Carbon Sequestration in Tidal Salt Marsh Restoration Projects in Northern Humboldt Bay, California

State Coastal Conservancy- Arcata Bay Adaptation Measures Grant Agreement # 12-099

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We provide here a literature review and methodology for quantifying carbon sequestration associated with the restoration of tidal salt marshes and construction of a proposed living shoreline structure in Humboldt Bay, California. The rate of carbon sequestration can be used by the City of Arcata to quantify the benefits of restored tidal wetlands and for the City's own carbon balance documentation. This work scope focused on a) gathering and analyzing existing data sets to estimate carbon sequestration in restoring local tidal salt marshes, b) assessing existing carbon sequestration models to quantify carbon sequestration rates; and c) performing a literature search to inform approaches to quantify carbon sequestration and identify key factors that affect rates.

This memo summarizes the results of our review in two sections: Section (1) presents estimates of carbon sequestered for two restoring salt marshes and a proposed Living Shoreline project in Humboldt Bay; Section (2) utilizes the Marsh Equilibrium Model (MEMIII) to quantify carbon sequestration rates in evolving tidal salt marshes coordinately with sea level rise scenarios. Further analysis is presented in Appendix 1 with discussion and literature review of factors that may improve predictive power of current carbon sequestration modeling and a summary of published carbon sequestration values; Appendix 2 presents a parameter sensitivity analysis for the Marsh Equilibrium Model (MEMIII) to illustrate which parameters exert the most influence on calculated carbon sequestration rates using this model. We conclude that upon restoration of the two tidal salt marshes and proposed living shoreline in Humboldt Bay to mature salt marsh vegetation, approximately 100 metric Tons per year of carbon will be sequestered above current condition.

Background

Tidal salt marsh systems are essential elements of functional coastal ecosystems. These systems can maintain tidal plain elevations that keep pace with sea level rise (SLR), provide resiliency to impacts of climate change and sequester carbon through regulating sediment flux and soil carbon accumulation. The mature salt marsh plant community is a mixture of multiple species of salt tolerant wetland plants that occurs around the same elevation as mean higher high water (MHHW). A significant benefit of tidal wetland restoration is to not only capture carbon dioxide (CO_2) and sequester carbon, but also to provide habitat displaced by infrastructure and development. As such, tidal wetlands provide a highly productive biomass community and food web for estuarine aquatic species including coho salmon and steelhead, some of which are federally and state listed species based on geographical location. Using the features of resilient tidal salt marshes, living shorelines have become an attractive alternative to hardscape engineered shoreline protection structures. Living shorelines buffer existing shorelines with a sloping vegetated marsh plain that can sequester carbon, attenuate wave energy and protect existing infrastructure while providing habitat benefits for multiple species.

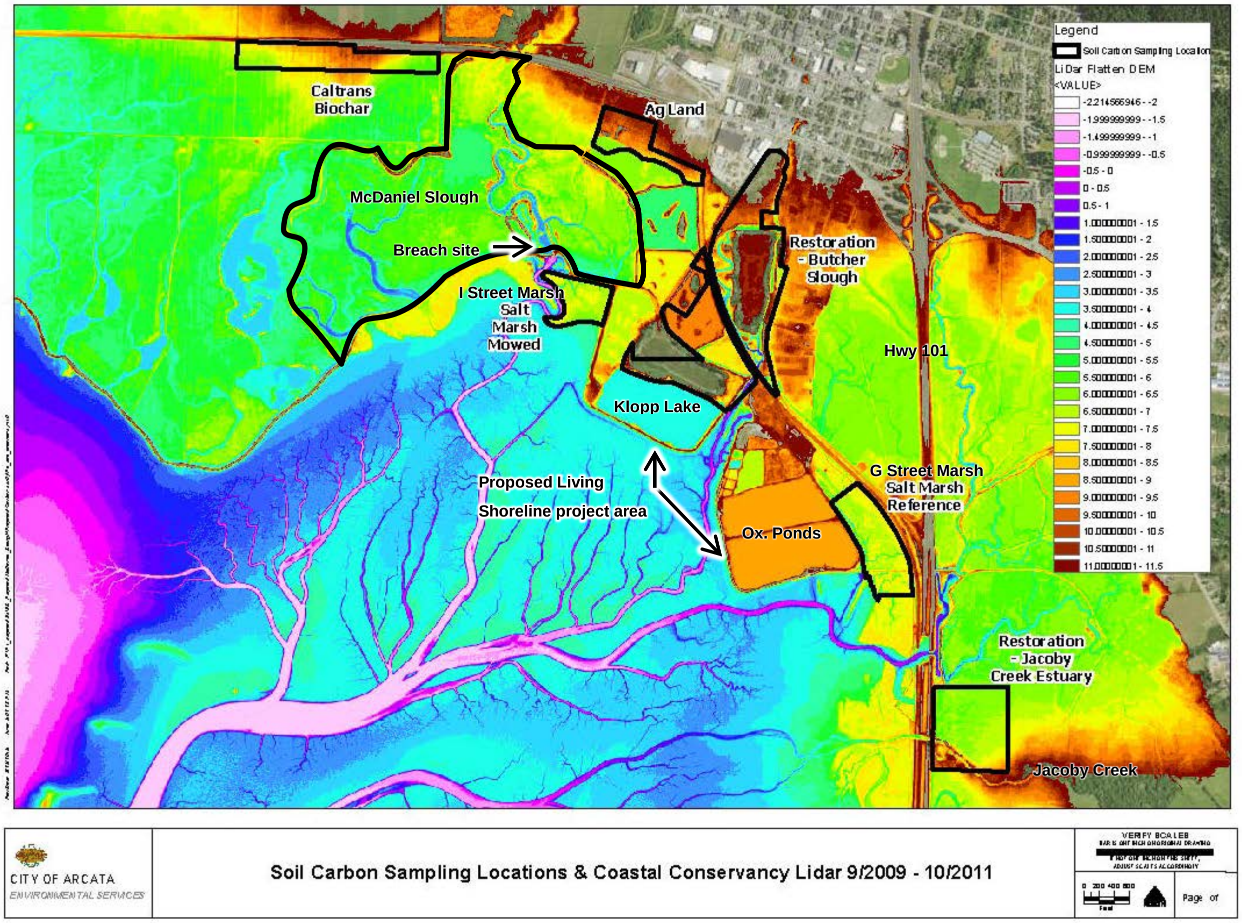


Figure 1. Reference and restoring tidal salt marsh locations on Humboldt Bay; Arcata, California. Reference sites: Salt Marsh Reference = G Street marsh; Salt Marsh Mowed = I Street marsh. Restoring sites: Jacoby Creek Estuary and McDaniel Slough. Potential locations for living shoreline project shown with arrows. Butcher Slough, Ag Land and Caltrans Biochar are HSU soil sampling locations.

<u>Project Site and Data Sources</u>

The City of Arcata is located along the northern portion of Humboldt Bay. The City owns property along the waterfront that includes salt marsh in the process of being restored and existing tidal salt marsh shown in Figure 1. A section of mudflat is being considered for conversion to a living shoreline as described below and shown in Figure 1. All elevations used in this analysis were provided by the City of Arcata (courtesy of Brian Kang) and are NAVD 88 datum. Quantification of elevation classes was generated by City staff using GIS analysis. Data on vegetation cover was based on City memos and other referenced studies, namely Eicher, 1987. Data was provided by Joe Seney on biomass samples collected in the field by students of the Humboldt State University Wetlands Soil class (2015) and analyzed for carbon content and bulk density.

Reference salt marsh sites – G Street Marsh and I Street Mowed Marsh

The G Street marsh located to the west of South G Street is a tidal wetland with a single opening to Humboldt Bay (Fig. 1, labeled G Street Salt Marsh Reference, lower right). The marsh is bound by dikes and road infrastructure on all sides with a single opening to the Bay at the southwest corner. The railroad and G Street were built along the east of the marsh with a railroad dike that extended into the Bay along the south of the marsh. The City's oxidation ponds and corps yard were established to the west and north of the marsh. The majority (74.8%) of the marsh plain is between 6.6 – 7.5 feet (Fig. 2, left panel). The vegetation in the G Street Marsh is native salt marsh and invasive *Spartina* (20).

The I Street Marsh is the tidal marsh located to the south of I Street, (Fig. 1, labeled I Street Salt Marsh Mowed) and has full tidal access to Humboldt Bay. The marsh is positioned to the south of McDaniel Slough breach site and to the west of I Street. Similar to the G Street marsh, the majority (74.7%) of the marsh plain ranges between 6.6 – 7.5 feet (Fig. 2, left panel). The vegetation is native salt marsh and invasive *Spartina*, and this site has been mowed as a part of a Humboldt Bay region attempt to eradicate this invasive vegetation.

The G Street and I Street marshes can be considered mature salt marsh as both sites have persisted as naturally occurring salt marsh throughout known history. The fact that the reference sites are similar in percentage salt marsh elevation characteristics even though they have different tidal influences and openings (single vs fully opened) indicates that these reference sites have kept pace with sea level rise, and that they provide an adequate local representation of mature salt marsh vegetation and elevation from which to derive the carbon sequestration potential of restoring tidal wetlands.

Restoration tidal salt marsh sites – McDaniel Slough and Jacoby Creek Estuary

The McDaniel Slough site is a 250 acre parcel on the northern perimeter of Humboldt Bay (Fig. 1, upper section). This parcel was an historic tidal salt marsh until converted to grassland by construction of a perimeter dike. This parcel had a single leaking tide gate allowing Janes Creek to flow into Humboldt Bay. With the removal of the tide gate and a portion of the levee in late September 2013, tidal influence was restored to the site. The width of the breach site was originally as wide as the reach of the earth-moving equipment that removed the section of dike or approximately 45 feet across. Based on physical observation and 2014 digital imagery, it appears that tidal action and associated scour widened the breach site to approximately 75 feet across. The majority (71.9%) of the site's elevation currently ranges between 4.6-6.5 feet with only 12.9% between elevations of 6.6-7.5 feet (Fig. 2, right panel). The City is monitoring vegetation to document the conversion to salt tolerant species following the breach (28).

The Jacoby Creek Estuary site is located on the east side of Highway 101, and to the east and south of the oxidation pond perimeter dike and the South G Street salt marsh reference site (Fig. 1, lower right). This parcel was an historic tidal salt marsh until diked and drained and managed as grazing pasture. Jacoby Creek flows along the southern edge of the parcel. In 2011, the City restored tidal access to part of lower Jacoby Creek. Almost half (49.8%) of the site's elevation is between 5.6–6.5 feet and 27.7% is at elevations between 6.6-7.5 feet (Fig. 2, right panel). The restored area's vegetation is being monitored by the City to document the conversion to salt marsh vegetation and for native and non-native species.

Native vegetation has shifted from 42.5% in 2013 to 51% in 2015 and total percent cover has increased from 56.5% in 2013 to 66.5% in 2015. The dominant vegetation by percentage is *Salicornia virginica* which has increased in percent cover from 5% in 2013 to 15% in 2015 (37). The site is trending toward more native salt tolerant plants and toward greater percent cover.

Studies in the literature support the idea that diked and drained tidal marshes blocked from tidal influence have lower elevations in part due to subsidence and compaction of soil. This in turn is associated with lower carbon content and higher bulk density (4, 41, 42 and references therein). This is analogous to the case of McDaniel Slough and Jacoby Creek restoring sites assessed here, which have less acreage in the 6.6-7.5 ft range, and instead fall one or more feet lower at 5.6-6.5 ft range.

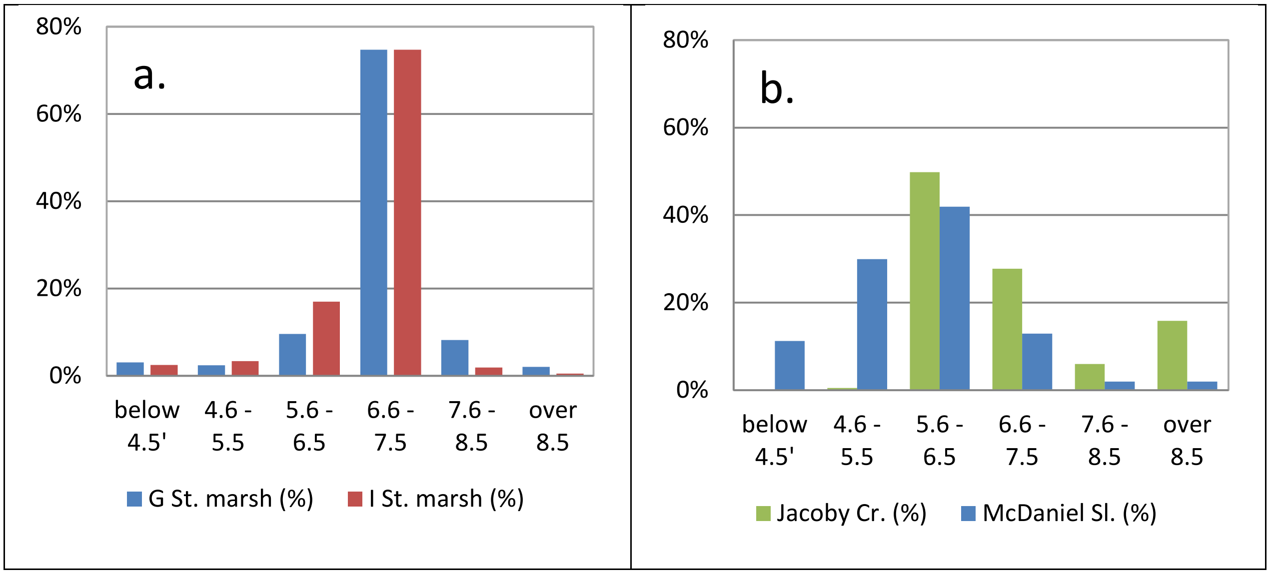


Figure 2. Elevations at (a) Reference sites: G Street Marsh and I Street Marsh; and (b) Restoring sites: Jacoby Creek and McDaniel Slough as percentage of total acreage for each site. Elevations were analyzed in 0.5 ft increments and summed into 1 ft categories.

Living shoreline project site

A living shoreline concept is being proposed for a 22 acre site either bordering the levees to the south of Klopp Lake or along the western and southern levee of the City of Arcata's oxidation ponds as shown in Figure 1 (47). This project is under development in response to rip-rap levees installed as an emergency measure for bank stabilization in 2009 to protect the Arcata Marsh and Wildlife Sanctuary and the Arcata Wastewater Plant. The levee structures are not preferred long-term solutions to buffer against sea level rise, storm surge damage and repeated tidal shoreline scouring.

The proposed living shoreline area is mudflat with a current elevation ranging between 3-4 feet, colonized by algae and other mudflat biota. The project comprises placement of fill material to raise the existing mudflat elevation to approximately MHHW. Pilot designs for the living shoreline concept have been submitted to the City of Arcata for review (47), but are not finalized. Thus, the dimensions used in this report for calculating carbon sequestered within the living shoreline project site are approximate.

Section I: Carbon Sequestration Calculation

The primary factor in restoring a diked and subsided former tideland to a condition similar to reference salt marsh is rebuilding the salt marsh substrate. Both of the City's restoring sites have at least half of the total area at elevations mostly one to two feet below elevation of mature salt marsh. If the MHHW were expected to be constant, the soil accretion would only need to rebuild the 1-2 feet of substrate that has subsided. With projections for sea level to rise, the rate of accretion also has to account for the increasing MHHW level. Data from studies presented below indicate that rates of sediment accretion may be possible to rebuild the lower restoring sites and keep pace with sea level rise.

The sequence of calculations is as follows:
i) Calculate elevations as percentages of marsh area for reference and restoring sites (Table 1).
ii) Calculate area expected to convert to mature salt marsh for restored marshes at each elevation (Table 2).
iii) Determine number of years to achieve mature salt marsh vegetation at relevant elevations in context of sea level rise at assigned sediment accretion rate (Section I-2).
iv) Use Marsh Equilibrium Model (MEMIII) to calculate range of carbon sequestration rates during century restoration period in context of sea level rise (Section II).
v) Use MEMIII value to calculate amount carbon sequestered (metric Tons) in designated area (m^2) of restoring and reference marshes (Table 3).

Wetlands are complex systems that diverge in morphology and biological processes. In the absence of the resources to provide detailed information about each parameter, we used the following assumptions to provide a simple calculation for estimating the area of salt marsh that will be restored to a mature salt marsh vegetation and the efficiency with which this restored area would sequester carbon.

The following assumptions are used in the calculations:
i) Sediment accretion rates in a young subsided marsh that is in the process of restoration may be faster than rates of accretion in mature reference marshes;
ii) The amount of carbon sequestered in the restoring sites and the living shoreline at maturity is comparable to analogous reference tidal wetlands and is found around the elevation of MHHW;
iii) Carbon from gaseous exchange is negligible in this context given that the majority of carbon sequestered in a restored tidal wetland is in the soil and the production of methane is minimal due to saline aqueous conditions.

I-1. Relative elevations of mature and restoring tidal salt marshes

The site elevation information was prepared using LiDAR NAV88 data that represent the elevations within each site boundary (Figure 1). The elevations for each site were analyzed in 0.5 ft elevation increments and summed into 1 foot increments to produce the area within each elevation category. The area within each elevation class was divided by the total area within the site to provide a percent of total area in each elevation class (Table 1).

Table 1. Elevations as a percentage of marsh area for reference and restoring sites.

	Percentage of reference sites elevation			**Percentage of restoring/new sites elevation**		
Elevation	G St	I St	avg	McD Sl	J Cr	Lv Sh
feet NAVD 88	%	%	%	%	%	%
<4.5	3.1%	2.5%	2.8%	11.2%	0.1%	100%
4.6-5.5	2.4%	3.4%	2.9%	30.0%	0.5%	0%
5.6-6.5	9.6%	17.0%	13.3%	41.9%	49.8%	0%
6.6-7.5	74.8%	74.7%	74.7%	12.9%	27.7%	0%
7.6-8.5	8.2%	1.9%	5.0%	2.0%	6.0%	0%
>8.5	2.0%	0.5%	1.3%	2.0%	15.9%	0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100%

Note the mature salt marsh is represented in light green at an elevation of between 6.6-7.5 feet.
(G St = G Street marsh, I St = I Street marsh, McD Sl = McDaniel Slough, J Cr = Jacoby Creek estuary,
v Sh = proposed living shoreline project)

Based on the MHHW of 6.86 ft at G Street marsh and 7.04 ft at Mad River Slough tidal marsh (13) and Eicher's Humboldt Bay tidal marsh vegetation colonization elevations (Fig. 3), the elevation between 6.6 and 7.5 feet NAVD 88 comprises mixed salt marsh vegetation. Both reference sites have 75% of the area within the mixed salt marsh elevation range.

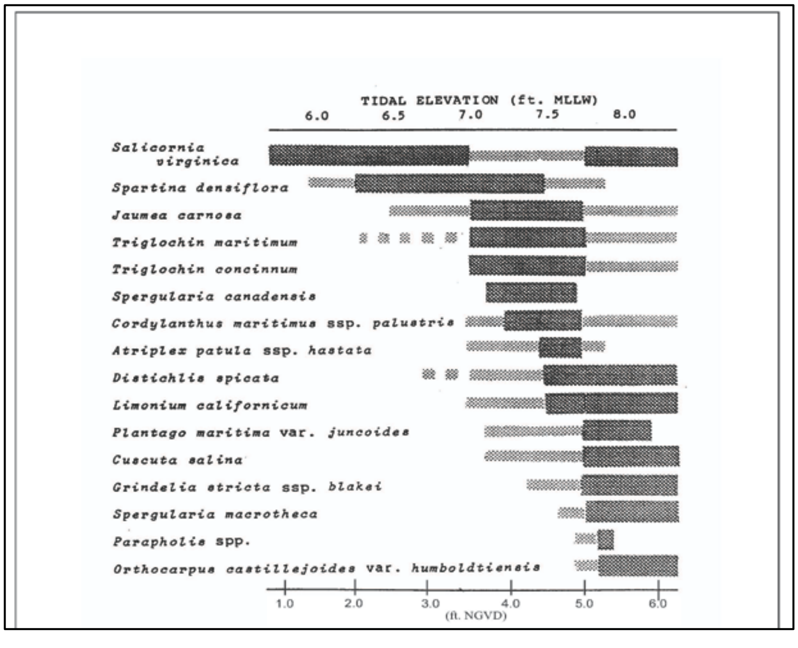


Figure 3. Mature tidal salt marsh vegetation by elevation. From PWA (46) and as excerpt from Eicher (27).

