TECHNICAL REPORT

Carbon Burial in Natural and Created Fringing Marshes of Northwest Florida (Choctawhatchee to Pensacola Bay)

SERDP Project RC-2245

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14. ABSTRACT
The Living Shoreline approach to erosion control is growing in popularity, and the cumulative impacts of living shorelines in terms of carbon burial have the potential to be substantial, but a better understanding of carbon sequestration rates in these sites is necessary to estimate their real carbon impacts. The research effort described in this report is an attempt to quantify burial rates and standing stocks of carbon in several natural and created (aged 3 to 28 years) marshes in Northwest Florida from eastern Choctawhatchee Bay to Pensacola Bay. The goal of this work was to provide data that are useful in determining the carbon sequestration value of the sites in question and to contribute to a broader understanding of the geographical variability of carbon storage rates in both natural and create marshes. This report was prepared as part of the *Defense Coastal/Estuarine Research Project (DCERP)*, a 10-year integrated monitoring and research project designed to support ecosystem-based management on coastal military installation in the Southeastern United States.

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Acronyms

°C	degree Celsius
BB	Bruce's Beach
CAR	carbon accumulation rate
cm	centimeter
DCERP	Defense Coastal/Estuarine Research Program
DoD	U.S. Department of Defense
g	gram
$g\ C\ m^{-2}$	grams of carbon per square meter
$g\ C\ m^{-2}\ yr^{-1}$	grams of carbon per square meter per year
$g\ cm^{-3}$	grams per cubic centimeter
$g\ m^{-2}$	grams per square meter
$g\ m^{-2}\ yr^{-1}$	Grams per square meter per year
GS	Green Shores
HB	Hogtown Bayou
HF	Hurlburt Field
LO	Live Oak
m^2	square meter
$m^{-2}\ yr^{-1}$	square meter per year
Nat	natural marsh
PC	polycarbonate
RB	Rocky Bayou
SERDP	Strategic Environmental Research and Development Program
SR	Santa Rosa
UTM	Universal Transverse Mercator

Background

Living Shorelines are an erosion control strategy that involves the use of natural vegetation either alone, or in combination with structural elements such as oyster reefs and rock sills (Currin et al., 2010). In addition to providing erosion control, living shorelines deliver many of the same ecosystem services attributed to natural marsh shorelines, including water quality mediation and habitat provision. Similar to natural marshes, living shorelines can also serve as sinks for atmospheric carbon (Davis et al., 2015).

Coastal wetlands, and salt marshes in particular, are among the most efficient carbon storing ecosystems on the planet (Mcleod et al., 2011). The high rates of carbon sequestration stem from naturally high biomass production and the fact that much of the biomass produced by salt marsh plants is in the form of roots and rhizomes. Because these tissues are buried in waterlogged soils with low oxygen availability, they tend to decompose slowly. As a result, the carbon in these tissues can remain buried in the soil for centuries to millennia. Furthermore, carbon-rich marsh sediments tend to expand in volume over time as flooding tidal waters deposit particles onto the marsh surface, resulting in elevation gain. The longer a marsh is inundated during a tidal cycle, the more particles are deposited, and the greater the elevation gain (Bricker-Urso et al., 1989). This feedback between flooding and elevation gain allows marshes to maintain intertidal elevations despite rising sea levels. This feedback also results in a slow, but steady increase in sediment volume and is one of the reasons why these marsh systems are so valuable in terms of carbon sequestration.

Published rates of carbon sequestration in natural marshes vary across an order of magnitude (Chmura et al., 2003; Ouyang and Lee, 2014). This variability is driven in part by geographical differences in plant productivity, salinity, and tide range, among other factors. Furthermore, it is unclear how well carbon sequestration rates of created living shoreline marshes are represented by published values from natural marshes. The Living Shoreline approach to erosion control is growing in popularity, and the cumulative impacts of living shorelines in terms of carbon burial have the potential to be substantial, but a better understanding of carbon sequestration rates in these sites is necessary to estimate their real carbon impacts. The research effort described in this report is an attempt to quantify burial rates and standing stocks of carbon in several natural and created (aged 3 to 28 years) marshes in Northwest Florida from eastern Choctawhatchee Bay to Pensacola Bay. The goal of this work was to provide data that are useful in determining the carbon sequestration value of the sites in question and to contribute to a broader understanding of the geographical variability of carbon storage rates in both natural and created marshes.

