

CONNECTING SURFACE PROCESSES TO STRATIGRAPHIC ARCHITECTURE
AND CARBON STORAGE IN COASTAL DELTAS

AN ABSTRACT

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OF

DOCTOR OF PHILOSOPHY

BY



Jose R. Silvestre

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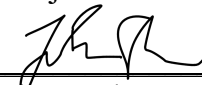
Kyle M. Straub, PhD
Director



Nicole M. Gasparini, PhD



Torbjörn E. Törnqvist, PhD



John B. Shaw, PhD

ABSTRACT

Organic-rich sedimentary deposits in coastal wetlands of deltaic systems represent a critical, yet understudied reservoir, in Earth's carbon cycle. These coupled wetland-deltaic systems have the potential to store substantial amounts of carbon on geological timescales. However, we lack an understanding of how carbon preservation is influenced by surface processes in coastal systems. This dissertation explores this influence through a series of reduced-scale physical delta experiments and analysis from modern field system point data for coastal Louisiana. In Chapter 2, I propose a predictive framework for quantify the longitudinal scales of preserved organic-rich deposits in marginal marine successions. This framework integrates key processes such as sediment deposition, long-term subsidence, and channel migration, to quantify the maximum distance that a shoreline migrates due to processes internal to a sediment routing system. This migration distance is then used to estimate the extent of organic-rich subsurface deposits. Chapter 3 expands on Chapter 2 by investigating how highly variable discharge influences the morphology and area of wetlands and deltas, and ultimately subsurface preservation of carbon. Results show that highly variable discharge reduces wetland area, which subsequently reduces the longitudinal spatial extent of carbon preservation. In Chapter 4, I test if the shift from mineral-rich to organic-rich deposition influences carbon accumulation in coastal Louisiana. I compare the ability of teal and blue carbon wetlands to accumulate carbon. I find that organic matter content is a poor predictor for organic carbon accumulation rate. In addition, I determine that teal carbon wetlands are comparable to their marine-influenced counterparts in their ability to accumulate carbon and recommend that they be included in blue carbon frameworks.

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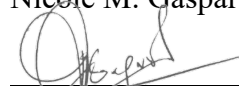
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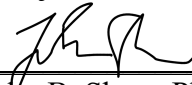
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Director



Nicole M. Gasparini, PhD



Torbjörn E. Törnqvist, PhD



John B. Shaw, PhD

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Chapter 1

Introduction

Coastal deltas are dynamic landscapes that form at the boundary of rivers and standing bodies of water (e.g., ocean) and are home to approximately 300 million people globally (Edmonds et al., 2020). Their associated teal and blue carbon ecosystems (freshwater and marine-influenced marshes, mangroves, and seagrass beds) are among Earth's most significant ecosystems, serving as critical sinks within the global carbon cycle (C. M. Duarte et al., 2005; Maxwell et al., 2024; McLeod et al., 2011). Plant community gross primary production generally exceeds respiration in vegetated coastal habitats (Carlos M. Duarte et al., 2013; C. M. Duarte et al., 2005). As a result, plants that grow in wetlands aid in regulating the elevation of coastal environments through primary production of organic matter and by trapping inorganic sediment (Cahoon et al., 2006; Drexler, 2011; J. A. Langley et al., 2009; Morris et al., 2002; J. A. Nyman et al., 1993; John A. Nyman et al., 2006; Turner et al., 2000). Maximum primary production occurs at an ideal elevation relative to sea level (Kirwan & Guntenspergen, 2012; Kirwan & Mudd, 2012; A. J. Langley et al., 2013; Morris et al., 2002; Voss et al., 2013) and decreases upslope and downslope of this peak zone (Morris et al., 2002). This production and associated high burial rates of organic carbon in wetlands allow for carbon storage over long timescales and the persistence of wetlands over time (Ward et al., 2008). These systems are vulnerable to threats from climate change and anthropogenic influences, including altered river discharge regimes and relative sea level rise. Understanding how these stressors influence the preservation of organic matter and subsurface architecture in deltaic systems is essential

for predicting resilience and the ability to sequester carbon under changing climates. Yet studies exploring the combined evolution of coastal deltas and their wetlands are limited.

In addition to steady environmental forcings, coastal deltaic systems are influenced by environmental variability and stochastic internal processes (Hajek & Straub, 2017), but the impact of these aspects have largely been unexplored. Many models that aim to predict the fate of organic matter in coastal systems do not consider how temporally and spatially variable dynamics resulting from these internal and external processes drive the evolution of delta and wetland morphology, which ultimately influence preservation of organic-rich material in the subsurface and can influence the spatial organization of strata.

This dissertation advances the understanding of how surface processes influence the deposition and preservation of organic-rich material and resulting stratigraphic architecture through (1) development of a simplified framework to estimate the longitudinal extent of subsurface carbon reservoirs, (2) quantification of the influence of variable discharge on experimental delta and wetland morphology, and carbon storage, and (3) analysis of the influence of mineral-sediment on carbon accumulation rates in coastal Louisiana wetlands.

In Chapter 2, I explore how surface processes influence spatial scales of preserved organic matter in deltaic systems under constant forcing conditions. Intrinsic (autogenic) channel processes drive shoreline movement through time. However, it is unclear how these autogenic processes influence how and where organic matter is preserved. We develop a simplified framework that predicts spatial scales of preserved organic matter in the subsurface. We test this framework with observations from a physical laboratory experiment and stratigraphic data from a field-scale system. We show that autogenic

timescales exert a control on shoreline movement. Thus, we find that incorporating these autogenic timescales in our framework increases the prediction accuracy for subsurface carbon reservoirs.

In Chapter 3, I assess how flood discharge variability influences delta and wetland morphology and the preservation of organic material within deltaic environments. Coastal wetlands evolve as a function of relative sea level and can be longitudinally extensive in lowland delta systems. We hypothesize that increasing discharge variability reduces delta and wetland area. We document such changes in a reduced-scale physical experiment with similar boundary conditions to the experiment in chapter 2, but where high variability floods have been incorporated. We find that organic matter is preserved over a shorter longitudinal extent due to enhanced channel mobility and increased delta slopes, and that there is a reduction in the preserved volume of organic matter in the subsurface. We highlight that while relative sea-level rise poses a risk to the continued persistence of wetlands, the impacts of increased discharge variability also pose challenges to modern wetlands and their ability to store carbon in the subsurface.

In Chapter 4, I transition from the laboratory to coastal Louisiana where I explore the ability of coastal inland freshwater wetlands to accumulate organic carbon compared to their marine-influenced counterparts. Likewise, we test the hypothesis that the shift from a mineral-dominated to organic-rich depositional system increases organic carbon accumulation rates. We use a rich dataset of monitoring stations from the Coastwide Reference Monitoring System that record sediment properties to calculate organic carbon accumulation rates across coastal Louisiana wetlands. We find that freshwater marshes and swamps can be as effective at accumulating organic carbon as marine-influenced wetlands.

We then determine that mineral-dominated deposits are at least as efficient at burying organic carbon as organic-rich strata. We then determine that organic matter content is not necessarily a good predictor of organic matter accumulation rates.

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Chapter 2

Autogenic shoreline migration and its effect on the storage of carbon in marginal marine successions

Jose R. Silvestre, Kelly M. Sanks, Samuel M. Zapp, Yi Hou, John B. Shaw, Udit Mukherjee, Rhodri M. Jerrett, Robert A. Duller, Kyle M. Straub

Abstract

The accumulation of organic matter near shorelines, known as blue carbon, is a key sink in the global carbon cycle. This accumulation is influenced by elevation relative to sea level and shoreline perturbations which evolve through time. The influence of internally generated, or autogenic, delta dynamics on long-term ($>10^5$ yr) organic matter preservation in river deltas is unknown. We develop a framework that links local autogenic shoreline migration to the spatial extent of preserved organic-rich strata, which we term paleo-blue carbon, and validate this against observations from a physical experiment that couples a clastic delta to a coastal wetland environment. We show that autogenic processes exert a control on shoreline migration and preservation of organic material; the longitudinal subsurface extent of paleo-blue carbon is approximately seven times larger than the wetland accumulation zone on the surface at any given period. Further, significant amounts of carbon are buried fast enough to be preserved from degradation. Given that autogenic processes operate in sedimentary environments that accumulate appreciable quantities of organic matter, we recommend incorporation of this framework into any predictions of the spatial extent of paleo-blue carbon stored in strata.

Introduction

Deltas are major coastal sinks of transported clastic and organic particulates. They also host a variety of wetland ecosystems (e.g., marshes, swamps, and bogs) in which organic matter is grown and preserved in-situ, particularly under anoxic conditions that limit decomposition (i.e., as peats and associated organic-rich deposits). Consequently, delta systems can sequester large amounts of organic carbon over geologic timescales ($>10^5$ yr) (Blair & Aller, 2012). This long-term sequestration forms a carbon reservoir that we propose to term “paleo-blue carbon”—a stock of organic carbon that is not at risk of disturbance over human timescales or contributing to climate change mitigation but remains an integral part of the global carbon cycle. The accumulation and burial of organic matter in these coastal systems, (“blue carbon sequestration”), constitutes a crucial yet imprecisely constrained reservoir in the global carbon cycle (10-24 PgC) (Lovelock & Reef, 2020). Here, we focus on coastal marshes—semi-aquatic ecosystems dominated by herbaceous plants that form the interface of land and sea—which are diverse ecosystems that occupy large areas of deltas (e.g., $\sim 16,000$ km² in the Mississippi delta) (Couvillion et al., 2013) and account for a large portion (up to 47%) of the total carbon sequestered by blue carbon ecosystems (McLeod et al., 2011). Plants that grow in these marshes contribute to the maintenance of elevation in coastal environments through primary production of organic matter and by trapping inorganic sediment (Cahoon et al., 2006). Maximum primary production occurs at an optimal elevation relative to mean high tide (Kirwan & Guntenspergen, 2012; Morris et al., 2002) and decreases above and below this peak zone (Morris et al., 2002). The accumulation and preservation of this material as peat and associated organic-rich accumulations (henceforward “organic deposits”) is an important

sink of organic carbon over geologic timescales (Ward et al., 2008). However, much of what is known about the loci and rates of carbon accumulation in coastal environments comes from active monitoring and studies of the shallow (upper 0-125 cm) subsurface (Nahlik & Fennessy, 2016), representing timescales generally less than 10^2 yr. Little is understood of how short-term (i.e., $<10^2$ yr) processes translate to the longer-term (i.e., $>10^5$) storage of carbon or the spatial scales involved.

In deltas, the position of shorelines (and therefore the locus of marsh accumulation and carbon sequestration) are a function of allogenic forcings (i.e., environmental forcings external to a system such as climate, tectonics, and eustacy) and autogenic processes (i.e., dynamics that come about from components interacting within a system such as river avulsion) (Hajek & Straub, 2017; Paola, 2016) operating at different timescales. On short time scales ($<10^2$ yr), shoreline migration rates are susceptible to events such as storms and changes in energy regime (e.g., those imparted by tide and/or wave action) (Galgano & Leatherman, 2019). Physical and numerical experiments and stratigraphic studies indicate that the position of shorelines, even in environments with steady forcings, are mobile over meso-timescales (10^2 - 10^5 yr) (Kim & Jerolmack, 2008; Kim et al., 2006; Muto & Steel, 2004; Muto et al., 2007; Powell et al., 2012; Van Dijk et al., 2009) and dictated by autogenic lobe-scale avulsions that alter the flux of sediment to shorelines (Kim et al., 2006). Over geologic timescales migration results from basin-wide imbalances between the generation of accommodation and sediment supply (Muto & Steel, 1997). When the rate of sediment accumulation outpaces accommodation production, shorelines prograde seaward (regression), and when generation of accommodation outpaces sediment accumulation, shorelines retreat landward (transgression) (Jervey, 1988; R, 1964; Vail et

al., 1977). The coupling of shoreline migration and accommodation production impacts where marshes accumulate on the surface (Morris et al., 2002) and the spatial extent that organic-rich sediment is preserved in the subsurface (Bohacs & Suter, 1997).

A link between autogenic processes and shoreline migration patterns (Kim et al., 2006; Martin et al., 2009; Powell et al., 2012) has been established from prior delta experiments. Experiments that use non-cohesive or cohesive sediment both establish a link between shoreline migration and the storage and removal of sediment from the delta top attributed to an autogenic cycle (Powell et al., 2012; Straub et al., 2015). The autogenic cycle is associated with an avulsion process that redirects the locus of deposition (Hamilton et al., 2013; Hoyal & Sheets, 2009). The timescale of this process is longest in depositional environments with large amounts of cohesive sediment and/or substantial vegetation (Edmonds & Slingerland, 2009; Hoyal & Sheets, 2009; Martin et al., 2009; Straub et al., 2015). Longer avulsion timescales result in larger magnitude autogenic transgressions and regressions (Straub et al., 2015).

In this study, we couple knowledge of in-situ organic matter accumulation in marshes with the mobility of shorelines over meso-timescales in a reduced-scale delta experiment. We quantify the areal extent of paleo-blue carbon in the subsurface and how this is linked to the surface expression of marshes and surface dynamics at any one period. We hypothesize that the time and length scales of autogenic shoreline migration can influence the geometry and fraction of organic-rich strata resulting in aerially extensive subsurface organic-rich deposits, even in the absence of large-magnitude environmental change. We test this hypothesis via a physical experiment that couples a clastic sediment transport system in a deltaic setting with organic-rich non-fluvial sedimentation typical of

coastal delta environments. This study develops a framework that accounts for the three-dimensional nature of autogenic processes governing organic sediment accumulation in marginal marine environments. By integrating autogenic processes that set the locus and relocation of sediment deposition responsible for shoreline migration, the framework provides insight into the relative size of carbon reservoirs found in coastal depositional systems.

Quantifying organic carbon fluxes to strata in physical experiments

This study develops a quantitative framework to link the accumulation of organic matter (OM), its subsurface distribution, and its relation to shoreline migration in deltaic environments. To accomplish this, we conducted a physical delta experiment where clastic sediment and water were delivered at a constant rate (Figure 1; Table S1) through a self-organizing channel network and to floodplains via levee overtopping. A proxy material for organic-rich non-riverine deposition in deltaic settings (e.g., tidal flats and wetland platforms) was deposited from overhead using elevation-based rules (Sanks et al., 2022) (see methods). The proxy material (henceforward non-riverine sediment) readily compacted under loading, reflecting behavior of non-riverine sediment in field-scale systems (Keogh et al., 2021; Zapp et al., 2023). To promote the accumulation of strata, the experiment was forced with long-term accommodation creation through a constant sea-level rise. Accommodation production was such that the average long-term size of the delta remained constant (Sanks et al., 2022), but with superimposed autogenic perturbations.

To quantify autogenic controls on transgression and organic-rich non-riverine sediment accumulation, we measured the compensation timescale (T_c), the maximum

duration that a deltaic surface remains abandoned before being revisited by the clastic transport system. T_c is derived as a function of the vertical roughness scale (l) and the basin-wide long-term subsidence rate ($\bar{r}$) (Straub & Esposito, 2013; Wang et al., 2011):

$$T_c = \frac{l}{\bar{r}} \quad (1)$$

In this study, (l) is approximated as the maximum channel depth (H_c). We also quantified the channel mobility timescale (T_{ch}) (Cazanacli et al., 2002; Straub & Esposito, 2013; Wickert et al., 2013), the time required for 95% of the delta-top area to be visited by channelized flow (Sanks et al., 2023; Straub et al., 2015). These autogenic timescales provide a quantitative link between shoreline migration, OM accumulation, and the dynamic behavior of channel systems.

Connecting shoreline migration to autogenic timescales

Deposition and accumulation of organic-rich, non-riverine sediment within low-lying areas near the shoreline should partially offset accommodation produced by relative sea-level rise, and thus reduce the length scale of autogenic transgressions. While this reduction occurs, it does not completely stall shoreline migration. Due to the compaction of the non-riverine sediment with depth, sites abandoned by active deposition of clastic sediment were not able to keep up with relative sea level rise through aggradation of the OM alone. This occurs even though non-riverine sediment was set to accumulate on the delta surface at a near-surface rate comparable to the long-term base-level rise rate. A similar process likely takes place in field scale systems (Keogh et al., 2021). In our experiment, shoreline

migration was observed to result from a combination of shallow surface compaction and autogenic channel migration which determined the areal extent of the non-riverine sediment accumulation during the experiment (Figure 2a). This resulted in strata with rich spatial structure to the seams of organic-rich deposits (Figure 2b, c).

To characterize the rate at which shoreline migration occurred, we measured shoreline position (the intersection of the sediment surface and sea level) at two-hour intervals over the duration of the experiment. The longest timescales of statistically correlated shoreline migration should result in the largest transgressions or regressions and, therefore, the widest areas of organic-rich deposits. These measurements were taken at angular increments (α), beginning from one side of the basin to the other, which allowed us to create a time-series that captures changes in shoreline position (Figure 3a, S1). Spectral analysis (Multi-Taper Method, tapers = 4; see methods) indicates that large-scale shoreline migration occurred at periods of 56.8 hrs in both experiments. (Figure 3b), which is similar to the compensation timescale of the experiment (average basin $T_c = 54 \pm 13.9$ hrs; Table 1, Figure S2, S3). This means that the timescales of vertical accretion and horizontal progradation are tightly coupled.

Spatial distribution of preserved organic sediment proxy

We quantified subsurface preservation of the organic-rich deposits by subsampling at 10 cm intervals along each strike section (1-2.7 m wide). For each strike-section, we quantified the number of seams (i.e., the strata dominantly composed of organic-rich deposits) in the vertical, the thickness of each seam, and the total deposit thickness (i.e., the thickness of the strike-section deposit). The mean deposit thickness was divided by the

product of the mean number of seams and the mean seam thickness to estimate a conservative value of the bulk fraction of preserved organic deposits. On average, the active wetland accretion zone (B_w) on the delta surface was only 0.31 m wide, but the subsurface extent defined by the preservation of at least 25% of the maximum fraction present for all cross-sections was 2.20 m wide, a difference of a factor of ~ 7 . The spatial distributions of the preserved seam thicknesses and organic-rich fraction measured at cross-sections from proximal to distal are normally distributed (Shapiro-Wilk Test; p-value = 0.9395 for thicknesses and p-value = 0.2920 for organic-rich fraction). We find the thickest seams approximately 0.1 to 0.6 m upstream of the mean delta shoreline (Figure 4a). The number of seams increases from proximal to distal and reaches a peak near the mean shoreline (~ 1.2 m downstream from the basin entrance) (Figure 4b). The fraction of preserved organic-rich deposits within a given strike-section peaks at $\sim 23\%$ near the mean shoreline (Figure 4c).

Simplified framework to quantify maximum length of autogenic transgression

To estimate a maximum length of transgression, we conceptualize an abandoned location on the delta (i.e., does not receive clastic sediment deposition). Then, the background relative sea-level rise rate forces transgression at a rate linked to the delta top slope and internally derived subsidence associated with compaction (Zapp, 2023) (Figure 1). However, transgressions cannot continue indefinitely, and both the compensation and channel mobility timescales influence the maximum length scale. We quantify the maximum length of autogenic transgression (L_t) as:

$$L_t = RSLR_b * \frac{1}{s} * T_c * \gamma \quad (2)$$

where s is the delta top slope, $RSLR_b$ is the relative base level rise rate and γ is a factor that accounts for the influence of reworking at timescales less than T_c (see methods). This scaling argument for the maximum length of transgression does not account for the aggradation of organic-rich sediment, which would reduce the value of L_t . However, given that the near-surface porosity of organic-rich deposits is often close to 90% (Zapp et al., 2023), this reduction would likely be a second-order influence on L_t .

In Equation 2, the compensation timescale is representative of the maximum autogenic timescale and can be set in different ways. In some systems that experience little to no alternation between deposition and erosion during long-term aggradation, the autogenic timescale relates to the maximum amount of time of abandonment at a location, which agrees well with our simplified framework. In other systems, sites on a delta-top frequently alternate between erosion and deposition. In these systems, the compensation timescale represents the amount of time necessary for sufficient aggradation to bury sediment to a depth that is no longer susceptible to autogenic erosion, meaning the length of transgression will be much less. The γ term in Equation 2 accounts for this through incorporation of sediment reworking timescales relative to aggradation timescales. In this study we limit our exploration to systems where gamma equals one, which are systems with low channel mobility for their long-term aggradation due to sediment cohesion or vegetation.

We estimate L_t for the experiment and compare this estimate to the observed extent of organic-rich, non-riverine sediment from proximal to distal in the experimental subsurface, in addition to an estimate of the length scale in a geometric model that lacks autogenic dynamics. We use the mean T_c value to calculate a L_t of 0.79 m for the experiment. While L_t provides a conservative estimate for the longitudinal extent of preserved non-riverine sediment, the wetland accretion zone (B_w) extends downslope and upslope of the shoreline, which increases L_t by the proximal-to-distal extent of the wetland accretion zone on the Earth's surface at any given period. Furthermore, autogenic regression of the shoreline in basins with shallow oceans where delta lobes extend far out, could result in multiple factors of L_t , x , such that:

$$L_{OM} = xL_t + B_w \quad (3)$$

where L_{OM} is the longitudinal extent of preserved organic-rich, non-riverine sediment. In our experiment, the shoreline location extended up to $\sim 2L_t$ beyond the mean shoreline (Figure 3a), likely enhanced relative to field scale systems due to an initial deltaic planform configuration inherited from the experimental spin-up stage that featured a constant sea level (see methods). The calculated L_{OM} of 1.89 m agrees well with the 2.2 m subsurface extent of preserved proxy material. We hypothesize that x is unlikely to exceed a value of two in lowland field settings due to compensational effects resulting from topography and avulsion, which allows for one L_t upstream and downstream of the mean shoreline.

While 1D geometric delta models reproduce the balance between accommodation and organic matter accumulation (Lorenzo-Trueba et al., 2012), they do not fully capture

autogenic processes that exist in field systems. We convert the elevation window where non-riverine deposition occurs in the experiment (-9 mm to 5 mm relative to sea level) to a Euclidean distance to estimate the theoretical longitudinal extent where organic sediments would be deposited if a geometric model were applied to our experiment. The highest elevation (5 mm) and lowest elevation (-9 mm) within the deposition window are divided by the terrestrial delta top and delta foreset slopes, respectively, and then summed to obtain a length scale for the geometric model. The L_t estimate (0.79 m) is approximately two and a half times larger than the length scale estimate for the theoretical deposition window. We find that because autogenic processes cause shoreline migration, there is a more extensive spatial distribution where organic strata can occur compared to geometric models of delta growth that lack stochastic autogenic processes (Figure 4c).

Discussion

Field application

This study addresses a knowledge gap identified in previous theoretical, experimental, and field stratigraphic analyses that predict the fate of organic-rich, non-riverine deposition in coastal systems. For the first time, we quantify the relationship between autogenic shoreline migration and preservation of this non-riverine sediment to develop a framework that estimates the longitudinal spatial extent of organic-rich strata in the subsurface. The framework predicts an upper bound on shoreline migration resulting from the internal dynamics of deltaic landscapes emphasizing the mobility of shorelines and wetland accretion zones due to autogenic processes. This framework is particularly applicable to stratigraphic predictions and/or inversions for time periods with relatively minor eustatic

sea-level change. For example, deep-time strata deposited during “eustato-stasis” intervals during greenhouse Earth conditions (Haq, 2014) and Holocene (Stanford et al., 2011) deltas. We quantitatively compare our method of predicting spatial scales of organic-rich strata with a data-rich field system. We explore if the framework produces reasonable predictions relative to observed organic material preserved in the subsurface as a method of gaining confidence to apply to data-poor locations. Due to the high temporal resolution of strata in the Holocene, we apply the framework to the Rhine-Meuse delta through a scaling analysis, acknowledging challenges in reproducing any one system due to either relatively recent rapid sea-level rise or loss in temporal resolution in deep time systems.

The Rhine-Meuse delta (RMD) is situated in the southeastern part of the North Sea Basin, with the delta apex region currently located 150-160 km upstream of the shoreline (Stouthamer et al., 2011). This system’s Holocene deltaic wedge thickens towards the west (downstream), to over 20 m near the North Sea coast. It is comprised of a stacked sequence of clastic fluvial and estuarine deposits interspersed with organic layers (Gouw & Hijma, 2022). While ombrotrophic peats (i.e., peats that rely on precipitation for water and nutrient supply) in the higher topographic areas have largely disappeared due to drainage and excavation, thick beds of minerotrophic peat (i.e., receive water and nutrients from groundwater) are abundant in the topographically lower regions and were formed under changes to base-level rise during the Holocene (e.g., Makaske & Maas, 2023). Much of this peat material is woody (*Alnus*) or reed (*Phragmites*) (van Asselen et al., [2017]), which are typical of freshwater environments. The spatial distribution of these minerotrophic peats is dependent on groundwater table elevation, which can be set by relative sea level, and the depositional history and the stratigraphic architecture of the RMD are well-

documented (e.g., Gouw & Hijma, 2022), making this an ideal field system to test our framework.

We use estimates of delta-top slope (s), T_c , T_{ch} , and $\bar{r}$ to estimate L_t for the RMD (Table 1), for which a high spatial resolution subsurface record for organic-rich strata exists. Previous work estimates avulsion timescales (T_A) that range between 500-1000 yr for the RMD (Stouthamer & Berendsen, 2007; Tornqvist, 1994), channel belt widths ranging up to 3 km (Gouw & Berendsen, 2007; Gouw & Hijma, 2022), and an alluvial plain width of ~50 km (Gouw & Hijma, 2022). Given the ratio between channel belt width to alluvial plain width, we conservatively estimate T_{ch} to be greater than T_c for the RMD because it would take more than six avulsion events (equivalent to the timescale of $T_c = 6$ kyr (Li et al., 2016)) for channelized flow to visit most of the delta's surface, which results in γ equal to 1. We estimate the subsurface extent of organic material of the RMD from previous coring campaigns (from apex to shoreline) along valley-wide cross-sections that are oriented perpendicular to the general flow direction (Cohen, 2003; Gouw & Erkens, 2007; Hijma et al., 2009; Hijma & Cohen, 2011; Tornqvist, 1993). The proportion of organic sediment preserved in the subsurface in the cross-sections of the RMD (Figure S4) displays a parabolic-like curve similar to our experiment (Figure 4c). The peak of this curve for the RMD exists inbound of the mean shoreline likely due to tidal and ecological effects that push the max production zone inbound of the mean shoreline.