The rate of carbon sequestered in the newly restoring salt marsh is expected to be low because area available for plant colonization requires time to undergo sediment accretion. Studies show that sediment accretion will likely be higher in compacted marsh in early years of restoration (4, 5, 45) but have lower carbon sequestered due to immature marsh vegetation. As sediment accumulates during initial years, characteristic mature marsh vegetation evolves coordinately with increased below ground carbon sequestration.

The restoring salt marshes are expected to build elevation and mixed salt marsh vegetation in the same proportions as the reference marshes. In order to estimate the distribution of elevations that would be found in a mature salt marsh system the reference marsh proportions were applied to the restoring and new sites. For each site, the average percent elevation of the reference sites was applied to the total area to produce an estimate of the area in each elevation class of the future restored salt marshes (Table 2).

Table 2. Estimation of area expected to convert to mature salt marsh elevation (in green). Elevations for future restored salt marsh sites according to average reference marsh elevation class distribution.

	Reference salt marsh area	**Area at existing elevations**			**Area estimated for future restored salt marsh elevations**		
Elevation	avg	McD Sl	J Cr	Lv Sh	McD Sl	J Cr	Lv Sh
feet NAVD 88	%	acres	acres	acres	acres	acres	acres
<4.5	2.8%	22.4	0.0	22.0	5.6	0.7	0.6
4.6-5.5	2.9%	59.8	0.1	0.0	5.8	0.7	0.6
5.6-6.5	13.3%	83.7	12.6	0.0	26.5	3.4	2.9
6.6-7.5	74.7%	25.8	7.0	0.0	149.2	19.0	16.4
7.6-8.5	5.0%	4.0	1.5	0.0	10.0	1.3	1.1
>8.5	1.3%	3.9	4.0	0.0	2.6	0.3	0.3
Total	100%	199.6	25.4	22.0	199.6	25.4	22.0

I-2. Sediment accretion rates of mature and restoring tidal salt marshes

If a sediment supply is not available to a restoring marsh, it is expected that the marsh will "drown" and convert to mudflat as the sea level rises. Using the reference marshes as an example of tidal salt marsh keeping pace with SLR, the accretion rate can be assumed to have been keeping pace with local SLR at 0.34 cm/year (30). A study by Callaway et al (4) analyzed soil core samples from six sites in the San Francisco Bay Estuary by ^{137}Cs and ^{210}Pb dating and determined that sediment accretion values ranged between 0.2 – 0.5 cm/year independent of whether the sites were low, mid or high tidal marsh. Although this is an expected range for sustained accretion, short term accretion rates in low marsh areas have been documented at 0.6 cm/yr to >1.0 cm/yr in the San Francisco Bay area (48, 49, 50). For McDaniel Slough, preliminary data from a Humboldt State University class project indicated that 0.6-1.2 cm of sediment accumulated at the study plots on the McDaniel Slough marsh plain in six months between May and November 2014 (25). This range is consistent with the PWA report on McDaniel Slough for sedimentation rate (19). Further studies on local sites using soil carbon dating and ground-truthed LiDAR will further clarify actual accretion rates for existing and restoring salt marsh.

Using the sediment accretion value of 0.34 cm/yr to estimate the amount of time for sediment to accrete on Arcata's restoring sites would require 90 years to build one foot (30.48 cm) of elevation in the absence of sea level rise. However, the studies in Callaway et al (5) and the MEMIII analysis indicate that the marsh elevation will not only build elevation to mature salt marsh but will also keep pace with sea level rise. The total elevation change to accommodate one foot of accretion (30.5 cm) while keeping pace with a century of sea level rise (86.2 cm) would be 116.7 cm. The rate of accretion to accomplish the building of elevation would need to be 1.2 cm/yr. If two feet of accretion were needed to build a mature salt marsh elevation, the rate of accretion to achieve keeping pace with sea level rise would require 1.5 cm/yr.

I-3. Carbon Sequestration in Restoring Salt Marshes

In order to provide an estimate for carbon sequestration for a defined area, the MEMIII-generated carbon sequestration rates were applied to the mature marsh elevation area of 6.6 - 7.5 feet in elevation. The MEMIII model indicates that short-term carbon sequestration would occur at a lower rate of 63.5 g C/m2/yr and increase to 145 g C/m2/yr at the century mark. For comparison, a summary of published carbon sequestration rates is presented in Appendix 1. Rates of carbon sequestration in tidal, saline wetland soils, from around the world average at 210 +/- 20 g C/m^2/yr compared to Callaway (4) as a regional point of reference for tidal wetlands at approximately 79 g C/m^2/yr.

Data provided by the HSU Wetland Soils class (Appendix 3a) provides an assessment of soil carbon for varying depths and plant community types within and near to the project areas (Figure 1). The general trend in percent carbon demonstrates greater carbon values in the lower soils profiles of tidal marsh and pickleweed compared to the grazed pasture and pasture. The summary provided in Appendix 3b highlights a three-fold difference between tidal marsh soil carbon and pasture soil carbon. This finding supports the increasing rate of carbon sequestration as tidal influence transforms freshwater pasture to salt marsh vegetation. The bulk density values for the HSU study appeared higher than literature values (24) and the resulting calculations for total carbon using the HSU class data fell outside the range of literature values. The MEMIII model sensitivity analysis (Appendix 2, page 15 #4) demonstrates the linear relationship between bulk density and carbon sequestration. The MEM III model was therefore used to calculate the rate of carbon sequestration for the project areas.

Assuming that the amount of carbon sequestered currently is the baseline condition, the increased amount above baseline condition is the amount of carbon sequestered upon restoration of tidal access to the City properties via maturation of mixed tidal salt marsh morphology between 6.6-7.5 feet in elevation (Table 3).

Table 3. Expected amount of carbon sequestered in metric tons per year in the City of Arcata's tidal salt marshes at current area and at future area of 6.6-7.5 feet elevations using MEMIII model results.

	McD Sl	J Cr	Lv Sh
	mT C/yr	mT C/yr	mT C/yr
Current C-Seq in project area within 6.6-7.5 ft elevation using short-term rate	6.6	1.8	0.0
100 year C-Seq projection for project area within 6.6-7.5 ft elevation using century mark rate	87.6	11.1	9.6
Carbon Sequestered (Row 2 minus Row 1 in respective columns)	80.9	9.3	9.6

Once the sites reach mature conditions the amount of carbon sequestered due to restoring the tidal system and creating the living shoreline is estimated to be approximately 100 T C per year above current conditions. Elevations above and below the mature mixed salt marsh were not included because the vegetation community associated with those elevations would not reflect the same rate of carbon sequestration, especially in mud flat and upland conditions. This is the sum of McDaniel Slough (80.9 mT) plus Jacoby Creek (9.3 mT) and Living Shoreline area (9.6 mt) = 99.8 mT carbon for the total restoration area.

The dynamics of a tidal wetland are complex because water levels fluctuate, sediment inputs are difficult to quantify, and the physical dimensions and hydrologic features are intricate and challenging to measure. Each tidal wetland feature plays a direct role in the ability of a restored wetland to catch up or keep up with mean sea level and therefore be able to sequester its maximum potential of carbon. Given the complexity of the system and the need to develop robust local data sets, the estimates provided in this memo can be validated or adjusted as more information becomes available.

The USGS has collected core samples in the region to be analyzed for accretion rates using a carbon or cesium dating method that will yield much more accurate rates of accretion and bulk density for the tidal wetlands. Additionally, USGS staff has secured funding to further study sedimentation dynamics in Humboldt Bay.

Section II: Carbon Sequestration by Marsh Equilibrium Model

MEM III (Marsh Equilibrium Model) is used here to project carbon sequestration in the context of sea level rise for tidal salt marsh restoration projects. MEM was derived by Jim Morris (University of South Carolina) and co-workers (1) and was utilized as the baseline model by the NCEAS Working Group for Tidal Salt Marsh Restoration (2). This model was calibrated as described in Schile et al (3; 2014) for four tidal salt marshes in the San Francisco Bay Estuary. Data reported in Callaway et al (4; 2012) was also used for model calibration in which sediment accretion rates, mineral accumulation rates and carbon sequestration rates were calculated at an overlapping set of sites using ^{137}Cs and ^{210}Pb soil core sample dating and other quantitative analyses. MEM incorporates most of the key parameters above, and integrates feedback between an inundation regime (elevation) and organic matter productivity. It fits a parabolic curve to productivity of saltmarsh vegetation.

From Schile et al (2014) and references cited therein: *Some modeling efforts have utilized a hybrid approach, merging results from mechanistic elevation based models with digital elevation models to examine projections at site and landscape levels. However, hybrid approaches thus far have only mechanistically modeled the mineral contribution to marsh accretion and have not incorporated processes that affect the organic contribution to accretion, or interactions between mineral and organic matter contributions. Multiple studies have identified the importance of below-ground biomass contribution to vertical accretion, sustainability of marsh soils, and resiliency to increases in SLR. Therefore, it is valuable to integrate these feedbacks of vegetation with inundation, elevation, and sediment supply into a hybrid modeling approach. We incorporated a rich dataset of above- and belowground plant productivity and physical characteristics across tidal marshes spanning a salinity* *gradient into a mechanistic elevation-based model, the Marsh Equilibrium Model version 3.76 (MEM). Model results were then applied to a high spatial resolution LiDAR-based digital elevation model to project changes in marsh elevation and extent, including upland migration, under a variety of SLR and suspended sediment concentration scenarios.*

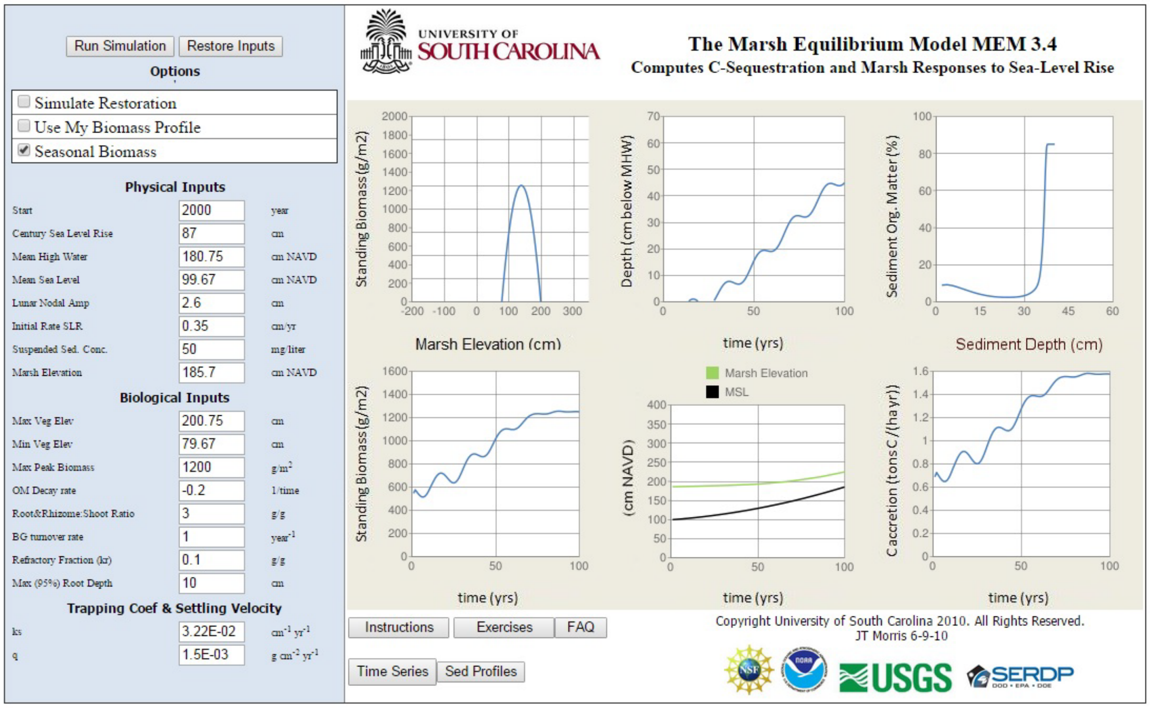
Additional models are available that predict early stage tidal marsh restoration characteristics and carbon sequestration (5, 6), but do not have a readily available user-interface. For example, the WARMER Model (7) built on earlier models from Krone (8) and French (9) to incorporate organic matter accumulation, decay and compaction relative to SLR and mineral sediment accumulation (10). WARMER utilizes observations that mass of new organic matter decreases exponentially with increasing depth; the rate of decomposition is a function of depth and OM age; and compaction is a function of mass above a given area and porosity. This model also derives z* which is local MSL – determined from interpolated sea surface topography at NOAA Datum database of regional tidal datums for SF Bay.

Table 4. Key inputs for carbon sequestration modeling for salt marsh restoration and sea level rise impacts.

	Key Data Input	**Common abbreviations**	**Units**
1)	Century Sea Level Rise	Century SLR	cm
	IPCC 2013 projection range		
2)	Mean Sea Level, Mean High Water (Tidal Range)	MSL, MHW	cm NAVD
	Data available from NOAA tide tables		
3)	Sea Level Rise – initial Rate	SLR	cm
4)	Suspended sediment concentration	SSC	mg/L
	Varies spatially and temporally – key parameter		
5)	Sediment Accretion Rate		g/cm^2/yr
	Data from local sources and regional published data		
6)	Soil Organic Matter	SOM	g/cm^2
	Determined by LOI then Craft derivation for % carbon		
7)	Bulk Density	BD	g/cm^3
8)	Marsh elevation		cm NAVD
	Data available from Lidar - DEM		
9)	Vegetation – Min and Max elevations with marsh vegetation		cm
	Percent occupancy, location and dominant vegetation		
10)	Vegetation – max peak		g/m^2
	Max peak vegetation estimate – range/seasonal		
11)	Organic matter decay rate, and belowground turnover	OM, BG	g/yr
12)	Root/Rhizome: Shoot Ratio		g/g
	Mass of carbon stored belowground, compared to standing biomass		
13)	Max Root Depth		cm
	Depth at which 95% of roots are found		

In addition to the above data input, MEMIII utilizes trapping coefficient (Ks in cm^2/g/yr) relating to standing biomass impact on sediment flux; settling velocity (q in /yr) relating to particle size of sediment; and lunar nodal amplitude to incorporate gravitation impact on tides.

Figure 4 illustrates the User Interface for the online Marsh Equilibrium Model in which Physical and Biological Inputs can be entered with various sea level rise scenarios. The MEM program calculates the carbon sequestration over a 100 year period (lower right graph) and provides a series of graphs relevant to marsh equilibrium and whether it can keep pace with the input sea level rise.



☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	$year^{-1}$
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	$cm^{-1}\ yr^{-1}$
q	1.5E-03	$g\ cm^{-2}\ yr^{-1}$

Figure 4. MEM User Interface. Input values shown on left; resulting graphs shown on right.

Table 5. Description of physical and biological inputs for Marsh Equilibrium Model.

Physical Inputs	Units	Range	Input Value	Source
Century Sea Level Rise	cm	28 – 98	87	Range = IPCC 2013 (11) RCP 2.6, RCP 4.5 and RCP 8.5 models (12) slide 10; Input Value = 87 (13) Note: 75 cm without local vertical land motion impact—close to mid value cited by IPCC 2013. Analysis could be refined by using 86.2 cm as defined in Final report for local SLR (30)
Mean High Water	cm NAVD		180.75	NOAA Tidal Datum for Samoa Site; Gauge 9418817; converted ft to cm NAVD; Location 40° 49.6’ N, 124° 10.8’ W.

				Directions on NOAA datums page at http://tidesandcurrents.noaa.gov/ benchmarks/9418817.html
Mean Higher High Water	cm NAVD		214.6; 209.1	Input Value = From Anderson Mad River Slough (MRS) Sea Level Rise 2013 Salmonid Restoration Federation presentation (13) slide 7: Observed MHHW at MRS = 2.146 m; slide 14: Observed MHHW at G Street Marsh = 2.091 m.
Mean Sea Level	cm NAVD		99.67	NOAA Tidal Datum for Samoa Site; Gauge 9418817; converted ft to cm NAVD
Lunar Nodal Amplitude	cm		2.6	MTL 99.36 cm * 0.026 (14,15); Lunar Nodal Cycle = 18.6 years
Initial Rate SLR	cm	0.34-0.50	0.35	IPCC 2013: 1901 – 1990 0.15 cm/yr SLR; 1993-2010 0.32 cm/yr (11); Input value = 0.35 (13). Initial SLR rates and subsidence discussed in (16, 17,18) Analysis could be refined by using 0.34 cm as defined in Final report for local SLR (30)
Suspended Sediment Concentration	mg/L	20 – 125	50	More SSC data needed locally, but low ~20 mg/L, mid ~50 mg/L; high ~75-125 mg/L. From Schile 2014 (3) Table S1 (modeled low, med high SSC); Anderson (13; slide 8; 70 mg/L); PWA McDaniel Slough Report (19; 125 mg/L; Table 7-1). Data from McDaniel Slough and Butcher Slough Total Suspended Solids (Hurst_ Humboldt_Bay_Water_Quality_Data_ 2012-2014)
Marsh Elevation	cm NAVD		185.7	Marsh elevation input 6.1 feet = 185.7 cm; McDaniel Slough 6-7 ft elevation = range 182.88 - 213.36 cm). NCEAS formula: MSL (99.67) + 2.82 ft (85.95 cm) = 185.62 cm (2)
Max Veg Elevation	cm NAVD		206 (model runs 200.75)	From NCEAS formula, should be MHW 9180.85) + 25 cm = 206 cm. From LiDAR datat should be about 206 cm (Kang, City of Arcata). However, model constricts max (200.75) and min (79.67) when running simulation w/ SLR.
Min Veg Elevation	cm NAVD		152.4 (model runs 79.67)	From LiDAR about 5 feet. = 152.4 cm, but model constricts min to 79.67.
Max peak biomass	gm/m^2	150 – 1815	1200	From Schile (3) used 1200 g/m^2 for tidal salt marsh with similar vegetation distribution as Arcata tidal salt marsh, up to 3300 g/m^2 in brackish marsh. Highly variable by site (e.g. 150-1750 gm/m^2) - may be seasonal differences. LaGarde HSU thesis data for Spartina invasive marsh ave 3654 gm/m^2 (20).

OM decay rate	1/yr	-0.2 to -0.3	-0.2	Ranges from -0.2 for salt marsh sites to -0.3 for brackish marsh (3), sites as described in (4).
Root:Shoot Ratio	g/g	2.5-3.0	3.0	Range used in (3); Typical tidal salt marsh vegetation of *S. virginica, D. spicata, J. carnosa,, T. maritima,* should have similar R:S ratio (19).
BG Turnover Rate	1/yr		1	Value used in (3). Assign no net gain/loss in belowground carbon in absence of data that indicates otherwise; model calibrate to 1.0.
Refractory Fraction	g/g		0.1	Value used in (3); model calibrated—essentially 10% of belowground SOM inaccessible to decay/tidal influence.
Max 95% Root Depth	cm	10-40	20	Seney data from HSU 2015 soils class – tidal salt marsh 95% carbon within top 20 cm (20).
Trapping Coefficient (ks)	cm/yr		0.0322	Constant; function of standing biomass that traps sediment
Settling Velocity (q)	g/cm^2/yr		0.0015	Constant; function of sediment particle size.

Conclusions: The carbon sequestration rate under these parameter conditions ranged from 63.5 g C/m2/yr (0.7 tons C/ha/yr) to 145 g C/m2/yr (1.6 tons C/ha/yr) over a century. At the given input values, marsh elevation kept pace with sea level rise. These calculated values are in line with published values for carbon sequestration in tidal salt marshes in San Francisco Bay area of California of 79 g C/m2/yr (Callaway 2012) based on soil core dating, and less than global estimates of 210 gC/m2/yr (Callaway 2012, Appendix 1). Discussion and literature review of additional factors that may improve predictive capability of the tidal salt marsh carbon sequestration modeling is in Appendix 1. A sensitivity analyses for the MEM model runs is included as Appendix 2.

