

# Carbon Sequestration of Dwarf Red Mangrove in The Bahamas

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**Abstract.**—Mangrove ecosystems are being lost globally at an alarming rate due to deforestation, reclamation, and urbanization. Not only is the loss of these ecosystems detrimental to the commercially and ecologically important marine species they support, there is also a reduction in the ecosystem services they provide, namely mitigating rising carbon dioxide levels by serving as carbon sinks. These ecosystems, labeled as “blue carbon” sinks, potentially sequester more than 10 times the carbon that tropical and temperate ecosystems do. Thus, conservation and restoration of these blue carbon sinks is imperative. We explored how much carbon is currently stored in dwarf red mangrove *Rhizophora* mangle biomass in tidal creeks of Eleuthera, Bahamas. In October of 2012, four sites were selected near Cape Eleuthera, maximizing site variability. All sampling was done from six plots established at each site. The quantity of carbon stored in mangroves was determined from plant biomass, which was extrapolated from plant volumes. Mangrove volumes were determined from growth parameters of individuals. It was observed that there were large differences from site to site in number of individuals, sediment depth, biomass accumulation, and carbon allocation of mangroves, but the total amount of carbon stored from site to site in mangroves did not differ. The site with the greatest biomass and carbon storage also had the greatest sediment depth, suggesting a correlation between the two. Regardless of the site to site variability, mangroves proved to be good stores for carbon. Future work should search for the factors that explain site to site variability.

## Introduction

A goal for both conservation and restoration of fish habitats should be to select sites that maximize ecosystem services. In general, mangrove ecosystems provide several valuable ecosystem services. Mangroves serve as a boundary between terrestrial, estuarine, and nearshore marine ecosystems while also protecting communities from storms and coastal erosion (Lee et al. 2014). Mangroves are considered to be a foundation species

supporting nurseries (Lee et al. 2014) and are heavily involved in controlling ecosystem dynamics, including fluxes of energy and nutrients, hydrology, food webs, and biodiversity. Mangrove leaf litter has also been shown to be an essential part of the diet of brachyuran crabs (Bui and Lee 2014). Serving as a home for many different species, they generate more than one billion U.S. dollars each year in ecosystem services, and it is estimated that 80% of global fish catches are in some way related to mangroves (Polidoro et al. 2010).

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Beyond these services, mangrove ecosystems may play a large role in mitigating the effects of climate change caused by rising levels of atmospheric CO<sub>2</sub> by serving as a natural sinks for carbon (Alongi 2012; Donato et al. 2012; Lee et al. 2014). Mangrove ecosystems, which have been labeled as blue carbon sinks (along with sea grass beds and salt marshes), have been mostly overlooked in their role of carbon sequestration, but recent reports highlight them as highly efficient sinks (McLeod et al. 2011). Mangroves have proven to be good sinks by way of sequestering carbon within their underlying sediments and aboveground and belowground biomass that would otherwise be left as atmospheric CO<sub>2</sub> (McLeod et al. 2011). In the short term mangrove ecosystems store carbon in plant biomass while storing carbon in the sediment for the long term. These ecosystems trap sediment and organic carbon from internal and external riparian and oceanic sources, representing a carbon sink for a larger area (McLeod et al. 2011).

Though they are extremely important resources, mangrove forests have declined drastically. It is estimated that only half of mangrove ecosystems remain, with a loss of more than 150,000 ha a year (Alongi 2002; Spalding et al. 2010). Mangrove deforestation will result in an estimated 0.01–0.02 pentagrams C/year in global carbon emissions (Donato et al. 2011). It is thought that human activities in coastal areas may disrupt carbon sequestration by mangroves and instead cause these traditional carbon sinks to switch to a net carbon sources (McLeod et al. 2011).

The role of mangrove ecosystems of the Caribbean on the global carbon cycle is unexplored, but understanding this role and determining the amount of carbon stored in mangrove ecosystems should help warrant their conservation. This study focuses on determining how much carbon is typically stored in the biomass of dwarf red mangroves *Rhizophora mangle*, the most domi-

nant species of mangrove in the Bahamas. In this work, multiple sites were compared to explore whether or not there were differences in carbon storage of red mangroves from site to site. With the aim of determining how much carbon is stored in mangroves, it was hypothesized that carbon storage would be variable from site to site. Should mangroves prove to be good stores of carbon, then conservation and restoration measure of these ecosystems would be further justified.

