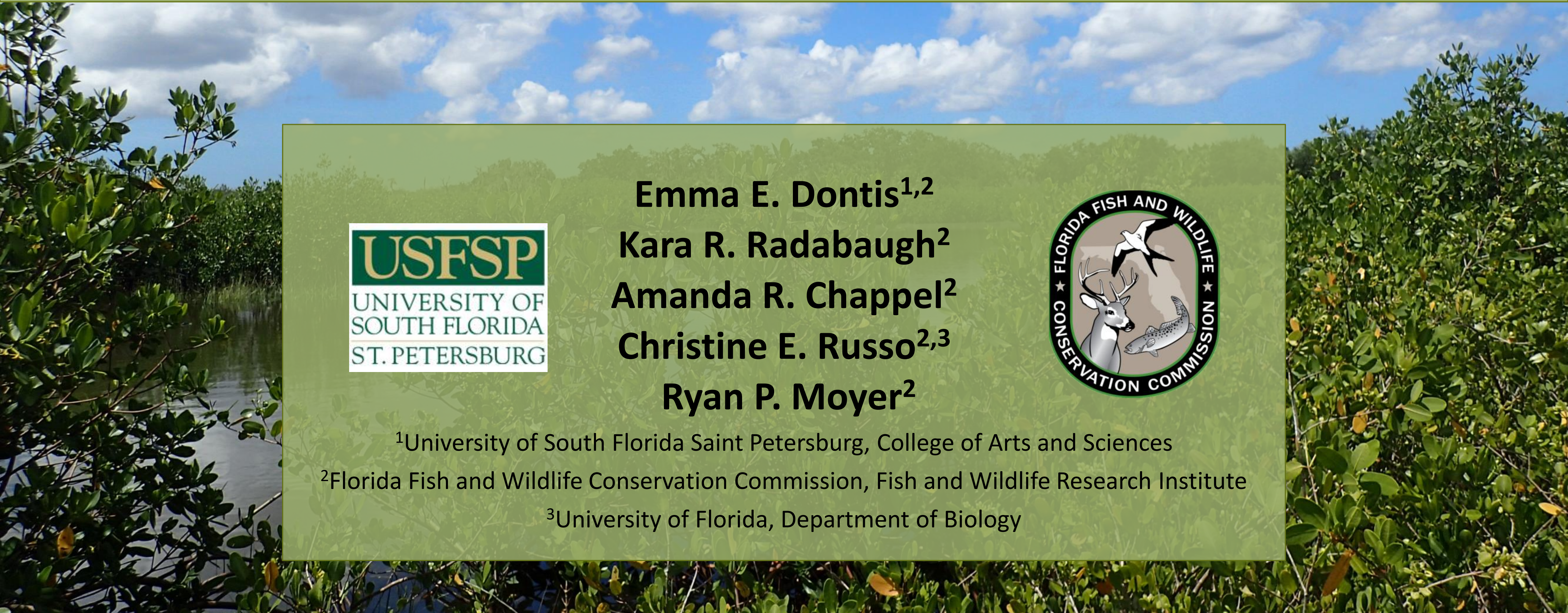
Carbon Storage Increases with Site Age as Created Salt Marshes Transition to Mangrove Forests in Tampa Bay, Florida (USA)



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Coastal Wetlands in Tampa Bay

8100 – 8300 hectares of remaining and restored coastal wetland habitat

Mangroves
76%

Salt marshes
22%

Salt barrens
2%

(Robison et al. 2010; SWFWMD 2012)

