

ECOLOGICAL ASSESSMENT OF MANGROVE, FISHES, AND SEAGRASS
HABITATS IN ANTICIPATION OF CLAM BAYOU RESTORATION

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HYDROLOGICAL RESTORATION AND ECOLOGICAL RESPONSE IN AN IMPAIRED MANGROVE LAGOON

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ABSTRACT

The response of mangrove, submerged aquatic vegetation (SAV), and fish communities to hydrological impairment and subsequent restoration was determined on a Florida barrier island. A catastrophic hurricane made landfall during the study period and presented a unique opportunity to evaluate the ecological response to both anthropogenic disturbance and meteorological disturbance. Quantitative observations of mangrove stem and seedling densities, SAV distribution, and fish community composition were made in an impaired lagoon (Clam Bayou) and an adjacent reference embayment (Dinkins Bayou). Planning, permitting, and engineering resulted in a permanent solution to restore necessary hydrological conditions for sustaining mangrove, SAV and fish communities in the impaired lagoon. Mangrove stem and seedling density decreased significantly in the impaired lagoon and increased significantly in the reference embayment. The effect of hydrological impairment on mangroves was a severe depression in seedling availability and a complete loss of canopy structure. The effect of hurricane disturbance on mangroves was also a loss of canopy structure; however, there were high densities of

mangrove seedlings. SAV distributions were greater after hydrological restoration near the constructed culvert suggesting that tidal currents were distributing vegetative fragments that had settled in new areas. Fish species richness was significantly greater when the impaired lagoon was connected to either the Gulf of Mexico by an emergency opening or the reference embayment via the constructed culvert. This observation supports the conclusion that mangrove-associated fishes require connectivity with open water habitats to complete their life cycle. The successes of the restoration can be summarized as the elimination of seasonal residential flooding and a return to the hydrological conditions favorable sustaining mangrove, seagrass and fish communities.

INTRODUCTION

Quantitative ecological studies of mangrove wetlands are necessary to understand community-level responses to disturbances. There are many types of disturbances common in tropical mangrove systems including wind disturbance (Milbrandt et al. 2006), storm surge (Cahoon et al. 2003), wetland hydrological impairment (Worley 2005), timber harvest, and sea level rise. Each of these can undercut the linkages between hydrology, mangrove productivity, and juvenile fish productivity. Restoration and creation of mangrove wetlands offers the potential to re-connect functional linkages in mangrove systems after impairment. Restoration activities in mangrove systems often include planting mangrove propagules, re-establishing natural tidal variation, or planting marsh plants to improve mangrove seedling establishment (Milbrandt and Tinsley 2006). However, there are few long term quantitative studies that profile the critical re-establishment of soil-organic content, normal above and below ground productivity,

adjacent submerged aquatic vegetation and mangrove-associated faunal populations of restored mangrove stands.

There are several factors that affect the population dynamics, community structure, and succession of mangroves in disturbed, natural, and restored mangrove wetlands (Smith 1992). The collapse of the underlying peat and soil structure accompanying subsidence (Cahoon et al. 2003) or alterations in the tidal hydroperiod which result in an inundation time above the critical level tolerated by live mangrove trees and seedlings (Lewis 2005) can cause mangrove die-offs. Light promotes growth of advanced recruits in canopy gaps (Smith 1987) and increases stem and seedling densities. The proximity to a propagule source can also (Sengupta et al 2005) increase seedling densities. There are species specific preferences to soil conditions (McKee 1995), water movement (Rabinowitz 1978), and nutrients (Feller 1995). Herbivores and parasites (Sousa 2003) are species specific and provide a competitive advantage to certain species.

Fish communities associated with mangroves can be found throughout the tropics where the inundated roots line marine, estuarine, and riverine shorelines. These habitats provide feeding areas, daytime refugia (Laegdsgaard and Johnson 2001), and nursery areas (Vance et al. 1996, Nagelkerken et al. 2002). There are few studies on how the linkages between fish species and mangrove habitat are modified in response to disturbance.

Here, we report on the response of mangrove, fish, and seagrass communities to wetland hydrologic modifications and the subsequent response to hydrologic restoration. Concurrently, we compare this response to an adjacent mangrove forest severely impacted by hurricane induced wind disturbance. In doing so, we evaluate the effectiveness of a habitat restoration project while evaluating the ecological response to two different types

of disturbances; sustained anthropogenic disturbance due to hydrological impairment and a single meteorological disturbance.

STUDY SITE

Clam Bayou (26.467°N, 82.168°W) is a shallow, mangrove-lined lagoon cut off from the Gulf of Mexico to the west by a sand bar. Aerial photographs of the region suggest a dynamic connection with the Gulf of Mexico as sand moves onshore and offshore. The greater area incorporates a mix of artificially created waterways, natural embayments, resource protection areas, undeveloped land, and residential/commercial development. Located adjacent to Clam Bayou is Dinkins Bayou, a similarly shaped area containing a number of shallow, elongated bays with extensive mangrove shorelines. Dinkins Bayou is connected to Pine Island Sound on the east side of the barrier island. Since 2001, water within the bayou has reached critically high levels where residential properties were threatened by flooding. Three of these events triggered the City of Sanibel to apply for an emergency Joint Coastal Permit (JCP) through the Florida Department of Environmental Protection to mechanically dredge a temporary tidal cut to the Gulf of Mexico.

In 2002, the City of Sanibel Natural Resources Department sought a more permanent solution to reestablish tidal variation and relieve the seasonal flooding of the lagoonal system. A series of public meetings were held by the City of Sanibel to collect input from the island's stakeholders. Presentations were made to two residential associations, the Dinkins Bayou Home Owners Association and the Clam Bayou Home Owners Association during the planning process. Comments on the potentially positive and negative impacts to the island's residents were presented to the City of Sanibel

Council prior to the drafting of a resolution to move forward. Subsequently, a feasibility study was initiated to develop a solution based on a historical connection from Clam Bayou to Dinkins Bayou through a narrow strip of mangroves that allowed water to flow between the bayous during times of extreme high water (Wilson 2003).

The solution for hydrological restoration and relief from temporary flooding was three 10' x 6' box culverts through the historical connection. Hydrological parameters were modeled which established the dimensions of the culverts and the volume of water necessary to restore tidal variation. Two permits were necessary to begin construction of the culvert; a Noticed General Permit (36-0233299-001) through the Florida Department of Environmental Protection (FDEP) and a Nationwide Permit (SAJ-2004-6950 (NW-MN)) through the U.S. Army Corps of Engineers. The permitting agencies agreed that the final placement of the culvert provided the least impact to the surrounding properties and to the existing plant communities. Kelly Bothers Marine (Fort Myers, FL) was contracted to perform the work. The first phase of the project included diverting traffic on Sanibel-Captiva Road to construct half of the culvert. The second phase was to shift the lanes and construct the second half of the culvert system. After the culvert was constructed on 27 February 2006 and tidal flow restored, rip rap and hay bales were placed along the wings to the edge of the mangroves to prevent erosion. Shortly thereafter, red mangroves were planted to stabilize the channel around the culvert.

