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Improving Community-Based Shoreline Erosion Stabilization Projects: Impacts of Potential Nurse Plants on Red Mangrove Biomass Production and Survival

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ABSTRACT: Mangrove communities provide habitat for many terrestrial and aquatic species and act as nurseries and breeding grounds for fish, crustaceans, and birds. They also protect coastal areas from erosion and storm events. However, globally 35% of mangrove habitat has been degraded or destroyed, making mangroves one of the most endangered ecosystems on earth. Thus, there is a demand for methods to restore mangrove habitats successfully. The red mangrove (*Rhizophora mangle*) is often associated with other marsh plants. We investigated whether two marsh plants (*Batis maritima*, *Sarcocornia perennis*) act as nurse plants and increase *R. mangle* success by altering seedling biomass production (aboveground and belowground) under greenhouse conditions and by improving shoreline stabilization, thus increasing survival and retention of *R. mangle* in the field. To test these goals, we ran a replicated experiment at the University of Central Florida greenhouse to determine whether the marsh plants had negative, positive, or neutral impacts on *R. mangle* and examined if marsh plants increased survival and retention of *R. mangle* at Castle Windy shell midden in Mosquito Lagoon, Florida. Based on our experiments, *S. perennis* and *B. maritima* do not act as nurse plants for *R. mangle*, since the marsh plants had no statistically significant impact on *R. mangle* total dry weight, change in height, final height, leaf count, field survival, or retention. However, our marsh plants had less biomass than naturally occurring meadows found in the field. Additional field research is needed to determine if meadows of *S. perennis* and *B. maritima* will facilitate *R. mangle* success.

KEYWORDS: red mangrove, shoreline stabilization, nurse plants, facilitation

INTRODUCTION

Mangrove ecosystems protect coastal areas from erosion and storm surges, and act as accumulation sites for sediment, carbon, and nutrients, making them essential components of coastal environments (Alongi 2002). Mangroves also provide important habitat for many marine species and act as nurseries and breeding grounds for fish, crustaceans, and birds (Alongi 2002). However, 35% of mangrove habitat has been degraded or destroyed globally, making mangroves one of the most endangered ecosystems on earth (Valiela et al. 2001).

Mangrove restoration is critical because it has the potential to combat soil erosion and invasion by exotics (McKee et al. 2007). To date, most mangrove restoration studies have focused on the use of resources (e.g., nutrients) and the impacts of regulators (e.g., salinity) on the system; few focus on facilitation between mangroves and other plants (Twilley and Rivera-Monroy 2005). We must understand interactions of mangroves and co-occurring marsh plants to improve restoration success.

In terrestrial habitats, facilitation is a common mechanism observed in the succession of plant species (Connell and Slayter 1977), since facilitative plants tend to establish in open areas (López 2007). In the facilitation model of succession, early colonizing species (benefactors) change the abiotic conditions in order to make the habitat suitable for the entry of the second species (beneficiaries) (Connell and Slayter 1977). An example of facilitation is the "nurse plant"— a mature plant (benefactor) that promotes the success of young plants (beneficiaries) (López 2007). This form of facilitation requires the nurse plant to have a positive impact (i.e., increased survival) on another plant species. For example, Egerova et al. (2003) aimed to improve coastal wetland restoration in Louisiana by studying the interaction of groundsel trees (*Baccharis halimifolia*) and smooth cordgrass (*Spartina alterniflora*).

In a created salt marsh, they found higher seedling retention, growth, and survival of *B. halimifolia* when grown in the presence of *S. alterniflora*. Thus, *S. alterniflora* acted as a nurse plant by facilitating the growth and survival of *B. halimifolia* (Egerova et al. 2003). Likewise, Milbrandt and Tinsley (2005) found that when *Avicennia germinans* (black mangrove) was planted with *Batis maritima* (saltwort), *A. germinans* experienced a significantly lower mortality rate. Thus, *B. maritima* acted as a nurse plant by increasing mangrove seedling survival. However, the role of *B. maritima* in regeneration of red mangrove forests remains unclear, and no one has yet documented if this type of facilitation can benefit shoreline stabilization efforts.

According to McKee et al. (2007), there is a need for site-specific restoration research to understand local facilitation mechanisms and to improve management and restoration strategies in a particular geographic region. This study focused on Mosquito Lagoon in Canaveral National Seashore, New Smyrna Beach, Florida. Mosquito Lagoon is located in the northernmost section of the Indian River Lagoon system and encompasses both the temperate North Atlantic and tropical Atlantic zones. This location gives rise to a unique mixture of vegetation, including the species used in this study, *Rhizophora mangle*, *Batis maritima*, and *Sarcocornia perennis*. *Rhizophora mangle* (red mangrove) is a woody-halophyte intertidal plant that is often associated with marsh plants in tropical and subtropical locations (Alongi 2002, Cardona-Olarte et al. 2006).

