ERDC TR-24-6

National Regional Sediment Management Program

A Beneficial Placement Decision Support Framework for Wetlands

Case Study for Mobile Harbor, USA

Kyle D. Runion, Brandon M. Boyd, Candice D. Piercy, Don E. Mroczko,
Elizabeth S. Godsey, Herbert M. Bullock, and Richard J. Allen

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Development Center

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Final report

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Abstract

The US Army Corps of Engineers, in the responsibility of maintaining navigational infrastructure, has a unique opportunity to improve coastal wetland resiliency and conserve coastal natural infrastructure through the beneficial use of dredged material for wetland restoration. Opportunities are widespread, and tools such as biophysical models can aid coastal managers in assessing habitat vulnerability and planning restoration. In this study, the Marsh Equilibrium Model was utilized in concert with observed data to predict future conditions and evaluate potential effects of beneficial use of dredged material to restore marshes in Mobile Harbor, Alabama. A range of site conditions and two restoration strategies were considered, and the subsequent impact to dredged material management area volumes evaluated. Results showed that wetland restoration via the thin-layer placement of dredged material can restore marsh elevation to combat sea level rise and conserve fill capacity at dredged material management areas. This approach is demonstrated for adoption nationwide by coastal managers.

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Preface

This study was conducted for the USACE National Regional Sediment Management Program under Funding Account Code U4375160; AMSCO Code 031398. The program manager was Dr. David W. Perkey.

The work was performed by the Technical Programs Office, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication of this report, Mr. Charles E. Wiggins was the technical director for Navigation Research and Development. The deputy director of ERDC-CHL was Mr. Keith Flowers, and the director was Dr. Ty V. Wamsley.

The chief of the Wetlands and Coastal Ecology Branch was Ms. Patricia M. Tolley, and the chief of the Ecosystem Evaluation and Engineering Division was Mr. Mark D. Farr. The deputy director of ERDC Environmental Laboratory was Dr. Brandon J. Lafferty, and the director was Dr. Edmond J. Russo, Jr.

Appreciation is expressed to Mr. James T. Morris, research professor and distinguished professor emeritus at the Belle Baruch Institute for Coastal and Marine Science, University of South Carolina, for guidance in biophysical modeling.

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The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

1 Introduction

1.1 Background

The beneficial use of dredged material (BUDM) can provide both environmental and economic benefits through efficient resource allocation. Millions of cubic yards of sediment are dredged by the US Army Corps of Engineers (USACE) each year, and opportunities exist for this material to provide value to coastal communities and habitats (Schrader 2019). According to the USACE Regional Sediment Management (RSM) Sediment Placement Data Viewer (https://rsm.usace.army.mil/BUDB), the USACE removes approximately 210 million cubic yards (MCY)[1,2] annually from navigation projects. The majority of dredged material is generally suitable for BUDM, but only approximately 38% of US dredged material is used beneficially (Figure 1) (USACE, n.d., "RSM"). Of this BUDM, nearly half of the volume of material is placed in-river, 17% is placed in wetlands, and the remainder is placed in beach, littoral, upland, and open-water environments (USACE, n.d., "RSM"). A recent 2020 South Atlantic Division RSM Optimization Update highlighted that 42% of the dredged material from the Mobile Harbor Federal Navigation Project (MHNP) is managed by RSM strategies that bring a conservative annual average RSM value of over $13.2 million to the nation. The USACE has an interest in integrating wetlands in RSM strategies as well as utilizing natural and nature-based features for coastal storm risk management. Consequently, there is potential for widespread adoption of BUDM practices to restore wetlands in degraded systems from developmental and climate related stressors (Craft et al. 2009) as a part of a RSM strategy.

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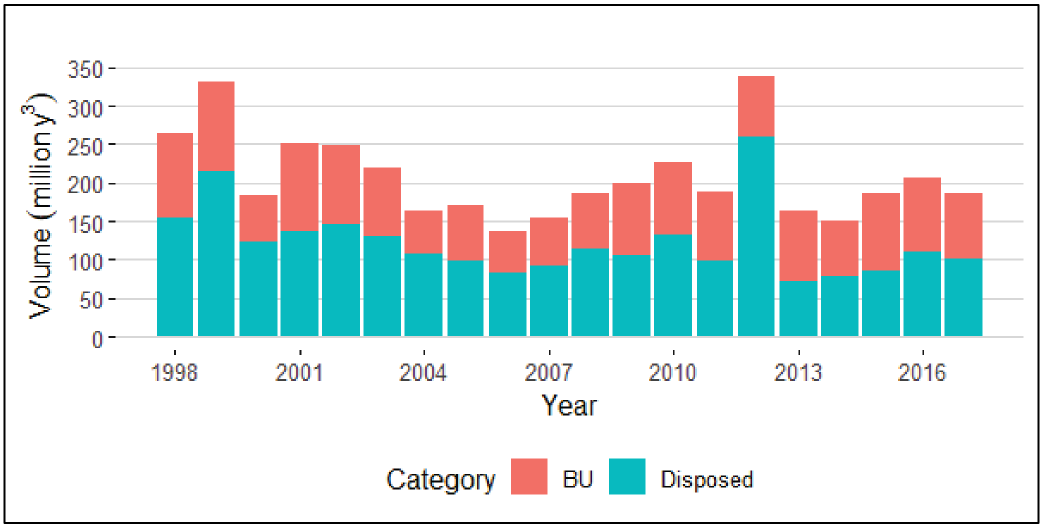
[1] For a full list of the spelled-out forms of the units of measure used in this document, please refer *to US Government Publishing Office Style Manual, 31st ed. (Washington, DC: US Government Publishing Office 2016*), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

[2] For a full list of the unit conversions used in this document, please refer to *US Government Publishing Office Style Manual, 31st ed.* (Washington, DC: US Government Publishing Office 2016), 345-7, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

Figure 1. Total volume by year of US Army Corps of Engineers (USACE) dredging activity with fate of dredge material placement or beneficial use.



By (1) conserving dredged material management area (DMMA) capacity, (2) reducing dredging costs, and (3) improving wetland resiliency, BUDM can assist coastal managers in long-term planning. DMMAs often occupy coastal land near dredging locations to reduce transportation costs. As these areas are generally becoming more developed, increasing DMMA capacity may be impractical due to real estate constraints or cost concerns. The lifespan of DMMAs may be extended with the application of BUDM. Further, material transportation costs may be reduced through BUDM if the placement site is closer than the current DMMA. The practice may improve riverine conditions as stable wetlands can trap suspended sediment and reduce edge erosion, curtailing the filling of a channel. Finally, improving wetland resiliency supports multiple USACE missions such as ecosystem restoration and flood control.

1.2 Objective

This study was conducted to develop a framework to implement BUDM for wetland restoration. The application of the framework is demonstrated on Blakeley Island in Mobile Bay, Alabama.

1.3 Approach

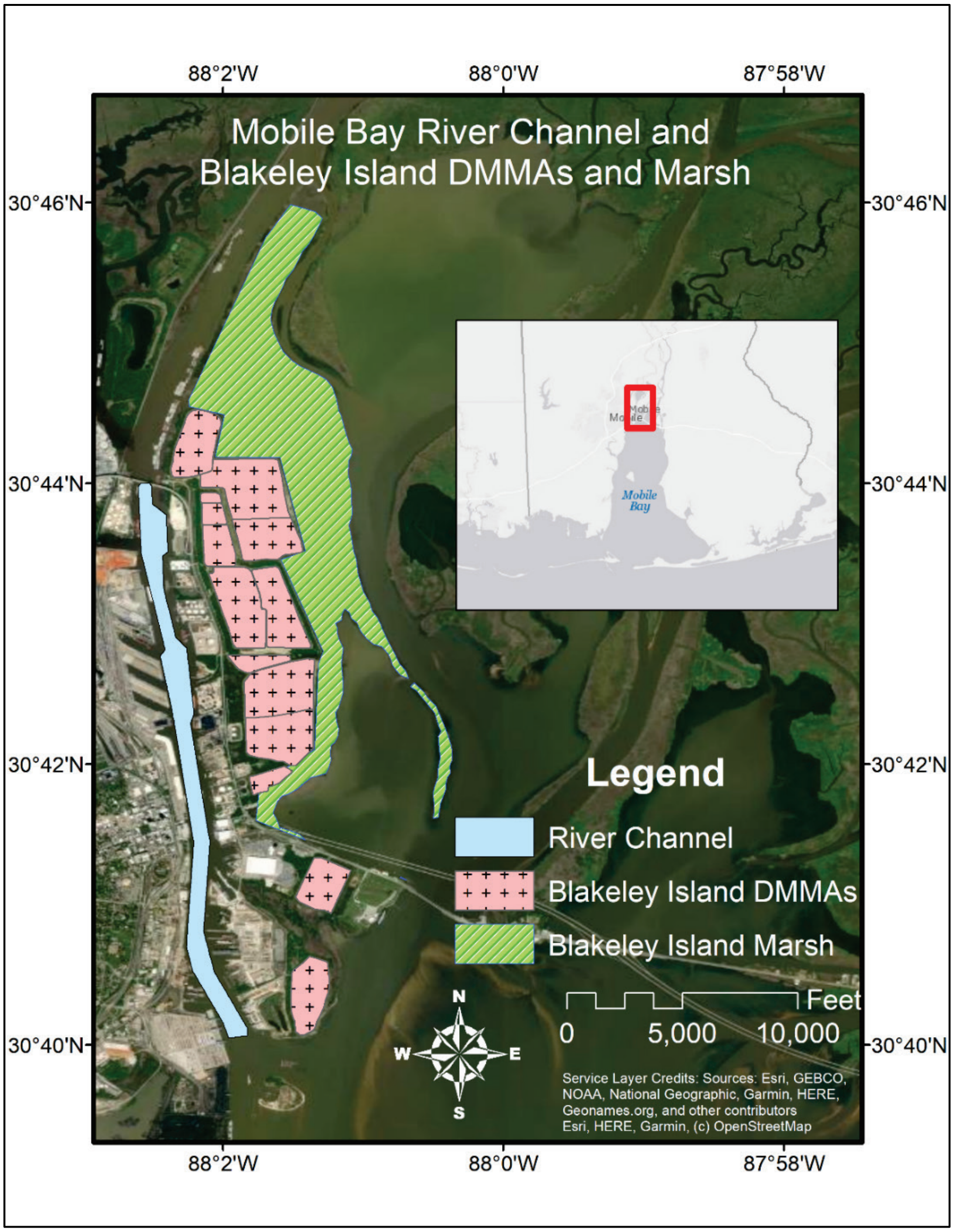
Field data collection combined with modeling efforts, can be used to develop broad plans of wetland restoration. Field observations can be used to validate model results, which then provide estimates of the timeline and scale of restoration needed. In this study, data such as soil composition and accretion rate inform a marsh elevation model to generate a conservative estimate of restoration potential (i.e., how much dredged material can the marsh accommodate, and pairs that need with available resources from nearby dredging activities).

