Literature Review

**Simple Outline of Introduction Section**

CSI weather station

<https://one.weatherflow.com/login>

Username: CSI\_LDubbs

Password: weatherflowNC

Biostatistics Guide

http://www.biostathandbook.com/index.html

Study Site

* Geography of the Currituck and Croatan Sounds
* Salinity
* Wind-driven tides
* Oregon Inlet
* Storm over wash

Water in Wetlands

* Groundwater
* Surface water
* Salt vs brackish vs fresh water
* Ecosystem services

Carbon Storage in Water

* Dissolved organic carbon
* Inorganic carbon in the form of CO2
* Ecosystem services
  + Why is carbon storage important? Relate to climate change

Nutrients in water

* Nitrogen
* Phosphorus
* Ecosystem services
  + Why are these nutrients important?

Future Research

* Nitrogen and Carbon relationship and correlation
  + increasing nitrogen pollution in coastal waterways affecting marshes
* Sea level rise and water inundation affecting marsh systems

**Sources:**

* Article title, citation, brief description and note about application, quotes that could be of use

**Gaps (what literature review is missing):**

* Surface waters in marshes
* Croatan Sound/Oregon Inlet history
* Nutrients in water besides nitrogen
* Methods other than water sampling and in situ sensors for water level, conductivity, etc (maybe this is fine if all of data is from water sampling and sensors)

1. **Surface Water and the Groundwater Interactions in Salt Marshes and Their Impact on Plant Ecology and Coastal Biogeochemistry (Xin et al. 2022)**

Xin, P., Wilson, A., Shen, C., Ge, Z., Moffett, K. B., Santos, I. R., et al. (2022). Surface water and groundwater interactions in salt marshes and their impact on plant ecology and coastal biogeochemistry. Reviews of Geophysics, 60, e2021RG000740. https://doi. org/10.1029/2021RG000740

Secondary article that encompasses the current state of knowledge on surface water and ground water interactions in salt marshes. Surface water and groundwater interactions affect plant zonation, and carbon and nutrient upwelling. Useful for defining the types of water found on wetlands and how they interact – used to explain ground water and surface water interactions and purpose behind sampling ground water and surface water.

