2017

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Recommended Citation
Judd, F. W., Sunny, K. R., Lonard, R. I., & Mazariegos, R. A. (2017). Survivorship and Growth Among Three Developmental Stages of Black Mangrove (Avicennia germinans) Seedlings in Southernmost Texas. Subtropical Agriculture and Environments, 68, 13–17.

Subtropical Agriculture and Environments 68:13-17.2017

Survivorship and Growth Among Three Developmental Stages of Black Mangrove (*Avicennia germinans*) Seedlings in Southernmost Texas

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ABSTRACT

Black mangrove is useful for shoreline stabilization in Texas and Mexico but there is insufficient information regarding propagule survivorship and seedling growth. We compared survivorship and growth of three developmental groups of black mangrove seedlings planted on three dredge spoil islands in the Lower Laguna Madre of Texas, to better understand optimum planting strategy. Each spoil island had 100 seedlings without emergent radicles, 100 seedlings with emergent radicles, and 75 head-started seedlings. Survivorship of seedlings with and without emergent radicles was low, (0-16%). Survivorship of head-started seedlings was higher, (60 – 62.7%). Variation in survivorship among developmental categories was significant but variation among islands was not. The 16 surviving seedlings with emergent radicles censused 346 days after planting were similar in mean height (32.9 cm) and mean number of pairs of leaves (13.2) to head-started seedlings grown for 376 days (105 days in nursery, 271 days on Island 1). Growth rates for height ranged from 0.041 cm/day to 0.058 cm/day. Growth in mean pairs of leaves ranged from 0.042 pairs/day to 0.051 pairs/day. Comparison of the person-days required to have 300 seedlings alive one year after field planting shows that head-starting is clearly the preferable planting strategy.

Additional Index Words: Avicennia germinans, black mangrove, seedling propagation, Lower Laguna Madre of Texas, shoreline stabilization, head-started plants, revegetation.

Mangrove communities constitute a distinctive habitat in Texas Gulf Coast bays and on barrier islands. Mangroves are characteristic of tropical shores, but typically one or two cool tolerant species extend into warm temperate zones in both the northern and southern hemispheres. For example, four mangrove species occur along northern Tamaulipas, Mexico shores, but only the black mangrove, *Avicennia germinans*, has extensive populations extending into Texas (Sherrod and McMillan, 1981). Black mangrove populations occurring on Texas shores are capable of surviving colder temperatures than populations of the same species from tropical Mexico (McMillan, 1975). Black mangrove occurs as far north as Galveston Island in Texas, but the specimens here are small, sparse and the above ground parts are readily killed by hard winter freezes (McMillan, 1971; Sherrod and McMillan, 1981).

Mangroves are extremely important marine communities in bays and along barrier islands in Texas. The aerial roots (pneumatophores) of black mangrove trap sediment, and in doing so help to prevent erosion and extend shorelines. Black mangroves provide perching and nesting sites for birds in areas where shrubs and trees (e.g. South Padre Island) are absent or scarce. The dense tangle of black mangrove stems and pneumatophores provide protection from larger fish predators to small and medium sized fish and invertebrates. Consequently, mangrove communities serve as nursery areas for many fish and shellfish species and they increase species richness. However, its utility in restoration is diminished by inefficient propagation. Black mangrove is a viviparous plant. Germination occurs on the parent plant and the propagule for the new generation is already a seedling when it drops free of the parent plant. La Rue and Muzik (1951) report that the radicle is free from the cotyledons at this point and that the radicle acts much as a spear and enters the sediment when the seedling drops. On South Padre Island, Texas, most seedlings do not drop in this fashion, but rather fall on their sides where many are washed away by tides and currents to new locations. In addition, many seedlings drop before the radicle is emergent.

The most common method of propagation of black mangrove is said to be the transplantation of green-house-grown seedlings to field sites when the plants are 38 to 64 cm in height. Toledo et al. (2001) report seventy four percent survivorship of nursery–initiated mangrove seedlings two years after transplantation to field sites on the west coast of Mexico. Nursery propagation is time-consuming and costly. Can survivorship be adequate if mangrove seedlings are directly sown in place at field sites?

We compared the survivorship and growth of three developmental groups of black mangrove seedlings:

a. seedlings lacking an emergent radicle planted directly to a field site.
b. seedlings with an emergent radicle planted directly to a field site.
c. seedlings head-started in a nursery and subsequently transplanted to a field site.

We tested the null hypothesis that there would be no significant difference in percent survival or growth among the three groups.