1.4 Study Site

Mobile Harbor is a federal navigation channel in Mobile, Alabama, that the Alabama State Port Authority and USACE are responsible for overseeing. As a large, open-water body, sediment transported from upland sources through riverine networks deposit in the bay and navigation channel. Through the federally authorized MHNP, managed by the USACE Mobile District (SAM), maintenance dredging supports harbor infrastructure, including the navigation channel. According to the Mobile Harbor General Reevaluation report (USACE 2019), approximately 5.9 MCY of material is dredged through MHNP maintenance activities annually. This dredging creates an excess of sediment resources, which are typically placed at an offshore, open-ocean location, open-water bay placement locations or in upland DMMAs.

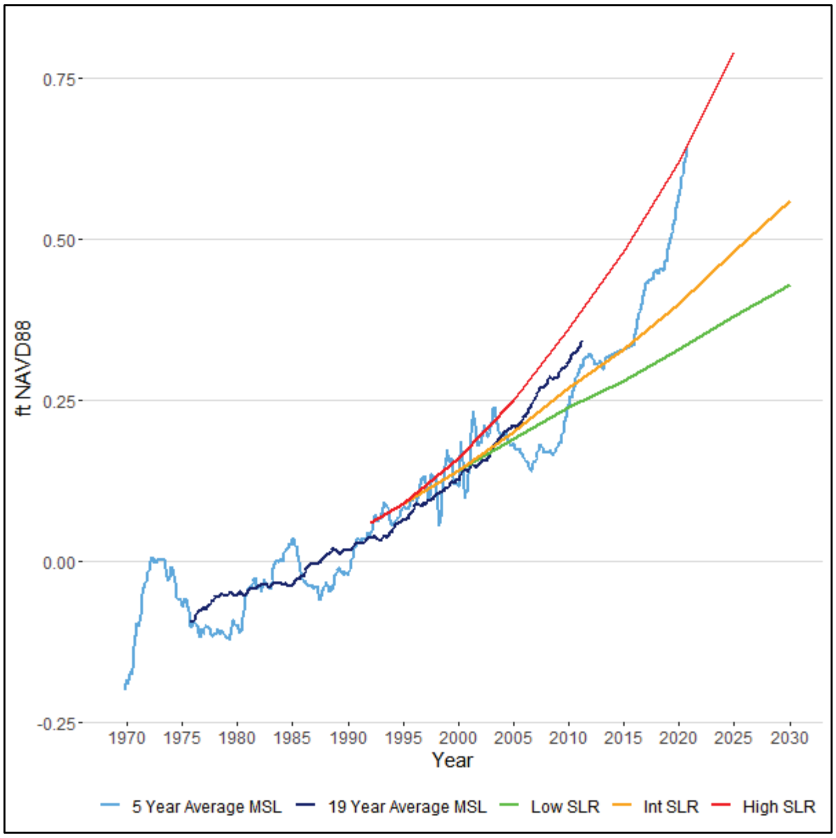
Blakeley Island, located between the Mobile and Spanish Rivers, contains a collection of five DMMAs that support maintenance dredging in the Mobile Bay River Channel (Figure 2). Developed in the early 1970s, the five DMMAs combine to total 616.1 acres of surface area. The average maintenance dredging requirement for navigation in the Mobile Bay River Channel between 2011 and 2016 was approximately 2.6 MCY/year; approximately 1.3 MCY/year is added to the Blakeley Island DMMAs (UASCE 2019). Depending on equipment availability, the remainder of the dredged material is generally placed in an ocean dredged material disposal site using a large hopper dredge. DMMAs are filled with dredged material in rotation to allow for dewatering and consolidation. In 2019, the life expectancy of the collection of DMMAs was estimated to exceed 20 yr with routine maintenance and proposed expansions (BUDM to raise dike height; USACE 2019). BUDM can be utilized as a management strategy to reduce fill of the DMMAs and provide benefits to nearby ecosystems such as wetland creation and habitat enhancement. The majority of the dredged material from the Mobile Bay and River is characterized as fine-grained silts, soft clays, and sands. Historical beneficial use with this material includes construction activities such as landfill cover, dike raisings, and general fill, as well as environmental restoration activities including wetland rehabilitation (Parson et al. 2015).

Figure 2. Map of Mobile Bay River Channel and Blakeley Island dredged material management areas (DMMAs) and marsh.



The marsh adjacent to Blakeley Island is approximately 1,361 acres in area and ranges from low marsh to upland habitat. Suspended sediment concentration (SSC) at the Tensaw River Causeway, just south of the Blakeley Island site, ranged from approximately 15 mg/L to 200 mg/L as measured in January through April 2017 by Ramirez et al.[3] The mean tidal range at the nearby Mobile State Docks, Alabama, National Oceanic and Atmospheric Administration (NOAA) gauge (approximately 5 mi from study site; Station ID: 8737048) is 1.5 ft. Sea level rise (SLR) at the same station is projected at between 0.79 and 4.82 ft between 2020 and 2100 according to USACE 2013 projection curves (USACE, n.d., "Sea-Level"). The USACE Sea Level Tracker shows that at the Dauphin Island NOAA gauge (Station ID: 8735180), the 19 yr monthly average sea level is tracking near the high SLR projection while the 5 yr monthly average has generally been between the intermediate and high projections (Figure 3). A recent vegetation survey showed that the dominant type of vegetation within the marsh includes typical high marsh species such as *Phragmites australis* (common reed), *Panicum vergatum* (switchgrass), *Typha latifolia* (common cattail), and *Baccharis halimifolia* (eastern baccharis) (Berkowitz et al. 2018).

Figure 3. Past sea level and USACE sea level rise (SLR) scenarios at Dauphin Island, Alabama.



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[3] Ramirez, M., M. B. Taylor, N. Ganesh, and T. C. Pratt. In review. *Mobile Harbor Study Quantifying Sediment Characteristics and Discharges into Mobile Bay*. Vicksburg, MS: US Engineer Research and Development Center.

2 Methods

2.1 Field Data Collection and Laboratory Analysis

To assess marsh soil conditions and recent (decadal) sediment accumulation rates at the wetland adjacent to the Blakeley Island DMMAs, sediment cores were collected via piston coring from four areas in the marsh with varying vegetation diversity. Core locations are listed in Table 1. Cores BI1a and BI2 cores were located in high marsh habitat while BI3 and BI4 were from low marsh habitat.

Table 1. Blakeley Island core locations.

Core	Latitude (DD)[a]	Longitude (DD)
BI1a	30.735908	−88.025029
BI2	30.699315	−88.023738
BI3	30.733068	−88.018832
BI4	30.76875	−88.02241

[a] decimal degrees

Cores were processed via loss-on-ignition (LOI) and gamma spectroscopy to measure organic matter and radionuclide activity, respectively. Processing included slicing cores into 2 cm intervals between 0 and 60 cm, drying at 100°C overnight, and milling. Water content was measured by weighing samples before and after drying, and LOI was conducted by placing 4.000 ± 0.001 g of sample material in a muffle furnace to burn organic material at 360°C for 3 hr as established by Heiri et al. (2001).

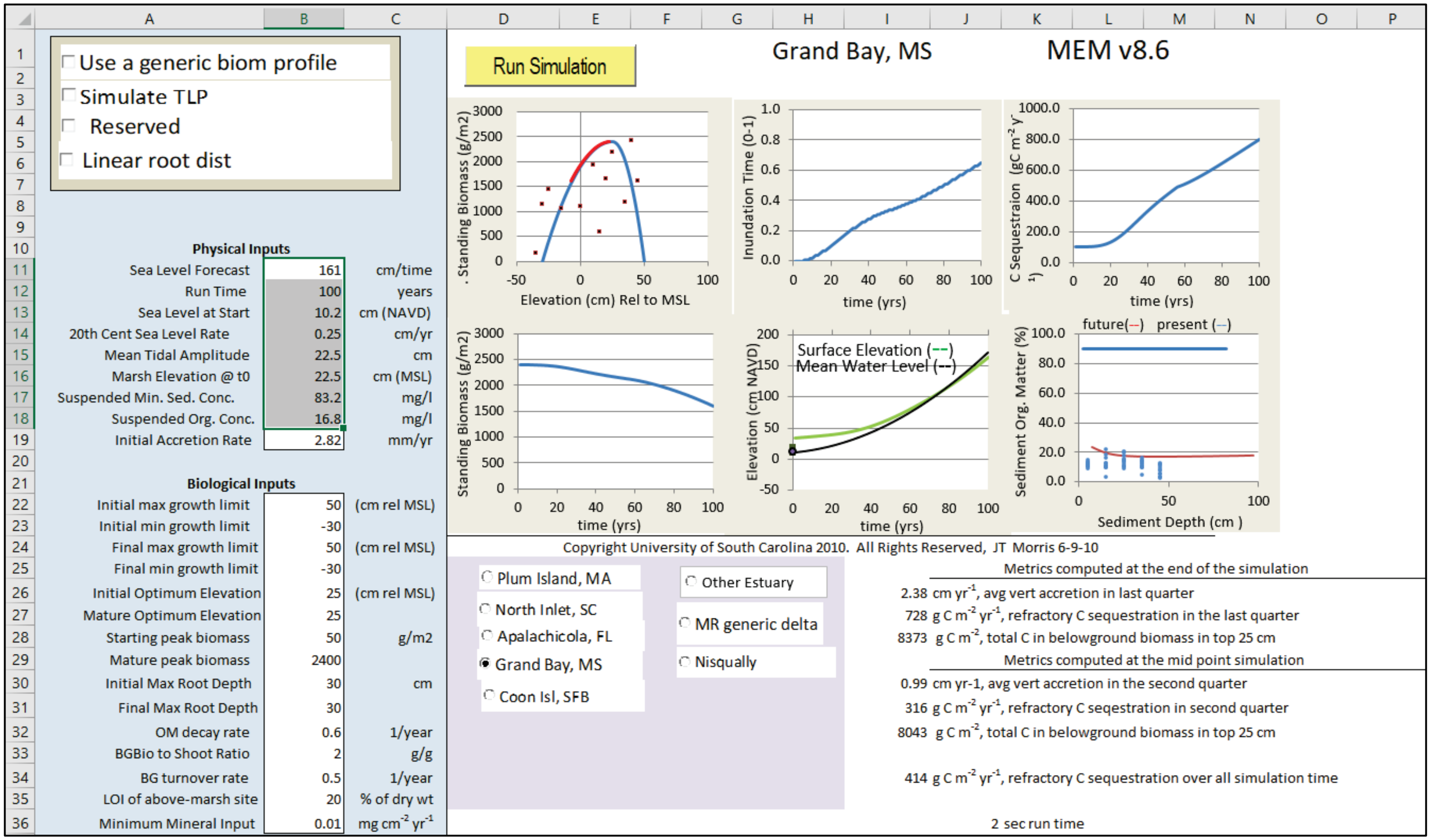
Samples were analyzed via gamma spectroscopy using a planar germanium detector (Ortec Model GEM-S7025P4) coupled to multichannel analyzer (Ortec Model DSPEC-50). Radionuclide activities were determined by comparison to a soil standard (NIST SRM 4357). Methods have been developed to ascertain sediment accumulation rates on decadal timescales through analysis of several different radionuclides. In this study, vertical profiles of Cesium-137 (^{137}Cs) are examined to determine sediment accumulation since widespread fallout (Ritchie and McHenry 1990). Activities were examined along the depth of the soil core and analyzed for peaks in activity of various radionuclides. Radionuclide analysis was not completed on all samples collected, due to COVID-19 related restricted laboratory access. However, analysis was sufficient to determine ^{137}Cs peak locations on two cores.