Methods

The sites chosen for this study were identified in collaboration with partners from the Choctawhatchee Basin Alliance, Hurlburt Field (part of Eglin Air Force Base), the U.S. Fish and Wildlife Service, and the Florida Department of Environmental Protection and include *Spartina alterniflora* and *Juncus* spp.–dominated marshes, as well as sites with mixed species assemblages. We targeted created shoreline marshes with the goal of including sites that spanned a wide range of ages. Where possible, a natural marsh was selected in proximity to created marsh sites to serve as a reference site. Sites spanned the region of the downtown Pensacola waterfront to eastern Choctawhatchee Bay (**Figure 1**). All sampling efforts were conducted from May 16 through 18, 2016.

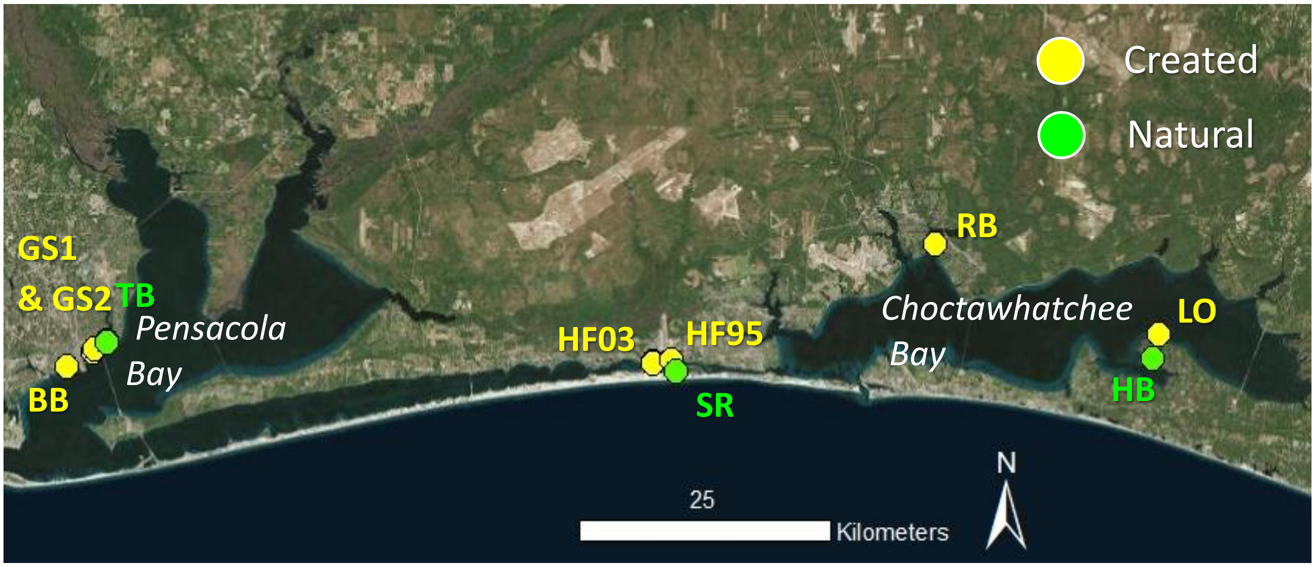

Figure 1. Created and natural sample sites. One to three cores were collected from each site.
Note: BB = Bruce's Beach; GS = Green Shores; HB = Hogtown Bayou; HF = Hurlburt Field; LO = Live Oak; RB = Rocky Bayou; SR = Santa Rosa; Texar Bayou = TB.

Created marshes studied at Eglin Air Force Base in Florida represented a variety of construction techniques. At both of the youngest (aged between 1 and 3 years) marsh sites studied, Live Oak (LO) and Rocky Bayou (RB), a shore-parallel oyster sill and reef was installed to abate wave energy and slow the recession of an eroding natural marsh edge. The two sites near Hurlburt Field (HF03 [aged 13 years] and HF95 [aged 21 years]) were created as mitigation for Base construction projects. At both sites, sand fill was used to achieve intertidal elevations. The fill was planted with wetland vegetation, and a rock sill was installed at the seaward edge. In Pensacola Bay, the two Green Shores sites (GS1 [aged 13 years] and GS2 [aged 8 years]) were part of a large habitat restoration project along the urban shoreline of downtown Pensacola that involved the creation of more than 15 acres of salt marsh. The project involved filling intertidal regions to appropriate elevations, and then planting with marsh vegetation. These sites are protected from wave attack by a series of offshore breakwaters. Because there is an expanse of open water between the breakwaters and the marsh islands, these sites have been dynamic over time, relative to the sill-lined marshes of Hurlburt Field. The oldest site, Bruce's Beach (BB; aged 28 years), is a tidal flat that was planted with *Spartina alterniflora* and surrounded by a large sill that extends well above mean sea level. In 2011, a channel was dug around the back of the marsh that clearly modified tidal exchange, but most of the site has remained colonized by *S. alterniflora* since its creation.