MATERIALS AND METHODS

Tidal Variation – A time series of water depth was collected before (2 May 2005 – 2 June 2005) and after (20 June 2006 – 20 July 2006) the construction of the culvert. Data were collected at 30 minute intervals with a Yellow Springs Instruments (YSI) 6600

autonomous data sonde programmed to record depth, salinity, temperature and date/time. Prior to each deployment, the depth sensor was calibrated according to manufacturer's instructions. The instrument was affixed to a wooden piling at a depth of approximately 3 feet.

Mangrove stem and seedling density – The density of large mangrove trees (stems) and the density of seedlings were measured in Clam Bayou and the adjacent Dinkins Bayou. Data were collected in April for three consecutive years, starting in 2004. Circular plots were established within the mangroves during the first year of data collection. A random number between 0 and 30 was generated from Microsoft Excel spreadsheet and was then used to determine the number of paces from the water's edge. The center of each plot was marked with a wooden stake and the circumference was marked with spray paint. For the first year (2004) individual stems and seedlings were not marked. Beginning in 2005, each stem and seedling measured in the plot was marked with a plastic zip tie. In 2006, a numerical, aluminum tag was assigned to each measured stem in the plot. Additionally, sub-sampling of the seedlings within the circular plots with 9 randomly chosen 1 m² quadrats was adopted to measure seedling densities. These changes were employed to improve the precision and reduce standard deviation of stem densities within the plots. Stems were measured with the forestry standard, the diameter at breast height (1.4 m). If the stem was less than 1 cm in diameter, it was considered a seedling. Data on seedlings was collected as heights from the ground to the top of the tallest branch, but below the terminal bud to avoid intraspecific variation in development. Data were not collected on seedlings less than 30 cm tall or if the plant was not living.

SAV distribution – Snorkel surveys were used to determine SAV distributions in 2003 and again in 2006. A set of sixty waypoints were generated at random in the study area with

ArcView 9.0. At each waypoint, the percent cover of SAV was measured with a 1 m² quadrat with the Blaun-Blanquet system for estimating cover.

Juvenile Fish Communities –A 70 ft. center-bag seine was deployed at three fixed locations in Clam Bayou and three fixed locations in the adjacent reference area (Polakis et al. 2003, Idelberger and Greenwood 2005). All samples were collected during daytime and processed in the field. All specimens were sorted to lowest practical taxon (usually species), enumerated, and up to 30 haphazardly selected individuals were measured to standard length. Representative samples were retained for quality control and the remaining fish were returned to the water. *Eucinostonus* spp. were identified to genus because species cannot be reliably distinguished at small sizes (Tsou and Matheson 2002). Detailed physical data were recorded for each pull of the seine net including date, time, samplers, latitude, longitude, dissolved oxygen, salinity, temperature, and shoreline type. Salinity, temperature, and dissolved oxygen were recorded with a Hydrolab© water quality instrument deployed to mid-water column depth.

Data analysis – Water level (m), the elevation of the surface of the water, was calculated as the difference between the elevation of the dock (NVDG '29) and the depth of the instrument. The elevation of the dock was determined by optical level from a USGS benchmark located nearby. The amount of fluctuation in water level was calculated from the 1 month time series and was reported as variance in the impaired lagoon prior to the construction of the culvert and after the culvert was completed. Variance is the statistical measure of dispersion of data values, calculated from raw data.

Mangrove and fish community data were entered into a Microsoft Access database and subsequently checked for errors prior to data analysis. All data were tested for normality using a one-way, Kolmogorov-Smirnov Test. Data were also tested for

homogeneity of variance with a Levene test. In all cases, data were not normal and/or was heteroscedastic, therefore the data were transformed logarithmically (\log_{10}). Again in cases, data were not normalized by transformation, therefore non-parametric statistics were used. Statistical tests were performed with SAS 9.0 and the significance level for all statistical tests was set at $p < 0.05$.

Mangrove stem densities were reported as mean stem plot^{-1} plus or minus one standard deviation. Seedling densities were reported as seedlings m^{-2} plus or minus one standard deviation (Roth 1992). The calculation from seedlings plot^{-1} to seedlings m^{-2} was calculated by dividing the raw data (seedlings plot^{-1}) by the area of the 6-m radius plot (226 m^2). A Wilcoxon Signed Ranks Test was used to test the changes in mangrove seedling and stem density for each species separately over the three year period. When a significant result was obtained, multiple Mann-Whitney U-tests were used for pairwise comparisons for each species among years (Scheiner and Gurevitch 2001).

SAV distributions were mapped with ArcView 9.0 as percent cover between 0-5, following the Braun-Blanquet. The following values were used to represent percent cover m^{-1} ; 5, 75-100%, 4, 50-75%, 3, 25-50%, 2, 5-25%, 1, less than 5%, 0.5, rare, 0, no cover.

Fish data were reported as the number of species (S), a measure of species diversity. The data were reported separately for catches in the impaired lagoon and the reference embayment. In two of the four years reported, data were collected during all 4 quarters of the year and pooled. Data for 2003 and 2006 were not inclusive of one or more quarters due to the timing of the start and the conclusion of the study period. These data were included in the analysis, however, it should be noted that differences in fish community composition have been associated with seasonal sampling periods, specifically, the wet period and the dry period (Poulakis et al. 2003).

RESULTS

Installation of the culvert coincided with a shift in the hydrologic patterns in the impaired lagoon. The shift was captured by a continuously recording instrument deployed during the same month in 2005 (pre-culvert) and 2006 (post culvert). The water level increased from 0.80 m to 1.22 m NGVD '29 in the impaired lagoon upon completion of the culvert (Table 1). Concurrently, the tidal variation (expressed as variance) increased from 0.01 to 0.15, indicating a greater daily difference between high and low tide. Plots of water level over time in the impaired lagoon (Figure 2) indicated reduced tidal variation and periodic, unpredictable increases in water levels over short periods (21-22 May 2005, 31 May 2005 to 2 June 2005). Rainfall data collected at the Sanibel-Captiva Conservation Foundation Marine Laboratory (Davis, Inc.) indicated rainfall events corresponded to the increases in water level over short periods (Milbrandt, unpublished data). Subsequently, plots of water level after the completion of the culvert (Figure 3) demonstrate an increase in daily tidal variation and reflected the increase in water level observed in the impaired lagoon.

Mangrove stem densities decreased in the reference embayment and in the impaired lagoon from 2004 to 2006 (Figures 4 and 5). Stem densities in the impaired lagoon were an order of magnitude lower in the impaired lagoon than the nearby reference embayment (Figure 5), visible in the scaling of the y-axis. There were significant decreases in white mangrove (*L. racemosa*) densities in the impaired lagoon from 33 stems plot⁻¹ in 2005 to 10 stems plot⁻¹ 2006. There were no red mangrove (*Rhizophora mangle*) stems found in the impaired lagoon during the entire study period (2004, 2005, 2006). In the reference embayment (Figure 4), densities of *R. mangle* stems were

significantly lower in 2005/2006 (20, 8 stems plot⁻¹) than in 2004. While there were decreases in *R. mangle* and *L. racemosa* stem densities in the reference embayment, there was a small increase in black mangrove (*Avicennia germinans*) stem densities from 5 stems plot⁻¹ in 2005 to 10 stems plot⁻¹ in 2006 (Figure 4).