Given channel depths, relative sea level rise rates in the Holocene, and delta-top slopes, we estimate a L_t of ~180 km. Early- to mid-Holocene paleogeographic maps document wetland areas spanning ~5-40 km downstream of the modern shoreline (Hijma & Cohen, 2011) resulting in an estimated L_{om} ranging 185-220 km. Our L_{om} estimate

approximates the most proximal longitudinal extent of documented preserved organic matter at ~135 km (Gouw & Hijma, 2022) within a factor of 2. The agreement between theoretical and actual length scales of organic-rich material gives confidence in the utilization of our experimental results to other data sets. This estimation will provide valuable insight into the preservation potential of organic material in global deltas and can be used to address the gap in the global carbon sink.

Estimation of organic matter degradation

The biogeochemical degradation of OM will result in subsidence that contributes to a relative rise in sea level, causing shoreline transgression even in the absence of eustatic sea level rise (Lorenzo-Trueba et al., 2012; Reddy & DeLaune, 2008). While our physical experiment provides a means to approximate the spatial extent of carbon reservoirs in coastal delta systems, our experiments do not capture the biogeochemical degradation of organic carbon (OC). OM decomposition occurs via a wide range of biotic and abiotic processes through the interplay between microbial processes and hydrologic conditions (Reddy & DeLaune, 2008). We applied a simplified linear carbon degradation model to stable and unstable locations within B_w as a proof-of-concept to estimate the preservation potential of carbon within our experiment (see methods). While this approach does not account for oxidants and therefore involves a significant margin of error, the primary objective was to demonstrate the feasibility of OC preservation rather than to achieve precise quantification. Our simplified model suggests at least a 50% OC preservation efficiency in the experimental strata after $1T_c$ (56.8 hr) for OM (Figure 5). Hence, it is

reasonable to expect significant paleo-blue carbon accumulation, even in autogenically active environments.

We recognize that the rate and extent of OM degradation can vary significantly depending on environmental conditions, particularly temperature. Warmer climates typically enhance degradation (Bernier, 2004), while colder conditions slow decomposition, leading to more stable OM accumulation and prolonged periods of shoreline stability. However, in cooler climates, rates of organic productivity are also inhibited, which can offset the reduced degradation (Charman et al., 2013). Productivity, rather than degradation, is often the dominant control on OM accumulation (Charman et al., 2013). These variations in degradation rates can result in complex patterns of shoreline migration over geologic timescales, complicating the interpretation of past sea level changes based solely on sedimentary records.

Bi-directional feedback between organic-rich, non-riverine sediment accumulation and scales of shoreline migration

To explore feedback between autogenic transgression scales and subsurface organic deposits, we compare our experiment (TDWB 19-2 or treatment experiment) with a previous experiment that lacked non-riverine deposition (TDB 18-1 (Straub et al., 2023) or control experiment). The control experiment, which was run with the same boundary conditions but did not incorporate a proxy material for non-riverine deposition, serves as an end case for a spectrum on how OM degradation might influence shoreline migration. In the treatment experiment, there is a dynamic interaction between the accumulation of organic-rich, non-riverine sediment, which reduces scales of transgression, and the role of

coastal wetlands in shaping delta morphology. Here, coastal wetlands do not simply conform to a delta formed by clastic sediment deposition but actively modify it (Sanks et al., 2022). In particular, the accumulation of non-riverine sediment on the delta surface reduces the delta-top slope, creating a slope break near the shoreline (Sanks et al., 2022) and expanding the longitudinal width of B_w . For example, the treatment experiment's average slope near the shoreline is ~ 1.5 times less steep than in the control. This should theoretically increase L_t compared to systems with limited marsh accumulation over time (Figure 3a, b). We note that estimates of L_t are 1.8 times longer in the treatment relative to control experiment (Figure 3a, b; Table 1).

Stabilizing shorelines solely through non-riverine sediment accumulation relies on a balance between non-riverine deposition and accommodation creation. This balance requires near-surface non-riverine sediment accumulation to exceed accommodation production, as some OM will degrade, and some will be compacted with burial. Thus, if primary production is insufficient to facilitate this balance, we should expect strong autogenic shoreline migration over meso-timescales. A reduction in non-riverine sediment accumulation through decomposition would enhance transgression length scales in low-lying, high-organic, coastal systems such as deltas (assuming no changes in clastic sedimentation) because the ability to counter sea-level rise by non-riverine sediment accumulation in the long term would be reduced. This scenario would enhance the spatial extent of preserved OC in the subsurface but volumetrically reduce the OC reservoir. However, a tipping point likely exists where too much reduction in near-surface non-riverine sediment via decomposition by accelerated microbial activity in warmer temperatures alters channel evolution and kinematics, specifically by increasing channel

mobility near shorelines (Sanks et al., 2023). Enhanced channel mobility would steepen delta-top slopes through enhanced fluvial sedimentation (Sanks et al., 2023; Sanks et al., 2022), limiting further expansion of autogenic transgressions and narrowing the active wetland accretion zone on the delta-top, which would reduce the aerial extent of preserved OC in the subsurface. While our two experiments explore the end-members states—one approximating minimal decomposition, which aligns more closely with peat preservation, and the other representing theoretical complete decomposition—further work is needed to explore the feedback loops in surface processes, tipping points, and resulting stratigraphic implications across a spectrum of decomposition rates.

Inferring autogenic and allogenic signals from organic-rich strata

Allogenic and autogenic factors influence the interplay of fluvial, tidal, and wave processes in ancient transgressive paralic successions. While attempts have been made to unravel the relative influence of allogenic and autogenic processes on ancient low-gradient coastal systems (Noorbergen, 2019), this still remains a challenge.

Prior research has applied sequence stratigraphic approaches to OC-rich strata (e.g., coal seams) to indicate environmental and relative sea level change (Diessel et al., 2000; Jerrett et al., 2011). These stratigraphic analyses of coal-bearing sequences identify transgressive and regressive phases, with thicker coal seams often associated with relative sea-level stability or slow-rise periods. Conversely, rapid sea level rise tends to produce thinner seams as the accommodation increases and sediment supply becomes more dispersed. We highlight that the preserved OC-rich strata from the experiment have complexity in thickness, lateral extent, and shape in the absence of temporal variable rates

of eustatic change. However, detailed characterization of the OC-rich strata is beyond the scope of this study.

Our experimental results provide insight into the relationship between autogenic processes and the preservation of organic matter in marginal marine environments. We show that autogenic processes play an important role in where and how organic carbon is deposited on a delta (Figure 2a), which ultimately influences the areal extent of subsurface carbon reservoirs (Figure 2c-e). One implication of our work is an expected proximal to distal scale for OC-rich strata due to autogenic transgressions. This scale would need to be exceeded to interpret changes in paleo-relative sea level rates from OC-rich strata confidently. Autogenic transgressions can span hundreds of kilometers in length (Noorbergen, 2019). Given the extent of many outcrops, it would be difficult to completely support predictions of allogenic forcing based solely on the geometry of coal seams. Many classical sequence stratigraphic studies focus on allogenic forcings to characterize the form and depositional history of OC-rich strata. Our findings suggest that the autogenic processes governing organic carbon deposition in deltas also significantly influence the spatial distribution of OC-rich strata, reinforcing the need to consider both autogenic and allogenic factors in such analyses.

Implications for carbon storage

Coastal river deltas are critical components in the global carbon cycle, functioning as significant long-term net carbon sinks. Large delta systems like the Mississippi and the Ganga-Brahmaputra-Meghna sequester large quantities of organic carbon transported from terrestrial ecosystems (Bianchi & Allison, 2009; Blum & Roberts, 2012). While the carbon

storage potential of deltas is not well constrained over geologic timescales, ancient clinothems have been found to store up to $\sim 16 \text{ t OC km}^{-2} \text{ yr}^{-1}$ (Hage et al., 2022). The sequestration of carbon over geologic timescales in marginal marine environments has significant implications for our understanding of carbon cycle feedback mechanisms. The complex processes driving the deposition and preservation of carbon in these settings are critical for deciphering past climatic conditions and predicting future climate scenarios. We highlight the natural variability in the fluxes tied to this budget, with implications for the subsurface extent of carbon-rich strata due to autogenic processes. Autogenic processes at the local and lobe scale play a crucial role in the degradation and decomposition of organic carbon by directly affecting how organic carbon is exposed to oxygen at the surface and reworked or buried below an active layer (Hou & Torres, 2022). Previously buried OC may be re-exposed to oxygen when channels shift course, enhancing decomposition rates. Conversely, rapid sedimentation caused by autogenic processes can quickly bury OC, limiting exposure to oxygen and reducing degradation. We hypothesize that autogenic processes increase the flux of OC into the long-term sediment record. This occurs because autogenic processes create conditions that facilitate rapid and efficient carbon burial. Abandonment and subsidence of sites on the delta surface create pockets of accommodation that are lower in elevation than the average graded profile. When sediment transport returns to these locations, accommodation is filled with limited to no reworking, leading to rapid and efficient carbon burial.

The three-dimensional dynamic nature of autogenics creates non-uniform patterns of shoreline migration and introduces heterogeneity in carbon burial and preservation, making it challenging to predict long-term carbon storage efficiency across deltaic

environments from measurements that span the instrumental record. However, a key aspect of understanding carbon sequestration in these environments is the consideration of channel mobility and compensation timescales. The balance of these timescales should influence the overall efficiency of carbon sequestration. We show that these autogenic processes do not need to be coupled with allogenic processes, such as temporally variable eustatic sea-level rise or other climatic changes, to create complex feedback mechanisms that influence carbon sequestration efficiency. However, the relative importance of autogenic versus allogenic controls can vary spatially and temporally, necessitating high-resolution studies to disentangle these influences.

Methods

Experimental setup

The experiment was conducted at the Tulane University Sediment Dynamics and Stratigraphy Laboratory. Although the physical experiment described here is of reduced scale and an idealized system, scale-independent processes allow for the construction of strata at laboratory scales with similar structure as natural systems (Paola et al., 2009). The input sediment mixture was based off experiments by Hoyal and Sheets (2009) and consisted of grain sizes ranging from 1 to 1000 microns with a mean grain size of 67 microns (Straub et al., 2015). The coarsest fraction of the distribution was dyed red to aid the visualization of stratigraphic architecture. A small amount of commercially available polymer (New Drill Plus) was added to the sediment mixture to enhance sediment cohesion, which aids the formation of channels (Hoyal & Sheets, 2009). The addition of a biodegradable dye to the input water helped characterize the morphodynamics. The

experiment took place over two stages: progradation (no base-level rise, 120 hours) and aggradation (steady base-level rise, 560 hours). The constant base-level rise rate mimics a spatially uniform long-term subsidence pattern, where generation of accommodation was set to balance the input clastic sediment supply.

A low bulk density kaolinite serves as the proxy for the organic-rich, non-riverine sediments in overbank regions. We acknowledge complexity in where and how organic-rich sediments from wetlands and tidal flats accumulate that are dependent on several forcings. However, we simplify adding a non-riverine sediment proxy in this experiment based solely on elevation relative to sea level, which acts as a first order control on field scale wetland accumulation. A rule-based parameterization developed by the ecology community (Fagherazzi et al., 2012; Morris et al., 2002) coupled with elevation information from topographic scans determined locations conducive to wetland formation and thus where the proxy deposition occurred. The maximum vertical roughness scale resulting from autogenic processes (i.e., maximum channel depth) from a prior experiment (TDB 18-1; Sanks et al. (2022)) served as a reference for elevations conducive to wetland formation. A programmable carriage mounted above the basin that can move in the three Cartesian directions deposited the non-riverine sediment proxy every two hours via a sieve attached to a ButtKicker LFE transducer (Figure S5). The proxy material was distributed in all locations with an average elevation between -9 mm and 5 mm relative to sea level. Sites within the ranges -9 mm to -5 mm and 0 to 5 mm received deposition 0.9 times relative sea-level rise (RSLR) (1.7 g of proxy), and locations within the -5 mm to 0 mm elevation window received deposition 1.8 times RSLR (3.4 g of proxy) (Figure S6).

Following compaction of the proxy material, ‘long-term’ deposition rates were all well below relative sea level rise rates allowing for autogenic transgression to occur.

Data collection

We collected data during each experiment to define system morphodynamics, surface topography, and stratigraphy. A digital camera positioned above the basin collected images of the active delta-top to capture surface dynamics at 15-minute intervals. Overhead RGB images were loaded into the software ImageJ to hand map river channel networks. Mapped channel networks were then exported as binary TIFF files (Sanks et al., 2023). A FARO Focus 3D S120 laser scanner collected topographic measurements every two hours to construct a Digital Elevation Model (DEM). Each DEM had a vertical resolution of ~0.5 mm on a horizontal grid with 5 mm x 5 mm cells.

Upon completion of the experiment, 27 strike-oriented sections of the deposit were made at 10 cm intervals from distal to proximal and one dip-oriented section (Figure 1c) was made at approximately the middle of the deposit. This allowed for the characterization and quantification of channel sandbodies, clastic overbank deposits, and organic-rich deposits. Images were taken of each strike-section and loaded into Agisoft Metashape Professional to produce orthophoto images referenced to the basin coordinate system. Orthophotos were used to link the known temporal and spatial position of the local shoreline to the vertical and spatial distribution of the proxy organic strata.

Error associated with deposition of proxy material

We compile a series of maps that define where non-riverine sediment proxy was deposited on the delta's surface based on the collected topographic maps used to deposit sediment every two hours. Due to the mechanical compaction of clay within our distribution system, rates of non-riverine sediment proxy deposition varied from programmed rates with an error of 33%. This error resulted in actual deposition rates that were 32% less than ideal rates for the entire experiment, and this error was incorporated when compiling non-riverine sediment proxy accumulation rates at each distribution site. Summing these maps allows us to create a map that shows the spatial distribution of organic sediment proxy accumulation on the delta surface for the entirety of the experiment (Figure 2a).

Quantifying experimental autogenic timescales

Characterizing the coupled dynamics between autogenic processes and non-riverine deposition in coastal wetlands can provide a means to understand the longitudinal spatial scales of carbon reservoirs in the subsurface. To start on this path, it is necessary to quantify the duration that an abandoned location on the delta can experience transgression, which would cause landward migration of coastal marshes. Theoretically, we link the maximum scale of transgression to the maximum autogenic abandonment timescale on the delta. After that maximum autogenic time, the abandoned location is revisited by the clastic system and, therefore, can aggrade clastic sediment to offset a relative sea-level rise rate (RSLR). Previous work suggests that a compensation timescale, T_c , characterizes the maximum autogenic timescale in a system (Wang et al., 2011). T_c is the timescale at which the deposits of a channelized system statistically switch from being controlled by the geometry of the system's sediment transport system to being controlled by its sediment supply and

accommodation production (Wang et al., 2011). Important for this study, we note that for this balance to be met, each spot on the delta must be visited by the clastic transport system at least once during a compensation timescale. Binary channel maps created from overhead images were coupled with topographic scans to quantify H_c for the system.

While the compensation timescale can be estimated using the scaling argument from equation (1), high spatial and temporal resolution data allows us to directly measure how T_c varies as a function of distance downstream from the channel inlet. The transition timescales identified for TDWB 19-2 and TDB 18-1 (Figure 3c, d) fall within the range of these compensation timescale values calculated as a function of distance downstream (Figure S2).

A second autogenic timescale characterizes the lateral mobility of a transport system (Cazanacli et al., 2002; Straub & Esposito, 2013; Wickert et al., 2013). This channel timescale, T_{ch} , equals the time necessary for 95% of a delta-top area to be visited by channelized flow (Sanks et al., 2023; Straub et al., 2015). We used established methods (Wickert et al., 2013) to quantify channel mobility through T_{ch} in the experiment.

L_t framework

To determine if cut-and-fill processes or stasis dominates the system, we calculate β , the ratio of the channel mobility timescale (T_{ch}) to the compensation timescale of the system (T_c).

$$\beta = \frac{T_{CH}}{T_C} \quad \begin{cases} \beta \leq 1, \gamma = \beta, \text{cut – and – fill dominates} \\ \beta > 1, \gamma = 1, \text{stasis dominates} \end{cases} \quad (4)$$

If β is less than or equal to one, then the channels in the system are highly mobile compared to the time it takes for locations on the delta to aggrade one channel depth, and thus cut-and-fill processes dominate. However, while cut-and-fill is occurring near the shoreline, the lateral distribution of sediment across the delta by the highly mobile channel reduces the maximum L_t that can occur. If β is greater than one, locations on the delta's surface are generally only visited once by a channel during the time it takes for locations on the delta top to aggrade one channel depth. Therefore, the maximum autogenic timescale that influences shoreline migration is T_c , and stasis dominates. β has been experimentally observed to span values from 0.16 – 2.0 (Li et al., 2017; Straub & Esposito, 2013). In general, channel networks on experimental deltas with high β values more resemble large low gradient field scale deltas constructed from single thread channels, compared to low β experiments.

Power spectra analysis

The two delta experiments referenced in this study were run for 560 hrs, approximately ten times the timescale associated with stochastic dynamics. Therefore, we consider our time-series data ergodic (i.e., long enough to be representative of all possible realizations). Prior to spectral estimation, time series data were pre-processed via mean subtraction and linear detrending. We used the Multi-taper method (MTM) (Thomson, 1982) for the spectral estimation of time series for every location along the shoreline. The MTM applies several overlapping windows (i.e., tapers) to the dataset to reduce leakage and distortion in the frequency spectrum. Power spectra were then ensemble averaged to reduce location-specific variability and obtain a representative signal of the entire shoreline's behavior.

Autogenic timescales can be observed as rollovers or slope changes in spectral estimation (Jerolmack & Paola, 2010). Our data exhibit a concave-up shape in log-log space, typically corresponding to power-law relationships with exponents greater than one. Therefore, we used a three-segment piecewise linear regression to identify breakpoints. We loop through all possible combinations of two breakpoints and calculate the Sum of Squared Residuals (SSR) and Akaike Information Criterion (AIC). The combination of breakpoints that results in the lowest AIC value are considered the most statistically significant locations where changes in slope occur. While we statistically determined two breakpoints, we focus on the breakpoint at the longest period, as it represents the interpreted transition from red to white noise and the first breakpoint is only a consequence of fitting a linear trend to power-law distributed data.

Boundary conditions for TDWB 19-2 resulted in a longitudinally extensive delta lobe at the initiation of the experiment (see Figure 1B, panel 1). To determine any potential impacts to the breakpoint location in the power spectra resulting from the initial condition, spectral estimation was applied to time series data after hour 150, when this lobe was no longer present due to transgression. Spectral analysis demonstrated a rollover point at $T = 51.2$ hr. (Figure S3), approximately five hours less than the rollover point when time series data associated with the delta lobe were included, and therefore, minimal impact to T_c .

Reactive continuum model

In the reactive continuum model, we assume that all OC degrades at the same rate and recognize that OC degradation is also dependent on depositional and climatic variables. Our experiment does not aim to replicate any one field setting. While we do not incorporate

tidal forcings in our experiment, tidal forcings can influence OC accumulation and burial. The potential for OC accumulation can range from low in tide-dominated environments with limited delta plains to high potential in tide-influenced environments, where tidal forcings can stabilize channels and reduce the migration of distributary channels, ideal for OC accumulation (Rossi et al., 2016; Shen et al., 2024).

Non-riverine sediment proxy was incorporated into the experiment such that the deposit thickness in the maximum wetland production zone would match the base-level rise rate. We use T_c , $\bar{r}$, and the mass of non-riverine deposition within a single hex cell area—1.7 g in the unstable/stable zone and 3.4 g in the max production zone (Sanks et al., 2022)—on the delta surface for a single run cycle in the experiment. We assume that all non-riverine deposition within the experiment is OM. OM is converted to OC using the relationship $OC \% = OM\% * 0.4541$ (Steyer et al., 2012). To estimate the mass of OC preserved at depth, we use a reactive continuum model:

$$\frac{\partial C}{\partial t} = -w \frac{\partial C}{\partial z} - kC \quad (5)$$

Where C is the organic carbon content, t is time, z is depth, k is the reaction rate constant, and w is the long-term sedimentation rate. In this model, sedimentation rate is $\bar{r}$ as there is no stochasticity to the rate at short timescales. We model OC degradation at steady state with a time-varying k over one T_c , such that:

$$0 = -w \frac{\partial C}{\partial z} - kC \quad (6)$$

$$k = \frac{u}{a+t} \quad (7)$$

where u is a measure of the distribution of intrinsic reactive types of OC, and a is the initial age of OC (Boudreau et al., 2008). We use the values for u and a reported by Boudreau et al. (2008), where a is a small but finite value to represent the initial age of the material at deposition. While the initial age is effectively zero, the inclusion of a small a avoids numerical issues at $t = 0$ and ensures a realistic starting degradation rate without significantly affecting the results. We assume that any reworked proxy leaves the system and is not stored downstream of its source.

List of Figures

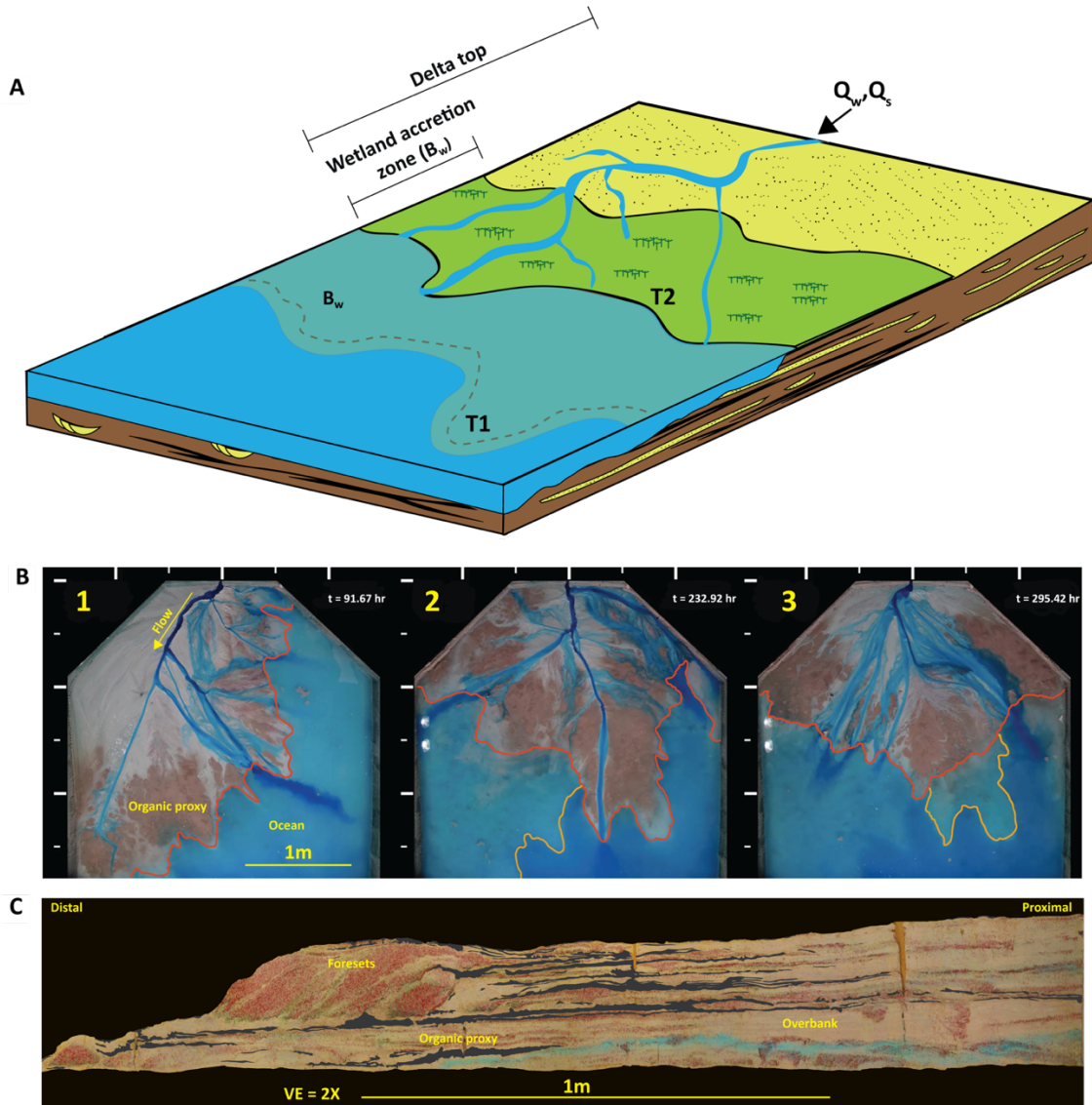


Figure 1. Autogenic transgressions. **a** Block diagram of autogenic transgression on a delta. Dashed and solid lines represent shoreline at times T1 and T2, respectively. The wetland accretion zone (B_w) extends upstream and downstream of the shoreline, which increases the longitudinal distance where organic-rich, non-riverine sediment is preserved (black colored seams in subsurface). The shaded region at T1 represents B_w at T1. **b** Overhead images of autogenic transgression during the experiment. Shorelines are outlined in orange and transgressed areas are outlined in yellow. In panels 1 and 2, the active lobe aggrades due to combined input of organic material and fluvial sedimentation, while topographic lows develop, and marine flooding occurs in regions abandoned by the clastic routing system. In panels 2 and 3, the main channel avulses to fill the topographically low area on the delta surface, causing the shoreline of the abandoned lobe to transgress landward. **c** Stratigraphic dip section from the resulting experimental deposit. Note the autogenically derived tapering of organic-rich deposits (dark gray) preserved. Maximum preservation occurs around the mean shoreline (~1.5-2 m downstream).