References

1. Morris, J.T. MEM relevant papers at http://ww2.biol.sc.edu/~morris/
2. Callaway, J., Morris, J., Crooks, S., Schile, L, Megonigal, P., Doherty, A., Ambrose, R., Aziz, O., Craft, C., Faulkner, S., Keller, J., Mooney, S., Reyes, E., Windham, L.M. (2010-2011) NCEAS Tidal Wetland Working Group Report. https://www.estuaries.org/pdf/2010conference/monday15/galleon2/session3/callaway.pdf https://www.nceas.ucsb.edu/projects/12503#
3. Schile, L.M., Callaway, J.C., Morris, J, Stralberg, D., Parker, V., and K. Maggi (2014) Modeling tidal marsh distribution with sea-level rise: Evaluating the role of vegetation, sediment, and upland habitat in marsh resiliency. *PLoS ONE.* **9**: p. e88760.
4. Callaway, J.D., Borgnis, E.L., Turner, R.E., and C.S. Milan (2012) Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands. *Estuaries and Coasts* **35**: p. 1163-1181.
5. Fagherazzi, S., Kirwan, M.L., Mudd, S.M., Guntenspergen, G.R., Temmerman, S., D'Alpaos, A., van de Koppel, J., Rybczyk, J.M., Reyes, E., Craft, C. and J. Clough (2012) Numerical Models of

Salt Marsh Evolution: Ecological , Geomorphic, and Climatic Factors. *Reviews of Geophysics* **50:** p. RG1002.

6. Rybczyk, J. M., and J. C. Callaway (2009) Surface elevation models, in Coastal Wetlands: An Ecosystem Integrated Approach, edited by G. M. E. Perillo et al., p. 834–853, Elsevier, Amsterdam.
7. Swanson, K.M., Drexler, J.Z., Schoellhamer, D.H., Thorne, K.M., Casazza, M.L., Overton, C.T., Callaway, J.C. and J.Y. Takekawa (2013) Wetland Accretion Rate Model of Ecosystem Resilience (WARMER) and Its Application to Habitat Sustainability for Endangered Species in the San Francisco Estuary. *Estuaries and Coasts* epublished 25 Sept 2013.
8. Krone, R.B. (1987) A method for simulating historic marsh elevations. In: Krause NC, editor. Coastal Sediments '87. New York, NY: American Society of Civil Engineers. p. 316-323.
9. French, J.R. (1993) Numerical simulation of vertical marsh growth and adjustment to accelerated sea-level rise, North Norfolk, UK. *Earth Surface Processes and Landforms* **18**: p. 63-81.
10. Callaway, J.C., Nyman, J.A. and R.D. DeLaune (1996) Sediment accretion in coastal wetlands: A review and simulation model of processes. *Current Topics in Wetland Biogeochemistry* **2**: p. 2-23.
11. Gregory, J. (2013) Projections of sea level rise. Intergovernmental Panel on Climate Change (IPCC) Climate Change 2013 Working Group: The Physical Science Basis. Contribution to the IPCC Fifth Assessment Report. https://www.ipcc.ch/pdf/unfccc/cop19/3_gregory13sbsta.pdf
12. Representative Concentration Pathways IPCC Data Sheet http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html
13. Anderson, J. (2013) Can Existing and Restored Humboldt Bay Tidal Marshes Keep Pace with a Rising Sea Level. Presentation at the 31st Annual Salmonid Restoration Federation Conference, Fortuna, California.
14. Morris, J. (2006) Dependence of Salt Marshes on the Lunar Nodal Cycle and Rate of Sea-level Rise. Presentation at American Institute Chemical Engineering Meeting. http://webpages.eng.wayne.edu/~as8971/AIChE_SEF/Visual%20Meeting/2006Dec13/saltmarshes2006.pdf
15. Baart, F., Van Gelder, P.H.A.J.M., De Ronde, J., Van Koningsveld, M. and B. Wouters (2012) The effect of the 18.6-year lunar nodal cycle on regional seal-level rise estimates. *J Coastal Research* **28**: p. 511-516.
16. Pritchard, C.J. (2004) Late Holocene Relative Sea-Level Changes, Arcata Bay, California: Evaluation of freshwater syncline movement using co-seismically buried soil horizons. Masters Thesis presented to Faculty of Humboldt State University. p. 1-64. http://www2.humboldt.edu/geology/documents/kelsey/Pritchard_MS_ths.pdf
17. Kalt, J. (2012) Rising Seas Pose Risks Around Humboldt Bay. Article from Policy Director Humboldt baykeeper, archived at North Coast Environmental Center. http://yournec.org/content/rising-seas-pose-risks-around-humboldt-bay
18. Swanson, C. (2014) Policy Brief on McDaniels Slough and Sea Level Rise Mitigation Using Wastewater. Report from HSU ENGR 532, p. 1-4.
19. PWA (2002) A Restoration Plan for the McDaniel Slough Tidal Marsh. Prepared for City of Arcata, Environmental Services Department. PWA Ref 1424. p. 1-102.

20. LaGarde, L. (2012) Invasive Spartina densiflora Brongn. Reduces Primary Productivity in a Northern California Salt Marsh. Masters Thesis presented to Faculty of Humboldt State University. p. 1-65.
21. Seney, J. (2015) Data from HSU Soils Class. Personal communication.
22. Environmental Resources Engineering Capstone Class (2015) Attachment A: Living Shoreline Pilot Project for the Arcata Wastewater Treatment Plant and Wildlife Sanctuary Background Section. Humboldt State University, ENGR 492 Capstone Design; p. 1-75.
23. Fagherazzi, S., Wibert, P.L., Temmerman, S., Struyf, E., Zhao, Y., and P.A. Raymond (2013) Fluxes of water, sediments, and biogeochemical compounds in salt marshes. *Ecological Processes* **2**: p. 1-16.
24. Crooks, S., Rybczyk, J., O'Connell, K., Devier, D.L., Poppe, K., Emmett-Mattox, S. (2014) Coastal Blue Carbon Opportunity Assessment for the Snohomish Estuary: The Climate Benefits of Estuary Restoration. Report by Environmental Science Associates, Western Washington University, EarthCorps, and Restore America's Estuaries. February 2014.
25. Friedman, J., McKenzie, M., and M. Vossmer (2014) Sediment Accretion in Three Arcata CA Salt Marshes. Humboldt State University, ENVS 410.
26. Chmura, G.L., Anisfeld, S.C., Cahoon, D.R. and J.C. Lynch (2003) Global carbon sequestration in tidal, saline wetland soils. Global Biogeochem Cycles **22**: p. 1-12.
27. Eicher, A. (1987). Salt Marsh Vascular Plant Distribution In Relation To Tidal Elevation, Humboldt Bay, California. <http://www.fws.gov/uploadedFiles/Region_8/NWRS/Zone_1/Humboldt_Bay_Complex/Humboldt_Bay/Sections/Documents/Eicher_1987_salt%20marsh_veg.pdf>. (Feb 6, 2015).
28. Eicher, A. (2014) MEMO: McDaniel Slough Estuarine Restoration Project: Vegetation Monitoring, Year 1. Prepared for City of Arcata, CA.
29. Lionberger, M.A. and D.H. Schoellhamer (2009) A tidally Averaged Sediment-Transport Model for San Francisco Bay, California. *U.S. Geological Survey Scientific Investigations Report* 2009-5104, 23 p.
30. Anderson, J.K./Northern Hydrology and Engineering (2015) Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping. Prepared for State Coastal Conservancy and Coastal Ecosystem Institute of Northern California. Final Report.
31. Anderson, J.K. / Northern Hydrology and Engineering (2014) Preliminary Data Release for the Humboldt Bay Sea Level Rise Vulnerability Assessment: Humboldt Bay Sea Level Rise Inundation Mapping.
32. Anderson, J.K. (2010) A Three-Dimensional Hydrodynamic and Transport Model of Humboldt Bay. Poster presented at the Humboldt Bay Symposium. April 2010.
33. Costa, S.J. (1982) The Physical Oceanography of Humboldt Bay. Proceedings Humboldt Bay Symposium. Mar 26, 1982, Eureka California.
34. Kirwan, M.L. and A.B. Murray (2007) A coupled geomorphic and ecological model of tidal marsh evolution. *Proc. Natl. Acad Sci USA* **104:** p. 6118-6122.
35. Sanchez, A. (2008) Interactions between Wetlands and Tidal Inlets. Army Corps of Engineers Technical Memo ERCD/CHL CHETN-IV-72.

36. Rogers, J. D. (1981) Net primary productivity of Spartina foliosa, Salicornia virginica, and Distichlis spicata in salt marshes at Humboldt Bay, California. Master's thesis. Humboldt State University, Arcata, California.
37. Nogueira, J. (2015) Jacoby Creek Estuary Vegetation Monitoring. City of Arcata Report.
38. Siegel, S., Toms, C., Gillenwater, D. and C. Enright (2010) Suisun Marsh Tidal Marsh and Aquatic Habitats Conceptual Model. From Suisun Marsh Habitat Management. Restoration and Preservation Plan: Chapter 3.
39. Craft, C.B., Seneca, E.D. and S.W. Broome (1991) Loss on ignition and Kjeldahl digestion for estimating organic carbon and total nitrogen in estuarine marsh soils: calibration with dry combustion. *Estuaries and Coasts* **14:** p. 175-179.
40. Verified Carbon Standard (2014) Methodology for Tidal Wetland and Seagrass Restoration. Prepared by Silvestrum, University of Maryland, Restore America's Estuaries, Dr. Stephen Crooks, Smithsonian Environmental Research Center, Chesapeake Bay Foundation, University of Virginia.
41. Keller, J.K., Takagi, K.K., Brown, M.E., Stump, K.N. et al. (2012) Soil Organic Carbon Storage in Restored Salt Marshes in Huntington Beach, California. Bulletin of the Southern California Academy of Sciences **111:** p. 153-161.
42. Beasy, K.M. and J.C. Ellison (2013) Comparison of Three Methods for the Quantification of Sediment Organic Carbon in Salt Marshes of the Rubicon Estuary, Tasmania, Australia. International J. Biology. **5:** p. 1-13.
43. Whittlesby, R., Brush, M. and S. Holler (2013) Salt Marsh Carbon Sequestration: a Baseline Study. City of Arcata, California. Capstone ENVS 410.
44. Laird, A., Powell, B. and A. Anderson (2013) Humboldt Bay Shoreline Inventory, Mapping, and Sea Level Rise Vulnerability Assessment. Prepared for State Coastal Conservancy by Trinity Associates, McBain and Trush; Northern Hydrology and Engineering.
45. Trulio, L., Callaway, J. and S. Crooks (2007) White Pater on Carbon Sequestration and Tidal Salt Marsh Restoration.
46. Philip Williams and Associates (2002) A Restoration Plan for the McDaniel Slough Tidal Marsh. Prepared for City of Arcata. PWA Ref # 1424. P. 1-102.
47. Gutierrez, E., Villanueva, J.L., Messina, V. and C. Penny (2015) Living Shoreline Pilot Design Project. Prepared for City of Arcata, Department of Environmental Services; Humboldt State University ENGR 492 – Capstone Design May 2015.
48. Callaway, J.C., Borgnis, E.L., Turner, R.E. and C.S. Milan (2012) Wetland Sediment Accumulation at Corte Madera Marsh and Muzzi Marsh. Prepared for San Francisco Bay Conservation and Development Commission.
49. Watson, E.B. (2008) Marsh expansion at Calaveras Point Marsh, South San Francisco Bay, California. *Estuarine Coastal and Shelf Science*. **78:** p. 593-602.
50. Williams, P.B. and M.K. Orr (2002) Physical evolution of restored breached levee salt marshes in the San Francisco Bay estuary. *Restoration Ecology* **10:** 527-542.

Appendix 1. Factors for future carbon sequestration modeling that may improve predictive power and Published Carbon Sequestration Rates Table

♦ Tidal Prism: Volume of water in an estuary or salt marsh between mean low tide and mean high tide that includes the volume of incoming tide plus river discharge. Tidal prism is a function of estuary depth and typically 1-3 meters. The tidal prism magnitude is a function of the estuarine area and the tidal range of estuary. Diurnal tidal prism from Table 7.3 in the PWA 2002 McDaniel Slough report (19) is estimated by calculating the volume between MLLW and MHHW of each drainage area from a DEM in ArcView (p.26). Also see Fig. 3.2 HB hydrodynamic model grid and bottom elevations for Humboldt Bay from Northern Hydrology and Engineering (30) and Anderson (31, 32). Also, Sanchez (35) on wetlands and estuary dynamics and tidal prism in navigable coastal waterways from ACE technical memo.

♦ Site directional aspect: Ocean opening morphology and wind data in wave action: physical properties of the site that generate susceptibility to wind action and wave behavior including storm surges. Factors discussed in Costa (33).

♦ Rainfall data: Incorporate select rainfall ranges that exert distinct impacts on salt marsh sediment deposition profiles through time: i) storm surges that cause large inundation events and high sediment deposition; ii) intense rainfall events that increase discharge from marsh-proximal rivers that erode existing sediment; iii) low to intermediate rainfall events that collect on salt marsh and contribute to net sediment accretion. From HSU capstone report (22), factors that influence flooding magnitude: tidal levels at time of storm, saturation of marsh, size marsh basin relative to storm intensity, rainfall-derived flooding of freshwater rivers into marsh. PWA 2002 McDaniels Slough report (19) p. 6 notes Janes Creek increases from several cfs to >1000 cfs during extreme floods (Klein and Anderson, 2000) and runoff from 8 mi^2 agricultural pasture - indicator of significant allocthonous sedimentation potential.

♦ Marsh morphology: The number, size, and location of channels has an effect on the marsh surface flow hydraulics and causes an alteration to sheet flow over the salt marsh plain. Sheet flow over marsh would theoretically be slower with less velocity than channels where velocity of flow and ebb is higher and causes an impact on suspended and deposited sediment. Fagherazzi 2013 (23) describes this relationship in a series of equations to cover laminar vs channel flow and sediment deposition. Also, as per the PWA 2002 McDaniel slough report (19), hydraulic geometry relates the channel cross-section morphology to marsh area and to tidal prism. (p. 26-27); reports expected tidal channel development will evolve over 50 years. Also, Kirwan and Murray (34) develop a 3D model of tidal salt marsh accretion and channel network development that couples physical sediment transport processes with vegetation biomass productivity. See Eicher table below (1987, ref 27) for vegetation distribution by elevation in Humboldt Bay, California.

♦ Tidal inundation characterstics: complex physical properties and incorporate some of the above parameters. Flow behavior is a function of marsh and tidal channel morphology, marsh directional aspect. Inundation chacteristics (sheet vs channel) impact sediment concentration and deposition, organic matter and chemical composition of substrate. As per the MEM model structure, inorganic deposition is a function of suspended sediment, elevation and bioamass, and organic sediment function of biomass productivity, decomposition rate, and refractory biomass.

Conditions for highest sediment accumulation are moderate storms that increase sediment resuspension near marshes, and don't trigger fast flows in the channels. For sediment export, most erosive conditions occur during meteorological low tides, when wind blows water away from the coastline and a large volume of water exits marsh system. To measure water fluxes in tidal salt marsh, i) tidal prism estimates total volume water exchanged; ii) static Boon model adequate for instantaneous dischage from marsh, iii) for flow velocity and residence time, use TIGER model.

Fagherazzi (23): Sediment fluxes to and from the marsh strongly depend on sediment resuspension by waves and currents. Recent results show that: a) during a flood the input of sediment to the marsh depends on resuspension of sediments in adjacent areas by wind waves, tidal currents, b) during ebb the export of sediments is strongly affected by the magnitude of water velocity in the channels draining the marsh, c) storm surges import large volumes of sediment to the marsh, but they also export a comparable amount during the subsequent ebb due to the high velocities in the channels and related bottom shear stresses, d) moderate storm conditions with limited surges maximize the sediment import to the marsh.

See also HSU ERE Capstone LS Report App A 2015 (22); Schile, Callaway et al 2014 (3); Callaway NCEAS ppt - MEM II model inputs (2); PWA McDaniel Slough report 2002 (19) - Appendix C has MARSH98 Sedimentation Model (based on Krone 1987, ref 8) that estimates long-term sediment accretion of constructed and natural marshes. Data from model Table 7-1 (pg. 24) PWA McDaniel report (19) summarizes data for model calibration and derives sedimentation rate (~0.02-0.04 ft/yr) for 3 sites including Arcata Salt Marsh. 1D French 1993 model (9) included OM accum and compaction to Krone; Callaway 1996 (10) further included OM decay. Lionberger and Schoelhamer, 2009 USGS Report on SF Bay Tidally Averaged Sediment Transport Model (29); Swanson et al 2013 Wetland Accretion Rate Model of Ecosystem Resilience (WARMER) and Application at 4 sites in SF Bay area (7).

♦ Freshwater streams flowing into marsh contributing autochthonous sediment through the process of decomposition of nearby river channel; allocthonous sediment from upstream sources.

♦ Aboveground biomass impact on net sediment deposition via ebb and flow dynamics: see HSU ERE Capstone Living Shoreline Report Attachment A 2015 (22) Fig A-9 Distribution of salt marsh plants by tidal elevation p. 14. LaGarde (20): results Table 2 and comparison with Rogers results (1981) re: net primary productivity of Spartina foliosa, Salicornia virginica,and Distichlis spicata in salt marshes at Humboldt Bay, California (36). For McDaniel Slough - existing ecological conditions in App B of PWA 2002 McDaniel Slough report (22). Vegetation and elevation relationship Table 7.2 PWA 2002 report (19). See J. Nogueira survey (37) in restored Jacoby Creek salt marsh - now at 66.5% cover since 2011. See A. Eicher Memo to J Neander City of Arcata (27) regarding veg survey in McDaniel Slough @ 1 yr restoration. Good map of Janes Creek and McD Slough in City of Arcata Fish and WQ survey report 2013,

Fig. 1. Also, Siegel et al 2010 Suisun Tidal Marsh Model (38) Fig 3.2 Vertical cross sections of plant communities in tidal salt marsh by elevation.

♦ Exotic/Invasive plants present: e.g. *S. densiflora*: lower below ground biomass (carbon sequestration) and lower net ecosystem exchange (NER); see LaGarde thesis (20).

♦ Microbial biomass carbon contribution: sum of marsh ecosystem biomass contributing carbon: mud flat organisms, algae, phytoplankton, bacteria, others.

♦ Soil Organic Material (SOM) – derive soil organic carbon. This is part of Marsh Equilibrium Model, but since a key aspect—should other approaches by used to quantify? Typically, take soil cores at varying depths and locations; run Loss-On-Ignition - main protocol for determining SOM and deriving % carbon (SOC) via Craft or other equations. Craft 1991 equation (39) can be used to derive SOC from SOM: SOC = (0.4 +/- 001) * SOM (by LOI) + (0.0025 +/- 0.0003) * SOM2 (by LOI). Per VCS Methodology (40): for Pacific marshes should use SOC = (0.38)*SOM + (.0012)*SOM2 (per Callaway, ref 4). Caveat: Different LOI methods and calculations for % carbon (via Craft or other) gives different results--see Keller 2012 (41); Beasy and Ellison 2013 (42); representative sampling is also issue in field testing (Whittlesby 2013 Arcata Salt Marsh study, 43); should also include oxidation of sulfur to SO^2 in LOI calculations if saline sample (Pasternak lab UC Davis).

♦ Soil Carbon Accretion Rate and Soil density (depends on depth and length of time in wetlands restoration). Use gas trap chambers to directly measure gas emission; analysis via gas chromatography or other methods; see VCS for GHG plot standardization and equations. Used Eddy covariance for methane (40). For native vs invasive species in marsh, see Table 3 LaGarde thesis (20). ^{137}Cs and ^{210}Pb dating of soil core samples is gold standard but about $3K-5K per sample (4). Typical accretion rates range between 0.25 – 5.0 cm/yr (4). Carbon sequestration may be overestimated in restoration projects due to fact that sediment is newly deposited (<100 yrs); see Discussion in (4) for more details.

Table S2 (Schile 2014, ref 3) shows that MEM model results for accretion rates (cm/yr) and mineral accumulation rates (g/m2/yr) were within range of observed from actual soil core sample data used in Schile (3) and Callaway (4) using Pb dated soil core samples for vertical accretion.

Callaway: Need both Cs/Pb dating of core samples and soil accretion rate to get a C-seq rate; aka need to know how quickly the sediment is accumulating and how much carbon is in it. If the site has been stable and kept pace with SLR – salt marshes usually accumulate C on the surface faster than SLR and then through compaction it evens out. Therefore, using a short term rate will over-estimate the long term carbon accumulation. Calibrate the model with historic data and project into the future.

Callaway data for the different types of marshes balanced out either low C content and high density or higher C and lower density.
General rule: 25-30 mg/cm^3 * 0.3 cm/yr (accretion rate) = 75 (similar value as calculated in Callaway 2012 paper for carbon sequestered - 79 g C/m2/year).

