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Title: Recovery of Saltmarsh Vegetation and Fauna Following Mosquito Impoundment Restoration in Volusia County, FL

Principal Investigator:

Melinda Donnelly, Ph.D. Candidate, Department of Biology, University of Central Florida, 4000 Central Florida Blvd., Orlando, FL, 32816,
321-403-0278, mwtd@bellsouth.net

Co-Investigators:

Jonas Stewart, Director of Volusia County Mosquito Control, 1600 Aviation Center Parkway, Daytona Beach, FL, 32114, 386-239-6516, jstewart@co.volusia.fl.us

William Greening, Environmental Scientist, Volusia County Mosquito Control, 1600 Aviation Center Parkway, Daytona Beach, FL, 32114, wgreening@co.volusia.fl.us

Ron Brockmeyer, Environmental Scientist V, St. Johns River Water Management District, 4049 Reid St., Palatka, FL, 32177, 386-329-4495, rbrockmeyer@sjrwmd.com

Linda Walters, Associate Professor, Department of Biology, University of Central Florida, 4000 Central Florida Blvd., Orlando, FL, 32816, 407-823-2148,
ljwalter@pegasus.cc.ucf.edu

Executive Summary

Background: In the 1960s, portions of saltmarsh habitat in the Indian River Lagoon, FL were impounded for mosquito management. The dikes and borrow ditches used to create mosquito impoundments decreased the total area of mangrove habitat by approximately 70% throughout the Indian River Lagoon and altered the hydrological characteristics of the system. These changes facilitated invasion by exotic and native terrestrial vegetation onto the elevated substrate of the dikes. Impoundments also decreased marsh-estuary connectivity and limited propagule and nutrient exchange. Opening culverts and breaching dikes in the 1980s restored connectivity. This was followed by complete removal of dikes beginning in the late-1990s.

Saltmarsh communities are often slow to recover and may require decades before structure and ecosystem functions are similar to pristine conditions. However, most projects lack a monitoring component and the time for recovery and recovery outcomes are still largely unknown. Our results from the first two years of monitoring provided initial insights on the effectiveness of the ongoing restoration. Additional monitoring is necessary to accurately estimate recovery rates and outcomes, and to provide valuable information for future saltmarsh restoration projects,

Purpose of Study: Vegetation monitoring began in fall 2005 at three impoundments in different stages of recovery and two reference marshes in Mosquito Lagoon, FL. This monitoring protocol was expanded in January 2007 to include the diversity and abundance of fiddler crabs, shorebirds, and vegetation at two additional restored impoundments, for a total of five restored impoundments and two reference marshes. Soil characteristics, organic matter content and elevation were also evaluated to compare

restored sites and neighboring reference marshes, and to evaluate their effect on floral and faunal recovery.

Findings:

- Significant natural recruitment of native saltmarsh vegetation is occurring at all restored impoundment sites.
- Interior marshes at restored sites supported similar plant abundances and diversity as reference marshes.
- Species richness and total density of plants increased with time since restoration on the impacted portions of the marshes.
- The elevated substrate of the dike was heavily invaded by the exotic Brazilian pepper prior to restoration; however, this invasive has not recruited to any monitored quadrats following substrate leveling.
- Initial recruitment occurred within one month of substrate restoration and was facilitated by new method of leveling began in fall 2006, which left native saltmarsh vegetation at the shoreline intact to serve as a seed source for recruitment into the leveled areas.
- Fiddler crabs were found at recently restored sites (< 1 year since restoration), suggesting initial recovery of food web processes are occurring at restored mosquito impoundment sites.
- Bird use differed between the restored sites and reference marshes, with the restored marshes having a higher frequency of wading birds foraging on the bare substrate. In comparison, reference marshes were primarily utilized by perching birds, such as the redwing black bird and osprey.

Introduction

Saltmarshes are highly productive systems. However, these marshes have suffered significant habitat loss and alteration due to anthropogenic activities (Pennings and Bertness 2001). In the 1960s, portions of saltmarsh habitat in Indian River Lagoon were impounded for mosquito management. The dikes and borrow ditches used to create mosquito impoundments decreased the total area of mangrove vegetation by approximately 70% throughout the Indian River Lagoon and altered the hydrological characteristics of the marsh system. The dikes changed the natural landscape by destroying existing vegetation, decreasing the area suitable for saltmarsh vegetation and facilitating the invasion of non-halophytic vegetation previously excluded from this habitat due to abiotic constraints (McKee and Faulkner 2000). In addition, dikes isolated the interior marsh, which decreased the connectivity of the interior marsh with the surrounding estuarine system and limited the exchange of propagules and nutrients (McKee and Faulkner 2000). In many areas, decreases in water and soil salinities resulted in the interior marsh converting to a cattail dominated, freshwater system. By the 1990s, many of these impoundments were no longer being actively managed for mosquito control. Dikes were breached and culverts were left open, restoring connectivity and tidal fluctuations to the interior marsh. Complete removal of the dikes began in the mid-1990s. A total of seven impoundments (15.5 dike miles) in Mosquito Lagoon have been restored and an eighth is currently undergoing restoration.

Salt marsh communities are often slow to recover and may require decades before structure and ecosystem functioning is similar to pristine conditions (McKee and Faulkner 2000). Recovery of the vegetation is important because of its role in the detritus based food web (Odum and McIvor 1990). It also provides habitat for a diverse assortment of taxa inhabiting estuarine systems and stabilizes the substrate (Odum and McIvor 1990). Restored areas that have similar flora structure and composition to pristine sites do not necessarily perform the same ecosystem functions because these may take longer to recover (McKee and Faulkner 2000). In addition to monitoring the vegetation, the presence of fiddler crabs (*Uca* spp.) was evaluated as an indicator for macroinvertebrate use of restored sites. These species are an important detritivore and serve as prey for higher taxa (Pennings and Bertness 2001). Past research has also suggested a link between burrows and primary production in mangroves and *Uca* burrows may influence the recovery of vegetation by aerating the anaerobic soils (Pennings and Bertness 2001).

The purpose of our monitoring program was to evaluate the recovery of vegetation and fauna at restored mosquito impoundments in Mosquito Lagoon, FL. Vegetation monitoring began in fall 2005 at three impoundments in different stages of recovery and two reference marshes and monitoring occurred every four months for one year. This study was expanded in January 2007 to include the diversity and abundance of fiddler crabs, shorebirds, and vegetation at two additional restored impoundments, for a total of five restored impoundments and two reference marshes. Soil characteristics, organic matter content and elevation were also evaluated for comparisons between restored sites and neighboring reference marshes, and to evaluate their effect on floral and faunal recovery.