2.2 Model Evaluation of Future Marsh Conditions

The Marsh Equilibrium Model (MEM) is a one-dimensional numerical model used to predict coastal marsh elevation given mineral and organic contributions in different sea level rise scenarios (Morris et al. 2002). MEM version 8.6 with thin-layer placement (TLP) feature was utilized in an Excel spreadsheet format for this project to evaluate marsh resiliency and assess potential for BUDM at the Blakeley Island site (Figure 4). The spreadsheet format removes the technological hurdle that may exist for coastal managers with complex modeling software. The model delivers a range of outputs of which marsh elevation and both standing and total biomass were of interest in this exercise.

The MEM is based on a set of understandings about salt marsh evolution as described by Morris and Renken (2019). Vegetative growth is dependent on elevation relative to mean sea level (MSL) with peak growth occurring at a site-specific optimal elevation between MSL and mean higher high water (MHHW). At too low or too high of an elevation, primary production is limited by hypoxia and osmotic stress, respectively, and growth declines. Below MSL, a marsh can be considered unstable as inundation may cause reduced growth and sediment accumulation, resulting in transition to a subtidal environment. Above this elevation, marshes may continue to trap mineral sediment and produce organic material, allowing for resiliency. Optimal elevation is species specific and can be adjusted within the model. Other physical and biological inputs can influence elevation and contribute to resiliency. For example, high SSCs allow for more mineral material accumulation through sediment trapping, and high peak biomass contributes to standing biomass and organic matter accretion.

Figure 4. Marsh Equilibrium Model (MEM) version 8.6 Microsoft Excel interface.



Grand Bay, MS

MEM v8.6

☐ Use a generic biom profile
☐ Simulate TLP
☐ Reserved
☐ Linear root dist

Physical Inputs

Sea Level Forecast	161	cm/time
Run Time	100	years
Sea Level at Start	10.2	cm (NAVD)
20th Cent Sea Level Rate	0.25	cm/yr
Mean Tidal Amplitude	22.5	cm
Marsh Elevation @ t0	22.5	cm (MSL)
Suspended Min. Sed. Conc.	83.2	mg/l
Suspended Org. Conc.	16.8	mg/l
Initial Accretion Rate	2.82	mm/yr

Biological Inputs

Initial max growth limit	50	(cm rel MSL)
Initial min growth limit	-30	
Final max growth limit	50	(cm rel MSL)
Final min growth limit	-30	
Initial Optimum Elevation	25	(cm rel MSL)
Mature Optimum Elevation	25	
Starting peak biomass	50	g/m2
Mature peak biomass	2400	
Initial Max Root Depth	30	cm
Final Max Root Depth	30	
OM decay rate	0.6	1/year
BGBio to Shoot Ratio	2	g/g
BG turnover rate	0.5	1/year
LOI of above-marsh site	20	% of dry wt
Minimum Mineral Input	0.01	mg cm^{-2} yr^{-1}

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○ Plum Island, MA
○ North Inlet, SC
○ Apalachicola, FL
● Grand Bay, MS
○ Coon Isl, SFB
○ Other Estuary
○ MR generic delta
○ Nisqually

Metrics computed at the end of the simulation

2.38 cm yr^{-1}, avg vert accretion in last quarter
728 g C m^{-2} yr^{-1}, refractory C sequestration in the last quarter
8373 g C m^{-2}, total C in belowground biomass in top 25 cm

Metrics computed at the mid point simulation

0.99 cm yr-1, avg vert accretion in the second quarter
316 g C m^{-2} yr^{-1}, refractory C seqestration in second quarter
8043 g C m^{-2}, total C in belowground biomass in top 25 cm

414 g C m^{-2} yr^{-1}, refractory C sequestration over all simulation time

2 sec run time

A low-medium-high range of future SLR projections, SSCs, and initial marsh elevations were used as MEM inputs to model an array of scenarios (Table 2). SLR projections were sourced from the low, medium, and high USACE 2013 curves (USACE, n.d., "Sea-Level"). SSCs were based on local assessments by Ramirez et al.[4] and scaled to 100%, 50%, and 25% of local concentrations following modeling efforts by Schile et al. (2014). A range of initial marsh elevations were developed through a model tuning process using soil organic matter (SOM) and elevation data from Weeks Bay, Alabama.[5] Tuning consisted of refining the initial marsh elevation input to allow the model to accurately generate organic matter during model initialization. Additional elevation inputs were selected based on elevation frequency at Weeks Bay. Each initial elevation was within biological growth limits established in the model; elevations represent those below MSL, near MSL, and above mean high water.

Table 2. Values for input variables used in MEM. Low, medium, and high values were determined based on the literature to capture a variety of potential scenarios.

Rate	SLR (cm/century)	SSC (mg/L)	Marsh Elevation (cm MSL)	TLP Placement
Low	30	23.75	−5	15 cm every 10 yr
Med	61	47.5	8	NA
High	161	95	50	30 cm every 20 yr
Source	USACE (n.d., "Sea-Level")	Ramirez et al.[a]	Morris et al.[b]	—

[a] Ramirez, M., M. B. Taylor, N. Ganesh, and T. C. Pratt. In review. *Mobile Harbor Study Quantifying Sediment Characteristics and Discharges into Mobile Bay*. Vicksburg, MS: USACE.

[b] J. Morris, University of South Carolina, personal communication, 26 September 2020.

The three low-medium-high inputs for SLR, SSC, and elevation led to a modeling effort consisting of 27 distinct scenarios. Other variables in the model, including biological inputs such as past SLR rate, optimal elevation for vegetation, and maximum biomass, can be adjusted within the model but are consistent throughout the scenarios in this study. Pre-set biological inputs and past SLR rate are provided for a number of regions in the model; those for Weeks Bay, Alabama, are used as a proxy for the conditions at Blakeley Island (Morris et al. 2016).

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4. Ramirez, M., M. B. Taylor, N. Ganesh, and T. C. Pratt. In review. *Mobile Harbor Study Quantifying Sediment Characteristics and Discharges into Mobile Bay*. Vicksburg, MS: USACE.

5. J. Morris, University of South Carolina, personal communication, 26 September 2020.

Two distinct TLP strategies to restore elevation were simulated (Table 2). Placement was simulated beginning 10 years after year 0 with a vegetation recovery time of 5 yr; the two scenarios placed 15 cm every 10 yr and 30 cm every 20 yr. These placement frequencies were believed to be operational and ecological feasible but in practice an adaptive approach could yield a different frequency. This analysis was applied only to the scenario with the most extreme elevation deficit (high SLR, low SSC, low initial marsh elevation) to determine maximum placement capacity and develop a conservative beneficial use estimate. Both placement strategies added a 150 cm lift of dredged material over the marsh area in 100 yr. Placement refers to the realized elevation added after 1 yr of settling, consolidation, and loss.

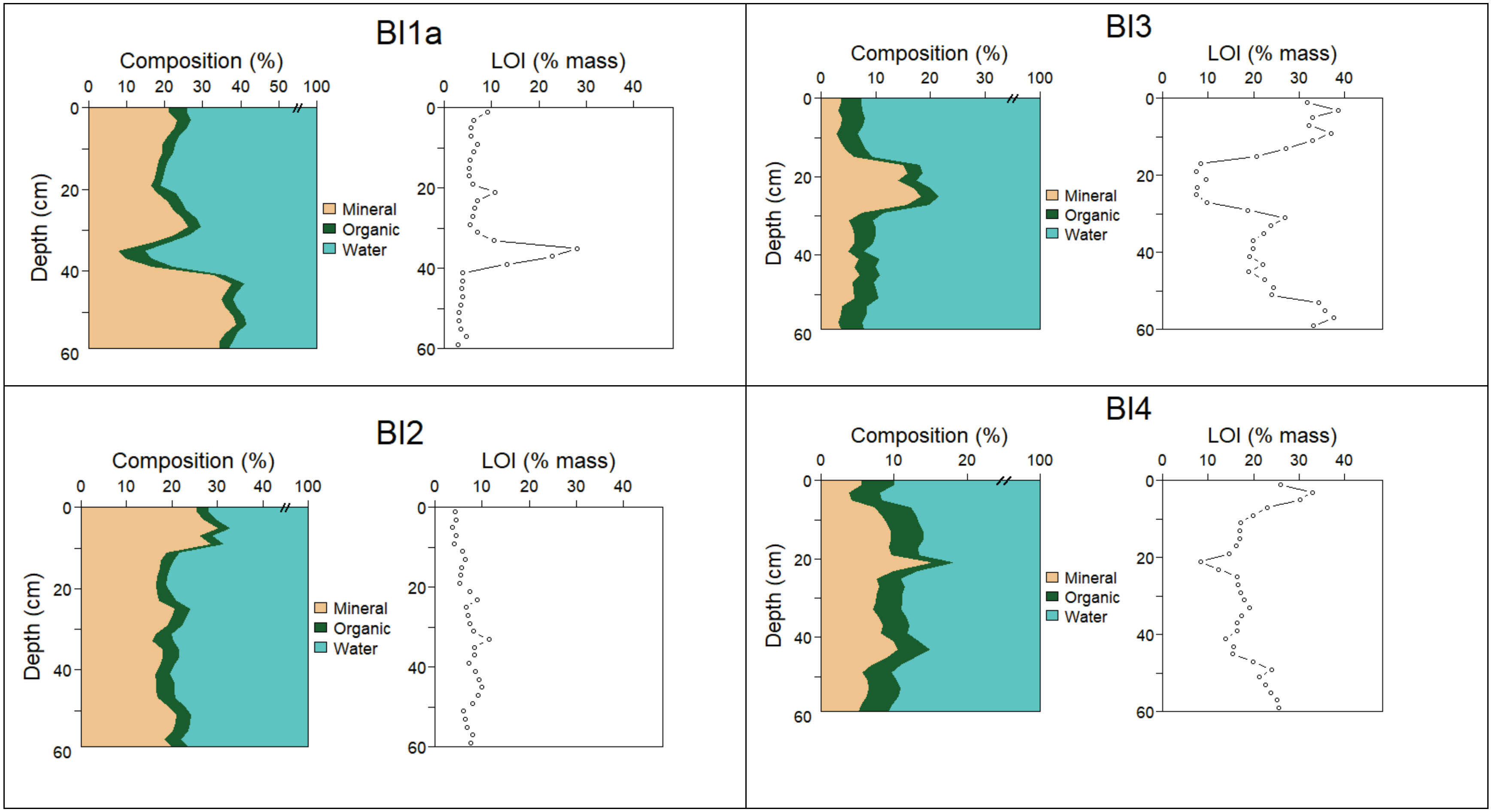
3 Results

3.1 Marsh Soil Properties and Accretion Rates

Blakeley Island soil cores varied in mineral, organic, and water content through depth (Figure 5). Water content ranged from 59% to 93%, organic content ranged from 2% to 7%, and mineral content ranged from 3% to 39% (all percentage of mass). The LOI fraction of dried cores, a measure of organic matter, ranged from 3% to 39% with mineral matter as the remaining 61% to 97%. Variations in composition with depth could indicate a change in sediment supply, vegetative community or productivity, or inundation status. Peaks of low or high organic matter could also be caused by biological processes such as bioturbation.