* “Located at the land-ocean interface as either shoreline ecosystems or near-shore islands, salt marshes are dynamic zones that are affected by both inland and oceanic forcing factors”
* “Outwelling refers to carbon and nutrients exported to the coastal sea that supports the productivity of near-shore marine ecosystems or long-term carbon sequestration in the ocean.”
* “At the interface between land and ocean, salt marshes serve as natural filters for the removal of nutrients, metals and other pollutants.”
* “They are regarded as an important blue-carbon ecosystem, sequestering greenhouse gases and partially offsetting climate change. About 430 Tg C are stored in the upper 0.5 m of soils in salt marshes globally. The average global rate of carbon sequestration in salt marsh ecosystems is estimated to be 168 g C m−2 y−1, leading to a total global rate of 48–59 Tg C y−1, which is equivalent to 30% of the organic carbon buried in the entire seafloor.”
* “SW-GW interactions significantly modify soil saturation (Armstrong et  al.,  1985; H. Li et  al.,  2005; Howes & Goehringer,  1994; L. R. Gardner,  2005a), groundwater salinity (Carol et  al.,  2012; Moffett, Robinson, & Gorelick, 2010; Pennings et al., 2005), and biogeochemical cycling (A. M. Wilson & Gardner, 2006; Hemond et al., 1984; Montalto et al., 2007; Nuttle & Hemond, 1988; Valiela et al., 1978) in salt marshes (Figure 3a).”
* “Groundwater flow through this system is driven by tidal fluctuations and infiltration of rainwater into the upland and the marsh surface. Net groundwater flow is toward the creek on average, with flow concen- trated in more permeable sediment layers. As discussed later, saline groundwater that discharges to tidal creeks is enriched in nutrients and other solutes, and therefore provides a source of nutrients to surface water.”
* “Tides are an essential part of salt marsh functioning. The baseline tidal elevation is further influenced by wind, as illustrated by the example of storm surges that can significantly raise sea level (A. M. Wilson et  al., 2011). Tides propagate through tidal creeks and flood marsh platforms, and so are a critical driver for movement of water and solutes in marsh systems. Tides then ebb off the marsh surface both by direct drainage to tidal creeks and by sheet flow over the marsh surface.”
* “During rising and high inundating tides, surface water overtops creekbanks, flows over the marsh platform and infiltrates through the marsh sediment surface.”
* “When the marsh platform is gradually exposed during falling tide, groundwater seeps out from the marsh sediments across the creek bank and bottom. This drainage lowers the water table and leads to the desaturation/reaeration of the soil (Cao et al., 2012; H. Li et al., 2005; Marani et al., 2006; Ursino et al., 2004), thus providing a mechanism for solute exchange near the creek bank, as well as preventing a buildup of salt or other solutes.”
* “Precipitation causes freshwater infiltration into marsh soils if the marsh is not inundated by the tide. The rate of infiltration depends on rainfall intensity and the infiltration capacity of the soil”
* “For example, the salinity of marsh creek water can decrease dramatically during rainfall events, with no obvious changes of groundwater salinity afterward”
* “Rainfall events can induce watertable fluctuations, although both the peak and decay of the watertable response to rainfall lag behind the rainfall event (C. E. Hughes et al., 1998) due to the low permeability of marsh sediments, which limits the rate of infiltration and drainage.”
* “Temperature information (e.g., from in situ probes, cables, or thermal imaging) can distinguish marsh ground- water seepage that has spent sufficiently long in the marsh subsurface to cool during a warm season or warm during a cold season. On average, more characteristic marsh groundwater should be similar to mean annual air temperature, whereas rapidly recirculated surface water should be more similar to recent or diurnal mean air or surface water temperatures.”
* “Many salt marshes are nutrient-limited, especially in the pristine or undisturbed systems, because mineral sediments provide little nutrition to support plant growth (Kachi & Hirose, 1983). However, compared to the pre- industrial era, human activities have remarkably enhanced the nutrient loadings to coastal areas. During recent decades, coastal ecosystems have received excessive nutrients from acid precipitation, sewage waste, and fertilizer runoff with nitrogen (N) and phosphorus (P) loads. With nutrient input from terrestrial groundwater and riverine supply, salt marshes became the most nutrient enriched ecosystem around the world.”
* “Part of the carbon accumulated in salt marsh sediments can be flushed out via shallow porewater exchange and deep groundwater flow, eventually reaching the coastal sea (Figure  13). The lateral transport of carbon and nutrients from salt marshes and other coastal ecosystems is referred to as outwelling. Outwelling functions as a long-term carbon sequestration mechanism that enables the storage of both particulate and dissolved carbon in the ocean. For example, DIC outwelling can store carbon as dissolved bicarbonate in the oceans.”
* “A synthesis of observations in salt marshes on the US East Coast revealed that about 80% of the carbon taken in by salt marsh vegetation is eventually outwelled to nearby estuaries (Najjar et al., 2018). In nearly all investigations, salt marshes seem to release disproportionally high carbon fluxes that often exceed both river fluxes draining much larger catchments and local carbon burial in sediments (Liu et al., 2021; Najjar et al., 2018).”
* “Salt marshes export detritus or particulate organic carbon (POC), DOC resulting mostly from leaching of vegetation and soil organic matter, and DIC resulting from biogeochemical reactions within sediments.”
* “At high pH approaching seawater values >8, most of the DIC will be present as carbonate alkalinity that can be stored in the ocean over long time scales. At low pH (<6.5), most of the DIC will be present as CO2 that returns quickly to the atmosphere. Therefore, the pH of coastal waters receiving salt marsh outwelling will control if DIC is stored in the ocean over long time scales (Sippo et al., 2019).”
* “Nutrient enrichment can enhance marsh productivity to some extent and ultimately carbon out- welling (Czapla et al., 2020).”
* “Salt marshes remove carbon from the atmosphere, accumulate it in their sediments and eventually discharge carbon, greenhouse gases and nutrients into the adjacent sea via tidal flushing. Salt marsh outwelling not only supports coastal ocean productivity, but also contributes to marine and atmospheric carbon budgets. The extent of outwelling depends on marsh production, soil properties, perturbation and tidal fluctuations and can be highly variable seasonally and spatially.”

