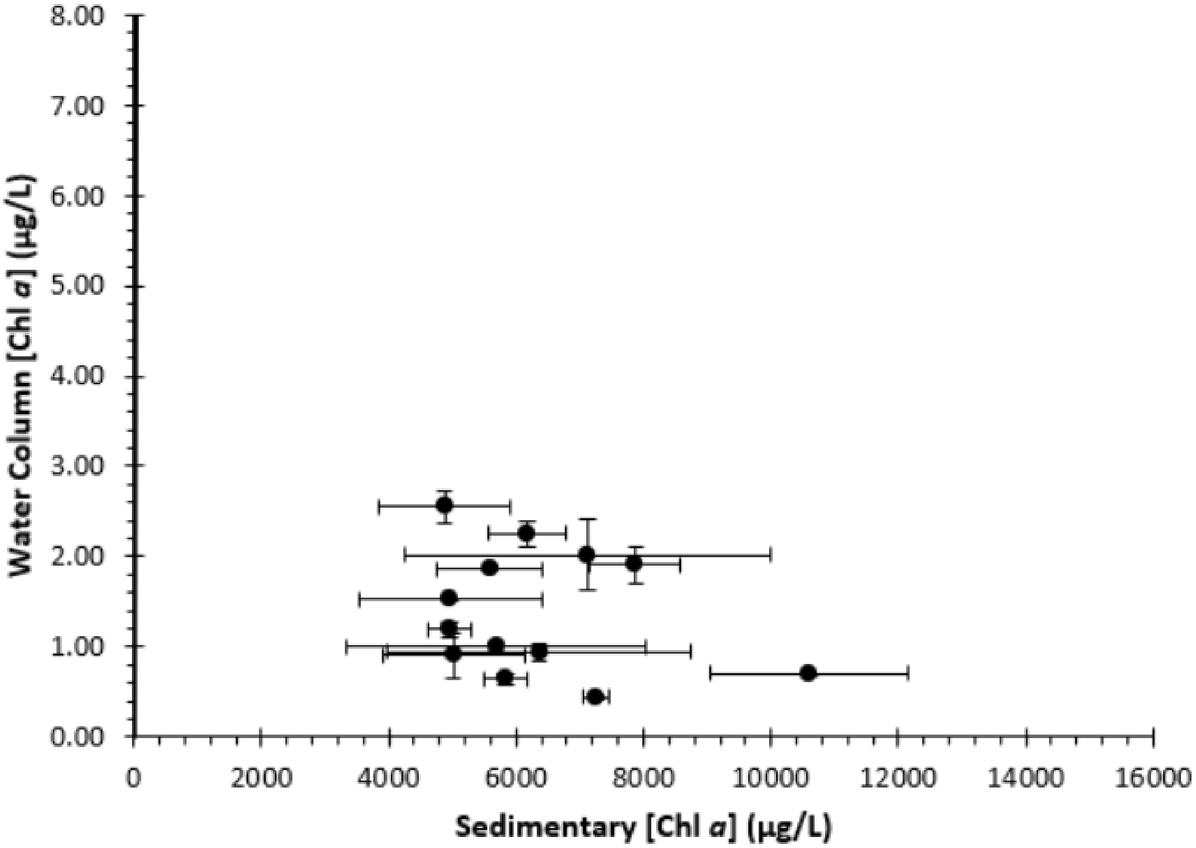

Figure 6. Scatter plot showing chlorophyll *a* concentrations in the water column (y-axis) and the sediment (x-axis), both in units of µg/L. Error bars indicate one standard deviation; if error bars are not visible, standard deviation is smaller than the symbols. The black line along the y-axis represents a 1:1 ratio and falls very closely along the y-axis.

