

Primary Research Paper

The role of saltwort (*Batis maritima* L.) in regeneration of degraded mangrove forests

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Abstract

While saltwort (*Batis maritima* L.) is common in the fringe mangrove forests of southwest Florida, its role in regeneration of degraded mangrove communities is not known. Given the potential encroachment and subsequent degradation of mangrove communities by sea-level rise, it is important to quantify the effect of early-colonizing vegetation to early mangrove seedling survival. A greater number of mangrove seedlings were observed in existing *B. maritima* patches compared to surrounding mudflats. A planting experiment was designed to determine whether *B. maritima* was responsible for the observed pattern. Black mangrove (*Avicennia germinans* L.) seedlings, raised in a nursery, were planted in previously established *B. maritima* patches and on mudflats with and without nursery-raised *B. maritima*. There was significantly lower mortality of *A. germinans* seedlings when planted in existing *B. maritima* patches (69%), compared to seedlings planted on the mudflats (93%), demonstrating that existing *B. maritima* improved *A. germinans* seedling survival. Nursery-raised *B. maritima* had lower mortality on open mudflats (28%), suggesting that it can tolerate conditions, which make it an early colonizer of newly available habitats. The primary mechanism proposed for improving seedling success is a slight increase in elevation provided by the dense root network of established *B. maritima*. These findings have implications for scientists and managers anticipating the response of mangroves to sea-level rise.

Introduction

At the boundary between marine and terrestrial communities, experimental studies have demonstrated that plant succession is driven by tolerance to physiological stress and plant–plant interactions (Bertness, 1991). There are several well-established physiological mechanisms influencing mangrove community composition (Smith, 1987, McKee, 1995, Duke et al., 1998), but it is unclear how interspecies interactions influence mangrove forest regeneration and community composition.

Given the species-poor nature of mangrove communities and the close proximity of conspecifics,

ecologically meaningful plant–plant interactions are likely (Ellison & Farnsworth, 2001). The white mangrove (*Laguncularia racemosa*, L.) was demonstrated to be an early colonizer of newly created mangrove wetlands (Proffitt & Devlin, 2005), but were eventually replaced by red mangroves (*Rhizophora mangle*, L.). While there was no experimental evidence; competition, crowding, and other interactions, such as facilitation, may have been at work. Facilitation is the most commonly evoked mechanism of succession in terrestrial habitats, whereby an early colonizing species changes the abiotic conditions in a way that allows a second species entry to a previously intolerable

habitat (Connell & Slayter, 1977). The later colonizing species then displaces the early colonist through a competitive interaction.

In this research, saltwort (*Batis maritima*) was observed to be an abundant initial colonizer of an extensive black mangrove (*Avicennia germinans* L.) die-off area. In mature mangrove forests, a dense overstory often limits the understory plant community. However, in frequently disturbed areas (e.g. roadsides along the edges of mangroves) there exists a community of non-woody, emergent vegetation such as sea blights (*Suaeda* spp.), glassworts (*Salicornia* spp.), sea oxeye (*Borrchia* spp.), and sea-purslanes (*Sesuvium* spp.). These species are found in mangrove die-off areas, and other areas of hydrologic disturbance.

Thus, the purpose of this investigation was to combine measurements of the sediment condition and a planting experiment to determine the role of *B. maritima* on the early colonization success of black mangrove (*Avicennia germinans* L.) seedlings. Given the potential encroachment of mangrove

communities by sea-level rise, it is important understand the factors which lead to early colonization success.

Materials and methods

Study site

The study area, Shell Point, falls under the management of Florida Department of Environmental Protection's Estero Bay Aquatic Buffer Preserve. The site lies on a peninsula between the Gulf of Mexico and the Caloosahatchee estuary, FL (Fig. 1). The wetlands are categorized as a tidal basin mangrove forest (Odum et al., 1982), dominated by *A. germinans*. Historic aerial photographs indicated that a large die-off area, approximately 0.75 hectares appeared in the 1980s, and was well-developed by the mid-1990s.