Typically, mangroves do not inhabit areas where temperatures reach below 19°C or areas where annual temperature fluctuations are more than 10°C (Waisel 1972). They release viviparous embryos called propagules, which are dispersed via tides (Gill and Tomlinson 1969). The propagules develop best in low wave energy areas (i.e., areas with low tidal stress); this allows them time to establish root systems once stranded after water dispersal (Alongi 2002). *Batis maritima* and *S. perennis* are similar to each other in terms of growth morphology and requirements. They frequently grow in mixed species assemblages; however, *B. maritima* has been studied more in relation to mangrove habitats. *Batis maritima* (saltwort) is a low-growing, perennial species with woody stems and bright green succulent leaves (Rey et al. 1990). It ranges from 0.1 – 1.5 m in height and forms dense colonies or meadows (Lonard et al. 2011). It is a halophyte, which tends to be associated with saline soils (Rey et al. 1990). It has the ability to propagate clonally, and can spread easily due to an underground rhizome network creating vast meadows (Pennings and Callaway 2000). *Sarcocornia perennis* (glasswort) is a perennial macrophyte that can reach up to 0.3 m with small succulent leaves. Meadows of *S. perennis* and other marsh plants are found in intertidal zones throughout salt marshes (Adams and Bate 1994, Davy et al. 2006). It is often associated with early colonization or bare sediments and is able to propagate clonally with rhizomes (Davy et al. 2006).

Our study investigated whether *B. maritima* or *S. perennis* acted as nurse plants and increased *R. mangle* success by altering seedling biomass production (aboveground and belowground) before deployment, and by improving shoreline stabilization, thus increasing survival and retention of *R. mangle* planted along an eroding shoreline in Canaveral National Seashore. The field site, Castle Windy, was chosen because it is a historical Timucuan shell midden on a barrier island in Canaveral National Seashore that was experiencing severe erosion. Castle Windy is historically significant because it contains debris of human activity (e.g., food sources, remains) left by the Timucuan Native Americans, who lived there 800 to 1200 years ago (Bushnell 1915, Ehrmann 1940). Assessing the interaction between *R. mangle* and potential nurse plants will help to inform community groups and resource managers attempting to restore shorelines and protect historically significant coastal sites.

METHODS

Experimental Design

In September 2012, 240 ripe *Rhizophora mangle* propagules were collected from trees within Canaveral National Seashore (28.7675° N, 80.7769° W) on the east coast of Florida. Following collection, the initial weights (Ohaus Scout Pro Balance) and heights of each propagule were recorded. Individuals were then planted in separate four-liter pots with potting soil filled to a height of 9.5 cm. The potted *R. mangle* propagules were divided among 40 plastic tubs (55 cm x 40 cm x 14 cm), with six pots per tub. The tubs were placed on tables within a greenhouse and filled with eight cm of freshwater. One month later, the seedlings were randomly assigned to one of six treatments in each tub: 1) no nurse plants (control), 2) addition of one 20-cm segment of *B. maritima*, 3) addition of one 20-cm segment of *S. perennis*, 4) addition of two 20-cm segments of *B. maritima*, 5) addition of two 20-cm segments of *S. perennis*, and 6) addition of one 20-cm segment of *S. perennis* plus one 20-cm segment of *B. maritima* (Figure 1). *B. maritima* and *S. perennis* were collected from Mosquito Lagoon on 13 October 2012, and immediately transported to the greenhouse in 19-liter buckets with enough water to cover roots and rhizomes. On the same day, plants were cut to 20-cm segments using pruning shears, weighed, and planted into their appropriate treatments. Only one segment was cut from each plant, with all segments having green leaves and no root structures. From previous experiments, we knew segments would grow vegetatively; any that did not were replaced within five days (T. Wolfenberger and L. Walters, pers. obs.).

Plant Survival, Growth, and Biomass Assessment

Survival and leaf production of *Rhizophora mangle* were recorded three times per week for 20 weeks. New leaves were only counted once fully open. On 10 March 2013, the final height and number of leaves were measured for *R. mangle*. Mangroves were then randomly assigned to one of two groups: biomass estimates or field study. Individuals of each treatment were randomly chosen from all plants using a random number generator.

All plants (*R. mangle*, *B. maritima*, *S. perennis*) within each pot in the biomass estimate trial were removed from the soil and rinsed with freshwater. Plants were placed in aluminum trays and dried in an Econotherm laboratory oven at 70°C for 24 hours. After drying, aboveground and belowground biomass for each plant was recorded. We tested for significant differences across treatments in *R. mangle* change in height, final height, and final leaf count using analysis of covariance (ANCOVA) with the covariant as initial *R. mangle* height. ANCOVA was also used to test for significant differences across treatments for the total dry weight of *R. mangle*, using the initial weights of *R. mangle*, *S. perennis*, and *B. maritima* as covariates. Data were examined for normal distribution, and Levene's Test for equality of error variances verified that all data met the assumptions of ANCOVA. All data analysis and summary statistics were generated with SPSS, version 11.5.

Plant Survival and Retention

The field experiment was deployed in the intertidal zone at Castle Windy (28.5338° N, 80.4829° W) on 3 March 2013 at low tide with the assistance of ten community volunteers. A gas-powered auger was used to create holes (approximately 15 cm deep with a 17 cm diameter) for the plants. The plants were spaced approximately one meter apart in the high-intertidal zone. Fifteen randomly assigned replicates of each of the six treatments were deployed haphazardly. The retention and survival of mangroves and potential nurse plants were monitored daily for one week (4-10 March 2013), and then monthly for two months (April and May 2013). Survival analysis using Wilcoxon-Gehan test statistic (SPSS version 11.5) tested for significant differences in mortality through time across treatments.