At each site, we used a Russian peat corer (**Figure 2**) to extract cores deep enough to represent the full depth of marsh sediments. Coring locations within each created marsh were determined in consultation with our local partners to target areas that were most likely to have been vegetated for the full life of the marsh. At natural marshes, cores were collected from areas visually determined to have representative coverage of above-ground biomass for the site.

Figure 2. (Left) Using Russian peat corer. (Above) Marsh sediment collected with Russian peat corer at Eglin Air Force Base in Florida.

This core was collected at the 13-year-old Hurlburt Field 2003 (HF03) site. Notice that surface sediments are dark and organic; deep sections of the core are sandy.

In addition to the peat cores, we collected several shallow (approximately 30 cm) cores using a polycarbonate (PC) core tube. PC core samples were collected at sites with organic, unconsolidated surface sediments, which is where we were concerned that water draining out of the Russian peat corer may carry a measurable amount of organic matter with it. This issue did not seem to be a problem in deeper sections where sediments were either very sandy (in created marshes) or consisted of firm peat (in natural sites). When constructing core profiles at these sites, PC core samples were used to represent the top 20–30 cm where available. Specific coring locations and depths are provided in **Table 1.**

Table 1. Core Locations, Depths and Dominant Vegetation in Salt Marshes at Eglin Air Force Base in Florida.

Site	Site Age	Site Code	Core No.	Peat Core Depth (cm)	PC Core Depth (cm)	Latitude	Longitude	Dominant Marsh Vegetation Type
Rocky Bayou	1	RB	10	72	—	3373645	553057	*J. roemerianus*
Live Oak 2	3	LO	7	60	29	3366430	572323	*S. alterniflora*
Green Shore 2	8	GS2	12	30	22	3364689	480772	*S. alterniflora*
Hurlburt 2003	13	HF03	1	32	—	3363948	528858	*S. alterniflora*
Hurlburt 2003	13	HF03	2	33	16	3363894	528937	*S. alterniflora*
Green Shore 1	13	GS1	13	60	29	3364970	480938	*J. roemerianus*
Green Shore 1	13	GS1	14	39	22	3364961	480934	*S. alterniflora*
Hurlburt 1995	21	HF95	3	61	28	3364101	530433	*J. roemerianus*
Hurlburt 1995	21	HF95	4	77	—	3364086	530429	*S. alterniflora*
Hurlburt 1995	21	HF95	5	76	26.5	3364078	530422	*S. alt + Ruppia*
Bruce's Beach	28	BB	11	50	27	3363511	478572	*S. alterniflora*
Santa Rosa	Nat	SR	6	66	—	3363214	530924	*S. alterniflora/ J. roemerianus*
Live Oak 2	Nat	LO	8	50	—	3366416	572321	*J. roemerianus*
Hogtown Bayou	Nat	HB	9	77.5	31	3364388	571744	*S. alterniflora*
Texar Bayou	Nat	TB	15	99	—	3365642	482073	*S. alterniflora*
Texar Bayou	Nat	TB	16	69	—	3365561	481974	*J. roemerianus*

Site age = time in years since marsh creation.

Nat = natural marsh (age unknown; geographic coordinates given in UTMs).

Note that multiple cores were obtained from several sites.

Figure 3. Dried 5-cm sections of marsh sediment cores collected at Eglin Air Force Base in Florida.

All cores were extruded in 5-cm increments and each 5-cm section was dried at 60°C for 48 hours (**Figure 3**). Dried sections were weighed, then homogenized, and a subsample was removed for elemental analysis. The remaining material was combusted at 450° C for 4 hours, and then re-weighed. Organic matter content was calculated from loss on ignition. The subsamples for elemental analysis were acidified with 1N hydrochloric acid (by dropwise addition until bubbling stopped) to remove carbonates, and then were re-dried at 60°C. Carbon content was determined with a Costech ECS 4010 elemental analyzer. In all, this sampling effort resulted in 196, 5-cm core sections.

Standing above-ground biomass was quantified at each sampling location by arbitrarily tossing a 0.0625-m^2 quadrat three times in the vicinity (within 5 m) of the coring site (**Figure 4**). All stems within the quadrat were counted and total stem lengths were measured for 10 (*Spartina alterniflora*) or 20 (*Juncus spp.*) random stems within each quadrat. Total standing biomass was estimated by using previously determined allometric relationships (Davis et al., 2015; Currin unpublished data).

Figure 4. Measuring above-ground marsh biomass.