An elevation survey from the roadbed, through the forested area, across the edge of the die-off

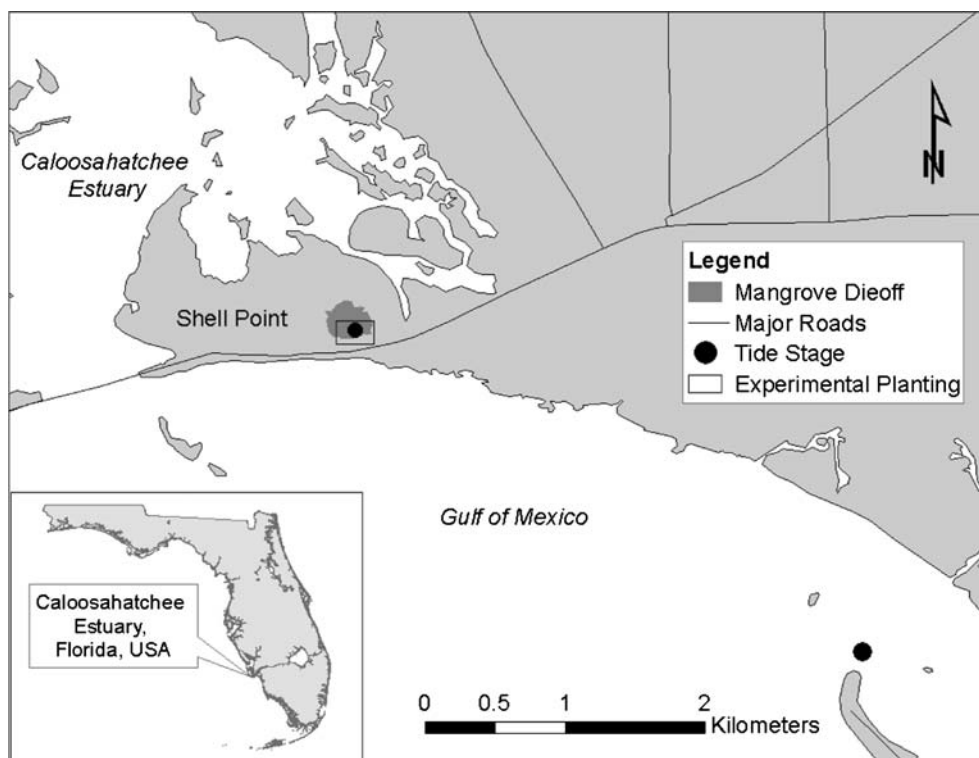


Figure 1. Map depicting the study area. The extent of the mangrove area is demarked in dark gray. The locations of sensors measuring tide stage are depicted with a filled circle; one in the study area and one in a nearby tidal pass. The planting experiment was carried out in both the mangrove die-off and in the adjacent forested area.

area, and into the die-off area revealed the topography of the study site (Fig. 2). The road bed elevation was well-above the high-tide mark and serves as a barrier to drainage of rainwater and tidewater. The elevation of the forested area was between + 0.50 and 0.68 m NGVD '29. The elevation of the die-off area was less than + 0.50 m NGVD '29.

Planting experiment

Nursery-raised *A. germinans* and *B. maritima* were planted in the die-off area and adjacent forested area. Plants were purchased from a native plant nursery (Horticultural Systems, Parish, FL) on 24 June 2005. Purchased *A. germinans* were considered seedlings, whose average height was 0.43 m ($n = 92$). *B. maritima* from the nursery were not measured, but had 3–5 branches and were considered to be seedlings. *A. germinans* were tagged, measured, and assigned a treatment group with the assistance of a computer-generated random number table. The five treatment groups are listed in Table 1, each treatment contained 18 *A. germinans* seedlings. Treatments A and B tested the hypothesis that *A. germinans* seedlings planted in existing *B. maritima* patches had greater survivability than *A. germinans* seedlings in isolation from existing *B. maritima* planted on the mudflat.

In order to test the influence of artifacts inherent to the study design, a total of three additional

Table 1. Experimental planting treatment groups

Treatment	Description
A	<i>A. germinans</i> planted on the mudflat
B	<i>A. germinans</i> planted in existing <i>B. maritima</i>
C	<i>A. germinans</i> planted in existing <i>B. maritima</i> with above ground biomass removed
D	<i>A. germinans</i> planted on mudflat with nursery <i>B. maritima</i>
E	<i>A. germinans</i> planted in the forested area

treatments were included. Treatment C tested the influence of existing *B. maritima* vegetation on survivability of black mangrove seedlings when above-ground *B. maritima* biomass was removed and below ground root structure was left intact. Treatment D tested the influence of newly planted *B. maritima* vegetation on black mangrove seedling survivorship where there was no existing above or below ground *B. maritima* biomass. Treatment E examined the survivorship of black mangrove seedlings in an adjacent forest with an enclosed canopy.