## Methods

### Study site

Four study sites were selected near Cape Eleuthera, Bahamas: Broad Creek (24°47.907 N, 076°17.395 W), Kemp's Creek (24°48.743 N, 076°18.444 W), Deep Creek (24°45.922 N, 076°15.725 W), and Wemyss Bight (24°43.438 N, 076°13.255 W) (Figure 1). Sampling locations included tidal creeks and flats dominated by dwarf red mangroves. Locations were chosen to maximize the variability of the environmental conditions and the characteristics within in them. These sites are characterized by sandy beaches, turtle grass *Thalassia testudium* beds, and algal plains with some sharp calcium carbonate outcroppings with the dwarf red mangroves surrounding these areas (Danylchuk et al. 2007). The sediments at all four sites consisted of a mix of calcium carbonate sand and silt mixed with mangrove-dominated decomposing litter. Maximum daily tidal range in the tidal creeks and mangroves studied on Cape Eleuthera is typically approximately 0.8 m (Murchie et al. 2013).

Two of the sites, Kemp's Creek and Broad Creek, were on the north side of the cape adjacent to Rock Sound while the other two sites, Deep Creek and Wemyss Bight, were on the south side of the cape, the Exuma Sound side of the island. Wemyss Bight appeared to be the most mature of all of the sites, with the most accumulated sediment as well as the tallest dwarf red mangrove individuals.

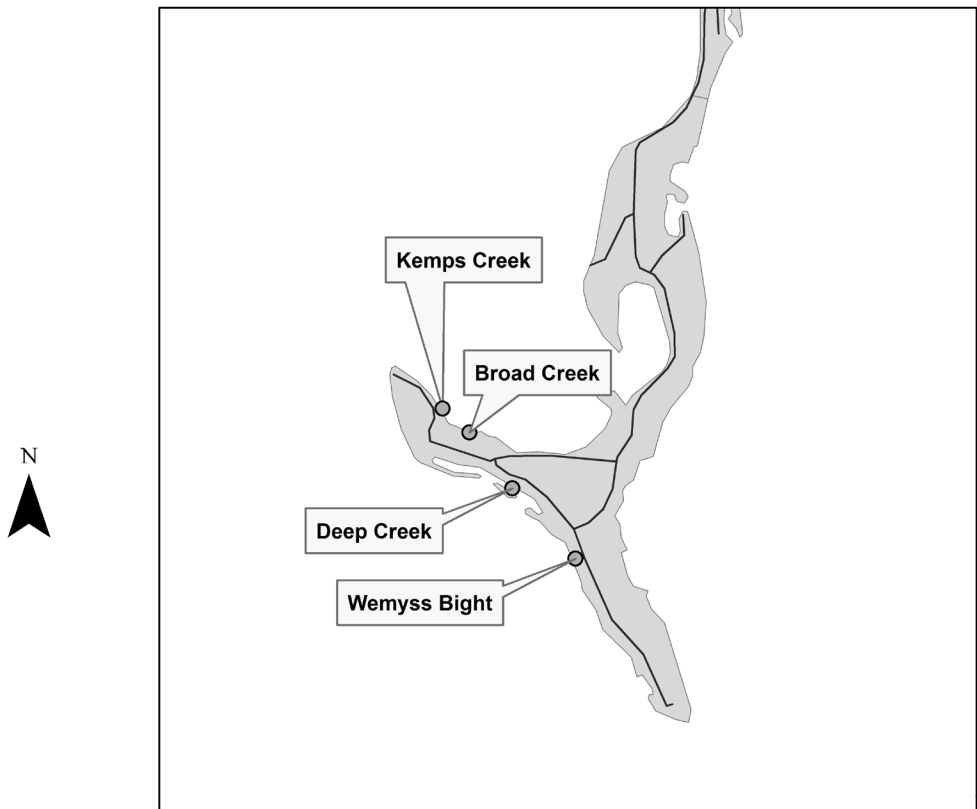
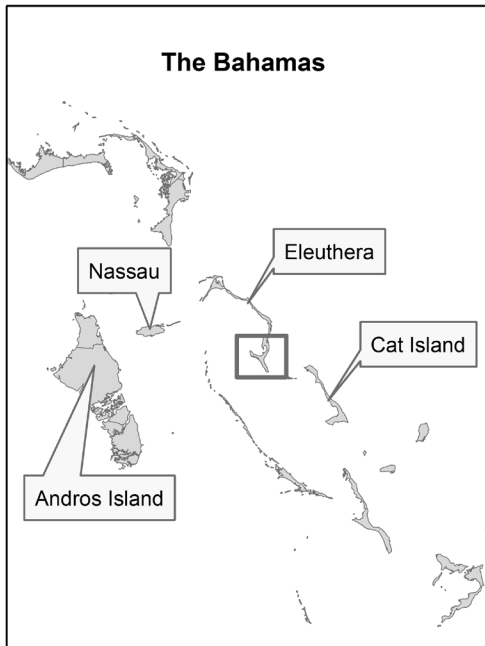


Figure 1.—Four study site locations on south Eleuthera.