Calculation: 25 mg/cm^3 (bulk density) x 0.3 cm/yr (accretion) X 10,000 cm^2/m^2 X1g/1000mg = 75 gm/m^2/yr
Also, if know subsidence rates (add subsidence + SLR = estimate of accretion) can calculate carbon sequestered; e.g. 3.45 mm/year x carbon density = carbon accumulation
MEM good for predictions for over 100 year timescale or longer; brackish marsh has faster decay. If there is more anaerobic activity, get slower decay rate. The model decomposition rate not a function of inundation.

♦ NER (Net Ecosystem Respiration) – CO_2 emissions, methane, other GHG. Use gas trap chambers to directly measure gas emission; analysis via gas chromatography or other methods; see VCS for GHG plot standardization and equations. Used Eddy covariance for methane (VCS, ref 40). For native vs invasive species in marsh, see Table 3 LaGarde thesis (20).

♦ Sea Level Rise and Subsidence:

SLR source	min SLR over 100 yrs	max SLR over 100 yrs	min avg/yr	max avg/yr	UNITS
Swanson (IPCC 2013) - global (feet Century Sea Level Rise)	0.92	3.21	0.0092	0.0321	feet/yr
converted inch to cm (1 ft = 30.48 cm)	28.04	97.84	0.28	0.98	cm/yr
Swanson SLR includes subsidence (inches)			0.29	0.64	in/yr
converted to cm (1 inch = 2.54 cm)			0.74	1.63	cm/yr
over 100 year time span			74	163	cm/yr

Since Chuck Swanson (18) SLR estimate includes subsidence, 0.74 cm/yr SLR includes 0.25 cm/yr subsidence (Kalt 2012; note this is ~2X higher than Anderson value (13) used as MEM input) and therefore 0.49 cm SLR (within mid-range of 0.28-0.98 SLR w/o subsidence component)
Per Laird in Humboldt Bay Shoreline Inventory (44): Humboldt Bay from North Spit Station has highest SLR in Cal at 18.6 inches/century = 47.24 cm/100 years = .47 cm/yr average
Laird projects conservative estimate of 36 inches by 2100 = 91.4 cm century SLR (p 113)
North Spit - subsidence estimated at 2.5mm/yr = 0.25 cm/yr
He cites Pritchard (16) soil accretion rate in Mad River Slough = 0.06 in/yr = 0.15 cm/yr (pg 54)
Pritchard - p 57. subsidence 0-1.64 m over epoch duration
Typical accretion = ~0.25-0.32 cm/yr based on Schile (3) Table S2 MEM validation and Callaway 2012 (4) soil core results at various locations within SF Bay Estuary.

WARMER paper (7) for SLR used IPCC 2007 4th assessment report
Gregory IPCC 2013 (11) SLR 1901-1990 1.5 mm/yr = 15 cm/yr; 1993-2010 = 3.2 mm/yr = 32 cm/yr

Elevation loss due to plate tectonics/earthquakes; also land use changes (e.g. marsh to ag). See 2.1 HBSLR Final Report, N. Hydrology and Eng doc (30) Fig. 2.1 for tectonic plates along Humboldt Bay. Also Table 2.3 for Relative SLR, Vertical Land Motion, Regional Mean SLR at HB tide gauges.

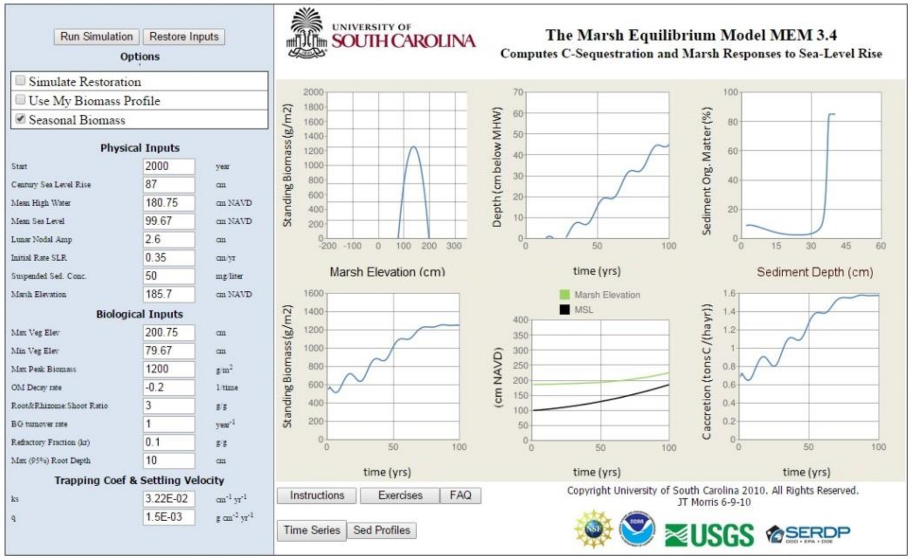
Appendix 1 continued - Published Carbon Seqestration Rates Tidal Salt Marsh

Reference	Location	Rate Carbon Sequestration	Notes
Chmura, G.L., Anisfeld, S.C., Cahoon, D.R. and J.C. Lynch (2003) Global carbon sequestration in tidal, saline wetland soils. *Global Biogeochem Cycles* **17** p. 22: 1-12.	Global	210 +/- 20 g C/m2/yr	Figure 3; large range: most are between 200-400 g C/m2/yr
McLeod, E., Chmura, G.L., Bouillon, S., Salm, R., Bjork, M., Duarte, C.M., Lovelock, C.E., Schlesinger, W.H. and B.R. Silliman (2011) A Blueprint for Blue Carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Front Ecol Environ* **9** p. 552-560.	Salt marsh	218 +/- 24 g C/m2/yr	Table 1; range is 18-1713 g C/m2/yr, n=96 sites; sources are Chmura (2003) and Duarte (2005).
Craft, C. (2007) Freshwater input structures soil properties, vertical accretion, and nutrient accumulation of Georgia and U.S. tidal marshes. *Limnol. Oceanogr* . **52** p. 1220-1230.	Tidal Freshwater Marsh	140 +/- 20 g C/m2/yr	Figure 5. Wetlands included in analysis from NE & SE Atlantic and Gulf Coast states excluding Texas, and west coast tidal marshes of continental U.S.
Ibid	Brackish Marsh	240 +/- 30 g C/m2/yr	Figure 5.
Ibid	Salt Marsh	190 +/- 40 g C/m2/yr	Figure 5.
Burden, A., Garbutt, R.A., Evans, C.D., Jones, D.L. and D.M. Cooper (2013) Carbon sequestration and biogeochemical cycling in a saltmarsh subject to coastal maanged realignment. *Estuarine, Coastal and Shelf Science* **120** p. 12-20.	UK salt marsh	58-199 g C/m2/yr	Results section 3.2 estimated 0.92 t C/ha/yr; noted as consistent with 0.64-2.19 t C/ha/yr (Cannell et al 1999); similar to estimate by Craft (2003).
Callaway, J.C., Borgnis, E.L., Turner, R.E. and C.S. Milan (2012) Carbon sequestration and sediment accretion in San Francisco Bay tidal wetlands. *Estuaries and Coasts* **35** p. 1163-1181.	Six natural tidal wetlands in San Francisco Bay estuary	79 g C/m2/yr	Measured sediment accretion, mineral and organic matter accumulation; analyzed by ^{137}Cs and ^{210}Pb dating.
Callaway, J.C., Borgnis, E.L., Turner, R.E. and C.S. Milan (2012) Wetland Sediment Accumulation at Corde Madera Marsh and Muzzi Marsh. *Report submitted to San Francisco Bay Conservation and Development Commission* 9/27/2012. p. 1-22.	Stations at different marsh locations: low, mid and high at Corde Madera Marsh	105-142.1 g C/m2/yr (low marsh) 81.4 - 172.8 g C/m2/yr (mid marsh) 89.0 - 106.8 g C/m2/yr (high marsh)	Table 3; Based on ^{210}Pb dating and ^{137}Cs dating
Duarte, C.M., Middelburg J.J and N. Caraco (2005) Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences* **2** p. 1-8.	Global	151 g C/m2/yr	Table 1, based on area covered by Woodwell et al (1973) and organic burial data from Chmura et al (2003).
Bridgham, S.D., Megonigal, J.P., Keller, J.K., Bliss, N.B. and C. Trenton (2006) The Carbon Balance of North American Wetlands. *Wetlands* **26** p. 889-916.	Mexican mangroves	330 g C/m2/yr	Summarized in **Quintana**-Alcantara thesis (University of San Francisco 2014); Carbon Sequestration in Tidal Salt Marshes and Mangrove Ecosystems; pp 26-27.
	U.S. mangroves	180 g C/m2/yr	
	U.S. tidal salt marshes	220 g C/m2/yr	
	Canada and Alaska tidal salt marsh	210 g C/m2/yr	
Mitsch, W.J., Bernal, B., Nahlik, A.M., Mander, U., Zhange, L., Anderson, C.J., Jorgensen, S.E. and H Brix. (2012) Wetlands, carbon, and climate change. *Landscape Ecol.* **28** p. 583-597.	North American salt marshes	190 +/- 40 g C/m2/yr; for brackish salt marshes: 240 +/- 30 g C/m2/yr	Table 2
Trulio, L., Callaway, J. and S. Crooks (2007) Carbon Sequestration and Tidal Salt Marsh Restoration. White paper for South Bay Salt Pond Restoration Project.	Greco Island - ancient marsh in South San Francisco Bay	180-200 g C/m2/yr	Callaway and Drexler, unpublished observations

Appendix 2: Marsh Equilibrium Model Usage - Sensitivity Analysis

MARSH EQUILIBRIUM MODEL SENSITIVITY ANALYSIS SPREADSHEET - CARBON SEQUESTRATION RATES AS A FUNCTION OF DIFFERENT PHYSICAL AND BIOLOGICAL INPUT VALUES																
		v1	v2	v3	v4	v5	v6	v7	v8	v9	v10	v11	v12	v13	v14	v15
Physical Inputs																
Start		2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Century Sea Level Rise		87	28	50	100	150	87	87	87	87	87	87	87	87	87	87
Mean High Water		180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75
Mean Sea Level		99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67
Lunar Nodal Amp		2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Initial Rate SLR		0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Suspended Sed. Conc.		50	50	50	50	50	20	100	50	20	100	50	20	100	50	20
Marsh Elevation		185.7	185.7	185.7	185.7	185.7	185.7	185.7	167.69	167.69	167.69	182.9	182.9	182.9	198.1	198.1
Biological Inputs																
Max Veg Elev		200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75
Min Veg Elev		79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67
Max Peak Biomass		1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
OM Decay rate		-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Root&Rhizome:Shoot Ratio		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
BG turnover rate		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Refractory Fraction (kr)		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Max (95%) Root Depth		20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Trapping Coef & Settling Velocity																
ks		0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322
q		0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
	initial	0.7	0.7	0.7	0.7	0.7	0.7	0.7	1.25	1.2	1.2	0.8	0.8	0.8	0.2	0.2
	gC/m2/yr	64	64	64	64	64	64	64	113	109	109	73	73	73	18	18
	final	1.6	1.2	1.5	1.6	1.1	1.6	1.6	1.6	1.4	1.6	1.6	1.5	1.6	1.6	1.6
	gC/m2/yr	145	109	136	145	100	145	145	145	127	145	145	136	145	145	145

v16	v17	v18	v19	v20	v21	v22	v23	v24	v25	v26	v27	v28	v29	v30	v31	v32	v33
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75	180.75
99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67	99.67
2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
100	50	20	100	50	50	50	50	50	50	50	50	50	50	50	50	50	50
198.1	213.36	213.36	213.36	185.7	185.7	185.7	185.7	185.7	185.7	185.7	185.7	185.7	185.7	185.7	185.7	185.7	185.7
200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75	200.75
79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67	79.67
1200	1200	1200	1200	600	2000	1200	1200	1200	1200	1200	2000	2000	2000	1200	1200	1200	1200
-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
3	3	3	3	3	3	3	3	1	5	10	1	5	10	3	3	3	3
1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.1	2	1	1
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	40
0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322	0.0322
0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
0.2	0	0	0	0.35	1.2	0.7	0.7	0.22	1.2	2.3	0.4	2.0	4.0	0.1	1.5	1.5	0.7
18	0	0	0	32	109	64	64	20	109	209	36	181	363	6	136	136	64
	til Yr40	til Yr40	til Yr40														
1.6	1.6	1.6	1.6	0.8	2.6	1.6	1.6	0.5	2.6	5.0	0.9	4.2	8.0	0.2	3.1	3.2	1.6
145	145	145	145	73	236	145	145	45	236	454	82	381	726	14	281	290	145



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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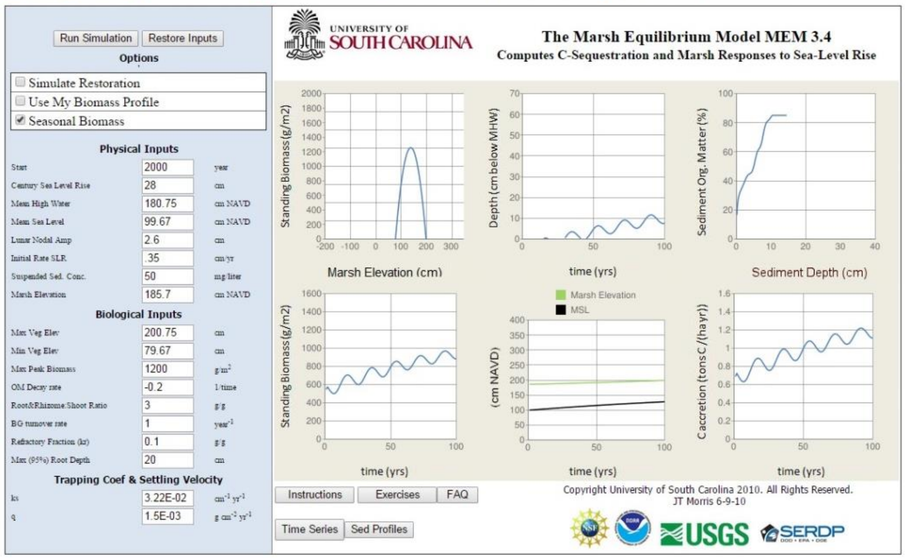
MEM v1 Baseline inputs for Arcata salt marsh
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	28	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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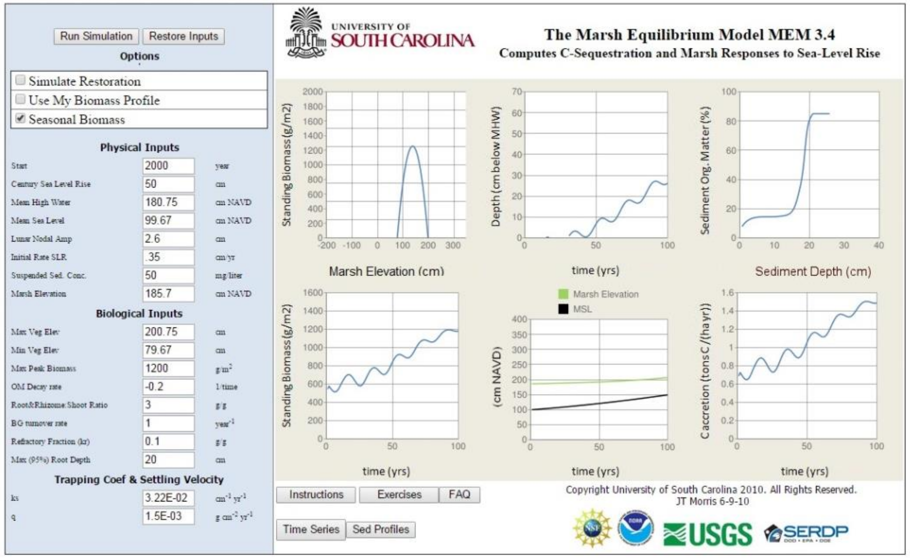
MEM v2 Low Century Sea Level Rise
C Seq= 64 g C/m2/yr Initial; C Seq= 109 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	50	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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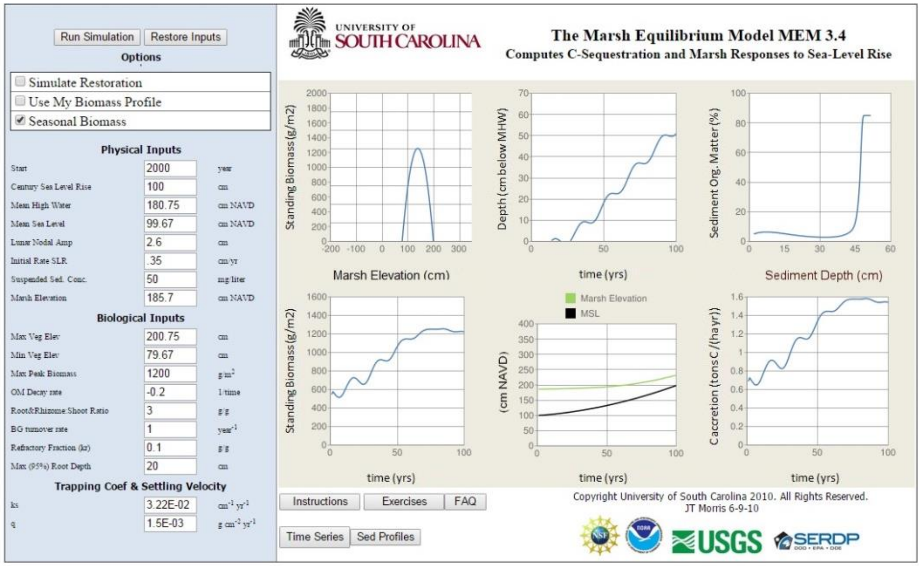
MEM v3 Mid Century Sea Level Rise
C Seq= 64 g C/m2/yr Initial; C Seq= 136 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	100	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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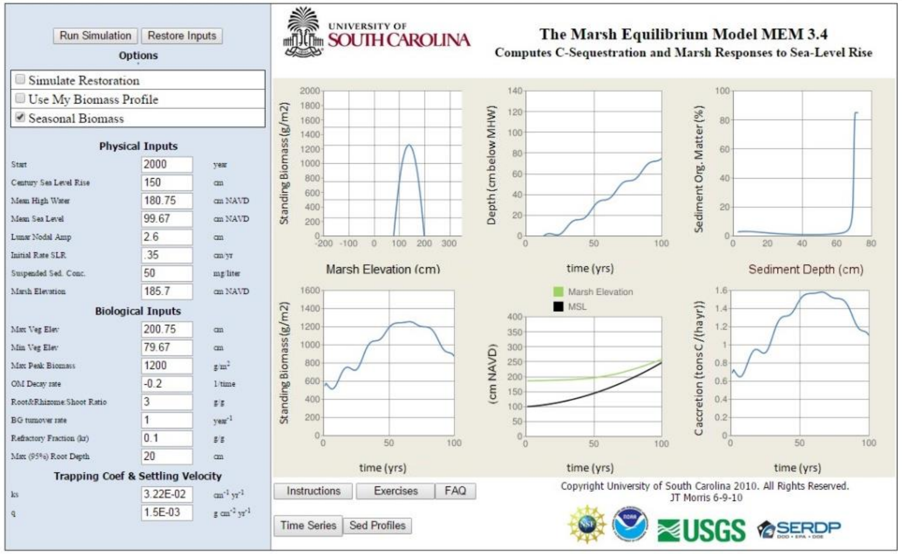
MEM v4 HIgh Century Sea Level Rise
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr
Looks similar to V1 Baseline Inputs



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	150	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	$year^{-1}$
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	$cm^{-1}\ yr^{-1}$
q	1.5E-03	$g\ cm^{-2}\ yr^{-1}$

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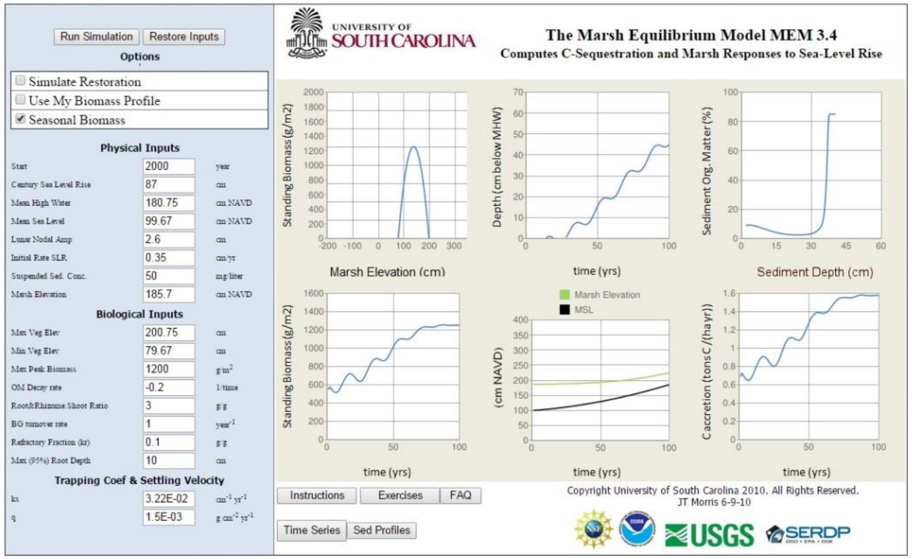
MEM v4 Very HIgh Century Sea Level Rise
C Seq= 64 g C/m2/yr Initial; C Seq= 100 g C/m2/yr 100-Yr

Conclusion: With these parameter inputs, the range of SLR assessed had little impact on carbon sequestration.