RESULTS

At the start of our experiments, *Rhizophora mangle* propagules had an initial mean weight (± S.E.) of 18.9 ± 0.6 g and initial mean length of 29.0 ± 0.4 cm, with the heaviest individual weighing 28.6 g and the tallest being 31.2 cm. *R. mangle* initial height after planting (=aboveground biomass) ranged from 21.4 to 39.0 cm with a mean of 28.4 ± 3.4 cm. All *R. mangle* had no leaves at the start of trial. The initial mean weight of *Sarcocornia perennis* was 3.4 ± 0.2 g and the initial mean weight of *Batis maritima* was 4.0 ± 0.6 g, with all segments measuring 20 cm in length and none of the cuttings having any underground root structures.

Plant Survival, Growth, and Biomass Assessment

Although all *R. mangle* survived, not all *S. perennis* and *B. maritima* fragments survived in the greenhouse. In the treatments with one or both species of fragments, only those with surviving fragments were included in the biomass data analysis or field study. At the end of our greenhouse trials, the mean leaf count (± S.E.) for *R. mangle* was 2.5 ± 0.1 leaves per plant, with most plants in all treatments having two leaves after five months. The highest leaf count for *R. mangle* was four leaves per individual. ANOVA results indicated that there was no significant difference in the *R. mangle* leaf count across treatments (F=0.881, p=0.495; Figure 2).

The results of the ANCOVA showed that *S. perennis* and *B. maritima* had no significant impact on the change in *R. mangle* height among treatments (F=0.963, p=0.442; Figure 3). The mean increase in *R. mangle* height (±S.E.) was 6.1 ± 0.2 cm after the five-month growing period in the greenhouse, with all plants increasing in height. The greatest change was an increase of 12.4 cm and the smallest increase was 0.5 cm. The mean final *R. mangle* height (± S.E.) was 34.5 ± 0.3 cm, with the tallest being 43.9 cm and smallest being 24.3 cm. Additionally, *S. perennis* and *B. maritima* had no significant impact on final *R. mangle* height when comparing among treatments (F=2.68, p=0.897; Figure 4).

The number of replicates used for the biomass assessments was not equal across treatments. Treatment 2 (one fragment of *Batis maritima*) had three replicates, treatment 6 (one segment of *S. perennis* plus one segment of *B. maritima*) had five replicates, and treatment 4 (one segment of *B. maritima*) had no replicates. There was a wide range in total dry weight (aboveground and belowground biomass) for *S. perennis* (mean ± S.E.: 2.8 ± 0.3 g) and plant weights ranged from 0.7 g to 7.9 g. *Batis maritima* also had a wide range in total dry weight (mean ± S.E.: 1.7 ± 0.2 g), ranging between 0.2 g and 5.3 g. All plants of *S. perennis* and *B. maritima* had aboveground and belowground biomass; however, some root material may have been lost when the plants were removed from soil. Total dry weights of *S. perennis* and *B. maritima* had no statistically significant impact on the total dry weight of *Rhizophora mangle* across treatments (F=0.786, p=0.539; Figure 5). The mean total dry weights of *S. perennis* and *B. maritima* was (± S.E.) of 13.5 ± 0.6 g.

Field Experiment

The survival of *R. mangle* for 70 days post-deployment was not significantly different across treatments (Wilcoxon-Gehan statistic=4.053, df=5.00, p=0.542; Table 1). One *R. mangle* was lost per treatment in treatments 1 (no nurse plants), 2 (one *B. maritima*), 4 (two *B. maritima*), and 5 (two *S. perennis*). Treatment 3 (one *S. perennis*) lost two *R. mangle*. Treatment 6 (one segment of *S. perennis* plus one segment of *B. maritima*) had 100% survival. During the monitoring period, weather conditions were variable in Mosquito Lagoon, including severe thunder and rainstorms (P.Y., personal observation). On the day of deployment, temperatures reached a low of 2.2° C, which was colder than any other day during the monitoring period. The highest temperature observed during the monitoring period was 32°C (P.Y. personal observation).

DISCUSSION

Community restoration is not always a straightforward process and requires knowledge of all target species involved (Milbrandt and Tinsley 2006). Understanding positive and negative interactions of local plant species is important for ensuring successful restoration and shoreline stabilization projects. Our biomass assessment indicated that *S. perennis* and *B. maritima* had no significant impact on *R. mangle*'s change in height, final height, leaf count, or total dry weight across treatments when growing in the greenhouse. At Castle Windy, all planted *R. mangle* survived except six individuals; individual losses did not occur within the first week, but were spread out over the 70-day period. Initial monitoring indicated that the field experiment acted as a successful restoration effort to help stabilize the shoreline at this shell midden.

Survival and retention were high in all treatments and there were no significant differences across treatments, suggesting that *B. maritima* and *S. perennis* did not facilitate *R. mangle* retention or survival in the field. From the results, it can be inferred that *S. perennis* and *B. maritima* did not act as nurse plants for *R. mangle*. A possible explanation for the high survival rate of *R. mangle* in the field may have been because all plants were planted in the high intertidal zone, which protected them from daily wave energy and prevented removal by tides. Additionally, a 70-day monitoring period may not be sufficient to quantify facilitation or competition. Thus, a longer monitoring period would be needed for related experimental designs.

