

Project Title: Impoundment Restoration Evaluation and Sediment Elevation Monitoring

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Final Project Report

September 2017

I. BACKGROUND

Monitoring restored coastal wetland sites over time is required for evaluating progress and improving restoration methods. Monitoring will also help understand how coastal wetlands are responding to sea-level rise that can affect their long-term status. One means of evaluating the long-term elevation response of coastal wetlands to sea-level rise and/or to water management is the measurement of wetland elevation or sediment accretion rates by a series of Sediment Elevation Tables (SET) distributed throughout representative wetland areas. Additional monitoring of vegetative recovery and faunal utilization are beneficial for demonstrating restoration success and the recovery of wetland functions.

In the northern portion of the Indian River Lagoon system (IRL; north IRL and Mosquito Lagoon), 20 impoundments were fully restored between 1999 and 2010. The time since restoration currently ranges from five to sixteen years. Previous efforts monitored 12 of these impoundments post-restoration between 2005 and 2011 to document initial recovery following substrate leveling to restore natural hydrology (from 0 to 11 years post-restoration). This effort included habitat structure variables (elevation, soil moisture, soil salinity, type of substrate) at twelve impoundments and biotic variables (species abundance and diversity of plants, fiddler crabs, birds, and nekton) at five impoundments. To complement this monitoring, SET stations were installed at three restored impoundments and three nearby natural wetlands in 2008 to track accretion (restored surfaces, interior wetlands and nearby control wetlands). Baseline measurements of surface elevation using SET arm (9 measuring pins at 4 positions/station) were recorded one month after installation and feldspar marker horizons were deployed on substrate surface at each station. Stations were re-measured one year later.

II. OBJECTIVE

The objective of this project is to expand the number of monitored sites and extend the period monitored to improve our understanding of the post-restoration recovery processes. This should allow the restoration methods used to be evaluated regarding their long-term success. In addition, SET station will be monitored to verify that restored surfaces are accreting at rates similar to un-impacted control sites, which will be a factor in their persistence over time. To gain limited information on a broader ecosystem level, a comparison regarding a higher trophic level ecosystem function will be undertaken by monitoring water bird use of restored and natural areas.

III. SCOPE OF WORK

This study conducted similar monitoring at the previous sites and eight additional restored impoundments over three years (2015-2017) to evaluate habitat recovery. Two impoundments were restored over multiple years and were monitored in multiple segments by year of restoration. A total of 24 restored impoundment sites with time intervals since restoration from five to eighteen years were included. Five natural, unimpounded wetlands were also included for comparison to restored sites. Monitoring focused on habitat structure variables measured previously (elevation, soil moisture, soil salinity, and substrate type) to allow for comparisons to earlier monitoring efforts, and include the biotic variables of abundance and diversity of vegetation and fiddler crabs. In addition, bird use of impoundments was monitored seasonally at a subset of impoundments as a biotic indicator of higher trophic levels in the restored habitats. To complement the monitoring, SET stations installed at three restored impoundments and three natural wetlands.

IV. COMPLETED TASKS

Task 1: Post-Restoration Habitat Recovery Monitoring

Methods

Within each restored impoundment site and at five natural wetland sites, the following methods were applied at five randomly chosen locations (Figure 1). Linear transects from the subtidal zone landward onto the intertidal wetland surface were established at each location (3 transects/location, 20 m in length). Relative elevation along one transect per site were measured with a laser level and stadia rod at 1-m intervals. Substrate cover (i.e. vegetation, oysters, mud/sand, etc.) was recorded from 0.25-m² quadrats using the point-intercept method at 4-m intervals along three transects per location. In addition, the number and species of plants, number of fiddler crab burrows, soil moisture and water depth were recorded in each quadrat (Table 1, Figure 2). Soil samples were taken from quadrats along one transect for soil salinity analysis in the lab using the dilution method.

Results

During 2015, eight of the nine restored impoundments and all natural wetlands were inundated at time of monitoring (Table 2). The only restored site not inundated was D-12S4. This impoundment had one of the largest maximum changes in elevation relative to the shoreline (24 cm) as well as low soil moisture and soil salinity (Table 2). It was also the only restored site during this monitoring period with non-native Brazilian pepper in the restored wetland area (Figure 3). In comparison to previous monitoring, soil moisture was similar for all restored sites over time, with mean soil moisture for the majority of restored sites over 90% (Table 2, Figure 4). Soil salinity tended to increase with time since restoration, with the exception of the oldest impoundments (180 months or 15 years post-restoration) (Figure 5). Soil salinities were lower at the V-5, V-2, and T-45 impoundments compared to more recently restored sites (Table 2, Figure 5). Higher soil salinities during the early stages of recovery may result from a combination of more frequent inundation after leveling combined with lower cover of vegetation.