MATERIALS AND METHODS

Seedlings were collected from black mangrove plants at South Padre Island, Texas, and on dredge spoil islands in the Lower Laguna Madre adjacent to South Padre Island. Field plantings were placed on the dredge spoil islands because stabilization of the spoil islands is a concern for the health of sea grass beds and it was thought that plantings would be less likely to be disturbed by humans there than on the South Padre Island bayshore. Three spoil islands were selected for the plantings. Island 1 is located at 26º20´30´´ N, 97º19´09´´ W, Island 2 at 26º20´40´´ N, 97º19´15´´ W, and Island 3 at 26º19´43´´ N, 97º18´57´´ W. All are located to the west of the Gulf Intracoastal Waterway and they range from 5.0 km to 6.5 km south of the mouth of the Arroyo Colorado. The islands had similar substrates and all possessed patchily distributed mangrove populations. Each of the three spoil islands had 100 seedlings without emergent radicles, 100 seedlings with emergent radicles and 75 head-started seedlings.

Seedlings without emergent radicles were defined as those in which the radicle did not extend past the cotyledons. Seedlings with emergent radicles were those where the radicle extended for 5 mm or more past the cotyledons. Seedlings with and without emergent radicles were separated into two groups of 300 each and divided into three replicates of 100 seedlings per replicate. Two hundred twenty-five seedlings with emergent radicles were selected for head-starting. These were planted individually into paper cups (10.2 cm tall, top diameter 8.5 cm, bottom diameter 5.0 cm, volume 380 ml) filled with potting soil, and grown for 134 to 144 days and a mean height of 17.14 cm or greater (Table 5) prior to being transported to field sites. The seedlings were watered every third day with 100 ml of 25% sea water.

Seedlings were planted in a line parallel to the bayshore of a spoil island with seedlings spaced one m apart and marked with a survey flag. The starting and ending points of the line were recorded using a Global Positioning System receiver with 3 to 5 m accuracy. Seedlings, with and without emergent radicles, were planted individually in shallow holes with the radicles pointing downward and the cotyledons covered lightly with soil. Head-started seedlings were planted individually in trowel dug holes about 150 mm deep. Seven--five head-started seedlings were planted on each of the three spoil islands. Data on percent survival were analyzed using a one-way Anova for developmental categories and a one-way Anova for islands. Survivorship of head-started seedlings was similar on Islands 1 (62.7%) and 3 (60%), but seedlings on Island 2 were pulled up by vandals (Table 1).

RESULTS

Survivorship. Only two survivors out of 300 seedlings (both on island 2) planted without emergent radicles survived for longer than 228 days (Table 1).

Survivorship also was low (16%) and limited to one island (#1) for seedlings planted with emergent radicles (Table 1). Island 3 had no survivors past 228 days in either the emergent radicle or no emergent radicle

Table 1. Comparison of percent survival among developmental categories and spoil islands, Laguna Madre, Cameron County, Texas. For the "no emergent radicle" and "emergent radicle" categories 100 seedlings were planted on each of the three spoil islands. For "head-started plants" 75 seedlings were planted on each spoil island. Head-started seedlings on Island 2 were pulled up by vandals. Thus, we do not have % survival for this cohort.

Developmental Category	Island #	% Survival	Elapsed Days
No Emergent Radicle	1	0	256
	2	2	403
	3	0	228
Emergent Radicle	1	16	337
	2	0	365
	3	0	200
Head Started Plants	1	62.7	271
	2	Plants vandalized	
	3	60	254

categories (Table 1). Head-started seedlings had markedly greater survivorship (60.0-62.7%). Survivorship of head-started seedlings was similar on Islands 1 (62.7%) and 3 (60%), but seedlings on Island 2 were pulled up by vandals (Table 1). An ANOVA showed that survivorship among developmental categories was significant (F = 72.58, 2&5 df, P < 0.001; Table 2) but

Table 2. One-way ANOVA table for variation of percent survival of black mangrove seedlings among developmental categories in the lower Laguna Madre, Cameron County, Texas. DF = degrees of freedom, SS = sums of squares, F&P = variance ratio and probability. Raw data are provided in Table 1.

Source	DF	SS	MS	F & P
Among categories	2	5139.715	2569.857	F = 72.588, 2&5 df, P < 0.001
Within categories	5	177.015	35.403	

that variation among islands was not (F = 0.437, 2&5 df, P >0.5; Table 3).