A large portion of the ground at Broad Creek and Deep Creek was covered by limestone and had little sediment accumulation.

### *Experimental design*

At each site, two 75-m transects were established parallel to each other and adjacent to the opening of the flat to the open water in a way that provided site variability. The distance between transects was different from site to site and dependent on mangrove distributions. Along each transect, three  $7 \times 7$  m<sup>2</sup> plots were established at 25-m intervals (six total plots per site). Analyses were conducted comparing both sites and transects. The patchiness of mangrove flats and variable differences in densities of dwarf red mangroves throughout the flats was well represented by the transect locations.

### *Plant biomass sampling and carbon estimations*

Data collection began in January 2013 and continued through January 2014 in three separate collection periods: January 2013, June 2013, and January 2014. Total counts of three size-classes: seedlings, samplings, and adult mangroves were quantified at each of the plots. Seedlings were identified as a single stem with no prop roots (hereafter called stilts) or branches. Saplings had one or two stilts and one or two branches. Individuals with more than two stilts were classified as adults.

Leaf counts were conducted of five individuals of each size-class of each plot. Means of these counts and the total counts of individuals per plot were used to extrapolate the total number of leaves per plot. Five fresh leaves were randomly sampled from each plot to determine mean biomass and for carbon analysis in the laboratory.

Five individuals from each class were randomly selected from each plot to estimate plant volume. Volumes of mangroves were determined by treating each mangrove as an accumulation of cylinders. Each stilt,

branch, and trunk was treated as an individual cylinder for which the volume was determined using the length ( $l$ ) and diameter ( $d$ ) of each (volume =  $\pi[d/2]^2l$ ). The cylinder volumes were summed to get total volume of each mangrove individual. Volumes of individuals were extrapolated using plot counts to estimate total plot mangrove volume. Plot volumes were converted to total plot aboveground biomass using regression analyses.

Stems and stilts were sampled from each plot from each site to be used for the regression analysis. The wet volume and dry weight of each sampled stem or stilt was determined. A regression analysis was performed between stem/stilt volume and its biomass to determine whether or not volume was a good predictor of biomass. It was determined that biomass could be determined from volume using the equation  $B = 3.133 + 0.032V$ , where  $B$  is biomass in grams and  $V$  is volume (cm<sup>3</sup>) at 95% confidence ( $R^2 = 0.89$ ). The sampled stems were taken back to the laboratory for carbon analysis.

Other studies cite using diameter at breast height to estimate volume and biomass of mangrove species (Komiya et al. 2008; Adame et al. 2013). This method was not applicable here as our study species rarely reached breast height for the measurement to be applicable and identifying a true bole proved to be challenging. Our methods of determining biomass are tedious and could be prone to errors, but our aim was to determine biomass estimates, which we believe were fairly conservative as not every branch was quantified and included in our calculations of volume and biomass.

Plant belowground biomass was determined using cores extracted from the sediment, which was extrapolated for the whole plot. Five root samples were randomly extracted at each plot using a root auger; thus, our belowground estimates of biomass are limited to the depth equivalent to the length of the auger we used. The auger used was

18 cm in length and 6.35 cm in diameter. Root samples dried for 48 h at 65°C and were then weighed. Once the root samples were weighed, the average weight for each plot was determined and used to calculate the weight per square meter based on the area of the auger and up to the depth 17.8 cm. Three of the five root samples from each plot were used in the laboratory for carbon analysis.

All leaf, stem, and root samples were then analyzed for percent carbon, percent nitrogen, and C:N ratios using a CN analyzer (Elementar CN analyzer, Germany). The analyzer works by combusting small samples (less than a gram) into small compounds that can be quantified using infrared spectroscopy. These percentages were multiplied against the calculated plot biomass numbers to estimate carbon content for the plot.

#### *Sediment depth measurements*

Sediment depth measurements were taken in June 2013 and January 2014 using a soil probe. A metal soil probe was pushed into the sediment until it was felt that the probe could not go any deeper. Usually this was when the probe reached the limestone beneath the sediment. The depth on the probe was then marked and measured. Ten random measurements were taken at each plot and averaged. The sediment measurements were averaged for the entire site in order to determine whether there was a correlation between sediment accumulation and total carbon.

#### *Statistical analysis*

Statistical analyses were performed to compare site means for sediment depth measurements, biomass and carbon values using SPSS version 18 (IBM, New York). All data were tested for normality and then normalized using log transformations when the data were nonnormal. An analysis of variance (ANOVA) was performed to compare means between sites when the data were normal

(root biomass, root carbon, and sediment depth) or normalized (stem biomass, stem carbon, total biomass, and total carbon). A Tukey's post hoc analysis was used after the ANOVA to decipher which means differed from which. In cases where normality was not achieved after transformation (leaf biomass and leaf carbon), a Kruskal–Wallis test (nonparametric test) was used on the raw data with a Wilcoxon post hoc analysis. The statistical significance was set at  $P < 0.05$  for all tests.