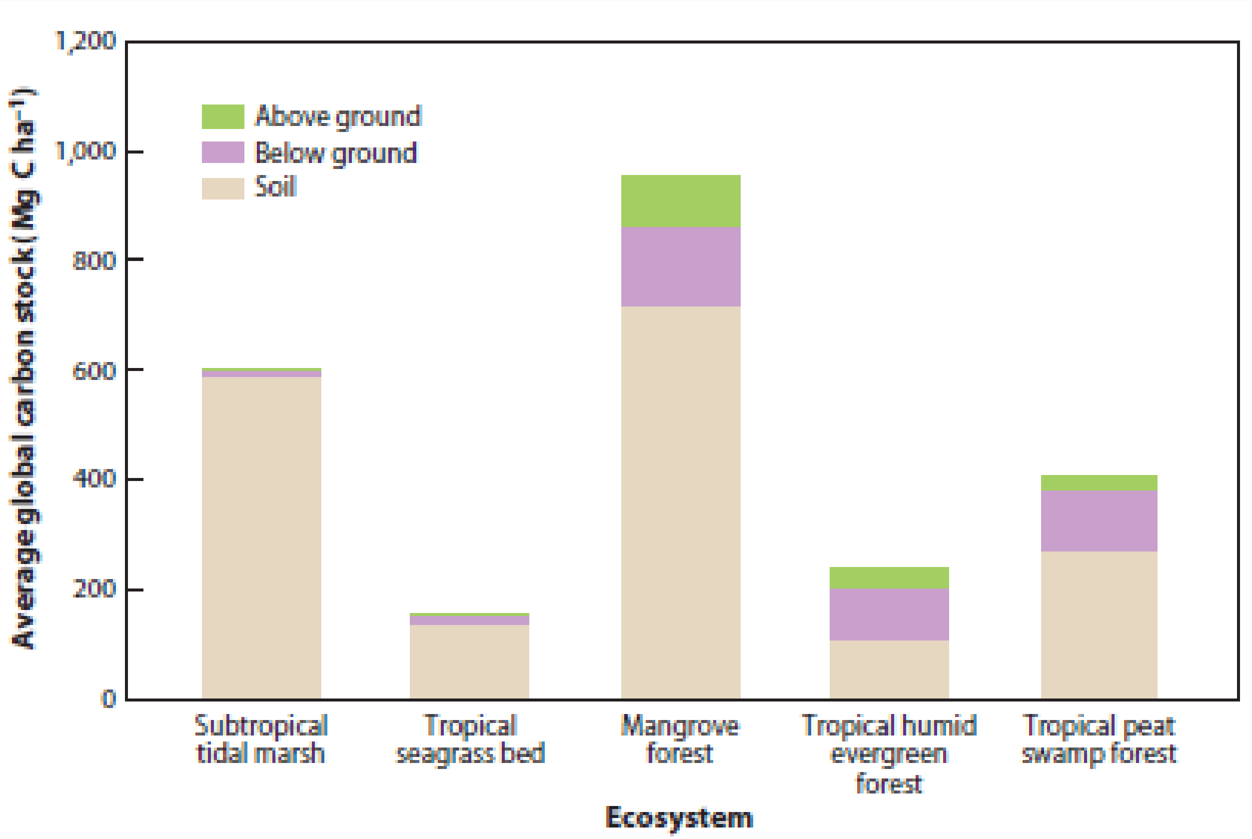
Created Coastal Wetlands

- Initially planted with *Spartina* spp.

- Naturally transition into mangrove forests – *Spartina* traps propagules and promotes colonization (Lewis 2005; Stevens et al. 2006)

- In 2004, 20% of the total cover of salt marsh and salt barren were observed to be transitioning to mangrove forests (Robison et al. 2010)

Rationale



(Alongi 2014)

- Blue carbon ecosystems provide many ecosystem services
- Store more organic carbon (OC) on a per-unit-area basis than terrestrial ecosystems (Nellemann et al. 2009; Donato et al. 2011)
- Global motivation for coastal wetland creation/restoration is linked to the possibility for carbon credits as a result of their carbon sequestration capability (Siikamäki et al. 2012; Mack et al. 2014; Sheehan et al. 2019)
- Few studies directly quantify the rates of carbon burial in created coastal wetlands

Objectives

- Examine ecosystem characteristics of created coastal wetlands
- Quantify carbon storage at ten created coastal wetlands of varying ages in Tampa Bay
- Calculate the rate of carbon accumulation across a 26-year chronosequence

