Marsh Equilibrium Theory & Poplar Island: Implications for Carbon Sequestration

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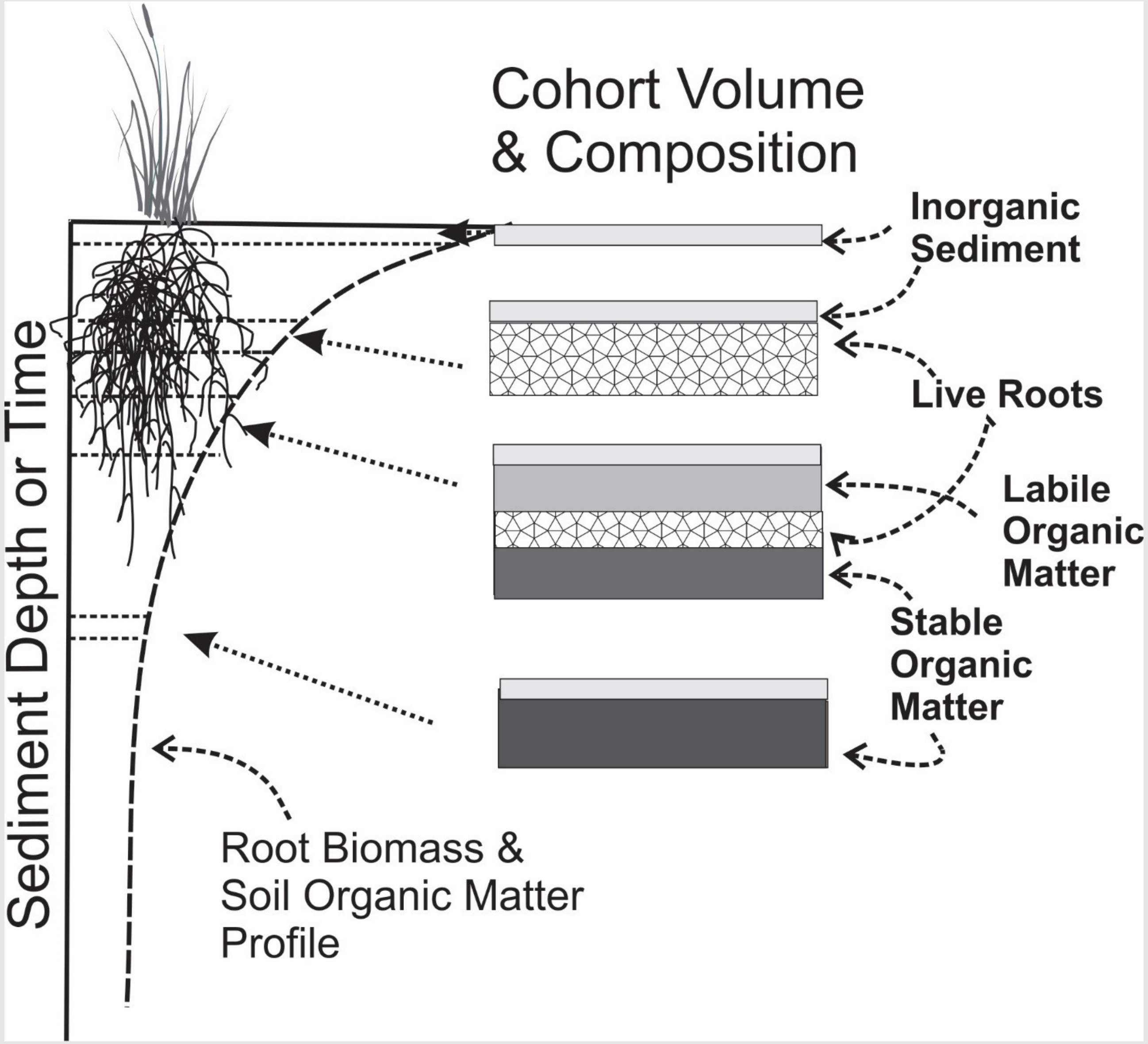
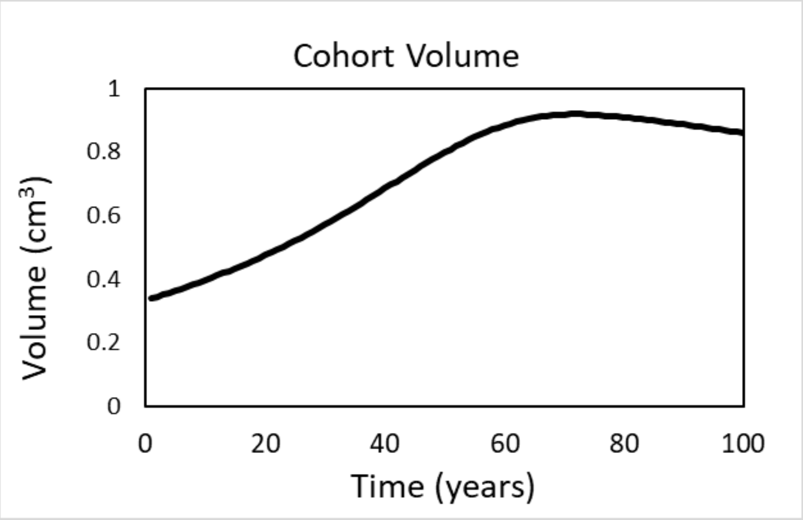
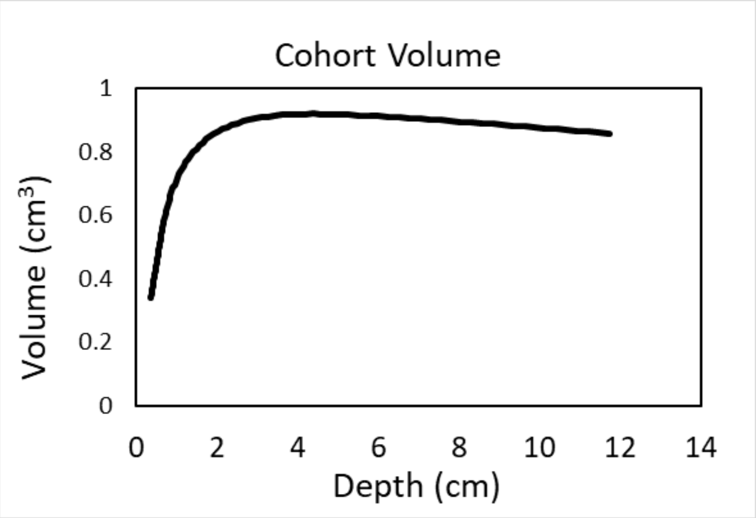
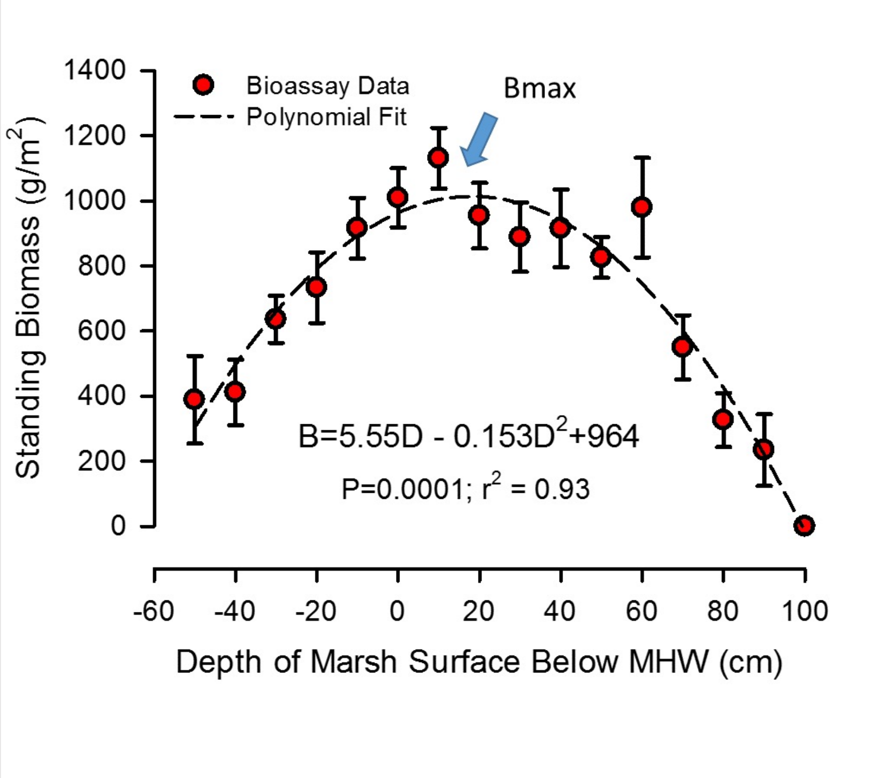