## **Results**

There was a higher percentage of seedlings at each site than any other size-class (Figure 2). For all four sites, the number of individuals decreased with each size-class, from juveniles to adults. Deep Creek had the highest percentage of seedlings at 79.48%. Broad Creek had the lowest percentage of seedlings at 58.40%. Broad Creek had the highest percentage of saplings at 23.5% while Deep Creek had the lowest percentage at 14.78%. Broad Creek had the highest percentage of adults at 18.1%. Deep Creek had the lowest percentage of adults at 5.74%.

At all sites, the sediment depth changed from June 2013 to January 2014, but this change, whether an increase in depth or a decrease in depth, was never significant (Figure 3). There was a significant difference in the sediment depth among sites ( $P < 0.0001$ ). Wemyss Bight and Kemps Creek were not statistically different in sediment depth, but they had greater mean sediment depth than Deep Creek, which was significantly greater than Broad Creek. Of all sites, Wemyss Bight had the greatest sediment depth in June 2013 ( $48.57 \pm 8.6$  cm) while the shallowest depth was observed at Broad Creek in January 2014 ( $6.61 \pm 5.2$  cm).

The greatest mean leaf biomass ( $\text{g}/\text{m}^2$ ) was found at Wemyss Bight, which had significantly greater leaf biomass than Broad and Kemps creeks ( $P = 0.019$ , Table 1); other than Wemyss Bight, the three sites had simi-

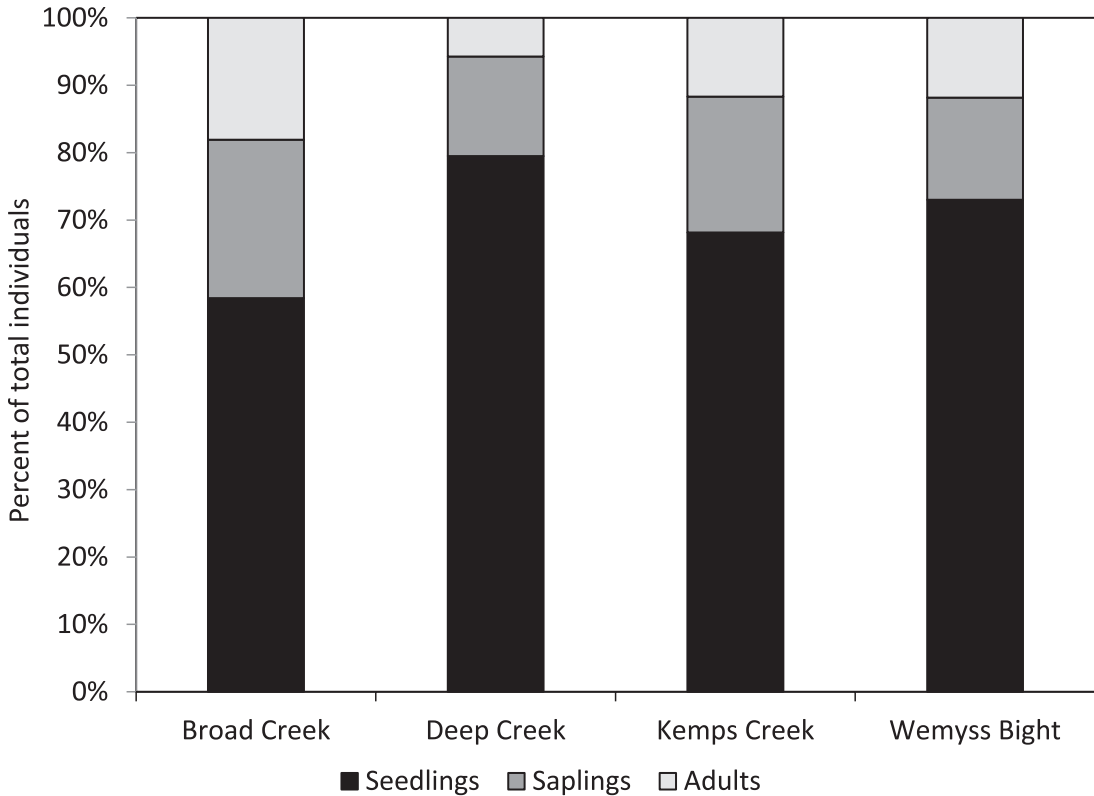


Figure 2.—Size-class distribution of dwarf red mangroves for the four study sites on Eleuthera.