Estuaries and Coasts
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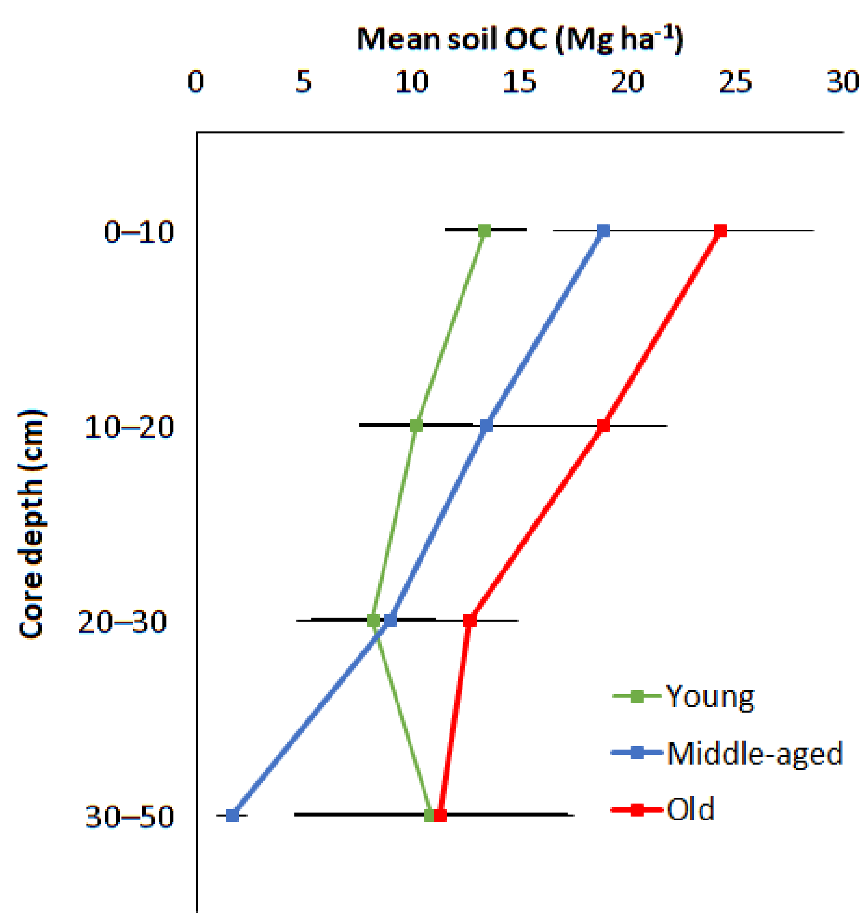
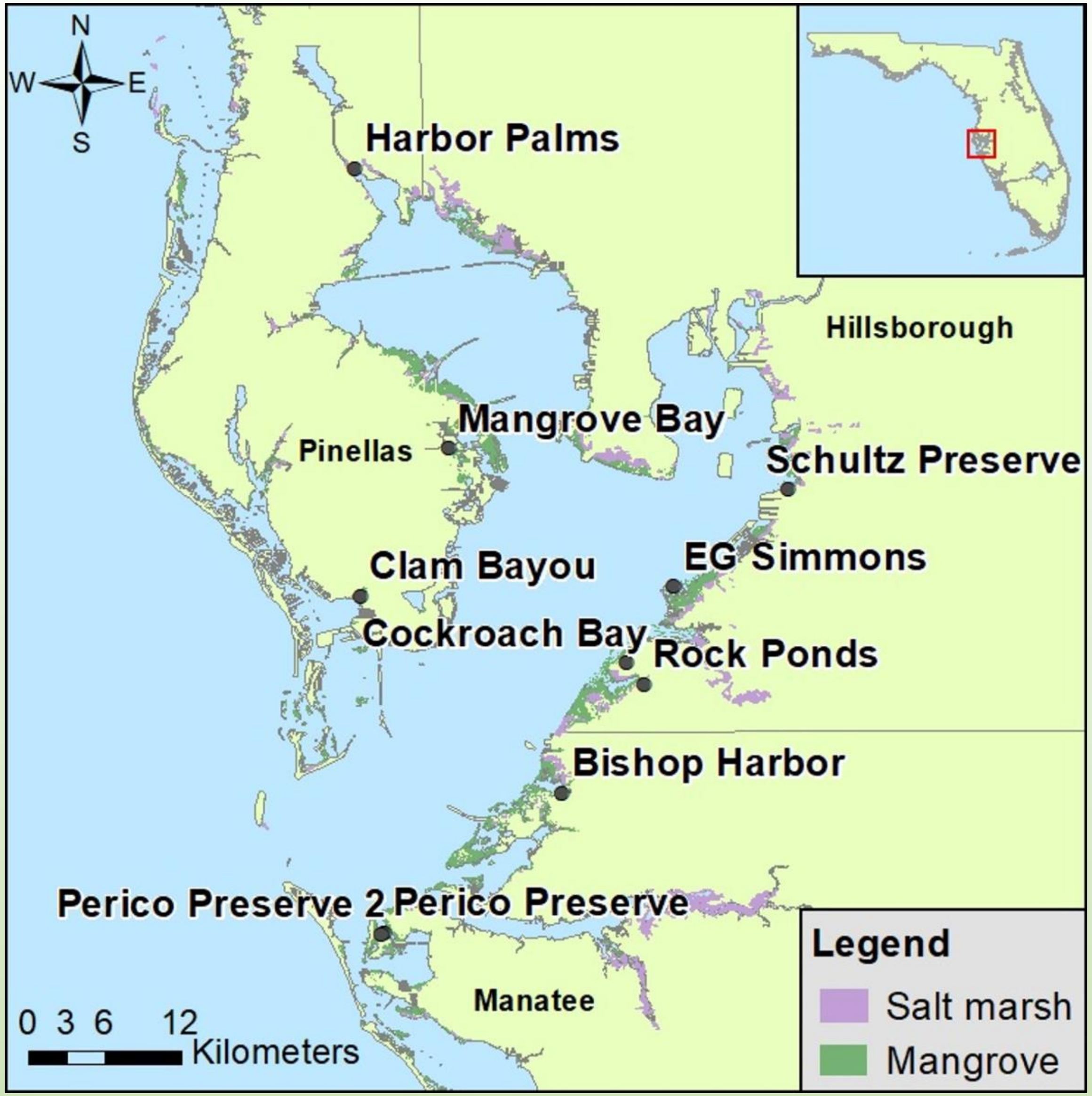
Results: Soil Characteristics