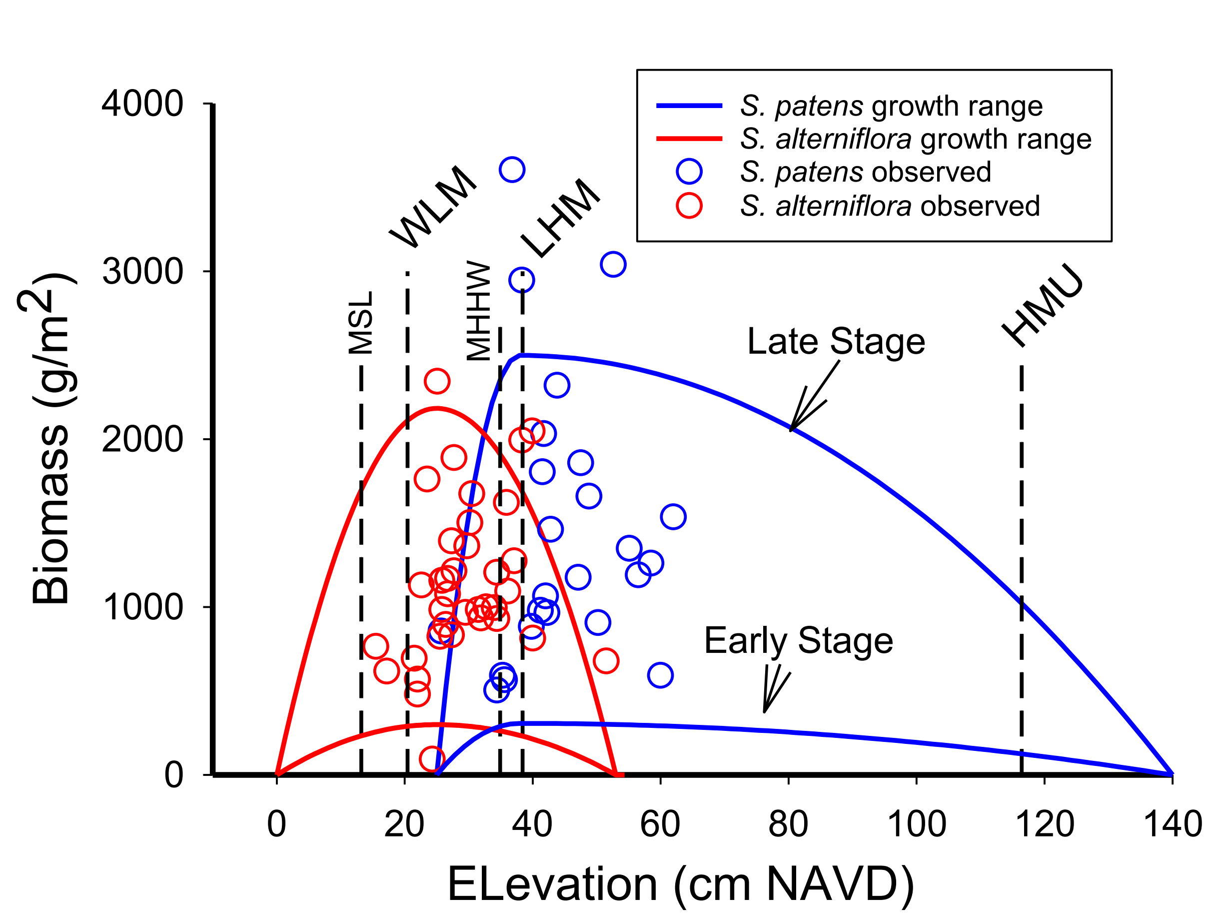
Morris, J.T. and W.B. Bowden. 1986. A mechanistic, numerical model of sedimentation, mineralization, and decomposition for marsh sediments. Soil. Sci. Soc. Amer. J. 50:96-105

Organic production is a function of relative marsh elevation. This determines the organic inputs to the cohorts.



