Growth and succession of *Avicennia germinans*, *Laguncularia racemosa*, and *Rhizophora mangle* by site age across three created mangrove wetlands

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Introduction

Wetlands around the world have been declining in health and area, often filled or drained for agriculture or development, or their hydrology is altered by channels or dams (Lewis 2005). Healthy wetlands maintain ecologically and economically important animal species, provide nutrients to support estuaries (Zedler 2000), prevent flooding and erosion, filter pollutants, and absorb atmospheric CO_2 (Erwin 2008). In response to this, restoration has been widely implemented (Matthews and Endress 2008).

Created mangrove forests in Tampa Bay are excavated to an acceptable tidal datum and planted with native salt marsh grasses to create immediate structural habitat, stabilize substrates, and accelerate secondary succession to mangrove forest (Lewis and Dunstan 1975; Osland, et al 2012). However, there is a poor understanding of the successional pathway of these forests. Starting conditions at our sites were *S. alterniflora* low marsh and *S. patens* high marsh, within which mangrove recruitment occurred naturally. It is very poorly documented that *Laguncularia* rather than *Rhizophora* initially recruits heavily into the lowest, most flooded elevations, but this is readily observed in the field (Smith, et al 2009). Our study uses a chronosequence to quantify the community development and succession from salt marsh to mangrove forest via natural recruitment in three created wetlands ranging in age from 3 years to 16 years in 2015, the first data collection year.

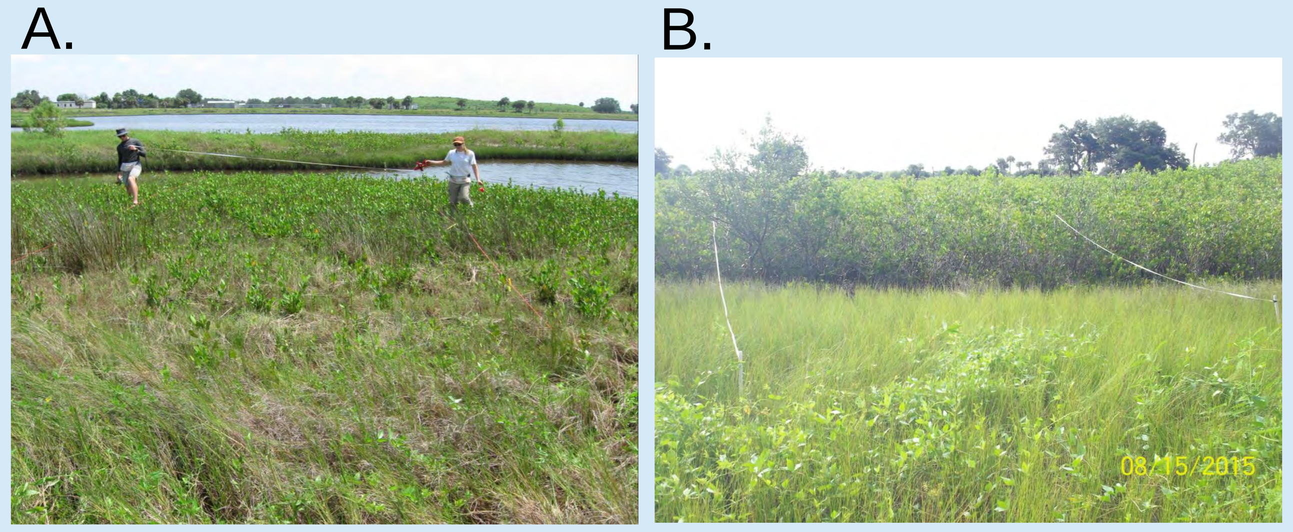

Figure 1. A.) 5 m spacing for a plot is measured at Shell Pit, the youngest site (3 years in 2015). B.) Two 14 m length boundaries of a plot are marked with transect tapes at Braided Creek, the intermediately-aged site (10 years in 2015).

Methods

In August 2015 and 2016, we collected data from three created mangrove wetlands within the Cockroach Bay Aquatic Preserve on the eastern shoreline of Florida's Tampa Bay estuary. At the end of the two year study (2015), ages of the three sites were 4 years (Shell Pit), 11 years (Braided Creek) and 17 years (Frog Pond) old.

At each of the three sites, we set up five replicate plots that extended 5 m parallel to the shoreline and 14 m perpendicular to and away from the shoreline (Figure 1). We used a randomized block design and plots were spaced at least 10 m apart to compensate for soil and hydrologic gradients.

• *Adult trees*: Within the entire 14 m x 5 m (70 m²) plot for adult mangroves (those trees with DBH≥6 cm), we measured their DBH (cm) at a height of 1.3 m on the trunk and recorded their species.