Site age category	Dry bulk density (g cm^{-3})	Soil OC %	Sand %	Mud %	Gravel and plant fragment %
Young	1.1 ± 0.0	1.1 ± 0.2	94.4 ± 3.1	0.8 ± 0.3	4.8 ± 2.9
Middle-aged	1.1 ± 0.0	2.4 ± 0.6	94.6 ± 0.7	1.3 ± 0.4	4.0 ± 0.9
Old	0.8 ± 0.1	6.0 ± 2.3	85.3 ± 4.0	3.4 ± 1.1	11.3 ± 4.8



Belowground carbon constituted the greatest carbon pool (59.4% of the total OC stock) across the ten sites

Study Location

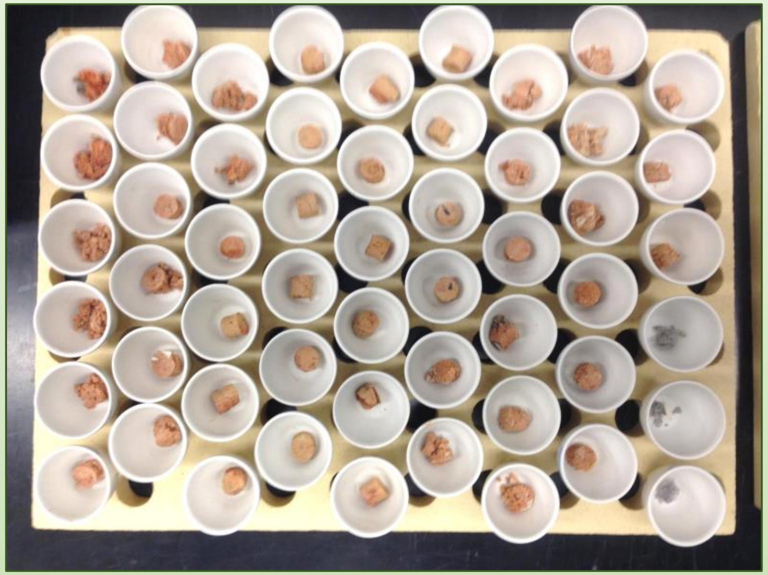


Site	Year planted	Age classification	Habitat classification
EG Simmons (EG)	1990	Old	Mangrove
Mangrove Bay (MB)	1991	Old	Mangrove
Harbor Palms (HP)	1994	Old	Mangrove
Schultz Preserve (SP)	2004	Middle-aged	Transitional
Cockroach Bay (CR)	2005	Middle-aged	Transitional
Bishop Harbor (BH)	2009	Middle-aged	Transitional
Clam Bayou (CB)	2011	Middle-aged	Transitional
Perico Preserve (PP)	2013	Young	Salt marsh
Rock Ponds (RP)	2016	Young	Salt marsh
Perico Preserve 2 (PP2)	2016	Young	Salt marsh

Methods: Field Sampling

- Transects ranging 8–68 m across the ecological zones at each site
- Six quadrats randomly placed within 20-m wide belt along transect
- Measured vegetation within and around plot
- Soil cores ranging 13–50 cm collected outside each plot
- Top 5-cm soil samples collected for grain size analysis