A randomized-block design was used to plant seedlings in existing patches of *B. maritima*. Existing patches of *B. maritima* were circular with a mean diameter of 350 cm ($n = 18$) and were used for blocking. There was a greater abundance of naturally-occurring mangrove seedlings observed in the existing *B. maritima*. Therefore, two of the

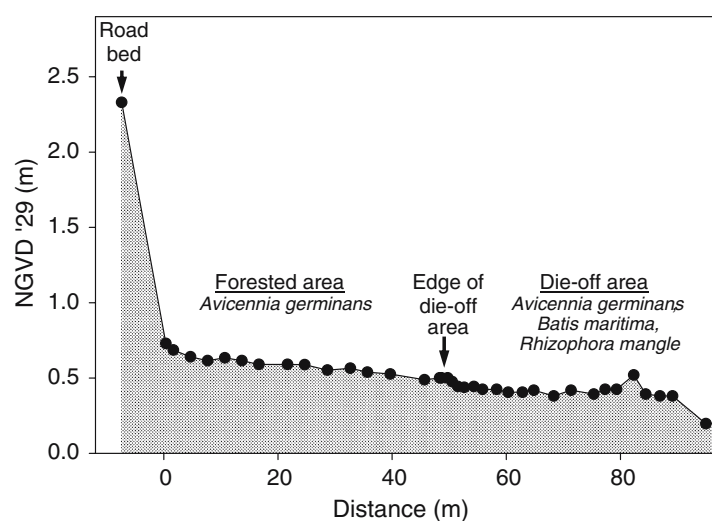


Figure 2. Elevation transect into the die-off area. Elevations were determined from the United States Geological Survey NGVD '29 datum.

naturally established *A. germinans* seedlings were tagged and measured in each of the 18 existing *B. maritima* patches to compare growth rates of naturally-established and nursery-raised seedlings. Seedlings were planted on 29 June 2005 and re-visited weekly to record seedling height and condition (i.e. dead, alive).

The response of *A. germinans* seedlings to the treatments was evaluated by counting the number of living seedlings and measuring growth rates after 8 weeks. Mortality for each treatment was calculated as the number of dead plants divided by 18, and expressed as a percentage. Growth rates were calculated by taking the difference between seedling heights at the end of the experiment from the beginning and dividing by the number of weeks in the study; growth data are reported in cm wk^{-1} .

Sediment conditions

Water depth, salinity, and porewater temperature in the study area were recorded to determine the conditions experienced by a mangrove seedling in the die-off area. Water depth, salinity, and temperature measurements were measured with a YSI 6600 (Yellow Springs Instruments, OH) in a semi-permeable well (Gator Plastics, LA). The well was made of PVC, surrounded with sand to prevent the well from clogging with fine clay and organics, while allowing porewater in to the sensor (Proffitt, personal communication). The well was dug in the mangrove die-off area to a depth of 1.5 m. Water depth was calibrated to 0.0 m prior to deployment. Salinity was calibrated to 50 mS, standard conductivity solution (YSI, Yellow Springs, OH). The instrument was deployed 06 June 2005 and left unattended until 03 August 2005, data were logged at 30-min intervals. Upon deployment and retrieval, the instrument was field calibrated to a Hydrolab[®] (Loveland, CO) handheld instrument. The depth offset from the top of the well to the depth sensor was measured to the nearest millimeter.

Porewater temperature data were also collected in small wells (5 cm, in diameter) dug in saltwort patches, mudflats and the forested area to simulate the thermal environments of treatment group A, treatment group B and treatment group E, respectively (see *Planting experiment*). Two,

HOBO Water Temp Pro (Onset, Pocasset, MA) data loggers were deployed in the die-off area for 1 week.

Elevations

A dual beam rotary level (CST, Watseka, IL) was used to determine the elevation of the die-off area and the adjacent forested area. A base station was established next to the road bed that provided data at 3–5 m intervals along a transect line. A second base station was established next to a USGS benchmark, and used to determine the elevation of the road bed and the elevation of the first base station. A third base station was established near the well (*Sediment Conditions*) to determine the elevation and water level in the die-off area. Tidal stage was calculated from the elevation of the well and the depth offset of the YSI 6600. All elevations were calculated relative to the National Geodetic Vertical Datum (NGVD) of 1929. Water level data from a nearby tidal pass (USGS, Ft. Myers, FL) were included for comparisons of tide stage.