The stress-gradient hypothesis suggests that the frequency of facilitation increases under more extreme abiotic conditions while competition increases under benign abiotic conditions (Maestre 2009). Consequently, it was expected that competition between *R. mangle* and the marsh plants (*B. maritima*, *S. perennis*) would have occurred under the benign abiotic conditions (e.g., shelter from wind and storms, constant humidity, unlimited access to freshwater) in the greenhouse. It was also expected that facilitation would be observed between *R. mangle* and marsh plants under the variable and extreme abiotic conditions (e.g., extreme temperatures, storms, salinity) in the field after plants were deployed. Contrary to this hypothesis, we found that *B. maritima* and *S. perennis* had no significant positive or negative effect on the change in height, leaf count, or biomass of *R. mangle*, suggesting no competition or facilitation in our greenhouse trials.

Additionally, we predicted facilitation in the field, as the increased total belowground biomass should have aided plant retention. When *R. mangle* was planted alone in previous trials, the primary source of mortality was plants washing away within 24 hours due to insufficient root attachment (T. Wolfenberger and L. Walters pers. comm.). We hypothesized that the root systems of *B. maritima* and *S. perennis* would reduce this problem. However, with the retention of all treatments so high, we were not able to observe this; thus, longer-term observations are needed. Knowing that no competition occurred in the greenhouse or field is important. A shoreline stabilization and restoration project aiming to increase biodiversity is more likely to succeed when species that can survive and grow in the same area have been previously identified.

Typically, mangroves do not inhabit areas where temperatures reach below 19°C or areas where temperature fluctuations are more than 10°C, which can be damaging to mangroves (Waisel 1972). The temperature range throughout the field trial was 2.2°C to 32°C. Survival and retention of *R. mangle* through the extreme temperature fluctuations of the monitoring period would suggest that facilitation should occur. However, *B. maritima* and *S. perennis* had no statistically significant impact on *R. mangle* survival or retention. Perhaps the existing surrounding vegetation formed a microclimate by protecting the young plants from the temperature variations (e.g., buffer from cold wind, shade during warmer temperatures).

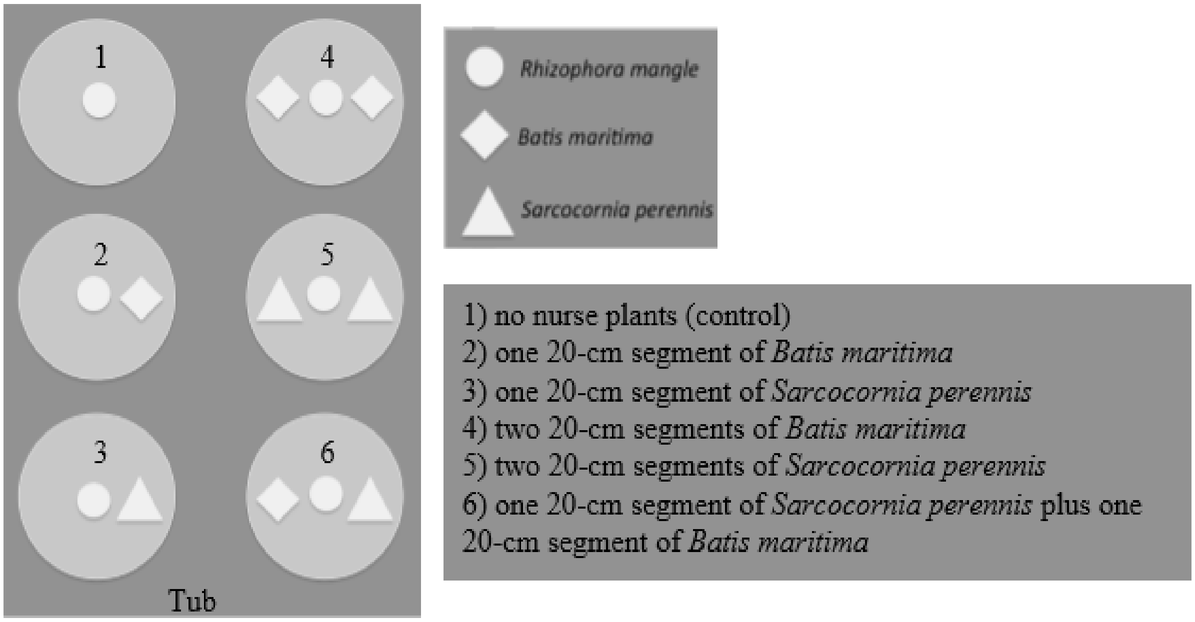
One possible explanation describing why facilitation was not observed in our field experiment can be found by comparing our experiments to that of McKee et al. (2007). They conducted a study in Belize where *R. mangle* propagules were collected and either planted or placed (laying down on top of sediment) in patches of two potential nurse plants (*Sesuvium portulacastrum*, *Distichlis spicata*) or on bare ground to determine if facilitation effects were present. The planted propagules had an 80 – 100% survival success rate regardless of vicinity to potential nurse plants. Our study only included planted seedlings in the field, and only six field *R. mangle* were lost out of 90 across all treatments. It is possible that different results would be obtained if *R. mangle* seedlings were planted and placed (laying down) in various combinations and densities of *B. maritima*, *S. perennis*, and on bare sediments. Vegetated shorelines with 100% coverage of *B. maritima* and *S. perennis* facilitated the retention of *R. mangle* propagules when placed on top of sediment instead of planted (Donnelly and Walters 2014). For our field experiment, an auger was used to ensure that holes created for plants were deep enough to support aboveground and belowground biomass. This planting method may have improved retention of seedlings in this study.