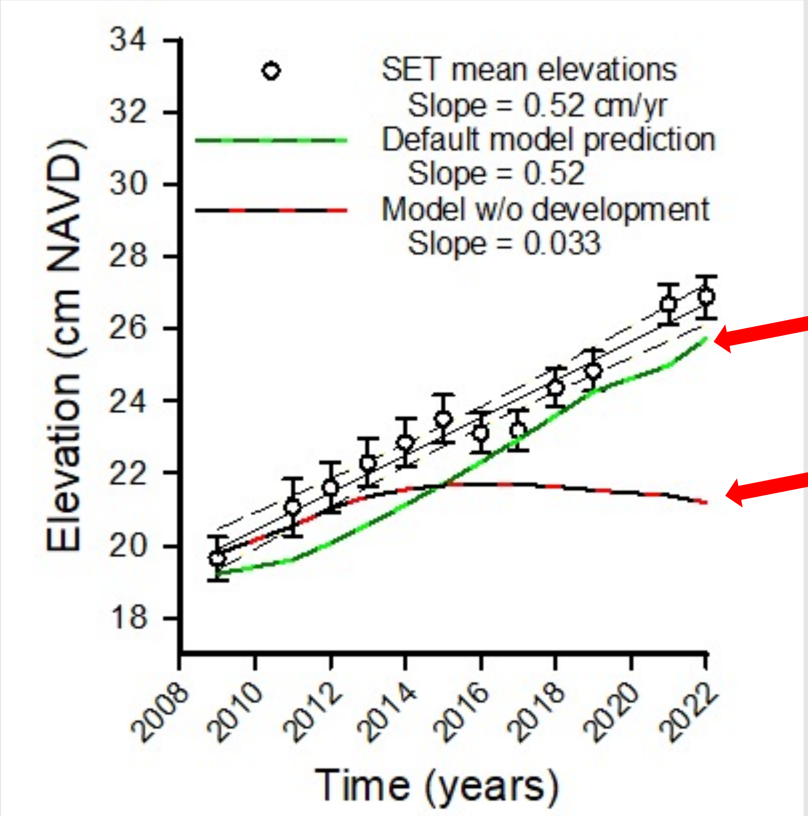
End-of-season (2008) total aboveground standing biomass (mean ±1 SE) of *S. alterniflora* from marsh organs at North Inlet as a function of depth below MHW.

These are the vertical growth profiles of *S. alterniflora* in the low marsh and *S. patens* in the high marsh at Poplar Island. The dashed lines are community boundaries (WLM, LHM, and HMU).



A hindcast of CWEM

Figure 8. Model hindcasts of marsh elevation with and without development. Mean elevation (± 1 SE) of all LM plots (o), excluding outlying 2010 and 2020, simulated elevations of a developing marsh (———), and a mature marsh (———), both started at 13.3 cm rel MSL. The high vertical accretion rates at Poplar Island are a consequence of marsh development.