Analysis

The proportion of surviving seedlings after 8 weeks was predicted to depend on the treatment type. Should the test of independence show that treatment and survival are not independent, then the conclusion is that one of the treatments is more susceptible to mortality than the other (Zimmerman et al., 1981, Sokal & Rohlf, 1991). A Model I design for a two-way table was applied to test departures from independence (chi-squared test) among the treatments.

Tide data are reported in Julian Day, a method for expressing dates where the days of the year are numbered consecutively 1–365. The amplitude of tides are reported as the mean difference between tide stage (m, NVGD) recorded at high tide and low tide. Daily sediment temperature ranges in the die-off area, established *B. maritima*, and forested areas were reported as means with standard deviation reported as the error around the mean. A one-tailed *t*-test was applied to determine whether the temperature in the existing *B. maritima* was significantly lower than on the mudflat (Dytham, 2003).

Results

The period, amplitude and frequency of tides in the die-off area were fundamentally different from the unaffected coastal area (Fig. 3). In the die-off area, diurnal tides were recorded during the 2 month deployment. In contrast, the tides at Matanzas Pass were recorded as mixed semi-diurnal. There were 61 high, slack tides recorded in the die-off and 107 high, slack tides recorded in Matanzas Pass during the same period. The tidal range in the die-off area was approximately half (0.82 m) of the tidal range at Matanzas Pass (1.62 m). A storm surge created by Hurricane Dennis, a category 4 storm, was recorded and was highly similar in amplitude and duration at both locations.

Survivorship of out-planted *A. germinans* seedlings differed depending on the treatment group.

The survivorship of *A. germinans* in the die-off area was improved by planting within existing patches of *B. maritima* (Fig. 4a). There were 6, 7 seedlings alive (treatments B and C, respectively) in the 18 existing patches of *B. maritima*. Seedlings planted in treatments B and C were grouped, after the proportion of surviving seedlings was determined to be independent of the treatment ($p > 0.5$). Similarly, seedlings in treatments A, D and E were grouped after the proportion of surviving seedlings was determined to be independent of the treatment ($p > 0.5$). The survival of seedlings was not independent ($p < 0.001$) when the seedlings were planted in existing *B. maritima* were compared to the survival of seedlings planted outside of existing *B. maritima* (Table 2). Therefore, mortality of seedlings within established *B. maritima* patches was significantly lower (69%) than expected while