At high SLR (150 cm Century), marsh can’t keep pace with sea level by 2100—upper left graph.



Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	$year^{-1}$
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	$cm^{-1}\,yr^{-1}$
q	1.5E-03	$g\,cm^{-2}\,yr^{-1}$

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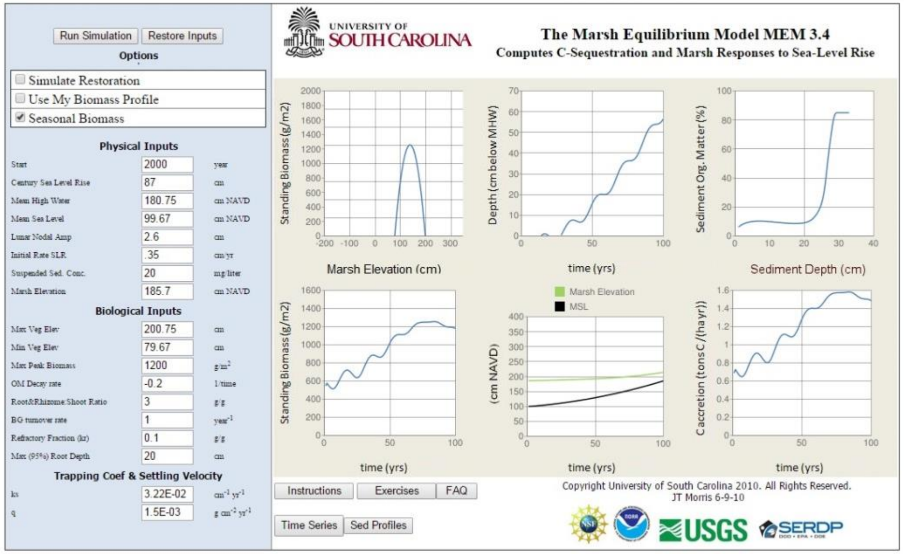
MEM v1 Baseline inputs for Arcata salt marsh with Mid SSC (50 mg/L)
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	.35	cm/yr
Suspended Sed. Conc.	20	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	$year^{-1}$
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	$cm^{-1}\,yr^{-1}$
q	1.5E-03	$g\,cm^{-2}\,yr^{-1}$

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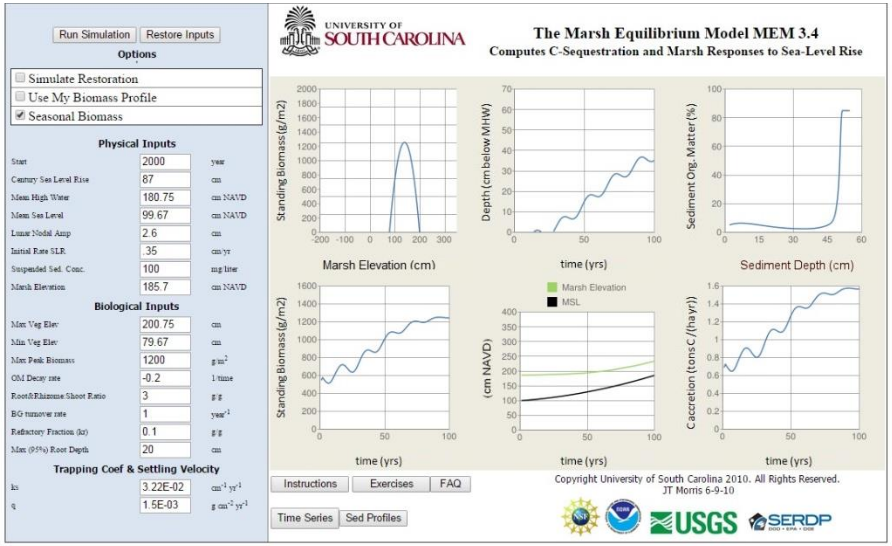
MEM v6 Baseline Inputs with Low SSC (20 mg/L)
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	.35	cm/yr
Suspended Sed. Conc.	100	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	$year^{-1}$
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	$cm^{-1}\,yr^{-1}$
q	1.5E-03	$g\,cm^{-2}\,yr^{-1}$

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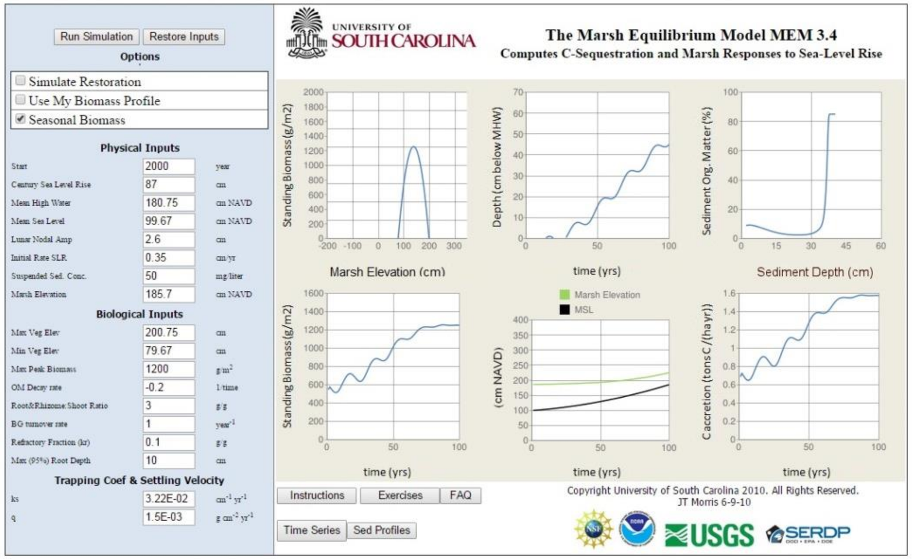
MEM v7 Baseline Inputs with High SSC (100 mg/L)
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr

Conclusion: With these parameter inputs,
SSC has little impact on carbon sequestration.



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options
☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs
Start 2000 year
Century Sea Level Rise 87 cm
Mean High Water 180.75 cm NAVD
Mean Sea Level 99.67 cm NAVD
Lunar Nodal Amp 2.6 cm
Initial Rate SLR 0.35 cm/yr
Suspended Sed. Conc. 50 mg/liter
Marsh Elevation 185.7 cm NAVD

Biological Inputs
Max Veg Elev 200.75 cm
Min Veg Elev 79.67 cm
Max Peak Biomass 1200 g/m²
OM Decay rate -0.2 1/time
Root&Rhizome:Shoot Ratio 3 g/g
BG turnover rate 1 year⁻¹
Refractory Fraction (kr) 0.1 g/g
Max (95%) Root Depth 10 cm

Trapping Coef & Settling Velocity
ks 3.22E-02 cm⁻¹ yr⁻¹
q 1.5E-03 g cm⁻² yr⁻¹

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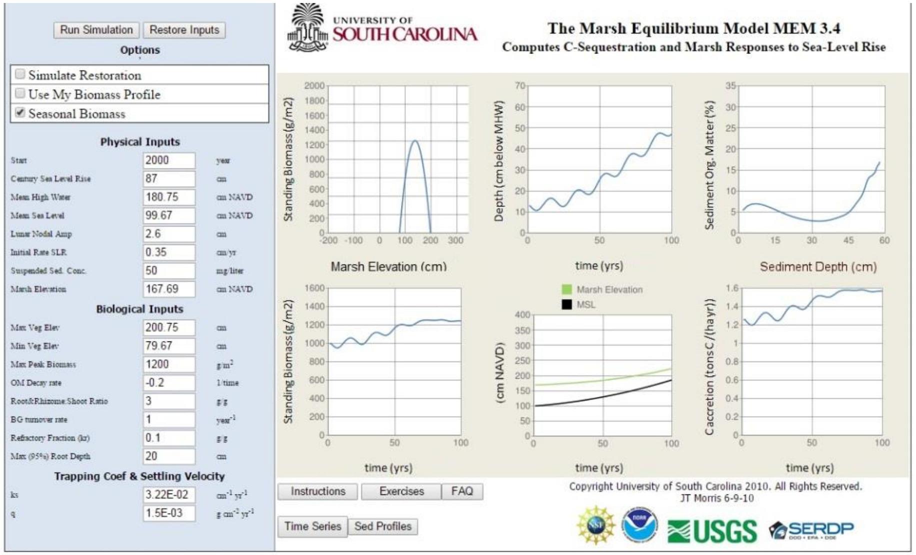
MEM v1 Baseline inputs for Arcata salt marsh with Mid SSC (50 mg/L)
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options
☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs
Start 2000 year
Century Sea Level Rise 87 cm
Mean High Water 180.75 cm NAVD
Mean Sea Level 99.67 cm NAVD
Lunar Nodal Amp 2.6 cm
Initial Rate SLR 0.35 cm/yr
Suspended Sed. Conc. 50 mg/liter
Marsh Elevation 167.69 cm NAVD

Biological Inputs
Max Veg Elev 200.75 cm
Min Veg Elev 79.67 cm
Max Peak Biomass 1200 g/m²
OM Decay rate -0.2 1/time
Root&Rhizome:Shoot Ratio 3 g/g
BG turnover rate 1 year⁻¹
Refractory Fraction (kr) 0.1 g/g
Max (95%) Root Depth 20 cm

Trapping Coef & Settling Velocity
ks 3.22E-02 cm⁻¹ yr⁻¹
q 1.5E-03 g cm⁻² yr⁻¹

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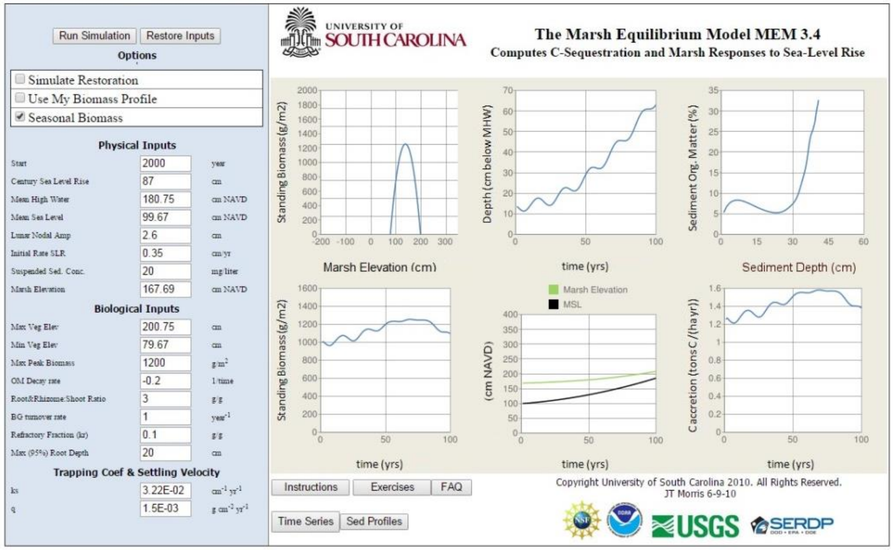
MEM v8 Low marsh elevation 5.5ft = 167.69 cm) and Mid SSC
C Seq= 113 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options
☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs
Start 2000 year
Century Sea Level Rise 87 cm
Mean High Water 180.75 cm NAVD
Mean Sea Level 99.67 cm NAVD
Lunar Nodal Amp 2.6 cm
Initial Rate SLR 0.35 cm/yr
Suspended Sed. Conc. 20 mg/liter
Marsh Elevation 167.69 cm NAVD

Biological Inputs
Max Veg Elev 200.75 cm
Min Veg Elev 79.67 cm
Max Peak Biomass 1200 g/m²
OM Decay rate -0.2 1/time
Root&Rhizome:Shoot Ratio 3 g/g
BG turnover rate 1 year⁻¹
Refractory Fraction (kr) 0.1 g/g
Max (95%) Root Depth 20 cm

Trapping Coef & Settling Velocity
ks 3.22E-02 cm⁻¹ yr⁻¹
q 1.5E-03 g cm⁻² yr⁻¹

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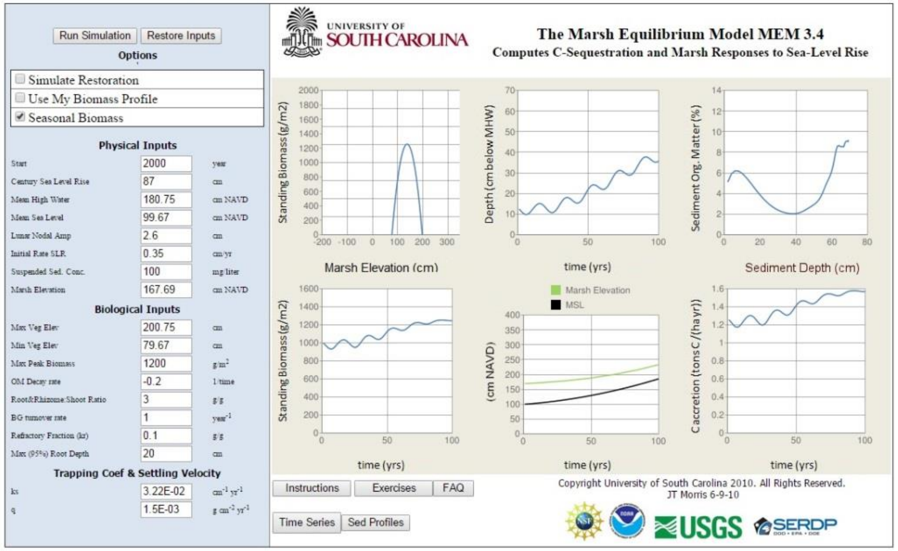
MEM v9 Low marsh elevation 5.5ft = 167.69 cm) and low SSC
C Seq= 109 g C/m2/yr Initial; C Seq= 127 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options
☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs
Start 2000 year
Century Sea Level Rise 87 cm
Mean High Water 180.75 cm NAVD
Mean Sea Level 99.67 cm NAVD
Lunar Nodal Amp 2.6 cm
Initial Rate SLR 0.35 cm/yr
Suspended Sed. Conc. 100 mg/liter
Marsh Elevation 167.69 cm NAVD

Biological Inputs
Max Veg Elev 200.75 cm
Min Veg Elev 79.67 cm
Max Peak Biomass 1200 g/m²
OM Decay rate -0.2 1/time
Root&Rhizome:Shoot Ratio 3 g/g
BG turnover rate 1 year⁻¹
Refractory Fraction (kr) 0.1 g/g
Max (95%) Root Depth 20 cm

Trapping Coef & Settling Velocity
ks 3.22E-02 cm⁻¹ yr⁻¹
q 1.5E-03 g cm⁻² yr⁻¹

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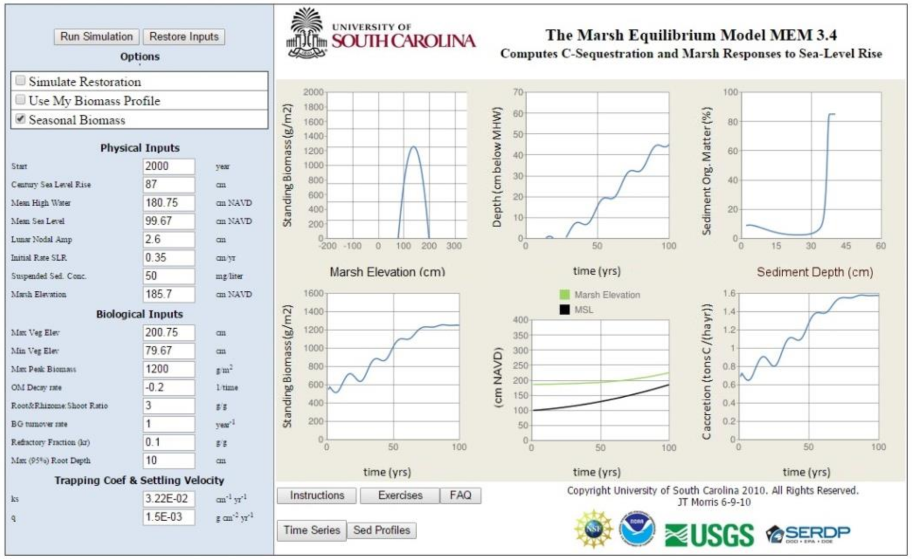
MEM v10 Low marsh elevation 5.5ft = 167.69 cm) and high SSC
C Seq= 109 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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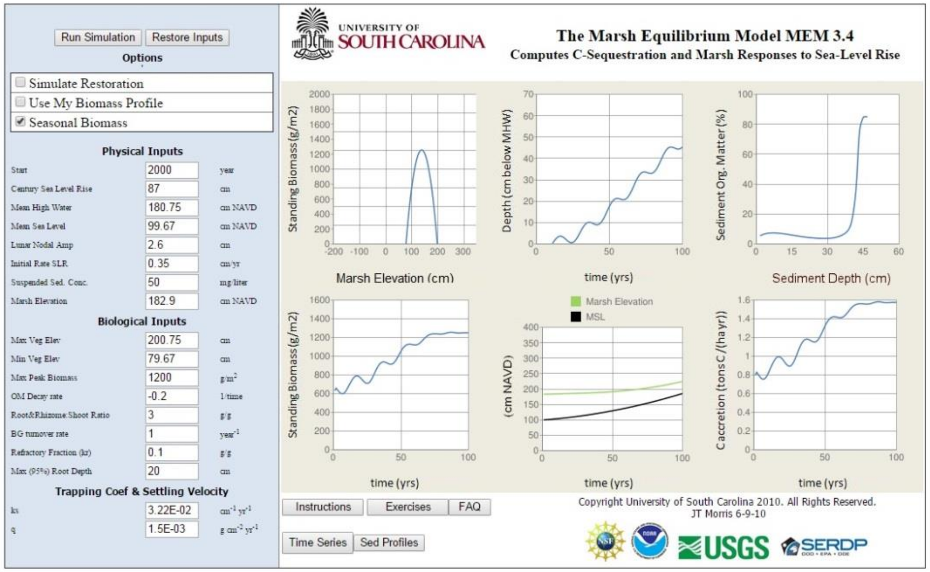
MEM v1 Baseline inputs for Arcata salt marsh with Mid SSC (50 mg/L)
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	182.9	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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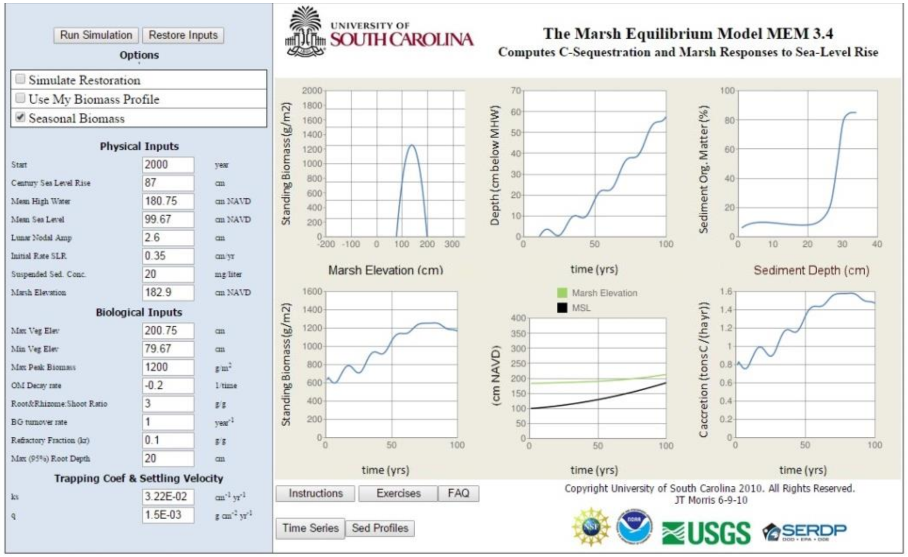
MEM v11 Low-Mid marsh elevation 6 ft = 182.9 cm) and Mid SSC
C Seq= 73 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	20	mg/liter
Marsh Elevation	182.9	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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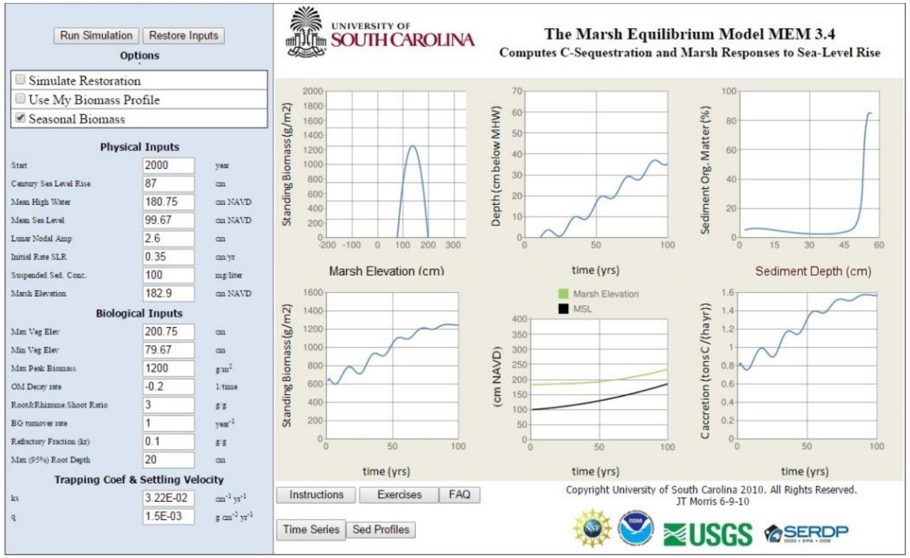
MEM v12 Low-Mid marsh elevation 6 ft = 182.9 cm) and Low SSC
C Seq= 73 g C/m2/yr Initial; C Seq= 136 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	100	mg/liter
Marsh Elevation	182.9	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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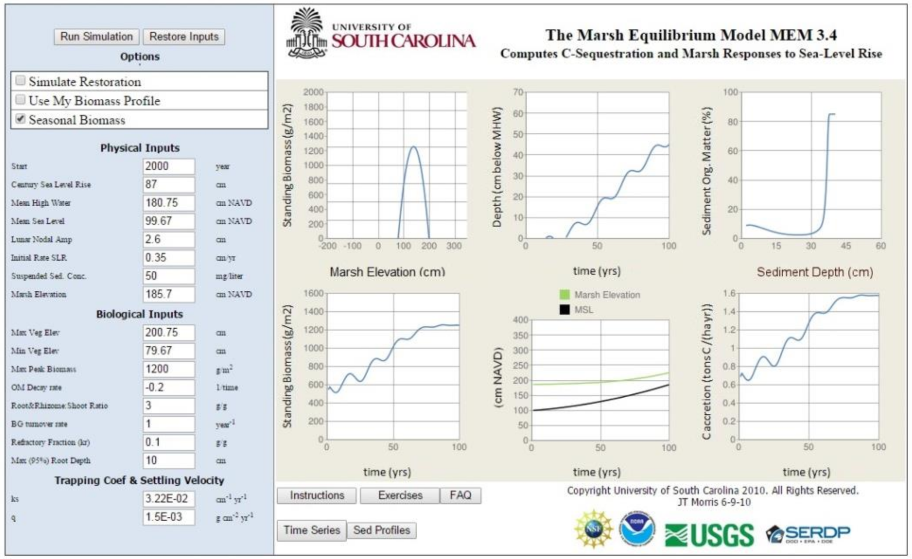
MEM v13 Low-Mid marsh elevation 6 ft = 182.9 cm) and High SSC
C Seq= 73 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