There is a growth premium for a developing marsh

Not for a mature marsh

Forecasted Marsh Elevation, Constant SLR

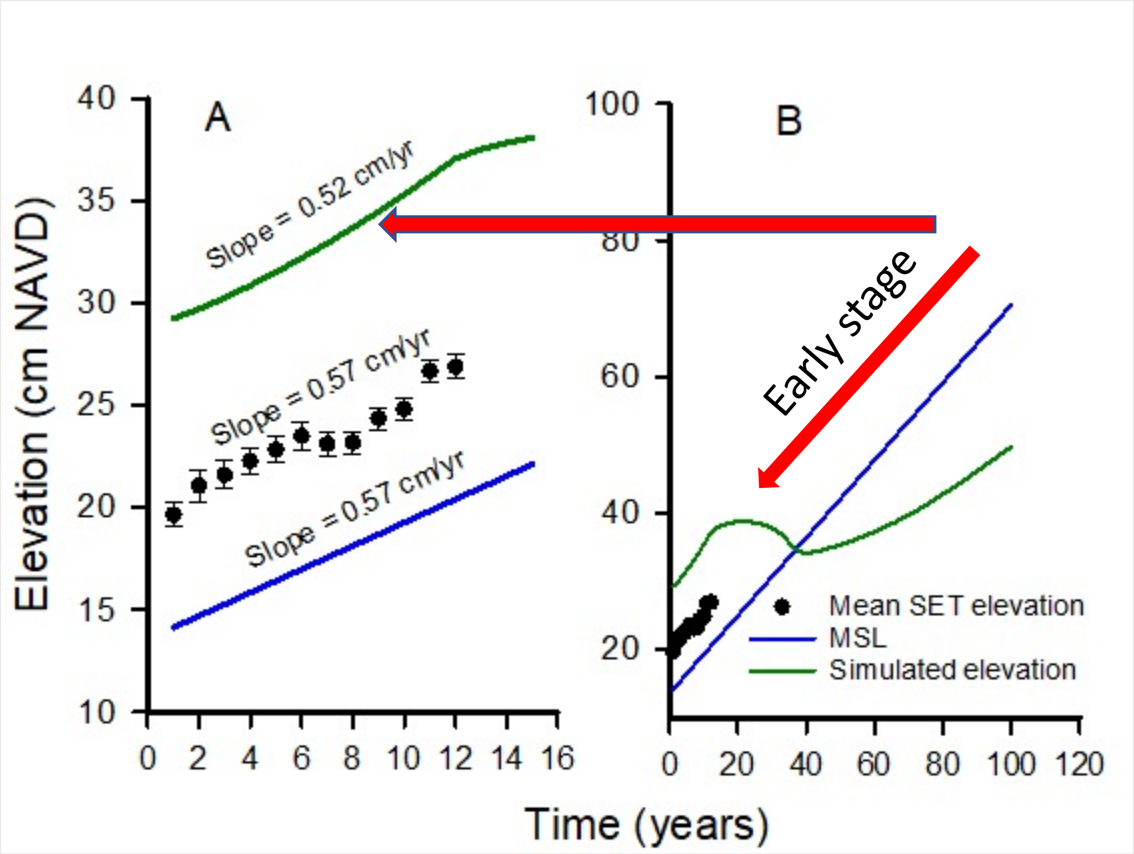


Figure 4. Time series of observed SET elevations (o), predicted elevations (—), and sea level forecasts (—). The first 15 yr are shown in A for a simulation in which the rate of sea-level rise was held constant at the current rate, 0.57 cm/yr, while in B the 100-yr simulation at constant SLR is shown.

Effect of Elevation

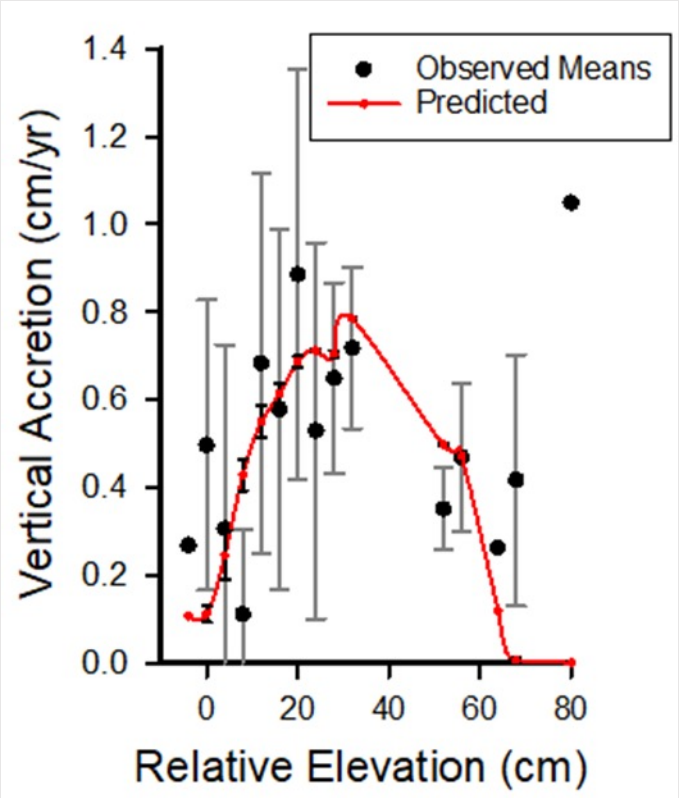


Figure 3. Observed accretion rates (•) and predicted rates vs mean SET plot elevation. Predictions (——) were generated from the static model.

Biomass Trajectories vs Relative Elevation Starting at LM Elevation (left) and HM elevation (right)

