Introduction

Coastal wetlands are extremely important ecosystems that exist at the nexus between the land and sea. These highly productive vegetative systems sequester and store disproportionately large amounts of carbon while covering a small fraction of the earth's surface (Mcleod et al. 2011). The ability to trap sediment and particles from water flow add to their storage capacity, while low levels of oxygen in saturated wetland sediments reduce decomposition (Reddy and DeLaune 2008). These attributes aid in the development of large carbon sinks (Mcleod et al. 2011), making coastal wetlands important mitigators of CO_2 emissions and climate change. Unfortunately, over 50% of the global area covered by these ecosystems has been lost between 1700 and 2020 due to human development (Fluet-Chouinard et al. 2023). In this age of unprecedented human activity, the balance of carbon accumulation in such ecosystems (net ecosystem carbon balance; "NECB") (Chapin et al. 2006) is under increasing duress due to human induced factors such as changes in coastal land use, impacts from nutrient loading, and various effects of climate change including sea level rise (Chambers et al. 2019).

Sea level rise is particularly impactful in South Florida due to the low-lying and porous limestone bedrock of the landscape. Historically, these conditions have been exacerbated by surface water diversions and reductions caused by canal and levee construction for development and agricultural use (Ehlinger 2014). These changes reduced water flow and peat volume which diminished habitat extent and limited animal movement in the Florida Everglades (Ehlinger 2014, Childers et al. 2019). Models predict these changes, combined with rising sea levels and predicted increases in rainfall, may initially result in the conversion of freshwater habitat and vegetation into a saltwater tolerant mangrove fringe habitat, but then may drown vegetation altogether (Flower et al. 2017). The federal government's Comprehensive Everglades Restoration Plan (CERP) aims to mitigate these effects and reduce the likelihood of this future by restoring freshwater flow (Ehlinger 2014). However, some models suggest only 30% of CERP benefits may be achieved in some areas of the Everglades (Dessu et al. 2021), and wetland peat collapse remains a concern.

Peat collapse is defined as the loss of soil structure and integrity resulting in elevation decline and the collapse of peat (Chambers et al. 2019). It is hypothesized that peat collapse occurs after the decline and death of vegetation and root structures as a result of sea level rise in the marshes of the Everglades (Wilson et al. 2018a, Wilson et al. 2018b). Persistent elevation decline and the inability for vegetation to reestablish itself can convert wetlands into open water ponds (Chambers et al. 2019), further reducing habitat in this system.

Research has indicated that saltwater intrusion and peat collapse negatively affects the NECB, resulting in carbon losses through fluxes from the soil to the atmosphere (Wilson et al. 2018b). However, how saltwater intrusion affects aquatic carbon fluxes, a key component of this balance, remains unclear. Many wetland studies often neglect the contribution of this flux to the NECB (Dinsmore et al. 2013), potentially underestimating its impact. For example, a cross-system review showed that global aquatic fluxes can offset terrestrial ecosystem productivity by as much as 590% (Webb et al. 2019). While models have indicated that aquatic carbon fluxes from marshes impacted by peat collapse may be a significant transport mechanism of dissolved carbon (Ishtiaq et al. 2022), field studies are needed to verify this.

Impacts to the NECB through processes like saltwater intrusion can reduce wetland ecosystem services such as habitat extent, flooding protection and carbon storage and sequestration (Reddy and Delaune 2008). Although the role of ecosystem services in wetland functionality is widely recognized, their less obvious yet equally significant contribution lies in the economic value they provide. Services like carbon storage, for example, which harness CO_2 from the atmosphere, prevent societal damages like lower crop yields, power grid issues, and destructive floods, caused by CO2-induced temperature. By assigning monetized value to ecosystem services through economic valuations, the value of these ecosystem services can be made readily apparent to stakeholders, provide a comparison point for future ecosystem states and assist policymakers in making complex decisions about natural resource management and restoration (Patterson and Cole 2013; Richardson et al. 2015). However, this tool has not been applied specifically to the Florida's Everglades marsh landscape, and saltwater intrusion's effect on the value of carbon storage in these marshes remains unexplored.

Research Questions

An integral question to the CERP, enacted by congress in the early 2000's, is whether and for how long restoration of freshwater flow can attenuate saltwater intrusion and keep vegetation, habitat, and carbon losses at bay in the Everglades (NASEM 2022). Answering these requires incorporating missing aquatic carbon fluxes into estimates of the NECB, which will allow us to gain a complete picture of the marsh ecosystem's response to restoration and continued effects of climate change. This will inform adaptive management strategies and monitoring efforts, while economic valuations can amplify Everglades' importance and visibility for securing funding and political support. Thus, this work seeks to answer the following research questions: **I) What is the magnitude of vertical and lateral aquatic carbon fluxes and how do they vary between intact freshwater and collapsing brackish water marsh in Everglades National Park? II) How does carbon storage vary between these ecosystems? III) What is the economic value of carbon storage in these ecosystems?**

Study area

The proposed work will be conducted in Everglades National Park within Shark River Slough, an estuary located on the southwest coastal margin of the Florida Everglades. The Shark River Slough is comprised of extensive mangrove forests and peat-dominated marshes, with hydrology that may be driven by freshwater and/or tidal inputs. This work will take place in a brackish water marsh that is impacted by saltwater intrusion and contains significant areas of collapsing peat, and an intact freshwater marsh that maintains low salinity levels (Figure 1 and 2)[1]. The brackish water marsh is dominated by *Cladium jamaicense* (sawgrass) while the freshwater marsh is co-dominated by sawgrass and *Eleocharis cellulosa* (spikerush).