1. **Sediment Deposition and Accretion in a Mid-Atlantic Tidal Freshwater Marsh (Neubauer et al. 2001)**

Neubauer, S., Anderson, I., Constantine, J., Kuehl, A. (2001). Sediment Deposition and Accretion in a Mid-Atlantic (U.S.A.) Tidal Freshwater Marsh. *Estuarine, Coastal and Shelf Science (2002)* 54, 713-727. doi:10.1006/ecss.2001.0854

Studied sediment deposition and accretion rates in a tidal freshwater marsh using sediment tiles and sediment cores. Observed a decrease in accretion rate, which was also less than the annual deposition rate. Purpose of study was to understand how these geological processes are changing on a time scale to maintain marsh surface elevation. This experiment is very similar to the purpose of the overall project at Pine Island. Could be useful for the future research section and related ideas.

* “Tidal freshwater marshes are among the first systems to interact with, and potentially remove watershed- derived sediments, nutrients, and pollutants”
* “Marshes that are regularly inundated rely on both autochthonous production and the deposition of mineral sediments to maintain marsh elevation relative to a rising sea level (Bricker-Urso et al., 1989; Craft et al., 1993).”
* “Rates of sediment deposition (the settling of material onto a marsh surface) and accretion (the net balance between deposition and removal processes) are linked.”
* “Although the marsh interior was flooded first and for a longer period than the creekbank levee, water that floods the marsh interior must first travel through small channels that incise the levee and then across the inner marsh flat. During this transport from creek to channel to marsh interior, sediments were constantly being deposited (French & Spencer, 1993; Leonard, 1997).”
* “In the absence of an external carbon source, this ‘excess’ respiration implies that some fraction of sediment carbon is being mineralized to CO2 or CH4 and lost from the marsh.”
* “The deposition of sediment-associated carbon during tidal flooding is sufficient to counteract the effects of respiratory marsh loss and relative sea level rise”

1. **Groundwater discharge drives water quality and greenhouse gas emissions in a tidal wetland (Wang et al. 2022)**

Wang, Z., Sadat-Noori, M., Glamore, W., Groundwater discharge drives water quality and greenhouse gas emissions in a tidal wetland (2022). *Water Science and Engineering* 2022, 15(2): 141 – 151. <https://doi.org/10.1016/j.wse.2022.02.005>

This study focuses on carbon dioxide and methane emissions from surface water in a tidal wetland. They used radon to understand the role of groundwater as a pathway for transporting dissolved inorganic carbon into the wetland. They found that groundwater discharge could be an important and unaccounted source of inorganic carbon to wetlands. This source will be useful for the “water in wetlands” section and understanding how carbon exists in groundwater in wetlands. Although they used a different method for quantifying DIC, their understanding of surface water and groundwater interactions is beneficial.