Methods: The current monitoring program for restored mosquito impoundments in Mosquito Lagoon includes two reference marshes and the following five impoundments in multiple stages of recovery after leveling of the substrate. D-12S is divided into three segments, based on the year the substrate was restored. At each impoundment or reference marsh, 5 replicate sites were randomly chosen using ArcGIS (45 total sites). At each site, monitoring occurred every four months for vegetation, fiddler crabs, and birds, beginning in February 2007. Elevation and soil samples were taken yearly (September 2007).

Table 1. Five impoundments and two reference marshes are included in this monitoring program. The D-12S impoundment is divided into three segments, based on the year the impoundment was restored.

Impoundment	Year Restored
V-1	1999-2000
V-2	2000-2001
D-12 S-1	2003-2004
D-12 S-2	2004-2005
D-12 S-3	2006
D-12 N	2007
C-8	2007
V Control	N/A
D-12 Control	N/A

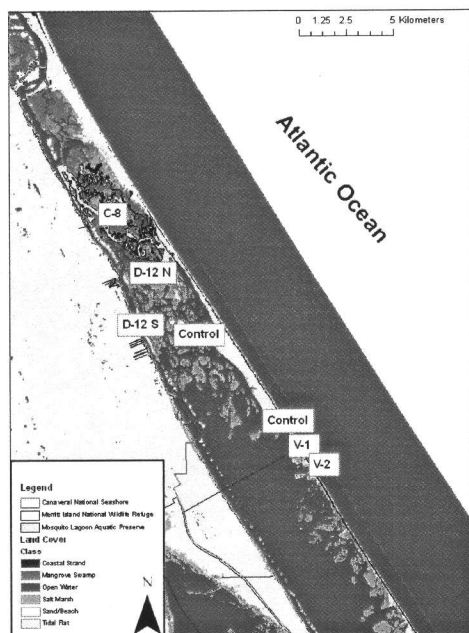


Figure 1. The location of five impoundments and two control marshes monitored for this study in Mosquito Lagoon, FL.

Table 2. The monitoring schedule for the 2007 impoundment monitoring study. Vegetation, birds and fiddler crabs were monitored every four months at all sites. Vegetation was monitored monthly at D-12N and C-8 for the first year following substrate restoration. Elevation and soil sampling occurred yearly.

Month	Sampling
January 2007	Set-up vegetation quadrats and obtained permits
February 2007	Vegetation (all 45 sites)
March 2007	Fiddler Crabs (all 45 sites); Vegetation at D-12N
April 2007	Birds (all 45 sites); Vegetation at D-12N
May 2007	Vegetation at D-12N
June 2007	Vegetation (all 45 sites)
July 2007	Fiddler Crabs (all 45 sites); Vegetation at D-12N
August 2007	Birds (all 45 sites); Vegetation at D-12N
September 2007	Elevation and Soil (all 45 sites), Vegetation at D-12N and C-8
October 2007	Vegetation (all 45 sites)
November 2007	Fiddler Crabs (all 45 sites); Vegetation at D-12N and C-8
December 2007	Birds (all 45 sites); Vegetation at D-12N and C-8

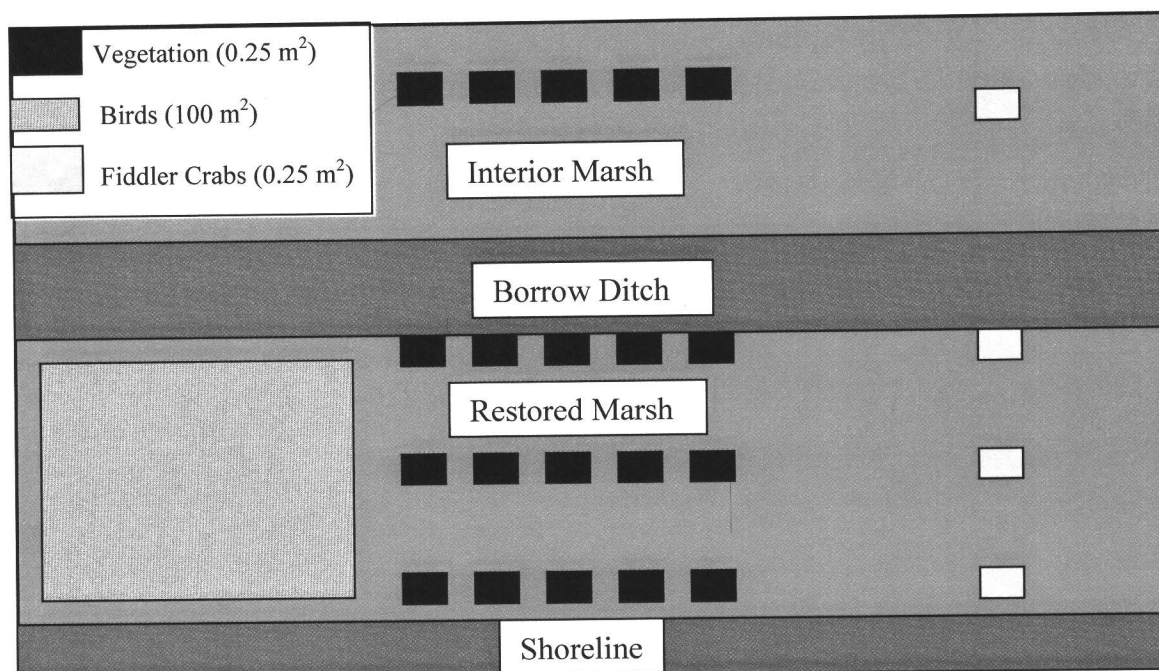


Figure 2. The arrangement of quadrats at each site for vegetation, bird and fiddler crab monitoring at the restored impoundment sites ($n = 45$ total sites). At reference sites or impoundment sites where the borrow ditch was filled in, vegetation and fiddler crab quadrats are located 0, 5, 10, and 30 m from shore. Substrate leveling at all five sites at D-12N and one site at C-8 differed from previous impoundments because the narrow strip of mangroves and other native shoreline vegetation was left intact. The first row of quadrats at these sites was immediately behind the shoreline vegetation to monitor the recruitment on impacted substrate.