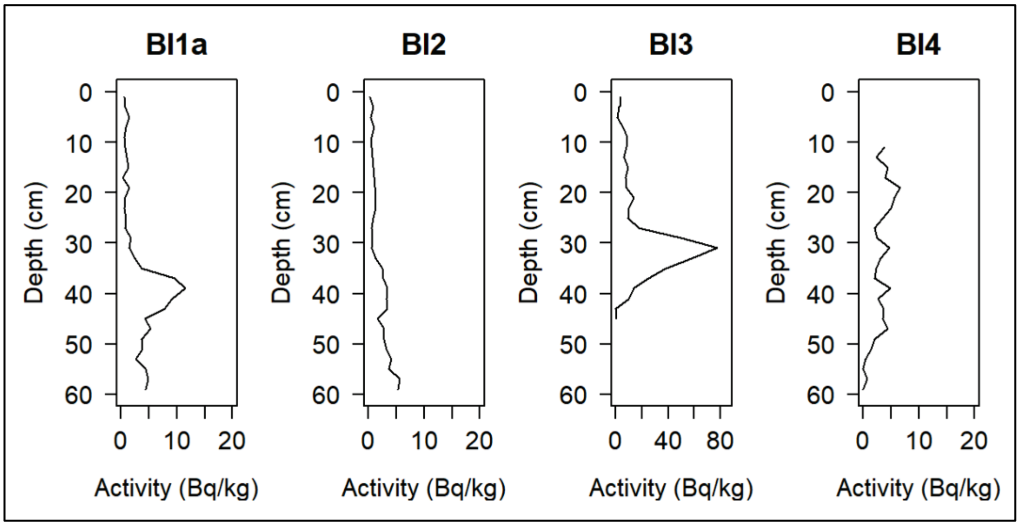
Coastal wetland studies have found vertical accretion can be dependent on either mineral material through deposition or organic material through in situ production, or a combination of the two (Nyman et al. 1993). The high fraction of mineral material compared to organic material in the Blakeley Island cores indicates that deposition events such as fluvial and coastal floods likely contribute substantially to maintaining marsh elevation. Cores in the low marsh range (BI3 and BI4) had higher fractions of organic matter and may be indicative of future conditions for current-day, mid- and high-marsh regions when considering SLR.

Figure 5. Physical composition and loss-on-ignition (LOI) of marsh cores.



Activities of ^{137}Cs, reported in bequerels/kilogram, are presented in Figure 6. Peaks of ^{137}Cs were found at 39 cm in core BI1a and 31 cm in core BI3. Though ^{137}Cs concentrations may be affected by soil composition and physical processes, a peak in ^{137}Cs through the vertical profile may roughly align a depth to a surface location in 1963 (Ritchie and McHenry 1990). With this, sediment accumulation rates for the BI1a and the BI3 cores are estimated to be 0.68 and 0.54 cm/yr, respectively. Peaks were not visually identified in the BI2 and BI4 cores. This may be because either (a) the core depth was not sufficient to capture the 1963 horizon or (b) processes such as postdepositional scavenging of ^{137}Cs (Benninger et al. 1975) or erosion and removal of ^{137}Cs (Ritchie and McHenry 1990) resulted in the lack of a measurable peak. Excess ^{210}Pb chronology may support one of these conclusions but was not available for inclusion in this study. If the peak of ^{137}Cs occurred deeper than the length of the core, the minimum average accretion rate is 1.1 cm/yr. Though sediment accretion in marsh environments may vary spatially with microtopography (Kearney et al 1994), causing measured accretion rate to differ by core, such a comparably high rate of accretion was assumed to be unlikely.

Figure 6. Cesium-137 (^{137}Cs) activity (Bq/kg) of each core from 0 to 60 cm by 2 cm intervals. Core profiles are incomplete due to time constraints. Note the varying scales on horizontal axes.



3.2 Modeling Case Study

The MEM calculates a number of annual outputs including

- marsh elevation (North American Vertical Datum of 1988 [NAVD88] and MSL),

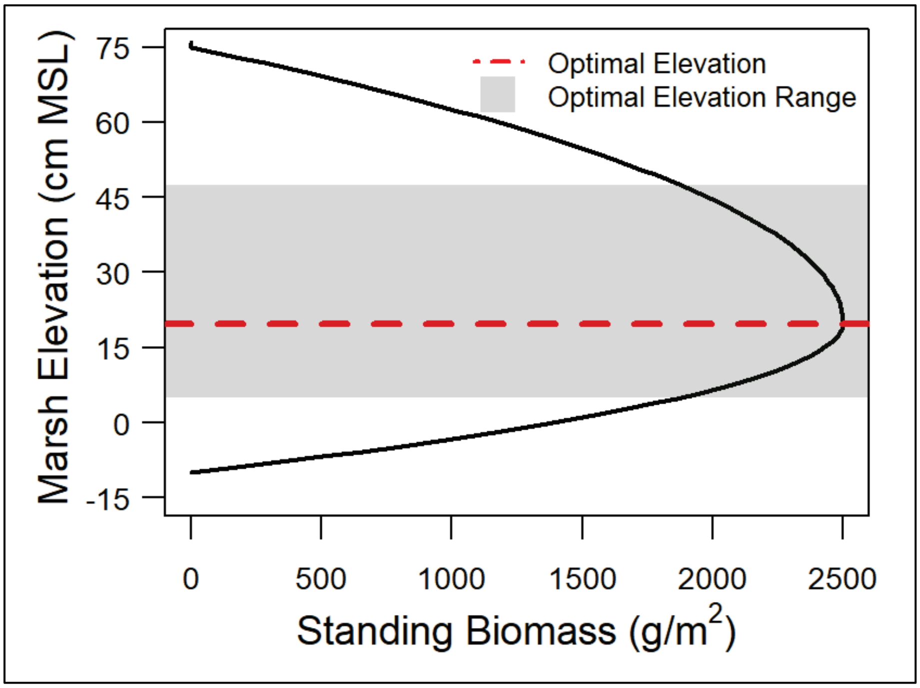
- MSL (NAVD88),
- marsh accretion rate (mm),
- standing biomass (g/m^2),
- belowground biomass (kg/m^2), and
- fractional inundation time (%).

Additionally, MEM calculates outputs representing conditions of hypothetical soil cores from 0 to 1 m depth at the start and the end of the model timespan, presenting

- organic matter through depth (%),
- bulk density (g/cm^3), and
- live and total belowground biomass (g/m^2).

Optimal elevation is a biological parameter in the model that determines vegetative productivity depending on marsh elevation. Vegetation species optimal elevation and tidal regime are used by the model to determine a biomass generation. During this modeling exercise, the optimal elevation was 20 cm above MSL (Figure 7). The relationship between elevation and productivity is not linear; vegetative growth drops to <75% of maximum growth below 5 and above 47 cm. These elevations of 75% productivity are indicated by the shaded region in Figure 7.

Figure 7. Optimal elevation of vegetative productivity for the MEM effort.



Marsh elevation and above and belowground biomass (vegetation) of model scenarios can help to assess marsh resiliency and potential for BUDM via TLP. Results of each model scenario can reveal the effect of SLR, SSC, and initial marsh elevation on these outputs in the timeframe of the model (100 yr). Marsh elevation in this modeling exercise after 100 yr ranged from –111 cm MSL to 42 cm MSL (Figure 8). According to the MEM, high rates of SLR may cause sea level to outpace sediment accumulation and create unstable and inundated marshes, consistent with findings from US Geological Survey and USACE (USACE, n.d., “RSM”). The level of SSC may help mitigate this effect as high SSCs can encourage sedimentation, which contributes to elevation. The effect of SSC on elevation was greatest when marsh elevation is within the tidal range, allowing for sedimentation. When outside of the tidal range, marshes experienced little change in absolute elevation. Marshes starting this modeling exercise at a higher elevation were more likely to persist in this exercise timeframe.

Standing biomass is an important indicator of marsh health and resilience as it provides habitat, encourages sedimentation, and contributes to belowground organic matter stocks. Among model scenarios, standing biomass was largely dependent on elevation and inundation status (Figure 9). With low elevation relative to MSL, extreme inundation caused hypoxic conditions, leading to a decline in standing biomass. Under extended inundation, the concentration of standing biomass fell to zero and signaled a marsh collapse. For each model scenario of high SLR and those of medium SLR and low SSC or initial marsh elevation, a marsh collapse occurred. The scenario of high SLR, low SSC, and low initial elevation experienced the earliest marsh collapse at model year 22. Standing biomass at the end of the model timespan in the low SLR, high SSC, and medium initial elevation scenario was at the maximum allowed within the model parameters, 2500 g/m^2.

Figure 8. Modeled marsh elevations with no beneficial use of dredged material (BUDM). Each row represents a different suspended sediment concentration (SSC) (labeled at *right*), and each column represents a different initial marsh elevation (labeled at *top*). Line pattern and color represent different SLR projections. Optimal elevation refers to surface elevation relative to sea level where primary production is maximized.