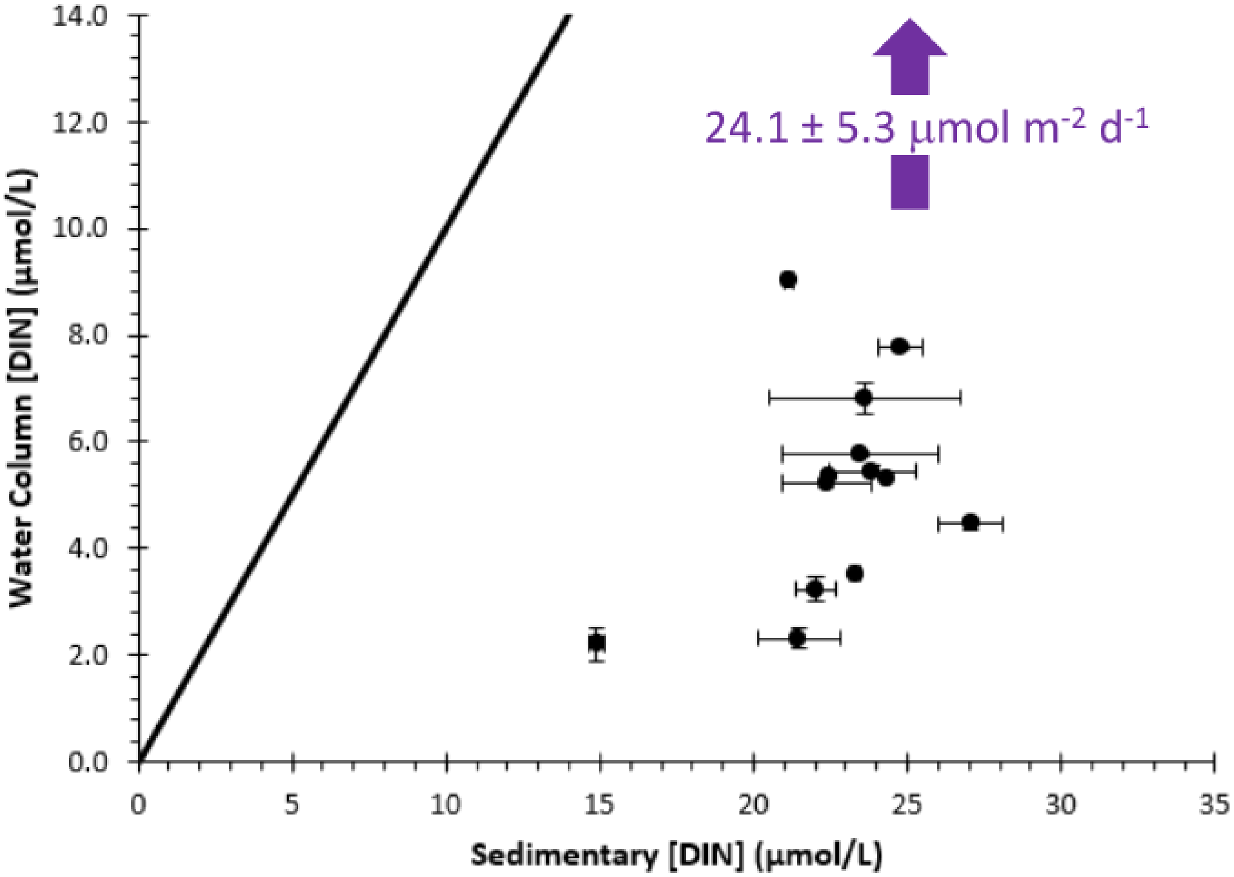

Figure 7. Scatter plot showing dissolved inorganic nitrogen (DIN) concentrations in the water column (y-axis) and in the sediment (x-axis) both in units of µmol/L. Error bars indicate one standard deviation; if error bars are not visible, standard deviation is smaller than the symbols. The black line represents a 1:1 ratio. The blue arrow and value represent the nutrient flux direction and magnitude in units of µmol m^{-2} d^{-1}.