Results

Sediment bulk density provides a proxy for the maturity of created marsh soils. The bulk density of pure sand (1.5–2.0 g cm^{-3}) is much greater than that of marsh peat (approximately 0.2 g cm^{-3}). Thus, as marshes planted in sand mature, they grow upward in elevation to keep pace with rising sea levels, and their sediment bulk density decreases due to the continual injection of below-ground biomass. As a result, elevation profiles in mature created marshes will show a trend of increasing bulk density with depth. This pattern is evident in the bulk density profile of Bruce's Beach (BB; **Figure 5**). The consistently elevated bulk density values below approximately 30 cm suggest that sediments in this depth range represent the initial sand into which the marsh was planted and that the bulk density of sediment greater than 30 cm decreases as a direct result of the presence of marsh vegetation. In contrast, the bulk density profile of the nearby natural marsh, Texar Bayou (TB), is much more uniform with depth, suggesting that this site has been vegetated by marsh

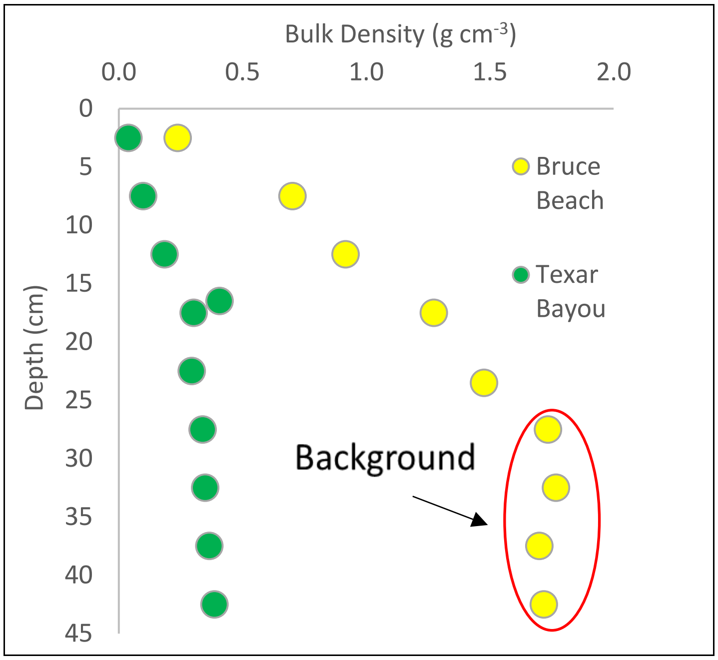

Figure 5. Example bulk density profiles from a natural (Texar Bayou [TB]) and created (Bruce's Beach [BB]) site at Eglin Air Force Base in Florida. The consistently high bulk density values in the red oval are indicative of the original substrate into which the marsh was established.

throughout the entire time captured by this core. We used the bulk density profiles at each created marsh to define the portion of the depth profile that is influenced by the presence of marsh. Values below this depth (e.g., 30 cm, in the case of Bruce's Beach [BB]) were considered to represent background conditions. For establishing the carbon accumulation rate of each created marsh, carbon that was present in these deeper layers was not counted. The average "background" carbon value was subtracted from the total carbon content of each of the core intervals above the background level.

Standing above-ground biomass ranged from 378 to 1,578 g m^{-2}, was similar among natural and created sites, and did not exhibit trends with created marsh age, dominant vegetation, or marsh type (natural versus created; **Figure 6**). Sediment carbon stocks (g m^{-2}) were calculated for each core by summing the carbon present in all 5-cm sections above the background depth, and then extrapolating to a square meter (**Table 2**). Carbon accumulation rates (g m^{-2} yr^{-1}) were calculated for created marshes by dividing carbon stock by site age (**Table 2**). The amount of time represented by depth profiles from natural sites is unknown and we are therefore unable to determine carbon accumulation rates for these sites.