lar mean leaf biomass. The greatest stem biomass ( $\text{g}/\text{m}^2$ ) was found at Wemyss Bight while the lowest stem biomass was found at Kemps Creek ( $P = 0.029$ , Table 1). The greatest mean root biomass ( $\text{g}/\text{m}^2$  up to a depth of 18 cm) was found at Wemyss Bight while the lowest mean root biomass was found at Deep Creek. No site differed statistically in mean root biomass ( $P = 0.17$ , Table 1). Wemyss Bight had the greatest total biomass (sum of leaves, stems, and roots) at  $4,127.57 \text{ g}/\text{m}^2$ . Deep Creek had the lowest total biomass at  $1,819.66 \text{ g}/\text{m}^2$ . Statistically all the sites were the same in mean total biomass ( $P = 0.113$ ).

There was a strong correlation between biomass and carbon content for all biomass ( $r = 0.964$ ,  $P < 0.001$ ). The leaves at Wemyss Bight had the most mean carbon at  $56.89 \pm 46.6 \text{ g}/\text{m}^2$ , which was significantly greater than the leaf stored carbon at Broad

and Kemps Creeks ( $P = 0.021$ , Table 2). The stems at Wemyss Bight had the most carbon at a mean of  $716.00 \pm 553 \text{ g}/\text{m}^2$  while the stems at Kemps Creek had the least amount of carbon at a mean of  $120.59 \pm 63.6 \text{ g}/\text{m}^2$  ( $P = 0.033$ , Table 2). There was no significant difference in the amount of carbon stored in roots from site to site ( $P = 0.198$ , Table 2). The roots at Kemps Creek had the most carbon content with a mean of  $1,099.29 \pm 638 \text{ g}/\text{m}^2$  while the roots at Deep Creek had the least carbon content with a mean of  $221.84 \pm 96.6 \text{ g}/\text{m}^2$ . There was no significant difference in the mean total carbon stored (sum of root, stems, and leaf carbon) from site to site in mangrove biomass ( $P = 0.125$ , Figure 4). Wemyss Bight had the most total carbon at  $1,518.38 \text{ g}/\text{m}^2$ . Deep Creek had the least total carbon at  $655.29 \text{ g}/\text{m}^2$ .

It was observed that there were differences from site to site in the carbon to ni-

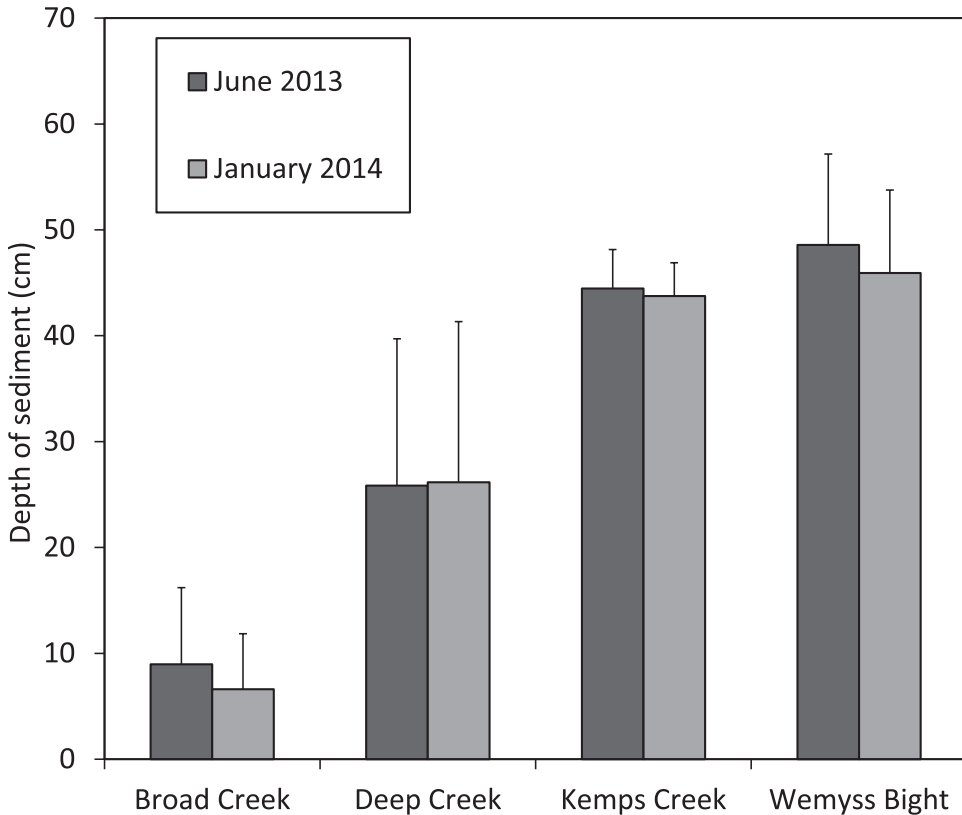


Figure 3.—Mean sediment depth measurements for the four mangrove sites on Eleuthera.