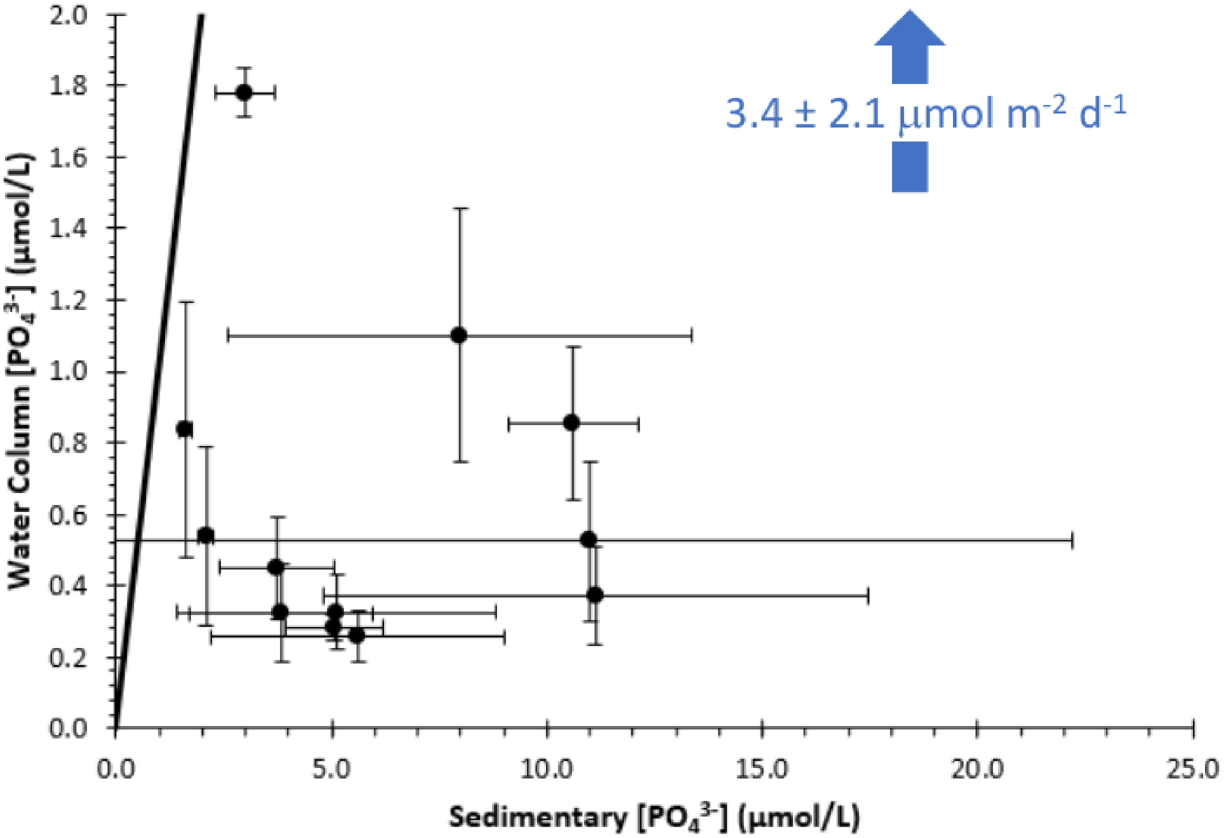

Figure 8. Scatter plot showing dissolved phosphate concentrations in the water column (y-axis), and in the sediment (x-axis), both in units of µmol/L. Error bars indicate one standard deviation; if error bars are not visible, standard deviation is smaller than the symbols. The black line represents a 1:1 ratio. The blue arrow and value represent the nutrient flux direction and magnitude in units of µmol m^{-2} d^{-1}.

Discussion

Hypothesis 1 was supported by the data in Figures 2, 3, and 4. Dredging events always led to a decrease in water level, which subsequently led to an increase in access to light for the benthic photosynthesizers. The time series plots and seasonal grouping plot suggested that on average, planktonic photosynthesizers were more dominant during the spring and summer months. This local pattern reflects the general regional pattern of an annual phytoplankton bloom that occurs in the Spring in the North Atlantic (Daniels et al. 2015).

Hypothesis 2 was supported by the data shown in Figure 5. Benthic macroalgal coverage showed correlation with water level. The chlorophyll *a* concentrations in the water column, which remained unaffected by water level, are explained by phytoplankton having unconstrained access to light through physical mixing. While sedimentary chlorophyll *a* concentrations showed a slight negative relationship with increased water level, it was not significant enough to draw any conclusions about its relationship to light availability.

Hypothesis 3 was supported by the data shown in Figures 6, 7, and 8. Sedimentary chlorophyll *a*, DIN, and dissolved phosphate all showed much higher concentrations in the sediment than in the water column. Both DIN and dissolved phosphate showed nutrient fluxes in the direction of sediment to water column across the sediment-water interface, as expected. This finding is important because there is competition for photosynthesizers at the sediment-water interface for nutrients. This flux direction suggests that as benthic photosynthesizers have primary control of any nutrients from sedimentary pore water, and planktonic photosynthesizers must consume any sedimentary nutrients that remain or those from other sources, such as surface runoff.

One deviation in expected results was seen in the magnitude of fluxes. The direction of the fluxes of nutrients was as expected, but the values were an entire order of magnitude lower than literature values (Burdige 2006). A possible explanation for this could be in the sampling methods. When pore water samples were collected, it is possible that water from the water column could have entered along the side of the sampling needle, diluting sediment pore water, and thus decreasing the determined concentration gradient. Another possible explanation for this could be an error in the permeability of the sediment. It is possible that permeability could be higher as a result of the sediment having a higher fraction of sand than assumed. This would allow for easier flux of nutrients through a more permeable interface.

This study is significant in validating methods of analysis for both pelagic and benthic marine photosynthesizers, while also confirming the hypotheses found in the Easterling (2023) paper. More evidence was provided to support the idea that benthic and planktonic photosynthesizer abundances are impacted by four main factors: varying light availability, changes in season, nutrient availability and water depth.

Acknowledgments

I would like to express my gratitude for Dr. Angelos Hannides for the effort he put into this study, the guidance he provided, and for giving me the opportunity to work on a topic that I am passionate about. Nathan Easterling's Honors thesis laid the groundwork for this study and I appreciate his work. Finally**,** I would like to thank Horry County, the City of North Myrtle Beach, the Township of Briarcliffe Acres, and the HTC Honors College at Coastal Carolina University for providing partial funding for various aspects of this project.

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