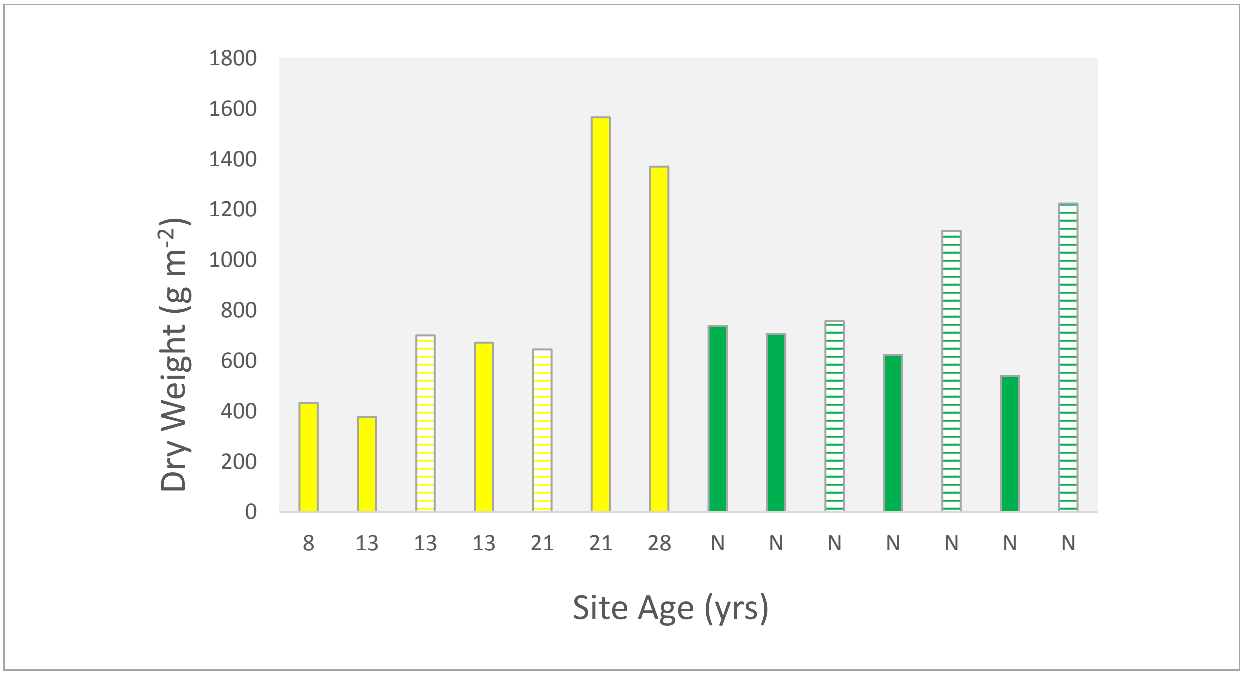

Figure 6. Above-ground standing biomass by marsh site age, marsh type, and species at Eglin Air Force Base in Florida.

Yellow = created marsh; green = natural marsh. Solid bars = *Spartina*; patterned bars = *Juncus*.

Table 2. Calculated Values of Total Carbon Stock, Carbon Accumulation Rate (CAR; for created marshes only) and Standing Above-Ground Biomass at the Time of Sampling

Site—Core No.	Carbon stock ($g\ m^{-2}$)	CAR ($g\ m^{-2}\ yr^{-1}$)	Above-ground Biomass ($g\ m^{-2}$)
Rocky Bayou—10	26,945	—	1,116
Live Oak 2—7	5,666	—	707
Green Shore 2—12	1,278	160	433
Hurlburt 2003—1	472	36	378
Hurlburt 2003—2	1,108	85	998
Green Shore 1—13	932	72	701
Green Shore 1—14	1,114	86	672
Hurlburt 1995—3	5,270	251	645
Hurlburt 1995—4	2,326	125	449
Hurlburt 1995—5	—	—	1,566
Bruce's Beach—11	3,971	142	1,371
Santa Rosa—6	15,063	—	—
Live Oak 2—8	8,635	—	758
Texar Bayou—15	3,709	—	540
Texar Bayou—16	18,923	—	1,224

The Live Oak (LO) and Rocky Bayou (RB) sites are unique among the created marshes in that they were "created" by stabilizing a receding marsh shoreline with an oyster sill. The area behind the sills has since started to accumulate sediment and has been recolonized with *S. alterniflora*; however, this is occurring on top of relict marsh sediment. At these sites, there is no clear "background" depth that can be used to establish baseline conditions. As a result, these sites are treated like natural marshes for this analysis.

Carbon accumulation rates ranged from a low of 36 to a high of 251 g m^{-2} yr^{-1}, and aside from particularly low values in the 13-year-old marshes (Hurlburt 2003 [HF03] and Green Shores 1 [GS1]), showed little change with site age (**Figure 7**). Carbon stocks increased with site age and, within the same site, were greater in *Juncus*– than *Spartina*–dominated cores (**Figures 8 and 9**).