Vegetation Surveys: To estimate density and recruitment of vegetation, five 0.25 m² quadrats were marked 5 meters apart, parallel to shoreline in the following areas: intertidal region, 5 m from shore, 10 m from shore (along posterior portion of restored impoundment adjacent to borrow ditch if present), and in the interior marsh (30 m from shore at control sites). The method of substrate leveling at the impoundments restored this year, D-12N (all five sites) and C-8 (one site), differed from previous impoundments because the narrow strip of mangroves and other native shoreline vegetation was left intact. The first row of quadrats at these sites was immediately behind the shoreline vegetation to monitor the recruitment on the impacted substrate. All plants within quadrats were identified to species and counted. Mangrove species were classified into one of three size categories: 1) small < 25 cm, 2) medium = 25 to 75 cm, 3) large > 75 cm. Monitoring occurred in February 2007 and all sites were monitored again in June 2007. D-12N and C-8 impoundments were monitored monthly for the first year following substrate restoration. At each impoundment or reference marsh, 5 replicate sites were randomly chosen using ArcGIS (45 total sites).

Fiddler Crabs: The abundance of fiddler crabs was estimated in one 0.25 m² quadrat in the following areas: intertidal region, 5 m from shore, 10 m from shore (along posterior portion of restored impoundment adjacent to borrow ditch if present), and in the interior marsh (30 m from shore at control sites). Within each quadrat, the top 20 cm of substrate was removed and substrate was sifted through a 2 mm sieve with saltwater and all fiddler crabs were counted and identified to species. Surveys were completed in March 2007 and again in July 2007. At each impoundment or reference marsh, 5 replicate sites were randomly chosen using ArcGIS (45 total sites).

Bird Surveys: At each site, 100 m² quadrats (10 m shoreline x 10 m inland) were marked with wooden stakes 24 hr prior to surveys. Each site was observed for 20 minutes during morning hours. Birds present within the marked area were identified to species and behavior (foraging, flying, resting) was recorded. Monitoring occurred in April 2007 and was repeated in August 2007. At each impoundment or reference marsh, 5 replicate sites were randomly chosen using ArcGIS (45 total sites).

Elevation Surveys: Elevation was estimated with a laser level and stadia rod. Measurements will be taken at 1-m intervals along a 30 m transect, running perpendicular to the shoreline, from water level in the intertidal region into the interior marsh. Elevation surveys will be completed in September 2007. Before restoration measurements were taken at the C-8 impoundment in March 2007. At each impoundment or reference marsh, 5 replicate sites were randomly chosen using ArcGIS (45 total sites).

Soil Characteristics: Two soil samples were taken from the anterior portion of the restored dike (5 m from water line at control sites) and in the interior marsh (30 m from water line) using a soil profile. Samples will be analyzed to determine soil grain size and composition, organic content, and soil salinity. Sampling will be completed in September 2007. At each impoundment or reference marsh, 5 replicate sites were randomly chosen using ArcGIS (45 total sites).

Results: Vegetation Surveys

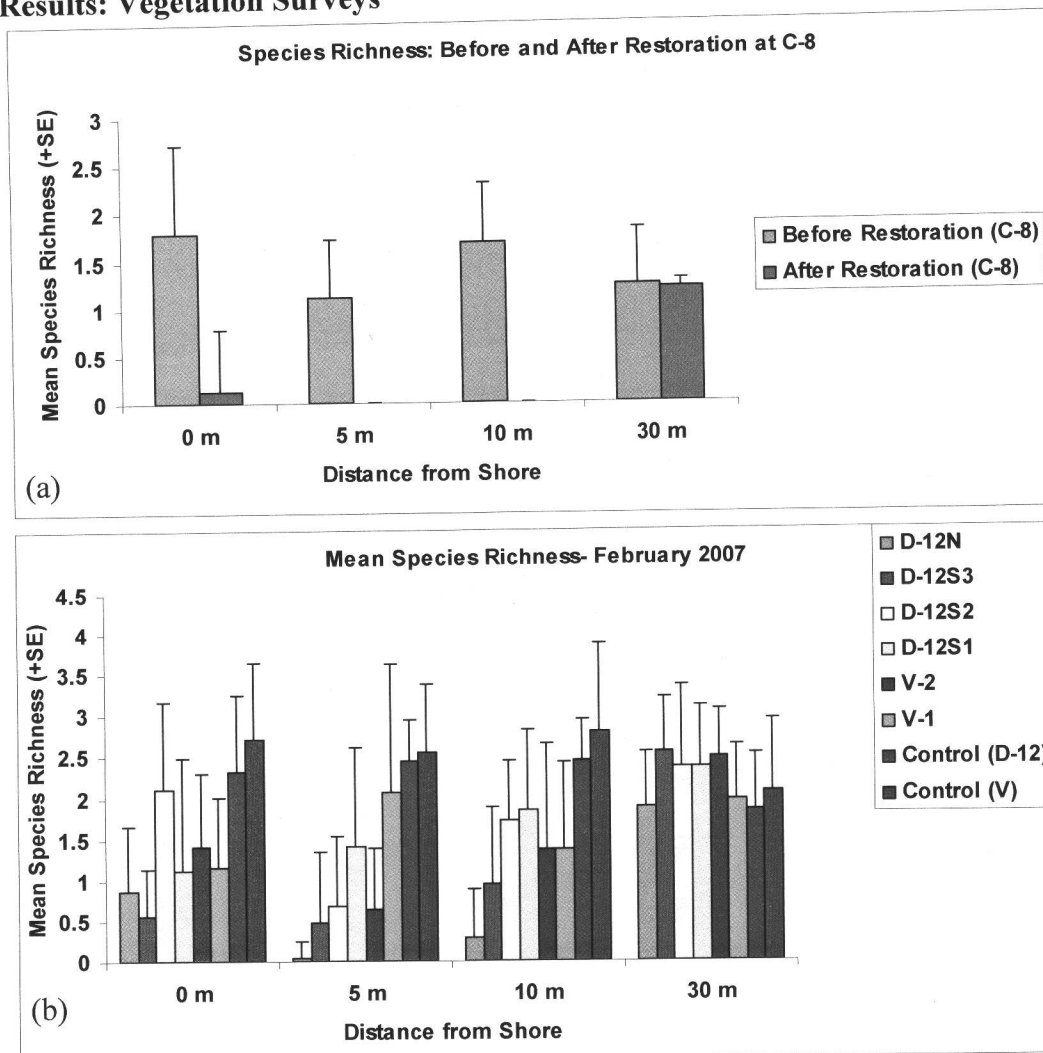


Figure 3. The mean species richness ($\pm$ SE) at (a) the C-8 impoundment before substrate restoration and one month after restoration, and (b) post-restoration impoundments, for quadrats located 0, 5, 10, and 30 m from shoreline. The order of the post-restoration impoundments is increasing in time since restoration, with D-12N being in the earliest recovery period (1-month post-restoration) and V-1 in the oldest period of recovery (7 years post-restoration).