Mangrove seedling densities decreased in the restoration lagoon (Figures 5 and 6) and increased in the reference embayment. In the impaired lagoon, there were significant decreases in *A. germinans* densities from 1 seedling m⁻² in 2005 to 0 seedlings m⁻² in 2006 (Figure 6). There were also few *R. mangle* seedlings (less than 1 m⁻²) in the impaired lagoon during the data collection period (2004, 2005, 2006). While there was a decrease in seedling densities in the impaired lagoon, there were increases in seedling densities in the reference embayment (Figure 7). There were no significant changes in seedling densities between 2004 and 2005, however there were significant increases between 2005 and 2006 in *R. mangle* seedling density (0.5 – 1.4 seedlings m⁻²), in *L. racemosa* seedling density (0.1 – 3.1 seedlings m⁻²), and in *A. germinans* seedling density (1.2 – 5.1 seedlings m⁻²).

SAV distributions were greater near the site of the culvert in 2006 than 2003. There were no SAV found in the reference embayment in either survey.

Fish species richness was significantly higher in the impaired lagoon in 2003, when the lagoon was temporarily open to the Gulf of Mexico (Figure 8). However, in subsequent years 2004 and 2005, species richness in the impaired lagoon was not different than the reference embayment. In 2006, after the completion of the culvert, there were slight, but not significant differences in species richness in the restored lagoon and the reference embayment. When the data were sorted into fish caught during periods when the impaired lagoon was open to either the Gulf of Mexico or connected to the reference

embayment via the culvert, there was significantly higher species richness (Figure 9) than during periods when the lagoon was hydrologically isolated.

Several recreational and commercially valued fish species were caught in the impaired lagoon during the study period (Table 3). Common snook (*Centropomus undecimalis*), mangrove snapper (*Lutjanus griseus*), and mullet (*Mugil spp.*) were more abundant in the impaired lagoon than in the reference embayment. Spotted seatrout (*Cynoscion nebulosus*) and red drum (*Sciaenops ocellatus*) were occasionally more abundant in the impaired lagoon and occasionally more abundant in the reference embayment.

DISCUSSION

Biological systems are constantly responding to changing conditions, with periods of growth and regeneration followed by periods of habitat loss. This research profiles the response and recovery of mangrove systems to two different types of disturbance; sustained anthropogenic disturbance and a single meteorological event. This is the first quantitative research to focus on the linkages between mangrove habitat, SAV distributions and juvenile fish communities by examining ecological responses under differing disturbance and recovery regimes.

The impaired mangrove system was historically sustained by occasional breaching events that decreased water levels while providing an opening for pulses of fish and invertebrate larvae to colonize. A decrease in water levels accompanying the breaching events accomplished two critical functions; to lower water levels, which increased the availability of light for submerged aquatic vegetation and to prevent the systemic death of mangroves caused by inundation periods that exceeded known tolerances (Lewis 2005).

Without periodic wet season breeches, the impaired lagoon was subject to inputs from storm surges and rainfall which caused sustained water levels above normal mean high water and resulted in sustained hypersaline and oligohaline conditions (Wilson 2003), distressed mangrove habitats, decreases in water clarity, and general degradation of fish habitats.

Mangroves subjected to this type of disturbance were degraded because the conditions necessary for sustaining growth were not met prior to the culvert construction. In 2004, there were moderate white mangrove densities which have been reported as the early colonizing species in created mangrove wetlands (Proffitt and Devlin 2005). Subsequent observations in 2005 revealed a precipitous decline in the density of white mangrove stems. The cause of this decline is uncertain but supports the conclusion that the conditions necessary for sustaining growth were not met prior to the culvert construction.

A critical component of a system capable of renewing itself without intervention is the ability to reproduce (Proffitt et al, 2005). A fundamental difference between the two types of disturbance was revealed by observations of seedling densities. In the reference embayment after meteorological disturbance, there was a sharp increase in the density of mangrove seedlings. The increase was attributed to increased light reaching the canopy floor following the loss of most of the canopy structure (Milbrandt et al. 2005). In contrast, the number of mangrove seedlings in the impaired lagoon was an order of magnitude lower than the reference embayment and showed a significant decrease during the study period.

There were no red mangrove stems observed in the impaired lagoon during the study period. Red mangroves are primarily found along the shorelines of embayment and

were a missing component from the restored system. When comparing the impaired mangrove lagoon to the reference embayment, there were significantly higher red mangrove stem densities (52.5 stems plot⁻¹) in the reference embayment. Therefore, the density of red mangrove stems in the impaired lagoon is expected to increase after restoration since the hydrologic conditions necessary for sustaining mangrove communities have been met by the completion of the culvert.

Submerged aquatic vegetation (SAV) is sensitive to the light attenuation conditions in the overlying water (Zimmerman 1995). Sustained periods of higher than average water levels during the growing season were hypothesized to limit the distribution of SAV in the impounded lagoon. Therefore, an increase in SAV distribution was expected after restoration. There were small increases in SAV distribution in the impaired lagoon near the site of the constructed culvert in 2006 compared to 2003. While these observations are preliminary because of the ephemeral nature of early colonizing SAV, they suggest that the movement of water associated with the culvert is transporting fragments of SAV to locations favorable for SAV establishment (Hall et al. 2006). There were no SAV observed in the reference embayment.

Restoration of habitats is usually accompanied by new or different avenues for fish passage (Bednarek 2004, Roni et al. 2003). Several highly commercial and game species use tidal passes to spawn while their juveniles settle and colonize in mangrove systems (Robas 1970, Bohlke 1993). Red drum, mullet, mangrove snapper, spotted seatrout, and common snook were found in the impaired lagoon and reference area during the study period. Since these and other fish species are highly dependent on passages, the culvert served to re-connect the impaired lagoon to open water. This conclusion was supported by observations that the number of fish species was significantly higher when there was a

connection to open water. This difference was due to observations made in 2003 when the impaired lagoon was temporarily connected to the Gulf of Mexico through an emergency opening and again in 2006 after the completion of the culvert. These observation plus previous observations of higher species richness of coral reef fishes in mangrove and seagrass islands (Nagelkerken et al. 2002) support the conclusion that mangrove-associated fishes require adequate passages to complete their life cycles.

Success criteria were developed during the planning process to improve conditions for both the residents in the study area and the critical wildlife habitat within the extended boundaries of the J.N. "Ding" Darling National Wildlife Refuge. The success criteria were as follows: 1.) restore tidal flow and eliminate flooding; 2.) increase mangrove canopy density and increase mangrove seedling recruitment by 50%; 3.) improve water quality and light attenuation; 4.) reestablish historic SAV coverage. At this time, the hydrological conditions necessary for sustaining mangroves, SAV, and fish communities have been established. Water level measurements, increases in SAV distribution, and the number of juvenile fish caught are observations that support the establishment of necessary hydrological conditions. There were no reports of residential flooding after the completion of the culvert suggesting that residential concerns have been met.