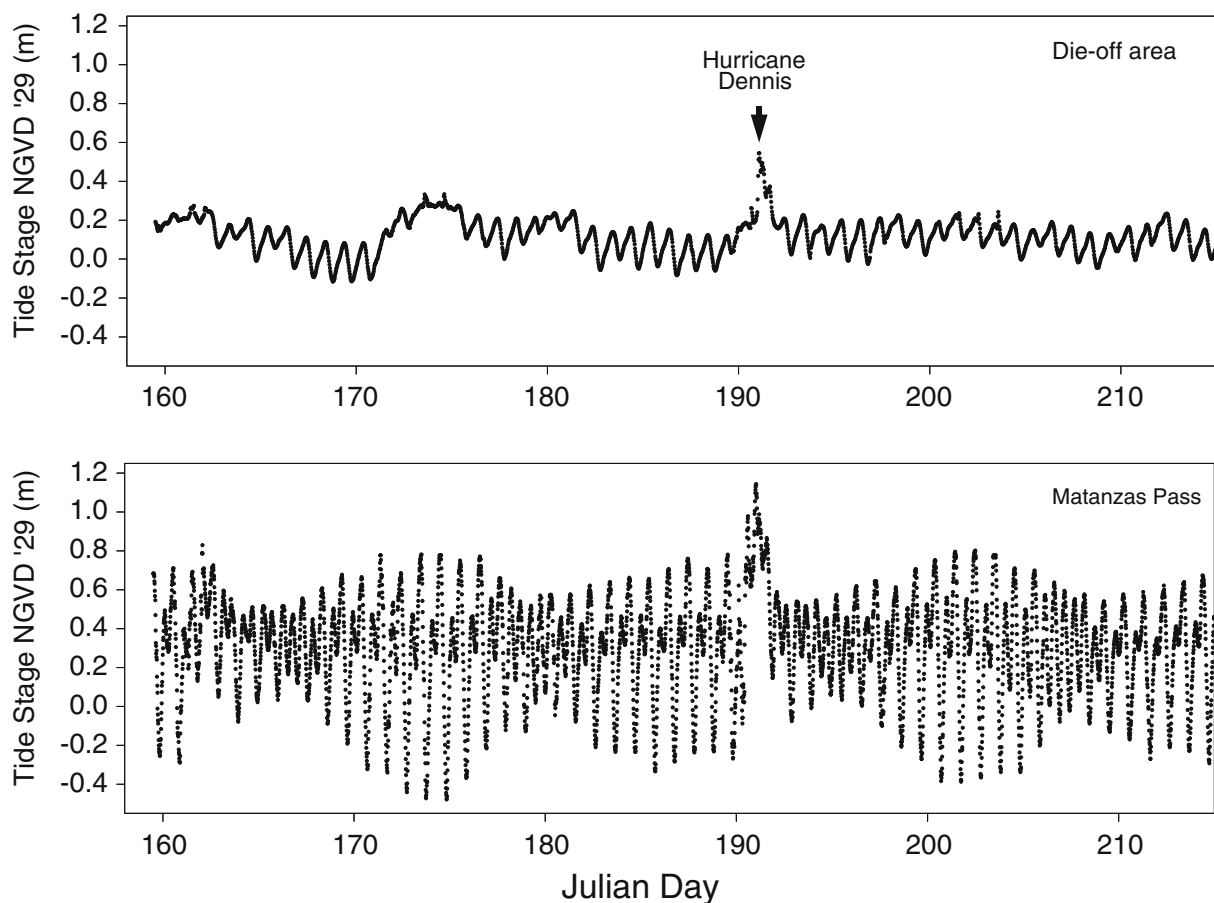


Figure 3. Tide stage (m) within the study area and at Matanzas Pass, FL. Diurnal tides observed in the die-off are in contrast to the mixed semi-diurnal tides at Matanzas Pass, FL (coastal area). An arrow demarks a storm surge associated with Hurricane Dennis, a Category 4 storm.