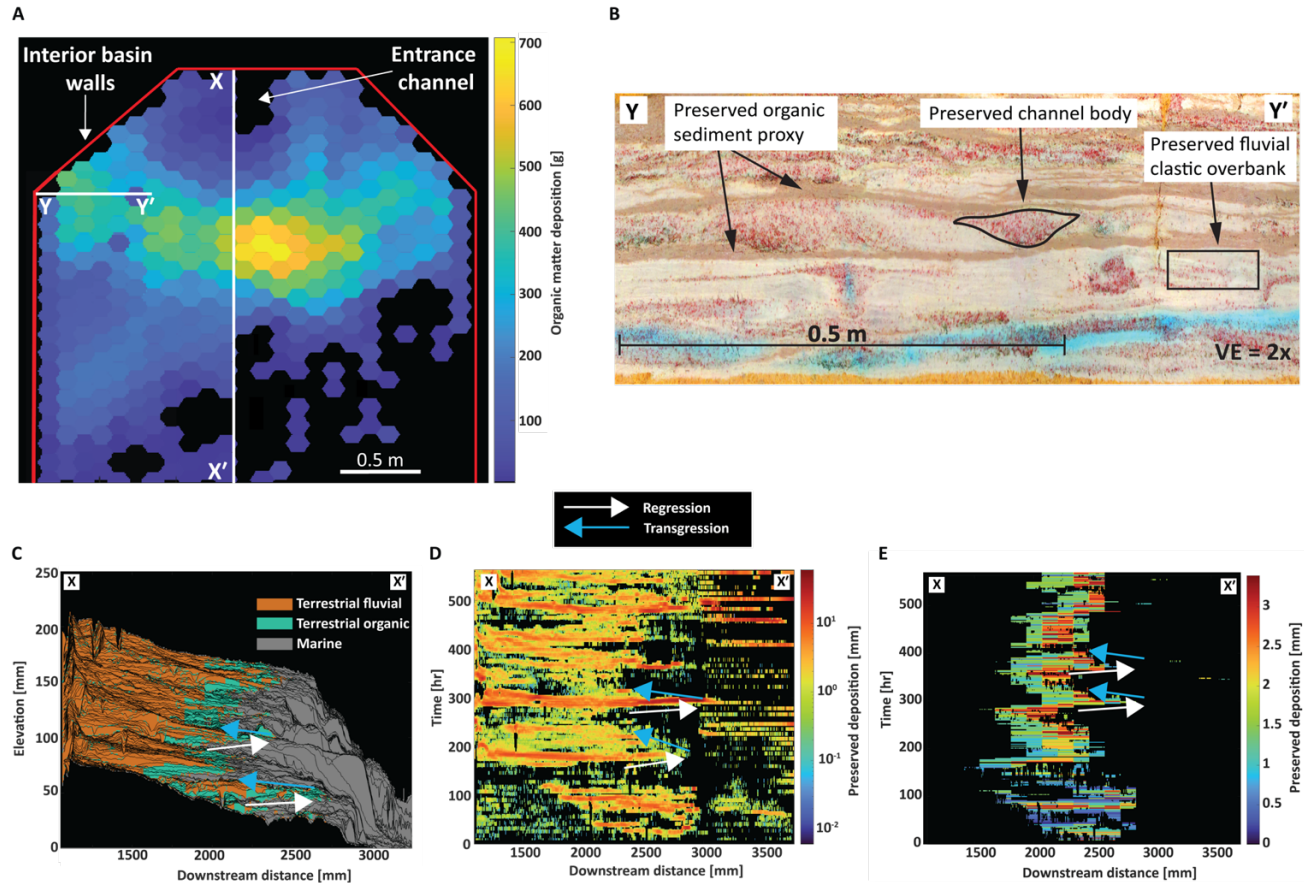


Figure 2. Spatial distribution of organic sediment proxy deposition. **a** Deposition map of proxy material over the 560 hr runtime. **b** Strike section of the deltaic stratigraphy at cross-section Y-Y' shown in **a**. White sediment is representative of overbank deposits, red sediment is representative of coarse clastic deposits, and brown sediment is the preserved organic sediment proxy. **c** Synthetic stratigraphy colored by depositional environment along dip-section X-X' shown in **a**. **d** Wheeler diagram of all sediment preserved deposition along X-X'. **e** Preserved deposition of only non-riverine deposition along X-X'.

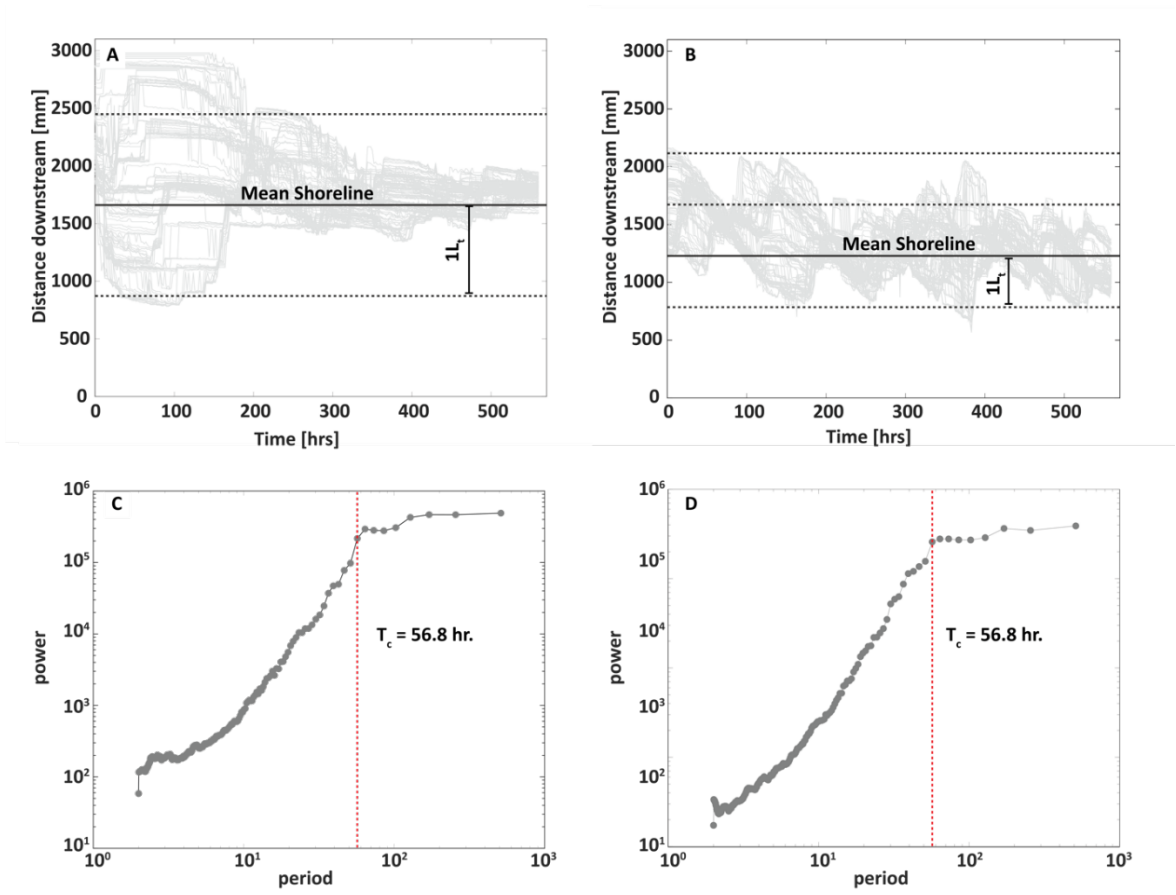


Figure 3. Correlation of shoreline movement with T_c . Time series of shoreline location (colored and gray lines) for (a) TDWB 19-2 (this study) and (b) TDB 18-1 (experiment with no non-riverine deposition). The bold black line is the location of the mean shoreline and dashed black lines represent distance of one L_r . c, d Ensemble averaged power spectra plots for time series in TDWB 19-2 and TDB 18-2, respectively. Dashed red line is the transition from red to white noise and indicates the period at which the longest correlated shoreline migration occurs.

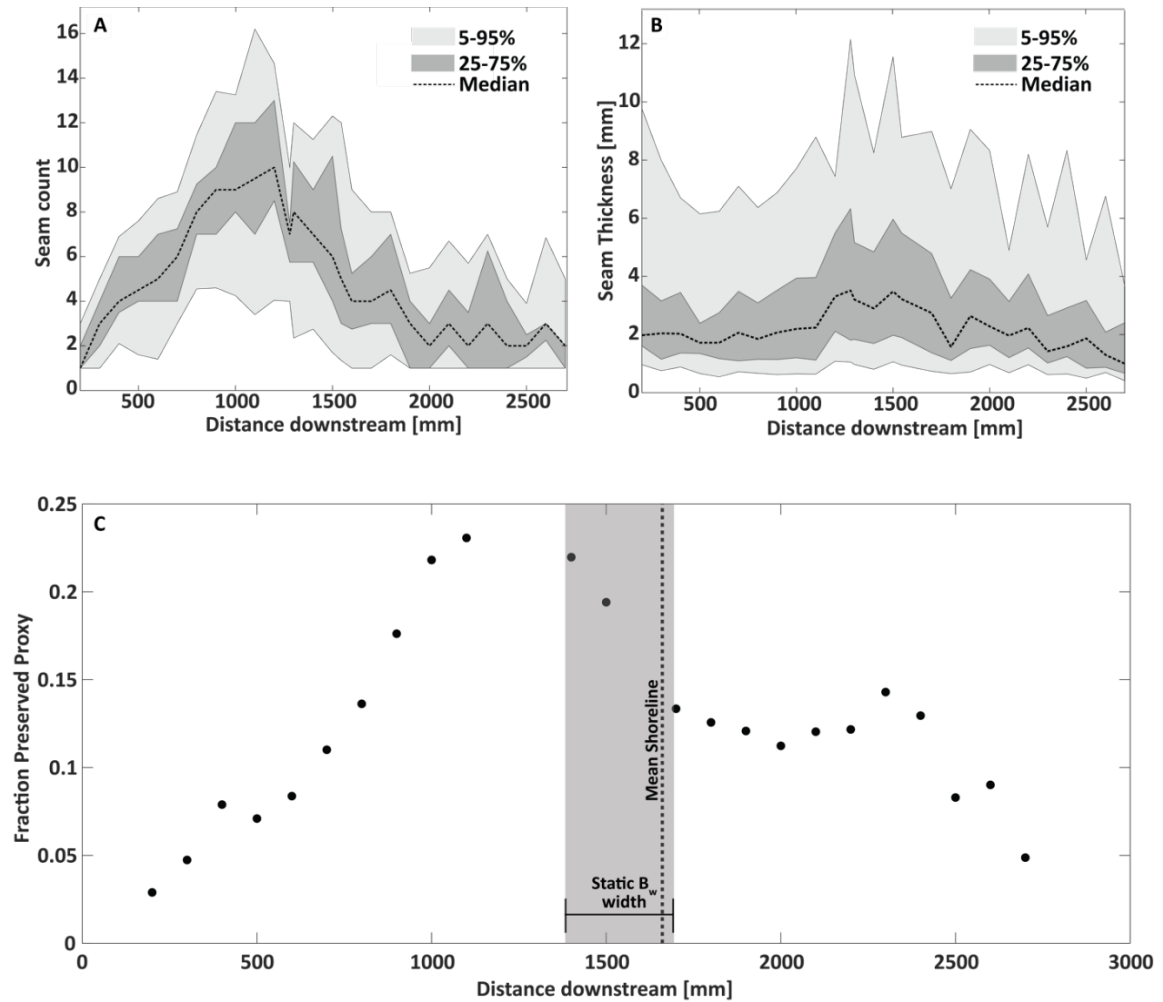


Figure 4. Measurements of proxy organic carbon preservation in experiment. **a** Distribution of the number of organic-rich proxy seams preserved in the subsurface. **b** Distribution of non-riverine sediment proxy seam thickness. **c** Fraction of strata that is organic-rich as a function of distance downstream. The spatial extent where non-riverine sediment is preserved in the subsurface is ~ 7 times greater than that of a geometric model constructed with average topset and foreset slopes (shaded region).

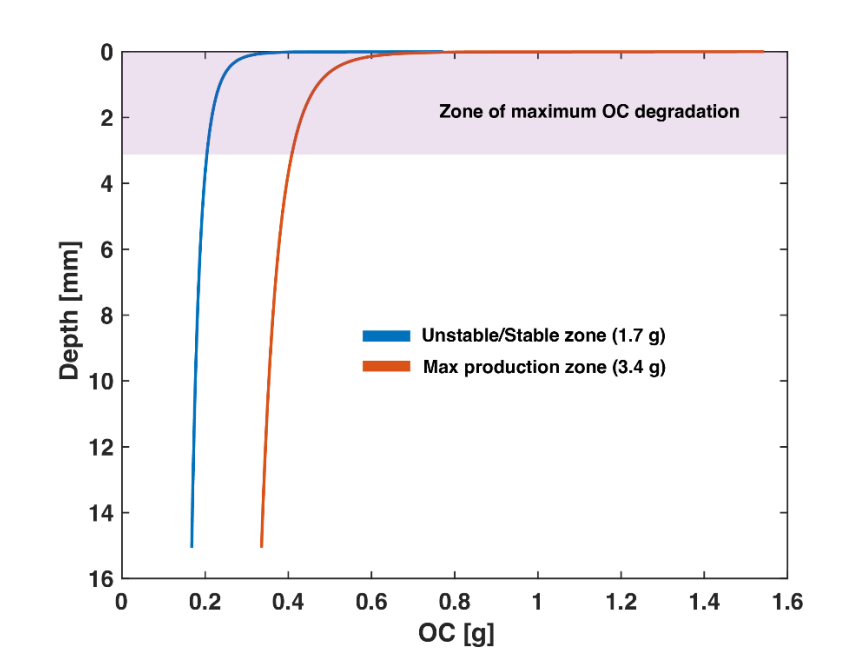


Figure 5. Estimation of OC degradation. Modeled OC degradation for $T = 58.6$ hrs. ($\sim 1T_c$) for unstable (1.7 g proxy) and max production (3.4 g proxy) zones within the experiment. Most OC degradation occurs at very shallow depths between 0-3 mm, after which OC degradation becomes minimal.

Table 1. Parameters for L_t estimation

	s [-]	RSLR	$\bar{T}_c$	T_{ch}	β	γ	L_t	L_{OM}
TDWB 19-2 (Treatment)	0.018	0.25 [mm/hr]	54.00 ± 13.90 [hr]	176 [hr]	3.26	1	788.89 [mm]	1887.78 [mm]
TDB 18-1 (Control)	0.032	0.25 [mm/hr]	59.28 ± 27.40 [hr]	170 [hr]	2.87	1	443.75 [mm]	
Rhine- Meuse	5E-5	0.0015 [m/yr]	6000 [yr]	$>> 6000$ [yr]	> 1	1	180 [km]	185- 220 [km]

*Reported $\bar{T}_c$ values are basin averages

Supplementary Material

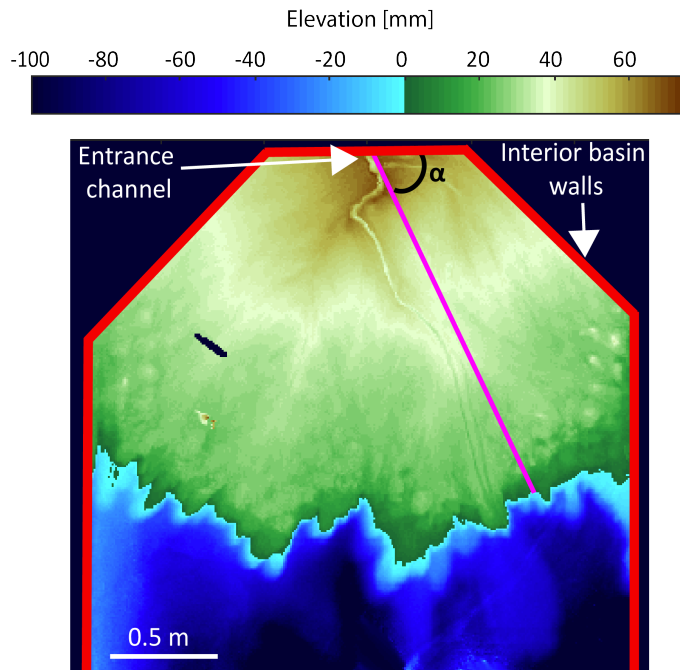


Figure S1. Measurement of delta shoreline. Example DEM of the delta with transect extending out from channel inlet to shoreline. Black area on the delta top represents a zone where no data was captured. Shoreline locations were measured at the intersection of the shoreline and transect.

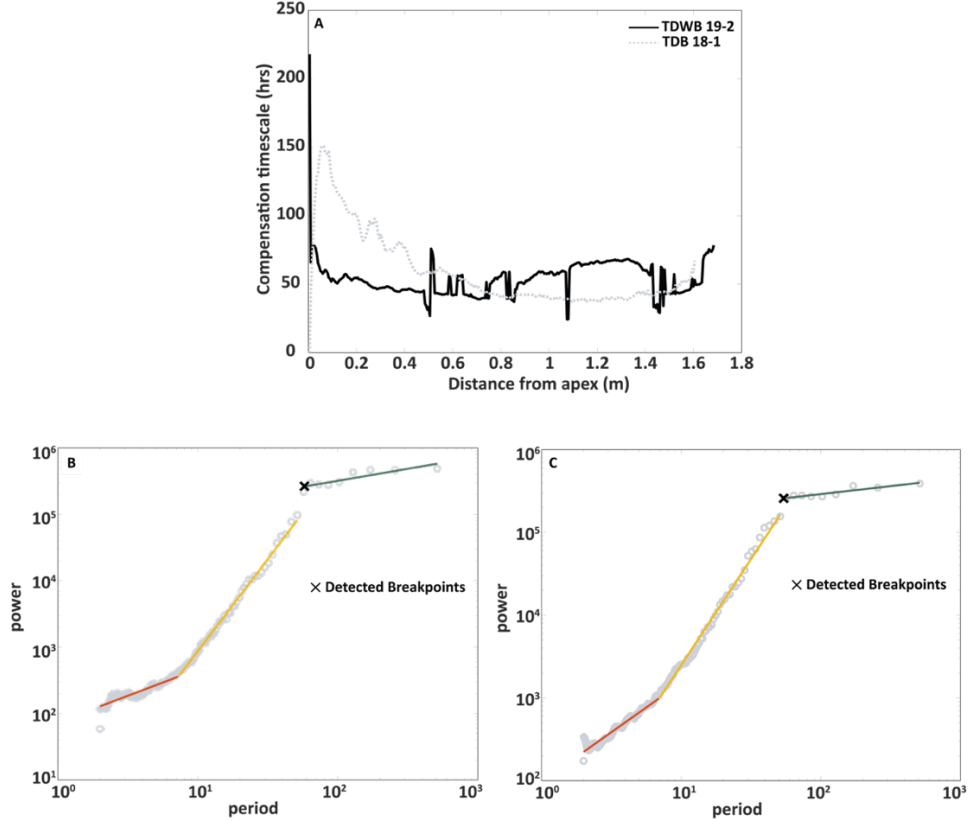


Figure S2. Measured T_c as a function of downstream distance. **a** T_c measured at radial distances at 5 mm increments from the delta apex for TDWB 19-2 and TDB 18-1. **b,c** Breakpoint detection for TDB 18-1 and TDWB 19-2, respectively.

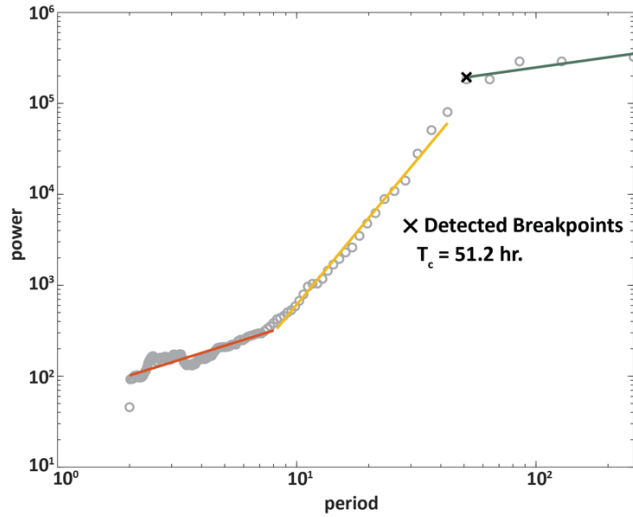


Figure S3. Measured T_c after runtime hour 150. T_c measured after $T = 150$ hr. to determine impact of delta lobe on T_c at initiation of experiment. T_c decreases by approximately five hours.

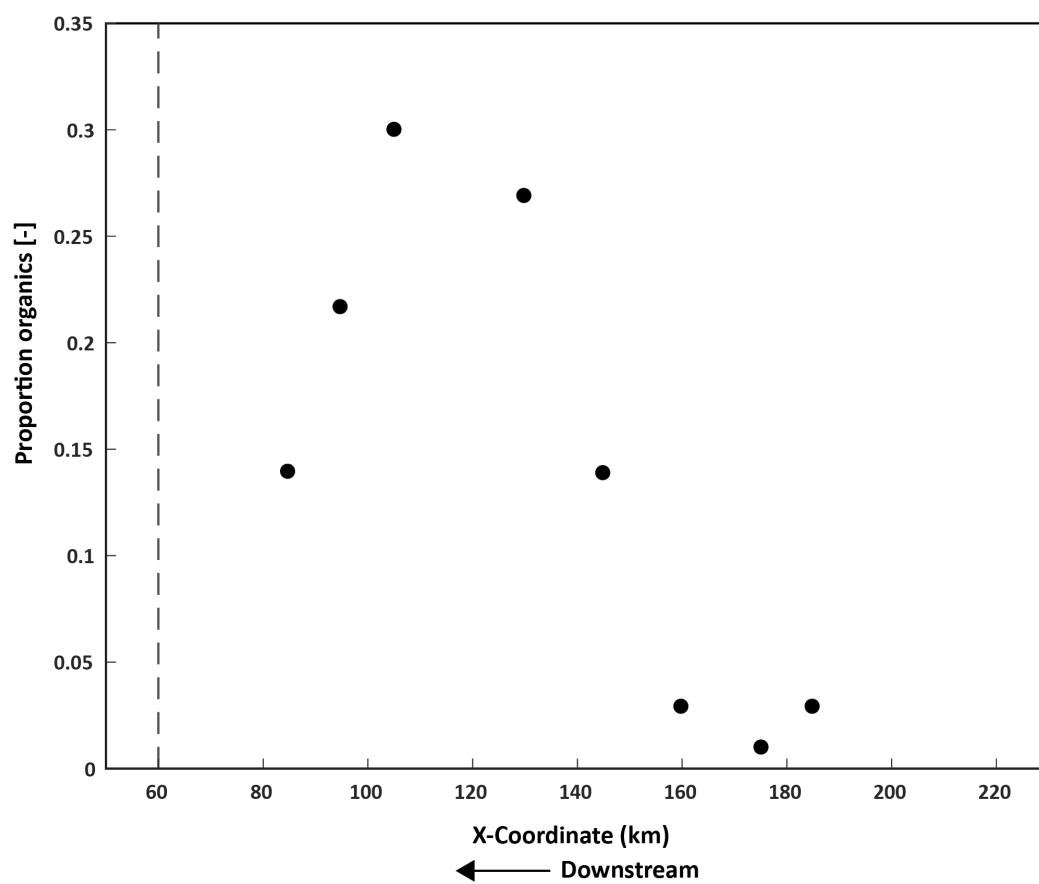


Figure S4. Proportion organics in RMD cross-sections. Proportion of organic matter for cross-sections reported in Gouw and Hijma (2022). X-axis shown in Dutch coordinate system (km). Dashed vertical line represents the modern shoreline location.