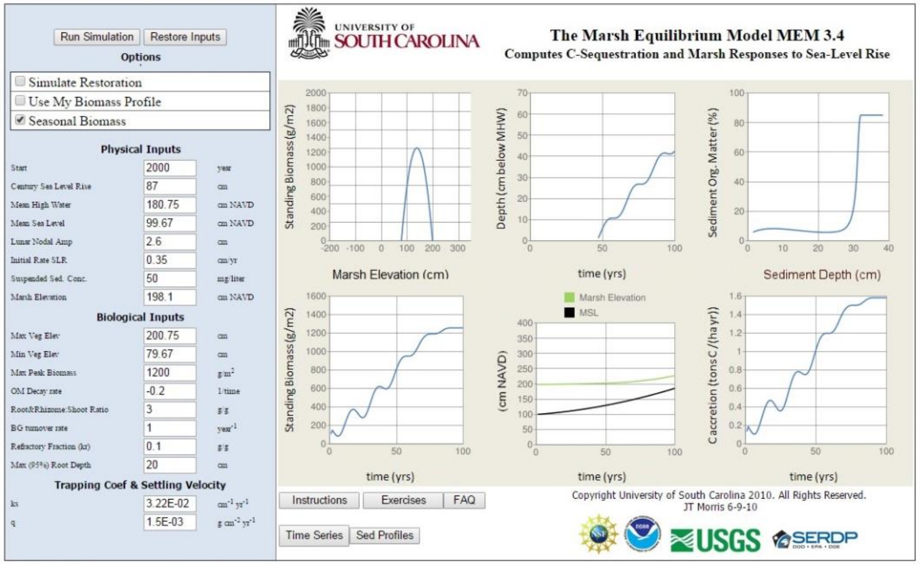
Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

MEM v1 Baseline inputs for Arcata salt marsh with Mid SSC (50 mg/L)
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	198.1	cm NAVD

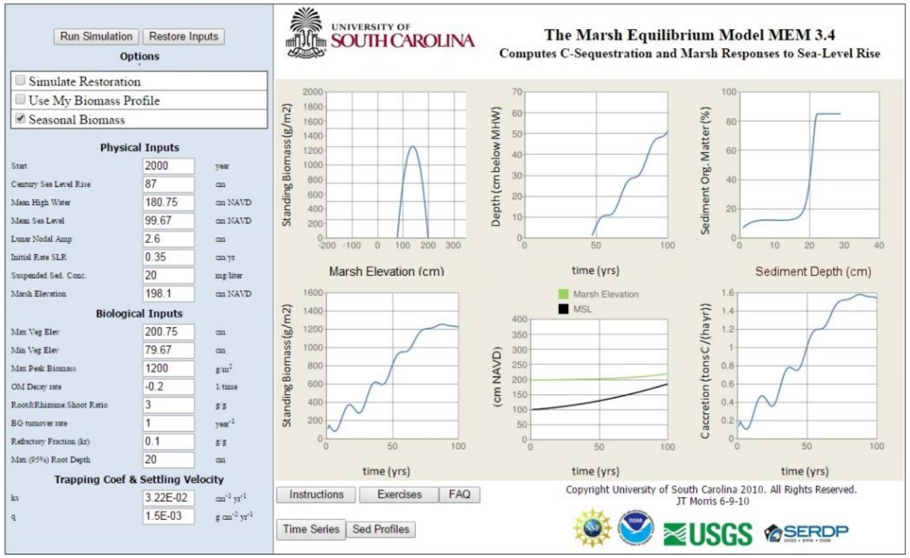
Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

MEM v14 Mid-High marsh elevation 6.5ft = 198.1 cm) and Mid SSC
C Seq= 18 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	20	mg/liter
Marsh Elevation	198.1	cm NAVD

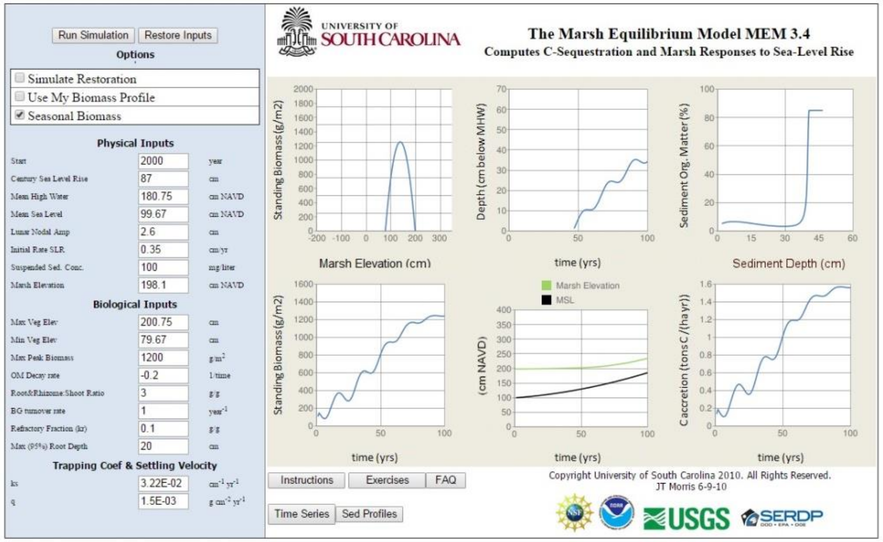
Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

MEM v15 Mid-High marsh elevation 6.5 ft = 198.1 cm) and low SSC
C Seq= 18 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	100	mg/liter
Marsh Elevation	198.1	cm NAVD

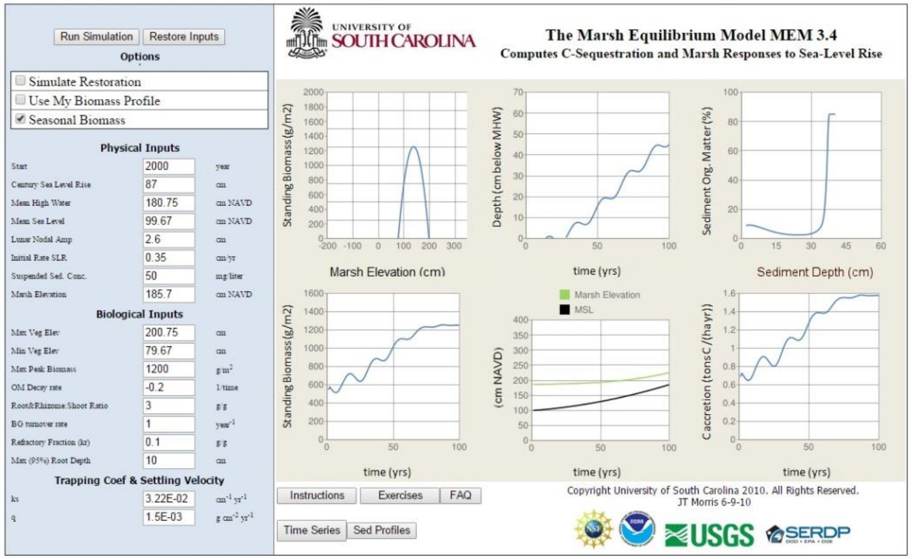
Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

MEM v16 Mid-High marsh elevation 6.5 ft = 198.1 cm) and high SSC
C Seq= 18 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options
- ☐ Simulate Restoration
- ☐ Use My Biomass Profile
- ☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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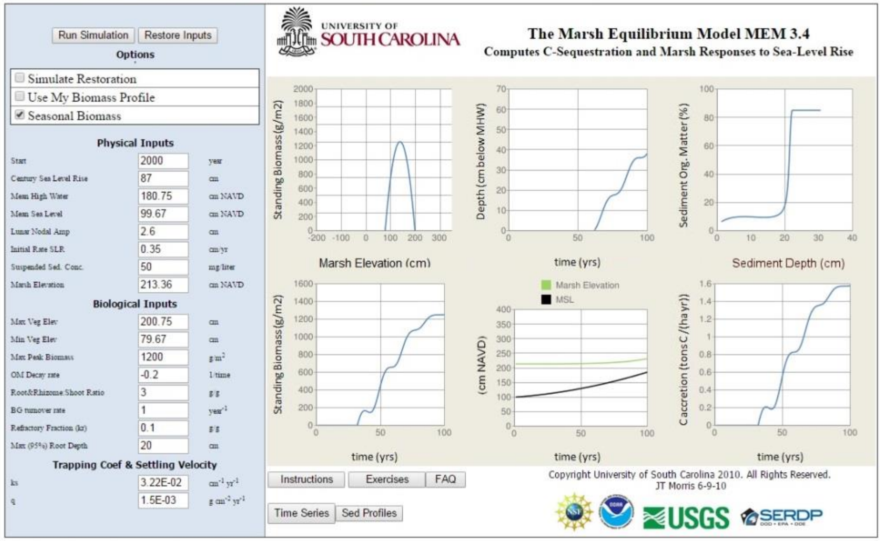
MEM v1 Baseline inputs for Arcata salt marsh with Mid SSC (50 mg/L)
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options
- ☐ Simulate Restoration
- ☐ Use My Biomass Profile
- ☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	213.36	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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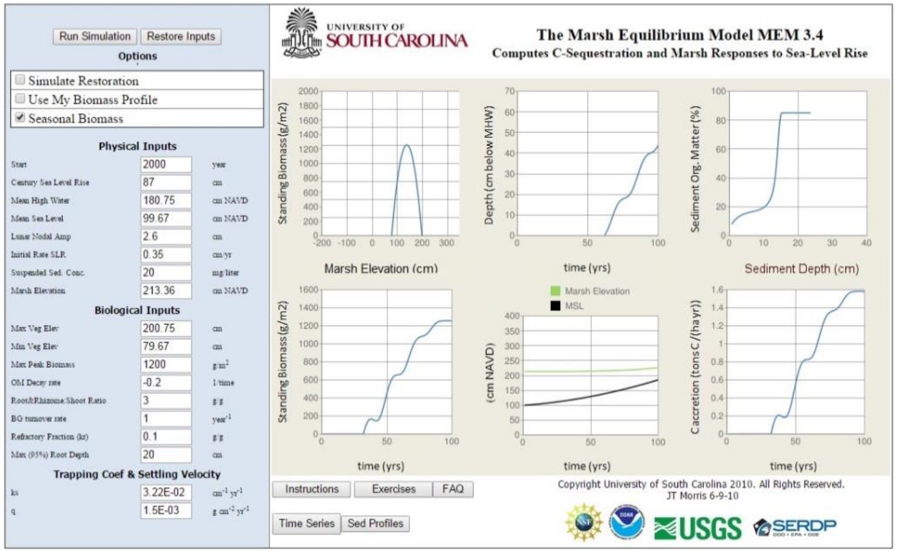
MEM v17 High marsh elevation 7 ft = 213.36 cm) and Mid SSC
C Seq= 0 g C/m2/yr Initial until Yr40; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options
- ☐ Simulate Restoration
- ☐ Use My Biomass Profile
- ☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	20	mg/liter
Marsh Elevation	213.36	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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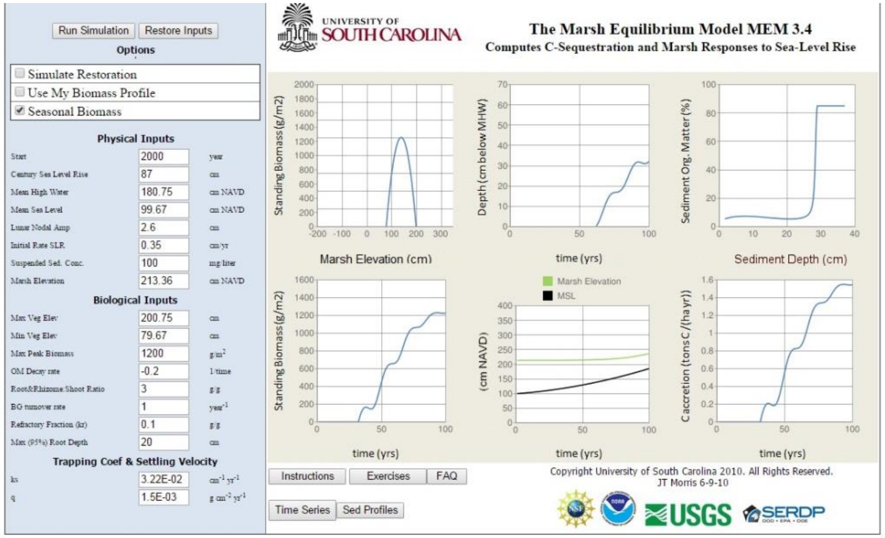
MEM v18 High marsh elevation 7 ft = 213.36 cm) and low SSC
C Seq= 0 g C/m2/yr Initial til Yr 40; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options
- ☐ Simulate Restoration
- ☐ Use My Biomass Profile
- ☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	100	mg/liter
Marsh Elevation	213.36	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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MEM v19 High marsh elevation 7 ft = 213.36 cm) and high SSC
C Seq= 0 g C/m2/yr Initial til Yr 40; C Seq= 145 g C/m2/yr 100-Yr

MARSH ELEVATION SENSITIVITY AND IMPACT OF SUSPENDED SEDIMENT CONCENTRATION (SSC)

Observations/Conclusions Slides 4-7:

1) At low marsh elevation (set here to 5.5 ft in context of MHW and MSL for Arcata -Samoa gaging station), carbon sequestration is high (initially) but maxes out same as baseline input values.

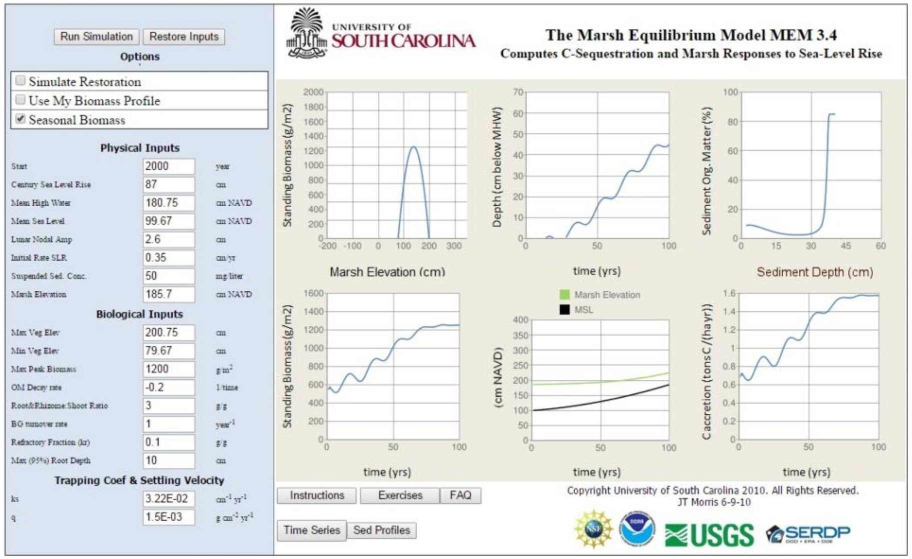
2) C Seq at various marsh elevations not sensitive to SSC.

3) At low marsh elevation, standing biomass is high and thus carbon sequestration higher.

4) The low-mid marsh elevation 182.9 graphs look similar to baseline as expected.

5) At mid-high to high marsh elevation, C-seq is low initially regardless of SSC, but maxes out at baseline values at 100 yrs out.

6) At high marsh elevation, C-seq is initially zero until about 40 years, where starts to climb rapidly and maxes out at baseline values at 100 yrs out.