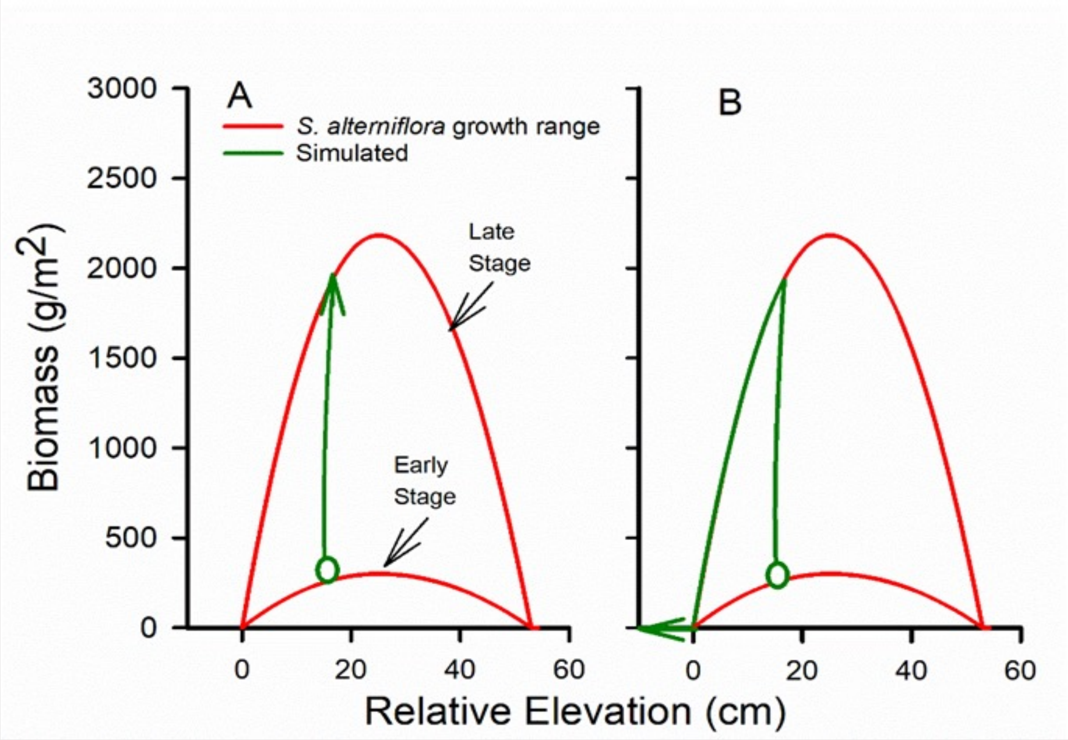


Fig. 5 shows the assumed vertical biomass profiles of the early and mature S. alterniflora low marsh community (—), and the predicted biomass trajectories (—) over the first 15 years (A) and 100 years (B). Initial elevation was 16.4 cm rel MSL (the midpoint between WLM and LHM), and CSLR was 57 cm (SLR 5.7 cm/yr).

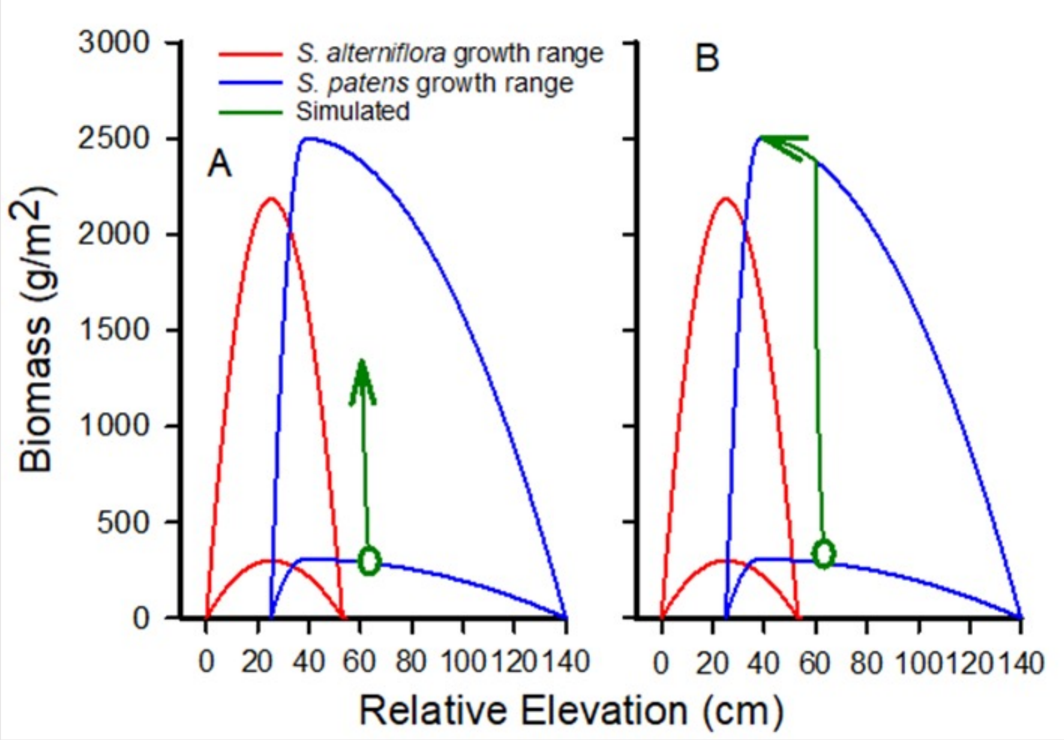


Fig. 7 shows the assumed vertical biomass profiles of the early and final mature S. alterniflora low marsh communities (—) and patens high marsh communities (—), and the predicted biomass trajectories (—) over the first 15 years (A) and 100 years (B). Initial restored marsh elevation was 64.5 cm rel MSL and the RSLR was 5.7mm/yr and constant.