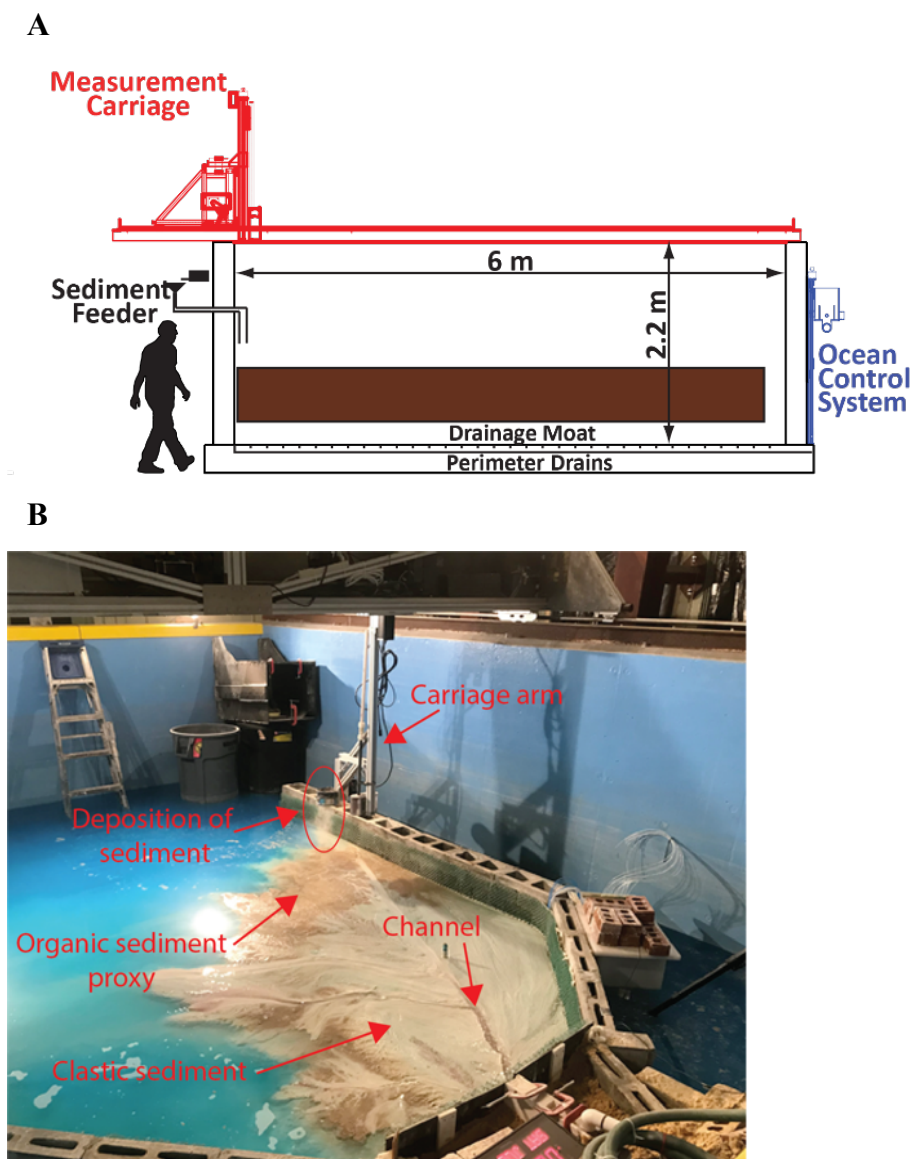


Figure S5. Experimental setup **a** Schematic of the Tulane Deepwater Basin with measurement carriage and ocean control system. **b** Image showing the deposition of the non-riverine proxy via the carriage system.

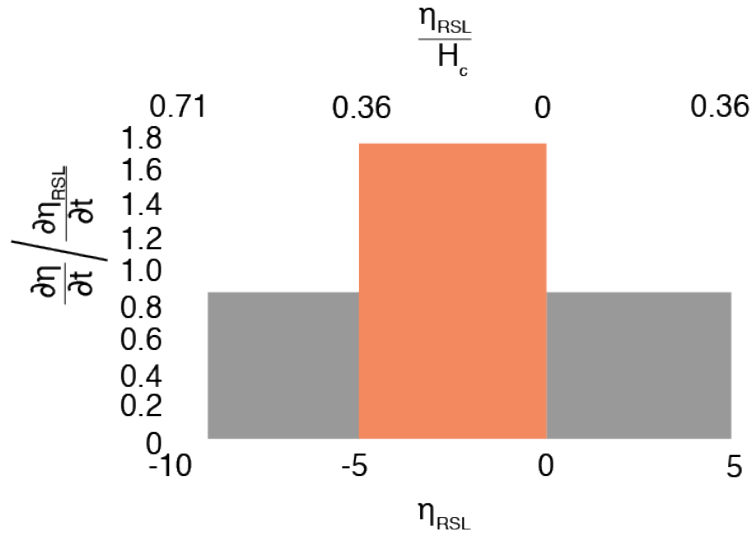


Figure S6. Simplified biomass production model applied to the treatment experiment. Short-term deposition rates normalized by accommodation production rate for elevations relative to sea-level (η_{RSL}) that are within the deposition window. The top x-axis shows elevations within the deposition window normalized by the maximum channel depth (H_c). The deposition window is approximately one-third of one channel depth above sea level and two-thirds of one channel depth below sea level.

Table S1. Boundary conditions for experiments

Delta Experiment	Run Time (hr)	Q_w (m^3/s)	Q_s (kg/hr)	RSLR (mm/hr)	Proxy (g/hr)
Treatment (TDWB 19-2)	560	1.70E-4	1.40	0.25	200
Control (TDB 18-1)	560	1.70E-4	1.40	0.25	

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Chapter 3

Variable flood discharge constrains organic carbon preservation in deltas: Insights from physical experiments

Jose R. Silvestre, Zachary Hom, Kelly M. Sanks, Samuel M. Zapp, John B. Shaw, Kyle
M. Straub

Abstract

Many global and regional climate models predict a hydrologic shift to enhanced flood discharge variability as temperatures warm. It is unclear how a transition to increased discharge variability will influence the development of deltas and their wetlands. We address this knowledge gap via two reduced-scale physical delta experiments: one with constant discharge and the other with variable discharge. Results document that floods with a peak discharge equal to three times the baseflow reduce the mean total delta-top area (combined terrestrial area upslope of the wetland and wetland area) by a factor of two and a half and increase slopes by a factor of two. These steeper slopes combined with enhanced channel mobility, limit the ability of the shoreline to undergo large-scale transgressions or regressions, restricting the spatial development of the wetland platform. We find that variable discharge conditions reduce the fraction of preserved organic material in the subsurface by approximately 35% compared to constant discharge conditions. These morphometric differences between systems constructed under constant vs. variable discharge highlight the potential impact to ecologically sensitive and economically important coastal wetlands, with implications for the ability to sequester carbon.

Introduction

The predicted increase in precipitation and high-magnitude flood frequency driven by ongoing climate change (Intergovernmental Panel on Climate, 2023) has implications for deltaic environments. These landscapes are shaped by wetlands interacting with sediment and water delivered sourced from rivers, in addition to coastal processes such as wave action and tidal dynamics (Edmonds & Slingerland, 2009; Lauzon & Murray, 2018; Nienhuis et al., 2020). Given this, they are particularly vulnerable to hydrological changes. Variable discharge influences channel morphology, sediment transport, and patterns of deposition (Plink-Björklund, 2015), thereby altering delta morphodynamics (Barefoot et al., 2021; Chadwick & Lamb, 2021; Esposito et al., 2018; Ganti et al., 2016; Plink-Björklund, 2015). Experimental and field studies have demonstrated that channels constructed under highly variable discharge conditions exhibit greater mobility and more dynamic morphologies than those formed under low discharge variability (Barefoot et al., 2021; Esposito et al., 2018; Leenman et al., 2025). This increased channel mobility raises questions regarding the resilience of deltaic systems and has implications for the continued stability of coastal wetlands.

The ecological and biogeochemical functions of deltaic wetlands, which offer vital ecosystem services, depend on sediment delivery. However, climatic and anthropogenic influences pose risks to these ecosystems. Rising sea levels threaten to outpace vertical accretion of wetlands, leading to land loss (Li et al., 2024). Human activities such as construction of dams and artificial levees can significantly reduce sediment delivery to the topset of coastal deltas (Edmonds et al., 2023; Nienhuis et al., 2020), further exacerbating the already fragile stability of these coastal wetlands. While the impacts of enhanced

discharge variability on wetlands are not fully constrained on any timescale, here we will focus on timescales equal to or exceeding those linked to delta lobe construction and abandonment.

The longitudinal extent of deltaic coastal wetlands is constrained by their elevation relative to mean high tide (Kirwan et al., 2023; Morris et al., 2002). We hypothesize that variations in river discharge can destabilize this equilibrium, influencing the spatial distribution and mobility of wetlands over time. These dynamics have implications for organic carbon preservation, as wetlands are a substantial source of organic-rich deposits (Chmura et al., 2003) that contribute to long-term carbon sequestration within deltaic stratigraphy. While previous studies document the effects of discharge variability on channel mobility, the quantitative impact of such variability on the preservation of organic-rich strata within deltaic environments remains unclear. Earlier studies found that deltas constructed under variable discharge exhibit more mobile channels, greater floodplain reworking (Esposito et al., 2018), steeper slopes, and more stable shorelines, all of which we hypothesize should influence the areal extent of wetlands on deltas and their preservation as carbon rich deposits in the subsurface.

This study aims to quantitatively assess how variability in river discharge influences wetland extent, channel mobility, and the preservation of organic-rich strata within deltaic environments. To address this research gap, we conducted two reduced-scale physical delta experiments: one under steady discharge and the other under highly variable discharge. The experimental conditions were designed to isolate the effects of discharge variability on delta morphodynamics observed in natural systems. We quantified temporal changes in delta-top area and slope, key factors controlling wetland extent (Sanks et al.,

2022). Additionally, we measured shoreline location as an indicator of channel mobility for each system, as lateral movement of channel position is often accompanied by corresponding changes in shoreline morphology (Kim et al., 2006; Martin et al., 2009; Straub et al., 2015). By quantifying these parameters, we investigate how discharge variability influences wetland stability, channel network dynamics, and the potential for organic carbon preservation in deltaic systems. These insights are critical for understanding how future discharge regimes may affect the resilience of deltaic wetlands and their role as long-term carbon reservoirs.

Methods

We investigate how variable discharge influences wetland and delta morphology, area, and preservation of carbon-rich strata using two reduced-scale physical delta experiments. One experiment was forced with a constant input flux, while the other was forced with variable discharge (Figure 1, S1, Table S1). Experiments were conducted at the Tulane University Sediment Dynamics and Stratigraphy Laboratory and allowed to evolve autogenically under constant base-level rise (i.e., pseudo-subsidence). Water and clastic sediment were delivered to the experiments through an entrance channel, while a proxy material for non-riverine deposition (kaolinite clay) was introduced via overhead deposition that accumulated on the delta-top following an elevation-based model, which is representative of all organic-rich, non-riverine sedimentation within deltaic coastal environments (e.g., wetlands and tidal flats) (Morris et al., 2002; Sanks et al., 2022). We henceforth refer to this material as non-riverine sediment for simplicity. A programmable carriage that can move in all Cartesian directions deposited the non-riverine sediment from overhead via a

motion-activated sieve. Error associated with the deposition rates was approximately 33% in the constant discharge experiment; however, delivery efficiency was greater in the variable discharge experiment. Non-riverine sediment was distributed in all locations with mean elevations between -9 mm and 5 mm relative to sea-level, which we define as wetlands. Elevations greater than 5 mm were defined as the area upslope of the wetland. Elevation windows -9 mm to -5 mm and 0 to 5 mm received non-riverine deposition ~ 0.9 times the base-level rise and elevations between -5 to 0 received deposition ~ 1.8 times base-level rise. After compaction, deposition rates were at or below base-level rise rates, which allowed autogenic movement of the shoreline.

All other boundary conditions were held the same in the two experiments. For the variable discharge experiment, the discharge of water and sediment during flood was three times that of low flow periods (base-flow). Sediment discharge generally increases faster than linear relative to water discharge (Nittrouer et al., 2008), but the ratio of sediment to water discharge was kept constant over the flood-interflood cycle for simplicity (Esposito et al., 2018). The average discharge of water and sediment during a flood-base flow cycle was identical to the constant discharge experiment. To achieve this, the base-flow discharge was $\sim 83\%$ of the discharge in the constant discharge experiment. Each cycle lasted 66 minutes – 59 minutes at base-flow and 7 minutes at flood. The ratio of flood to interflood duration and flood to baseflow discharge were motivated by yearly floods on the Mississippi River, but we emphasize that scaling experimental floods to field systems is challenging due to natural complexity. Rather than rigorous scaling to any modern system, our aim is to force the experimental fluvial network with a variable hydroclimate (Paola et al., 2009).

The fluvial clastic sediment mixture used in the experiments was based on a cohesive mixture developed by Hoyal & Sheets (2009) and consisted of grain sizes ranging from 1 to 1000 microns with a mean grain size of 67 microns. A small amount of polymer was added to the sediment mixture to enhance sediment cohesion, which aids in the formation of channels. Overhead imagery and surface topography of the active delta-top were captured at a frequency sufficient to quantify the surface dynamics. Strike-oriented sections of the resulting delta deposits were made at 10-cm intervals from distal to proximal to quantify the spatial distribution of proxy organic material preserved in the subsurface.

Results

Delta-top and wetland morphology

We first focus on a comparison of delta-top area in the two experiments. We compare the total delta-top area (>-9 mm), but also the area upslope of the wetlands (>5 mm) and the area of the wetlands (-9 mm to 5 mm) to quantify the response to floods in different geomorphic zones. We then measure delta-top slopes as this parameter influences the sensitivity of the delta-top to large shoreline fluctuations. Lower slopes are more sensitive to shoreline fluctuations and yield more wetland area, resulting in greater preservation of organic matter in the subsurface at any one time.

The mean area upslope of the wetland zone was larger by a factor of three in the constant discharge experiment than in the variable discharge experiment. In the constant discharge experiment, the area upslope of the wetland exhibited a large-scale oscillation with an amplitude of ~ 1.5 m² over a duration of ~ 300 hours. In contrast, the area upslope of the wetland within the variable discharge did not experience any large-scale oscillations.

Rather, the area upslope of the wetland experienced a steady increase from $\sim 0.5 \text{ m}^2$ to $\sim 1 \text{ m}^2$ and remained relatively constant over the duration of the experiment (Figure 2A).

Likewise, the wetland area in the constant discharge experiment also experienced a large-scale but inverse oscillation of $\sim 1.5 \text{ m}^2$ (Figure 2B). While the area upslope of the wetland experienced a decrease, the wetland area increased to an area of approximately 2.5 m^2 over a period of ~ 200 hours before reaching an apparent dynamic equilibrium. This phase of growth was characterized by consistent wetland development under steady hydrological conditions. These oscillations are a result of episodic terrestrial sediment storage events likely driven by large-scale autogenic processes (e.g., compensation filling of accommodation facilitated by avulsions) within the system. In this case, punctuated relocation of the clastic sediment transport system followed by long timescale network stability results in abandonment and drowning of old wetlands while new wetland platforms develop in other regions. In contrast, the variable discharge experiment exhibited a markedly different pattern. Mean wetland area was smaller than the wetland area in the constant discharge experiment by approximately a factor of 2.5 and remained relatively constant. The relative absence of large-scale cyclicity highlights frequent clastic sediment redistribution caused by forcing conditions that were constantly changing and increased channel mobility that favored consistent lateral migration over punctuated avulsions. In this case, variable discharge conditions reduced wetland growth. We also calculated total delta-top area by combining the area upslope of the wetland with the wetland area. The mean total delta-top area in the constant discharge experiment was approximately 2.5 times larger than that of the variable discharge experiment (Figure 2C). Combining these zones

reduces the magnitude of the oscillations observed in the constant discharge experiment when each zone is considered individually.

To calculate slopes, median elevation profiles were extracted along radial transects at 5 mm intervals and a regression performed on elevation versus radial distance for each timestep. The slope distributions across the delta-top exhibited differences between the constant discharge and variable discharge experiments, with consistently steeper slopes observed under variable discharge conditions. Upslope of the wetland zone, slopes were generally higher in the variable discharge experiment, with a median slope of approximately 0.055 compared to 0.03 in the steady discharge experiment (Figure 2D). Within the wetland zone, the slopes were lower overall but demonstrated distinct differences between the two experiments. The median wetland slope in the variable discharge experiment (0.04) was more than double that of the steady discharge experiment (0.018). Total delta-top area slope distributions further reflected the impact of highly variable discharge on delta surface morphology. The median slope in the variable discharge experiment was approximately 0.044, nearly double that of the steady discharge experiment (0.023). Interestingly, the total delta top area slope distributions capture the bimodality of slope distributions between wetland area and the terrestrial area above the wetland.

Fluctuations in terrestrial delta area in the two experiments must be linked to movement of shorelines, which would drive changes in where marshes accumulate on the Earth's surface and where organic-rich strata is found in the subsurface. We quantify this by performing a spectra analysis on time series of shoreline location. This has the dual advantage of informing us about the magnitude of shoreline movement and timescales of

network stability. Long timescale transgressions are linked to episodes of local abandonment coupled to relative sea level rise, and mobile channel networks rapidly change the locus of deposition, resulting in shoreline stability. Spectral analysis (Multi-Taper method) was applied to time series of shoreline location to identify the longest timescales of statistically correlated shoreline movement, which produce the most significant transgressions or regressions. These longest timescales for the constant discharge and variable discharge experiments occur at $T = 57$ hr and $T = 37$ hr, respectively (Figure 3). Channel migration in the constant discharge experiment was governed by longer timescales, which allowed for longer periods of shoreline transgression (Figure 1A). In contrast, the variable discharge experiment exhibited more frequent shifts in shoreline position (Figure 1B).

Preserved subsurface organic carbon

In both experiments, the fraction of preserved organic-rich, non-riverine sediment increases from the channel inlet to a peak before declining beyond the mean shoreline. The constant discharge experiment exhibits a more pronounced peak, reaching a maximum of approximately 0.23 at approximately one meter downstream of the channel inlet (Figure 4C). In contrast for the variable discharge experiment, there is a lower peak fraction of non-riverine sediment preservation (~ 0.17) at approximately 1.8 m downstream of the channel inlet. The decline of the fraction occurs over a distance approximately five times longer (1.3 m) in the constant discharge experiment compared to the variable discharge experiment (0.3 m). Efficiency of wetland delivery was less in the constant discharge experiment compared to the variable discharge experiment, but we present the total

organic-rich fraction as measured in the physical stratigraphy (e.g., see organic-rich seams in Figure 4A, 4B). Integrating the fraction of non-riverine deposition preserved in strike sections reveals that the high variability discharge experiment preserved less non-riverine sediment in the subsurface (0.24) than the low variability discharge experiment (0.33), a 35% decrease in preservation of non-riverine material. If we accounted for the differences in the measured efficiency of our proxy material distribution in the two experiments, the discrepancy in preservation of non-riverine deposition between experiments would likely be larger.

Discussion

Previous work has emphasized that wetlands are under threat from sea level rise and subsidence (e.g., Törnqvist et al. (2020)). However, there is an additional component of climate change that is detrimental to the continued persistence of coastal wetlands. Here, we highlight the role of enhanced discharge variability and its effect on present-day coastal wetlands and their ability to sequester organic-rich material as carbon in the subsurface. As global and regional climate models project an increase in precipitation and more frequent high-magnitude floods, our results suggest that these changes will cause global deltas on average to become steeper, smaller, have smaller wetland areas, and reduced shoreline movement, acknowledging that we do not consider influences from tides and waves. The results of this work provide insight into how climate-driven changes to the hydrologic flashiness of a system can alter the morphology of wetlands and deltas through modifications to channel and shoreline mobility, which reduce preservation of blue carbon and impact wetland ecosystem services.

Many of the morphometric differences observed in our two experiments mirror those quantified in prior physical delta experiments that evolved with and without floods but that lacked proxy non-riverine material (e.g., Barefoot et al., 2021; Esposito et al., 2018). Three key findings emerge from this study. First, high variability discharge significantly impacts the area of delta-tops and their wetlands while also impacting the slopes of these regions. The variable discharge experiment exhibited a smaller and more spatially constrained delta-top and wetland area (~60% decrease) compared to the constant discharge experiment. Contrary to previous physical delta experiments that did not incorporate non-riverine material and which documented an increase in delta area resulting from high discharge variability (Barefoot et al., 2021; Esposito et al., 2018), we find the opposite trend when incorporating non-riverine sediment accumulation. Floods influence the redistribution of sediment onto adjacent floodplains, where sediment accumulates prior to reaching the shoreline. This process promotes the growth of the terrestrial delta top and increases slopes in comparison to constant discharge conditions under which channels confine and transport sediment directly to the shoreline and marine environment – even under relatively low slope conditions. Consequently, in the absence of wetlands, floods increase terrestrial area (Barefoot et al., 2021; Esposito et al., 2018).

In contrast, the slower migration of channels in the absence of floods permits portions of the delta-top to transition from terrestrial to marginal marine environments characterized by exceptionally low slopes and shallow water depths over submerged portions of the delta topset. Such low-slope and shallow regions are particularly conducive to the development of spatially extensive wetland platforms, which contribute to offsetting relative sea level rise, while clastic deposition builds new land in other areas of the delta.

Previous work has demonstrated that variable discharge can inhibit levee development and promote avulsion (Barefoot et al., 2021). Likewise, in the variable discharge experiment, the steeper topset slopes arise due to flow loss to overbank regions, which are inefficient at sediment transport unless the topset slope is increased to compensate.

Wetlands provide critical ecosystem services such as fisheries, storm surge buffering, and pollutant capture and nutrient cycling (e.g., Engle, 2011). Alterations to the morphology of wetlands that ultimately lead to a reduction in wetland area can adversely affect these ecosystem services. Coastal wetlands provide critical habitats for coastal fishery species which can provide significant economic benefits. For example, the commercial shrimp fishery in the waters offshore of the Mississippi Delta accounts for approximately a billion-dollar annual industry (National Marine Fisheries Service, 2024). Previous work has found a log-linear relationship between area of vegetated habitats and shrimp yields (Turner 1977, 1992). Therefore, it is possible that reductions in wetland area can result in possible reductions in shrimp population, ultimately leading to significant economic impacts. Furthermore, wetlands play an important role in pollutant capture and nutrient cycling; thus, their reduction leads to decreased pollutant removal and nutrient cycling capacity (e.g., Brantley et al., 2008; Day et al., 2004), exacerbating eutrophication along coastal zones (Engle, 2011; Turner et al., 2007). Additionally, wetlands serve as natural buffers against storm surge by dissipating wave energy and reducing coastal erosion. Storm surge attenuation is a function of the hydrodynamic interactions between vegetation and water levels and distance a wave traverses a coastal wetland (e.g., Engle, 2011; Loder et al., 2009; Möller et al., 2014). Therefore, narrower wetlands, which may

become more prevalent under variable discharge conditions, can potentially lead to decreased storm surge attenuation, increasing flooding in coastal communities.

Second, increased discharge variability reduces the distances and timescales over which the shoreline can transgress or regress. The reduction in large-scale shoreline movement (Figure 3) results from the combination of increased slopes and enhanced mobility of channels. Conversely, the accumulation of organic matter under constant discharge reduces the delta-top slope. Coupled with reduced channel mobility, the shoreline in the constant discharge experiment can experience larger-scale shoreline movement (Figure 4A) leading to long wavelength roughness of the shoreline. River-dominated deltas can contain large interdistributary bays that are shallow, low energy settings that can trap sediment (Elliott, 1974) and organic carbon. Thus, a system under variable discharge, which will be less prone to developing interdistributary bays, might experience reductions in carbon storage near the shoreline.

Third, higher discharge variability results in less carbon burial. Both low and variable discharge experiments showed maximum preservation of organic-rich, non-riverine sediment near the mean shoreline position. However, the preservation of organic-rich strata was more tightly constrained to regions near the mean shoreline in the variable discharge compared to the constant discharge experiment. The observed patterns in non-riverine preservation have important implications for understanding carbon cycling in deltaic systems and interpreting the stratigraphic record. The maximum preservation near the mean shoreline in both experiments is critical for long-term carbon storage and is consistent with prior sequence stratigraphic models demonstrating maximum thickness of organic-rich strata near the shoreline where biomass production rates match

accommodation production rates (Bohacs & Suter, 1997; Diessel et al., 2000). However, the reduction in organic matter preservation in the high variability discharge experiment indicate that climate-driven changes in flood regimes could alter the efficiency and spatial distribution of sequestered carbon in marginal marine environments.

While our experimental observations provide insights into changes to modern systems under changing climate conditions, they also provide a framework for interpreting strata constructed during hyperthermal events in Earth's past, including the Paleocene-Eocene Thermal Maximum (PETM), which led to hydrologic changes and a prominent negative carbon isotope excursion in the sedimentary record (Cramer et al., 2003). The PETM often serves as a natural analogue to understand the effects of ongoing climate change. However, there is limited knowledge of carbon cycling on deltas during this event. There has been discussion of enhanced carbon burial in offshore locations (e.g., John et al., 2008) that might be linked to onshore reduction in carbon burial. Our results show a decrease in preservation of organic-rich, non-riverine deposition in deltas, which is partially linked to the reworking and export to the marine of the non-riverine sediment prior to long-term terrestrial burial. Future experiments might explore how changing hydrographic regimes influence the transport and site of storage of externally produced (allochthonous) sediment in marginal marine systems. This would aid development of theory to predict the total carbon capture potential of deltas subjected to various hydroclimates.

Summary

Relative sea level rise poses a risk to coastal wetlands globally. However, it is necessary to also recognize threats from allogenic controls that can often be overlooked, such as enhanced flood discharge variability resulting from a changing climate. In this study we quantified how flood discharge variability influences delta and wetland morphology and the preservation of organic material in the subsurface. We identify three key findings in our study:

1. Variable discharge increases deltaic slopes, which in turn leads to smaller deltas with smaller wetland areas.
2. Enhanced channel mobility and steeper slopes reduce the ability for large-scale shoreline movement, such as transgression or regression, to occur.
3. Variable discharge reduces the potential for carbon storage in the subsurface.