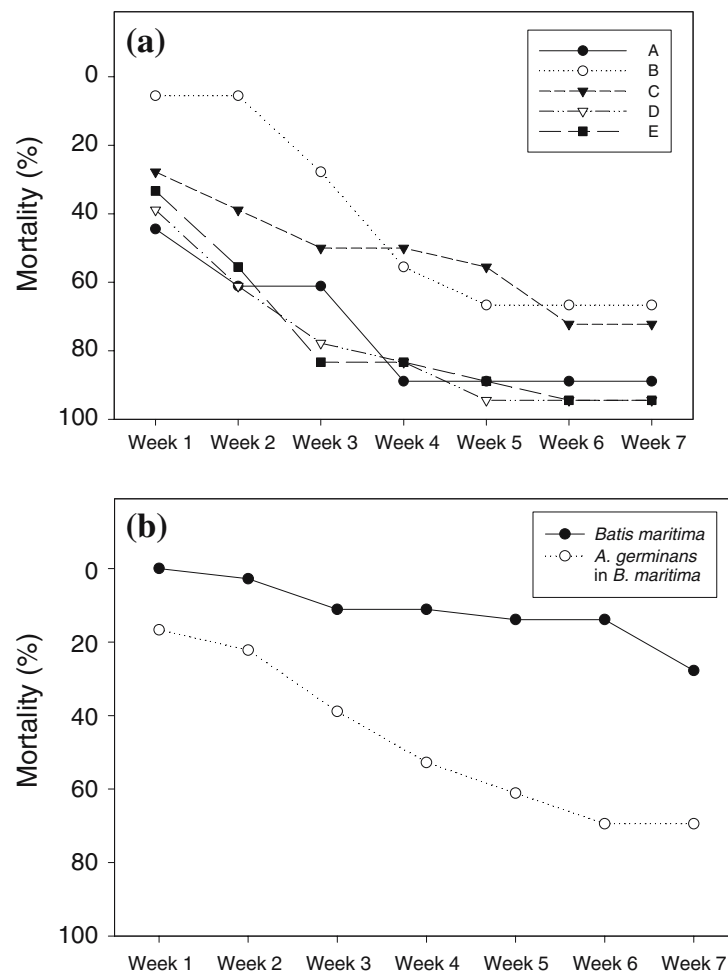


Figure 4. (a) Mortality of out-planted *A. germinans*. Letters indicate treatment conditions for the out-planting experiment; treatments B and C were planted in the die-off area within *B. maritima*, treatments A and D were planted in the die-off area in non-vegetated areas, and treatment E was planted in the *A. germinans* forest adjacent to the die-off area. (b) Mortality of *A. germinans* seedlings planted in established *B. maritima* vs. *B. maritima*.

seedlings planted outside of these patches was significantly higher than expected (93%). Naturally-established *A. germinans* grew faster (0.5 cm wk^{-1})

Table 2. Frequency of survival in *Avicennia germinans* seedlings

	Dead	Alive	Total
Seedlings planted in existing <i>B. maritima</i>	25	11	36
Seedlings planted outside existing <i>B. maritima</i>	51	3	54
Total	56	14	90

than nursery-raised *A. germinans* (0.2 cm wk^{-1}); however, some mortality of naturally-established seedlings was observed (13%).

Survivorship of nursery-raised saltwort, *B. maritima* was higher than nursery-raised *A. germinans* seedlings (Fig. 4b). The proportion of surviving *B. maritima* was 72% ($n = 18$), while the proportion of surviving *A. germinans* seedlings planted within established *B. maritima* patches was 31% ($n = 32$), and only 7% when planted outside of the established *B. maritima* ($n = 54$).

Temperature within existing patches of *B. maritima* was compared to the open mudflat (Fig. 5). Sediment temperature peaked near 1600

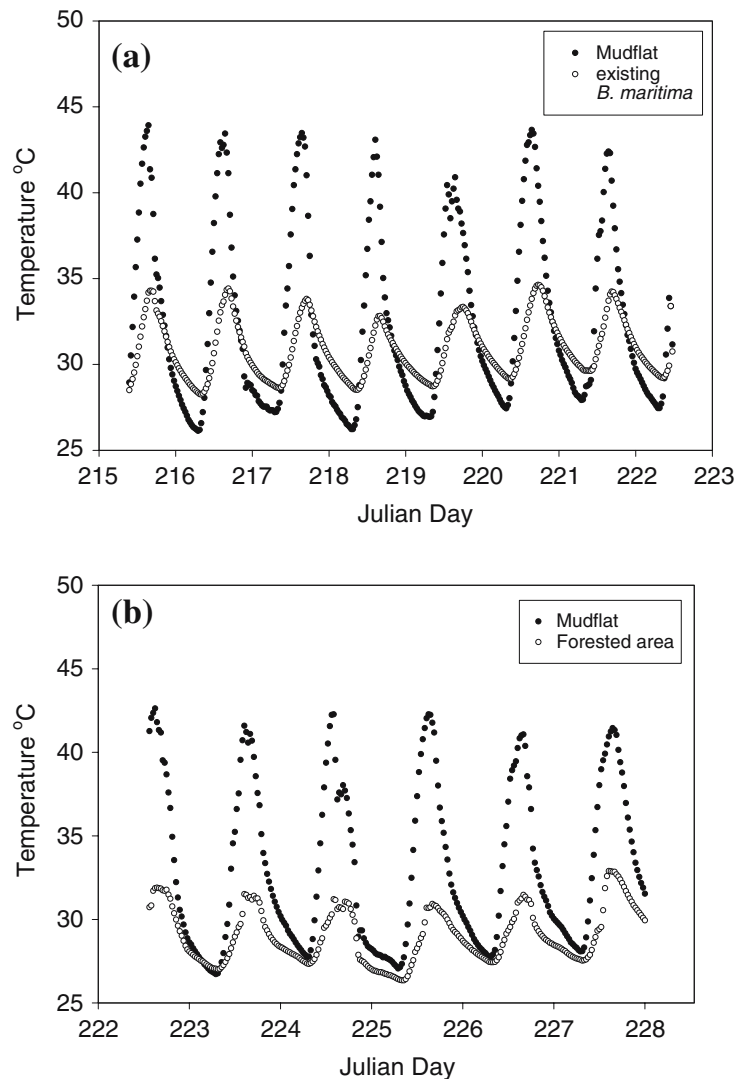


Figure 5. (a) Water temperature in previously established *B. maritima* patches and on the mudflats. (b) Water temperature on the mudflats and in the adjacent forested area.