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m²
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year⁻¹
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm⁻¹ yr⁻¹
q	1.5E-03	g cm⁻² yr⁻¹

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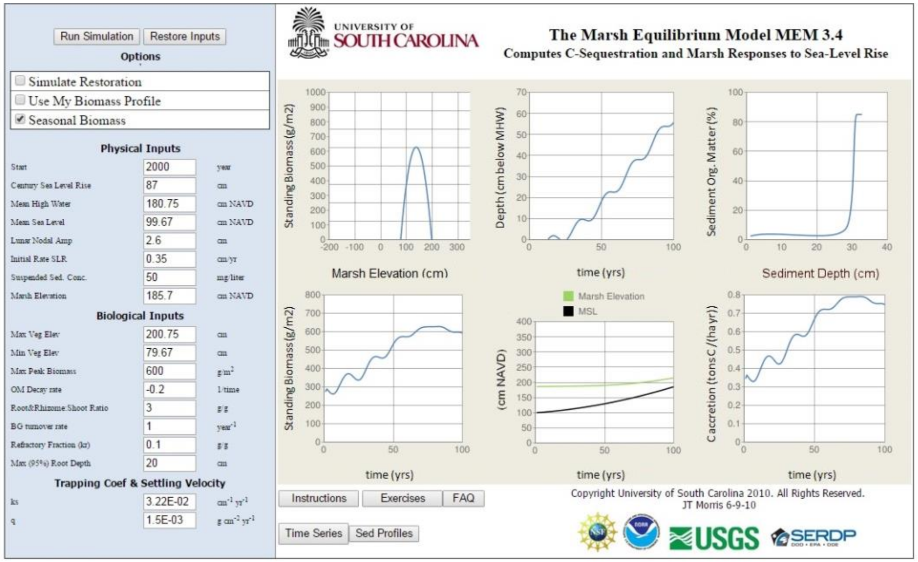
MEM v1 Baseline inputs for Arcata salt marsh with Mid MPB 1200 gm/m2
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	600	g/m²
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year⁻¹
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm⁻¹ yr⁻¹
q	1.5E-03	g cm⁻² yr⁻¹

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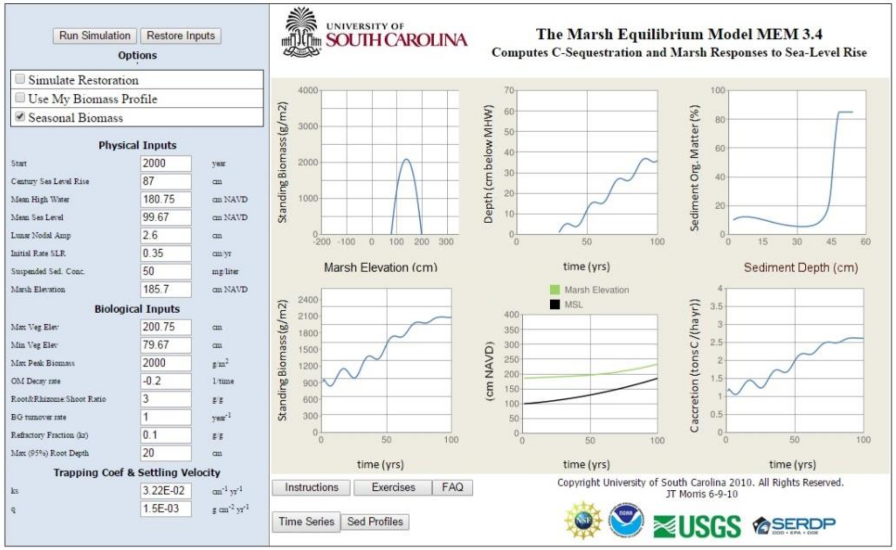
MEM v20 Low Max Peak Biomass 600 gm/m2
C Seq= 32 g C/m2/yr Initial; C Seq= 73 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	2000	g/m²
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year⁻¹
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm⁻¹ yr⁻¹
q	1.5E-03	g cm⁻² yr⁻¹

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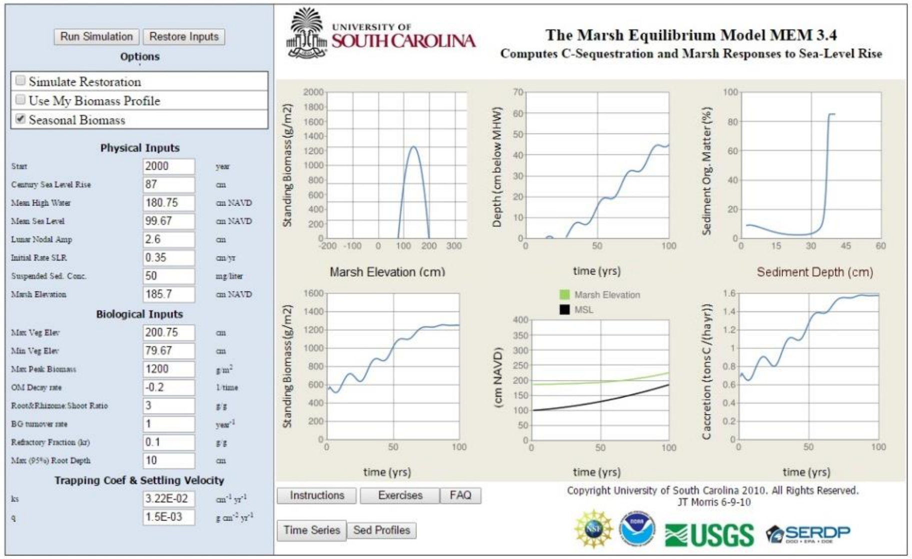
Conclusion: With these parameter inputs,
max peak biomass has high impact on carbon seq.
As MPB increases, so does C Seq. (appears linear)

MEM v21 High Max Peak Biomass 2000 gm/m2
C Seq= 109 g C/m2/yr Initial; C Seq= 236 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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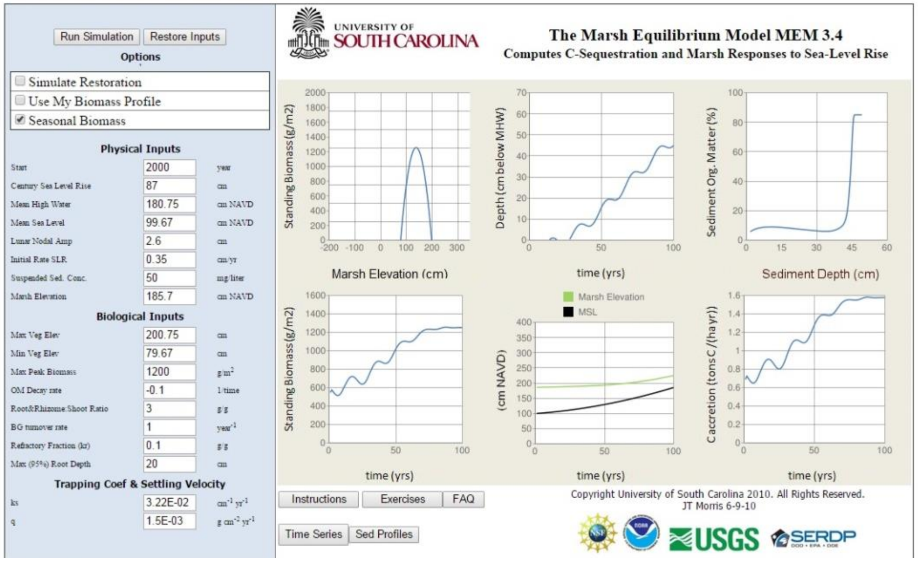
MEM v1 Baseline inputs for Arcata salt marsh with Mid OM Decay Rate
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.1	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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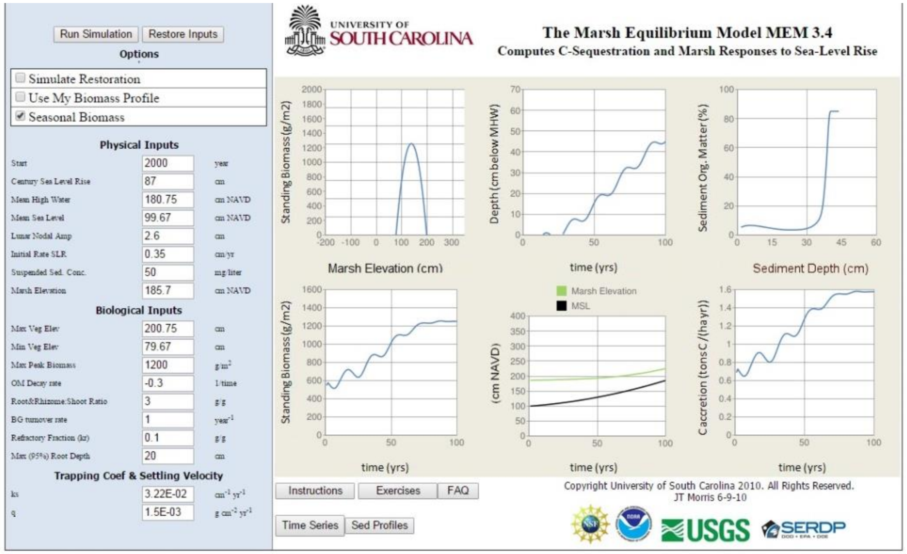
MEM v22 Low OM Decay Rate -0.1
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.3	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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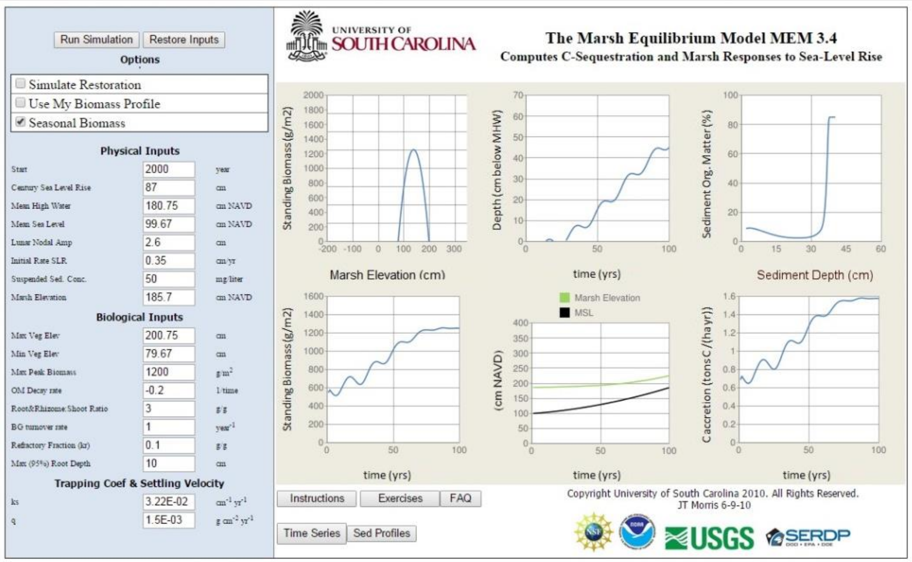
MEM v23 High OM Decay Rate -0.3
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr

Conclusion: With these parameter inputs, organic matter (OM) decay rate has little impact on carbon seq.



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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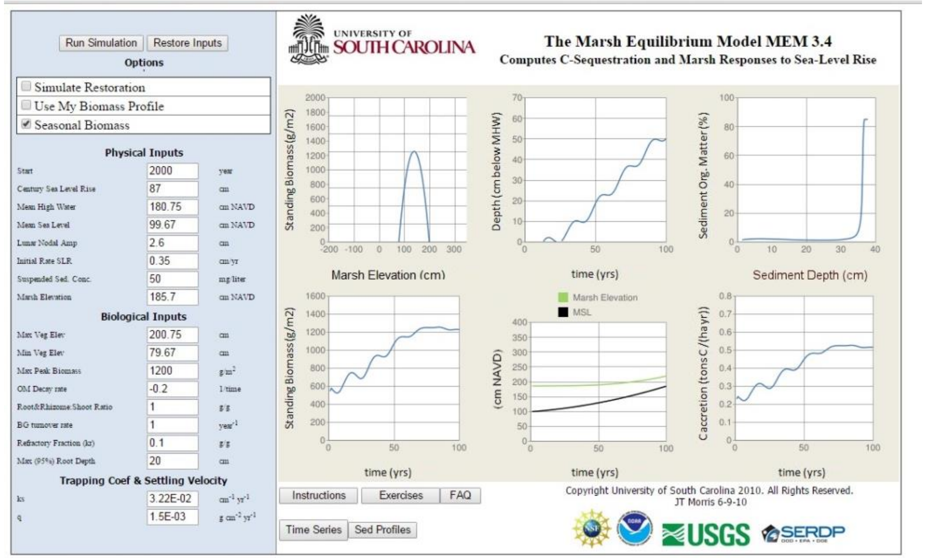
MEM v1 Baseline inputs for Arcata salt marsh with Mid Max Peak BM
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	1	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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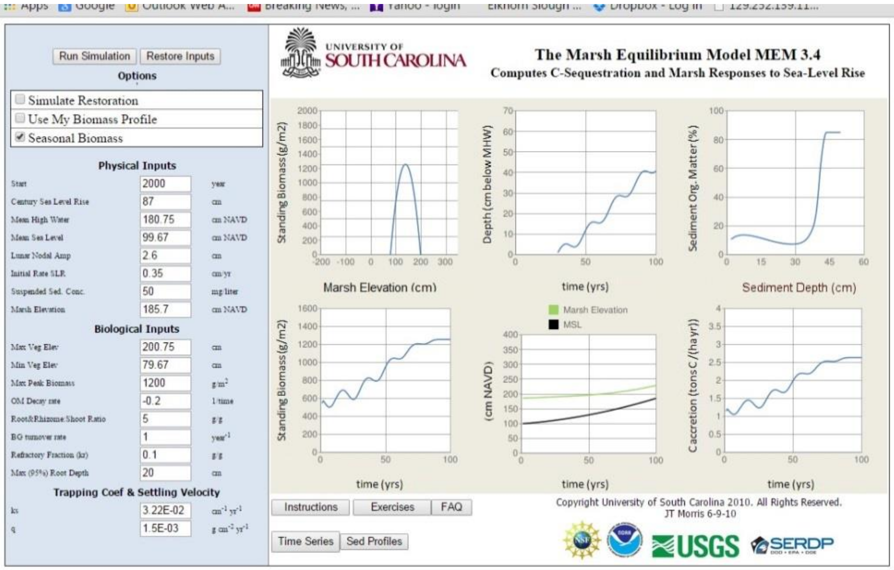
MEM v24 Low Root:Shoot Ratio (1) and Mid Max Peak BM (1200)
C Seq= 20 g C/m2/yr Initial; C Seq= 45 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	5	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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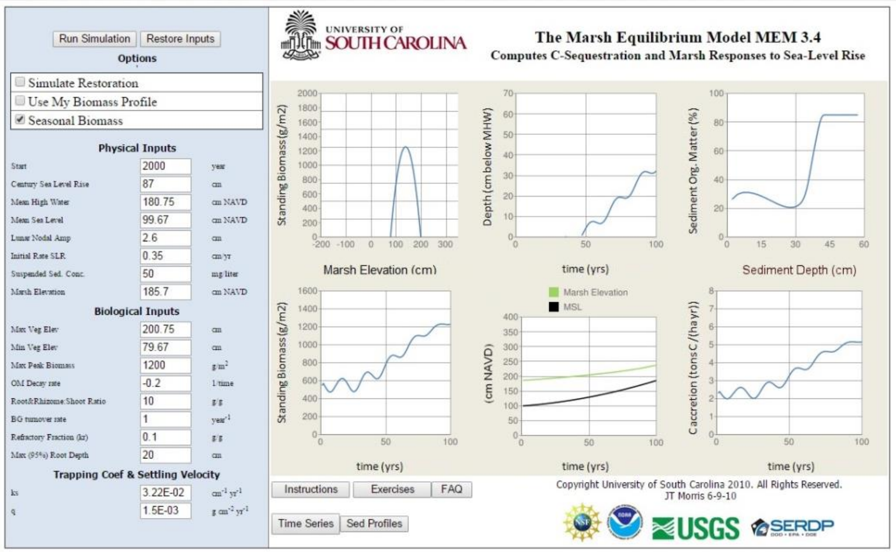
MEM v25 High Root:Shoot Ratio (5) and Mid Max Peak BM (1200)
C Seq= 109 g C/m2/yr Initial; C Seq= 236 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	10	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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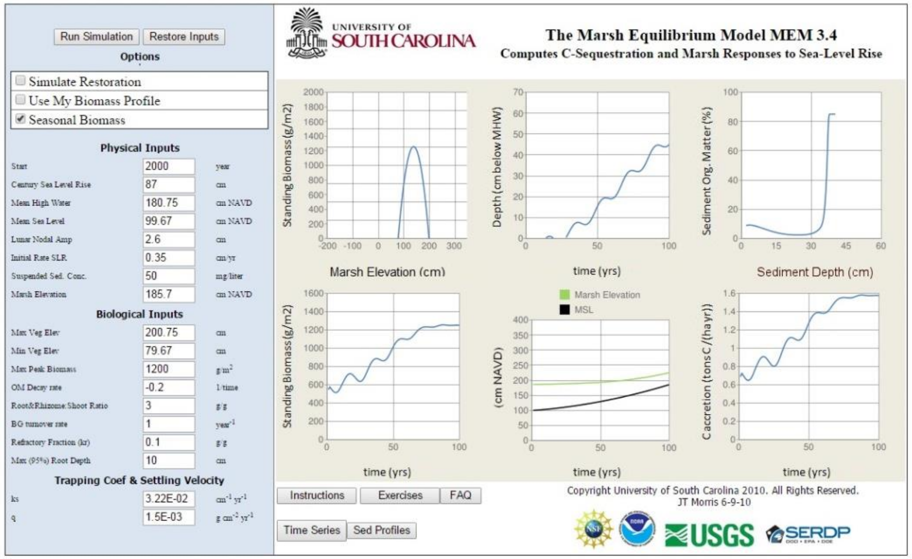
MEM v26 Very High Root:Shoot Ratio (10) and Mid Max Peak BM (1200)
C Seq= 209 g C/m2/yr Initial; C Seq= 454 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	$year^{-1}$
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	$cm^{-1}\ yr^{-1}$
q	1.5E-03	$g\ cm^{-2}\ yr^{-1}$

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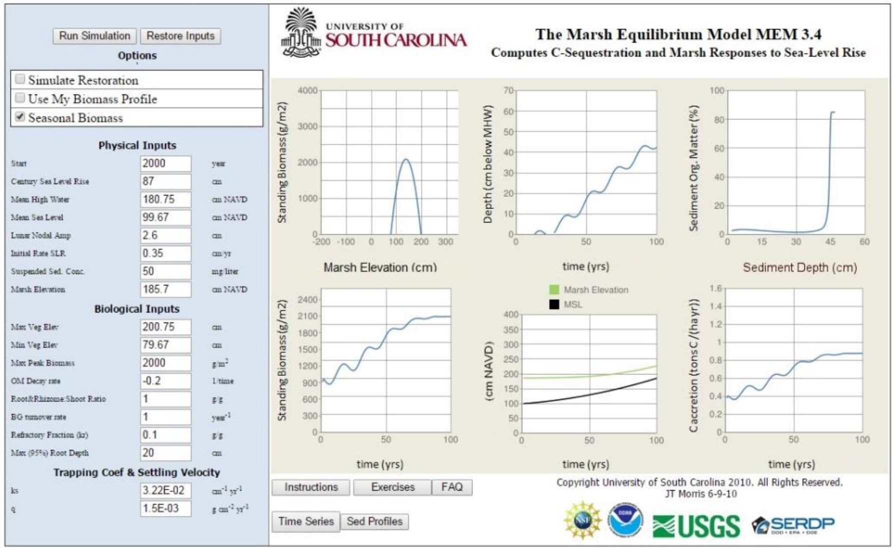
MEM v1 Baseline inputs for Arcata salt marsh with Mid Max Peak BM
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	2000	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	1	g/g
BG turnover rate	1	$year^{-1}$
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	$cm^{-1}\ yr^{-1}$
q	1.5E-03	$g\ cm^{-2}\ yr^{-1}$

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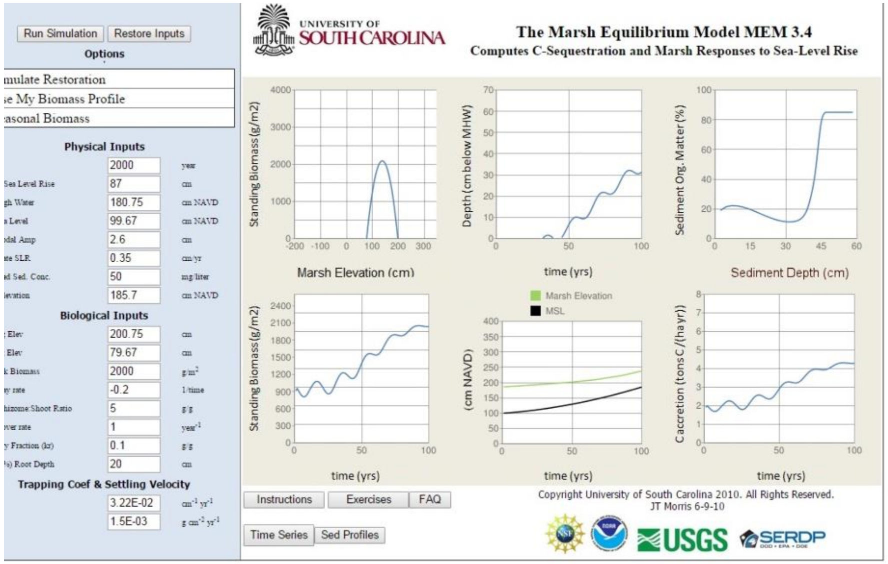
MEM v27 Low Root:Shoot Ratio (1) and High Max Peak BM (2000)
C Seq= 36 g C/m2/yr Initial; C Seq= 82 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

mulate Restoration
se My Biomass Profile
easonal Biomass

Physical Inputs

	2000	year
Sea Level Rise	87	cm
gh Water	180.75	cm NAVD
Level	99.67	cm NAVD
dal Amp	2.6	cm
te SLR	0.35	cm/yr
d Sed. Conc.	50	mg/liter
levation	185.7	cm NAVD