When facing the creek, the left-hand boundary of each plot was established as the 'quadrat transect' (Figure 2) where we placed 1 m x 1 m (1 m²) PVC quadrats along the quadrat transect at 0 m, 3 m, 6 m, 9 m and 12 m, with 0 m being at the waterline.

•*Young trees*: For trees taller than 3 m and with a DBH<6 cm we measured their DBH (cm) at a height of 1.3 m on the trunk and recorded their species. At Braided Creek, these were very few and were measured throughout the 70 m² plot, while they were more abundant and measured in the 1 m² quadrats at Frog Pond. There were no trees at Shell Pit.
•*Juveniles*: Height (cm) to the tallest point of all juvenile mangroves (30 cm-3 m tall) was measured and their species recorded.
•*Seedlings*: mangrove seedlings (<30 cm tall) were counted and their species recorded.

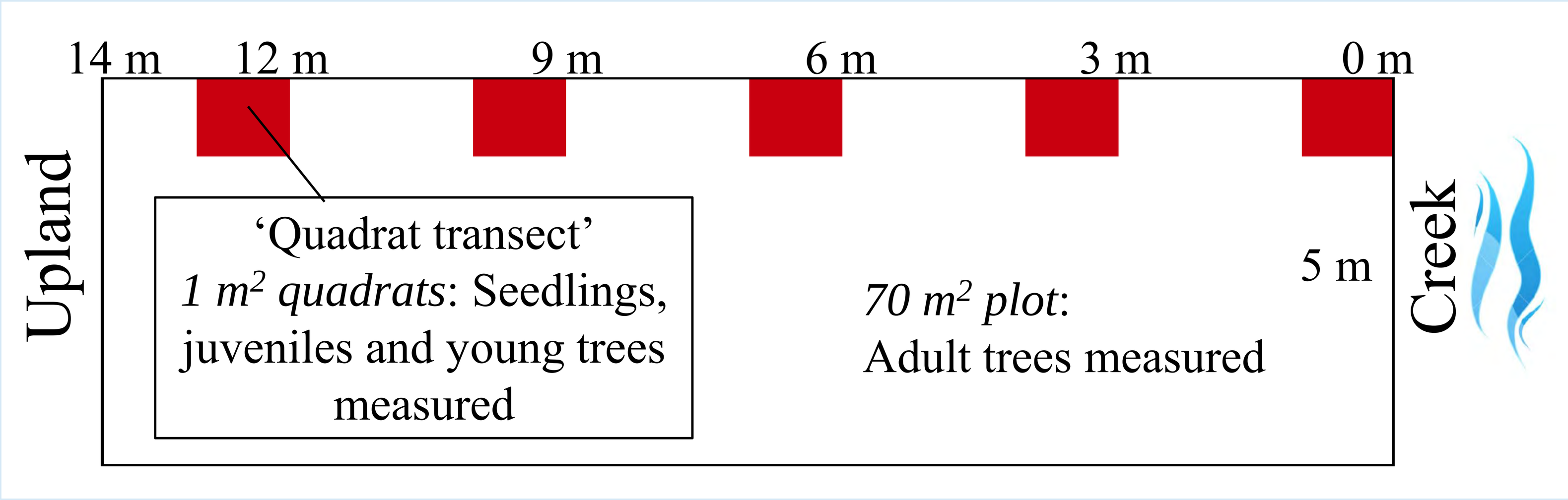

Figure 2. Illustration of one of five replicate 14 m x 5 m plots. Red boxes represent 1 m x 1 m quadrats placed along the quadrat transect. Seedling, juvenile and young tree data were collected inside the quadrats. Adult trees were measured throughout the entire plot.