List of Figures

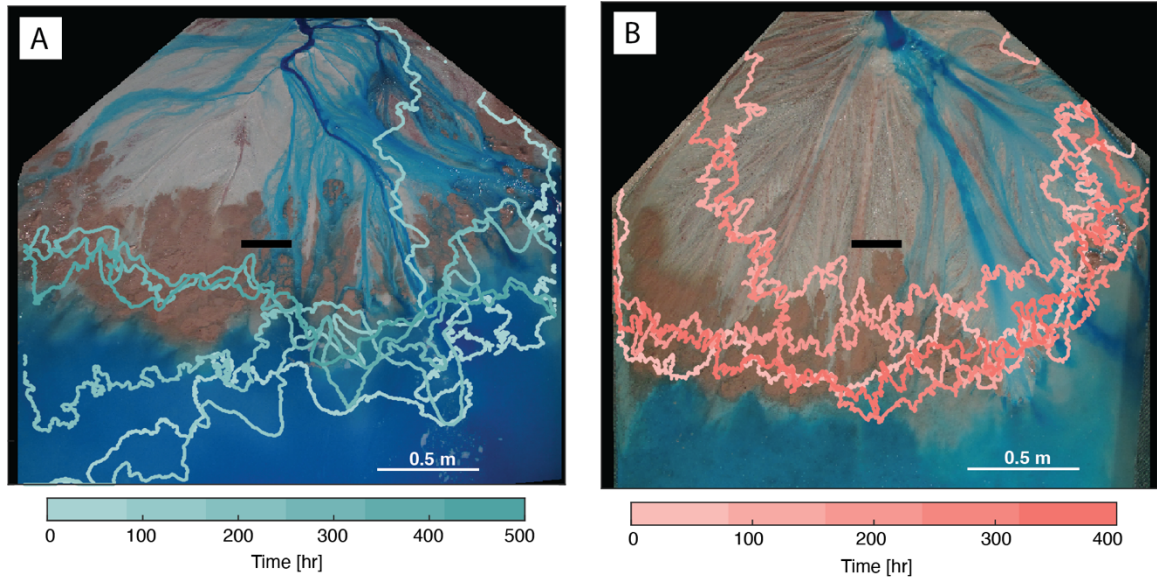


Figure 1 Shoreline location at 100-hour intervals for (A) Constant discharge experiment and (B) Variable discharge experiment overlain on images of the experiments. Flow is dyed blue to aid visualization of flow paths. Image of variable discharge experiment taken during base flow conditions. Note the increased presence of coarse material (red sediment) on the terrestrial delta top in the variable discharge experiment compared to the fine-grained overbank material (white sediment) in the constant discharge experiment. Horizontal black lines in images represent strike-sections in Figure 4.

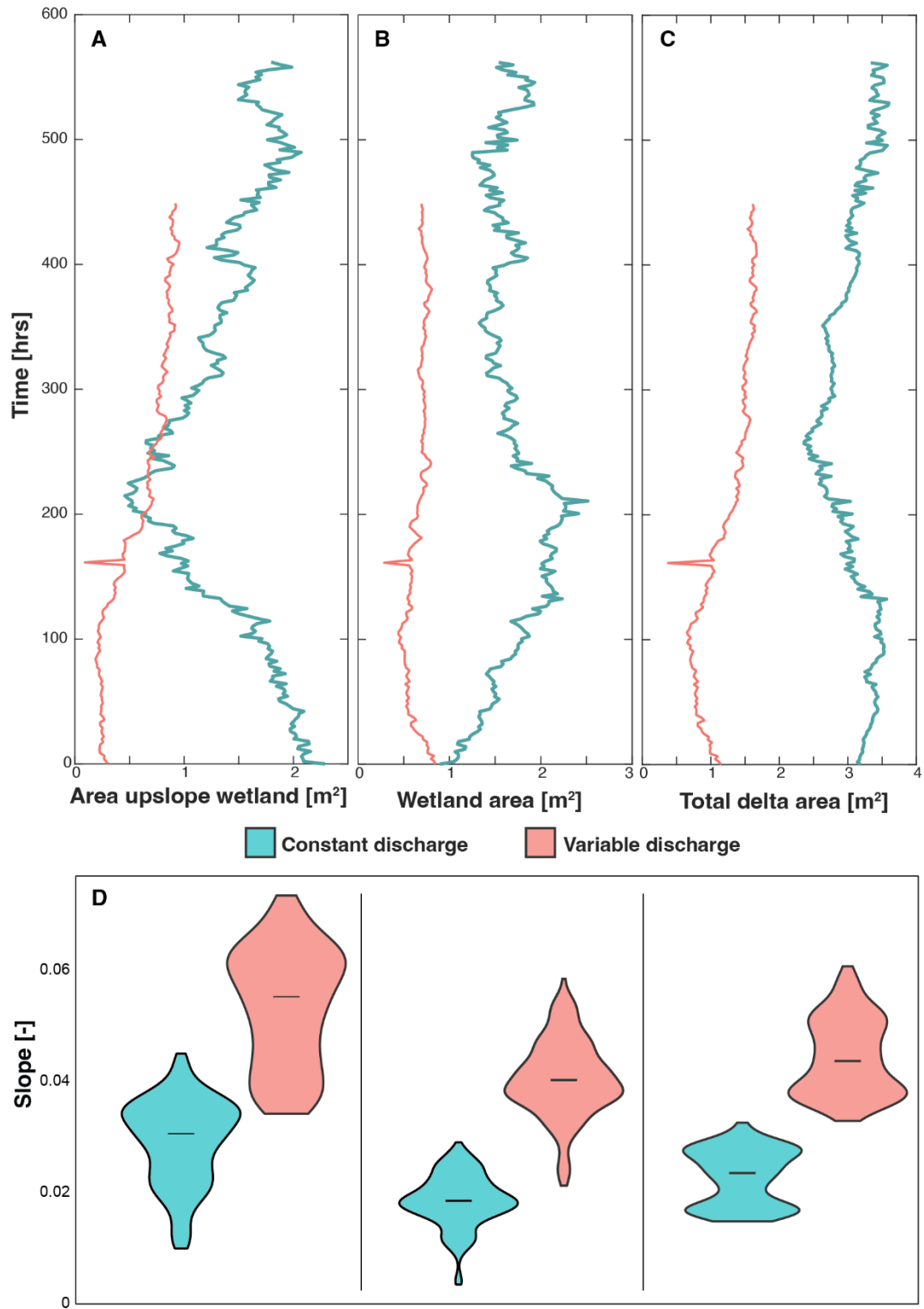


Figure 2 Time series of (A) area upslope of the wetland, (B) wetland area, and (C) total area for the constant discharge and variable discharge experiments. Slopes for each corresponding region are directly below each time series in (D). The median slope is denoted by the horizontal line inside the distribution.

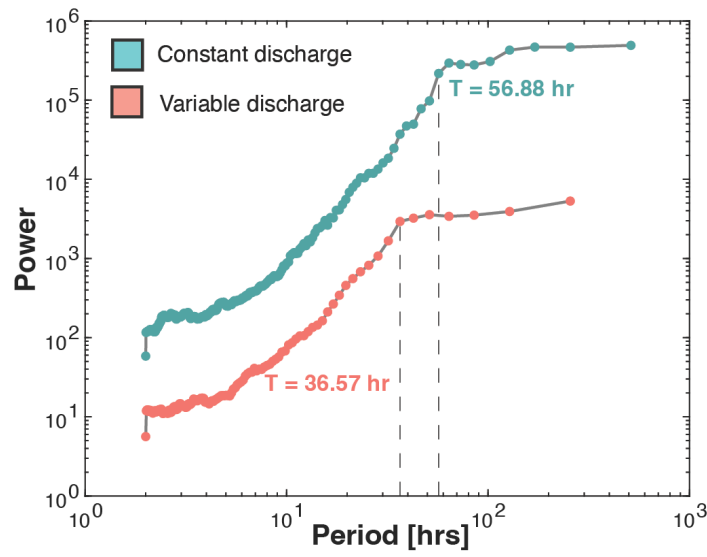


Figure 3 Power spectra for constant discharge experiment (teal) and variable discharge experiment (coral). Note the higher power associated with the constant discharge experiment, which is a result of increased shoreline roughness.

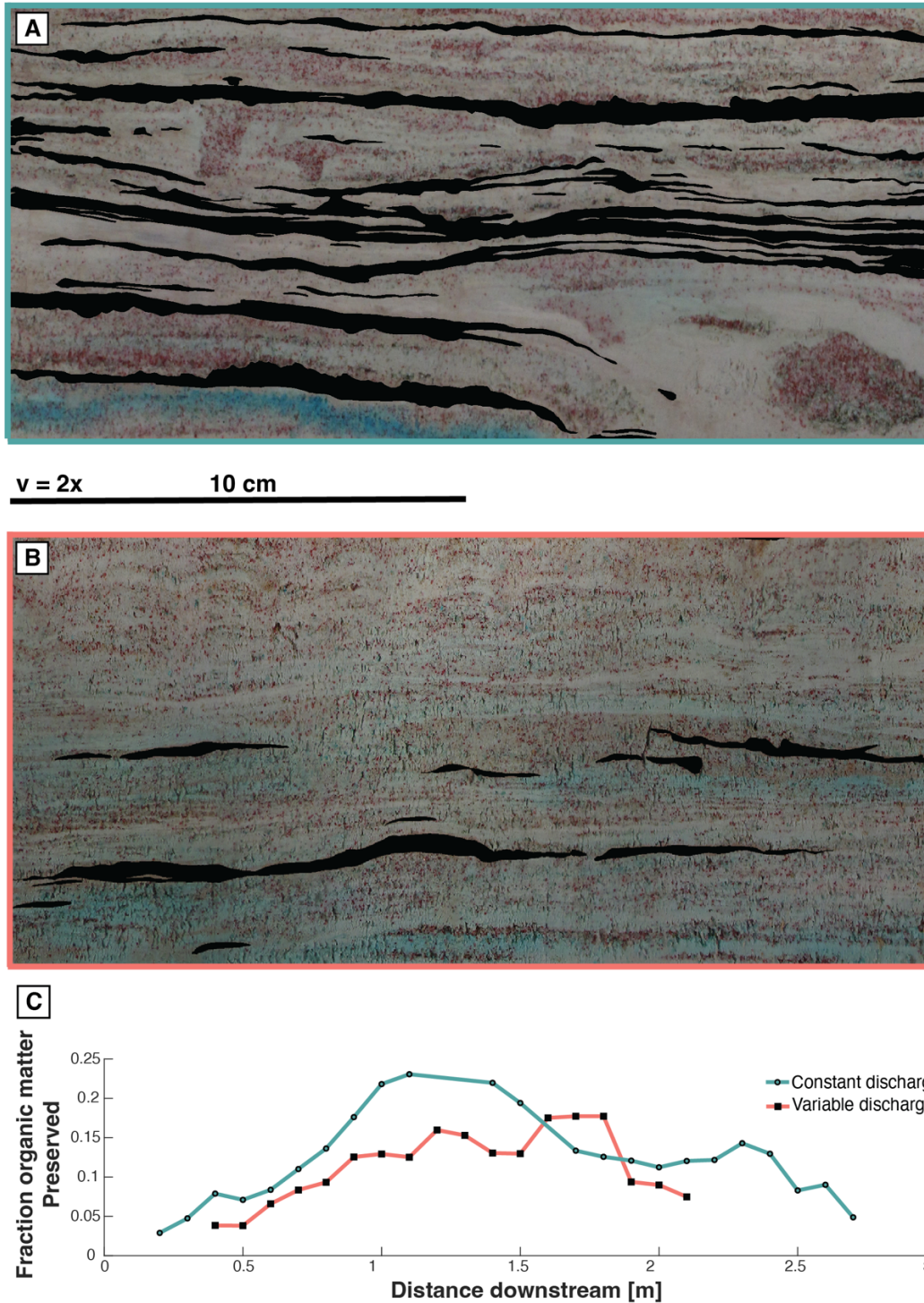


Figure 4 Stratigraphy for (A) Constant discharge and (B) Variable discharge experiments. Black areas represent preserved seams of organic-rich, non-riverine material. Note the sand-rich deposits in (A) compared to sand-poor deposits in (B). (C) Fraction of organic-rich, non-riverine deposition preserved as a function of distance downstream.

Supplemental Material

Expanded methods

Experimental setup

The constant discharge and variable discharge experiments were both conducted at the Tulane University Sediment Dynamics and Stratigraphy Laboratory in a 6 m long, 4 m wide, and 2.2 m deep basin (Figure S1). While these experiments are idealized and differences in governing dimensionless numbers exist, scale-independent processes allow for construction of strata at laboratory scales and morphodynamic metrics similar to field-scale systems (e.g., Paola et al. 2009). One experiment was run under constant flow conditions and the second under a variable hydrograph (Figure S2). The input sediment mixture used in both experiments ($D_{50} = 67\mu$) is based on a mixture developed by Hoyal and Sheets (2009). The coarsest grain size was dyed red to aid in characterization of stratigraphic architecture. A small amount of commercial polymer (New Drill Plus) was added to the sediment mixture to aid channelization. A blue biodegradable dye was added to the input water help characterize morphodynamics. Both experiments occurred over a progradation and aggradation stage. Progradation occurred over 120 hours with no base-level rise. Aggradation occurred under steady base-level rise for 560 hours and 450 hours for the constant discharge experiment and variable discharge experiment, respectively. Both experiments were run for approximately ten times the timescale associated with stochastic dynamics resulting in aggradation of tens of channel depths, and therefore an ergodic timeseries. The steady base-level rise rate (i.e., long-term pseudo subsidence) allowed for accommodation creation that balanced the input clastic sediment supply. A programmable carriage mounted above the basin and that can move in the three Cartesian

directions, deposited the proxy material for non-riverine sediment (i.e., kaolinite clay) every two hours for the constant discharge experiment and every two hours and twelve minutes for the variable discharge experiment via a sieve attached a ButtKicker LFE transducer. The proxy material was distributed in all locations with an average elevation between -9 mm and 5 mm relative to sea level.

Data collection

Data were collected in both experiments to characterize morphodynamics, topography, and stratigraphy. A digital camera positioned above the delta collected images at 15-minute intervals. Experiments were paused every two hours for the constant discharge experiment and every two hours and twelve minutes for the variable discharge experiment to collect topographic measurements of the dry surface via a FARO 3D S120 laser scanner (i.e., lidar) to construct a Digital Elevation Model (DEM). Each DEM had a vertical resolution of <1 mm with 5 mm x 5 mm horizontal grid spacing. Deltas were sectioned along strike-oriented sections at 10 cm intervals from distal to proximal ($n = 27$ for constant discharge and $n = 18$ for variable discharge) to characterize stratigraphy. Orthophoto images of strike sections referenced to the basin coordinate system were created using Agisoft Metashape Professional.

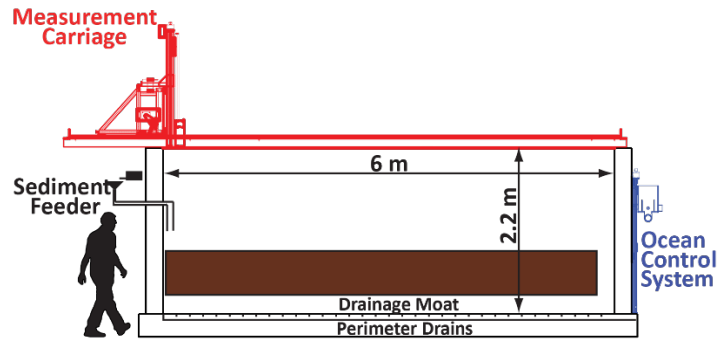


Figure S1. Schematic of experimental delta basin.

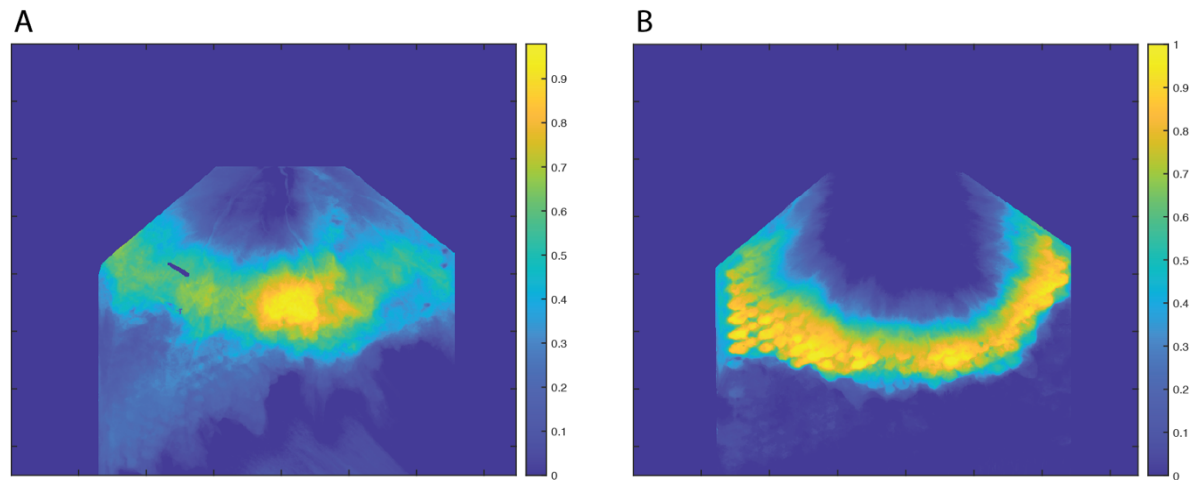


Figure S2. Proportion of time locations are considered wetland in (A) constant discharge experiment and (B) variable discharge experiment. Note the increased and less constrained spatial distribution of area considered wetland in (A) compared to (B).

Table S1. Experiment boundary conditions

	Constant Discharge	Variable Discharge Low flow	Variable Discharge High flow
Q_s (kg/s)	3.91 E -4	3.23 E -4	9.68 E -4
Q_w (m ³ /s)	1.72 E -4	1.42 E -4	4.25 E -4
Non-riverine deposition (g/hr)	200		200
Sea-level rise rate (mm/hr)	0.25		0.25
Cycle time	560 hr	59 min	7 min
Total run time (hr)	560		450

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Chapter 4

Going beyond blue carbon: Surprisingly high organic carbon accumulation rates in coastal deposits with low organic-matter content

Jose R. Silvestre, Guandong Li, Kelly M. Sanks, Torbjörn E. Törnqvist

Abstract

Wetlands play a significant role in global carbon sequestration, and blue carbon ecosystems (mangroves, marshes, and seagrass beds) have been singled out as particularly efficient at burying organic carbon (OC). Despite extensive research efforts in coastal environments, the relationship between these marine-influenced settings and their inland freshwater counterparts remains understudied. Likewise, little research of this nature has focused on the role of mineral versus organic deposits that make up coastal sedimentary environments. Here we take advantage of the abrupt transformation from mineral-dominated to organic-rich deposition in coastal Louisiana (due to embankment of the Mississippi River system) and test the hypothesis that this has increased OC accumulation rates. We capitalize on an extensive monitoring system of 306 shallow cores and marker horizon measurements that provide data on OC content, vertical accretion rates, and OC accumulation rates. We find mean OC accumulation rates of $\sim 200 \pm 170 \text{ gC m}^{-2} \text{ yr}^{-1}$, but with a weak negative correlation between organic-matter content and OC accumulation rate. In contrast, we find a strong positive correlation between vertical accretion rate and OC accumulation rate. We also find that freshwater marshes and swamps are at least as effective at accumulating OC as their blue carbon counterparts. We conclude (1) that organic-matter content is not necessarily a good predictor of OC accumulation rate; (2) that the recently introduced “teal

carbon” category which includes wetlands on upper delta plains and floodplains is potentially of major importance; and (3) that nature-based solutions that promote mineral sediment deposition in coastal environments may provide considerable benefits in terms of carbon burial. More broadly, we argue that a comprehensive understanding of the global carbon cycle will require more attention to alluvial plains landward of the blue carbon zone.

Introduction

Wetland ecosystems, including those found in terrestrial (including permafrost) peatlands, alluvial plains, and tidal wetlands, are critical components of the global carbon cycle because of their ability to sequester organic carbon (OC) (IPCC, 2021; Kirwan et al., 2023; McLeod et al., 2011; Miner et al., 2022; Sutfin et al., 2016; Yu, 2012). These ecosystems only comprise between 5-8% of the global land surface while storing significant amounts of carbon (~20-30% of the global soil organic carbon pool), making them indispensable in mitigating atmospheric CO₂ concentrations (Nahlik & Fennessy, 2016). Blue carbon ecosystems – tidal marshes, mangroves, and seagrass meadows – sequester particularly vast amounts of carbon (18-1713 g C m⁻² yr⁻¹) (Carruthers et al., 2024; Intergovernmental Panel on Climate Change, 2022; Lovelock & Duarte, 2019; Maxwell et al., 2024; McLeod et al., 2011). This carbon storage potential results from the slow organic matter decomposition under anoxic conditions and high sedimentation rates (Blair & Aller, 2012; Chmura et al., 2003).

Other wetland types – for example, fresh marshes and swamps that occupy flood basins in upper delta plains and floodplains – also function as substantial carbon sinks (Nahlik & Fennessy, 2016; Yu, 2012). These non-marine wetlands, currently known as teal

carbon environments (Nahlik & Fennessy, 2016), are generally excluded from blue carbon frameworks despite their capacity to accumulate and store OC over similar timescales as marine-influenced wetlands. Decomposition rates can vary along salinity gradients and are typically slower in fresh wetlands compared to marine-influenced wetlands (Stagg et al., 2018; Weston et al., 2006). This is a result of reduced sulfate availability, which allows methanogenesis to become the dominant decomposition pathway (Capone & Kiene, 1988) and allows for enhanced carbon preservation. Thus, significant gaps remain in our understanding of carbon dynamics across different wetland types, particularly how marine-influenced wetlands compare to their inland counterparts. Incorporating a broader range of wetlands is essential for developing a comprehensive understanding of carbon storage dynamics. However, these wetlands are vulnerable to anthropogenic influences, including hydrological modification, land conversion, and climate change-driven alterations to sediment dynamics (Li et al., 2024; Pendleton et al., 2012) highlighting the importance of understanding the factors that govern OC accumulation within wetland environments.

OC accumulation in wetlands results from the combination of biogeochemical and physical processes that regulate carbon input and storage (e.g., from hydrological processes) (Reddy & DeLaune, 2008). Primary biomass production and in situ sediment burial collectively contribute to the OC storage within wetland soils. Biogeochemical processes, such as photosynthesis and organic matter decomposition, play a role in the stability of OC, while physical factors, including sediment deposition and vertical accretion influence the extent and permanence of OC preservation (Fontaine et al., 2007; Spivak et al., 2019). Previous work has shown that the stability of OC can vary across wetland types, with fresh marshes exhibiting more stable carbon pools than marine-influenced marshes,

potentially because of lower salinity and slower decomposition rates (Williams & Rosenheim, 2015). Sediment composition – the proportion of mineral versus organic material – also plays a critical role in OC storage, with mineral sediments capable of enhancing carbon preservation by physically shielding organic matter from microbial decomposition (Delaune et al., 2018; Hemingway et al., 2019; Repasch et al., 2022; Sapkota et al., 2023). Organic-rich sediments can dominate in settings with high primary productivity but could be more susceptible to decomposition under changing environmental conditions (Stagg et al., 2018). Conversely, delivery of mineral sediments via fluvial and tidal processes can enhance vertical accretion rates and potentially influence OC burial efficiency by promoting rapid burial (Peck et al., 2020). This relationship between sedimentation rate and OC preservation is also well-documented in deep-marine sediments (Burdige, 2007; Canfield, 1994; Müller & Suess, 1979).

The fact that coastal Louisiana accounts for ~6-8% of tidal marsh blue carbon accumulation globally (Baustian et al., 2020) highlights the substantial role that Louisiana's coastal wetlands play in sequestering carbon. The wetlands of coastal Louisiana provide an ideal system for investigating the relationships between sediment composition, vertical accretion, and OC burial because of major changes in its recent depositional history. Numerous classic studies (e.g., Fisk & McFarlan, 1955; Gould & McFarlan, 1959) have shown that the thick Holocene strata are heavily mud (i.e., mineral) dominated, echoed by more recent work (e.g., Esposito et al., 2017). However, over the past century this region has experienced a relatively abrupt shift to dominantly organic-rich deposition (e.g., Hijma et al., 2017), mainly driven by embankment of the Mississippi and Atchafalaya rivers and the rapid decline in mineral sediment dispersal (Edmonds et al.,

2023). River embankments and hydrological modifications have significantly reduced sediment delivery to many deltaic wetlands, altering OC accumulation patterns by favoring the accumulation of autochthonous (in situ) organic matter in surface layers (Keogh et al., 2021; Sanks et al., 2020; White et al., 2019; Zhang et al., 2022). These changes in sedimentation and OC accumulation allow the opportunity to quantify how changes in sediment supply influence OC accumulation.

This study investigates how the organic carbon accumulation rate (CAR) in wetlands of coastal Louisiana is influenced by organic-matter content and sediment accretion. We test the hypothesis that the shift from mineral-dominated to organic-rich deposition within the system has enhanced the CAR. Additionally, we evaluate CAR differences between wetland and sediment types. To evaluate our hypothesis and examine differences between wetland and sediment types, we leverage a rich dataset from the Coastwide Reference Monitoring System (CRMS) to quantify the relationship between organic matter (OM) content, vertical accretion rate (VAR), and CAR across fresh and marine-influenced wetlands and swamps of coastal Louisiana.

Study Area

During the middle to late Holocene, deceleration of sea-level rise allowed the Mississippi River to form five subdeltas (initiated approximately every 1000-2000 years) with complex distributary networks, wetlands, and interdistributary bays, coalescing into one of the largest delta plains globally (Blum & Roberts, 2012; Coleman et al., 1998; Hijma et al., 2017). The resulting wetland platform is one of the world's most extensive and is characterized by variations in salinity, hydrology, and sediment dynamics. As such, it

consists of fresh, intermediate, brackish, and saline marshes, along with freshwater swamps farther inland (Visser et al., 1998) (Figure 2). The embankment of the Mississippi and Atchafalaya Rivers, which was largely completed about 100 years ago, dramatically changed sedimentation patterns. Most of the sediment flux (dominantly mud) was funneled into the Gulf of Mexico, whereas previously a significant portion contributed to accretion of the delta plan. As a result, vertical accretion in many portions of this region now dominantly consists of organic matter (Sanks et al., 2020).