* “Groundwater discharge into wetlands can affect the water chemistry and act as a source of dissolved greenhouse gases, including CO2 and CH4”
* “The results showed that groundwater discharge could be an important, yet unaccounted source of CO2 and CH4 to tidal wetlands. This work has implications for tidal wetland carbon budgets and emphasizes the role of groundwater as a subsurface pathway for carbon transport.”
* “The interaction between groundwater and surface water allows and enhances geochemical reactions between terrestrial and aquatic systems because groundwater and surface water have different chemical compositions (May and Mazlan, 2014). Hence, groundwater discharge can regulate both surface water quality and quantity in coastal wetlands.”
* “Due to the long residence time and the chemical interaction between water and sediment mate- rials, groundwater tends to have higher concentrations of solutes, including CO2, than surface water.”
* “Groundwater exchange be- tween sediment and surface water can be facilitated through tidal pumping in coastal wetlands (Gleeson et al., 2013; Call et al., 2015; Heron and Ridd, 2008).”
* “Tidal pumping occurs when estuary surface water infiltrates the permeable sediments and becomes groundwater during high tides. Afterwards, this water discharges from the sediment during low tides and returns to surface water due to gradient differences and hydrostatic pressure”
* “This recirculation of surface water can be important to the chemistry of water changes because surface water interacts with sediment particles. Thus, the water that flows back to the surface water contains a new chemical signature.”
* “Coastal wetlands can sequester large quantities of atmospheric carbon and store it in their sediments at a rate of 50% faster than terrestrial forests Cui et al., 2018; Mcleod et al., 2011; Wang et al., 2019). Greenhouse gases such as CO2 and CH4 can be produced by the respiration of plant roots and microorganism activity in sediments as well as organic matter decomposition and mineralization (Gudasz et al., 2010; Needelman et al., 2018; Kaur et al., 2016). When in contact with groundwater, the sediment-based carbon dissolves in groundwater, enriching it with carbon. Hence, groundwater discharging to wetlands contains high concentrations of CO2 and CH4 even if in small quantities”
* “Here, the time series data supported by the positive correlations of radon concentration with CO2 and CH4 concentrations indicated that groundwater was a source of CO2 and CH4 in the wetland.”
* “Once in surface water, CO2 and CH4 can be exported to the open ocean or evade to the atmosphere, or both processes may take place (Santos et al., 2021).”
* “In this study, the observed amount of CO2 released into the atmo- sphere from the wetland was much larger than that of CH4, indicating that CO2 emissions dominated carbon gaseous fluxes.”

1. **Late Holocene Evolution of Currituck Sound, North Carolina, USA: Environmental Change Driven by Sea-Level Rise, Storms, and Barrier Island Morphology (Moran et al. 2015)**

Moran, K.L.; Mallinson, D.J.; Culver, S.J.; Leorri, E., and Mulligan, R.P., 2015. Late Holocene evolution of Currituck Sound, North Carolina, USA: Environmental change driven by sea-level rise, storms, and barrier island morphology. Journal of Coastal Research, 31(4), 827–841. Coconut Creek (Florida), ISSN 0749-0208.

This is a geological study performed in the lower Currituck Sound to model how the Sound has changed in response to sea-level rise and climate patterns. They concluded that the Currituck Sound’s geologic profile shows its response to an increase in hurricane activity, sea-level rise, and regional climate and hydrological factors. I think this source will be useful for “setting the scene” of my study and explaining how the area is impacted by weather events and sea-level rise. This source also does a good job of explaining how dynamic the systems are in the Outer Banks and acknowledging lots of the different factors that impact the physical nature of the Sound.

* “During the Holocene evolution of Currituck Sound, several inlets opened and closed in the barrier island system, producing salinity and tidal variability (Fisher, 1962; Robinson and McBride, 2006; Stick, 1958; USACE, 2010)”
* “Currituck Sound is the northernmost estuarine component of the Albemarle– Pamlico estuarine system of North Carolina. It is approximately 58 km long and 5 to 13 km wide with a mean depth of 1.5 m (USACE, 2010), and it is separated from the Atlantic Ocean by a barrier (the northern Outer Banks); thus, there is effectively no astronomical tide.”
* “Wind tides are important and can move large volumes of water N and S, depending upon wind direction (Caldwell, 2001).”
* “The drainage area feeding directly into Currituck Sound is small (1898 km2), and the total flux of freshwater into and out of Currituck Sound is not well documented (Caldwell, 2001)”6
* “The present freshwater input to Currituck Sound is dominated by flow from the Roanoke and Chowan Rivers at the head of Albemarle Sound, which enters Currituck Sound from the south.”
* “At present, hydraulic connections between Currituck Sound and the Atlantic Ocean are remote and limited to Oregon Inlet approximately 40 km to the south. Thus, Currituck Sound has very low salinity, ranging from 2 to 3% in the northern end and 4to5% in the southern end and reaching up to 10% during large storm events with overwash (Robinson and McBride, 2006).”
* “The data reveal the evolution of this coastal system from a freshwater swamp forest; through episodes of changing salinity patterns, which were dictated by changing inlet activity; to a modern low- salinity estuary.”
* “Varying inlet activity, related to ocean shoreline recession, barrier narrowing, and direct storm impacts, further shaped the development of Currituck Sound and the barrier islands by altering the sediment supply, tidal ranges, and current velocities.”