Seedlings

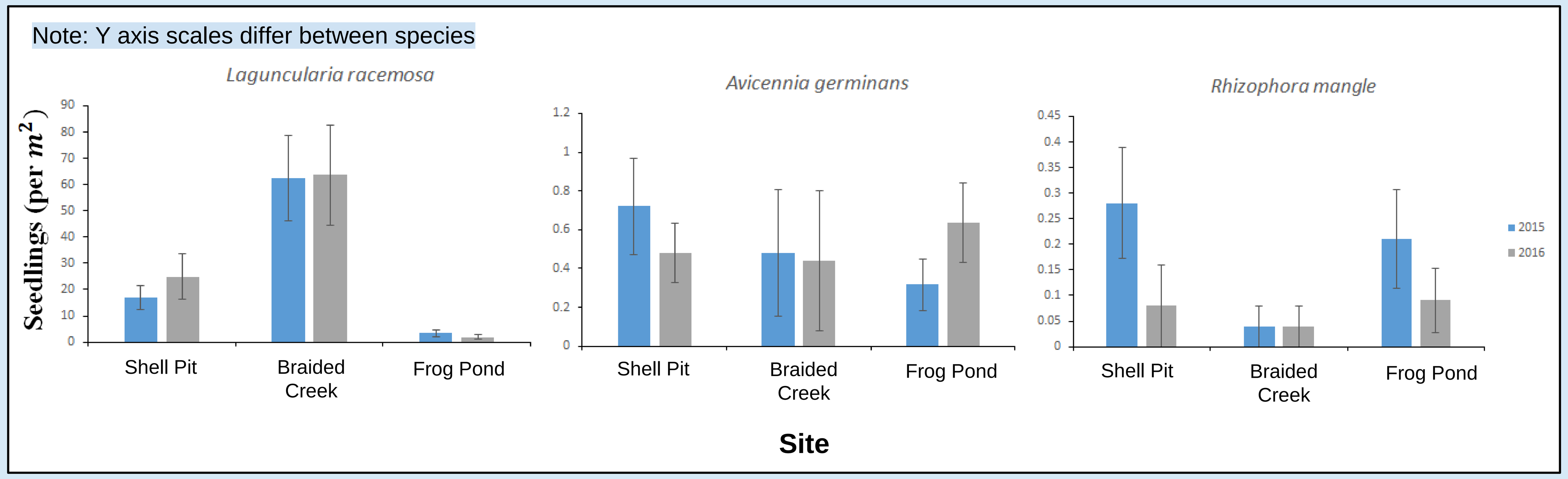

Figure 3. Mean (±s.e.) number of seedlings per m² by site for each species. Shell Pit is the youngest site (4 years in 2016) (n=25), Braided Creek is intermediate in age (11 years in 2016) (n=25), and Frog Pond is the oldest site (17 years in 2016) (n=19 in 2015 and n=22 in 2016). Note: y-axis scales differ. Difference between sample years was not significant.

Juveniles

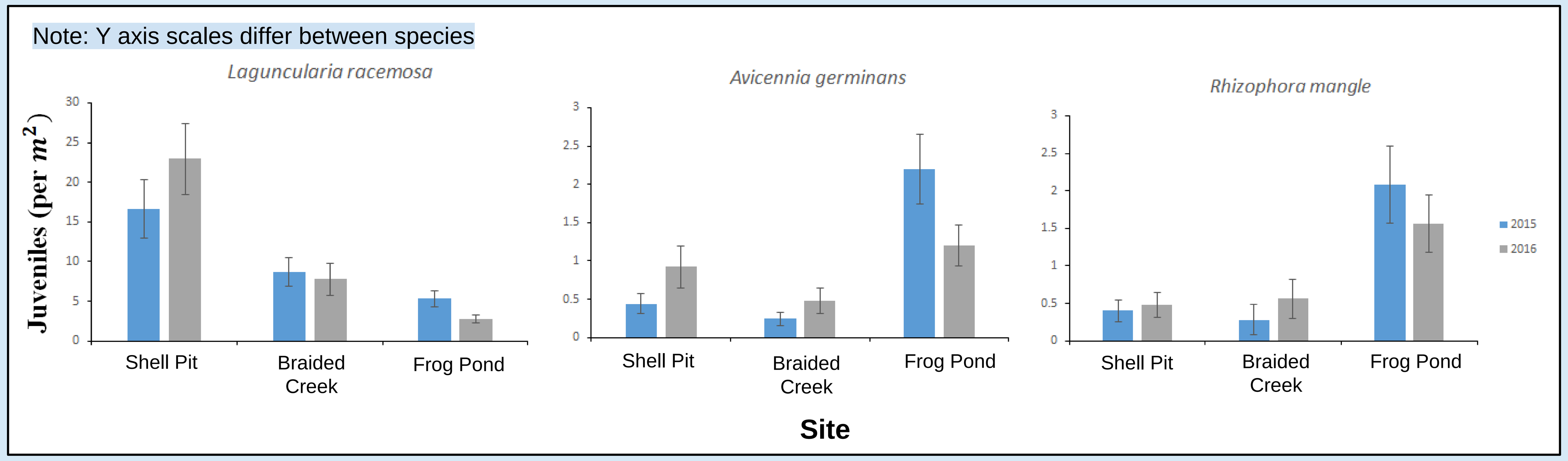

Figure 4. Mean (±s.e.) number of juveniles per m² by site for each species. Shell Pit is the youngest site (4 years in 2016) (n=25), Braided Creek is intermediate in age (11 years in 2016) (n=25), and Frog Pond is the oldest site (17 years in 2016) (n=25). Note: y-axis scales differ. Difference between sample years was not significant.