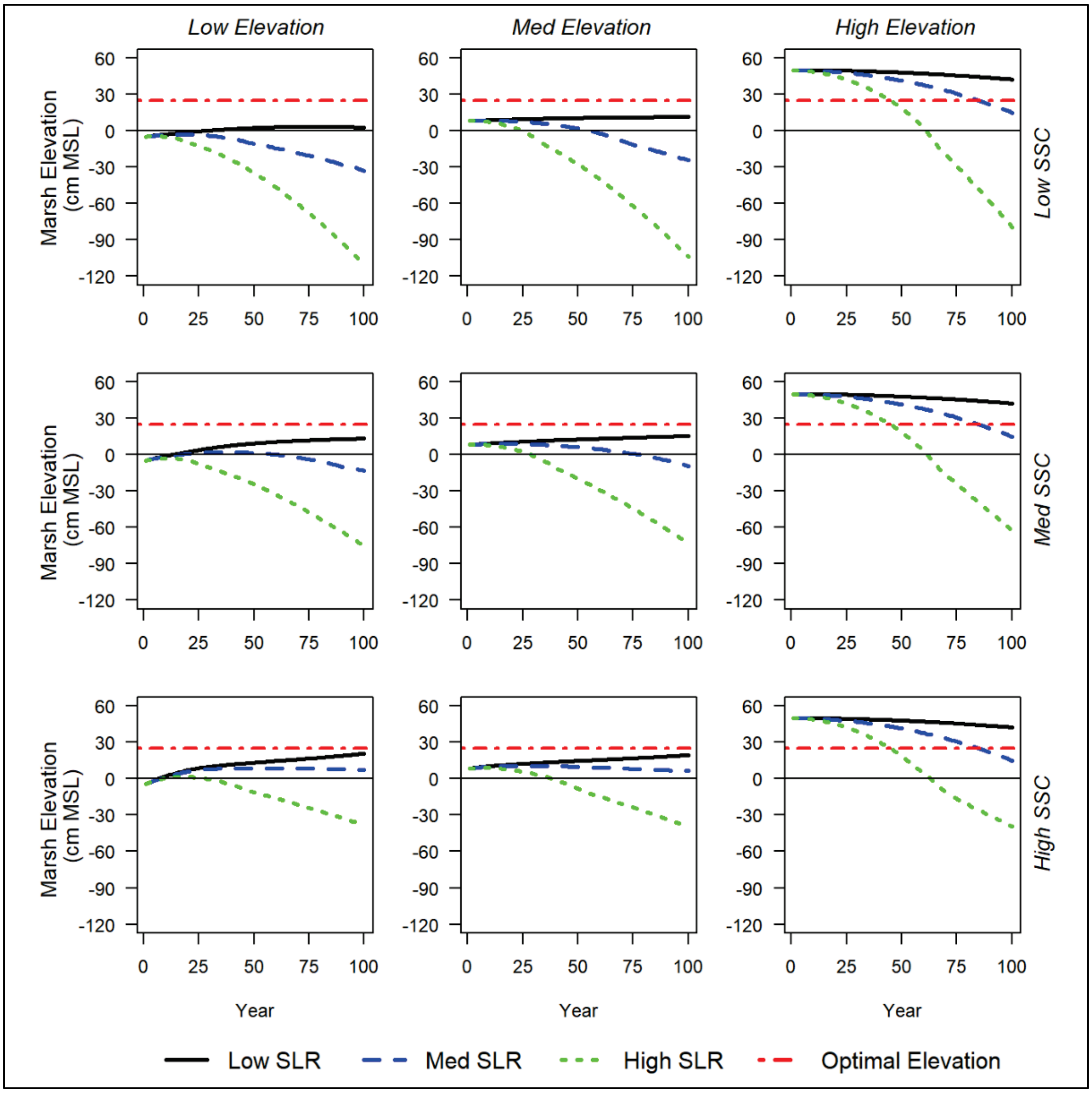
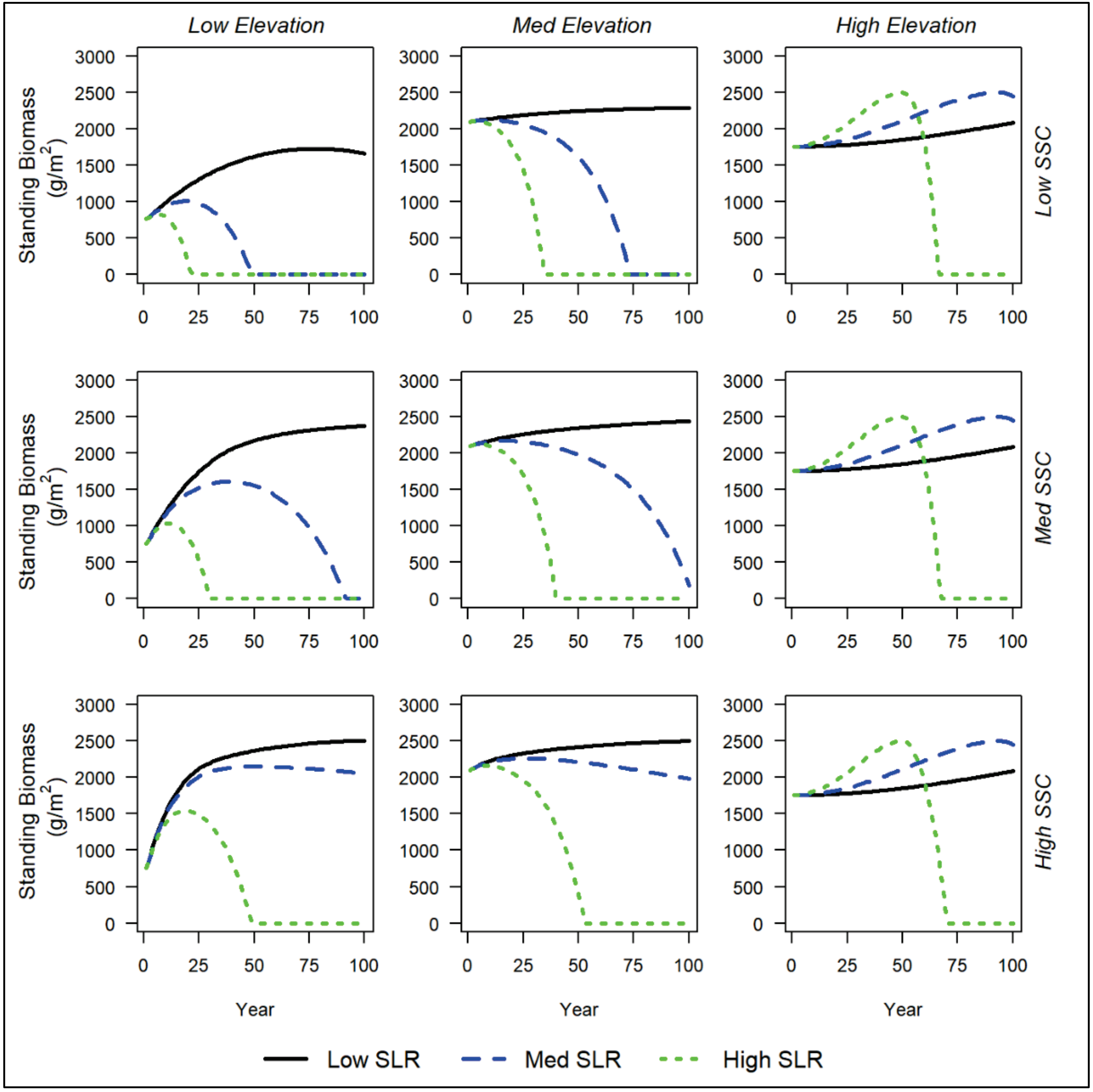
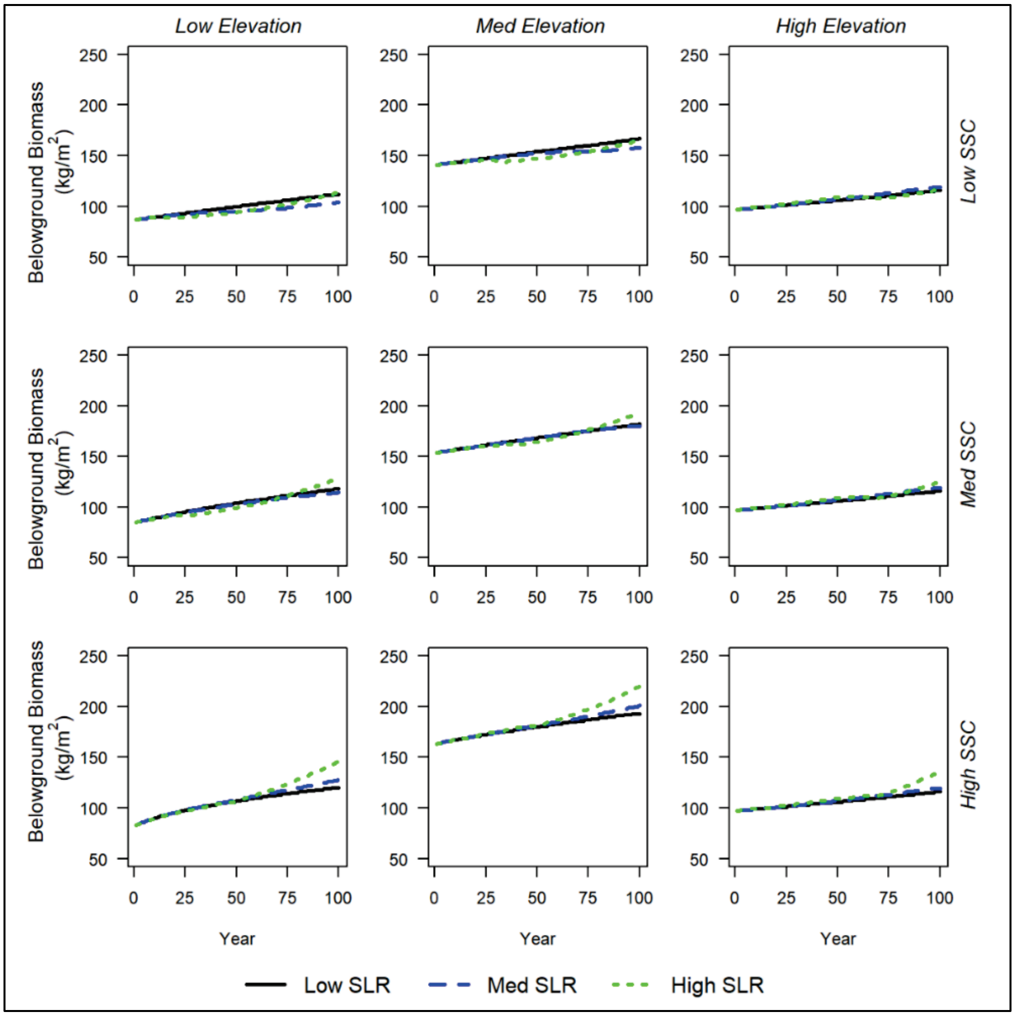


Figure 9. Modeled marsh standing biomass with no BUDM. Each row represents a different SSC (labeled at *right*) and each column represents a different initial marsh elevation (labeled at *top*). Line pattern and color represent different SLR projections.



Belowground biomass represents the collection of organic matter through the growth and slow decay of vegetation and other organic contributions and is a major component of marsh accretion. Decay rate is influenced by inundation and standing biomass; high vegetative productivity allows more accumulation of biomass, and increased inundation time can reduce organic matter decay (Figure 10). Final belowground biomass was lowest in the scenarios of medium SLR, low SSC, and low initial marsh elevation (104 kg/m^2) and highest in the scenario of high SLR, high SSC, and medium initial marsh elevation (220 kg/m^2). Vegetative productivity may fall as inundation time increases, establishing a positive feedback loop where the lack of in situ biological production hinders vertical accretion, further lessening rates of vegetative productivity.