Natural recovery of mangrove communities after the hydrological restoration was slower than expected. Delays in the construction of the culvert translated into more observations during the disturbance and fewer after the restoration. Consequently, the post-restoration goals for mangroves of increasing canopy density and seedling recruitment by 50% were not met. However, an effort was made to re-establish seedling densities by a volunteer planting effort. Residents in the study area and others, encouraged by the progress of the restoration, participated in a volunteer mangrove

planting day. Over 3,000 red mangroves were planted along the shoreline of the impaired lagoon after the construction of the culvert. Additionally, the culvert was stabilized by rip-rap and red mangrove seedlings.

The successes of the restoration can be summarized as the elimination of seasonal residential flooding and a return to the hydrological conditions favorable to sustaining mangrove, seagrass and fish communities. Another success is the partnership established between the citizens, a non-profit organization, and a city entity that allowed the restoration to move forward. These disparate groups shared the restoration of wildlife habitat as a priority.

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LITERATURE CITED

Bednarek, A.T., 2004. Undamming Rivers: A Review of the Ecological Impacts of Dam Removal. *Environmental Management* 27:803-813.

Bohlke, J.E., 1993. Fishes of the Bahamas and adjacent tropical waters, 2nd edition. University of Texas Press, 771 p.

Cahoon, D.R., P. Hensel, J. Rybczyk, K.L. McKee, C.E. Proffitt, B.C. Perez, 2003. Mass tree mortality leads to mangrove peat collapse at Bay Islands, Honduras, after Hurricane Mitch. *Journal of Ecology* 91:1093-1105.

E. Cocheret de la Morinière, P. H. Nienhuis, 2002. How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale. *Marine Ecology Progress Series* 244:299-305.

Feller I.C., 1995. Effects of nutrient enrichment on growth and herbivory of dwarf red mangrove (*Rhizophora mangle*). *Ecological Monographs* 65: 477–505.

Hall, L.M., M.D. Hannisak, R.W. Virnstein, 2006. Fragments of the seagrasses *Halodule wrightii* and *Halophila johnsonii* as potential recruits in the Indian River Lagoon, Florida. *Journal of Ecology* 310:109-117.

Nagelkerken, I., C. M. Roberts, G. van der Velde, M. Dorenbosch, M. C. van Riel, 2002. How important are mangroves and seagrass for coral reef fish? The nursery hypothesis tested on an island scale 244:299-305.

Idelberger C.F., Greenwood M.F.D., 2005. Seasonal Variation in Fish Assemblages Within the Estuarine Portions of the Myakaka and Peace Rivers. *Gulf of Mexico Scientist* 2005: 224-240.

Laegdsgaard P., C. Johnson, 2001. Why do juvenile fish utilize mangrove habitats? *Journal of Experimental Marine Biology and Ecology* 257:229-253.

Lewis, R.R., 2005. Ecological engineering for successful management and restoration. *Ecological Engineering* 24:403-418.

McKee K.L., 1995. Seedling recruitment patterns in a Belizean mangrove forest: effects of establishment ability and physico-chemical factors. *Oecologia* 101: 448-460.

Milbrandt, E.C., J.M. Greenawalt, P.D. Sokoloff, S.A. Bortone, in press, Impact and response of southwest Florida mangroves to the 2004 hurricane season, *Estuaries and Coasts*.

Milbrandt, E.C., M.N. Tinsley, 2006. The role of *Batis maritima* in regeneration of degraded mangrove forests. *Hydrobiologia* 568:369-377.
of mangrove forests. *Ecological Engineering* 24: 403-418.

Poulakis, G.R., D.A. Blewett, M.E. Mitchell, 2003. The effects of season and proximity to fringing mangroves on seagrass-associated fish communities in Charlotte Harbor, Florida. *Gulf of Mexico Science* 2003:171-184.

Proffitt, C.E. and D.D. Devlin, 2005. Long-term growth and succession in restored and natural mangrove forests in southwestern Florida. *Wetlands Science and Management* 13: 531-551.

Proffitt, C.E., S.E. Travis, E.C. Milbrandt, in press, Reproduction and Recruitment of *Rhizophora mangle* (Red Mangroves) in Charlotte Harbor Following Hurricane Charley, *Estuaries and Coasts*.

Rabinowitz D., 1978. Dispersal properties of mangrove propagules. *Biotropica* 10: 47-57.

Robas, A.K., 1970. South Florida's mangrove-bordered estuaries, their role in sport and commercial fish production. University of Miami Sea Grant Institutional Program, 28 pp.

Roni, P. T.J. Beechie, R.E. Bilby, F.E. Leonetti, M.M Pollock, G.R. Pess, 2003. A Review of Stream Restoration Techniques and a Hierarchical Strategy for Prioritizing Restoration in Pacific Northwest Watersheds. *North American Journal of Fisheries Management* 22:1-20.

Roth, L.C., 1992. Hurricanes and mangrove regeneration: effects of hurricane Joan, October 1988, on the vegetation of Isla del Venado, Bluefields, Nicaragua. *Biotropica* 24(3):375-384.

Smith, T.J. III, M.B. Robblee, H.R. Wanless, and T.W. Doyle. 1994. Mangroves, hurricanes, and lightning strikes. *BioScience* 44:256-262.

Smith, T.J., 1987. Effects of light and intertidal position on seedling survival and growth in tropical mangrove forests. *Journal of Experimental Marine Biology and Ecology* 110:133-146.

Sousa W.P., Quek S.P. and Mitchell B.J. 2003. Regeneration of *Rhizophora mangle* in a Caribbean mangrove forest: interacting effects of canopy disturbance and a stem-boring beetle. *Oecologia* 137: 436–445.

Sousa, W.P., S.P. Quek, B.J. Mitchell, 2003. Regeneration of *Rhizophora mangle* in a Caribbean mangrove forest: interacting effects of canopy disturbance and a stem-boring beetle. *Oecologia* 137:436-445.

Tsou, T.S., R.E. Matheson, 2005. Seasonal Changes in the Nekton Community of the Suwannee River Estuary and the Potential Impacts of Freshwater Withdrawal. *Estuaries* 25: 1372-1381.

Vance, D.J., MDE Haywood, D.S. Heales, R.A. Kenyon, N.R. Loneragen, R.C. Pendrey, 1996. How far do prawns and fish move into mangrove habitats? Distribution of juvenile banana prawns (*Penaeus merguensis*) and fish in a tropical mangrove forest in Northern Australia. *Marine Ecology Progress Series* 131:115-124.

Wilson H., 2003. Blind Pass eco-zone feasibility study. Hans Wilson and Associates technical report. <http://www.hanswilson.com/clambayou.htm>

Worley, K., 2005. Mangroves as an indicator of estuarine conditions in restoration areas. In: *Estuarine Indicators*, ed. S.A. Bortone, 247-260.

Zimmerman, R.C., J.G. Reguzzoni, R.S. Alberte, 1995. Eelgrass (*Zostera marina* L.) transplants in San Francisco Bay: Role of light availability on metabolism, growth and survival. *Aquatic Botany* 51: 67-86.