Methods: Soil Laboratory Analyses



- Grain size of soil samples using sieve shakers
- Loss-on-ignition (LOI) staged combustion process to determine organic matter content of soil cores
- LOI converted to OC using local equation for created coastal wetlands (Radabaugh et al. 2018):

$$\%OC = \%LOI550 \times 0.53587$$

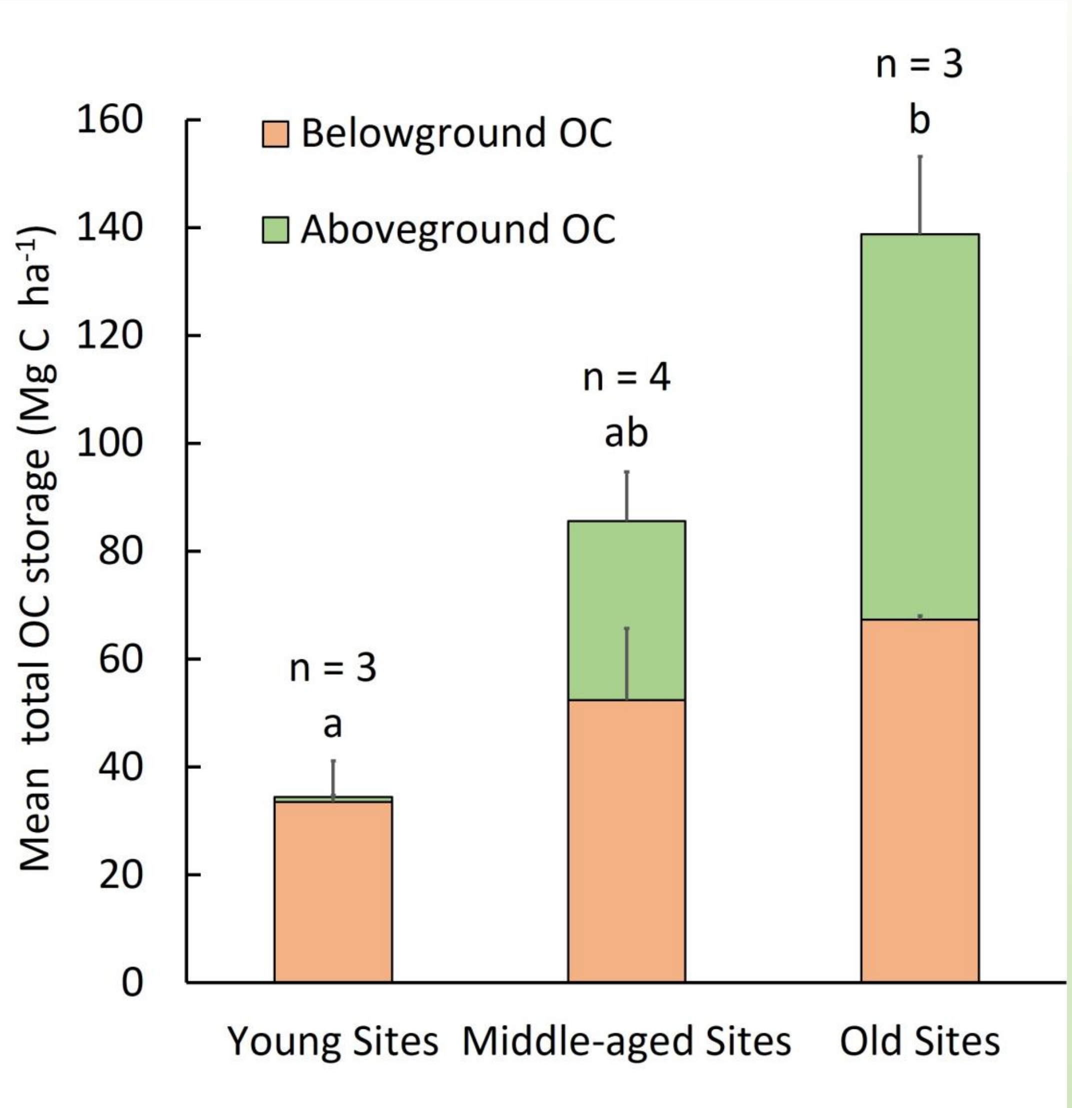
where $\%\text{LOI550} = 100 \times \frac{dry\ mass - 550\ mass}{dry\ mass}$