1. **Hydrologic and Salinity Characteristics of Currituck Sound and Selected Tributaries in North Carolina and Virginia (Caldwell, 2001)**

Caldwell, W.S., 2001. Hydrologic and Salinity Characteristics of Currituck Sound and Selected Tributaries in North Carolina and Virginia, 1989–99. U.S. Geological Survey Water-Resources Investigations Report 01–4097, 42p.

This was a study conducted by the USGS that focused on three tributaries of the Currituck Sound to classify the hydrological characteristics of the Sound. They used water level loggers, weather stations, and collected discharge and salinity at all three sites. I’m not sure how useful this study is to my project because it looks at the big picture of the Currituck Sound and doesn’t focus on wetlands at all. However, it provides some background to the weather and salinity that affects the Sound and that could be useful for the setting the scene of my project.

* “Salt also moves into Currituck Sound from the north by way of West Neck Creek through North Landing River or the Albemarle and Chesapeake Canal, or from the south by way of Albemarle Sound through the Atlantic Intracoastal Waterway (AIWW) or through the mouth of the sound (Bales and Skrobialowski, 1994).”
* “Currituck Sound is in northeastern North Carolina in the Coastal Plain Physiographic Province (fig. 1). The North Carolina portion of the sound has a surface area of about 97,900 acres, or about 153 square miles (mi2). Currituck Sound is a brackish-water estuary that extends 40 miles (mi) from the Virginia- North Carolina State line to its confluence with Albemarle Sound (Eagleson, 1994).
* “Flood-producing rainfall and high winds generally are associated with hurricanes or tropical storms and(or) convective thunderstorms during the summer or fall. Northeasters can generate strong winds, heavy rainfalls, and high-water levels or flooding during the fall and winter.”

1. **Documentation of Data Collection in Currituck Sound, North Carolina and Virginia (Fine 2008)**

Fine, J., 2008. Documentation of Data Collection in Currituck Sound, North Carolina and Virginia, 2006–2007. U.S. Geological Survey Open-File Report 2008-1147, 18p.

This is another USGS study conducted in the Currituck Sound that provides hydrology data and a bit of background information to the area. May not be super useful, but I found an interesting quote that characterizes the Currituck Sound with droughts, over wash, and sea water pumping.

* “Changes in salinity in Currituck Sound could be associated with droughts, ocean overwash, previous pumping of sea water into Back Bay, reduction of freshwater inflows, and transport of high-salinity waters between the sound and Chesapeake Bay to the north and the sound and Albemarle Sound to the south during wind events and tidal fluctuations (fig. 1; U.S. Army Corps of Engineers, 2001).”

1. **Flux of Dissolved Organic Carbon and Pore Water Through the Substrate of *Spartina alterniflora* marsh in North Carolina (Yelverton and Hackney, 1985)**

This study quantified the flux of DOC from a *Spartina* marsh in North Carolina. Groundwater was sampled in a similar way to the way I am collecting samples. Yelverton and Hackney actually concluded that export of DOC from belowground production was low compared to other areas. Even though this study is 30 years old, it is still interesting to include and use possibly as a comparison for the marshes I am sampling. *Spartina* marshes are very common along the east coast, but I’m not positive they dominate the Croatan and Currituck Sounds – there is a lot of *Juncus* where we sample. Nonetheless, this was a great source for me to understand everything going on in a marsh below the surface and I definitely want to touch on that in my paper because it gives a good preface to the importance of groundwater.