Table 1. Summary statistics of hydroperiod in Clam Bayou. Measurements were collected in June of 2005 and June 2006; before and after the construction of the culvert. Data were collected at 30 minute intervals.

| Year | Mean Water Depth (m, NGVD '29) | Variance | Minimum | Maximum |
|----------------------|-----------------------------------|----------|---------|---------|
| Pre-culvert 2005 | 0.80 | 0.01 | 0.53 | 1.08 |
| Post culvert 2006 | 1.22 | 0.15 | -0.64 | 2.38 |

Table 2. Summary of the number of recreationally-valued fish caught during the study period 2003 to 2006. IL, impaired lagoon (Clam Bayou) and RE, reference embayment (Dinkins Bayou)

| | 2003 | | 2004 | | 2005 | | 2006 | |
|--------------------------------|------|----|------|----|------|----|------|----|
| | IL | RE | IL | RE | IL | RE | IL | RE |
| <i>Centropomus undecimalis</i> | 17 | 0 | 111 | 14 | 15 | 12 | 2 | 1 |
| <i>Cynoscion nebulosis</i> | 7 | 1 | 0 | 0 | 0 | 8 | 0 | 0 |
| <i>Lutjanus griseus</i> | 10 | 0 | 14 | 0 | 18 | 16 | 0 | 11 |
| <i>Mugil</i> spp. | 48 | 0 | 18 | 16 | 1 | 7 | 0 | 0 |
| <i>Sciaenops ocellatus</i> | 4 | 0 | 0 | 11 | 1 | 0 | 0 | 0 |

Figure 1. Map of the study area. Inset includes Charlotte Harbor and associated barrier islands, including Sanibel Island. The star denotes the location of the culvert constructed to restore hydrological conditions.

Figure 2. Hydrological conditions in the impaired lagoon (Clam Bayou) before the culvert was constructed. Data were collected in June 2005.

Figure 3. Hydrological conditions in the impaired lagoon (Clam Bayou) after the culvert was installed. Data were collected in June 2006.

Figure 4. Mangrove stem density in the impaired lagoon (Clam Bayou) from 2004 – 2006. Star denotes significance $p < 0.05$.

Figure 5. Mangrove stem density in the reference embayment (Dinkins Bayou) from 2004 – 2006. Star denotes significance $p < 0.05$.

Figure 6. Mangrove seedling density in the impaired lagoon (Clam Bayou) from 2004 – 2006. Star denotes significance $p < 0.05$.

Figure 7. Mangrove seedling density in the reference embayment (Dinkins Bayou) from 2004 – 2006. Star denotes significance $p < 0.05$.

Figure 8. SAV distribution determined by snorkel surveys in 2003 and 2006. Scale for percent cover follows the Blaun-Blanquet as follows; 5, 75-100%, 4, 50-75%, 3, 25-50%, 2, 5-25%, 1, less than 5%, 0.5, rare, 0, no cover.

Figure 9. Fish species richness in the impaired lagoon and reference embayment, 2003 – 2006. Star denotes significance $p < 0.05$.

Figure 10. Fish species richness in the impaired lagoon and reference embayment with and without a tidal connection, 2003 – 2006. Star denotes significance $p < 0.05$.