Eastern Daylight Time. The maximum temperature recorded in open mudflat was 43.9 °C, while the maximum temperature in patches of *B. maritima* was 34.6 °C. The range in temperatures recorded was greater on the mudflats (17.8 °C) than in patches of *B. maritima* (6.4 °C). A similar comparison was made between the die-off area and the forest area. The maximum temperature recorded, during the 2 week period, was 42.6 °C on the mudflats while the maximum temperature in the forested area was 32.8 °C. The range recorded was greater on the mudflats (15.9 °C) than in the forested area (6.5 °C).

Discussion

Succession, in cases where the initial colonization conditions are severe, can be advanced by species that alter the conditions or the availability of resources in a habitat (Begon et al., 1996). In this study, several factors associated with mature *B. maritima* patches may be responsible for greater *A. germinans* seedling survivorship. *A. germinans* seedlings planted in existing patches of *Batis maritima* had significantly reduced mortality compared to seedlings planted on the mudflats. Greater early seedling success within existing

B. maritima partially explains the observation that *A. germinans* seedlings were naturally-recruiting in existing *B. maritima* and not on the adjacent mudflat.

It appears that the below ground structure found in established *B. maritima* patches is required. Removal of the above ground structure, and leaving the below ground structure intact had no significant effect on *A. germinans* mortality. However, seedlings planted outside of existing *B. maritima*, in the presence of *B. maritima* without extensive below ground structure, exhibited high mortality. The advantage conferred by the below ground root structure is thought to be a slight increase in elevation. This slight increase resulted in decreased inundation periods and less-stressful redox conditions for early *A. germinans* colonization (Pezeshki et al., 1997). The period of tidal inundation recorded in the die-off area was nearly double the period recorded in the tidal pass, which offers additional evidence for the lack of natural recruits on the mudflats (Wolanski et al., 1992).

Temperature recorded in existing *B. maritima* and on the mudflat suggests a second advantage conferred by existing *B. maritima* patches. The temperature of the standing water in *B. maritima* patches was significantly lower than the temperature on the mudflats. Lower fluctuations in daily temperature within existing *B. maritima* may have contributed to lower mortality; however, it was not possible to discern the different temperature regimes from other factors on the physiological response of *A. germinans* seedlings.

The relatively high survivorship of nursery-raised *B. maritima* suggests that it is an early colonizer of mangrove die-off areas. *B. maritima* was noted in portions of the bare ground and scrub mangroves in a restored stand of mangroves (Proffitt & Devlin, 2005), but was not quantified. There are few quantifiable studies of the role of understory vegetation in mangrove forest succession. The results presented in this research demonstrate the importance of understory vegetation to the successional process and can provide useful tools to ecosystem managers.

Ecosystem managers are charged with maintaining and restoring healthy mangrove forests. The process of restoration, however, is not straightforward and requires some understanding of processes and linkages that lead to a high

quality mangrove habitat. From this research, it appears possible to improve restoration success by planting mangrove seedlings in established *B. maritima*. Emergent vegetation was used in Tampa Bay, FL, to stabilize sediments to promote *Rhizophora mangle* seedling establishment (Crewz & Lewis, 1991). This type of approach to mangrove restoration was termed ecological engineering (*sensu* Lewis, 2005) and may provide a solution to the management of mangrove die-off areas.

It is important to consider the regeneration of mangrove die-off areas for other reasons, namely, to evaluate the response to global climate change. Sea-level rise, associated with global climate change, is predicted to cause large-scale losses of mangrove habitats (Semeniuk, 1994). Mangrove communities would likely retreat inland, as sea-level rise causes longer inundation periods. Mangrove die-offs are predicted to become more abundant as mangrove communities experience longer inundation periods (Ellison, 1993). While the response of mangroves to sea-level rise is uncertain, scientists and managers will be faced with greater abundances of mangrove die-off areas and will require the necessary tools to maintain high quality mangrove habitats. From this research, *Batis maritima* was demonstrated as a successful early colonizer and appears to promote the early establishment of mangrove seedlings.

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