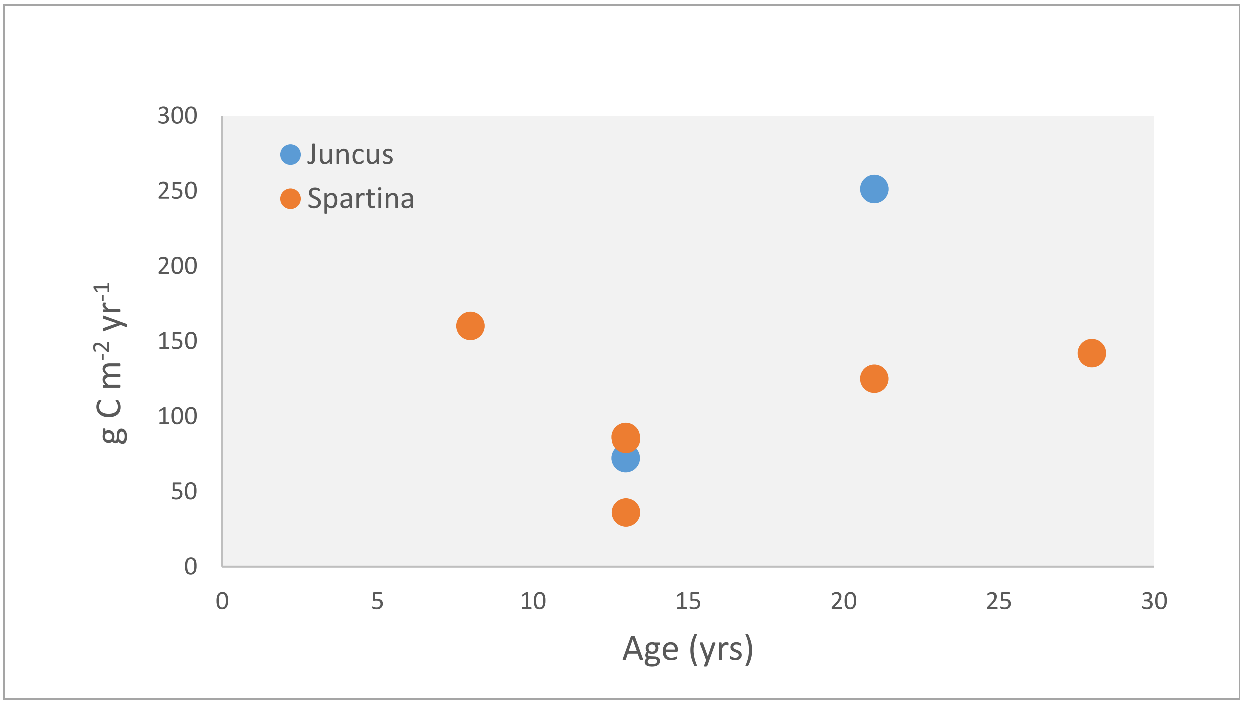

Figure 7. Carbon accumulation rates (in g C m^{-2} yr^{-1}) in created marshes by marsh age and species at Eglin Air Force Base in Florida.

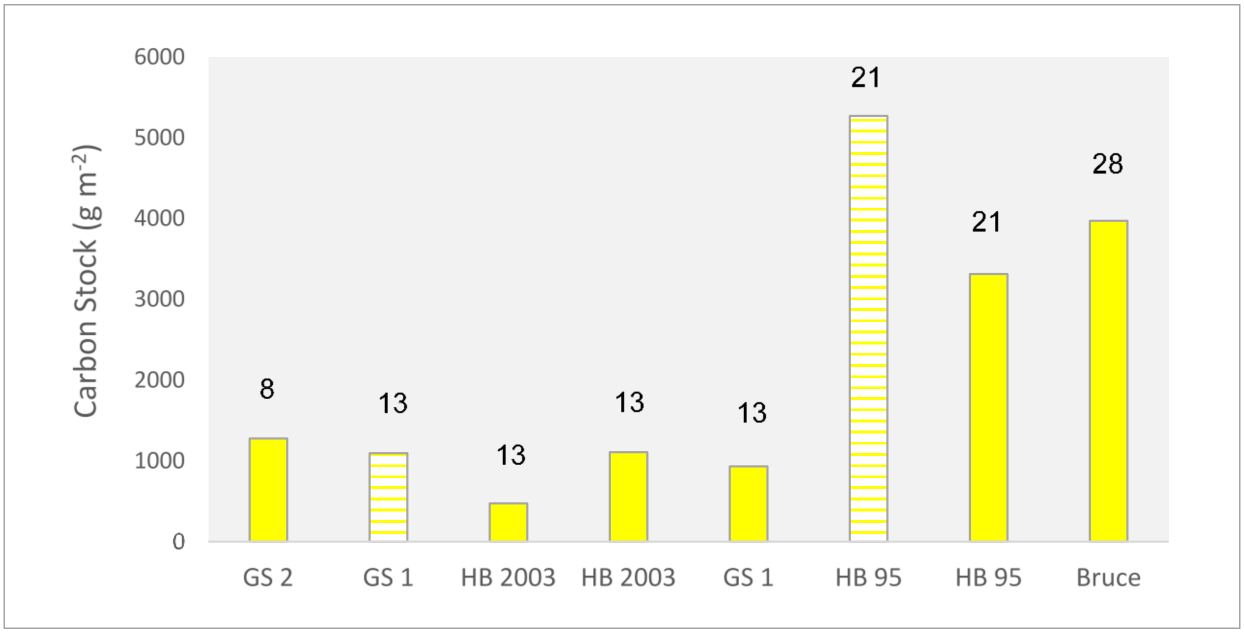

Figure 8. Carbon stocks (in g m^{-2}) in created marsh sediment at Eglin Air Force Base in Florida. Solid bars indicate *Spartina*–dominated sites; patterned bars indicate *Juncus*–dominated sites. Numbers represent marsh age. Note the different *y*-axis range than shown in Figure 9.