* “Production of roots and rhizomes generally exceeds or equals aerial production of leaves and stems (Good et al., 1982), but little of this material has been found in the shallow water of estuaries (Pickral & Odum, 1977), and the contribution of belowground materials to nearshore secondary productivity is not known”
* “Dead roots and rhizomes that remain in the marsh substrate may be deposited as peat or decomposed by a variety of microbe mediated processes.”
* “The energy contained in reduced sulfur compounds and dissolved organic carbon (DOC) exported from the marsh substrate may be used by microbes and be passed up the food chain (Pomeroy et al., 1977; Pomeroy & Wiegert, 1981).”
* “After the tide had receded from the marsh during each of the 12 months from August 1982 to July 1983, water was pumped from the wells to about 30 cm below the substrate surface. This allowed seepage of pore water into the wells from the entire root zone. A 100-ml sample was then collected by glass pipette from each well, and placed in acid washed BOD bottles. In addition, a surface water sample was collected at high tide 25 m from the creek and in the creek at high and low tide.”
* “Changes in groundwater levels were used to estimate the hydraulic gradient (H/L, or slope) between the wells (Figure 3). The hydraulic gradient along with hydraulic conductivity (K or soil permeability) calculated by the auger pump test method, was used to determine horizontal seepage rates (Shiver, 1982; USDI, 1978). For example, for the calculated seepage rate between stations 0 and 0.5 m .”
* “There was a decrease in sediment grain size toward the interior of the marsh (Table 1) while the percent organic content increased. The organic content of the sediment was always less than 15’&, which suggests that peat was not accumulating (Good et al., 1982).”
* “Highest concentrations occurred in summer (July-September) when marsh production with accompanying leachates and decomposition processes forming DOC were presumably at their peak. Correspondingly, DOC concentrations were minimal in winter (December-February) when biological activity was low (Figure 6).”
* “Assuming that the majority of the DOC source is belowground production, then < 1% of net primary production was exported as DOC. While this indicates that export of DOC from belowground production of sandy substrate coastal North Carolina marshes may be low, these results should not be extrapolated to other locations or different substrates.”

1. **Net Ecosystem Carbon Balance in a North Carolina, USA, Salt Marsh (Czapla, Anderson, and Currin, 2020)**

Czapla, K. M., Anderson, I. C., & Currin, C. A. (2020). Net ecosystem carbon balance in a North Carolina, USA, salt marsh. Journal of Geophysical Research: Biogeosciences, 125, e2019JG005509. https://doi.org/ 10.1029/2019JG005509

This was a study conducted at a salt marsh in North Carolina to understand how increasing nitrogen pollution affects carbon accumulation of an entire marsh ecosystem. Czapla and others concluded that increasing nitrogen pollution in coastal waters causes increasing net carbon loss in marshes. This was the first article I found that looked at the relation between nitrogen and carbon on salt marshes. I think it would be interesting to quantify that relationship and see what the correlation is at the marshes I am sampling. Also, this study is great background for how salt marshes are affected by nutrient pollution and will be good in my “further research” section.

* “Net ecosystem carbon balance (NECB), the accumulation or loss of C resulting from vertical CO2 and CH4 gas fluxes, lateral C fluxes, and sediment C inputs, varies across salt marshes; thus, extrapolation of NECB to an entire marsh is challenging.”
* “The amount of carbon accumulated in a marsh is the net result of carbon dioxide emissions to the atmosphere, fixation of carbon by photosynthesis, export of dissolved carbon to the creek, and accumulation of organic carbon in sediments deposited on the surface.”
* “Carbon may accumulate through plant production and/or by trapping and deposition of sediment by aboveground biomass (AGB); however, C is also lost due to plant and micro- bial respiration. Salt marsh net ecosystem carbon balance (NECB), which results from vertical CO2 exchanges with the atmosphere, lateral dissolved C exchanges, and allochthonous sediment C inputs (Chapin et al., 2006), is an estimator of total C accumulation or loss in the marsh.”
* “Nitrogen availability, which is increasing in many salt marshes as a result of anthropogenic inputs (Hopkinson et al., 2012; Pardo et al., 2011), is likely to have a strong impact on each component of salt marsh NECB and thus NECB itself.”
* “Three 50 cm deep piezometers were installed on the edge of FC marsh and sampled seasonally for ground- water DOC and DIC. Piezometers were flushed with N2 gas prior to sampling to remove reactive gases and pumped to flush out stagnant pore water. DOC samples were filtered in the field into scintillation vials (com- busted prior to sampling at 500°C for 5 hr) with 0.45 μm polyethylsulfone syringe filters, stored frozen, and analyzed on a Shimadzu TOC ‐V analyzer. DIC samples were collected without filtering in 8 ml Hungate tubes spiked with 8 μl of saturated HgCl2 solution and analyzed within 30 days of collection with a Li‐Cor 6252 infrared CO2 analyzer by injecting 100 μl of sample into 0.05 M H2SO4 sparged with N2 gas as described in Neubauer and Anderson (2003).”
* “We observed a clear difference in NECB between edge and interior marsh and confirmed that spatial heterogeneity of NECB must be considered for accurate extrapolation to whole marsh systems.”
* “Most estimates of C accumulation do not make a distinction between edge and interior accumulation rates and, thus, may overestimate C accumulation for the whole marsh.”
* “Although the concentrations of DIC were greater in groundwater than in tidal water, the more rapid rate of tidal water exchange compared to groundwater drainage caused a greater tidal C export rate relative to groundwater C export.”
* “Under natural conditions, lateral C export and net C loss were greater on the edge than the interior, but sediment C input was greater in the interior.”
* “Responses of NEE and NECB to fertilization were greater on the edge than the interior.”
* “Fertilization increased net CO2 emission, lateral C export, sediment C input, and net C loss for the marsh overall.”