Figure 1

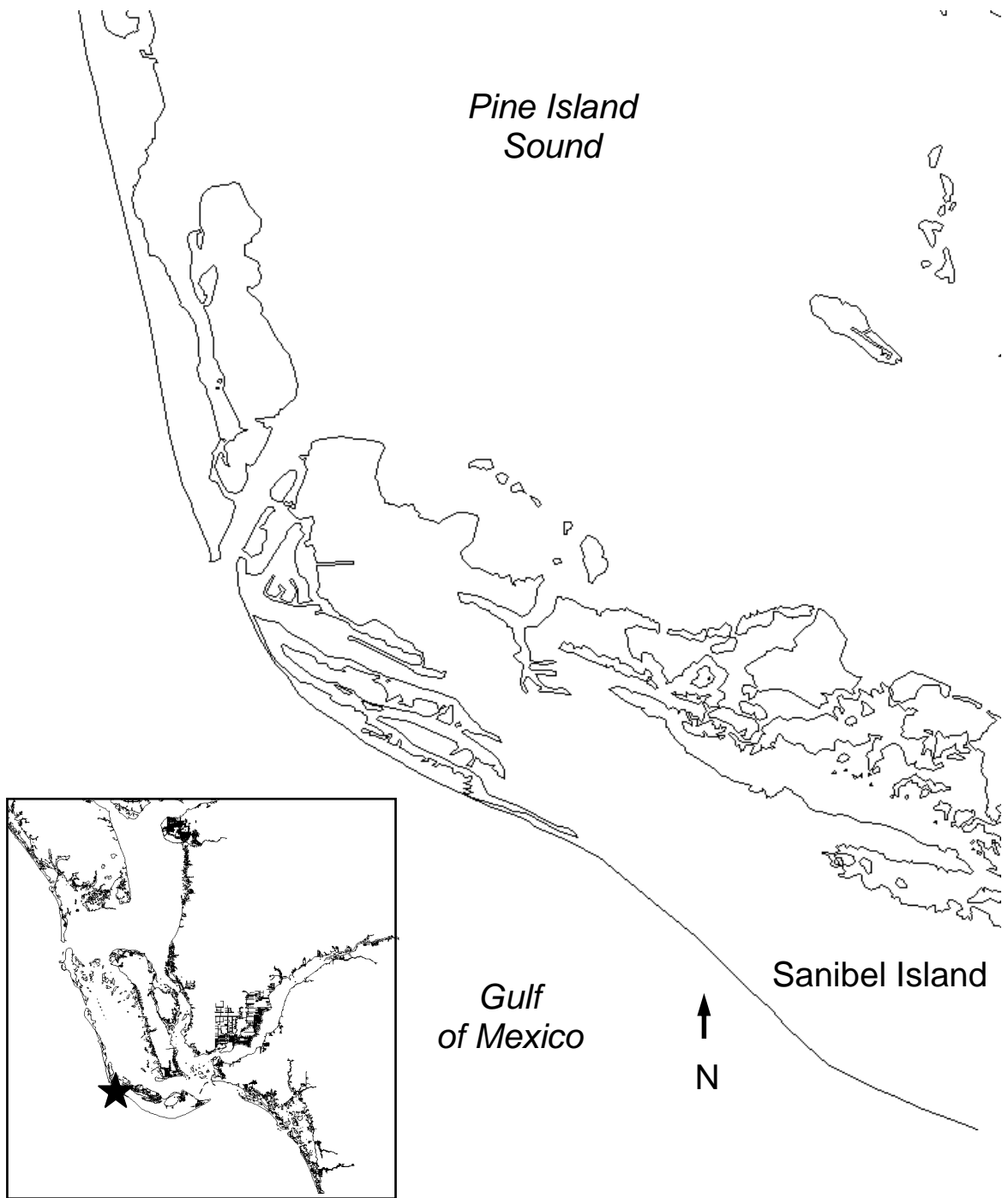


Figure 2

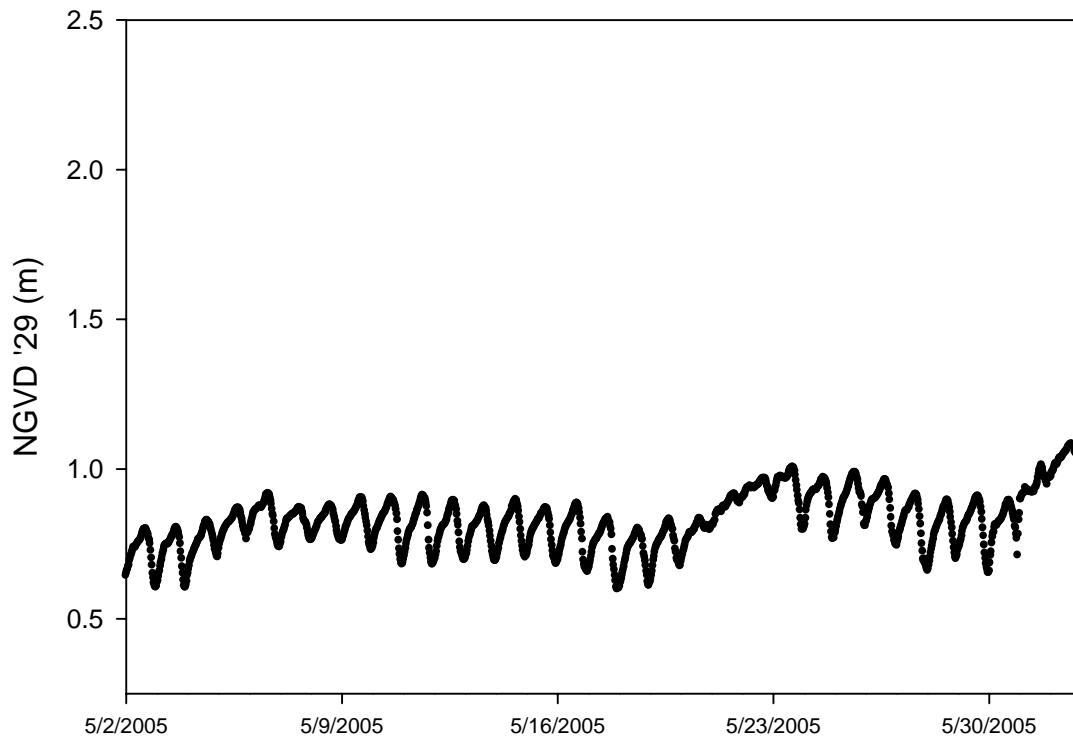


Figure 3

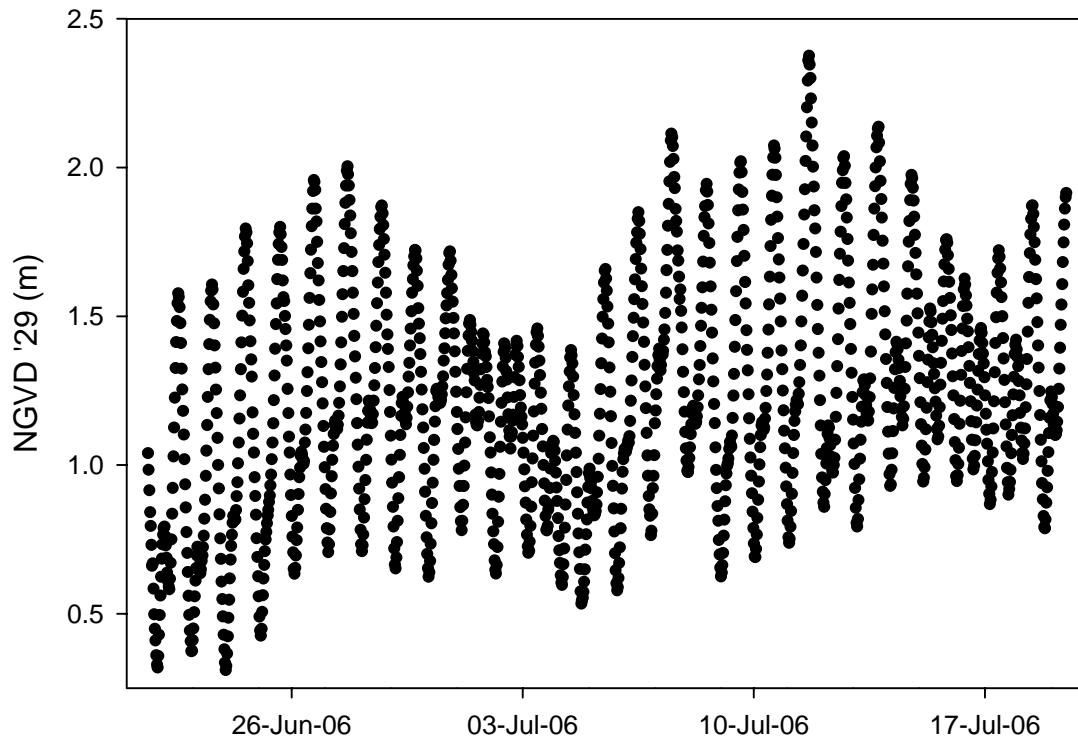


Figure 4