Whigham et al. (2009) sampled clear-cut and impounded mangrove forests throughout Belize and Florida and found that 88% of Belize sites and 55% of Florida sites indicated that mangrove establishment might have been facilitated by *B. maritima*. Additionally, Milbrandt and Tinsley (2006) concluded that *A. germinans* seedling restoration could be improved when seedlings are planted in established *B. maritima* patches. Thus, it is possible that, in order for *B. maritima* and *S. perennis* to facilitate mangrove survival, patches of the marsh plants must already be established and *R. mangle* needs to enter the community as a secondary settler (Rey et al. 1990). In that scenario, the marsh plants would act as facilitators by stabilizing *R. mangle* and not allowing them to be displaced by tidal fluctuations. In our experiment, *R. mangle* and marsh plants were planted at the same time; thus, the marsh plants were not established before the *R. mangle*. It is possible that the marsh plants would facilitate *R. mangle* survival and restoration success if the marsh plants were planted and established prior to planting the *R. mangle*.

Threats of sea-level rise and global degradation of mangrove forests make it imperative that we continue to examine plant-plant interactions of mangroves and surrounding marsh plants (Milbrandt and Tinsley 2006). According to Ellison (1993), mangrove forests have begun to retreat landward. This decreases coastal protection against storms and erosion, and also reduces habitat for many marine and terrestrial taxa. Likewise, Lu et al. (2013) found that higher tidal inundation due to sea-level rise would decrease the survival and growth of mangrove seedlings that are not already established. It is important that scientists and managers continue to research, understand, and gain more knowledge in all aspects involving mangrove ecosystems, and scientifically examine how to improve restoration on a local scale to restore and protect these habitats.

APPENDIX

Figure 1. Experimental setup of each tub that contained one treatment, with shapes representing each plant species



1) no nurse plants (control)
2) one 20-cm segment of *Batis maritima*
3) one 20-cm segment of *Sarcocornia perennis*
4) two 20-cm segments of *Batis maritima*
5) two 20-cm segments of *Sarcocornia perennis*
6) one 20-cm segment of *Sarcocornia perennis* plus one 20-cm segment of *Batis maritima*

Figure 2. Mean number of leaves per *R. mangle* (cm ± SE) after five months of growing in greenhouse among treatments. At time zero, all individuals had no leaves. Treatments were: 1) no nurse plants (control), 2) one 20-cm segment of *Batis maritima*, 3) one 20-cm segment of *Sarcocornia perennis*, 4) two 20-cm segments of *Batis maritima*, 5) two 20-cm segments of *Sarcocornia perennis*, and 6) one 20-cm segment of *Sarcocornia perennis* plus one 20-cm segment of *Batis maritima*.