Growth. Sample size of surviving seedlings without emergent radicles was too small (2) to facilitate comparisons of growth with other groups. Growth in height and number of pairs of leaves of the 16 survivors from the cohort of seedlings with emergent radicles planted directly into a field site on Island 1 is provided in Table 4. Mean height and mean number of pairs of leaves were similar to the same measurements in head-started seedlings censused 271 days after planting on Island 1 (Table 6). There was no significant difference in mean height (*t* = 0.380,61 *df, P> 0.5)* or mean number of pairs of leaves (*t* =1.768, 61 *df, P* > 0.05) of the two groups of seedlings.

Table 3. One-way ANOVA for comparison of percent survival among 3 spoil islands planted with black mangrove propagules. Raw data are given in Table 1. Explanations of abbreviations are given in Table 2.

Source of variation	DF	SS	MS	F & P
Among islands	2	792	396	F = 0.437, 2&5 df P > 0.5, < 0.75
Within islands	5	4524.7	904.94	

Table 4. Parameters for height and number of pairs of leaves for seedlings planted with emergent radicles and censused 346 days after planting.

Parameter	Height (cm)	Number Pairs of Leaves
Sample size (survivors)	16	16
Mean	32.87	13.19
Standard Deviation	4.3	4.83

The mean height and mean number of pairs of leaves of head-started black mangrove at the time of planting on three spoil islands in the lower Laguna Madre, Texas, are shown in Table 5. There was no significant difference in mean height of the three groups of seedlings (*F* = 2.161, 2 & 222 *df, P* > 0.1). Thus, difference in height among the three groups after planting was not due to difference in height at the time of planting.

Conversely, the mean number of pairs of leaves of head-started seedlings showed a strong significant difference among the islands at the time of planting (*F*= 64.976, 2 & 222 *df, P* < 0.001), Seedlings planted on Island 1 had significantly more leaves than seedlings planted on Island 2 (*t* = 3.152, 149 *df, P* < 0.01*)* and seedlings planted on Island 2 had a significantly greater mean number of pairs of leaves than seedlings planted on Island 3 (*t* = 12.174, 149 *df, P*< 0.001).

Table 6 shows a comparison of mean height of head-started black mangrove seedlings 254 to 271 days after planting. Head-started seedlings on Island 1 were significantly taller, (*t* = 3.051, 90 *df, P* < 0.01) than head-started seedlings on Island 3. Growth in height of head-started seedlings expressed as mean cm/day was 0.052 cm/day for Island 1, and 0.041 cm/day for Island 3. Unfortunately plants on Island 2 were vandalized.

Table 5. Mean height (cm) and mean pairs of leaves of head started black mangrove seedlings at the time of planting on three spoil islands in the lower Laguna Madre, Texas. N = sample size, SD = one standard deviation of the mean. Prs Leaves = pairs of leaves.

Parameter	Height			Prs Leaves		
	Island 1	Island 2	Island 3	Island 1	Island 2	Island 3
N	75	75	75	75	75	75
Mean	17.9	17.46	17.14	4	3.71	2.59
SD	7.77	2.18	3.16	1.05	0.75	0.5

A comparison of mean number of pairs of leaves of head-started black mangrove 254 to 271 days after planting is provided in Table 6. Seedlings on Island 1 had significantly more leaves at the end of the experimentthan seedlings on Island 3 (*t* = 3.05, 90 *df,*

Table 6. Comparison of mean height (cm) and mean number of pairs of leaves of head-started black mangrove seedlings 254 to 271 days after field planting. N = sample size, SD = one standard deviation of the mean.

Parameter	Island 1	Island 2	Island 3
Elapsed Days	271		254
N	47		45
Mean (height in cm)	32.1	Plants vandalized	27.5
SD (height)	7.73		6.76
Mean (pairs of leaves)	17.8	Plants vandalized	13.3
SD (pairs of leaves)	10.07		8.09

$P < 0.01$). Growth in mean pairs of leaves of head-started seedlings per day from field planting to the end of the study was 0.051 pairs of leaves/day for Island 1, and 0.042 pairs of leaves per day for Island 3.

DISCUSSION

Survivorship. Rabinowitz (1978b) reported that seedling mortality of *Avicennia* in the first year of life is high. She found that survival in Panama was 0% 262 days after planting. Conversely, Davis (1940) found that *Avicennia germinans* seedlings grown in open areas in Florida wetlands for a year had 30% survivorship. Toledo et al. (2001) reported direct sowing of black mangrove propagules in dry climate ecosystems is usually unsuccessful. The propagules may survive initially, but they eventually die within a few months. This also is what we observed in a semiarid environment. Plants lacking well-developed root systems i.e. those picked directly off shrubs and lacking emergent radicles or seedlings with small emergent radicles, but lacking additional roots had low survivorship.