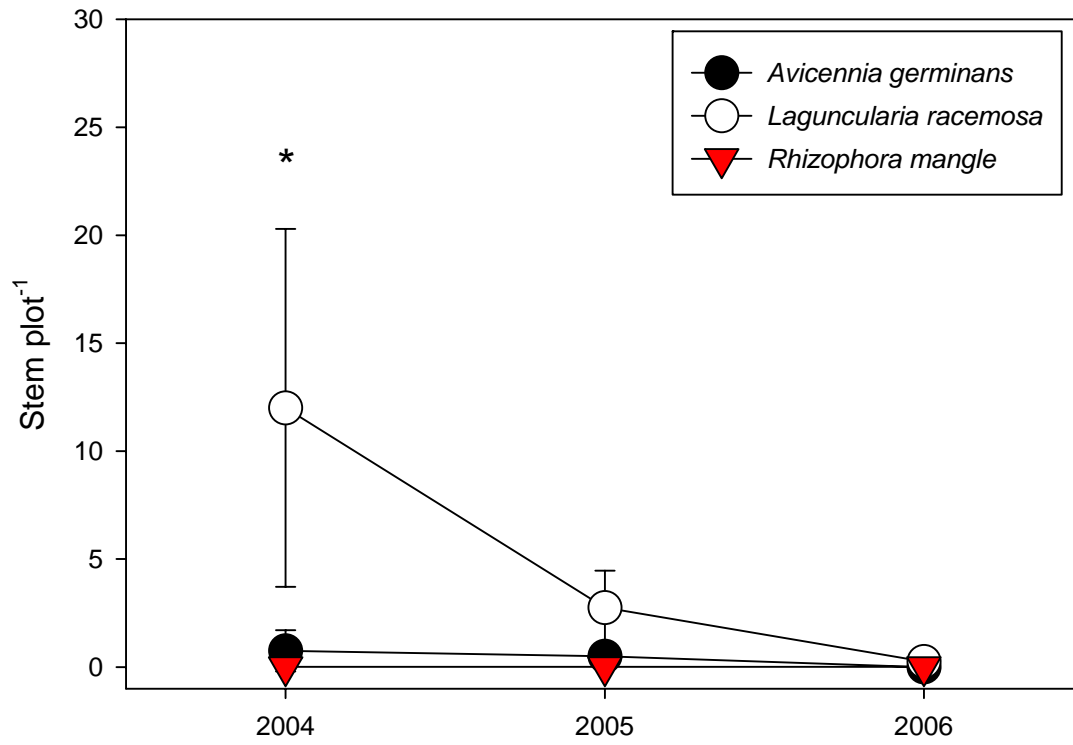


Figure 5

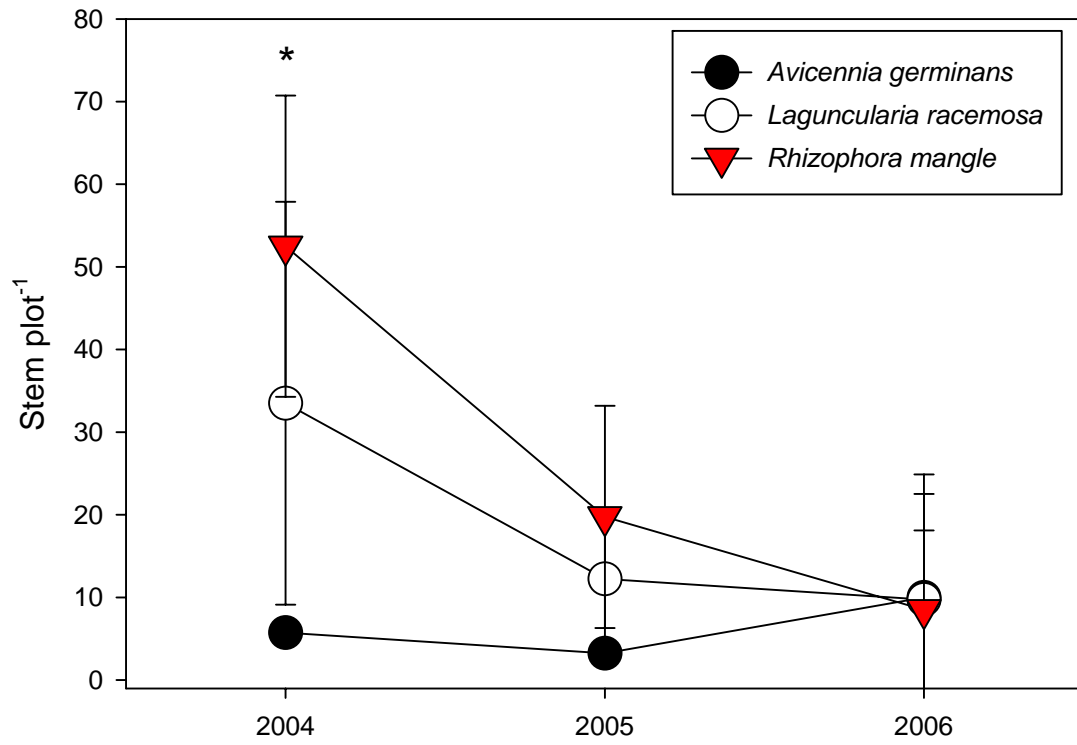


Figure 6

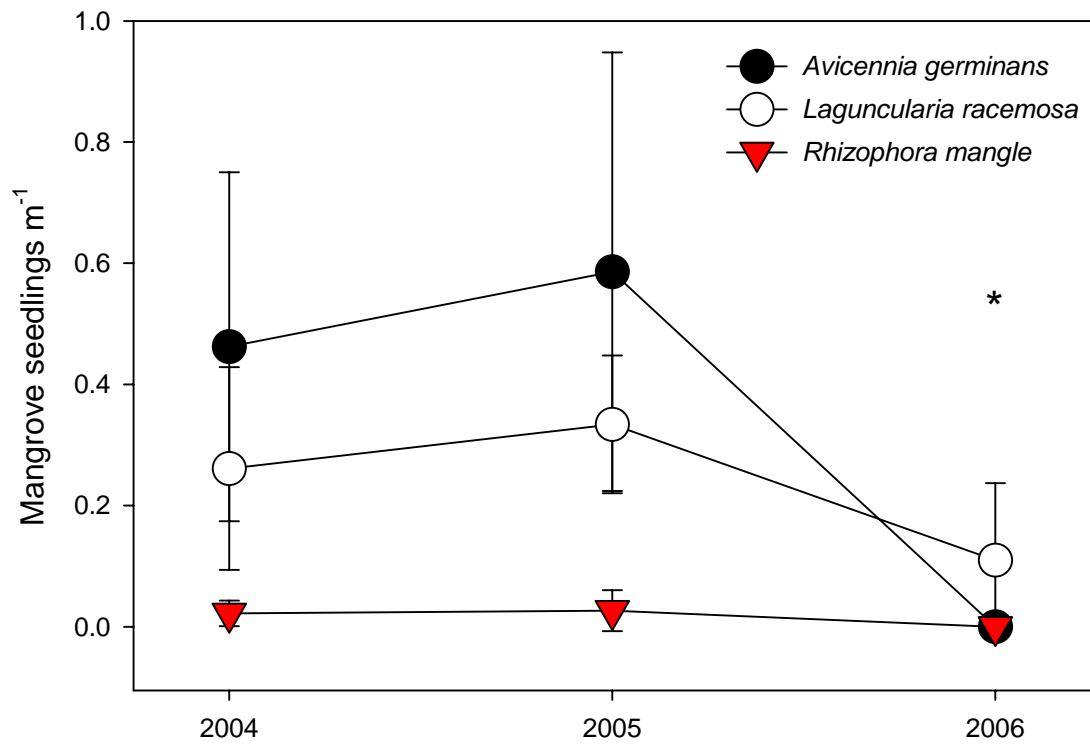


Figure 7

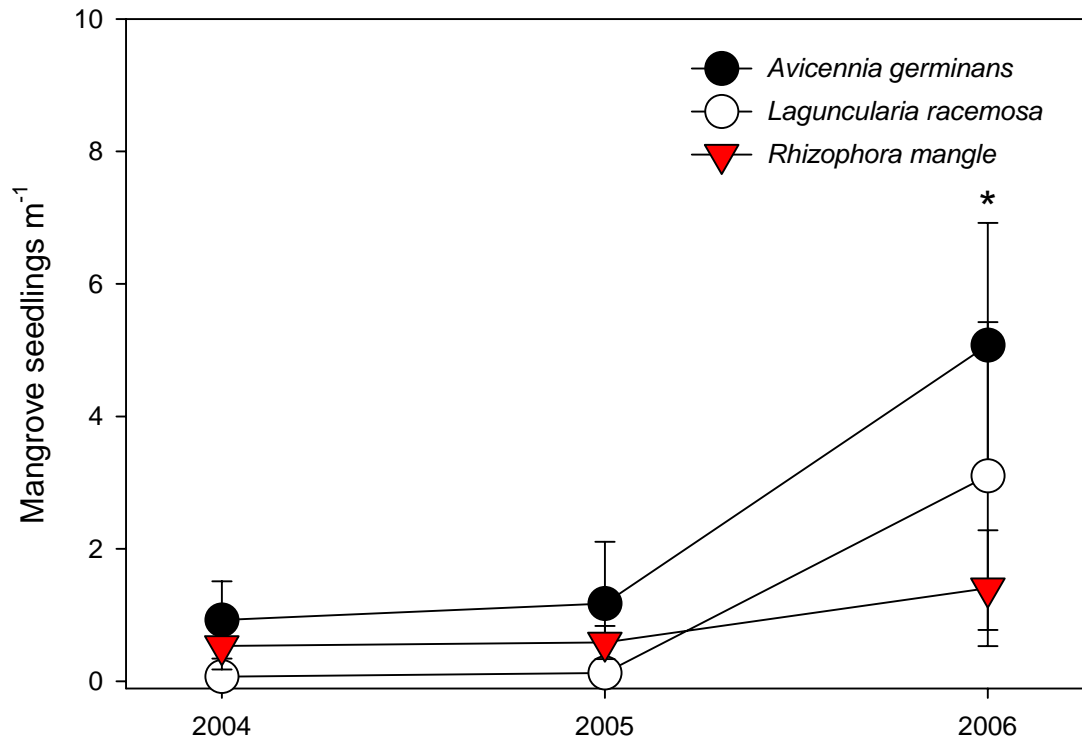