trogen ratios of the leaves and the roots ( $P = 0.004$ ,  $p = 0.039$ , respectively, Table 3). Broad Creek had the highest ratios in leaves, stems, and roots with  $49.03 \pm 8.2$ ,  $189.86 \pm 82.1$ , and  $58.24 \pm 9.4$ , respectively. Kemps Creek had the lowest ratios in leaves, stems, and roots with  $36.9 \pm 3.9$ ,  $123.16 \pm 25.4$ , and  $46.99 \pm 4.2$ , respectively.

## Discussion

Carbon stored in mangrove biomass on Eleuthera averages 11.12 Mg/ha. Combining this with what larger quantities of carbon likely stored in the sediment verifies the value these ecosystems have as carbon sinks. This work demonstrated that there were site to site differences in class distribu-

Table 1.—Mean biomass ( $\pm$ SD) of leaves, stems, and roots of dwarf red mangrove ( $\text{g}/\text{m}^2$ ) for the four study sites on Eleuthera. Note that significantly different means are accompanied by different letters ( $P < 0.05$ ).

Site	Leaves	Stems	Roots
Broad Creek	$27.25 \pm 20.6$ y	$617.62 \pm 434.7$ yz	$2,381.83 \pm 2,033.8$
Deep Creek	$41.36 \pm 13.7$ yz	$555.72 \pm 153$ yz	$1,222.56 \pm 1,084.6$
Kemps Creek	$30.64 \pm 22.1$ y	$302.72 \pm 170.4$ y	$3,326.18 \pm 1,906.6$
Wemyss Bight	$126.08 \pm 102.9$ z	$1,643.18 \pm 1,258.3$ z	$2,358.30 \pm 806.2$
P-value	0.019	0.029	0.170

Table 2.—Mean carbon stored ( $\pm$ SD) in leaves, stems, and roots of dwarf red mangrove ( $\text{g}/\text{m}^2$ ) for the four study sites on Eleuthera. Note that significantly different means are accompanied by different letters ( $P < 0.05$ ).

Site	Leaves	Stems	Roots
Broad Creek	$12.03 \pm 9.2 \text{ y}$	$258.27 \pm 183.6 \text{ yz}$	$773.37 \pm 692.7$
Deep Creek	$19.1 \pm 6.5 \text{ yz}$	$228.26 \pm 64.3 \text{ yz}$	$221.84 \pm 96.6$
Kemps Creek	$13.72 \pm 10.0 \text{ y}$	$120.59 \pm 63.6 \text{ y}$	$1,099.29 \pm 638.0$
Wemyss Bight	$56.89 \pm 46.6 \text{ z}$	$716.0 \pm 553.0 \text{ z}$	$745.48 \pm 247.9$
P-value	0.021	0.033	0.198

tion, sediment depth, carbon allocation, and nutrient availability in dwarf red mangrove flat ecosystems on Eleuthera. How carbon is stored in the mangrove ecosystems of the Bahamas and likely the rest of the Caribbean is variable from place to place. Some of the explanations that account for this variability

among sites include class distribution ratios, sediment accumulation, and potentially nutrient availability.

Across all sites, there were more seedlings than any other age-class. This result was expected, as the numbers of individuals in each class should decline as the indi-