Species richness was higher in the 0 m and 10 m area of C-8 before restoration, in comparison to the interior marsh (30 m, Figure 3a). These species included the exotic Brazilian pepper (*Schinus terebinthifolius*), sable palm (*Sable palmetto*), and Southern cedar (*Juniperus virginiana*). After restoration, recruitment of sea purslane (*Sesuvium portulacastrum*) and recovery of damaged black mangrove (*Avicennia germinans*) occurred within one month of leveling (Figure 3a). The black mangrove was the dominant mangrove species at all sites (Figure 3b). Other common flora found at all sites included sea purslane, saltwort (*Batis maritima*), perennial glasswort (*Salicornia perrennis*), and saltgrass (*Distichilis spicata*). These species occur naturally in saltmarshes throughout the Indian River Lagoon system.

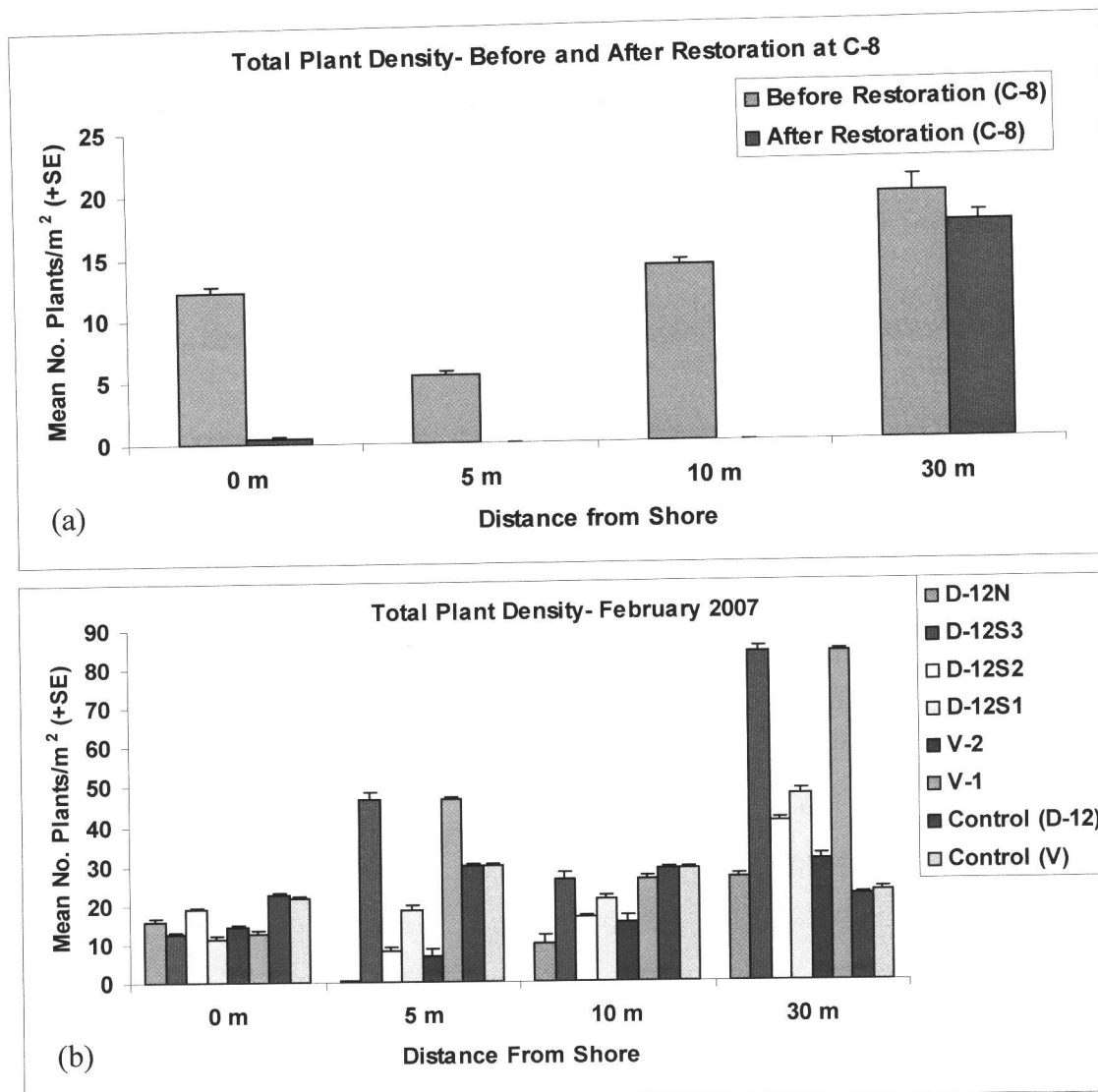


Figure 4. The mean number of plants/m² ($\pm$ SE) (all species combined) at (a) C-8 impoundment before substrate restoration and one month after restoration, and (b) post-restoration impoundments, for quadrats located 0, 5, 10, and 30 m from shoreline. The order of the post-restoration impoundments is increasing in time since restoration, with D-12N being in the earliest recovery period (1-month post-restoration) and V-1 in the oldest period of recovery (7 years post-restoration).

At the C-8 impoundments after substrate leveling, plants were only found adjacent to the tide line (Figure 4a). Total plant density at D-12N, one-month post restoration was higher than the density at D-12S3, one-year post-restoration. This results from a difference in substrate leveling methods (Figure 4b). At all sites at D-12N, dikes were completely leveled, whereas current leveling methods remove only the substrate behind the shoreline vegetation. The new method left the native mangrove and saltmarsh vegetation intact and this served as a seed source and increased the rate of recruitment to the adjacent leveled substrate.