Figure 8

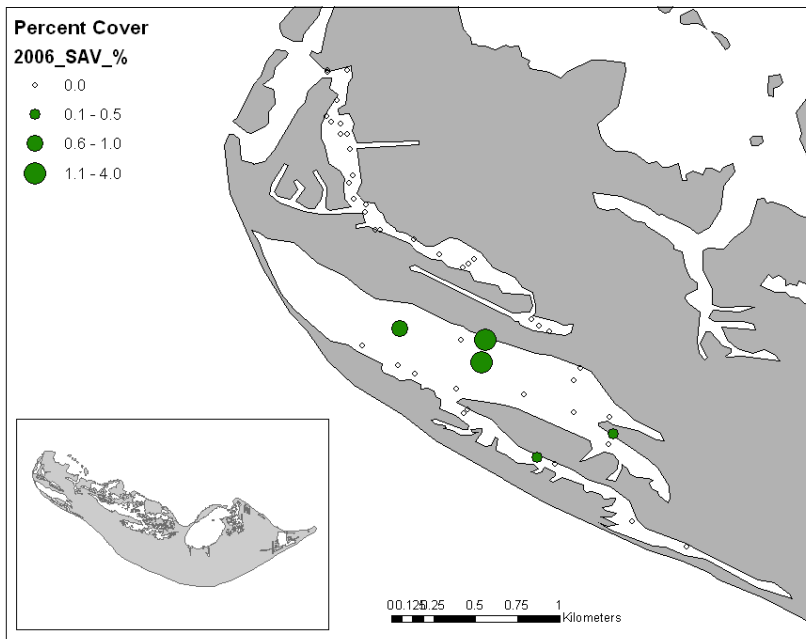
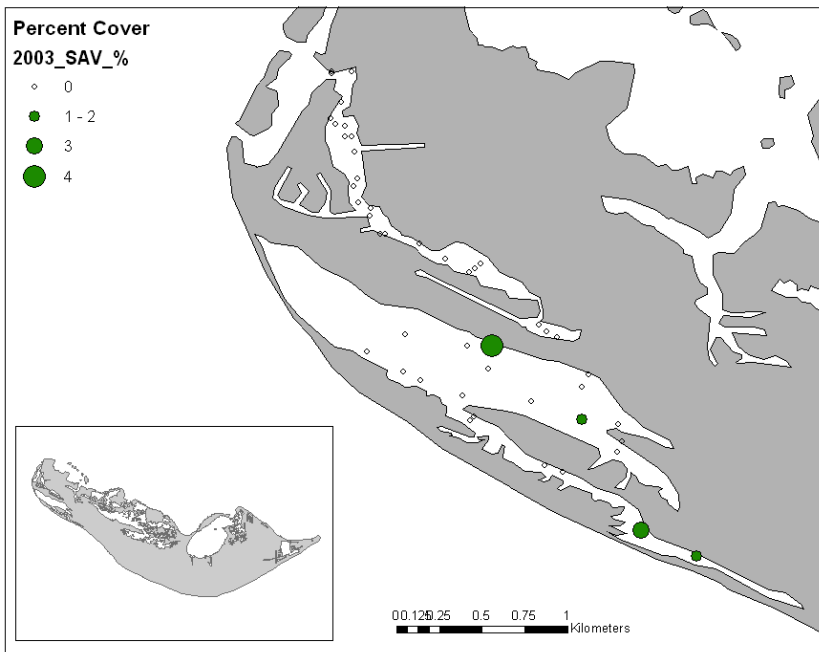


Figure 9

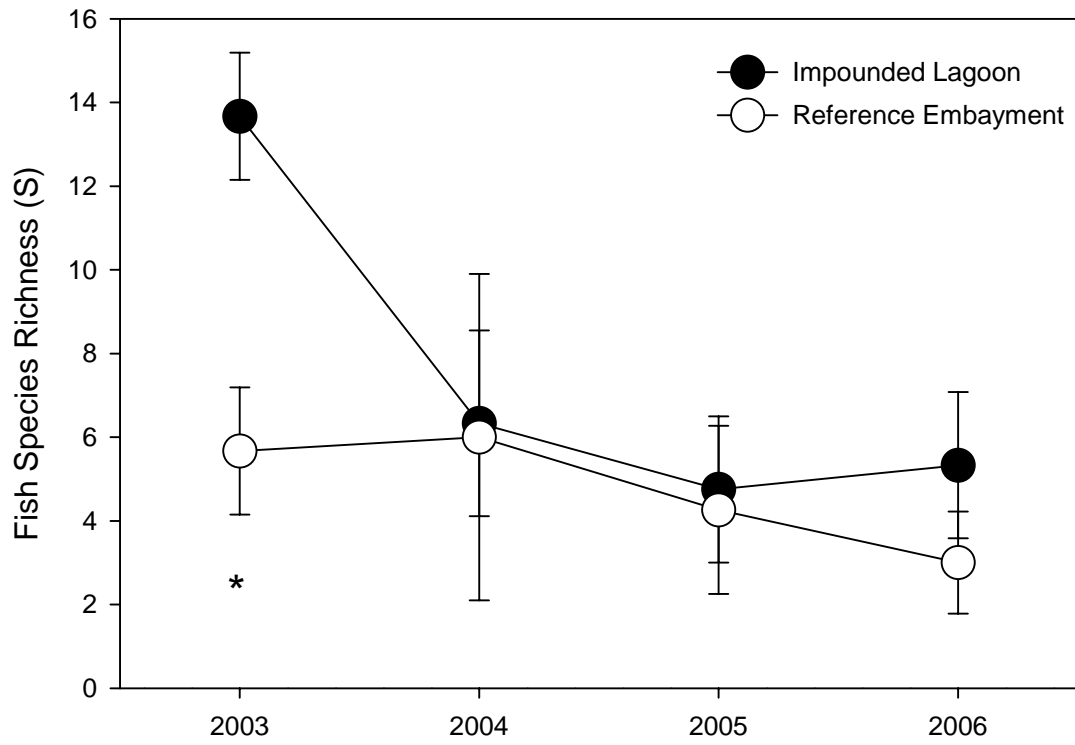


Figure 10