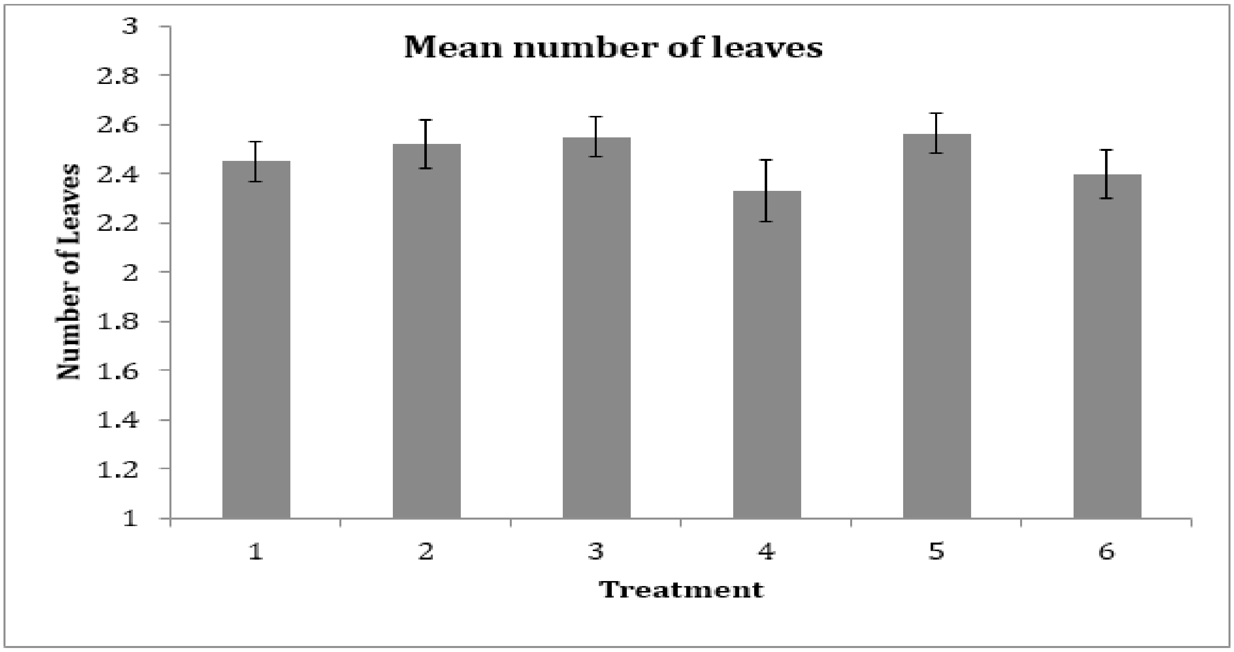


Figure 3. Mean change in height of *R. mangle* (cm ± SE) after five months of growing in greenhouse across treatments. Treatments were: 1) no nurse plants (control), 2) one 20-cm segment of *Batis maritima*, 3) one 20-cm segment of *Sarcocornia perennis*, 4) two 20-cm segments of *Batis maritima*, 5) two 20-cm segments of *Sarcocornia perennis*, and 6) one 20-cm segment of *Sarcocornia perennis* plus one 20-cm segment of *Batis maritima*.

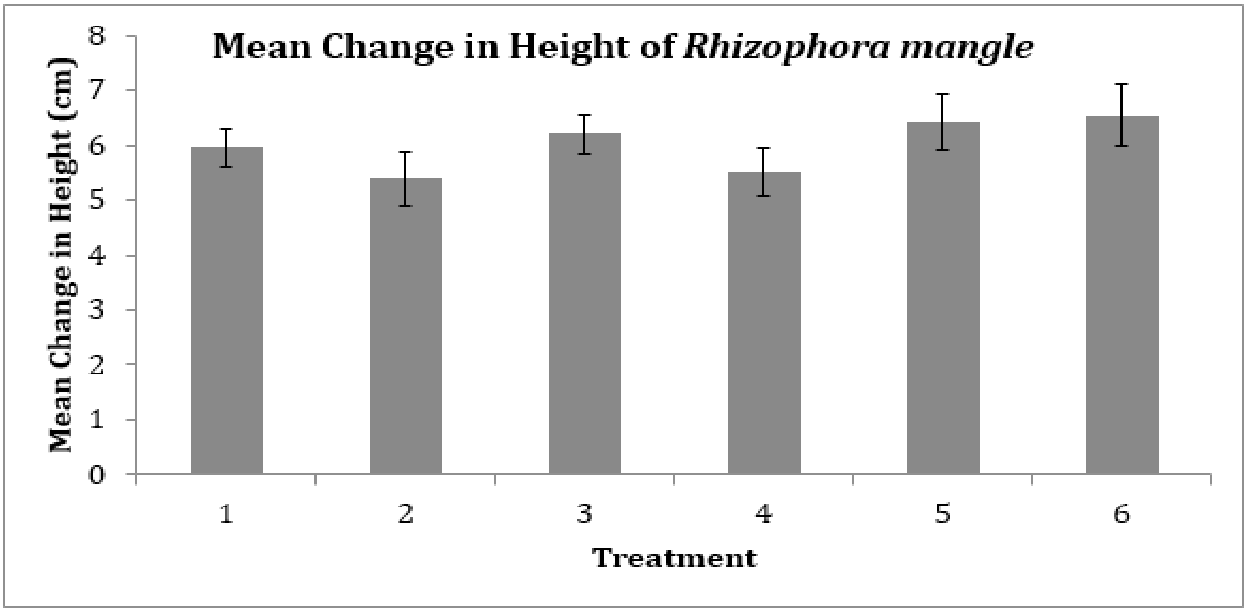


Figure 4. Mean final height (cm ± SE) of *Rhizophora mangle* across treatments after five months of growing in greenhouse. Treatments were: 1) no nurse plants (control), 2) one 20-cm segment of *Batis maritima*, 3) one 20-cm segment of *Sarcocornia perennis*, 4) two 20-cm segments of *Batis maritima*, 5) two 20-cm segments of *Sarcocornia perennis*, and 6) one 20-cm segment of *Sarcocornia perennis* plus one 20-cm segment of *Batis maritima*.