Westward of the Mississippi River Delta (MRD), the Chenier Plain (CP) extends another ~200 km and is characterized by mudflat progradation driven by longshore currents that transport fine-grained sediments from the Mississippi and Atchafalaya Rivers toward this portion of the coast (Draut et al., 2005; Gould & McFarlan, 1959; Hijma et al., 2017; McBride et al., 2007). Detailed vegetation mapping (e.g., Visser et al., 2000) describes the spatial distribution of plant communities across these mudflats. Despite the difference in geomorphic setting, the CP and MRD support similar wetland types.

Data and Methods

Coastwide Reference Monitoring System

Point data from cores used in this study (Figure 1) were collected as part of the publicly available Louisiana Coastwide Reference Monitoring System (CRMS; <https://lacoast.gov/crms/>). Monitoring sites were established between 2006 and 2010 to characterize wetland conditions across coastal Louisiana (Steyer et al., 2003). Triplicate sediment cores were collected for each monitoring site within one year of site establishment. Additional sediment cores for each site were collected between 2010 and

2023 and analyzed following methods described in Folse et al. (2008). Sediment cores were sliced at 4-cm intervals in the field. Bulk density and loss-on-ignition (LOI) measurements were made continuously over the 4-cm interval samples. Bulk density was calculated as the weight of the dry sample (sample dried at 60°C for 24 hrs) divided by the volume of the sample, and LOI was calculated as the difference between the weight of dried sediment samples before burning and the weight after burning at 500°C for two hours divided by the weight before burning. LOI is a common method used to estimate the OM content of sediments (Dean, 1974). While potential limitations to LOI are known to exist (e.g., duration of burning, sample size; Heiri et al. (2001)), Folse et al. (2008) adhere to strict QA/QC measures such as replicate analysis of 10% of samples ($\pm 5\%$ tolerance) to identify and correct for any inherent uncertainties in measurements. Our goal was to utilize sediment cores that coincide as much as possible temporally with vertical accretion data. Measurements for the three cores at each site were averaged to produce a single value with an error term of one standard deviation. Cores were classified by sediment type (Figure 2A) and wetland vegetation type (Figure 2B).

Vertical accretion rate calculations

Three marker horizons were established at each CRMS site during site initiation, using white feldspar clay (Folse et al., 2008). Collectively, these horizons form what is known as a plot set, providing a traceable reference framework for sediment accretion measurements. New plot sets were established every two years. Soil samples were taken at each CRMS site using cryogenic coring (Cahoon et al., 1996) every six months for the first two years, after which samples were taken every 18 months until the marker horizons were

no longer intact. Vertical accretion was determined as the distance measured between the marker horizon and the top of the soil core. The vertical accretion data from the three soil cores were then averaged to calculate the vertical accretion for the CRMS site during the period from the site establishment to the time of sample collection. Following Jankowski et al. (2017), only sites with records of at least five years before 2023 and a minimum of three valid measurement points during this period were retained for rate estimation (See Appendix A). Here, we used vertical accretion data collected from the first plot set, which typically has the longest record. A linear regression model was fitted to the vertical accretion data for each CRMS site to quantify the site specific annual vertical accretion rate (VAR).

Converting organic matter to organic carbon accumulation rates

Previous field-based studies in Louisiana have relied on linear regression to determine conversion factors between OM and OC content (Baustian et al., 2020; G. D. Steyer et al., 2012; Wang et al., 2017). However, Craft et al. (1991) had previously suggested that a non-linear fit might be preferable. We applied a second-order polynomial regression to previously published core data for 30 sites (n=1097 samples) from coastal Louisiana representative of fresh, brackish/intermediate, and saline marshes between 2006 and 2007 (Piazza et al., 2011) (Figure 3). Our analysis of the residuals for the linear and non-linear models indicated that the second-order polynomial regression more accurately captures the relationship between OM and OC.

The carbon accumulation rate (CAR) for each site was then calculated as

$$\text{CAR} = \text{VAR} * \text{OC} * \rho_{\text{bulk}} * 0.0001 \quad (1)$$

where VAR is the vertical accretion rate (cm yr^{-1}), OC is the organic carbon content percent by mass, ρ_{bulk} is the bulk density (g cm^{-3}), and CAR is the organic carbon accumulation rate ($\text{g C m}^{-2} \text{yr}^{-1}$).

Statistical analysis

A geostatistical analysis using a 1-km² grid covering the study domain was conducted to spatially interpolate OM fractions, VARs, and CARs using variogram modeling and Bayesian kriging. Bayesian kriging allows for the estimation of unknown values at unsampled locations within a spatial domain while accounting for the uncertainty inherent in estimating model parameter values from the data (Diggle & Ribeiro, 2007). Point data representing OM contents, OC contents, and VARs, were obtained from the CRMS dataset. A semivariogram was constructed to quantify spatial dependence in variables using a first-order polynomial trend model. The semivariogram ($\gamma(h)$) was calculated as a function of the lag distance, h , and was defined as:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (2)$$

Where $Z(x_i)$ and $Z(x_i + h)$ are values at locations separated by lag h , and $N(h)$ is the number of pairs. The best-fit variogram (nugget, sill, range) was determined using restricted maximum likelihood (REML) estimation.

A Box-Cox transformation was applied to normalize the data distribution and stabilize variance during variogram modeling:

$$Z^*(x) = \begin{cases} \frac{Z(x)^\lambda - 1}{\lambda} & \text{if } \lambda \neq 0 \\ \log(Z(x)) & \text{if } \lambda = 0 \end{cases} \quad (3)$$

where $Z(x)$ is the original value of the variable, $Z^*(x)$ is the transformed value, and λ is the Box-Cox parameter controlling the transformation strength.

Bayesian kriging (e.g., Diggle & Ribeiro (2007)) was applied for spatial interpolation using the variogram parameters derived from REML. A first-order trend model was specified for the mean function, and priors (σ^2 , ϕ , τ^2) were defined. Priors were updated using observed data, resulting in posterior distributions that estimate unknown values and measures of uncertainty. Model performance was evaluated using leave-one-out cross-validation. For each data point, predictions were generated by excluding that point from the dataset.

Results

Distribution of wetland and sediment types

Spatially, CRMS sites – classified by sediment (Figure 2A) and wetland (Figure 2B) type – show an increase in OM content and a spatial gradient from saline to fresh marsh and swamp with distance inland from the shoreline. The exception are sites located near the mouths of the Mississippi and Atchafalaya Rivers where freshwater inputs decrease

salinity, allowing for the formation of intermediate and fresh marshes. OC content ranges from 2 to 24%, and VARs and CARs display very wide ranges (0.18 to 84 mm yr⁻¹ and ~3 to 2000 g C m⁻² y⁻¹, respectively; Appendix A). VARs greater than 15 mm yr⁻¹ are mostly found in the MRD with <10 sites located in the CP. Saline marshes, occurring largely along the shoreline, show the lowest mean organic OC (~7%) but highest mean VAR (~12 mm yr⁻¹) and relatively high CAR (~250-300 g C m⁻² y⁻¹) (Table 1).

We first perform a one-way ANOVA to test if any differences exist in OC content, VAR, and CAR between different wetland and sediment types, respectively. We then perform a post-hoc multiple comparison test to determine which specific pairs of groups differ from each other. For wetland types, we reject the null hypothesis that all group means are equal ($P < 0.05$). This suggests that there are statically significant differences in OC content, CAR, and VAR among at least some of the wetland types. A multiple comparison test shows that in most cases, there is no statistically significant difference between groups (Table 2), except between saline and all other wetlands for OC content and between saline and brackish/intermediate for CAR. This is contrary to statistically significant differences found between swamps and all other wetland types by Suir et al. (2019).

Bayesian Analysis

We applied a Bayesian kriging to CRMS point data to quantify the spatial distribution of OC content, VAR, and CAR across the study area. While Bayesian kriging results in smoothed data, mean values remain comparable to the original data. OC content across coastal Louisiana exhibits significant spatial variability, ranging from approximately 3-20% (Figure 4A). Overall, the spatial distribution shows a strong seaward gradient, with

OC content progressively decreasing closer to the Gulf of Mexico where OC content ranges ~3-5%. Similar to the original data (Figure 2A), the highest OC concentrations (>15%) occur in well-defined hotspots inland in the CP and MRD. This spatial pattern aligns with previous work that highlights the role of storm-driven events in coastal regions, leading to significant mineral sediment deposition (J. A. Nyman et al., 1995; J. E. Smith et al., 2015; Tweel & Turner, 2012).

VAR displays a distinct spatial trend compared to OC content. VAR ranges from 3 to 15 mm yr⁻¹ and decreases from the MRD to the CP (Figure 4B). VAR is highest along the easternmost shoreline of the MRD and near the mouth of the Mississippi River (up to 15 mm yr⁻¹) and decrease westward toward the CP to ~3 mm yr⁻¹. Mean VAR for the MRD (~10 mm yr⁻¹) and CP (~6 mm yr⁻¹) fall within relative standard error and are consistent with previously reported values by Jankowski et al. (2017) (12.8 mm yr⁻¹ and 6.3 mm yr⁻¹, respectively) and Suir et al. (2019) (10.3 mm yr⁻¹ for the entire study area).

CAR ranges from 60 to 300 g C m⁻² yr⁻¹ across the study area, and like VAR, decreases westward across the MRD and CP (Figure 4C). By contrast, the raw point dataset included roughly 50 locations with CARs exceeding 300 g C m⁻² yr⁻¹. Areas with high CAR correlate spatially with high VAR, and by proxy, areas with rapid sedimentation such as the mouth of the Mississippi River. The observed east-west gradient in CAR is similar to previous findings by Suir et al. (2019), which documented elevated CAR in regions characterized by high river connectivity (i.e., sediment inputs). Mean CAR (~200 g C m⁻² yr⁻¹) is within a factor of two for previously reported recent values, e.g., (~382 g C m⁻² yr⁻¹; Baustian et al., 2020), (~370 g C m⁻² yr⁻¹; Suir et al., 2019), and (~320 g C m⁻² yr⁻¹; Herbert et al., 2021).

We calculate a mean estimate for the total mass of carbon accumulated per year (approximately 3 Tg C yr⁻¹) by multiplying the mean carbon accumulation rate by the total study area (~16,000 km²). This accumulation rate is less than previously reported values by approximately a factor of two; for instance, Baustian et al. (2020) estimate that Louisiana wetlands accumulate between 5.5 to 7.3 Tg C yr⁻¹ in blue carbon alone. However, their value is only representative of 24 10-cm deep samples within the MRD and Atchafalaya delta regions, and vertical accretion rates used were from previously collected data at 16 CRMS sites representative of different wetland types. This has potentially resulted in a bias towards high CAR.

Discussion

Controls of organic carbon accumulation rate

This study aims to assess how the shift from mineral-dominated to organic-rich deposition in coastal Louisiana wetlands has influenced CAR. We examined controls on CAR, focusing on organic-matter content and VAR across varying wetland and sediment types. We reject the null hypothesis that OM content is a primary driver of CAR (p-value < 0.05). Our finding that organic-rich sediments do not exhibit higher CARs runs counter to the hypothesis that elevated OM inherently increases carbon burial. Previous work has concluded in coastal Louisiana, OM content varies to a limited extent among wetland types, yet these differences exert minimal control on CAR when compared to VAR. The relationship between OM content and CAR is unexpectedly weak and slightly negative (Pearson correlation coefficient -0.22), a surprising result that challenges assumptions

about the direct role of organic matter content in driving carbon storage (Figure 5). In contrast, VAR strongly correlates with CAR (Pearson correlation coefficient 0.95).

The importance of teal carbon

Our study further highlights that different wetland and sediment types across coastal Louisiana possess broadly equivalent capacities for carbon accumulation, challenging the sometimes nearly exclusive focus on blue carbon ecosystems. Fresh inland wetlands – known for their teal carbon – demonstrate carbon accumulation rates and vertical accretion rates similar to their marine-influenced counterparts due to analogous processes of high accretion rates and low anaerobic decomposition (Nahlik & Fennessy, 2016). Our study focuses on alluvial and/or deltaic plains of large rivers. Despite their substantial carbon accumulation potential, teal carbon wetlands remain significantly underrepresented in wetland conservation strategies and carbon accounting frameworks (Nahlik and Fennessy, 2016, Adame et al., 2024). Previous studies have reported comparable CAR in fresh and saline marshes in coastal Louisiana (e.g., Hatton et al., 1983; Smith et al., 1983). Similarly, we find minimal statistically significant differences in CAR among wetland types (Table 2). Given that fresh marshes and swamps occupy ~2.5% of terrestrial land area yet store 30% of global soil carbon (Nahlik & Fennessy, 2016), ignoring teal carbon risks substantial underestimation of wetland contributions to climate mitigation. Therefore, recognizing and integrating teal carbon ecosystems into broader climate mitigation strategies will ensure a more accurate and holistic assessment of wetland contributions to global carbon sequestration.

Limitations

The erosion of marsh edges exposes carbon-rich soil to remineralization, leading to the release of CO₂ into the atmosphere (Haywood et al., 2020) and can be exported offshore. Our analysis has mainly focused on OC accumulation without accounting for potential carbon losses or gains via marsh-edge erosion or the influence of external versus in situ OC on carbon accumulation rates.

Additionally, the influence of allochthonous (external) versus autochthonous (in situ) OC is an important control on OC accumulation processes in coastal Louisiana wetlands. Previous work has shown that allochthonous OM is an important contributor to wetland accretion (Cahoon & Reed, 1995; Mariotti et al., 2020). Some studies have used molecular biomarkers and/or stable isotope proxies to trace carbon sources in shallow sediment cores (e.g., Bianchi et al., 2011). Our dataset currently lacks direct information regarding the relative contributions of autochthonous versus allochthonous organic material and the type of carbon (e.g., petrogenic), which can influence measured accumulation rates. Further research is needed to fully understand the complex interactions between coastal erosion and carbon cycling within coastal systems.

Nature-based solutions to enhance carbon burial

The observed CARs are similar to previously reported estimates for coastal Louisiana wetlands (Baustian et al., 2020; Hatton et al., 1983; Herbert et al., 2021; Nyman et al., 2006; Smith et al., 1983; Suir et al., 2019). Our study relies on short-timescale measurements compared to long-term measurements using Pb-210 or Cs-137 dating. Observed differences in CAR may reflect short-term variability rather than differences in

long-term accumulation potential. Our rejection of OM content as the primary driver of CAR reframes coastal restoration towards strategies that enhance vertical accretion through sediment delivery (e.g., river diversions). As coastal Louisiana experiences ongoing sediment deficits and related wetland degradation, targeted sediment diversions – designed to transport sediment sediment-rich river water into adjacent marshes – are increasingly viewed as essential restoration measures (CPRA, 2023; Day, 2014). These engineered diversions effectively deliver sediment necessary for wetland accretion, thereby promoting conditions favorable for elevated accumulation rates (Baustian et al., 2020; Delaune et al., 2018). Enhanced sedimentation from diversion projects not only counteracts land loss but also facilitates vertical accretion and biomass productivity (Esposito et al., 2017; Twilley et al., 2016). Thus, sediment diversions have the potential to substantially augment OC storage ability within Louisiana’s coastal wetlands.

An important consideration when evaluating carbon cycling in coastal wetlands, particularly in embanked systems such as the MRD, is the fate of sediment that is no longer connected to floodplains and wetlands but instead bypasses into the marine environment. Consequently, the decreased sedimentation in wetlands may suggest a reduction in wetland carbon burial capacity (Mariotti et al., 2020, Shen et al., 2021). However, there is potential for offshore burial of allochthonous carbon (Shen et al., 2021; Shields et al., 2017), which may partially offset or even balance carbon burial reductions in coastal wetlands and warrants further investigation.

Summary

Our results challenge the assumption that organic matter content is a good predictor of CAR. Even though sediment deposition in coastal Louisiana over the past century has become much more organic than the Holocene norm, it has not resulted in higher rates of OC burial. We show that vertical accretion rates, driven by sediment deposition, rather than organic matter content, are the primary driver for carbon accumulation in coastal Louisiana wetlands. Mineral-rich systems demonstrate higher carbon burial efficiency because of rapid sediment deposition. In contrast, organic-rich deposits (peat), while still accumulating appreciable amounts of organic carbon, accrete slower and have a greater susceptibility to degradation. These findings support nature-based solutions focused on sediment-delivery, which not only aid in resilience but also enhance carbon accumulation.

Additionally, our results show that carbon accumulation rates across wetland types, including fresh marshes and swamps (teal carbon) and marine-influenced marshes (blue carbon), are broadly comparable. Despite their similar carbon storage potential, teal carbon remains underrepresented in coastal carbon policy and climate mitigation frameworks. Our results promote the inclusion of teal carbon into carbon accounting frameworks.

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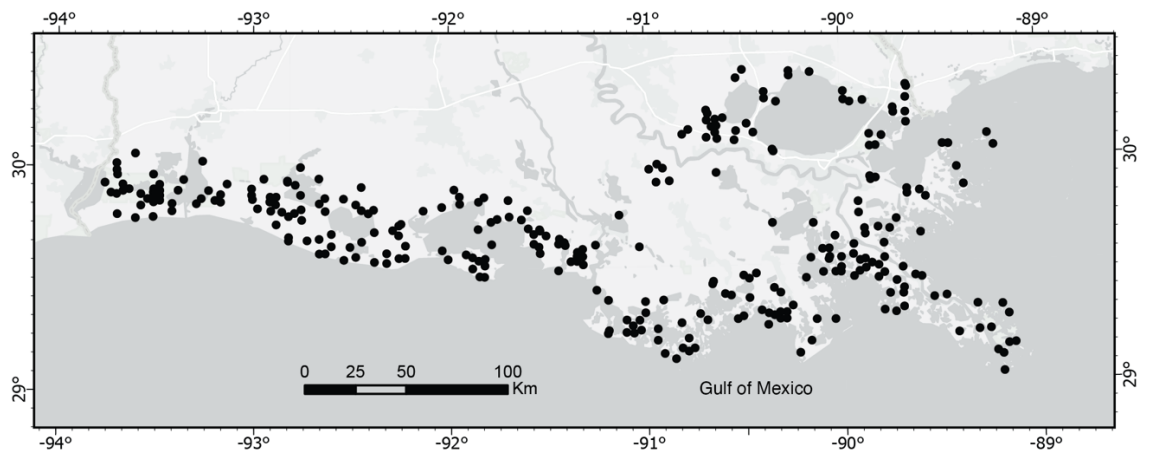


Figure 1. Map of coastal Louisiana with dots representing 306 Coastwide Reference Monitoring System (CRMS) sites.

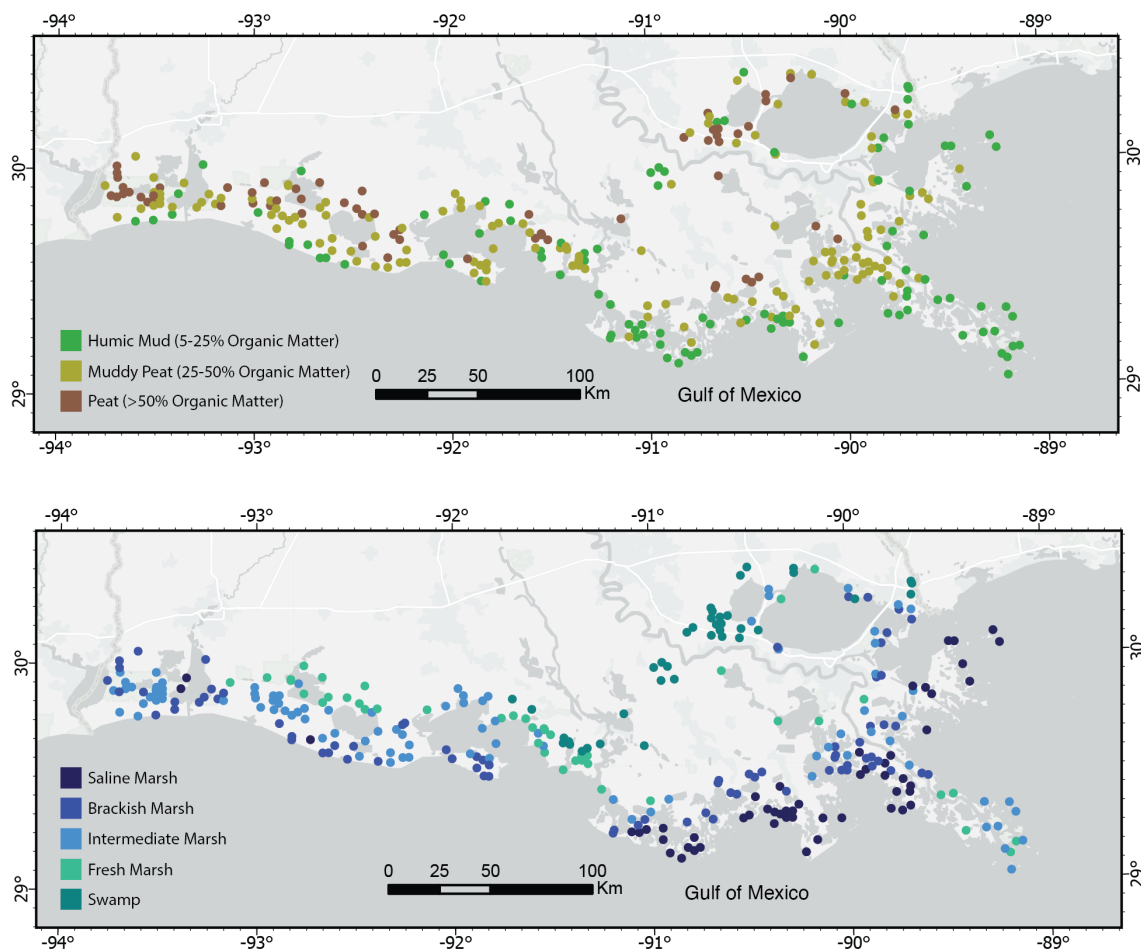


Figure 2. A) Map of sediment type for CRMS sites. Sediment type was determined using the mean organic matter percentage in 24-cm cores. B) Map of wetland vegetation type. Wetland classifications were obtained from <https://cims.coastal.louisiana.gov/>.

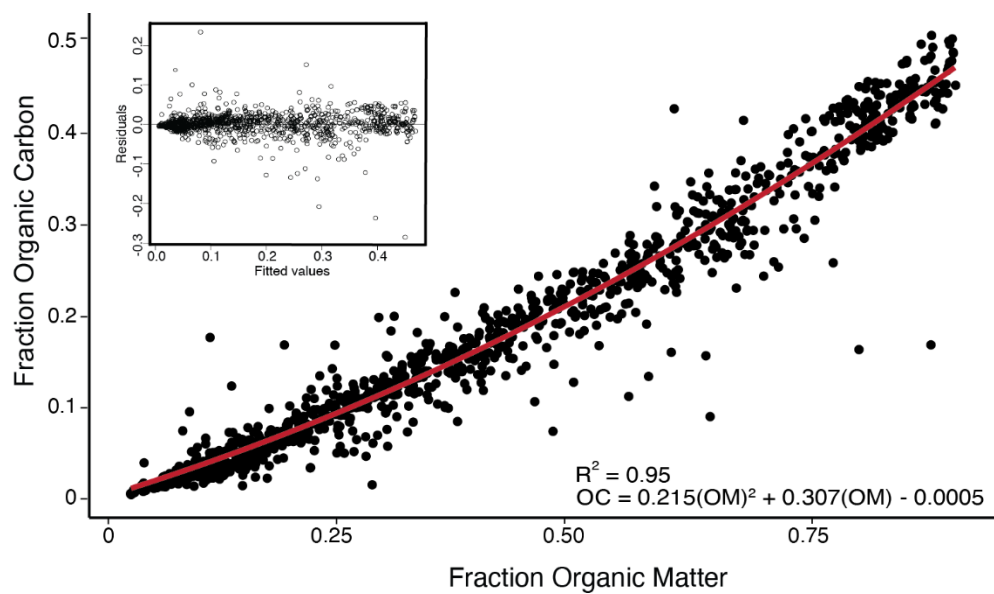


Figure 3. Relationship between organic matter (OM) and organic carbon (OC) content in 1097 samples from 100-cm-deep cores from coastal Louisiana wetlands. Data from Piazza et al. (2011). Inset shows residuals vs. fit for the non-linear model. The symmetric scattering around zero suggest a lack of heteroscedasticity.