Figure 10. Modeled marsh belowground biomass with no BUDM. Each row represents a different SSC (labeled at *right*), and each column represents a different initial marsh elevation (labeled at *top*). Line pattern and color represent different SLR projections.

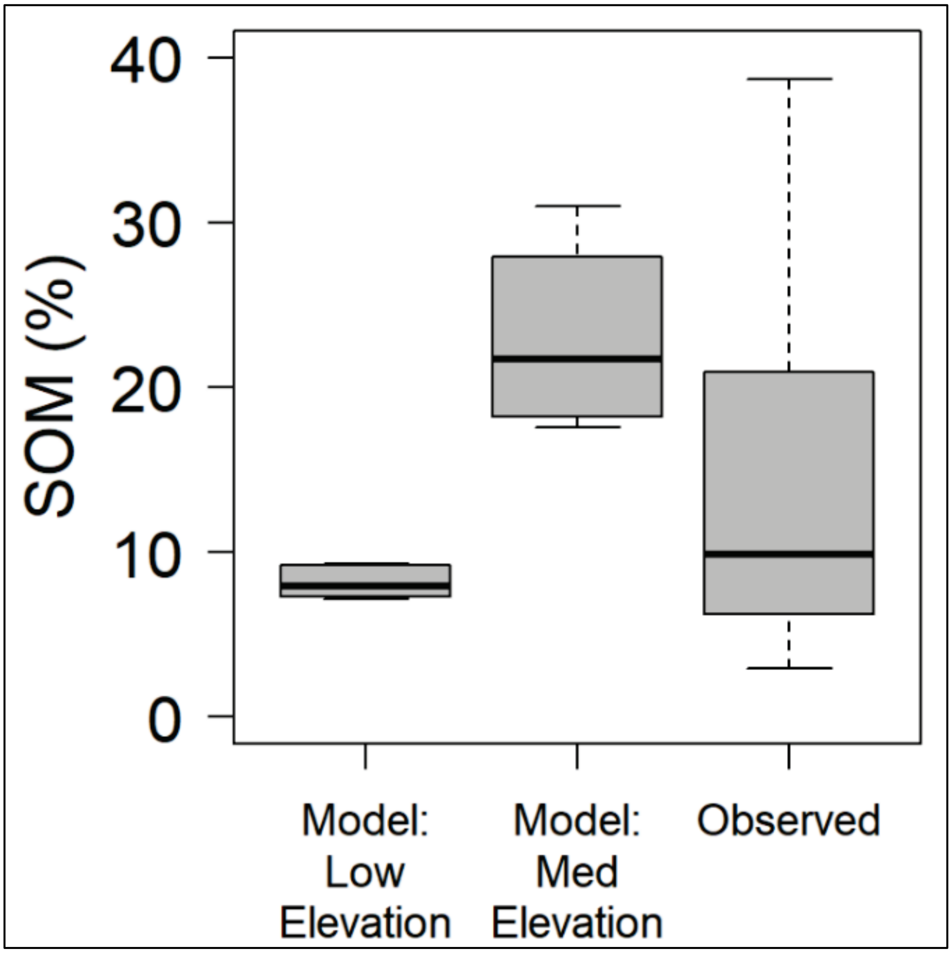


3.3 Model Validation

Results from model initialization of the array of MEM scenarios can be compared to data from sediment cores collected on site for optimization and to assess applicability. Model results shown in Figure 11 and Figure 12 refer to initial conditions generated by the model based on past conditions, and *observed* refers to measurements from the soil cores.

The median of observed SOM was 9.9% (Figure 11). Model SOM was strongly affected by initial marsh elevation. Median modeled SOM at a low initial marsh elevation was 8.2%, and at a medium initial marsh elevation was 23.0%. At a high initial marsh elevation, all modeled organic matter estimations were near 90%, and these data were removed from Figure 11. Organic matter was slightly higher in low SSC scenarios, as in those scenarios autochthonous organic matter had a larger relative effect on total organic matter. Scenarios with high SSC were more impacted by allochthonous mineral and organic material, which consisted of 94.7% mineral and 5.3% organic matter.[6] At low and medium initial marsh elevations, there was good agreement between observed and modeled SOM.

Figure 11. Observed (uncorrected LOI) and modeled (MEM) soil organic matter (SOM) results for two of the three initial elevations: low and medium. The high initial elevation model SOM was near 90% for all scenarios and is not shown. The *bold horizontal line* represents the median value. The upper and lower bounds of the box represent the 75th and 25th percentile, respectively. The upper and lower whiskers represent maximum and minimum SOM values.



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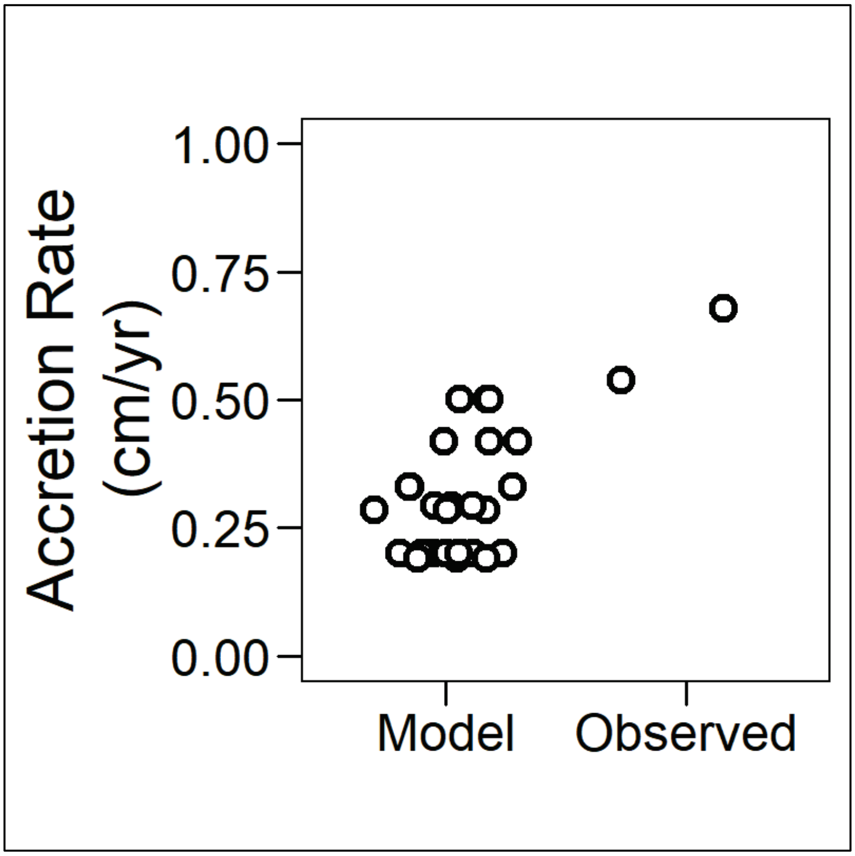
[6] J. Morris, University of South Carolina, personal communication, 26 September 2020.

Modeled accretion rates ranged from 0.20 to 0.50 cm/yr and were slightly lower than the observed rates estimated from the collected cores (0.54 to 0.68 cm/yr) as shown in Figure 12. Model results indicated that accretion rate varied slightly by scenario. Scenarios with high SSC and low initial elevation had higher accretion rates given higher rates of sediment deposition and more vertical space between the marsh surface and sea level to accrete; initial accretion rate in these scenarios best matched observed data. However, a lack of observations could also explain this disagreement.

Figure 12. Observed (core) and modeled (MEM) initial accretion rates. The initial model accretion rates were lower than observed accretion rates.

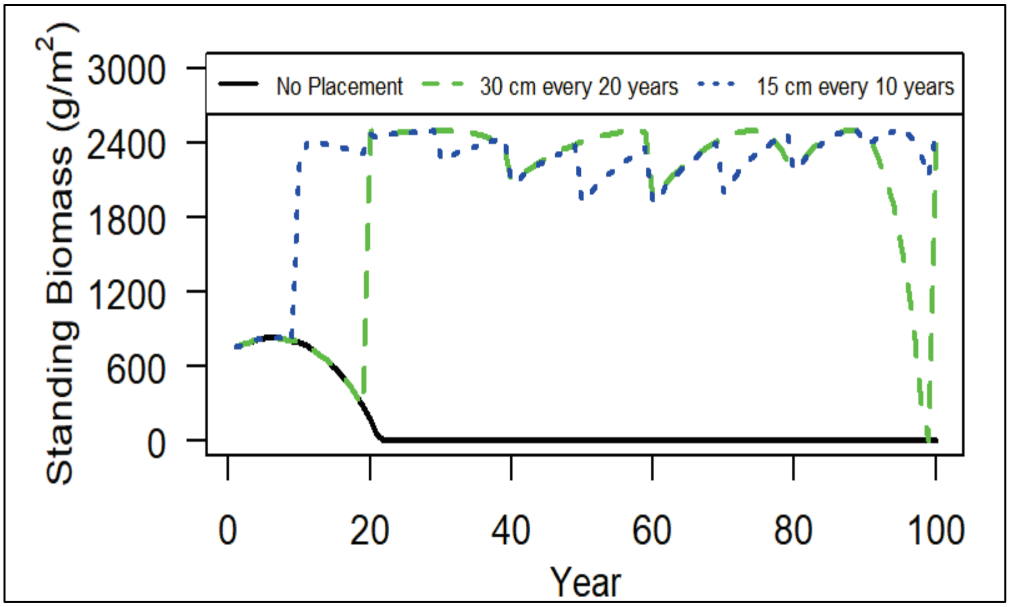


3.4 Marsh Response to Thin-Layer Placement (TLP)

The two MEM placement scenarios (Table 2) provide different options of BUDM when considering logistical and economic costs and economic and ecological benefits. Both scenarios place 150 cm of material over 100 yr at different placement frequencies. The following section analyzes standing and belowground biomass and marsh elevation with no placement, and the two placement scenarios during the model scenario that represented the largest deficit in marsh elevation relative to MSL (high SLR, low SSC, and low initial marsh elevation).