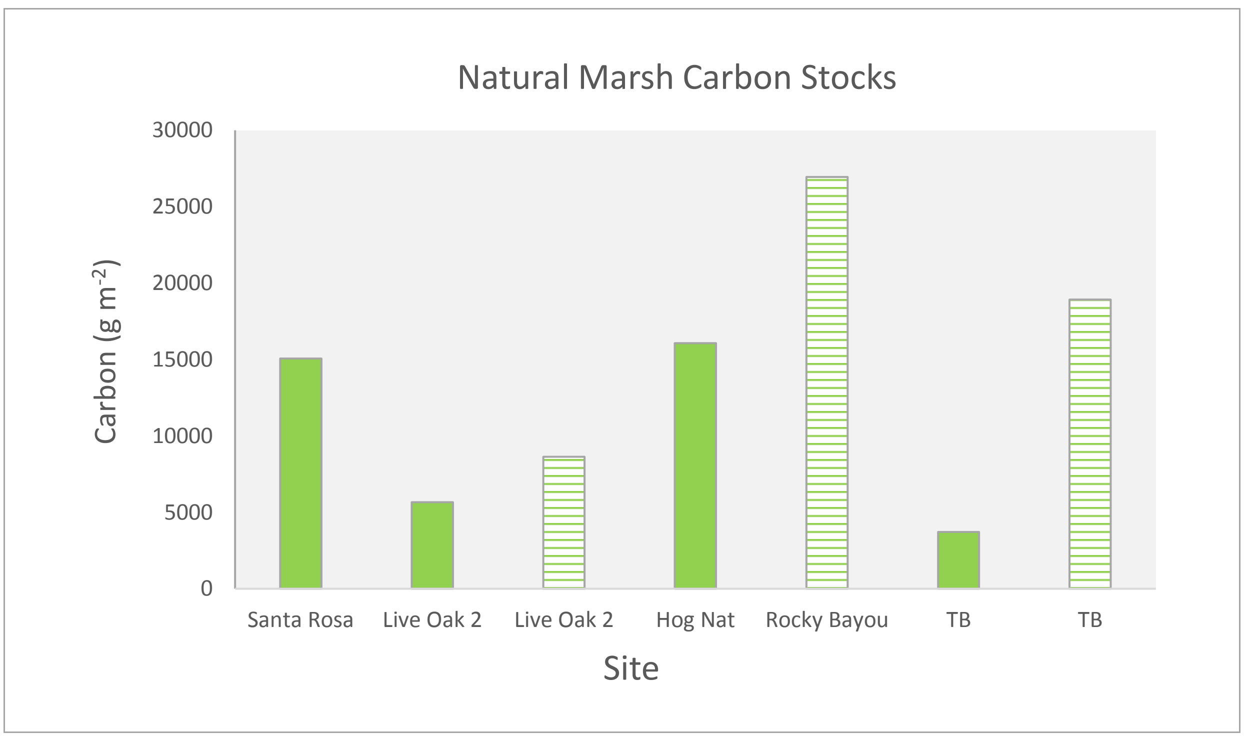

Figure 9. Carbon stocks (g m^{-2}) in natural marsh sediment at Eglin Air Force Base in Florida. Solid bars indicate *Spartina*–dominated sites, patterned bars indicate *Juncus*–dominated sites. Note the different *y*-axis range than shown in Figure 8.

Discussion

Carbon in marsh sediments originates with below-ground root-rhizome production and represents what remains after decomposition; therefore, variability in plant production between sites can introduce variability in carbon burial rates. The vegetation surveys conducted in this study at Eglin Air Force Base represent a single point in time and should be not be interpreted as reflective of long-term trends. However, these values do provide a metric for comparison among sites and indicate that the above-ground marsh biomass at these sites is within the range of reported values for the Gulf Coast region (approximately between 500–800 g dry weight m^{-2}; Turner and Gosselink, 1975). Previous research has shown that in created marshes, above-ground vegetation becomes indistinguishable from that of natural marshes within two to three growing seasons (Craft et al., 2002, Currin et al., 2008). Consistent with this finding, we found no significant difference in average above-ground vegetation between natural and created sites (p=0.64; **Figure 6**). As a result, we conclude that natural marshes sampled here represent an endpoint that the created marshes will reach, given enough time.