During summer 2016, three restored impoundment sites (D-12S3, D-12N, T-42) were not fully inundated at time of monitoring, however, mean soil moisture was greater than 95% at all locations (Table 2). Maximum elevations of restored sites was 29 cm or less at all sites, with a small berm on the exposed shoreline of the C-21CS restored impoundment having the highest elevation of all sites (Table 2). This may explain the presence of Brazilian pepper in the restored area of this location (Figure 3). All other impoundment sites and control wetlands monitored in 2016 were inundated at time of monitoring. Soil moisture was similar for all restored sites, with mean soil moisture for the majority of restored sites over 90% (Figure 4). Soil salinities at sites monitored in Mosquito Lagoon had higher soil salinities (35+ ppt), compared to NIRL and Banana River sites (less than 35 ppt). Higher soil salinities observed during this monitoring year may have been caused by long periods without rain prior to summer monitoring, potentially leading to high rates of evaporation and build-up of salts in upper layers of soil.

All sites monitored in summer 2017 were not inundated at time of data collection, however, soil moisture was over 90% for all sites and times since restoration (Table 2). Soil salinities ranged between 20.1 ppt and 42.2 ppt, with the lowest observed salinities at the C-12D impoundment in the Banana River sites (Table 2). Maximum change in elevation ranged between 9 cm and 25 cm, with the greatest change observed at D-12S2 sites restored during 2004. This was also the only restored site during this monitoring period to have Brazilian pepper in the restored area (Figure 3).

Natural wetlands and interior wetlands had a mean soil moisture of 90% or greater consistently through time for all three years of monitoring. Soil salinities at control sites and interior wetlands tended to be higher at wetlands in Mosquito Lagoon compared to NIRL and Banana River sites (Table 2).

In the subtidal zone, seagrass was observed along the shoreline of twelve of the restored impoundments (D-12S, T-42, D-12N, T-41, T-43, T-45, V-1, V-2, V-5, C-21CN, T-39S, T-37B) and three control wetlands (V, D-12S, D-12N) (Figure 6a). Mean percent cover of seagrass ranged from 13% (D-12N) to 100% (V-2). In addition to seagrass along the estuarine shoreline of restored wetlands, we also observed seagrass in the remnant borrow ditches at V-impoundments and D-12S impoundments, with percent cover ranging from 25% to 55%. Oysters were observed at one natural wetland (D-12N) and two restored impoundments (D-12N, C-8) in the lower intertidal zone and attached to red mangrove roots at the shoreline (Figure 6b).

As time since restoration has increased, differences in percent cover among quadrats on the anterior, middle, and posterior locations of restored wetland area has decreased and means were calculated for the total restored area (4 m to 16 m locations on transect) in Figure 7 and Table 2. In comparison to previous monitoring, percent cover of vegetation increased at all restored impoundment sites (Figure 7) and continues to average 100% at interior wetlands (20 m location on transects at restored impoundments) and natural wetlands (all locations along transects) (Table 2, Figure 8). However, rates of recovery at restored impoundments where shoreline vegetation was left intact continue to be higher compared to restored impoundments where all vegetation was removed (Figures 7, 9). For example, the restored wetland at T-34 has a mean percent cover of 97.2% after only 5 years of recovery, compared to mean percent covers ranging between 66% and 78% for impoundments restored 15 to 18 years ago (Table 2, Figure 7).

Increases in percent cover occurred through new recruitment as well as expansion of initial colonizers, particularly *Sarcocornia perennis* and *Batis maritima*, which continue to be found at all restored impoundments and natural wetlands. Increased densities and sizes of mangroves were also observed at all impoundments and restored wetlands, with *Avicennia germinans* being the most common mangrove species at all monitored sites (Figure 9). In general, species richness tended to be highest in the early stages of recovery (0-5 years) and showed a decreasing trend as time since restoration increased (Figure 10). Restored impoundments with longer recovery times had high abundances of medium (75 cm to 125 cm) and large (> 125 cm) mangroves and the common halophytes, *S. perennis* and *B. maritima*, whereas impoundments with shorter recovery times had a greater variety of species, including halophytic grasses (*Distichlis spicata*, *Spartina alterniflora*), succulents (*Sesuvium portulacastrum*), and small shrubs (*Borrichia frutescens*). The only non-native species observed at restored impoundments was Brazilian pepper. C-21CS, C-20B, T-18B, D-12S4, T-37B and T-35 had Brazilian pepper growing in the interior wetlands; however, Brazilian pepper was only observed in the restored wetland area of C-21CS, D-12S2, and D-12S4 (Figure 3).

Task 2: SET Monitoring Associated with Restoration Sites.

Methods

Working with partners from the District, USGS, and NASA, nine SET stations associated with impoundment restorations sites were monitored, following the design from Don Cahoon and published measurement methods (Cahoon et al. 2006).

Results

All 9 SET stations were evaluated in September 2015 (Figure 11). Six of the nine stations were readable (V-restored, V-interior marsh, V-control, D-12S- restored, D-12N- interior, D-12N-control) and three stations were unreadable due to corrosion at the pipe-soil interface (D-12S-interior, D-12S- control, D-12N- restored). The SET station in the interior marsh at the V impoundment site broke-off during the movement of the arm from the third to the fourth position; therefore, only three of the four directions were readable. Further evaluation in following years found two additional pipes were also damaged and prevented readings (D-12S and D-12N).