Biological Inputs

Elev	200.75	cm
Elev	79.67	cm
k Biomass	2000	g/m^2
y rate	-0.2	1/time
hizome:Shoot Ratio	5	g/g
ver rate	1	$year^{-1}$
y Fraction (kr)	0.1	g/g
%) Root Depth	20	cm

Trapping Coef & Settling Velocity

	3.22E-02	$cm^{-1}\ yr^{-1}$
	1.5E-03	$g\ cm^{-2}\ yr^{-1}$

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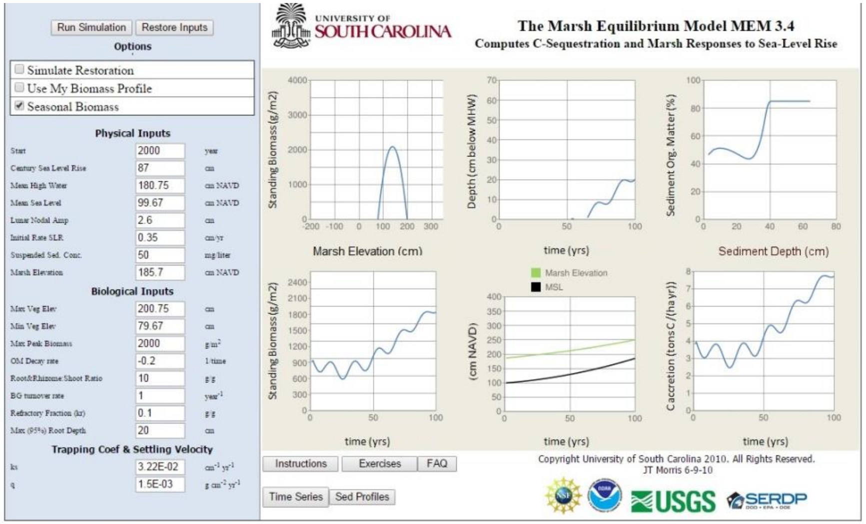
MEM v28 High Root:Shoot Ratio (5) and High Max Peak BM (2000)
C Seq= 181 g C/m2/yr Initial; C Seq= 381 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

Options

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	2000	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	10	g/g
BG turnover rate	1	$year^{-1}$
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	$cm^{-1}\ yr^{-1}$
q	1.5E-03	$g\ cm^{-2}\ yr^{-1}$

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MEM v29 Very High Root:Shoot Ratio (10) and High Max Peak BM (2000)
C Seq= 363 g C/m2/yr Initial; C Seq= 726 g C/m2/yr 100-Yr

ROOT AND RHIZOME: SHOOT RATIO (R:S Ratio)

Observations/Conclusions (slides 11-12:

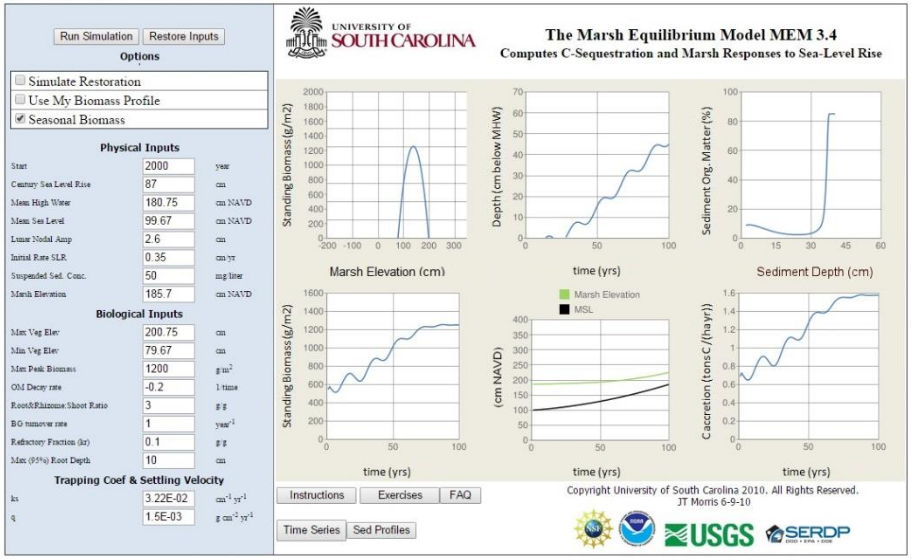
1) The Root:Shoot Ratio has high impact on carbon sequestration, and appears to be linear relationship whereby if double R:S ration (e.g. 5 to 10), nearly double carbon sequestion rate.

2) Model calibrated to R:S Ration of 3 which may be standard for typical California coastal tidal salt marsh dominant vegetation.

3) Above ground standing biomass can limit positive impact of high R:S Ratio (compare lower right graphs on slides 11 and 12).

4) Need to get this right in terms of quantifying Max Peak Biomass (consistent seasonal assays, representative sampling locations), and soil core samples how calculate SOM, bulk density and % carbon. Errors in these two inputs will have high impact on carbon sequestration rates projected.

5) Ideal salt marsh restoration scenario has high peak biomass above ground, and high Root: Shoot Ratio below ground, and high turnover rate (see slide 14).



☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

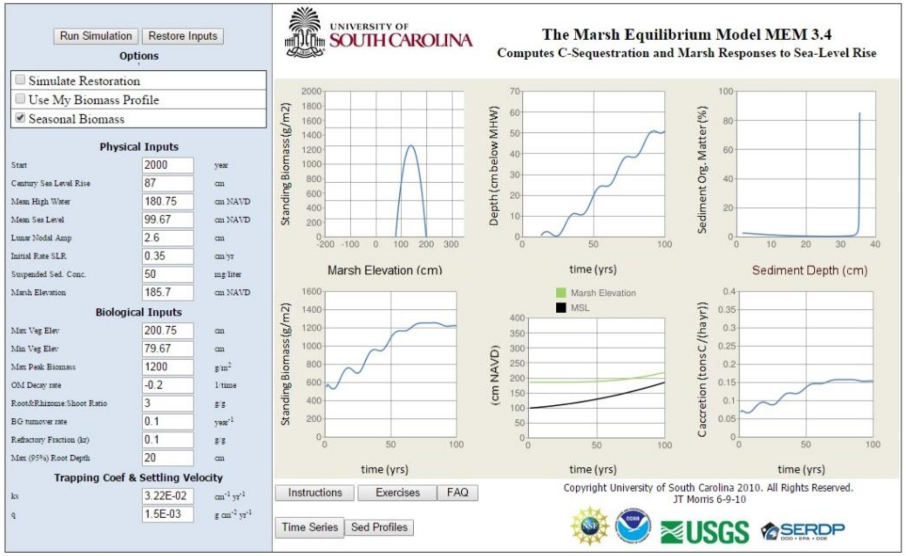
Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m²
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year⁻¹
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm⁻¹ yr⁻¹
q	1.5E-03	g cm⁻² yr⁻¹

MEM v1 Baseline inputs for Arcata salt marsh with Std BG Turnover Rate (1)
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

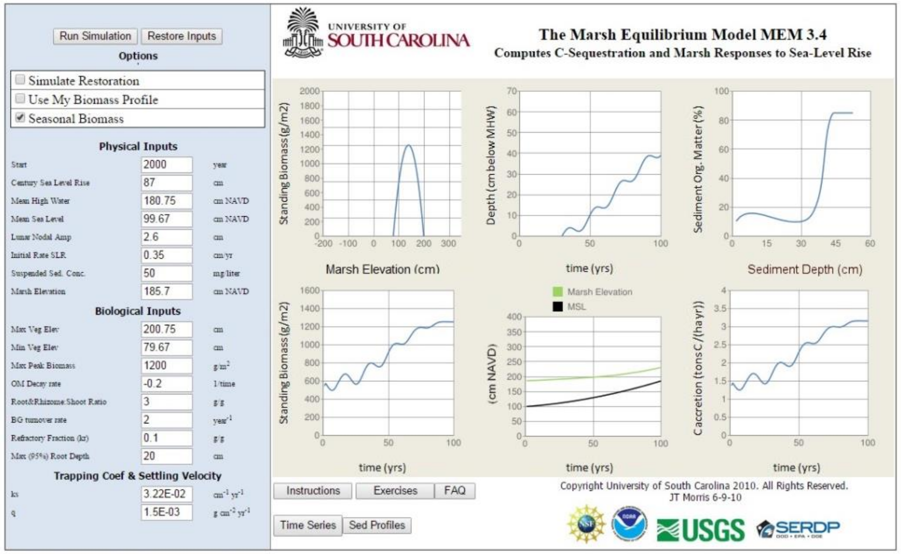
Biological Inputs

Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m²
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	0.1	year⁻¹
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm⁻¹ yr⁻¹
q	1.5E-03	g cm⁻² yr⁻¹

MEM v30 Low BG Turnover Rate (0.1)
C Seq= 6 g C/m2/yr Initial; C Seq= 14 g C/m2/yr 100-Yr



☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs

Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD

Biological Inputs

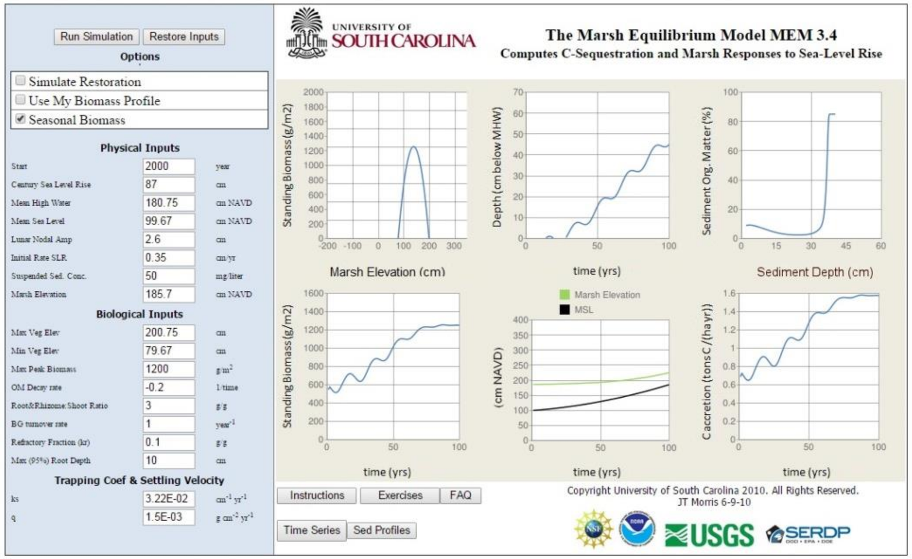
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m²
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	2	year⁻¹
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	20	cm

Trapping Coef & Settling Velocity

ks	3.22E-02	cm⁻¹ yr⁻¹
q	1.5E-03	g cm⁻² yr⁻¹

MEM v31 High BG Turnover Rate (2)
C Seq= 136 g C/m2/yr Initial; C Seq= 281 g C/m2/yr 100-Yr

Conclusion: With these parameter inputs, Belowground turnover rate has high impact on Carbon seq.
If rate is decreased 10X, carbon seq'd is decreased 10X.
If rate is doubled, carbon seq'd is doubled.



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	10	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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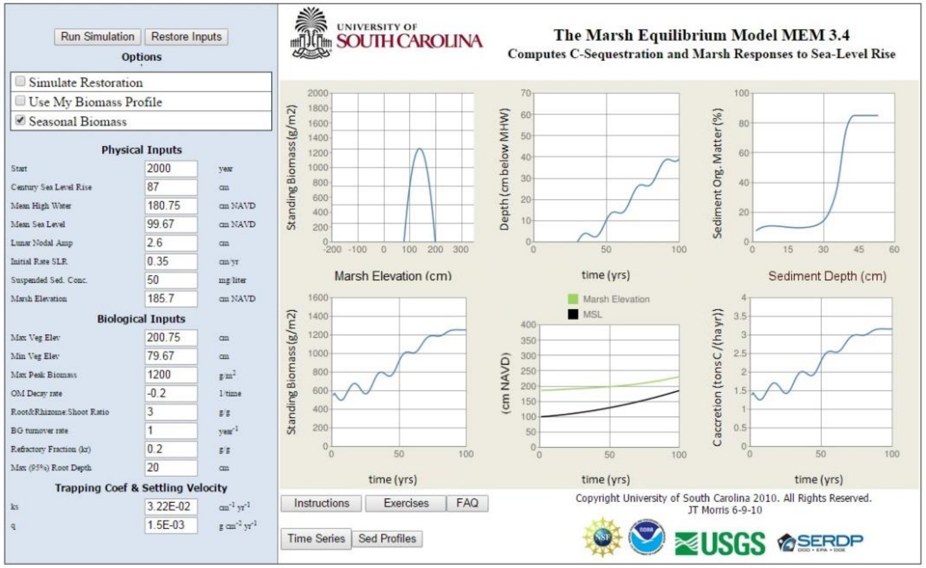
MEM v1 Baseline inputs for Arcata salt marsh with Std Refractory Fxn (0.1)
C Seq= 64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.2	g/g
Max (95%) Root Depth	20	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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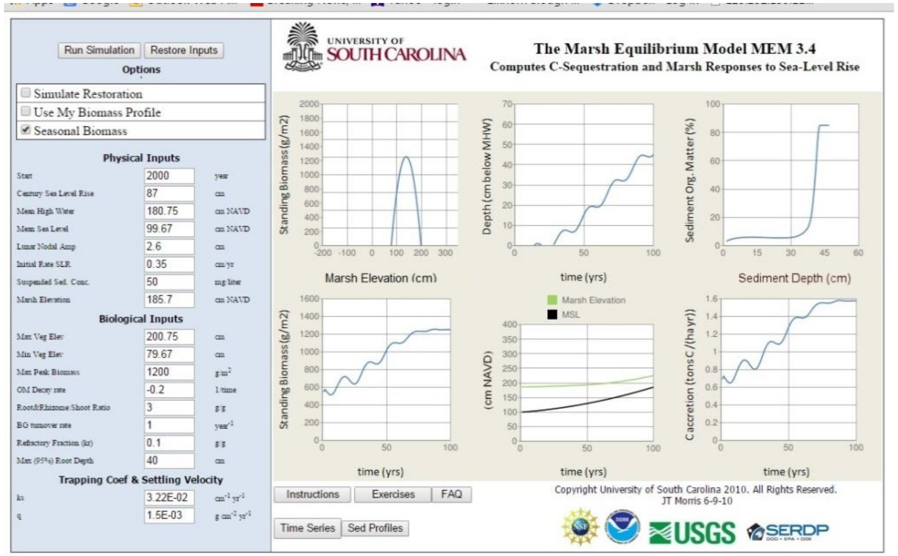
MEM v32 Higher Refractory Fraction (0.2 = 20%)
C Seq= 136 g C/m2/yr Initial; C Seq= 290 g C/m2/yr 100-Yr



The Marsh Equilibrium Model MEM 3.4
Computes C-Sequestration and Marsh Responses to Sea-Level Rise

☐ Simulate Restoration
☐ Use My Biomass Profile
☑ Seasonal Biomass

Physical Inputs		
Start	2000	year
Century Sea Level Rise	87	cm
Mean High Water	180.75	cm NAVD
Mean Sea Level	99.67	cm NAVD
Lunar Nodal Amp	2.6	cm
Initial Rate SLR	0.35	cm/yr
Suspended Sed. Conc.	50	mg/liter
Marsh Elevation	185.7	cm NAVD
Biological Inputs		
Max Veg Elev	200.75	cm
Min Veg Elev	79.67	cm
Max Peak Biomass	1200	g/m^2
OM Decay rate	-0.2	1/time
Root&Rhizome:Shoot Ratio	3	g/g
BG turnover rate	1	year^{-1}
Refractory Fraction (kr)	0.1	g/g
Max (95%) Root Depth	40	cm
Trapping Coef & Settling Velocity		
ks	3.22E-02	cm^{-1} yr^{-1}
q	1.5E-03	g cm^{-2} yr^{-1}

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MEM v33 High max root depth (40 cm vs 20 cm baseline)
C Seq=64 g C/m2/yr Initial; C Seq= 145 g C/m2/yr 100-Yr

Conclusions: With these parameter inputs,
Refractory Fraction has high impact on C seq.
If double refractory fraction to 0.2 (20%), then get
4x increase in C-seq.

In contrast, max root depth has little impact.
Doubling mas root depth to 40 cm yield same
carbon sequestered.

Table A: HSU Spring 2015 Wetland Soils Class Humboldt Bay Soil Carbon Study

Vegetation Type	Soil	Thickness	OSU	BD	Total carbon	Samples	OSU-HSU
	Depth (cm)	(cm)	Carbon %	(g/cm3)	(g/cm2)	#	R-squared
Mowed Tidal Marsh	0 to 12	12	15	0.8	1.44	2	All=0.12
	12 to 20	8	10	1.1	0.88	3	
	20 to 30	10	4	1.4	0.56	7	
Pickleweed (Resto)	0 to 20	20	17	1.1	3.74	3	All=0.37
	0 to 12	12	5	1.3	0.78	5	A=0.44
	12 to 40	28	9	1.6	4.03	2	
Saltgrass (Resto)	0 to 20	20	2	1.7	1.36	4	All=0.99
	20 to 50	30	1	1.8	0.54	1	
Spartina (Resto)	0 to 15	15	15	1.1	2.48	2	All=0.97
	15 to 30	15	7	1.1	1.16	2	
	30 to 50	20	6	1.1	1.32	2	
Algal mat (Resto)	0 to 8	8	11	1	0.88	3	All=0.15
	8 to 20	12	6	1.5	1.08	2	
Grazed Pasture	0 to 10	10	15	1.1	1.65	1	All=0.34
	0 to 12	12	7	1.1	0.92	30	
	12 to 30	18	2	1.6	0.6	11	
Pasture	0 to 5	5	27	1.1	1.49	1	All=0.03
	0 to 10	10	10	1.1	1.1	2	
	10 to 30	20	2	1.6	0.64	11	
Non-Grazed Pasture	0 to 15	15	8	1.1	1.32	8	All=0.04
Carex	0 to 30	30	9	1.1	2.97	3	All-A=0.51
Balsamroot	0 to 45	45	10	1.1	4.95	2	All-B=0.74
	45 to 60	15	11	1.1	1.82	1	
Tufted Hairgrass	0 to 10	10	3	1.7	0.51	3	All=0.33
	10 to 40	30	2	2	1.2	3	
Rush	0 to 8	8	13	1.1	1.14	3	All=0.03
	8 to 25	17	2	1.6	0.54	3	
Cattail and Willows	0 to 12	12	3	2	0.72	7	All=0.8
	12 to 30	18	1	1.9	0.34	3	
FAC non-native	0 to 12	12	2	2	0.48	3	All=0.48
	12 to 30	18	3	1.8	0.97	3	

Table B: HSU Spring 2015 Wetland Soils Class Humboldt Bay Soil Carbon Study
Joe Seney

Land Type	Soil	Thickness	Soil Carbon	BD	Total carbon
	Depth	(cm)	(%)	(g/cm3	(g/cm2)
Tidal Marsh	0 to 20	20	20	0.8	3.2
	20 to 40	20	15	1.1	3.3
	40 to 50	10	5	1.3	0.65
Tidal Marsh Summary	0 to 50	50	15	1.02	7.15
Pasture	0 to 5	5	8	1.1	0.44
	5 to 15	10	5	1.3	0.65
	15 to 50	35	2	1.6	1.12
Pasture Summary	0 to 50	50	3.2	1.5	2.21