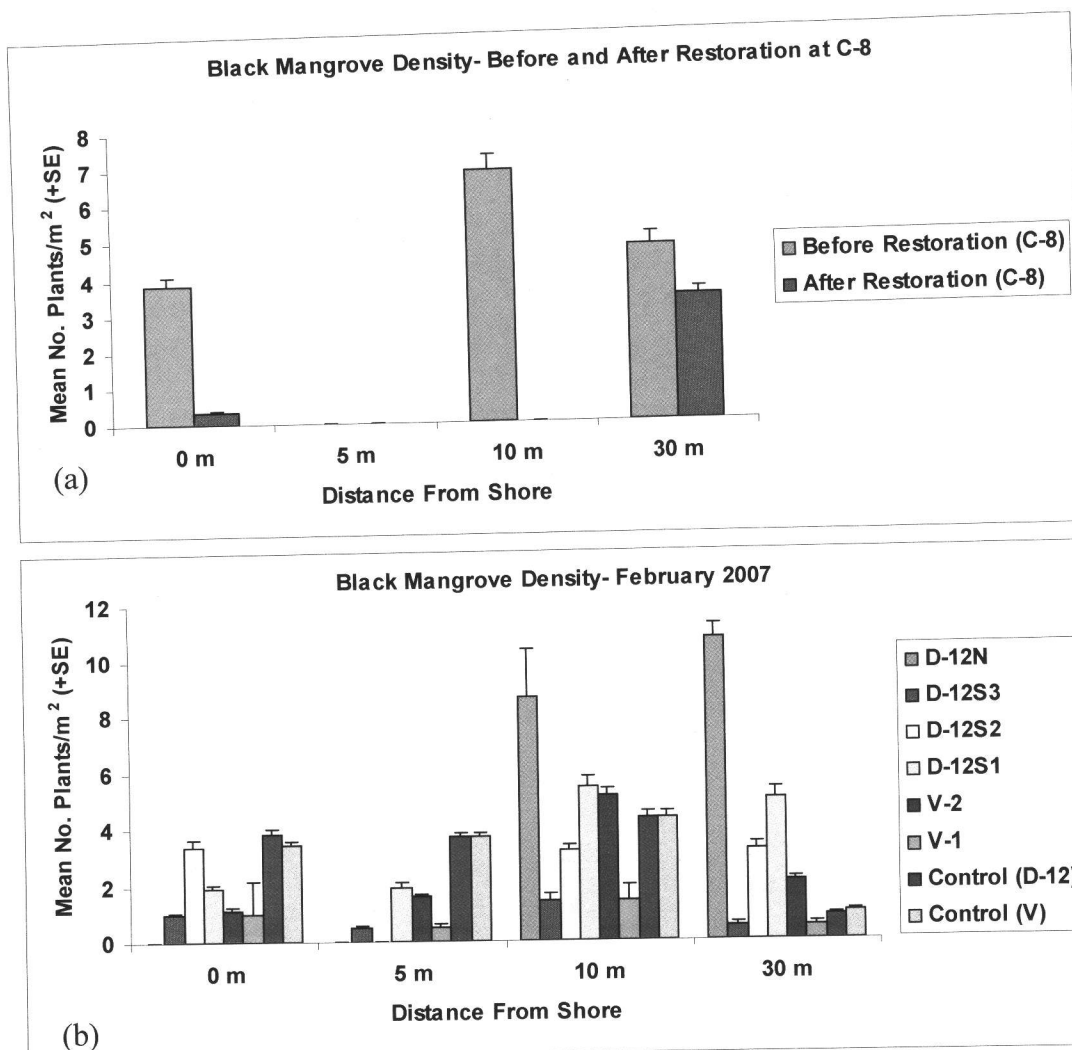


Figure 5. The mean number of black mangroves (*Avicennia germinans*)/m² ($\pm$ SE) at (a) C-8 impoundment before substrate restoration and one month after restoration, and (b) post-restoration impoundments, for quadrats located 0, 5, 10, and 30 m from shoreline. The order of the post-restoration impoundments is increasing in time since restoration, with D-12N being in the earliest recovery period (1-month post-restoration) and V-1 in the oldest period of recovery (7 years post-restoration).

The black mangrove (*A. germinans*) was an early colonizer of the shoreline at the C-8 impoundment following substrate restoration (Figure 5a). The D-12N impoundment (one month post-restoration) had high levels of recruitment in the impacted region adjacent to the rear borrow ditch (10 m region, Figure 5b). The interior marsh at this impoundment also had a high density of black mangroves and served as a propagule source. D-12N impoundment was restored in early 2007 and black mangrove propagules were dispersing at this time, which led to high recruitment levels to the recently restored substrate adjacent to the borrow ditch. At the reference marshes, the black mangrove density within the 30 m portion of the marsh is low, where it dominates the shoreline but becomes less abundant in the interior marsh, where saltmarsh perennials and grasses were more abundant.