Toledo et al. (2001) reported that black mangrove seedlings grown in an outdoor nursery for three months and transplanted to a clear-cut area in a black mangrove forest at Laguna de Balandra, Baja California Sur, Mexico, had a survivorship of 96% after one month, 77% after one year and 74% after two years. The one year and two year data are slightly higher than the survivorship that we obtained on Islands 1 and 3 for head-started seedlings, but both studies show that head-starting greatly improves survivorship over the planting of propagules lacking root systems.

One of the causes of the high mortality on early seedlings is likely predation. Smith (1987) showed that small crabs belonging to the family Grapsidae were significant predators on early seedlings (cotyledons present) of five mangrove species. Indeed, 75.7% of the seedlings he used in experiments were consumed by crabs (Smith, 1987). We noted an abundance of crab burrows in the areas were we planted seedlings. Seedlings with and without emergent radicles were inserted directly into the soil, so it was easy for crabs to find and consume or carry away seedlings to their burrows. Conversely, head started seedlings had developed partially woody stems and no longer had cotyledons with stored starch available. This may account (in part) for the higher survivorship of head-started seedlings for they were no longer susceptible to predation by crabs.

A second cause of high mortality in *Avicennia* seedlings was provided by Rabinowitz (1978a) who showed that propagule weight and survivorship of mangroves are positively correlated. She reported that this relationship suggests that photosynthetic assimilation is being outstripped by respiration and that the seedlings die from gradual exhaustion of embryonic reserves.

Rabinowitz (1978b) collected propagules from *Avicennia bicolor* and *Avicennia germinans* trees in Panama. Because she was unable to distinguish between the propagules of the two species in the first year of study, they were combined and reported under the genus name, *Avicennia*. The propagules were collected after the pericarp was shed but before the cotyledons had spread fully. Consequently, our categories of emergent and non-emergent radicles corresponded with this group of propagules. Rabinowitz (1978b) placed propagules flat on their sides on the mud, covered with coarse cheesecloth and anchored with wire to help prevent them from being washed away with tides. Until the first measurements were taken, the propagules were replaced if some of them rotted or washed away.

Rabinowitz (1978b) found that *Avicennia* propagules grew 6.76 cm in height in 83 days and 10.38 cm in height in 121 days. Expressed as cm/day, the values were 0.081 and 0.086. We found that growth in height was 0.052 cm/day on Island 1 over a period of 271 days and 0.041 cm /day over 254 days on Island 3. Clearly growth was more rapid in Panama than in southern Texas. This was no doubt due in large part to continually high temperatures in Panama while lower temperatures prevailed during the relatively cool months of December through March in this study. Additionally, the growth of *A. bicolor* might be more rapid than that of *A. germinans* and could have affected the growth reported for *Avicennia* in Panama (Rabinowitz, 1978b).

Optimum planting strategy. The average percent survival of propagules (with and without emergent radicles combined) taken from parent shrubs and planted directly in the field is 3.0%. The survival of head started seedlings on Islands 1 and 3 was 20 times greater than this. One would have to plant 10,000 field collected and direct planted seedlings to get 300 seedlings alive after one year. Conversely, one would need to plant 500 head-started seedlings to get 300 seedlings alive at one year after field planting. Experience gained in this study showed that one would need to plant about 550 seedlings in an outdoor nursery to have 500 seedlings ready for field planting in 105 days.

Both direct seeding and head-starting require collecting propagules to use for planting but head-starting requires far fewer propagules. One person could collect enough propagules to provide 550 seedlings in one-half day. Collecting enough propagules for direct seeding of 10,000 individuals would take 20 times as long, i.e. about 10 days

One person can plant 550 head-started seedlings in two days. Direct seeding is faster, but it still requires measuring for proper spacing and digging small holes to plant the propagules in. It will take one person at least 20 days to accomplish the planting of 10,000 individuals. And, one may have to move from one site to another to get the 10,000 propagules planted in appropriate habitat. This will take additional time.

After planting there is no maintenance associated with maintaining direct seeded propagules. However, head-started seedlings will require watering at least twice a week for 15 weeks, i.e. about 30 times while they are growing in a nursery. Each watering period will take one person about one day to accomplish. Thus, the per person days required by the two strategies to have 300 seedlings alive one year after field planting is similar, i.e. 30 days for direct seeding and 32.5 days for head-starting. Given the markedly higher survival of head-started seedlings this strategy is clearly preferable.

ACKNOWLEDGEMENTS

Thanks are extended to the Coastal Conservation Association of Texas for financial support.

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