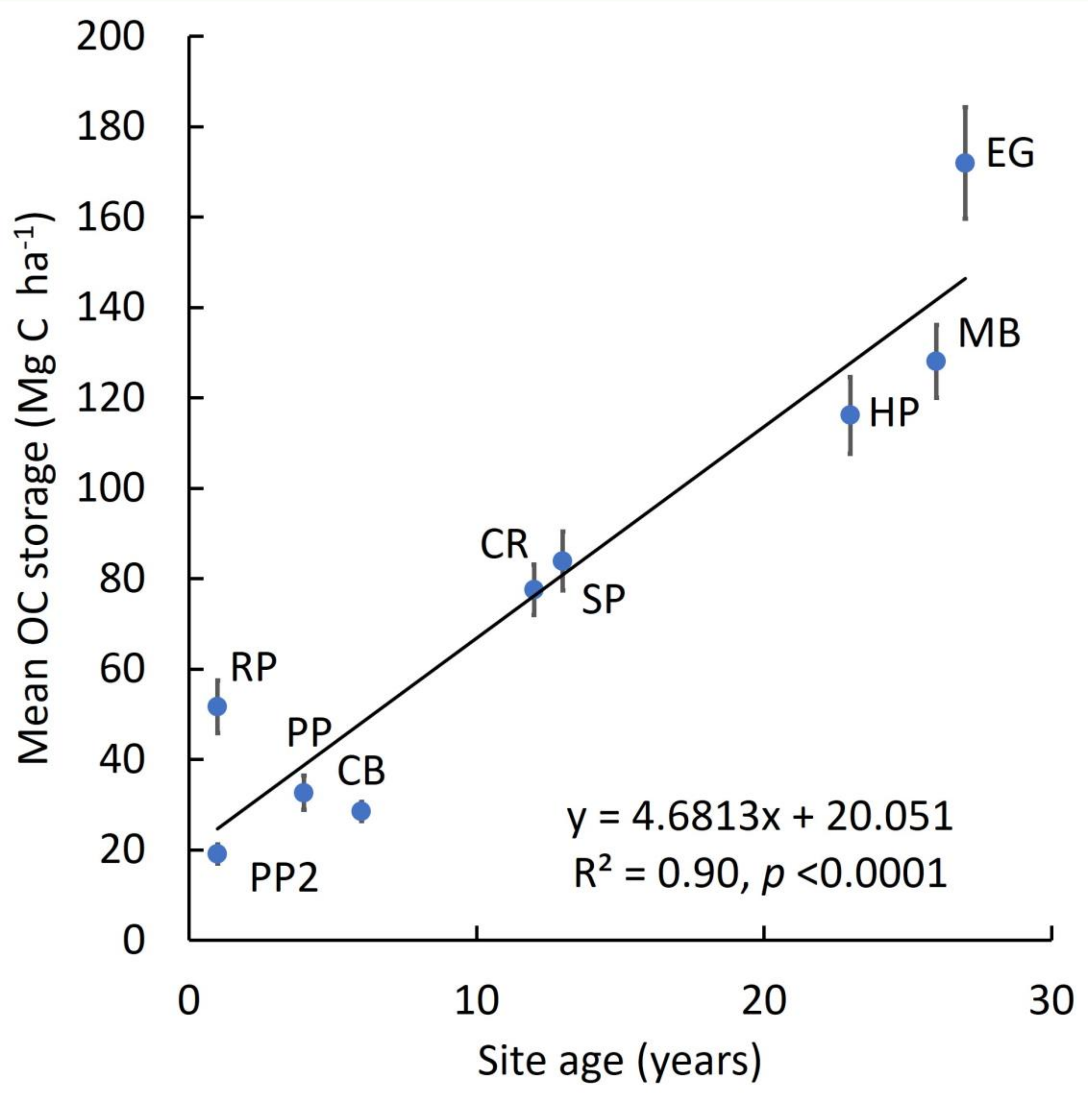
Methods: Allometric Equations

- Allometric equations used to estimate vegetative biomass
- Biomass multiplied by a carbon conversion value to calculate aboveground OC stocks
- Carbon stored in soil and vegetation added to determine total OC storage at each site