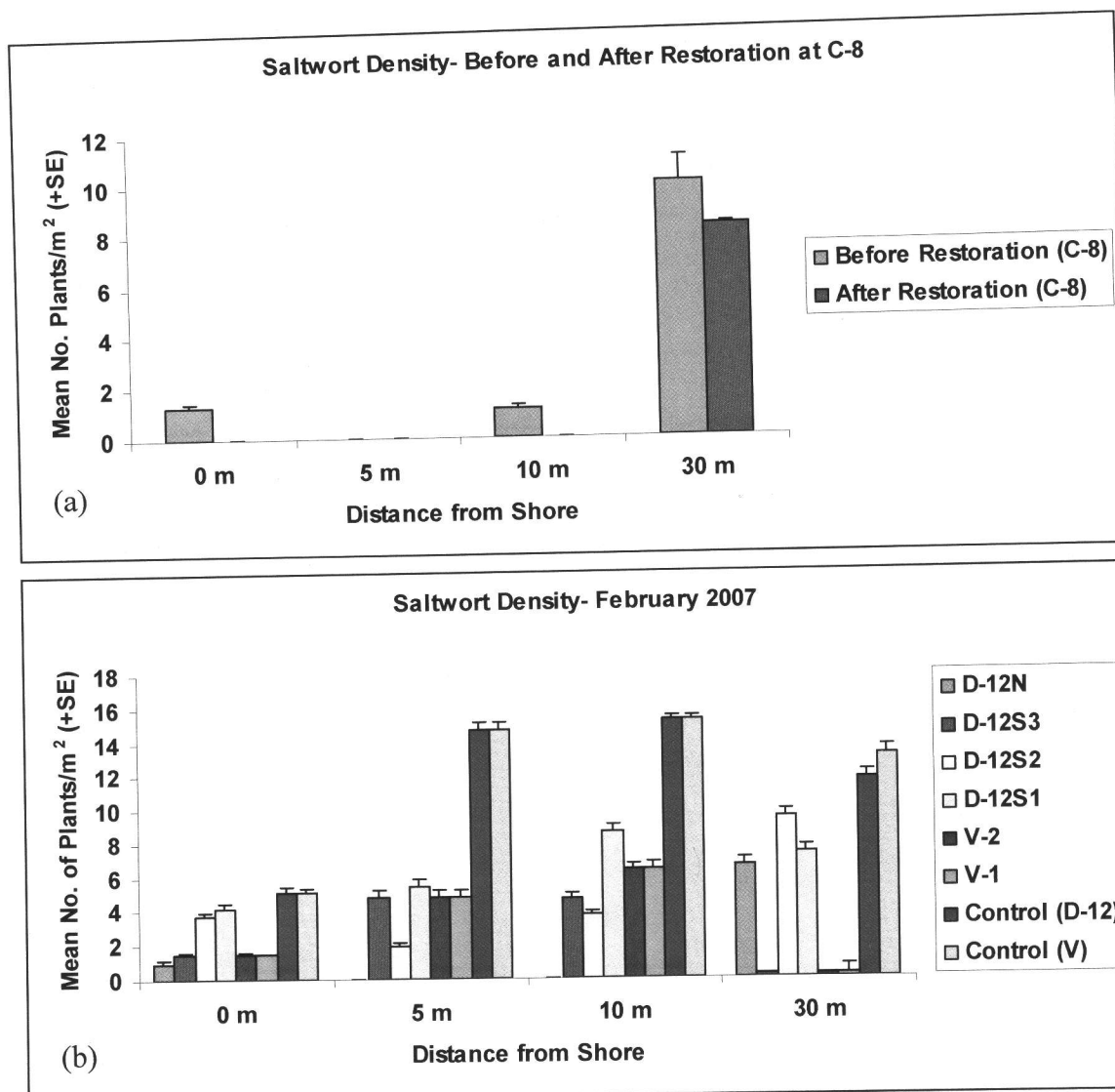


Figure 6. The mean number of saltwort (*Batis maritima*)/m² ($\pm$ SE) at (a) C-8 impoundment before substrate restoration and one month after restoration, and (b) post-restoration impoundments, for quadrats located 0, 5, 10, and 30 m from shoreline. The order of the post-restoration impoundments is increasing in time since restoration, with D-12N being in the earliest recovery period (1-month post-restoration) and V-1 in the oldest period of recovery (7 years post-restoration).

The perennial saltwort (*B. maritima*) was not recorded on the mid-portion of the dike (5m) before restoration at C-8 impoundments, as this portion was drier and dominated by terrestrial flora (Figure 6a). Saltwort was a dominant plant in the interior portions of the reference marshes (5-30m). The density of saltwort was greater at the restored portion of the marsh at the D-12 S impoundments, compared to the V impoundments (Figure 6b). At the V impoundments, saltgrass (*D. spicata*) and perennial glasswort (*S. perrennis*) composed a greater percentage of the plant cover.

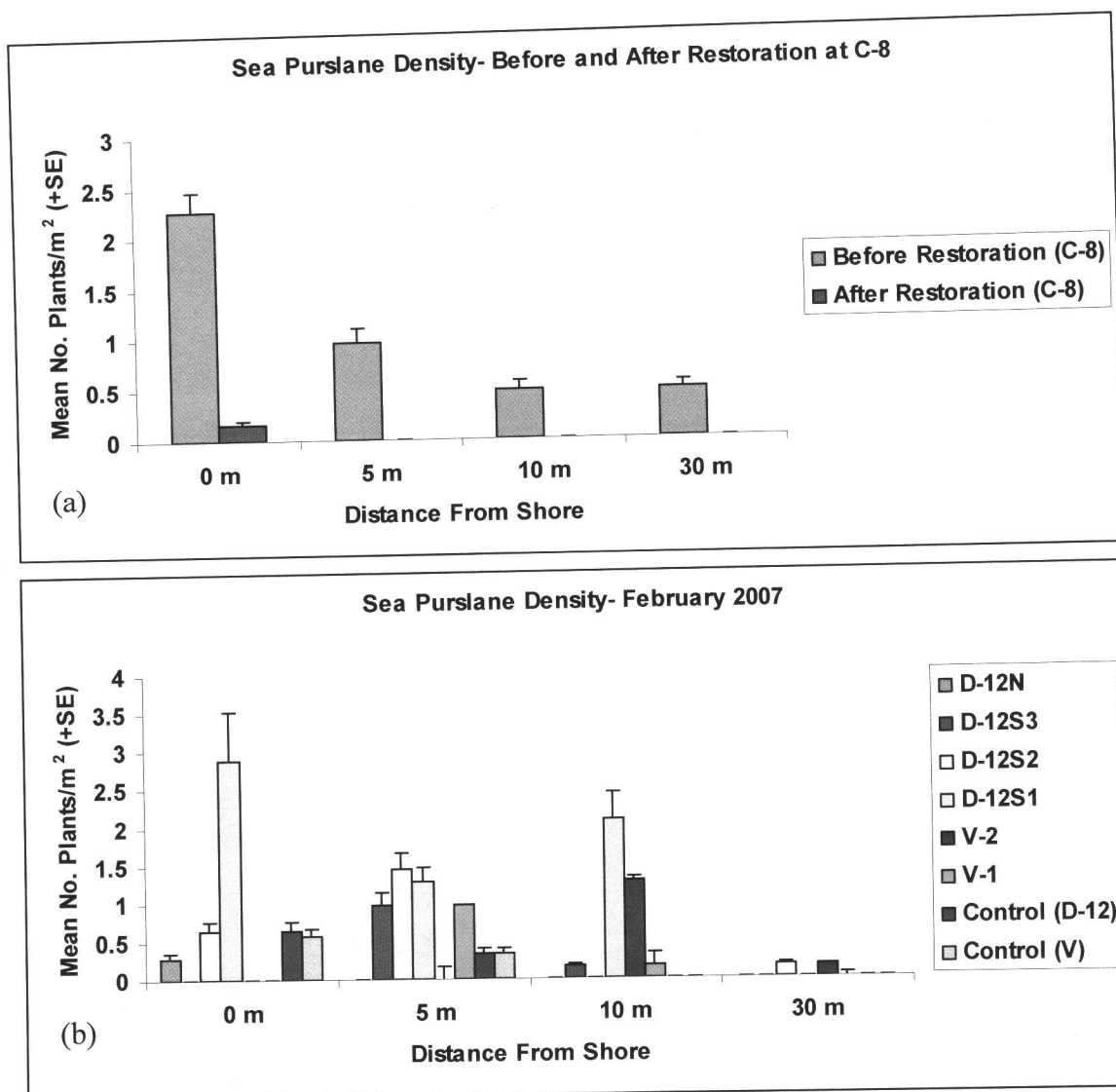


Figure 7. The mean number of sea purslane (*Sesuvium portulacastrum*)/m² ($\pm$ SE) at (a) C-8 impoundment before substrate restoration and one month after restoration, and (b) post-restoration impoundments, for quadrats located 0, 5, 10, and 30 m from shoreline. The order of the post-restoration impoundments is increasing in time since restoration, with D-12N being in the earliest recovery period (1-month post-restoration) and V-1 in the oldest period of recovery (7 years post-restoration).