1. **Wind-Driven Dissolved Organic Matter Dynamics in a Chesapeake Bay Tidal Marsh-Estuary System (Clark et al., 2017)**

Clark, J., Long, W., Tzortziou, M., Neale, P., Hood, R. (2017). Wind-Driven Dissolved Organic Matter Dynamics in a Chesapeake Bay Tidal Marsh-Estuary System. *Estuaries and Coasts (2018) 41: 708-723.* doi:10.1007/s12237-017-0295-1

This study aimed to understand how different factors affected biogeochemical exchanges in an estuary in the Chesapeake Bay. Long et al. concluded that there is a correlation between wind strength and direction on residence time, salinity, and flushing, which in turn also affect nutrient cycling. This is the first paper I was able to find that touched on wind-driven tides and their impact on carbon and other nutrient cycling in marshes. Information from this source will be useful to introduce the variables I want to pay attention to when comparing and contrasting the marshes I am sampling.

* “… strong relationship between marsh creek salinity and dissolved organic matter fluorescence (fDOM), with wind velocity indirectly driving large amplitude variation of both salinity and fDOM at certain times of the year”
* “A recent estimate of a tidal wetland organic carbon flux of 1.2 –2.5 Tg C year −1 to the eastern coastal waters of the USA indicates tidal wetlands play an important role in the coastal carbon cycle (Herrmann et al. 2015).”
* “For example, Childers et al. (1993) reported that salt marshes in coastal Georgia have varying inorganic nutrient flux responses associated with changes in wind direction and wave height at ex- posed marsh sites, and that more exposed marshes have higher amounts of potentially wind-driven DOM ex- change.”
* “Wetlands make up 1% of the total watershed in the mid-Atlantic Bight but contribute up to 40% of the total organic carbon export into estuarine and coastal waters (Herrmann et al. 2015)”
* “Wind also affects flushing, residence time, and salinity variability in shallow water estuaries (Geyer 1996).”
* “These experiments reveal that wind forcing affects inundation timing and extent and significantly alter marsh creek flow velocity, with northerly winds enhancing marsh water efflux.”
* “Winds have an indirect local effect on the marsh water level, either enhancing or depressing marsh inundation at the onset of storm events and thus affecting marsh-estuary water exchange”
* “Water flow and inundation ultimately govern the timing and magnitude of biogeochemical ex- changes and processes between the marsh and estuary.”

Studies mentioned

* Herrmann et al 2015
* Herrmann, Maria, Raymond G. Najjar, W. Michael Kemp, Richard B. Alexander, Elizabeth W. Boyer, Wei-Jun Cai, Peter C. Griffith, Kevin D. Kroeger, S. Leigh McCallister, and Richard A. Smith. 2015. Net ecosystem production and organic carbon balance of US East Coast estuaries: a synthesis approach. Global Biogeochemical Cycles 29.1: 96–111.
* Childers, Daniel L., Stephen Cofer-Shabica, and L. Nakashima. 1993. Spatial and temporal variability in marsh-water column interactions in a southeastern USA salt marsh estuary. Marine Ecology Progress Series 95.1-2: 25–38.