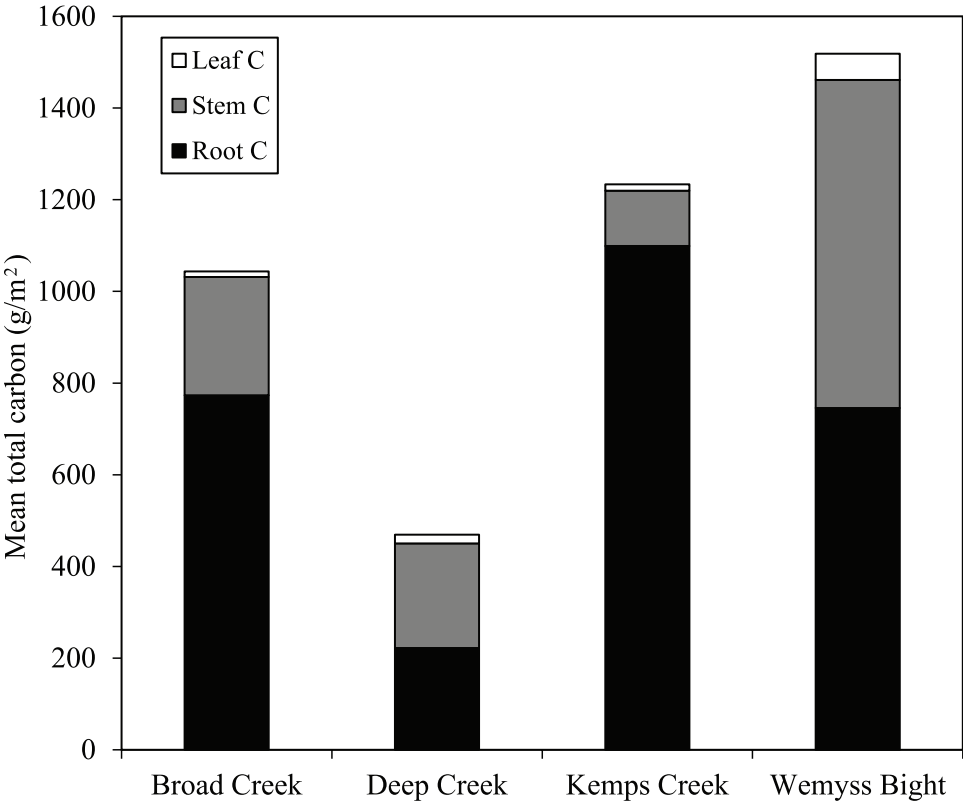


Figure 4.—Mean total carbon stored in dwarf red mangroves per square meter of the four study sites on Eleuthera. Root carbon represented up to a depth of 18 cm. There was no significant difference in mean total carbon storage from site to site ( $P = 0.125$ ).

*Table 3.*—Mean C:N ratios ( $\pm$ SD) of leaves, stems, and roots of dwarf red mangrove for the four study sites on Eleuthera. Note that significantly different means are accompanied by different letters ( $P < 0.05$ ).

Site	Leaves	Stems	Roots
Broad Creek	49.03 $\pm$ 8.2 z	189.86 $\pm$ 82.1	58.24 $\pm$ 9.4 yz
Deep Creek	37.45 $\pm$ 4.3 y	136.14 $\pm$ 39.4	59.57 $\pm$ 8.7 z
Kemps Creek	36.9 $\pm$ 3.9 y	123.16 $\pm$ 25.4	46.99 $\pm$ 4.2 y
Wemyss Bight	45.07 $\pm$ 5.9 yz	143.48 $\pm$ 17.2	57.81 $\pm$ 8.3 yz
<i>P</i> -value	0.004	0.304	0.039

viduals mature. As mangroves mature, the probability of death increases with age and size due to intraspecific competition and self-thinning, which is why there are fewer adults than seedlings or saplings at each site (Rajkaran and Adams 2012). Resource demands also increase as the mangrove individuals mature; thus, limiting resources then become a thinning factor. Light is not a limiting factor for establishing seedlings, even in dense mangrove, as dwarf red mangrove has been shown to have traits that allow it to be both light demanding and shade tolerant (Farnsworth and Ellison 1996).

Our estimates of carbon storage in seedlings thus are values for a specific moment in time and may not project into future carbon estimates. It was observed that Deep Creek had the most number of seedlings, which suggests great potential for high productivity and carbon storage in the future as those individuals mature. Broad Creek had the most adults and the lowest number of seedlings. This may imply that either the site is mature or that it is a poor site for seedling recruitment. This site had a lot of bedrock and very little sediment accumulation, which is necessary for the establishment of new individuals.

The depth of the sediment changed from June 2013 to January 2014 at all sites. Deep Creek increased in sediment depth while the other three sites decreased in sediment depth, but none of these changes were statistically significant. These changes in sediment depth were expected as the tides move sediment in and out of the creeks as has been

observed globally at several sites in several coastal ecosystems (Gourgue et al. 2013). These changes in depth would most likely become significant after longer periods of time. We expect that all sites would accumulate large quantities of sediment after several years. Mangroves have proven to be quite valuable in regard to sediment accumulation contributing to inorganic sedimentation, soil development, vertical land building, and stabilization (Lee et al. 2014).

The depth of the sediment may have been tied partially to mangrove productivity and carbon accumulation. High productivity has been reported to increase sediment accumulation rapidly (Osland et al. 2012). Wemyss Bight had the largest individual mangroves and the greatest sediment depth, suggesting a correlation between mangrove biomass and sediment depth: the larger the individual, the more sediment they will accumulate (Osland et al. 2012). An increase in sediment depth should bring in an influx of nutrients, which could pulse productivity and biomass accumulation. If large mangroves trap more sediment and more sediment brings more nutrients, which promote mangrove biomass production (Duarte et al. 1998), then there is a two-way positive feedback mechanism, where sediment accumulation and mangrove productivity fuel each other. This feedback cycle does not seem apparent for Broad Creek, which had the lowest sediment depth but mean total biomass comparable to the other sites. The sediment depth values at Broad Creek were due to abundant areas of

bare limestone rock, which were recorded as a depth of zero whenever the limestone rock areas were randomly sampled for sediment depth measurements. Disregarding these bare areas, the sediment depth mean for the site would be greater and potentially linked to mangrove growth.