Sea purslane (*S. portulacastrum*) was one of the early colonizers at newly restored impoundments and was one of the first colonizers of the shoreline portion of the restored portion of C-8 (Figure 7a). It is found in higher densities at the restored portion of impoundments compared to the reference marshes and the interior portion of the marsh (30m) at all sites (Figure 7b). Its ability to spread by extending out runners has led to it covering large portions of the restored substrate; however, overtime it is out-competed by other saltmarsh perennials and grasses at reference sites and within the interior marsh of restored impoundments.

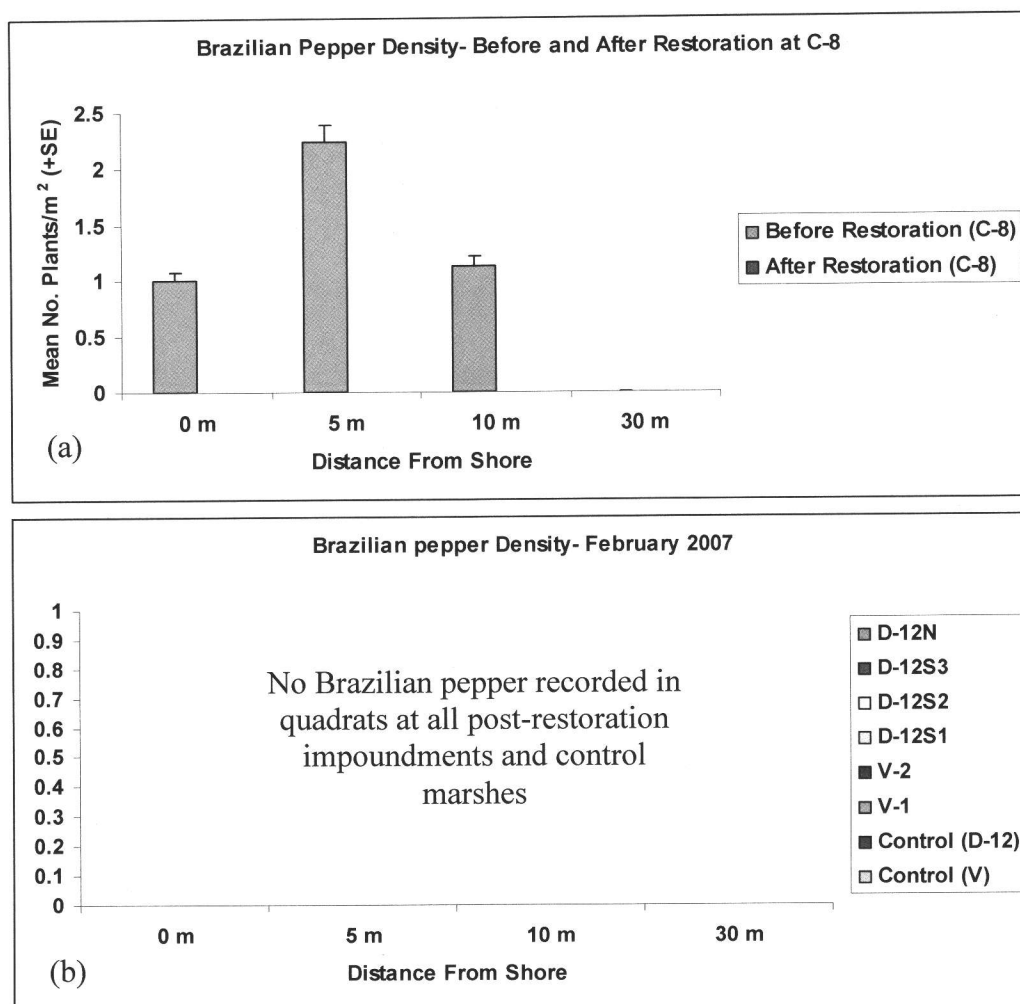


Figure 8. The mean number of Brazilian pepper (*Schinus terebinthifolius*)/m² ($\pm$ SE) at (a) C-8 impoundment before and one-month after substrate restoration, and (b) post-restoration impoundments, for quadrats located 0, 5, 10, and 30 m from shoreline.

The exotic Brazilian pepper (*S. terebinthifolius*) had heavily colonized the dike portion of the impoundment prior to substrate restoration (Figure 8a). Brazilian pepper is a highly invasive terrestrial tree species found in a variety of habitats throughout Florida. It often forms dense stands, decreasing biodiversity. It also produces inhibitory compounds, which decreases growth of native mangroves and *Spartina alternifolia* (Donnelly, 2006). It is not typically a threat in saltmarsh systems because it cannot tolerate prolonged tidal inundation and high salinity soil conditions. However, increases of the substrate elevation during the creation of mosquito impoundments changed the hydrological characteristics and created drier and less saline conditions. These changes facilitated the invasion of Brazilian pepper onto the dike portion of mosquito impoundments. This exotic was removed during the substrate leveling (Figure 8a) and has not recruited to any quadrats in the restored impoundment sites (Figure 8b). However, recruitment and recovery of damaged stumps has been observed in low numbers at other restored impoundments where complete tidal inundation has not been restored due to higher elevation of the substrate. Results of our monitoring program

identified areas where additional scraping was needed to decrease elevation and increase tidal inundation to prevent new recruitment of this exotic species.

Fiddler Crab Surveys

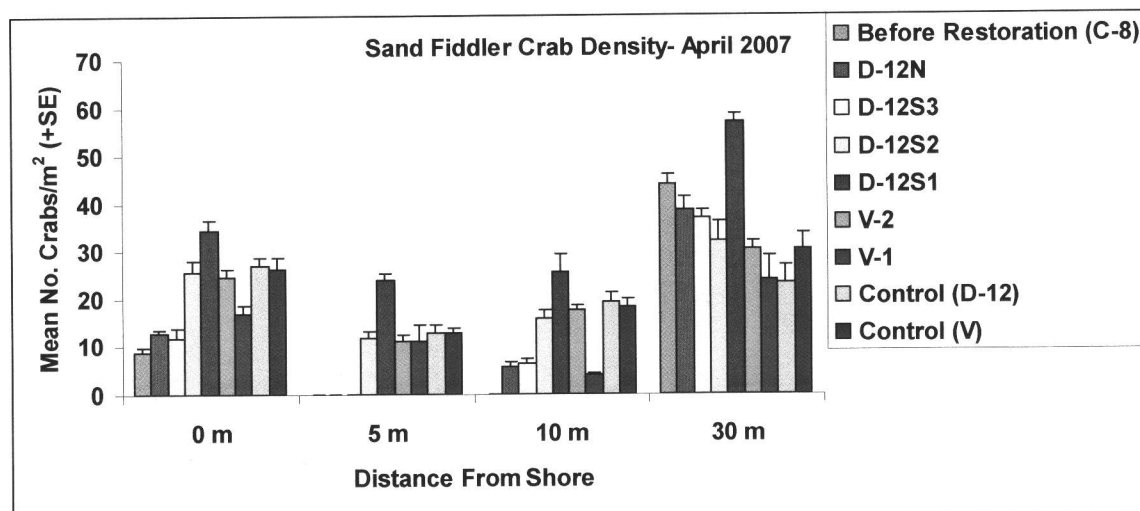


Figure 9. The mean number of sand fiddler crabs (*Uca pugilator*)/m² ($\pm$ SE) at C-8 impoundment before restoration of substrate (fiddler crab surveys after restoration of C-8 have not been completed at this time) and post-restoration impoundments, for quadrats located 0, 5, 10, and 30 m from shoreline. The order of the post-restoration impoundments is increasing in time since restoration, with D-12N being in the earliest recovery period (1-month post-restoration) and V-1 in the oldest period of recovery (7 years post-restoration).