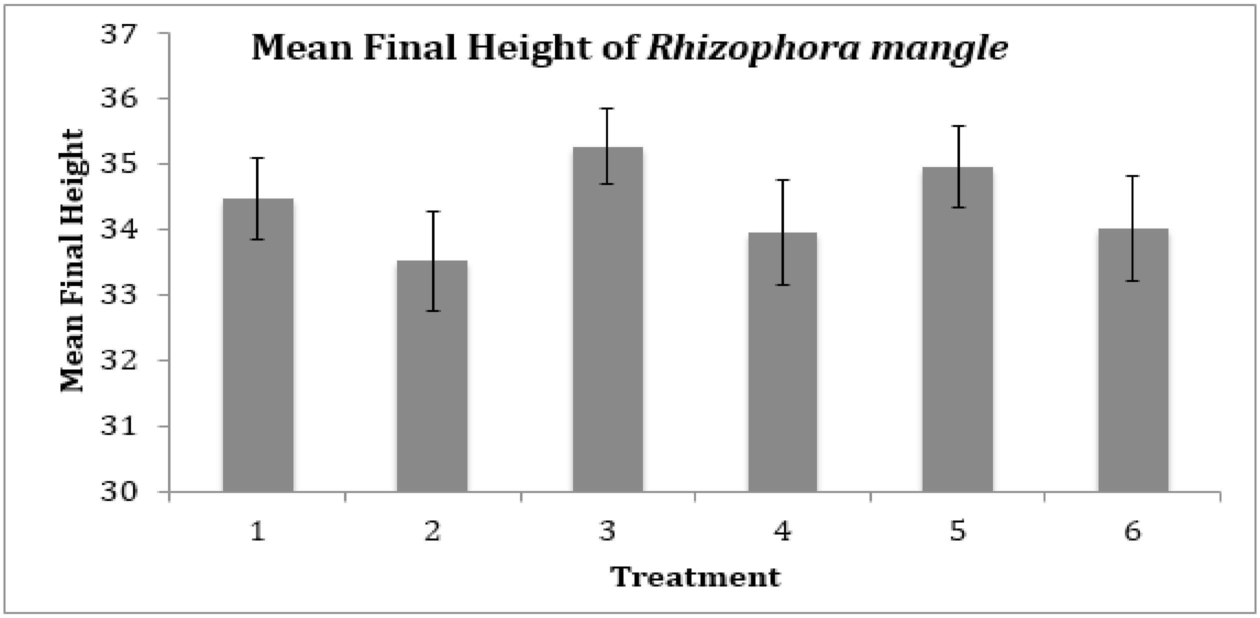


Figure 5. Mean total dry weight of *Rhizophora mangle* (aboveground and belowground biomass combined) in cm ± SE by treatment after five months of growing in greenhouse. Treatments were: 1) no nurse plants (control), 2) one 20-cm segment of *Batis maritima*, 3) one 20-cm segment of *Sarcocornia perennis*, 5) two 20-cm segments of *Batis maritima*, and 6) one 20-cm segment of *Sarcocornia perennis* plus one 20-cm segment of *Batis maritima*.

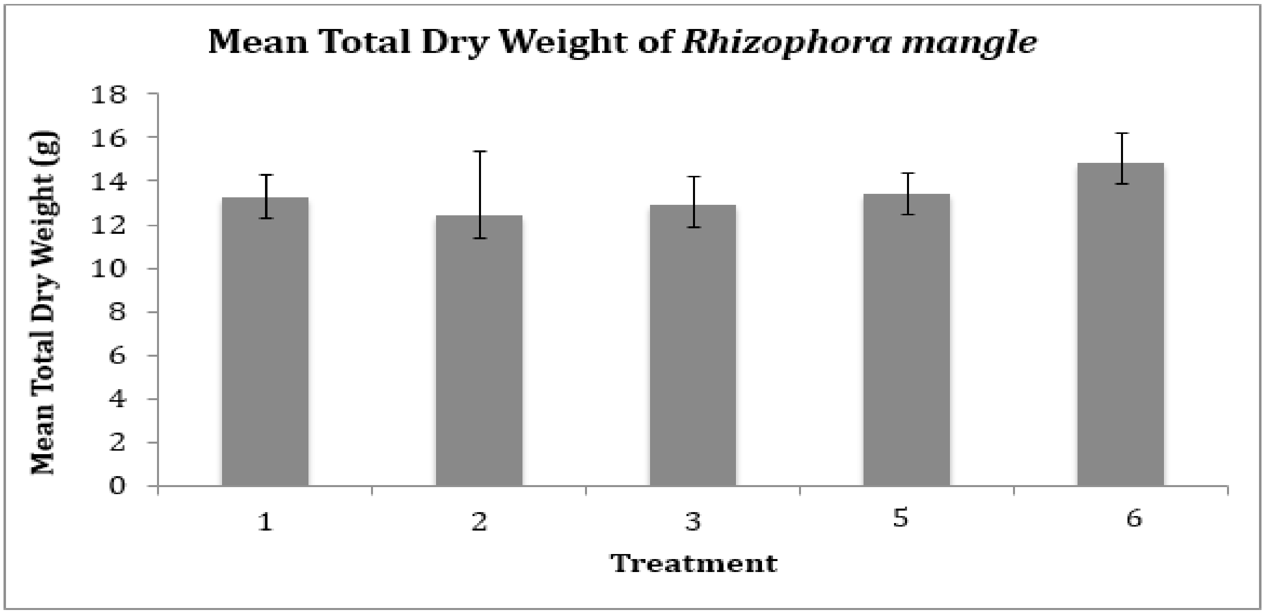


Table 1. Mortality by treatment of *Rhizophora mangle* after 70 days at Castle Windy, Canaveral National Seashore, New Smyrna, FL. Mortality was not significantly different across treatments (Wilcoxon-Gehan statistic=4.053, df=5.00, p=0.542). Treatments were 1) no nurse plants (control), 2) one 20-cm segment of *Batis maritima*, 3) one 20-cm segment of *Sarcocornia perennis*, 4) two 20-cm segments of *Batis maritima*, 5) two 20-cm segments of *Sarcocornia perennis*, and 6) one 20-cm segment of *Sarcocornia perennis* plus one 20-cm segment of *Batis maritima*.