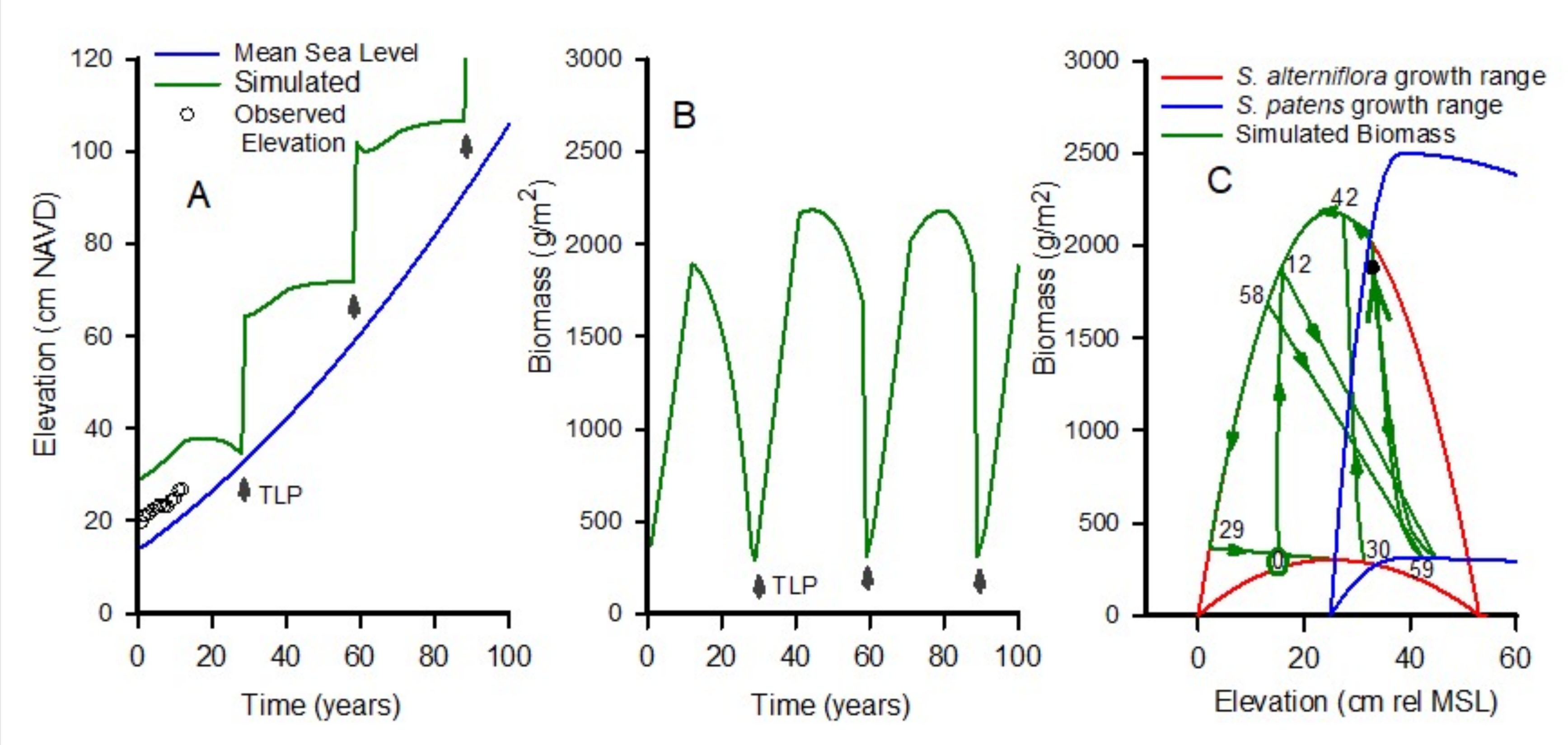


Figure 9. Results of thin layer placement (TLP) simulation. Results of simulated TLPs of 30 cm in years 30, 60, and 90 show in A the observed elevations (o), MSL rising to 91.4 cm NAVD in a century (—), and the predicted marsh elevation (—). The predicted standing biomass is shown in B. In C, biomass is plotted against relative elevation. Also in C are the early and late growth ranges of *S. alterniflora* (—) and *S. patens* (—). The biomass trajectory begins at 16.4 cm rel MSL at year 0.