1. **Modern saltmarsh diatom distributions of the Outer Banks, North Carolina, and the development of a transfer function for high resolution reconstructions of sea level (Horton, 2006)**

Horton, B., Corbett, R., Culver, S., Edwards, R., Hillier, C. (2006). Modern saltmarsh diatom distributions of the Outer Banks, North Carolina, and the development of a transfer function for high resolution reconstructions of sea level. *Estuarine, Coastal and Shelf Science 69 (2006) 381-394.* doi:10.1016/j.ecss.2006.05.007

This study focused on analyzing diatom samples from different areas in the Outer Banks to understand how marshes are responding to sea level rise. I don’t think this source is very useful for my own research, but the background it gave on the location of the study could be useful, so I will probably follow up on the sources it cited.

* “The tidal conditions of the Outer Banks are unique; the astronomical tidal range is small (e.g. diurnal range of 0.36 m at Oregon Inlet) but with significant, very variable and rapidly changing wind tides from less than 30 cm to more than 3 m (during hurricanes) in amplitude (Riggs, 2002)”
* “Currituck Barrier Island is the most northerly back-barrier site, with the greatest distance (56 km) from Oregon Inlet, a major inlet which has existed since 1846 AD. The salinity of open water at Currituck Sound is low (c. 5 psu) at the time of sample collection (August 2002). The marsh at this site is approximately 200 m in width and displays a succession from narrow tidal flat through Juncus roemerianus low marsh to a mixed J. roemerianus and Spartina cynusoroides high marsh.”
* “The diatom assemblages of Currituck Barrier Island, Oregon Inlet and Pea Island marshes show vertical zonations suggesting that distribution of diatoms in saltmarsh environments are a function of elevation (e.g. Zong and Horton, 1998).”

Related sources

* Riggs 2002
* Riggs, S.R., 2002. Life at the edge of North Carolina’s coastal system: the geologic controls. In: Beal, C., Prioli, C. (Eds.), Life at the Edge of the Sea: Essays on North Carolina’s Coast and Coastal Culture, Vol. I. Coastal Carolina Press, Wilmington, NC, pp. 63e95.

1. **The influence of tidal forcing on groundwater flow and nutrient exchange in a salt marsh-dominated estuary** **(Wilson and Morris, 2010)**

Wilson, A., Morris, J., (2010). The influence of tidal forcing on groundwater flow and nutrient exchange in a salt marsh-dominated estuary. *Biogeochemistry (2012) 108: 27 – 38.* DOI 10.1007/s10533-010-9570-y

This study assessed the effect of tides and water level on porewater exchange between salt marshes and tidal creeks. Wilson and Morris found that increases in tidal amplitude increased groundwater flushing. They also found that small increases in water level associated with sea level rise could increase nutrient export in marshes. Because this study utilized a lot of large scale modeling, it was hard to follow, but I think it will be useful when considering the larger implications of my study and the importance of salt marshes in the face of sea-level rise.

* “Data from salt marshes in the U.S. Southeast show that long-term variations in mean water level (MWL) correlate strongly with salt marsh productivity and porewater salinity.”
* “Results are consistent with field observations and showed that increases in tidal amplitude increased groundwater flushing, particularly when increasing the tidal amplitude caused the marsh platform to be inundated at high tide.”
* “Results suggest that small increases in MWL associated with sea level rise could increase nutrient export significantly in marshes with elevations that are equilibrated near mean high water, but rising sea level could decrease the export of nutrients to, and thus fertility in, estuaries adjacent to marshes that are equilibrated lower in the tidal frame.”
* “We speculate that the early stages of rising relative sea level may significantly impact water quality in estuaries that are not river-dominated by raising the discharge of nutrients from coastal wetlands.”
* “Groundwater flow is an important control on nutrient exchange between salt marshes and adjacent estuaries, and this exchange is influenced by long- and short-term variations in the tidal signal.”
* “These results also suggest that the effects of rising sea level on marsh nutrient and salt dynamics will depend on the relative elevation of those marshes. Seasonal and climate-related rises in mean water level could increase groundwater and nutrient fluxes if that rise causes the marsh platform to be inundated more frequently or if it causes greater areas of the marsh to be inundated at high tide.”