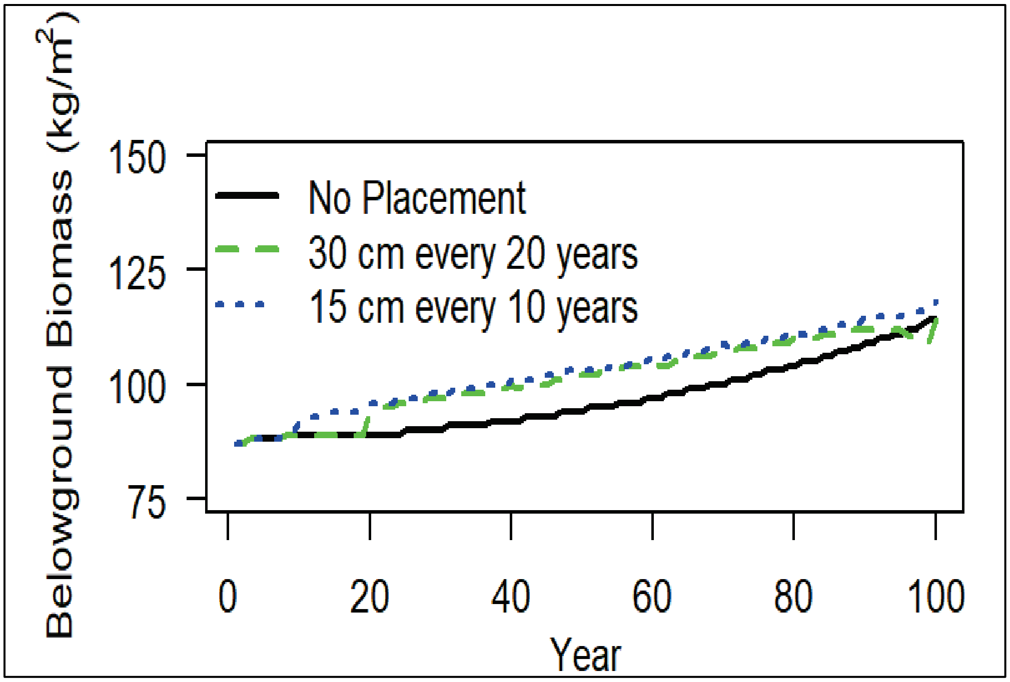
As the simulated marsh with no placement fell in elevation, the vegetative growth limit (−10 cm) was surpassed. Standing biomass declined and reached zero at model year 22, indicating marsh collapse (Figure 13). Through placement events, marsh elevation was sufficient to support standing biomass. For both types of placement scenarios, standing biomass reduced following each placement event through a simulated burial event where material smothered the vegetation, which the recovered over the following years.

Figure 13. Standing biomass by placement scenario. Marsh conditions were near optimal elevation in placement scenarios for much of the model timespan, leading to high concentrations of standing biomass. Without placement, standing biomass was projected to reach zero at model year 22.



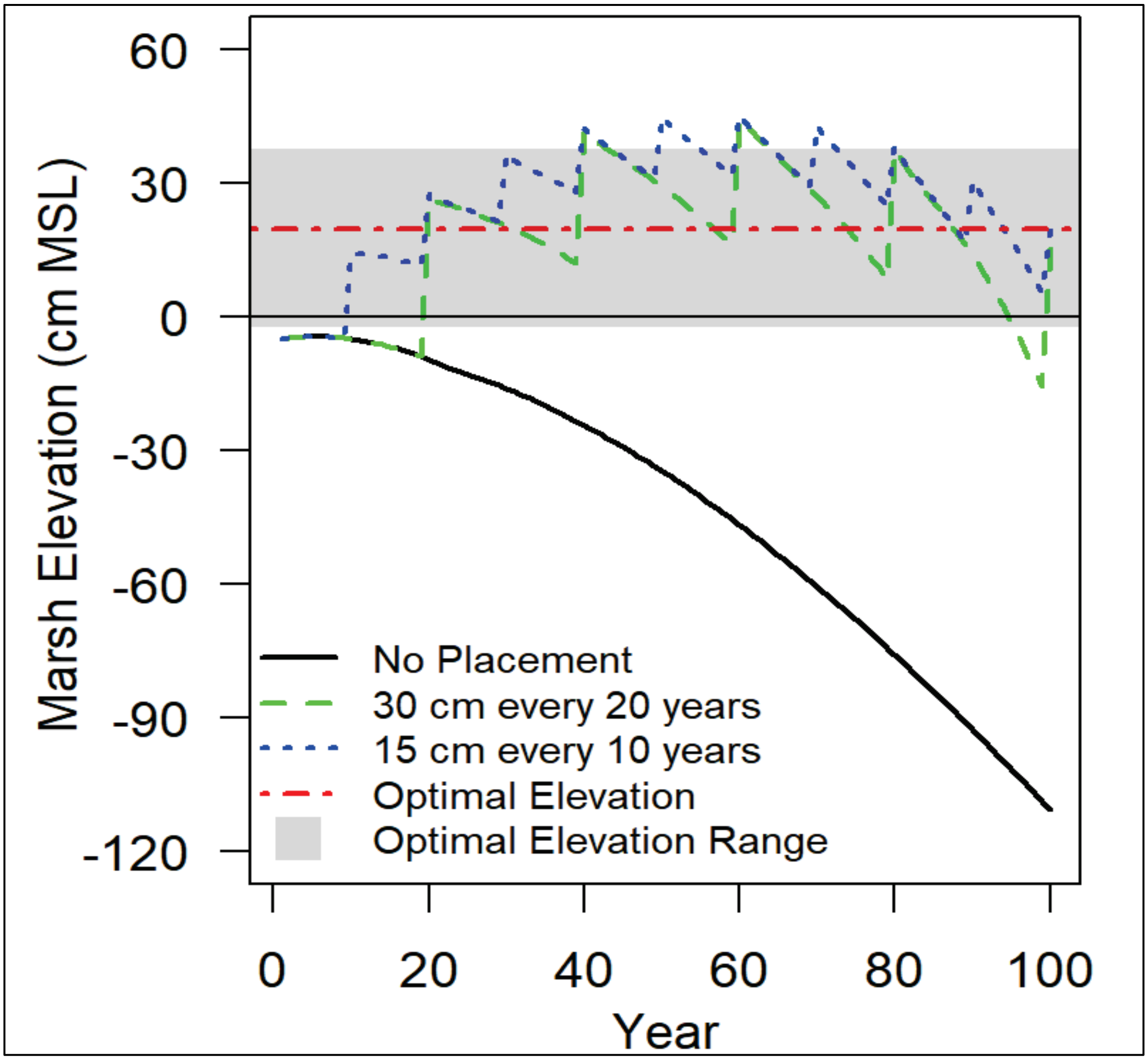
Concentrations of marsh belowground biomass were higher throughout most of the model timespan in the placement scenarios compared to the no placement scenario (Figure 14). The two placement scenarios developed belowground biomass through high vegetative productivity. In the no-placement scenario, inundation caused the decay rate to fall, allowing for belowground biomass to increase.

Figure 14. Belowground biomass by placement scenario. Belowground biomass was slightly higher in the placement scenarios due to increased vegetative productivity.



Placement strategies increased marsh elevation to an elevation near optimal for vegetative productivity for most of the model timespan (Figure 15). In these scenarios, the marsh was able to accrete through sedimentation and in situ biological production, though regular placement via BUDM was necessary to keep pace with SLR. Without placement, marsh elevation quickly dropped below the minimum growth limit (−10 cm MSL), limiting accretion of organic matter and suspended sediment. Marsh elevation in this scenario continued to fall at approximately the rate of SLR once the marsh collapsed. In each placement scenario, marsh elevation was outside of the optimal range at some point, indicating that an adaptive placement strategy will be required.

Figure 15. Marsh elevation over the model timespan with no BUDM, BUDM of 30 cm every 20 yr, and BUDM of 15 cm every 10 yr. Both BUDM scenarios raised marsh elevation to near the optimal elevation for vegetative productivity over the model timespan while without placement, the marsh fell well below mean sea level (MSL).



To calculate volume of material sourced from the DMMA, two assumptions were required: (1) bulk density of pre- and postsediment were identical and (2) losses were estimated to be 5%. The first assumption states that a volume of sediment sourced from the DMMA is the same volume of sediment 1 yr after placement on the marsh. The second assumption was that the summation of sediment loss incurred through the remobilization, transport, and placement operations is estimated to be 5% of sediment sourced from DMMA. Postplacement sediment consolidation is accounted for intrinsically in MEM. Based on these assumptions, 150 cm of material placed over the approximately 1,361 acres marsh equates to 10.3 MCY sourced from DMMAs.

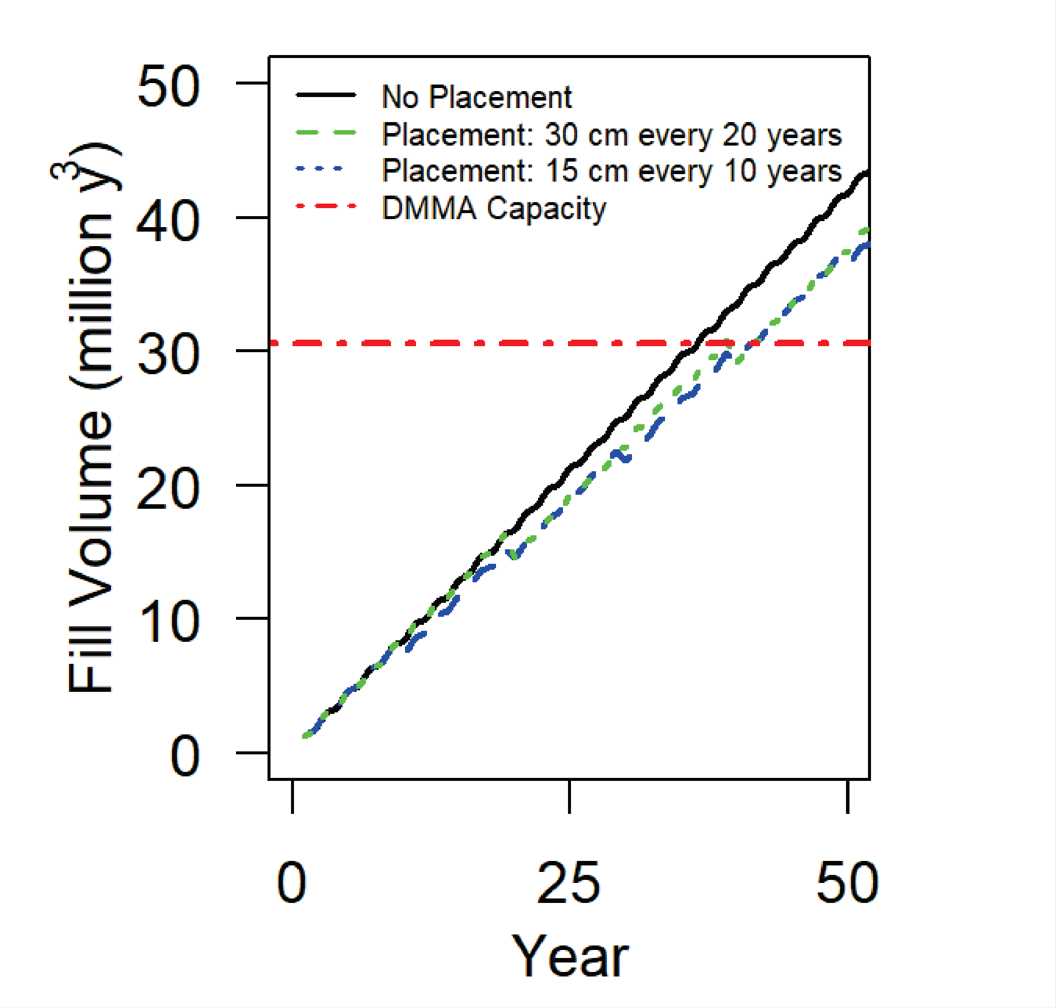
4 Discussion

Model validation of SOM and accretion rate suggested that the model performed adequately for general planning purposes. When initial marsh elevation was at or above MHHW, modeled soil organic matter reached an equilibrium near 90%, much higher than observed conditions. At elevations near MLW or MSL, accuracy of modeled organic matter improved. Model application should be limited to marsh elevations within MHHW and MLW. While the model did estimate lower initial accretion rates than those observed, those estimations for scenarios with high SSC and low initial marsh elevation were similar to observations. The researchers of this study are confident that the estimates generated by the MEM in this application are reasonable to generally assess BUDM and DMMA reduction capacity.