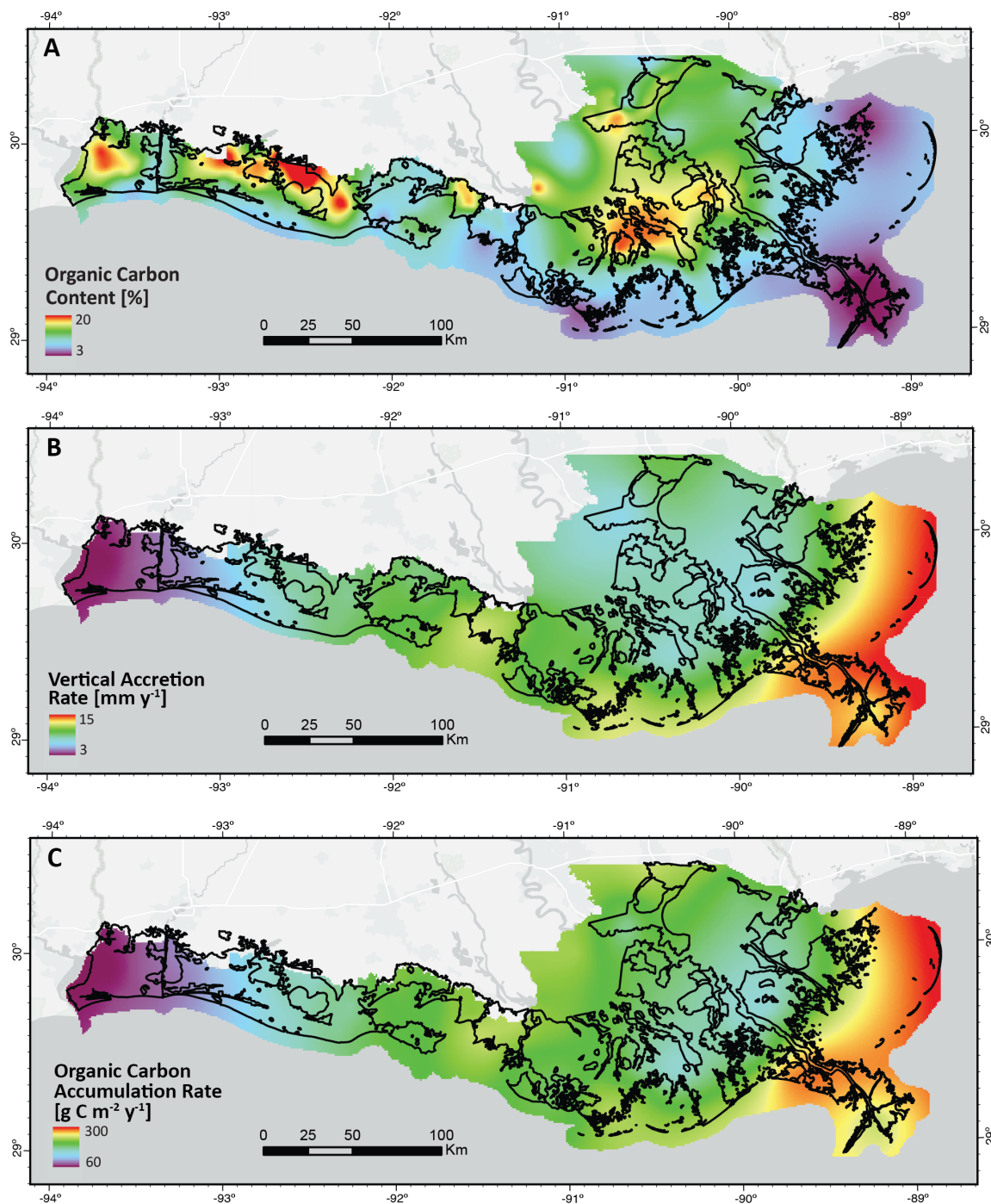


Figure 4. Bayesian interpolation for the study area of A) organic carbon content, B) vertical accretion rate, and C) organic carbon accumulation rate.

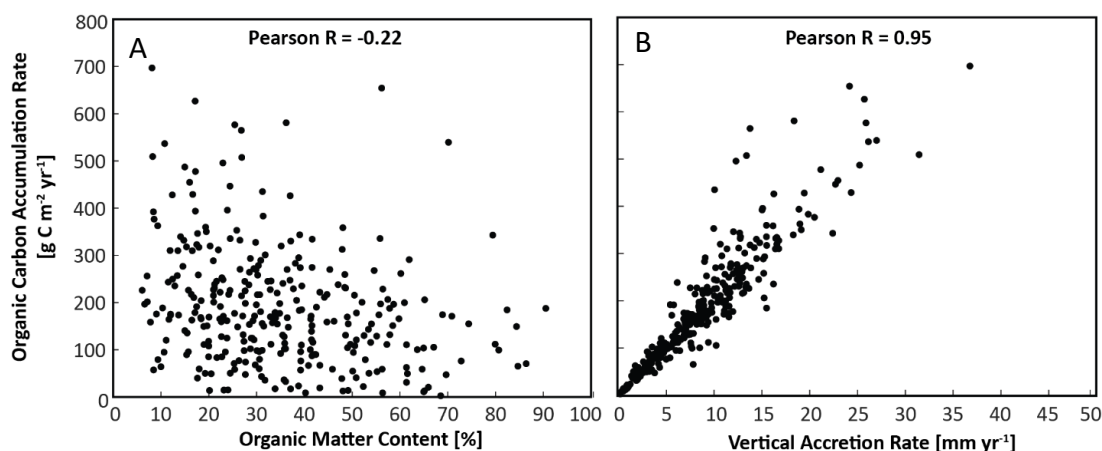


Figure 5. Relationship between organic carbon accumulation rate and organic matter content (A) and vertical accretion rate (B) for 306 CRMS sites.

Table 1. Mean organic carbon content, vertical accretion rate, and carbon accumulation rate across sediment and wetland types.

	Organic carbon content [%]	Vertical accretion rate [mm yr ⁻¹]	Organic carbon accumulation rate [g C m ⁻² yr ⁻¹]
<i>Wetland Type</i>			
Saline marsh	7.10 ± 2.78	11.96 ± 11.98	248 ± 277
Brackish marsh	9.75 ± 3.67	8.34 ± 5.97	173 ± 138
Intermediate marsh	11.49 ± 4.58	8.18 ± 5.02	162 ± 102
Fresh marsh	11.62 ± 5.99	11.52 ± 7.17	230 ± 161
Swamp	10.42 ± 5.42	8.83 ± 4.43	236 ± 133
<i>Sediment Type</i>			
Humic mud (5-25% OM)	5.27 ± 1.50	10.97 ± 6.78	232 ± 136
Muddy peat (25-50% OM)	10.51 ± 1.87	9.11 ± 8.17	200 ± 200
Peat (>50% OM)	17.32 ± 2.46	7.70 ± 5.50	142 ± 116

Table 2. Multiple comparative analysis between wetland types for organic carbon content, vertical accretion rate, and carbon accumulation rate

Pairs		P-Value VAR	P-Value OC	P-Value CAR
Saline	Brackish	0.0756	0.0074*	0.0370*
Saline	Intermediate	0.0194*	8.58E-08*	0.0176*
Saline	Fresh	0.9844	7.05E-06*	0.9983
Saline	Swamp	0.9968	0.0037*	0.2297
Brackish	Intermediate	0.9941	0.0869	0.9999
Brackish	Fresh	0.3550	0.1814	0.1374
Brackish	Swamp	0.2906	0.9430	0.9970
Intermediate	Fresh	0.1643	0.9999	0.0849
Intermediate	Swamp	0.1297	0.7181	0.9899
Fresh	Swamp	0.9999	0.7393	0.4352

*Significant value

Table 3. Multiple comparative analysis between sediment types for vertical accretion rate and carbon accumulation rate

Pairs		P-value VAR	P-value CAR
Humic Mud	Muddy Peat	0.3072	0.1183
Humic Mud	Peat	0.0021*	0.0135*
Muddy Peat	Peat	0.0535	0.4052

*Significant values

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Chapter 5

Conclusions

Summary of work

Deltas are home to large populations and coastal wetlands, which provide several critical ecosystem services, such as sequestering significant amounts of carbon. Coastal deltas are dynamic systems that grow via deposition of both mineral (clastic) and organic sediments. Allogenic forcings and autogenic processes largely dictate where these sediments are deposited, thereby influencing the morphology of deltas and wetlands through time. However, studies exploring the interactions between surface processes, wetlands, and their subsurface expressions are limited. The goal of this dissertation was to show how the morphology of deltas, wetlands, and their carbon capture efficiency is influenced by autogenic processes and allogenic forcings.

In Chapter 2, I characterized and quantified how autogenic processes influence the deposition and preservation of organic-rich, non-riverine sediment. I determined that shoreline migration driven by autogenic processes sets the spatial distribution over which non-riverine sediment is preserved in the subsurface. Additionally, autogenic processes do not need to be coupled with allogenic forcings to create complex feedback mechanisms that influence carbon capture efficiency. Furthermore, I introduced an autogenics-based framework to estimate the longitudinal spatial scales of preserved organic-rich, non-riverine sediment in the subsurface. The framework integrates the multi-dimensional nature of autogenic processes that influence the locus and relocation of sediment deposition responsible for shoreline migration. This new framework advances our ability to further constrain carbon reservoirs within data-limited marginal marine successions.

In Chapter 3, I explored how variable discharge conditions influence delta and wetland morphology, strata, and carbon capture efficiency. I compared observations from two reduced-scaled experiments both of which contained a proxy for organic-rich, non-riverine deposition. However, one experiment was run with a constant discharge and a second with variable discharge (flood-interflood cycles) conditions. Here, high variability discharge results in steeper and smaller deltas with smaller wetland areas. The reduced length-scales that shorelines can migrate through time result in a more constrained extent of non-riverine sediment in the subsurface. This has potential impacts on modern systems, where a reduction in wetland area can significantly impact ecosystem services, such as storm surge attenuation, nutrient cycling, pollutant capture, and fisheries. Additionally, the reduction in carbon capture efficiency can potentially lead to a positive feedback loop under ongoing and predicted climate conditions. Increased outputs of CO₂ result in a warming climate characterized by changes to frequency and magnitude of flooding events. This variable discharge then results in smaller wetlands with a reduced ability to capture carbon. This additional component of climate change can be harmful to coastal wetland sustainability and should be considered along with changes to relative sea level rise.

In Chapter 4, I tested the hypothesis that the transition from mineral-dominated deposition to organic-rich deposition in coastal Louisiana wetlands has increased carbon accumulation rates. Using an extensive dataset of monitoring stations from the Coastwide Reference Monitoring System, I quantified organic carbon content, vertical accretion rates, and carbon accumulation rates. I reject the hypothesis that organic matter content is good predictor for organic carbon accumulation rate. I showed how fresh marshes and swamps (teal carbon systems) contain high amounts of organic material but have low vertical

accretion rates. The reverse is true for saline marshes (blue carbon systems), which contain low amounts of organic carbon content, but high vertical accretion rates. I find no statistical difference in carbon accumulation rates between teal and blue carbon marshes within the study area. Here, fresh marshes and swamps can be as effective at accumulating organic carbon as their marine-influenced wetlands.

Future work

The work in this dissertation attempts to capture the dominant surface process controls on organic-rich sediment capture. However, several questions remain to be answered. This dissertation advances knowledge for estimating the longitudinal extent of subsurface carbon reservoirs; however, little knowledge exists on the total volume of carbon that coastal deltas capture over geologic timescales. The autogenics framework in Chapter 2 provides a foundation for estimating this total volume. For example, coupling information on the length of transgression, the theoretical distribution for biomass production, and the relationship between channel mobility and compensation timescales for a given field system, might be able to provide an estimate for the volume of carbon stored with depth.

Here, I explore the influence of variable discharge on a system with wetlands, but how do our observations for an experimental system with variable discharge, compare to field-scale systems? It would be interesting to explore the morphometric variability for systems within similar temperature gradients, but with different hydrologic regimes. Future experiments might also investigate how changes to the period and magnitude of sea-level cycles will influence the morphology and carbon burial efficiency. Additionally, environmental conditions can influence stratigraphic architecture (e.g., spatial arrangement

of channel sandbodies), which has implications for inverting strata and for fluid transport. How do different hydrographs influence stratigraphic architecture and our ability to differentiate between autogenic and allogenic signals?

Furthermore, future work should aim to quantify and characterize the nature of organic carbon and its influence on carbon accumulation rates in coastal Louisiana. The experimental work and the meta-analysis of field data from coastal Louisiana wetlands in this dissertation shed light on the deposition and preservation of organic material in coastal deltaic systems.

Appendix A

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0002'	30.1003	-89.7918	'Brackish'	Humic Mud	0.25	22.64	6.91	7.29	127.91
'CRMS0003'	30.0994	-89.2528	'Saline'	Humic Mud	0.59	10.77	3.47	26.14	536.66
'CRMS0006'	30.2635	-89.9822	'Brackish'	Muddy Peat	0.23	30.54	9.13	4.59	96.31
'CRMS0008'	30.2283	-90.6852	'Swamp'	Peat	0.13	68.90	18.99	6.84	174.35
'CRMS0030'	30.2609	-90.3266	'Fresh'	Muddy Peat	0.19	30.23	9.04	15.19	258.19
'CRMS0033'	30.2764	-90.3875	'Intermediate'	Peat	0.11	58.67	16.51	10.91	196.38
'CRMS0034'	30.3056	-90.3886	'Intermediate'	Peat	0.13	50.90	14.55	9.44	178.10
'CRMS0035'	30.2671	-89.6647	'Swamp'	Humic Mud	0.33	23.80	7.24	6.82	161.60
'CRMS0038'	30.2134	-90.6776	'Swamp'	Muddy Peat	0.23	33.30	9.89	6.91	157.15
'CRMS0039'	30.1072	-90.6857	'Swamp'	Peat	0.21	61.35	17.17	1.75	62.64
'CRMS0046'	30.4057	-90.4976	'Swamp'	Humic Mud	0.95	8.41	2.76	15.02	392.22
'CRMS0047'	30.1343	-90.5340	'Swamp'	Peat	0.17	50.55	14.46	4.47	108.59
'CRMS0056'	30.1257	-90.4462	'Swamp'	Muddy Peat	0.46	31.23	9.32	10.05	435.04

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0059'	30.0931	-90.5430	'Swamp'	Muddy Peat	0.30	36.19	10.68	18.36	580.82
'CRMS0061'	30.1874	-90.6399	'Swamp'	Humic Mud	0.42	18.32	5.67	7.11	168.41
'CRMS0063'	30.1286	-90.6410	'Swamp'	Peat	0.13	65.94	18.29	0.87	20.72
'CRMS0065'	30.1227	-90.8100	'Swamp'	Peat	0.10	74.37	20.28	7.58	155.07
'CRMS0086'	30.2534	-89.9506	'Swamp'	Humic Mud	0.40	18.99	5.87	4.79	111.14
'CRMS0097'	30.1547	-90.6594	'Swamp'	Peat	0.19	61.93	17.31	9.07	291.03
'CRMS0103'	30.3960	-90.2594	'Swamp'	Muddy Peat	0.23	34.29	10.16	9.54	220.17
'CRMS0108'	29.9531	-89.4121	'Saline'	Muddy Peat	0.25	28.88	8.67	5.80	124.69
'CRMS0114'	29.7589	-89.9168	'Intermediate'	Muddy Peat	0.17	44.72	12.95	7.22	158.87
'CRMS0117'	29.8090	-89.9179	'Fresh'	Muddy Peat	0.19	36.41	10.74	8.13	167.95
'CRMS0118'	29.3772	-89.5420	'Fresh'	Humic Mud	0.36	23.88	7.27	15.07	395.76
'CRMS0119'	29.4759	-89.6355	'Brackish'	Muddy Peat	0.34	26.34	7.96	36.61	978.59
'CRMS0121'	29.6937	-89.8198	'Brackish'	Muddy Peat	0.20	37.12	10.93	0.79	17.26

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0129'	29.4687	-89.6031	'Brackish'	Humic Mud	0.46	15.47	4.85	6.10	135.66
'CRMS0131'	29.6890	-89.8889	'Brackish'	Muddy Peat	0.27	30.08	9.00	4.03	98.25
'CRMS0132'	29.6640	-89.8856	'Intermediate'	Muddy Peat	0.18	42.07	12.25	4.06	90.02
'CRMS0135'	29.6864	-89.7609	'Brackish'	Humic Mud	0.30	23.80	7.24	5.76	124.83
'CRMS0136'	29.6214	-89.7915	'Intermediate'	Humic Mud	0.37	22.00	6.73	12.57	311.61
'CRMS0139'	29.3827	-89.4793	'Fresh'	Humic Mud	0.49	11.89	3.80	16.76	310.27
'CRMS0146'	29.7294	-89.7263	'Intermediate'	Muddy Peat	0.24	28.49	8.56	7.58	153.62
'CRMS0147'	29.6656	-89.6039	'Saline'	Humic Mud	0.36	19.64	6.06	6.98	150.73
'CRMS0148'	29.5123	-89.6978	'Intermediate'	Humic Mud	0.64	11.65	3.73	6.93	164.43
'CRMS0154'	29.1153	-89.1998	'Fresh'	Humic Mud	0.61	9.98	3.23	3.27	64.12
'CRMS0156'	29.1622	-89.1700	'Fresh'	Humic Mud	0.71	8.11	2.67	36.75	696.92
'CRMS0157'	29.1313	-89.2270	'Intermediate'	Humic Mud	0.65	8.45	2.77	3.18	57.42

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0159'	29.0391	-89.1979	'Intermediate'	Humic Mud	0.74	7.79	2.58	8.29	158.62
'CRMS0161'	29.2938	-89.1667	'Intermediate'	Humic Mud	0.36	12.87	4.09	16.21	235.38
'CRMS0162'	29.1655	-89.1363	'Intermediate'	Humic Mud	0.53	9.03	2.95	11.15	175.77
'CRMS0163'	29.2169	-89.4209	'Fresh'	Humic Mud	0.49	10.32	3.33	11.57	188.65
'CRMS0164'	29.1938	-90.1698	'Saline'	Muddy Peat	0.18	36.98	10.89	12.72	247.37
'CRMS0171'	29.3237	-89.7950	'Saline'	Humic Mud	0.55	12.42	3.95	11.53	249.69
'CRMS0172'	29.3147	-89.7376	'Saline'	Humic Mud	0.37	17.92	5.56	15.50	317.19
'CRMS0173'	29.4537	-89.7308	'Saline'	Muddy Peat	0.18	36.06	10.64	5.49	102.36
'CRMS0174'	29.3973	-89.7651	'Saline'	Muddy Peat	0.24	33.14	9.85	83.66	1976.85
'CRMS0175'	29.2888	-90.1409	'Saline'	Muddy Peat	0.27	25.38	7.69	8.65	177.12
'CRMS0178'	29.2874	-90.0456	'Saline'	Humic Mud	0.49	14.57	4.59	12.40	276.72
'CRMS0179'	29.3961	-89.6984	'Saline'	Humic Mud	0.39	19.33	5.97	15.47	359.74

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0181'	29.3355	-89.6963	'Saline'	Humic Mud	0.39	17.18	5.35	18.87	393.76
'CRMS0194'	29.9917	-90.9404	'Swamp'	Humic Mud	0.58	22.95	7.00	12.29	495.72
'CRMS0197'	29.9117	-90.9459	'Swamp'	Humic Mud	0.61	17.45	5.42	5.77	191.39
'CRMS0200'	29.9698	-90.9820	'Swamp'	Humic Mud	0.60	21.20	6.50	6.15	238.60
'CRMS0209'	29.4905	-89.7917	'Brackish'	Muddy Peat	0.17	35.46	10.48	7.53	131.18
'CRMS0217'	29.9165	-90.8781	'Swamp'	Muddy Peat	0.31	32.86	9.77	7.50	227.42
'CRMS0220'	29.5650	-90.0689	'Brackish'	Muddy Peat	0.18	38.92	11.41	8.94	183.37
'CRMS0224'	29.4992	-89.9174	'Saline'	Muddy Peat	0.22	29.71	8.90	3.46	68.07
'CRMS0225'	29.5632	-90.0096	'Intermediate'	Muddy Peat	0.16	39.43	11.55	9.74	185.03
'CRMS0226'	29.5124	-89.8854	'Brackish'	Muddy Peat	0.22	27.35	8.24	6.53	117.99
'CRMS0232'	29.4977	-90.0126	'Brackish'	Humic Mud	0.34	22.30	6.82	7.21	165.38
'CRMS0237'	29.4765	-89.9461	'Saline'	Muddy Peat	0.22	27.65	8.33	2.57	47.67

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0248'	29.6022	-90.0709	'Brackish'	Muddy Peat	0.21	34.33	10.17	7.10	154.57
'CRMS0251'	29.5186	-90.0105	'Brackish'	Muddy Peat	0.22	29.45	8.83	6.29	121.20
'CRMS0253'	29.5553	-90.0730	'Brackish'	Muddy Peat	0.25	28.50	8.56	12.33	264.32
'CRMS0258'	29.5239	-89.8201	'Saline'	Muddy Peat	0.29	29.41	8.82	10.77	271.79
'CRMS0260'	29.5341	-89.8542	'Brackish'	Muddy Peat	0.15	48.46	13.92	12.43	259.51
'CRMS0261'	29.6014	-90.1044	'Intermediate'	Muddy Peat	0.25	36.39	10.73	10.16	269.98
'CRMS0263'	29.5532	-89.8881	'Brackish'	Muddy Peat	0.19	35.83	10.58	5.05	101.76
'CRMS0272'	29.4207	-89.6939	'Saline'	Humic Mud	0.29	22.37	6.84	11.23	221.95
'CRMS0276'	29.6193	-89.9450	'Brackish'	Muddy Peat	0.17	42.51	12.37	8.93	190.24
'CRMS0292'	29.1411	-90.2280	'Saline'	Humic Mud	0.40	17.48	5.43	14.76	322.82
'CRMS0293'	29.2402	-91.2012	'Brackish'	Humic Mud	0.35	19.99	6.16	5.04	107.92
'CRMS0302'	29.1482	-90.9146	'Saline'	Humic Mud	0.48	9.35	3.04	5.38	79.30

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0303'	29.2411	-91.0689	'Saline'	Humic Mud	0.42	14.99	4.71	7.04	140.59
'CRMS0305'	29.3889	-91.1977	'Intermediate'	Humic Mud	0.27	22.98	7.01	12.97	248.51
'CRMS0307'	29.2839	-90.8265	'Brackish'	Muddy Peat	0.22	29.80	8.92	16.76	327.48
'CRMS0309'	29.2536	-91.1957	'Brackish'	Humic Mud	0.37	16.54	5.16	16.41	309.84
'CRMS0310'	29.2948	-90.2932	'Saline'	Humic Mud	0.29	24.48	7.43	15.47	335.50
'CRMS0311'	29.2147	-90.7919	'Saline'	Muddy Peat	0.29	26.54	8.01	11.68	270.49
'CRMS0315'	29.4026	-90.5732	'Brackish'	Muddy Peat	0.22	39.38	11.53	4.36	110.15
'CRMS0318'	29.2949	-90.3255	'Saline'	Humic Mud	0.25	21.63	6.62	14.66	245.20
'CRMS0319'	29.3239	-90.3258	'Saline'	Humic Mud	0.23	23.15	7.06	0.92	14.69
'CRMS0322'	29.2447	-91.1068	'Saline'	Muddy Peat	0.22	29.95	8.97	9.70	195.49
'CRMS0326'	29.2737	-91.0741	'Brackish'	Humic Mud	0.33	19.96	6.15	5.86	118.18
'CRMS0332'	29.2982	-91.0398	'Brackish'	Humic Mud	0.51	12.00	3.83	8.88	173.52

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0335'	29.2690	-90.3870	'Saline'	Humic Mud	0.37	16.34	5.10	11.67	217.35
'CRMS0336'	29.3200	-90.3834	'Saline'	Muddy Peat	0.27	27.39	8.25	4.46	98.31
'CRMS0337'	29.3108	-90.3551	'Saline'	Humic Mud	0.30	17.10	5.32	11.08	178.80
'CRMS0338'	29.3341	-90.4191	'Saline'	Humic Mud	0.26	24.01	7.30	0.80	14.98
'CRMS0341'	29.3092	-90.5122	'Saline'	Humic Mud	0.42	17.20	5.35	21.15	477.57
'CRMS0345'	29.1705	-90.7625	'Saline'	Humic Mud	0.41	14.97	4.70	25.22	487.09
'CRMS0354'	29.3310	-91.0093	'Intermediate'	Muddy Peat	0.18	33.87	10.05	0.99	17.46
'CRMS0355'	29.2969	-90.5409	'Saline'	Muddy Peat	0.29	25.42	7.70	25.89	576.47
'CRMS0369'	29.2945	-90.6949	'Brackish'	Humic Mud	0.27	24.43	7.42	22.69	446.60
'CRMS0374'	29.1569	-90.7928	'Saline'	Humic Mud	0.34	18.40	5.70	10.42	204.08
'CRMS0376'	29.1241	-90.8578	'Saline'	Humic Mud	0.46	10.64	3.43	6.01	94.91
'CRMS0377'	29.2539	-91.0327	'Saline'	Humic Mud	0.40	15.73	4.92	4.88	95.86

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'CRMS0383'	29.2076	-90.9487	'Saline'	Humic Mud	0.34	16.63	5.19	24.33	429.09
'CRMS0385'	29.4097	-90.6035	'Brackish'	Muddy Peat	0.20	49.14	14.10	0.50	13.98
'CRMS0386'	29.4327	-90.3542	'Saline'	Muddy Peat	0.13	48.98	14.06	9.24	169.51
'CRMS0387'	29.4108	-90.3221	'Brackish'	Muddy Peat	0.12	48.06	13.82	0.80	12.87
'CRMS0390'	29.4656	-90.6624	'Brackish'	Peat	0.10	60.93	17.07	11.22	199.73
'CRMS0392'	29.4543	-90.6671	'Brackish'	Peat	0.10	70.14	19.29	26.99	539.42
'CRMS0397'	29.3525	-90.2606	'Saline'	Muddy Peat	0.12	48.61	13.96	7.83	130.95
'CRMS0398'	29.3863	-90.9173	'Intermediate'	Muddy Peat	0.22	29.88	8.95	13.83	269.58
'CRMS0399'	29.2999	-91.1053	'Intermediate'	Humic Mud	0.23	24.16	7.34	13.10	217.29
'CRMS0400'	29.4904	-90.5084	'Brackish'	Peat	0.11	55.12	15.62	7.51	129.01
'CRMS0403'	29.7673	-91.1374	'Swamp'	Peat	0.10	86.41	23.00	3.15	70.64
'CRMS0416'	29.4762	-90.4803	'Brackish'	Peat	0.14	57.84	16.30	8.36	187.82
'CRMS0421'	29.1712	-90.8236	'Saline'	Humic Mud	0.40	15.98	5.00	22.95	454.69
'CRMS0434'	29.3229	-90.7313	'Brackish'	Humic Mud	0.30	22.72	6.94	4.09	85.12