Species	Common Name	Allometric Equation	R^2 value	Number of specimens	Height range (cm)
Cyperus esculentus[a]	Yellow nutsedge	$\ln(b) = 2.0813\ln(ht) - 6.4251$	0.86	25	14.0–129.0
Cyperus rotundus[a]	Purple nutsedge	$\ln(b) = 0.8651\ln(ht) - 4.4539$	0.53	61	1.5–28.0
Dichanthelium sp.[b]	Rosette grass	$\ln(b) = 1.8048\ln(ht) - 6.1295$	0.71	43	2.5–14.0
Distichlis spicata[b]	Saltgrass	$\ln(b) = 1.2539\ln(ht) - 5.6389$	0.79	52	6.0–36.0
Panicum sp.[b]	Switchgrass	$\ln(b) = 1.1238\ln(ht) - 5.1012$	0.64	53	6.0-39.0
A. germinans pneumatophore[b]	Black mangrove pneumatophore	$b = 0.3008e^{0.0768(ht)}$	0.86	53	5.0–47.0
S. terebinthifolia seedling[b]	Brazilian pepper seedling	$b = 0.0007(ht) - 8 \times 10^{-5}$	0.37	63	3.5–7.5
Scoparia dulcis[a]	Licorice weed	$\ln(b) = 2.0325\ln(ht) - 7.1049$	0.82	37	12.0–74.5
Seutera angustifolia[a]	Gulf coast swallowwort	$b = 0.0041(ht) - 0.0773$	0.76	40	6.0–152.0
Spartina bakeri[b]	Sand cordgrass	$\ln(b) = 1.928\ln(ht) - 7.8901$	0.89	44	21.0-89.0
Suaeda linearis[a]	Annual seepweed	$\ln(b) = 2.3682\ln(ht) - 7.8355$	0.81	27	12.0–91.0
Triglochin striata[b]	Arrowgrass	$\ln(b) = 1.4639\ln(ht) - 6.5292$	0.68	44	4.0–23.0
Vigna luteola[a]	Hairypod cowpea	$\ln(b) = 1.6325\ln(ht) - 6.9224$	0.89	17	16.0–202.0