SLR and initial elevation affect carbon sequestration

The greatest volume of SOM, C-inventory, and greatest sequestration rate was found when the simulation was started as high marsh and lower SLR. The lowest volume of SOM, C-inventory, and lowest sequestration rate was found when the simulation was started as low marsh and high SLR.

Table 3. Summary results showing vertical gains and carbon inventories and sequestration for experiments in which parameters were permutated: projected centenary SLR (CSLR) (cm) the starting marsh elevation (cm rel MSL), and thin layer placement (TLP). The TLP applications were 15 cm in years 30, 60, and 90. The measured LOI profile (see Fig. 5) was used to populate time zero cohorts, which numbered 60. Soil organic matter initially occupied 16.5 cm of vertical space of a total of 24.4 cm sediment depth and contained 7.72 kg C m^{-2}.

Parameters	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
CSLR (cm/century)	57	91.4	91.4	91.4	57
Zo (cm rel MSL)	16.4	16.4	16.4	64.5	64.5
TLP	No	No	Yes	No	No
Final EOS metrics: organic matter volume and inventory in all cohorts					
SOM volume (cm per cm^2)	20.7	19.4	22.3	36.7	50.8
Total EOS C inventory (kg C m^{-2})	9.67	9.08	10.41	17.18	23.77
Refractory C sequestration over 100 yr (g C m^{-2} yr^{-1})	25.7	19.7	33.9	100.6	117.1
total depth (cm)	44.8	54.5	84.5	45.2	58.4

Effects of TLP on Carbon Sequestration in the low marsh

The greatest inventory of carbon and sequestration rate were obtained at the present and constant rate of SLR, 5 mm/yr. The greatest carbon inventory was obtained with TLP applications of 15 cm every 30 years. The greatest rate of carbon sequestration was obtained with 5 TLP applications of 15 cm every 15 yrs beginning in year 30. The do nothing scenarios are not sustainable at the current or any higher rate of SLR. At the higher rate of SLR, the lowest volume of TLP applications (3 applications x 15 cm) also is not sustainable.

Table 4. Numerical tests of the effects of different TLP applications: none or starting 30 yr from the start and repeated 3 or 5 times at 15 or 30-yr intervals during the following century at applied depths of 15 or 30 cm. Selected maxima are shaded ochre; conditions resulting in non-sustainable (not surviving at year 100) solutions are shaded pale blue.

SLR	TLP applications (cm)	Elev. (yr 100)	SOM vol (cm^3)	Sediment depth (cm)	EOS C inventory (kg C m^{-2})	Seq. Rate (g C m^{-2} y^{r-1})	Sustainable (active at yr 100)
57 cm	none	49.8	20.7	44.8	9.7	25.7	no
	3 x 15 = 45 cm	100.5	42.8	95.8	20.0	139.3	yes
	5 x 15 = 75	123.0	35.4	118	16.5	156.5	yes
	3 x 30 = 90	136.1	33.5	131.1	15.7	108	yes
91.4 cm	none	59.4	19.4	54.4	9.1	19.7	no
	3 x 15 = 45 cm	89.5	22.3	84.5	10.4	33.9	no
	5 x 15 = 75	127.8	39.9	122.8	18.6	150	yes
	3 x 30 = 90	138.6	35.7	133.6	16.7	91.7	yes

What have we learned?

1. A marsh acts like a subterranean forest. Its rhizomes are like the branches in a tree canopy, its "stems and shoots" are leaves.
2. Marshes grow biomass for at least a decade after first establishing, much like forest succession. The buildout of belowground biomass adds volume and results in higher vertical accretion rates. When the marsh matures, the accretion rate slows.
3. The vertical accretion rate and carbon sequestration are proportional to net ecosystem production (gross photosynthesis minus total respiration).
4. The rate of carbon sequestration is sensitive to the trajectory of mean sea level. Higher rates of SLR lead to lower rates of sequestration and lower carbon inventories.
5. Thin layer placement of sediment (TLP) is a strategy that can increase the resilience of a marsh and increase carbon sequestration. There is an optimum TLP sequence; it depends of the trajectory of mean sea level.