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0461'	29.5849	-91.3252	'Fresh'	Humic Mud	0.34	15.75	4.93	13.64	226.18
'CRMS0479'	29.5233	-91.4492	'Fresh'	Humic Mud	0.60	8.25	2.72	31.44	509.32
'CRMS0482'	29.5858	-91.3543	'Fresh'	Muddy Peat	0.14	34.82	10.30	11.96	177.18
'CRMS0488'	29.7071	-91.5434	'Fresh'	Peat	0.10	61.36	17.17	1.87	31.07
'CRMS0489'	29.6012	-91.5418	'Fresh'	Humic Mud	0.46	17.14	5.33	25.71	626.61
'CRMS0490'	29.6793	-91.5104	'Fresh'	Peat	0.06	79.92	21.55	9.40	111.89
'CRMS0493'	29.7553	-91.7590	'Fresh'	Muddy Peat	0.27	27.65	8.33	8.68	198.38
'CRMS0494'	29.7428	-91.7906	'Intermediate'	Muddy Peat	0.24	35.74	10.56	1.47	36.46
'CRMS0496'	29.6298	-91.5473	'Intermediate'	Humic Mud	0.29	21.15	6.49	12.14	230.57
'CRMS0498'	29.5004	-91.8499	'Brackish'	Humic Mud	0.27	22.61	6.91	8.70	159.38
'CRMS0499'	29.5704	-91.8541	'Brackish'	Muddy Peat	0.15	41.77	12.17	6.28	115.88
'CRMS0504'	29.5359	-91.8856	'Brackish'	Muddy Peat	0.22	28.38	8.53	12.69	237.67

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0507'	29.5854	-92.2290	'Intermediate'	Muddy Peat	0.29	27.53	8.29	10.02	244.90
'CRMS0508'	29.6401	-92.2270	'Intermediate'	Muddy Peat	0.28	38.11	11.19	8.99	283.04
'CRMS0511'	29.8880	-91.9779	'Intermediate'	Muddy Peat	0.51	26.80	8.09	13.76	564.76
'CRMS0513'	29.7926	-91.6041	'Swamp'	Peat	0.10	70.85	19.46	9.18	171.19
'CRMS0514'	29.8525	-91.8253	'Intermediate'	Humic Mud	0.38	20.98	6.44	8.83	214.89
'CRMS0517'	29.6430	-91.5729	'Fresh'	Muddy Peat	0.22	30.88	9.22	14.44	289.40
'CRMS0520'	29.5858	-91.8857	'Brackish'	Muddy Peat	0.26	30.37	9.08	11.76	278.51
'CRMS0522'	29.4985	-91.8253	'Brackish'	Muddy Peat	0.20	33.98	10.07	8.22	167.61
'CRMS0523'	29.5783	-91.8219	'Intermediate'	Muddy Peat	0.20	32.33	9.62	12.66	245.06
'CRMS0524'	29.5486	-91.8231	'Brackish'	Muddy Peat	0.15	41.41	12.07	9.39	171.47
'CRMS0527'	29.7111	-91.8564	'Intermediate'	Humic Mud	0.48	15.33	4.81	13.76	318.01
'CRMS0529'	29.5990	-91.9183	'Intermediate'	Peat	0.10	55.59	15.74	11.55	174.07

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0530'	29.5778	-92.0104	'Brackish'	Humic Mud	0.30	24.43	7.42	10.26	225.81
'CRMS0531'	29.8566	-91.9508	'Intermediate'	Muddy Peat	0.26	29.58	8.86	7.42	171.66
'CRMS0532'	29.8244	-91.9492	'Intermediate'	Muddy Peat	0.20	33.03	9.82	12.41	245.68
'CRMS0535'	29.6429	-91.7877	'Intermediate'	Muddy Peat	0.17	35.88	10.59	6.20	113.74
'CRMS0536'	29.5849	-92.2604	'Intermediate'	Muddy Peat	0.17	38.36	11.26	10.43	204.83
'CRMS0541'	29.6179	-92.0399	'Brackish'	Humic Mud	0.80	7.13	2.38	10.60	201.64
'CRMS0543'	29.7520	-91.6356	'Fresh'	Muddy Peat	0.16	48.05	13.82	16.16	358.57
'CRMS0544'	29.6866	-91.5731	'Intermediate'	Peat	0.09	59.79	16.78	11.55	165.83
'CRMS0545'	29.7119	-91.6009	'Fresh'	Muddy Peat	0.15	39.47	11.56	13.39	235.23
'CRMS0547'	29.8389	-91.7024	'Swamp'	Humic Mud	0.43	20.98	6.44	8.19	227.34
'CRMS0549'	29.8329	-91.8534	'Intermediate'	Muddy Peat	0.27	27.68	8.33	3.30	74.03
'CRMS0550'	29.7654	-91.6977	'Fresh'	Humic Mud	0.40	22.73	6.94	9.20	252.55

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'CRMS0551'	29.7012	-91.5407	'Fresh'	Peat	0.17	55.83	15.80	12.76	335.66
'CRMS0552'	29.7952	-92.1357	'Fresh'	Humic Mud	0.29	21.03	6.45	10.85	200.93
'CRMS0553'	29.8499	-93.0064	'Intermediate'	Peat	0.11	54.03	15.35	9.37	154.81
'CRMS0554'	29.8297	-92.6656	'Fresh'	Muddy Peat	0.45	25.84	7.82	9.96	353.05
'CRMS0556'	29.9134	-92.7876	'Intermediate'	Peat	0.07	79.41	21.44	22.40	342.87
'CRMS0557'	29.9408	-92.6670	'Fresh'	Peat	0.04	84.67	22.62	7.82	65.30
'CRMS0560'	29.8508	-92.5418	'Fresh'	Peat	0.07	90.51	23.90	11.22	187.73
'CRMS0562'	29.8683	-92.7609	'Fresh'	Peat	0.14	54.60	15.49	12.77	267.91
'CRMS0565'	29.7992	-92.4511	'Fresh'	Peat	0.07	69.66	19.17	3.78	47.24
'CRMS0567'	29.9025	-92.4511	'Fresh'	Peat	0.10	65.12	18.09	0.76	13.17
'CRMS0568'	29.7852	-92.4161	'Intermediate'	Muddy Peat	0.25	26.51	8.01	16.44	332.07
'CRMS0570'	29.8009	-92.3887	'Fresh'	Peat	0.17	56.17	15.89	24.16	654.30
'CRMS0571'	29.7093	-92.2918	'Intermediate'	Peat	0.05	82.41	22.11	15.49	184.53
'CRMS0574'	29.7956	-92.6353	'Intermediate'	Muddy Peat	0.16	45.33	13.11	13.07	269.99
'CRMS0575'	29.9406	-92.9478	'Fresh'	Peat	0.09	84.38	22.55	7.45	149.34
'CRMS0576'	29.5912	-92.4802	'Intermediate'	Muddy Peat	0.20	26.03	7.87	9.22	148.56
'CRMS0580'	29.6068	-92.3228	'Intermediate'	Peat	0.10	53.51	15.22	3.22	50.35

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0581'	29.6655	-92.7283	'Saline'	Humic Mud	0.40	21.69	6.64	3.15	83.59
'CRMS0583'	29.8390	-92.9179	'Intermediate'	Peat	0.10	61.56	17.22	2.95	49.62
'CRMS0584'	29.7935	-92.8564	'Intermediate'	Muddy Peat	0.19	36.62	10.79	7.09	147.84
'CRMS0587'	29.7982	-92.9127	'Intermediate'	Muddy Peat	0.34	28.70	8.62	3.52	102.30
'CRMS0588'	29.7736	-92.8225	'Intermediate'	Muddy Peat	0.13	49.03	14.07	5.54	104.36
'CRMS0589'	29.6649	-92.8231	'Brackish'	Humic Mud	0.34	18.40	5.70	8.49	165.65
'CRMS0590'	29.9323	-92.8273	'Fresh'	Muddy Peat	0.21	31.17	9.30	7.99	155.78
'CRMS0593'	29.9922	-92.7607	'Fresh'	Humic Mud	0.53	17.65	5.48	12.02	346.30
'CRMS0595'	29.8536	-92.6368	'Fresh'	Muddy Peat	0.13	48.62	13.96	12.59	230.79
'CRMS0599'	29.6067	-92.6659	'Brackish'	Humic Mud	0.31	19.47	6.01	19.12	350.29
'CRMS0600'	29.5784	-92.5409	'Brackish'	Humic Mud	0.40	15.36	4.82	4.71	89.66
'CRMS0603'	29.8038	-92.7582	'Intermediate'	Peat	0.06	67.06	18.55	10.22	105.46

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0604'	29.7570	-92.7553	'Intermediate'	Muddy Peat	0.20	33.84	10.04	8.64	172.61
'CRMS0605'	29.8605	-92.9160	'Intermediate'	Muddy Peat	0.16	41.23	12.03	5.22	100.34
'CRMS0608'	29.6719	-92.6669	'Intermediate'	Muddy Peat	0.24	38.81	11.38	10.80	295.06
'CRMS0609'	29.6390	-92.6050	'Brackish'	Muddy Peat	0.21	31.16	9.30	5.14	98.89
'CRMS0610'	29.6073	-92.6359	'Brackish'	Humic Mud	0.41	18.94	5.85	6.19	149.53
'CRMS0614'	29.7371	-92.8855	'Brackish'	Muddy Peat	0.33	26.85	8.10	8.00	214.37
'CRMS0615'	29.6803	-92.8222	'Brackish'	Humic Mud	0.37	20.50	6.30	2.09	49.33
'CRMS0616'	29.7301	-92.2606	'Brackish'	Peat	0.11	58.49	16.46	8.68	151.22
'CRMS0618'	29.7374	-92.2491	'Brackish'	Muddy Peat	0.14	43.22	12.55	1.08	19.31
'CRMS0619'	29.6864	-92.2617	'Intermediate'	Peat	0.08	72.80	19.91	5.00	76.29
'CRMS0622'	29.8086	-92.9806	'Intermediate'	Humic Mud	0.54	19.24	5.94	1.56	50.14
'CRMS0623'	29.6356	-92.5096	'Brackish'	Muddy Peat	0.23	30.83	9.21	8.46	180.67
'CRMS0624'	29.8606	-92.8856	'Intermediate'	Peat	0.08	64.94	18.04	7.61	103.76

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0626'	29.6935	-92.6044	'Intermediate'	Muddy Peat	0.36	25.30	7.67	2.60	70.90
'CRMS0630'	29.7876	-92.7925	'Intermediate'	Muddy Peat	0.17	47.82	13.76	1.68	39.10
'CRMS0632'	29.5685	-92.3855	'Brackish'	Muddy Peat	0.22	28.69	8.62	15.28	293.38
'CRMS0633'	29.5632	-92.3231	'Intermediate'	Muddy Peat	0.25	30.65	9.16	9.33	216.63
'CRMS0635'	29.9174	-93.4799	'Intermediate'	Peat	0.15	55.93	15.82	8.42	197.13
'CRMS0638'	29.8680	-93.5105	'Intermediate'	Peat	0.12	50.87	14.54	6.73	121.02
'CRMS0639'	29.8898	-93.4793	'Intermediate'	Muddy Peat	0.14	45.22	13.08	-0.24	-4.47
'CRMS0641'	29.8969	-93.5104	'Intermediate'	Muddy Peat	0.14	45.86	13.25	3.13	58.93
'CRMS0642'	29.8680	-93.4792	'Intermediate'	Muddy Peat	0.19	39.21	11.49	4.40	96.00
'CRMS0644'	29.8309	-93.2924	'Brackish'	Muddy Peat	0.18	35.78	10.56	6.86	127.69
'CRMS0645'	29.8461	-93.1982	'Brackish'	Muddy Peat	0.19	41.58	12.12	3.72	87.23
'CRMS0647'	29.8463	-93.4794	'Intermediate'	Muddy Peat	0.13	40.85	11.93	4.18	66.78
'CRMS0648'	29.8382	-93.1691	'Intermediate'	Peat	0.13	50.10	14.34	2.97	54.87

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0650'	29.9188	-93.1357	'Fresh'	Peat	0.10	55.20	15.64	3.49	53.72
'CRMS0651'	29.9625	-93.5113	'Intermediate'	Muddy Peat	0.30	35.03	10.36	3.00	92.22
'CRMS0655'	29.7991	-93.4169	'Brackish'	Humic Mud	0.28	24.49	7.44	2.42	50.41
'CRMS0656'	30.0205	-93.2606	'Brackish'	Humic Mud	0.31	23.45	7.14	4.31	95.47
'CRMS0658'	30.0559	-93.6042	'Brackish'	Muddy Peat	0.20	30.61	9.15	4.40	79.93
'CRMS0660'	29.9183	-93.6675	'Intermediate'	Peat	0.16	56.36	15.93	0.35	8.72
'CRMS0663'	30.0132	-93.6991	'Brackish'	Peat	0.12	52.48	14.95	7.19	130.15
'CRMS0665'	29.9619	-93.6950	'Intermediate'	Peat	0.07	68.52	18.90	0.19	2.64
'CRMS0669'	29.8814	-93.7280	'Intermediate'	Peat	0.13	53.87	15.31	5.82	115.69
'CRMS0672'	29.8322	-93.4164	'Brackish'	Muddy Peat	0.25	25.40	7.70	3.06	58.45
'CRMS0677'	29.8536	-93.5418	'Intermediate'	Peat	0.08	64.64	17.97	4.30	59.00
'CRMS0680'	29.7738	-93.5128	'Brackish'	Humic Mud	0.76	11.08	3.56	4.47	120.29
'CRMS0682'	29.8243	-93.5759	'Intermediate'	Muddy Peat	0.24	30.56	9.13	2.75	59.96
'CRMS0683'	29.8893	-93.6668	'Intermediate'	Peat	0.09	64.97	18.05	0.67	11.12
'CRMS0685'	29.8911	-93.3859	'Saline'	Humic Mud	0.38	17.99	5.58	2.83	59.52

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS0687'	29.9388	-93.3574	'Saline'	Muddy Peat	0.27	27.18	8.20	5.94	132.06
'CRMS0693'	29.8971	-93.6355	'Intermediate'	Peat	0.18	56.27	15.91	2.07	59.03
'CRMS0978'	29.3235	-90.2925	'Saline'	Muddy Peat	0.17	41.63	12.13	16.55	334.21
'CRMS1024'	29.8747	-89.3789	'Saline'	Humic Mud	0.38	17.79	5.52	12.48	258.57
'CRMS1069'	30.0459	-89.2216	'Saline'	Humic Mud	0.95	6.06	2.06	11.60	226.07
'CRMS1100'	29.6585	-92.4501	'Intermediate'	Peat	0.12	60.17	16.88	12.92	261.61
'CRMS1130'	29.7012	-92.3855	'Intermediate'	Muddy Peat	0.15	41.33	12.05	9.17	165.19
'CRMS1205'	29.8755	-93.5761	'Brackish'	Peat	0.10	50.25	14.38	6.41	94.41
'CRMS1277'	29.8246	-92.4793	'Fresh'	Peat	0.06	80.66	21.72	7.69	99.47
'CRMS1409'	29.8690	-93.0106	'Intermediate'	Muddy Peat	0.13	49.62	14.22	6.21	111.65
'CRMS1413'	29.8970	-93.0106	'Intermediate'	Peat	0.09	60.29	16.91	-0.78	-12.49
'CRMS1446'	29.9269	-92.8271	'Fresh'	Muddy Peat	0.13	39.25	11.50	4.98	76.40
'CRMS1650'	29.8108	-92.0409	'Intermediate'	Muddy Peat	0.19	35.15	10.39	16.56	319.75
'CRMS1738'	29.8538	-93.2675	'Brackish'	Muddy Peat	0.16	36.07	10.64	1.97	32.77

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS1743'	29.8897	-93.2303	'Brackish'	Muddy Peat	0.16	39.20	11.49	3.17	57.09
'CRMS1838'	29.7855	-93.6961	'Intermediate'	Muddy Peat	0.23	42.40	12.34	3.12	89.97
'CRMS1858'	29.8386	-93.5110	'Intermediate'	Muddy Peat	0.18	31.75	9.46	2.05	35.70
'CRMS2156'	29.8758	-93.6992	'Brackish'	Peat	0.15	56.41	15.94	9.27	228.59
'CRMS2166'	29.9824	-93.6983	'Brackish'	Peat	0.07	63.62	17.72	8.50	100.38
'CRMS2189'	29.9257	-93.7590	'Brackish'	Muddy Peat	0.15	40.23	11.76	0.52	8.80
'CRMS2219'	29.7683	-93.6033	'Intermediate'	Humic Mud	0.49	20.03	6.17	5.57	169.31
'CRMS2334'	29.8826	-93.5122	'Intermediate'	Peat	0.13	52.74	15.02	3.98	79.12
'CRMS2418'	29.8721	-93.1689	'Brackish'	Muddy Peat	0.17	41.48	12.10	6.69	139.08
'CRMS2493'	29.8262	-92.8884	'Intermediate'	Muddy Peat	0.16	47.06	13.56	10.91	238.00
'CRMS2568'	29.5641	-91.3542	'Fresh'	Muddy Peat	0.27	27.61	8.31	10.01	224.98
'CRMS2608'	29.2285	-89.3175	'Intermediate'	Humic Mud	0.65	8.56	2.81	20.49	376.69
'CRMS2614'	29.3420	-89.3241	'Intermediate'	Humic Mud	0.42	14.10	4.45	18.28	339.51

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS2634'	29.2310	-89.2594	'Intermediate'	Humic Mud	0.85	6.58	2.21	10.39	196.64
'CRMS2825'	29.4984	-90.4441	'Brackish'	Peat	0.11	57.45	16.21	11.62	206.53
'CRMS2830'	30.0399	-90.3448	'Intermediate'	Muddy Peat	0.25	29.09	8.73	5.66	124.49
'CRMS2854'	30.3009	-89.9833	'Intermediate'	Peat	0.12	57.26	16.16	5.93	111.31
'CRMS3054'	29.7220	-90.3566	'Fresh'	Muddy Peat	0.15	48.43	13.92	11.12	232.21
'CRMS3136'	29.9498	-90.6386	'Fresh'	Peat	0.12	50.46	14.44	12.96	215.67
'CRMS3296'	29.3899	-90.4794	'Saline'	Muddy Peat	0.25	31.03	9.26	1.86	43.47
'CRMS3565'	29.4984	-90.1027	'Brackish'	Muddy Peat	0.20	32.99	9.80	5.70	111.67
'CRMS3601'	29.5750	-89.9481	'Saline'	Muddy Peat	0.17	38.78	11.37	1.23	23.51
'CRMS3617'	29.5477	-89.9142	'Brackish'	Muddy Peat	0.21	31.36	9.36	19.84	383.23
'CRMS3626'	30.1076	-89.8543	'Intermediate'	Muddy Peat	0.18	35.51	10.49	12.67	240.69
'CRMS3639'	29.9053	-89.8516	'Brackish'	Muddy Peat	0.15	41.49	12.10	6.87	121.34
'CRMS3641'	29.9192	-89.8555	'Intermediate'	Muddy Peat	0.12	46.20	13.34	10.20	160.49

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS3650'	30.0564	-89.8232	'Brackish'	Humic Mud	0.40	16.85	5.25	10.03	210.66
'CRMS3664'	29.9124	-89.8267	'Brackish'	Humic Mud	0.46	16.45	5.13	6.86	162.91
'CRMS3667'	30.2588	-89.8844	'Brackish'	Muddy Peat	0.24	37.02	10.90	16.24	426.23
'CRMS3680'	29.5574	-89.7903	'Saline'	Muddy Peat	0.16	47.92	13.78	14.20	312.57
'CRMS3784'	30.1566	-89.6646	'Brackish'	Humic Mud	0.36	19.96	6.15	3.80	85.23
'CRMS3800'	29.8401	-89.6677	'Intermediate'	Muddy Peat	0.19	32.89	9.78	9.11	169.89
'CRMS3913'	30.1659	-90.4794	'Intermediate'	Peat	0.07	65.16	18.10	15.23	205.95
'CRMS3985'	29.7177	-90.1488	'Fresh'	Peat	0.09	61.37	17.17	7.56	110.77
'CRMS4014'	29.5485	-91.3231	'Fresh'	Muddy Peat	0.19	27.08	8.17	11.02	171.56
'CRMS4016'	29.5630	-91.3856	'Fresh'	Muddy Peat	0.20	31.50	9.40	8.18	150.07
'CRMS4045'	29.3806	-91.0097	'Fresh'	Muddy Peat	0.14	49.16	14.10	7.70	154.97
'CRMS4094'	30.3893	-90.1510	'Fresh'	Muddy Peat	0.20	39.14	11.47	11.76	273.99
'CRMS4103'	29.6585	-90.0397	'Intermediate'	Peat	0.12	57.88	16.31	6.97	132.02

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS4107'	30.0548	-89.8534	'Intermediate'	Muddy Peat	0.19	43.23	12.56	2.75	67.17
'CRMS4110'	30.2017	-89.6666	'Intermediate'	Muddy Peat	0.21	30.17	9.03	11.37	216.57
'CRMS4218'	29.5632	-90.1652	'Intermediate'	Muddy Peat	0.16	37.70	11.08	13.29	229.16
'CRMS4406'	30.2019	-89.7279	'Brackish'	Muddy Peat	0.15	41.58	12.12	8.61	151.32
'CRMS4407'	30.2227	-89.7305	'Intermediate'	Peat	0.15	53.39	15.18	6.37	143.30
'CRMS4455'	29.2585	-90.9479	'Saline'	Humic Mud	0.30	20.95	6.43	15.14	288.59
'CRMS4529'	29.4700	-89.8221	'Saline'	Humic Mud	0.34	20.15	6.20	0.66	13.91
'CRMS4548'	29.8616	-89.6687	'Saline'	Humic Mud	0.47	11.99	3.83	9.78	175.45
'CRMS4551'	29.8535	-89.6041	'Saline'	Muddy Peat	0.26	26.31	7.95	3.71	77.06
'CRMS4557'	29.8246	-89.5741	'Saline'	Muddy Peat	0.18	34.84	10.31	10.40	198.00
'CRMS4572'	30.0569	-89.4812	'Saline'	Humic Mud	0.32	23.03	7.03	7.70	171.19
'CRMS4596'	30.0557	-89.4513	'Saline'	Humic Mud	0.51	13.41	4.24	11.98	257.13

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS4626'	29.3375	-89.1980	'Intermediate'	Humic Mud	0.63	9.30	3.03	18.97	362.67
'CRMS4690'	29.4984	-90.0402	'Brackish'	Muddy Peat	0.21	33.87	10.05	8.50	179.00
'CRMS4779'	29.6421	-91.4474	'Swamp'	Muddy Peat	0.16	44.18	12.81	10.64	211.24
'CRMS4782'	29.6645	-91.4429	'Swamp'	Humic Mud	0.97	7.08	2.37	11.12	256.21
'CRMS4808'	29.6356	-91.4136	'Swamp'	Muddy Peat	0.24	31.81	9.48	13.20	301.06
'CRMS4809'	29.6485	-91.4187	'Swamp'	Muddy Peat	0.24	29.25	8.77	7.70	161.74
'CRMS4900'	29.6356	-91.2596	'Swamp'	Humic Mud	0.56	12.36	3.94	19.43	428.04
'CRMS4938'	29.6175	-91.3252	'Swamp'	Humic Mud	0.56	14.77	4.64	12.73	331.82
'CRMS5035'	29.6249	-91.0364	'Swamp'	Muddy Peat	0.21	37.15	10.94	14.42	330.28
'CRMS5116'	29.9735	-90.9119	'Swamp'	Humic Mud	0.52	22.41	6.85	5.40	191.74
'CRMS5167'	30.1435	-90.7787	'Swamp'	Muddy Peat	0.47	26.90	8.12	13.39	507.32
'CRMS5255'	30.1928	-90.6015	'Swamp'	Humic Mud	0.64	13.53	4.28	11.34	309.94

Station ID	Latitude	Longitude	Wetland Type	Sediment Type	Bulk Density (g/cm ³)	Organic Matter (%)	Organic Carbon Content (%)	Vertical Accretion Rate (mm/yr)	Organic Carbon Accumulation Rate (g C/m ² yr)
'CRMS5373'	30.1007	-90.6310	'Swamp'	Peat	0.21	50.83	14.53	1.37	40.87
'CRMS5414'	30.1581	-90.6337	'Swamp'	Peat	0.16	52.33	14.91	0.93	22.19
'CRMS5452'	30.3696	-90.5312	'Swamp'	Muddy Peat	0.24	39.02	11.44	12.68	343.52
'CRMS5845'	30.1836	-90.6836	'Swamp'	Muddy Peat	0.20	43.22	12.55	8.77	221.99
'CRMS6038'	29.6047	-91.3522	'Swamp'	Muddy Peat	0.17	41.61	12.13	13.38	274.49
'CRMS6088'	30.3153	-89.6580	'Swamp'	Humic Mud	0.56	13.68	4.32	7.19	173.56
'CRMS6090'	30.3253	-89.6628	'Swamp'	Humic Mud	0.64	11.52	3.69	10.27	243.34
'CRMS6209'	30.3760	-90.2588	'Swamp'	Peat	0.15	52.05	14.84	8.89	200.66
'CRMS6299'	30.0484	-90.3504	'Brackish'	Humic Mud	0.48	20.28	6.24	10.65	319.80
'CRMS6303'	29.4743	-90.1905	'Intermediate'	Muddy Peat	0.18	44.73	12.95	9.33	217.19
'CRMS6304'	29.4347	-91.2561	'Fresh'	Humic Mud	0.32	17.62	5.47	2.28	40.10