Statement of Work

To measure subsurface aquatic flux (question 1), this work requests funding for the installation, maintenance, and sampling of multiple piezometer wells and peeper sampling devices in Everglades National Park. Permits for this work have already been granted by Everglades National Park. Wooden platforms (8ft by 1ft) enacted to prevent soil disturbance in sampling areas have been installed as the basis for piezometer clusters at the brackish water and freshwater marsh (Figure 3). At each site, I propose to install seven deep piezometers (40 m depth) at least 25 m apart to establish the direction of groundwater flow and lateral subsurface aquatic fluxes following Fetter 1994 (Figure 4). Once the direction of groundwater flow is established, I will install three shallow piezometers (15 m depth) near (1 m apart) to three deep piezometers oriented to one another in the predominant direction of groundwater flow to establish vertical subsurface aquatic flux (Figure 4). Each piezometer well will be evaluated for hydraulic head using a water level meter to estimate depth to water. I will also install 10 cm by

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[1] Figures were not included in this application in order to meet the length requirement. Figures can be made available upon email request.

60 cm peeper sampling devices within the three deep + shallow piezometers clusters in order to establish dissolved organic carbon (DOC), dissolved inorganic carbon (DIC) and methane (CH_4) concentrations at these sites. These sampling devices have previously been acquired (Figure 5). In order to prevent chemical reactivity that would misrepresent sample concentrations, each peeper sampling device will be deoxygenated following Johnston et al. 2009 before being directly inserted into the soil for sample collection. Each piezometer and peeper sampling device will be surveyed for elevation using Trimble R8 global navigation satellite system.

To determine lateral surface water carbon fluxes, this work requests funding for surface water sample collection and discharge estimates. I will take discharge measurements in waters draining from a culvert adjacent to the freshwater marsh using an acoustic doppler velocimeter belonging to the department of Earth and Environment at Florida International University (FIU). In lieu of nearby culverts with flow at the brackish water marsh, I will use discharge estimates from previous tracer experiments (Harvey et al. 2005) to estimate discharge at the brackish water site. I will characterize environmental variables such as temperature, salinity, and pH in surface waters using a YSI belonging to the department of Earth and Environment at FIU. Porewater, surface water, hydraulic head, discharge measurements and environmental sampling will occur once a month during the 2024 wet season (May – November).

Funding is requested for laboratory sample analysis. Porewater and surface water samples will be analyzed in the laboratory for DIC, DOC and CH_4 at the Cache Lab at FIU. I will calculate subsurface aquatic carbon fluxes from hydraulic head measurements and porewater concentrations using Darcy's Law following Troxler and Childers 2010 and Fetter 1994. I will calculate lateral surface water carbon fluxes using discharge measurements and surface water carbon concentrations. Additional analytical methods will be applied.

This work also requests funding for the collection and laboratory analysis of samples taken from the marsh ecosystem in order to quantify carbon storage (question 2). I will determine the organic carbon stock within soil, aboveground and belowground biomass from cores extruded near the aforementioned piezometer clusters at both the freshwater and brackish water marsh ($n = 24$) following methods described in Simpson et al. 2017. Samples from the three carbon pools will be analyzed in the laboratory for total carbon by the Blue Carbon Analysis Lab at FIU. To estimate the amount of carbon stored in the two sites, the sum of aboveground, belowground and soil total carbon in each core will be extrapolated to value per unit area (Jerath et al. 2016). To determine the economic value of carbon storage (question 3), I will apply economic valuation tools based off CERP initiatives and the social cost of carbon as described in Jerath et al. 2016. Additional analyses will be applied.

Significance to Coastal Wetland Research and Sharing Opportunities

This works seeks to resolve a key unknown in our understanding of the Everglades NECB. Carbon flux dynamics have long been biased towards terrestrial fluxes and an understanding of how aquatic carbon fluxes respond to saltwater intrusion is lacking. This work is needed to fully understand whether the actions taken to restore and increase the resiliency of the south Florida ecosystem will buttress this system to the effects of climate change. Data and analyses from this effort will be instrumental in informing, aiding, and expanding research and management strategies aimed at understanding and continuing the success of restoration efforts.

This work also presents a cross-disciplinary opportunity to apply economic principles to a scientific understanding of ecosystem services within the Everglades. These assessments are often considered in cost benefit analyses of potential development, environmental advocacy and policy making, and can be used to foster financial and community support for restoration. This work could provide economic justification for the continued preservation of this system and can serve as a benchmark for the effects of any future policy, management, or climactic changes.

I plan to share the results of my work with the Florida Coastal Everglades Long-Term Ecological Research program (FCE-LTER). Sponsored by the National Science Foundation, the FCE-LTER is one of 28 federally funded long-term research programs in the United States with the goal of exploring the causes and consequences of changes in the Everglades coastal ecosystem. I also plan to share the results of this work with the greater scientific community by publishing this work through peer-reviewed journals and by attending and presenting at national conferences such as the Ecological Society of America.

Furthermore, I plan to share the results of my research with the local south Florida community. As a graduate fellow within the education department of Fairchild Tropical Botanic Gardens, I plan to design educational activities for high school students based on my research findings for The Fairchild Challenge, an educational program in its 23rd year. I also plan to share my results at the Greater Everglades Ecosystem Restoration conference, a conference that is geared towards policymakers, planners, scientists, and private citizens so that I may emphasize the value of the Everglades marsh ecosystem to a greater audience.

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