The sand fiddler crab (*Uca pugilator*) was the primary fiddler crab found at all impoundments and restoration marshes (Figure 9). The density was highest in the interior marsh (30 m from shore) at all sites. Within the restored portion of marsh, D-12S1 had the highest density at the 0, 5 and 10 m locations. Three of the five sites of this portion of the D-12S impoundment had the borrow ditch completely filled in and the restored portion is directly connected to the interior marsh. This may facilitate movement of the fiddler crabs between the interior marsh and the restored region, resulting in overall higher densities at this site. Fiddler crabs were not found in the 5 m region at the D-12 N (two months post-restoration) and D-12S3 (1 year post-restoration). The middle portion of these two restored impoundments remained higher than the mean high tide line compared to the middle regions of other impoundment areas. The drier conditions at these newly restored sites may be less suitable for fiddler crab habitat.

Bird Surveys

Bird surveys had relatively low numbers (< 3 birds during 20 min. monitoring period) at all restored sites and reference marshes. Approximately 40% of the total quadrats had no birds during the monitoring period. At the C-8 impoundments and restoration marshes, the most abundant birds were redwing blackbirds and osprey. In comparison, the restored sites had higher frequencies of wading birds, such as herons, egrets, and sandpipers, foraging on the bare, sandy substrate of the restored portion of the impoundments. D-12S3 had the lowest occurrence of birds. The restored portion of this impoundment is higher and drier than other restored sites and has a steeper shoreline adjacent to the borrow ditch, which may have led to the decreased use of this portion of D-12S by wading birds.

Elevation

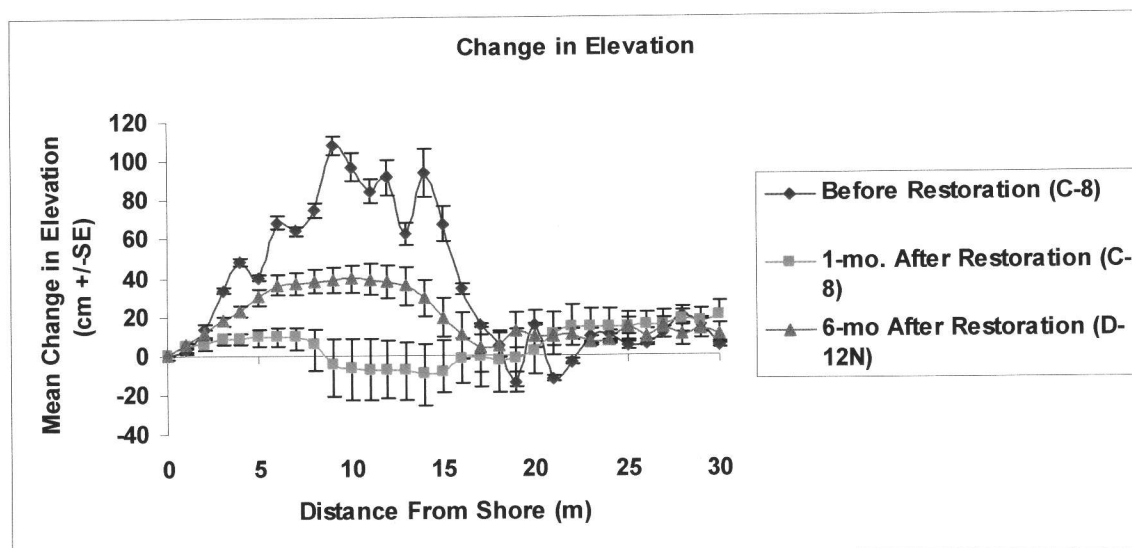


Figure 10. The mean change in elevation (cm $\pm$ SE) from the shoreline into the interior marsh at C-8 impoundment before and after restoration and at the D-12N impoundment, six months after substrate leveling. Elevation at other sites is currently ongoing and will be completed by the end of September 2007.

Before restoration of the substrate at C-8 impoundment, the elevation increased over 1 m from the shoreline at the peak of the dike (Figure 10). After restoration, the substrate was leveled to the mean high tide line. This site was surveyed the second week of September and the restored portion of the marsh was inundated during high tide. The D-12N impoundment (six months post-restoration) has a greater increase in the elevation in the mid-portion of the restored substrate, and this may partly explain the decreased recruitment of vegetation and fiddler crabs to the corresponding quadrats at this site. Elevation at other sites is currently being measured and will be completed by the end of September 2007.

Conclusions: Results from the two years of vegetation monitoring found significant natural recruitment of native vegetation at all restored sites. Interior marshes at restored sites supported similar plant abundances and diversity as reference marshes. The species richness and density of plants increased with time since restoration on the impacted portion of the marsh. The density of the exotic Brazilian pepper was high at the C-8 impoundment before substrate leveling and remains at zero following substrate leveling. Initial recruitment of native mangroves and saltmarsh plants occurred within one month of substrate restoration at D-12N and C-8 and was facilitated by the new method of leveling. By retaining the existing native saltmarsh vegetation at the shoreline, there was an available seed source for recruitment into the leveled areas and increased recruitment rates. In addition, fiddler crabs were also found at recently restored sites, suggesting initial recovery of food web processes is occurring at restored mosquito impoundment sites in Mosquito Lagoon. Bird use differed between the restored sites and reference marshes, with the restored marshes having a higher frequency of wading birds foraging on the bare substrate. In comparison, reference marshes were primarily utilized by perching birds, such as the redwing black bird and osprey. Further monitoring of these impoundments is needed to provide insight on the effectiveness of restoration methods, estimate recovery rates and potential outcomes, and to provide valuable information for future saltmarsh restoration projects.

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