Young Trees and Adult Trees

Table 1. Mean (±s.e.) number of young and adult trees per m² by species at Braided Creek (aged 11 years in 2016) and Frog Pond (aged 17 years in 2016) (n=5, except n=25 for young trees at Frog Pond). There were no trees at the youngest site, Shell Pit (aged 4 years in 2016) in either 2015 or 2016. Difference between sample years was not significant.

Year	Site	Young Trees			Adult Trees		
		Avicennia germinans	*Laguncularia racemosa*	*Rhizophora mangle*	*Avicennia germinans*	*Laguncularia racemosa*	*Rhizophora mangle*
2015	Braided Creek	0.0003 ± 0.0003	0	0	0	0	0
	Frog Pond	0.0400 ± 0.0400	0.8400 ± 0.2926	0.2400 ± 0.1661	0.0400 ± 0.0181	0.0114 ± 0.0083	0
2016	Braided Creek	0.0114 ± 0.0083	0	0.0057 ± 0.0057	0	0	0
	Frog Pond	0.1600 ± 0.0945	0.8400 ± 0.2561	0.2800 ± 0.1781	0.0514 ± 0.0277	0.0171 ± 0.0105	0.0057 ± 0.0035

Results

High numbers of *L. racemosa* dwarf *A. germinans* and *R. mangle* as seedlings and juveniles, but decrease with both tree and site age.

***L. racemosa* seedlings dominated, regardless of site age or of sample year**. *A. germinans* and *R. mangle* seedling numbers ranged from 0.77% to 9.38% of *L. racemosa* seedlings in 2015 and 0.06% to 33.3% in 2016, with the largest differences at the intermediately-aged site, Braided Creek (Figure 3). Number of *A. germinans* and *R. mangle* seedlings was less than 1 seedling/m², regardless of site age. However, *L. racemosa* seedling numbers ranged from 1.90-63.60 seedling/m², being **lowest at the oldest site** (17 year old Frog Pond) and **greatest at the intermediately-aged site** (11 year old Braided Creek) (Figure 3). ***L. racemosa* seedlings established heavily in numbers at all elevations** (data not shown), including along the creek edge, while *R. mangle* and *A. germinans* seedlings were comparatively few.

***L. racemosa* juveniles were dominant at all sites for both years, as well.** At the youngest site, Shell Pit, *L. racemosa* numbers were 25%-38% greater than *A. germinans* and 42%-48% greater than *R. mangle*. At the oldest site, Frog Pond, *L. racemosa* numbers were only 2.3%-2.4% greater than *A. germinans* and 1.7%-2.3% greater than *R. mangle* (Figure 4). ***L. racemosa* juveniles were greatest at the youngest (4 year old) site, Shell Pit.**

By 2016 young trees were present only at the older sites, Braided Creek (11 years) and Frog Pond (17 years). Adult trees were only present at Frog Pond where there were approximately three times more *A. germinans* trees/m² (0.051 ± 0.028) than *L. racemosa* trees (0.017 ± 0.011), and over eight times more *A. germinans* than *R. mangle* trees (0.006 ± 0.004) (Table 1).

Discussion

Our results strongly support that *L. racemosa* is the pioneer mangrove species at all elevations in the secondary succession of a created salt marsh transitioning to a mangrove forest. Overwhelming numbers of *L. racemosa* seedlings and juveniles at the creek edge and in the low marsh indicates that *L. racemosa* has the physiological tolerance to live at these elevations, while the faster transition of *R. mangle* and *A. germinans* recruits into trees suggests that these species dominate in lower elevations due to competitive exclusion of *L. racemosa*. This early and dominating presence of *L. racemosa* is rarely documented in the scientific literature (Smith et al 2009).

These data also support other studies that estimate wetland creation requires a scale of decades to reach vegetative success, usually at 20 years or later (Zedler 2000; Lewis 2005; Spieles 2005, Erwin 2008; Osland et al 2012), and Frog Pond (at 17 years old) is still not yet equivalent to a mature forest. Continued assessment of these sites is essential to determining pathways of mangrove succession post-restoration and to assess functional equivalency of created mangroves to natural mangrove forests.

While the success of vegetation at Frog Pond is encouraging, assessing vegetation alone cannot conclusively indicate that the mangrove forest is a fully functioning wetland ecosystem. Previous studies have found that vegetation reaches equivalency far sooner than soil conditions (Whigham 1999, Osland et al 2012). Soil organic matter, redox potential, hydrology, salinity, and invertebrate community all need to be assessed to accurately determine the restored functionality of a site (McKee and Faulkner 2000, Smith et al 2009, Osland et al 2013).

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