Treatment	Number of *Rhizophora mangle* Deployed	Number of *Rhizophora mangle* Survived	Mortality Rate
1	15	14	6.67%
2	15	14	6.67%
3	15	13	13.3%
4	15	14	6.67%
5	15	14	6.67%
6	15	15	0.00%

REFERENCES

Adams, J.B., & Bate, G.C. 1994. The effect of salinity and inundation on the estuarine macrophyte *Sarcocornia perennis* (Mill.) A.J. Scott. *Aquatic Botany*, 47:34-348.

Alongi, D.M. 2002. Present state and future of the world's mangrove forests. *Environmental Conservation*, 29:331-49.

Bushnell D.I. 1915. The origin and various types of mounds in Eastern United States. *Proceedings of the Nineteenth International Congress of Americanists*, Washington, 19:43-47.

Cardona-Olarte, P., Twilley, R.R., Krasuss, K.W., & Rivera-Monroy, V. 2006. Responses of neotropical mangrove seedlings grown in monoculture and mixed culture under treatments of hydroperiod and salinity. *Hydrobiologia*, 569:325-41.

Connell, J.H., & Slatyer, R.O. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. *The American Naturalist*, 111:1119-44.

Davy, A. J., Bishop, G.F., Mossman, H., Redondo-Gomez, S., Castillo, J.M., Castellanos, E.M., Luque, T., & Figueroa, M.E. 2006. Biological flora of the British Isles: *Sarcocornia perennis*. *Journal of Ecology*, 94:1035-48.

Donnelly, M., & Walters, L. 2014. Trapping of *Rhizophora mangle* propagules by coexisting early successional species. *Estuaries and Coasts*, published on-line, DOI: 10.1007/s12237-014-9789-2.

Egerova, J., Proffitt, C.E., & Travis, S.E. 2003. Facilitation of survival and growth of *Baccharis halimifolia* L. by *Spartina alterniflora Loisel* in a created Louisiana salt marsh. *The Society of Wetlands Scientists*, 23:250-56.

Ehrmann W.W. 1940. The Timucuan Indians of sixteenth-century Florida. *The Florida Historical Quarterly*, 18(3):168-91.

Ellison, J.C. 1993. Mangrove retreat with rising sea-level, Bermuda. *Estuarine, Coastal, and Shelf Science*, 37:75-87.

Gill, A.M., & Tomlinson, P.B. 1969. Studies on the growth of red mangrove (*Rhizophora mangle L.*) I. habit and general morphology. *The Association of Tropical Biology and Conservation*, 1:1-9.

Lonard, R.I., Judd, F.W., & Stalter, R. 2011. The biological flora of coastal dunes and wetlands: *Batis maritima* C. Linnaeus. *Journal of Coastal Research*, 27:441-49.

López, R. P. 2007. The role of nurse plants in the establishment of shrub seedlings in the semi-arid subtropical Andes. *Oecologia*, 152:779-90.

Lu, W.Z., Chen, L.Z., Wang, W.Q., Tam, N.F.Y., & Lin, G.H. 2013. Effects of sea level rise on mangrove *Avicennia* population growth, colonization and establishment: Evidence from a field survey and greenhouse manipulation experiment. *Acta Oecologica-International Journal of Ecology,* 49:83-91.

Maestre, F.T., Callaway, R.M., Valladares, F., & Lortie, C.J. 2009. Refining the stress-gradient hypothesis for competition and facilitation in plant communities. *Journal of Ecology,* 97:199-205.

McKee, K.L., Rooth, J.E., & Feller, I.C. 2007. Mangrove recruitment after forest disturbance is facilitated by herbaceous species in the Caribbean. *Ecological Applications*, 17:1678-93.

Milbrandt, E.C., & Tinsley, M.N. 2006. The role of saltwort (*Batis maritima* L.) in regeneration of degraded mangrove forests. *Hydrobiologia*, 568:369-77.

Pennings, S.C., & Callaway, R.M. 2000. The advantages of clonal integration under different ecological conditions: A community-wide test. *Ecology*, 81:709-16.

Rey, J.R., Crossman, R.A., & Kain, T.R. 1990. Vegetation dynamics in impounded marshes along the Indian River Lagoon, Florida, USA. *Environmental Management*, 14:397–409.

Twilley, R.R., & Rivera-Monroy, V.H. 2005. Developing performance measures of mangrove wetlands using stimulation models of hydrology, nutrient biogeochemistry, and community dynamics. *Journal of Coastal Research*, 40:79-93.

Valiela, I., Bowen, J.L., & York, J.K. 2001. Mangrove forests: One of the world's threatened major tropical environments. *BioScience*, 51:807-15.

Waisel, Y. 1972. The biology of halophytes. Academic Press.

Whigham, D.F., Whigham, M.C., Feller, I.C., & Rodriquez, W. 2009. Ecological characteristics of *Batis maritima* in Florida and Belize. *Smithsonian Contributions to the Marine Sciences*, 38:491-99.