Published values of carbon accumulation rates across a range of tidal salt marshes are on the order of 20–1,200 g C m^{-2} yr^{-1}, with global average values ranging between 200–250 g C m^{-2} yr^{-1} (Chmura et al., 2003, Ouyang and Lee, 2014) and a median value of 137 g C m^{-2} yr^{-1}. The carbon accumulation rates measured here are within the range of previously reported values (average across all sites = 120 g m^{-2} yr^{-1}; **Figure 7**) for natural marshes. In a previous effort to determine carbon accumulation rates in created *Spartina alterniflora* marshes in North Carolina, we documented rates similar to those measured in this study at Eglin Air Force Base (58–283 g of carbon m^{-2} yr^{-1}; Davis et al., 2015). The North Carolina study included fringing shoreline marshes transplanted into sandy sediments with similar environmental conditions (e.g., standing biomass, mean monthly temperature, mean sea level rise) as the sites investigated here. Taken together, these two efforts suggest that the carbon accumulation rates of shoreline *S. alterniflora* marshes are similar, particularly when environmental conditions are similar. This information is valuable for carbon accounting efforts because the extent of geographical variability in rates of carbon accumulation is currently not well understood.

A comparison of carbon stocks across sites illustrates the slow pace over which carbon-rich marsh soils develop. Carbon stocks in the younger created sites (Green Shores 1 [GS1], Green Shores 2 [GS2], and Hurlburt Field [HF03]) are all characterized by total carbon stocks of less than 1,300 g C m^{-2} **(Figure 8**). Stocks increase in the older created marshes (Hurlburt Field [HF95] and Bruce's Beach [BB]) to values ranging from between approximately 3,000–5,000 g C m^{-2} (**Figure 9**), but these sites still fall far behind the stocks contained in the carbon-rich natural marshes such as Santa Rosa [SR] and Texar Bayou [TB] (15,000–25,000 g C m^{-2}). Choi et al. (2001) reported similarly high standing stocks of carbon (13,000–29,000 g C m^{-2}) in coastal wetlands of northern Florida. The large carbon stores of natural marshes are the product of centuries-worth of preservation of below-ground plant biomass and increasing sediment volume as marshes grow upward in the tidal frame. In some cases, carbon-rich sediments extended to nearly a meter below the marsh surface.

Creating new marsh area in the form of living shorelines results in increased carbon burial capacity (in this case, on the order of 100 g C m^{-2} yr^{-1}) in the estuarine ecosystem (**Figure 10**). However, the larger benefit to be gained from use of Living Shoreline strategies may be in the form of protecting existing carbon stocks from erosion (Pendleton et al., 2012).

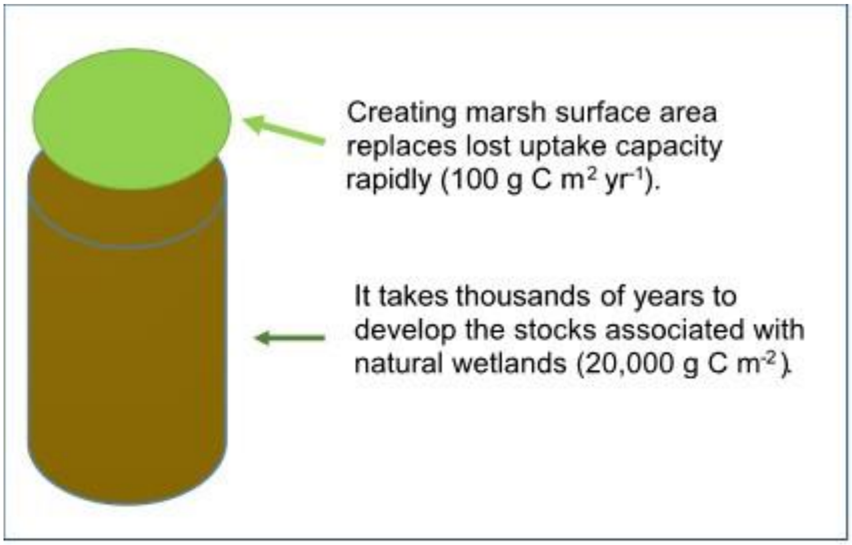

Figure 10. Living shorelines not only increase carbon burial in estuarine ecosystem, but they also protect stored carbon reserves.

Conclusions

Carbon accumulation rates in fringing shoreline marshes of northwestern Florida range between 36 and 251 g C m^{-2} yr^{-1}, with an average of 120 g C m^{-2} yr^{-1}. These values are consistent with previously reported values for created Living Shoreline marshes in North Carolina and may reflect the limited geographic variability in the factors that determine rates of carbon burial in northern Florida and North Carolina. These created shoreline marshes can provide a quantifiable carbon benefit that scales to marsh area and is an added benefit of this nature-based approach to estuarine shoreline stabilization.

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