The least amount of biomass was stored in the leaves and the average leaf weight differed across sites. Leaf texture and average size are variable in Rhizophoraceae, which could potentially account for the differences in average weight (Tomlinson et al. 1979). High leaf production is important as it would feed back to greater overall mangrove productivity by being the location of photosynthesis (Medeiros and Sampaio 2011). Nutrient inputs most likely influenced leaf biomass. This would have to be explored in a study examining nutrient availability of these sites in the sediment.

The least amount of total carbon was stored in the leaves as compared to the stems and roots. However, leaves had the highest percentage of carbon values across all sites compared to the roots, which had the lowest percentage of carbon values across all sites. Thus, there is value in leaf production in terms of serving as good carbon sinks. At the same time, roots have a low percentage of carbon, but because of the high volume/biomass of overall roots, roots remain the largest pool of carbon of mangrove biomass.

Most of the mangrove biomass was in the formation of roots, which was also observed in the Florida Everglades (57–78% of the total productivity was in root production; Castaneda-Moya et al. 2011). Across all sites, roots were only sampled to a depth of 18 cm using an auger. Some of the sites had three times that depth in sediment, meaning that not all of the root biomass is reported here, and there may be significantly more root biomass. How much root biomass accumulated in the nonmeasured sediment depths would be dependent on root penetration, which can be dictated by several factors, including wa-

terlogging, hypoxia, and sediment compactness (McKee 1996). Thus, it is unlikely that roots were consistent through the sediment depth. Root production was most likely tied to high nutrient availability that comes through sediment accumulation (Castaneda-Moya et al. 2013). The C:N data presented here suggests there may be potential differences in nutrient availability, which would have to be determined from further sediment analysis. High C:N could result from high nitrogen in the sediment or low carbon capture rates via photosynthetic rates.

There are some possible explanations as to why the greatest productivity and carbon accumulation were observed at Wemyss Bight. First, Wemyss could simply be the oldest site and has had the most time to accumulate biomass. Aging mangroves in tropical areas can be difficult as they do not form annual rings like most deciduous woody species found in temperate environments. Beginning with this work, we have been monitoring growth of the marked mangrove individuals over time. We should be able to use these to calculate growth rates, which can be used to determine how old the individuals are assuming constant growth rates. Afterwards, site differences may be explained by age.

Freshwater input could also potentially explain why Wemyss Bight had the most productivity. Several works have tied mangrove productivity to freshwater availability. As salinity increases, the stature of mangroves decline (Castaneda-Moya et al. 2013). In the Middle East, a study found that groundwater was the major contributor to sustaining mangrove density (Drexler and Carlo 2002). The sites in Eleuthera are highly saline environments; further studies would need to be done to determine if there are freshwater inputs at the more productive sites.

Our results indicate that mangroves in the Caribbean are good carbon sinks and have the potential to help mitigate the effects of global climate change by reducing atmospheric CO<sub>2</sub>. This picture will be clearer

when belowground carbon storage in the sediment has been described in future work. Comparing to other mangrove ecosystems, the dwarf red mangrove flats ecosystems of the Bahamas may not hold as much carbon per hectare as observed in other mangrove ecosystems (Alongi 2012; McLeod et al. 2011); however, they are just as valuable when compared to terrestrial ecosystems and when all of the ecosystem services they provide (Lee et al. 2014) are considered.

There is some evidence that mangrove ecosystems, particularly those along islands, function as sinks and sources (exporters) of carbon through consumption of mangrove leaf litter by migrating detritivores and washouts caused by large rainfall events (Bui and Lee 2014; Lee et al. 2014). Rainfall events that could increase in frequency with climate change in tropical areas could destroy the value of mangroves as carbon sinks. Sea level rise associated with climate change also threaten mangrove ecosystems as islands are squeezed, leading to losses in suitable coastline for mangrove establishment (Donato et al. 2012). Tragically, the mitigating effects of the mangroves as carbon sinks may not prevent the climate change events that will alter their ecosystem services and deprive mangroves of suitable areas to establish on tropical islands.

## Acknowledgments

We would like to thank the Fisheries Conservation Federation and Monmouth University Urban Coast Institute for their financial support. Thanks to Carleigh Engstrom and Mitchell Mickley for their support in the laboratory. Thanks to Richard Bastian, Lauren Johnson, Kaitlyn Kramer, and Alex Moncman for guidance on statistical analyses.

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