The collection of DMMAs at Blakeley Island have a combined total idealized volumetric capacity of 34.8 MCY (RMG 2010), and in 2019, the combined existing capacity when considering dike wall extensions was 30.6 MCY (USACE 2019). Various management practices are utilized by SAM to maximize lifespan, including site rotation, sump haul-out, and the use of dredged material to raise and maintain dike walls. With this, the lifespan in 2019 was estimated to surpass 20 yr.

Figure 16 presents an estimated DMMA lifespan from the detailed 2019 estimate given the following management: (1) material removal of 0.7 MCY every other year (RMG 2010) and (2) using fill material to build projected maximum dike height cross sections (USACE 2019). In Figure 16, DMMA fill volume is presented with no material removed for BUDM (no placement) and material removed for the two placement schedules described in the case study.

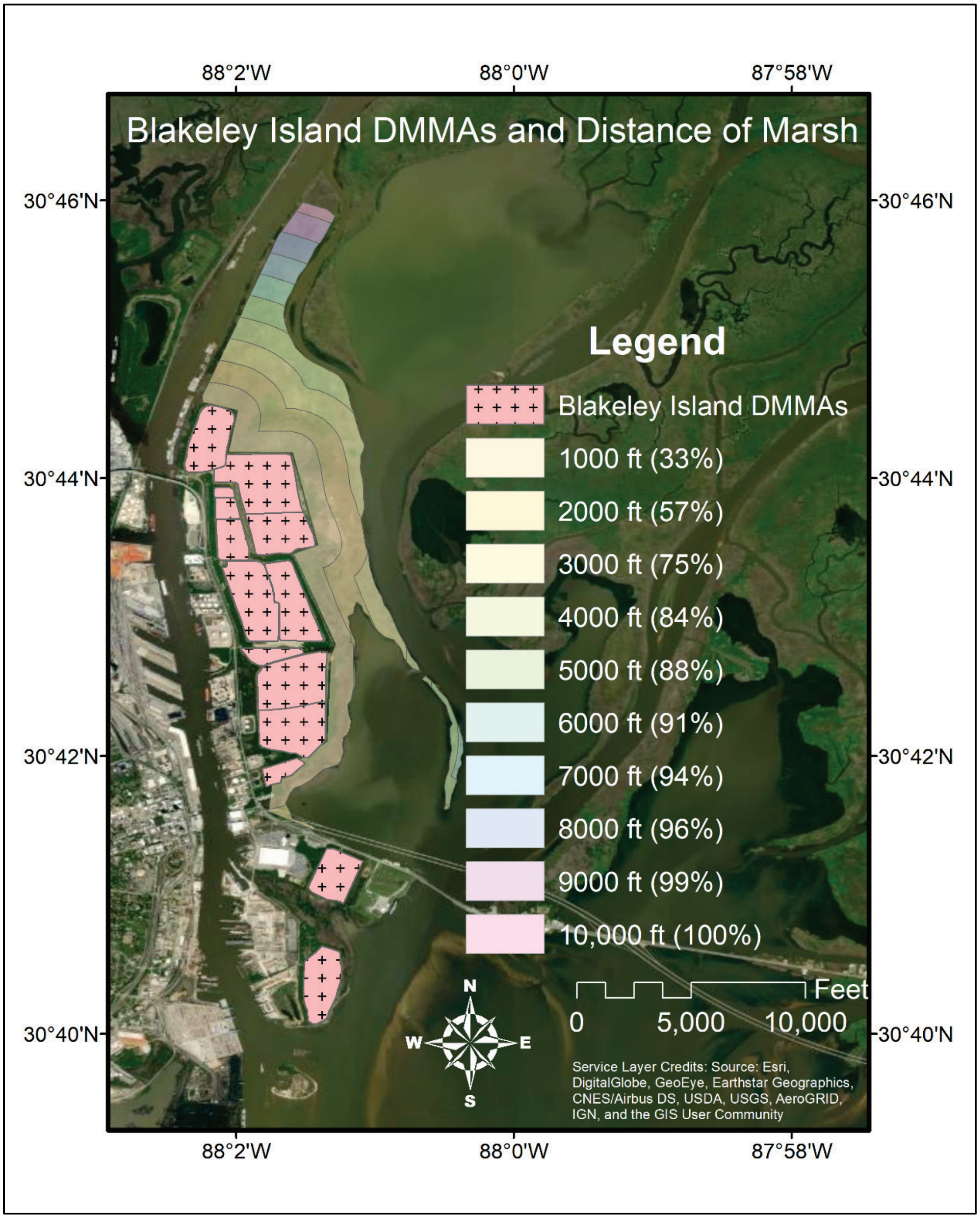
Figure 16. Estimated DMMA fill volume with no material removed and two BUDM placement scenarios under the assumption that the volume of dredged material is equivalent before dredging and after placement in the DMMA and minimal management. The DMMA capacity is based on the existing capacity in 2019. Placement includes 5% loss.



DMMA capacity is estimated to be sufficient to take material from maintenance dredging of the Mobile Harbor River Channel until year 37 (calendar year 2029). Both restoration strategies removed enough material to all fill in the DMMA until year 42 (calendar year 2035). Assuming similar restoration strategies and placement volumes, it would require placement in an additional 2,866 acres of wetlands, approximately 2.1 times the marsh area of Blakeley Island, to conserve remaining DMMA capacity to extend over a 50 yr timespan.

Cost of placement is dependent on distance from source. As shown in Figure 17, over half of the marsh area (57%) is within 2,000 ft of a DMMA, and the majority of the marsh area (84%) is within 4,000 ft. Pipelines for cutterhead dredges can typically reach 3 mi in length (15,840 ft; may be extended using booster pumps), allowing the entire marsh area to be in reach with standard equipment for BUDM operations (USACE 2015).

Figure 17. Map of Blakeley Island DMMA and adjacent marsh. Distances from the Blakeley Island DMMA are outlined within the marsh. Cumulative area within distance is labeled in the *legend*.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

To assess the feasibility of BUDM at a potential project site, managers must have an understanding about system characteristics including dredging management and wetland resilience. Factors such as material location, sediment properties, dredging schedule, and dredging technique can impact BUDM[7] (USACE 2015). Aside from logistical factors, wetland resilience and sediment need in a system will ultimately drive these types of BUDM opportunities. Sediment is typically not a limiting resource to restoration in areas where dredging occurs. Over 1.5 million acres of wetlands in the coastal continental United States are in proximity to dredged material sources and thus estimated to be suitable for BUDM, and sufficient dredged material exists to support BUDM over this entire area (Runion et al. 2021). Rates of local SLR can be compared to marsh elevation and historical levels of accretion along with modeling efforts to predict how BUDM may alleviate pressures of SLR. Once a sediment need is identified, a source such as dredging can be paired to drive forward restoration. Optimizing a placement schedule will depend on logistics, economics, and ecological and environmental attributes.[9]

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5 Conclusions and Recommendations

5.1 Conclusions

Wetland stability and dredge material storage capacity are issues coastal managers face that may serve as solutions for each other. Wetland restoration via BUDM can provide environmental and economic benefits but must be informed by ecological and physical characteristics of the system. Modeling tools such as the MEM allow coastal managers to simulate various physical and biological conditions and in order to develop appropriate management action. As environmental conditions and forecasts change, adaptive management is vital to promote project success. Analysis using an array of physical, biological, and management scenarios can help managers balance ecological, economic, and operational concerns to support coastal resources most efficiently and effectively.

5.2 Recommendations

Technological advances, including those in modeling, will promote this process. Several advancements to the MEM to improve its operational use in the USACE are

- the ability to incorporate adaptive placement schedules,
- the ability to model erosion and deposition from storm events,
- capacity to include multiple sets of biological characteristics to differentiate between low and high marsh vegetation or specific species of vegetation,
- two-dimensional implementation within a geographic information system environment, and
- fully accessible code to allow integration with other models.

Given the high volume of dredging activities and large supply of material, BUDM should be applied broadly where appropriate to increase lifespans of DMMAs and coastal wetlands. For USACE to implement widespread BUDM into regional sediment management plans, an operationalized method is required for determining wetland BUDM needs. The framework demonstrated in this case study can allow coastal managers to evaluate BUDM needs and management options. Once the hurdles of identifying restoration needs, BUDM opportunities, and logistical concerns are overcome, USACE capacity to conduct BUDM can grow, improving the ability to manage coastal resources.

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Abbreviations

BUDM	Beneficial use of dredged material
DD	Decimal degrees
DMMA	Dredged material management area
LOI	Loss-on-ignition
MCY	Million cubic yards
MEM	Marsh Equilibrium Model
MHHW	Mean higher high water
MHNP	Mobile Harbor Federal Navigation Project
MSL	Mean sea level
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
^{137}Cs	Cesium-137
RMG	Resource Management Group, Inc.
RSM	Regional Sediment Management
SAM	Mobile District
SLR	Sea level rise
SOM	Soil organic matter
SSC	Suspended sediment concentration
TLP	Thin-layer placement
USACE	US Army Corps of Engineers

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14. ABSTRACT

The US Army Corps of Engineers, in the responsibility of maintaining navigational infrastructure, has a unique opportunity to improve coastal wetland resiliency and conserve coastal natural infrastructure through the beneficial use of dredged material for wetland restoration. Opportunities are widespread, and tools such as biophysical models can aid coastal managers in assessing habitat vulnerability and planning restoration. In this study, the Marsh Equilibrium Model was utilized in concert with observed data to predict future conditions and evaluate potential effects of beneficial use of dredged material to restore marshes in Mobile Harbor, Alabama. A range of site conditions and two restoration strategies were considered, and the subsequent impact to dredged material management area volumes evaluated. Results showed that wetland restoration via the thin-layer placement of dredged material can restore marsh elevation to combat sea level rise and conserve fill capacity at dredged material management areas. This approach is demonstrated for adoption nationwide by coastal managers.

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