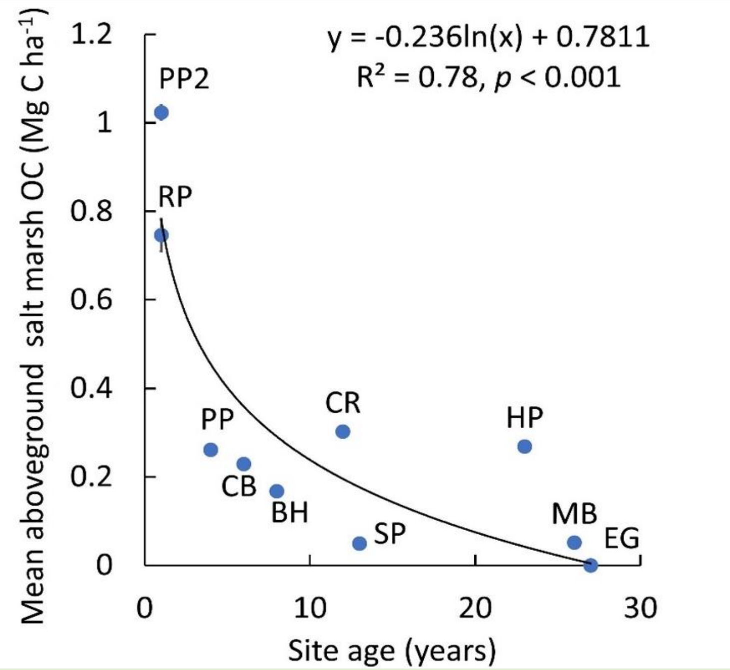
Results: Total Carbon Stocks

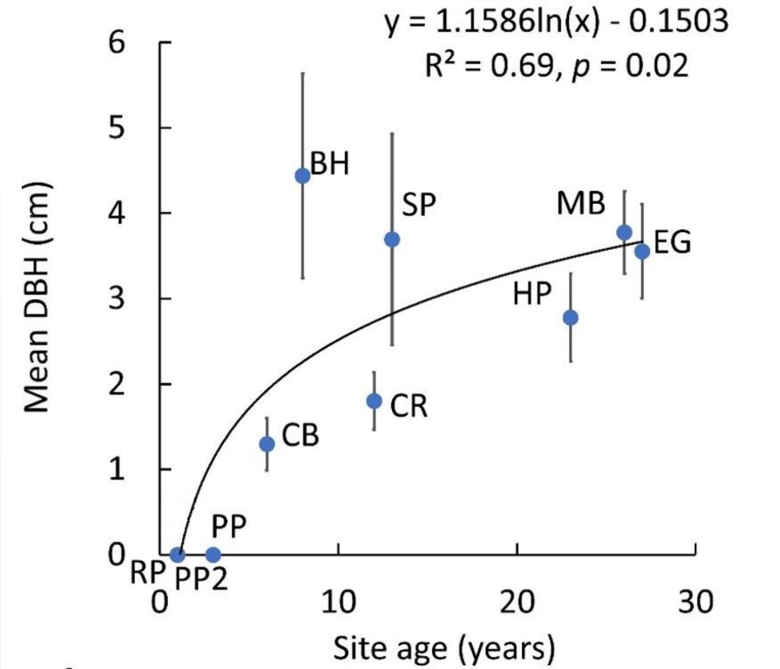


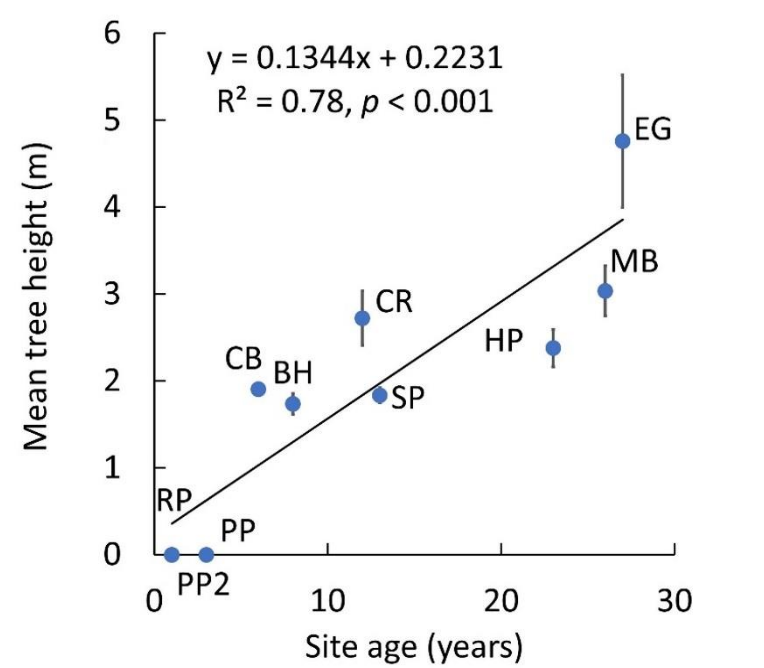


Rate of OC accumulation in created coastal wetlands in Tampa Bay: 4.7 Mg C ha^{-1} $year^{-1}$

Results: Vegetative Characteristics







- **Young sites (1–5 years old):** salt marsh vegetation dominant, some scrubs/seedlings, no trees
- **Middle-aged sites (6–13 years old):** abundance of mangrove scrubs and seedlings, small trees, still support salt marsh vegetation
- **Old sites (≥ 14 years old):** tall trees, scarce salt marsh vegetation

Aboveground carbon stock contributions:

Mangrove trees: 78.2%

Non-mangrove trees: 12.4%

Mangrove scrubs and seedlings: 5.4%

Salt marsh vegetation: < 1%

Standing dead wood: 3%

Carbon Storage and Sequestration

- Aboveground OC stocks were needed to drive the significant difference among site age classes

- Longer time required for soil characteristics to reflect aboveground vegetative characteristics (Osland et al. 2012)

Rate of total carbon accumulation:
4.7 Mg C ha^{-1} $year^{-1}$

Belowground carbon accumulation rate:
1.57 Mg C ha^{-1} $year^{-1}$

- Advantage: true age of sites known

- Other studies utilized radiometric dating
  - Age error increases as time scale increases, but shorter timescales may overestimate

- Carbon accumulation rate over 26-year chronosequence likely an overestimation

Comparison to Natural Sites

- Created and restored wetlands do not follow predicted or linear trajectories of growth and succession (Zedler and Callaway 1999)

- Vegetation type progresses simultaneously with site age

- No differences between OC stocks of created sites in this study and natural sites (Doughty et al. 2016; Yando et al. 2016; Radabaugh et al. 2018)

- Higher OC stocks in natural Tampa Bay marshes dominated by *Juncus roemerianus* (Radabaugh et al. 2018)

Implications for Restoration

- Ecosystem development after site creation may alter species composition, abundance, and distribution of coastal habitats (Robison et al. 2016; Gabler et al. 2017)

- Mangrove expansion may pose a threat to salt marsh-dependent organisms

- Mangroves have greater resilience to storms and yield greater OC storage than marshes

Conclusion

- Mangrove expansion into Tampa Bay estuary expected to continue, while salt marsh cover decreases
- Mangrove expansion and future seagrass recovery are estimated to increase greenhouse gas sequestration potential in Tampa Bay by 2.1 ± 0.5 million tonnes CO2e by 2100 (Sherwood et al. 2019)

- Given global and regional carbon sequestration rates, conservation and restoration/creation of mangroves is economically viable (e.g., Mack et al. 2014; Vázquez-González et al. 2017)

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