All six stations showed increases in sediment height since the initial reading in February 2008. The smallest change in height was observed in the interior wetland of D-12N (9.96 ± 5.6 mm) and the greatest change was observed in the interior wetland at the V impoundment (47.3 ± 1.7 mm). Recent estimates of sea level rise in Canaveral National Seashore were approximately 2.4 mm per year, based on calculations from Florida State University's Center for Ocean-Atmospheric Prediction Studies. Therefore, from 2008 to 2015, sea level increased by approximately 18 mm during this time. Increases in sediment heights at the SET stations suggest all sites but the interior wetland at D-12N have accreted sediment at rates faster than current sea level rise in Mosquito Lagoon.

Six new SET stations using updated methodology were installed near the restored marsh at Marine Discovery Center in New Smyrna Beach in August 2016 (Figure 12). Three stations were installed on the isolated island within the restored marsh at the Center and three stations were installed in adjacent unimpacted marshes near restored marsh. Initial readings were completed in fall 2016 and first reading was completed in summer 2017.

Task 3: Higher Trophic Level Monitoring

Methods

To understand more about one of the ecosystem functions wetlands, and particularly restored wetlands, may provide, seasonal bird surveys were conducted at five locations at six impoundment sites and two natural wetlands where past bird monitoring was conducted (D-12S1, D-12S3, V-1, V-2, D-12N, C-8). Surveys began in August 2015 and were conducted every four months through summer 2017 to compare bird community structure and utilization over longer recovery periods. Surveys were conducted by recording all individual birds entering a 100 m² quadrat (10 m shoreline x 10 m inland) during a 20-minute time period during morning hours. Birds were identified to species and behavior (i.e. foraging, resting, perching, flying) was recorded. For birds foraging in quadrats, the number of feeding behaviors was also recorded. After the surveys, quadrats will be visually inspected for presence of nests during active breeding seasons.

Results

A total of 1607 birds from 44 total species were observed at restored impoundments and control wetlands during seasonal surveys between August 2015 and August 2017. The osprey was the most abundant species overall and was observed at all restored impoundments and both control wetlands (Figure 13). Gulls, great blue herons, tri-color herons, reddish egrets and snowy egrets

were also commonly observed at restored impoundments and control wetlands (Figure 13). There was a significant effect of both type of wetland (restored compared to control) and time since restoration on bird abundance and diversity. Restored impoundments had significantly higher numbers of birds ($p=0.001$) and species richness ($p=0.03$) compared to control wetlands. Number of birds and species richness also increased significantly with time since restoration ($p=0.02$ and 0.03 , respectively). The highest abundances and species richness occurred during the December surveys with the presence of migratory bird species, including white pelicans and waterfowl. In comparison to past bird surveys at restored sites, total number of birds and species richness were both higher at all sites.

A total of 7 species were observed foraging at control wetlands, compared to 18 species at restored impoundment locations. Ospreys were the most common bird observed foraging during surveys, accounting for 30% of the foraging behaviors and a success rate of 80%. Ospreys foraged in all areas of the restored impoundments, including anterior shorelines, restored wetland surfaces when flooded, and borrow ditches when present. Herons and egrets showed a variety of behaviors at restored impoundments, including resting on restored wetland, perching on mangrove trees, and foraging on restored impoundment surfaces, anterior shorelines, and borrow ditches. Nesting by Wilson's plovers was observed at the D-121 impoundment (1 nest, 3 eggs) and the V-1 impoundment (4 nests, 2-3 eggs per nest) during the April 2016 surveys (Figure 13). In 2017, Wilson plover nests were observed at the D-121 impoundment (1 nest, 2 eggs) and the V-1 impoundment (3 nests, 2-3 eggs per nest).

V. CONCLUSIONS

This study documented the effectiveness of dike removal on the long-term recovery and sustainability of coastal wetland habitat and results from this study provide management recommendations for future wetland restoration. Natural regeneration following hydrological restoration has supported the development of plant communities similar to natural wetlands in species diversity and abundances. Differences between natural and restored wetlands in percent cover and species richness have decreased with time since restoration. Conserving wetland vegetation during dike removal had a positive effect on the rate of recovery. Restored wetlands in younger stages of recovery (5 to 10 yrs) are reaching percent cover values equal to or greater than impoundments with 10 to 15 years since restoration. Elevation and the return of tidal flow is a critical factor in plant community recovery and excluding non-native vegetation. Inundation of the restored impoundment during the high water season has promoted the recruitment of water-dispersed propagules and seeds and maintained more favorable abiotic conditions for the establishment and growth of wetland vegetation (higher soil moisture, intermediate soil salinities). This has limited the plant community at most restored sites to obligate and facultative wetland species and reduced the overall distribution and abundance of non-native species. The higher abundance and diversity of birds, as well as a variety of behaviors including foraging and nesting, at restored sites suggest the development of the plant community and associated fauna is providing quality habitat for native bird species. In conclusion, hydrological restoration of mosquito impoundments has resulted in the development of functional wetland ecosystems in the Indian River Lagoon and has reversed some of the extensive habitat loss caused by the construction of mosquito impoundments.

VII. TABLES AND FIGURES

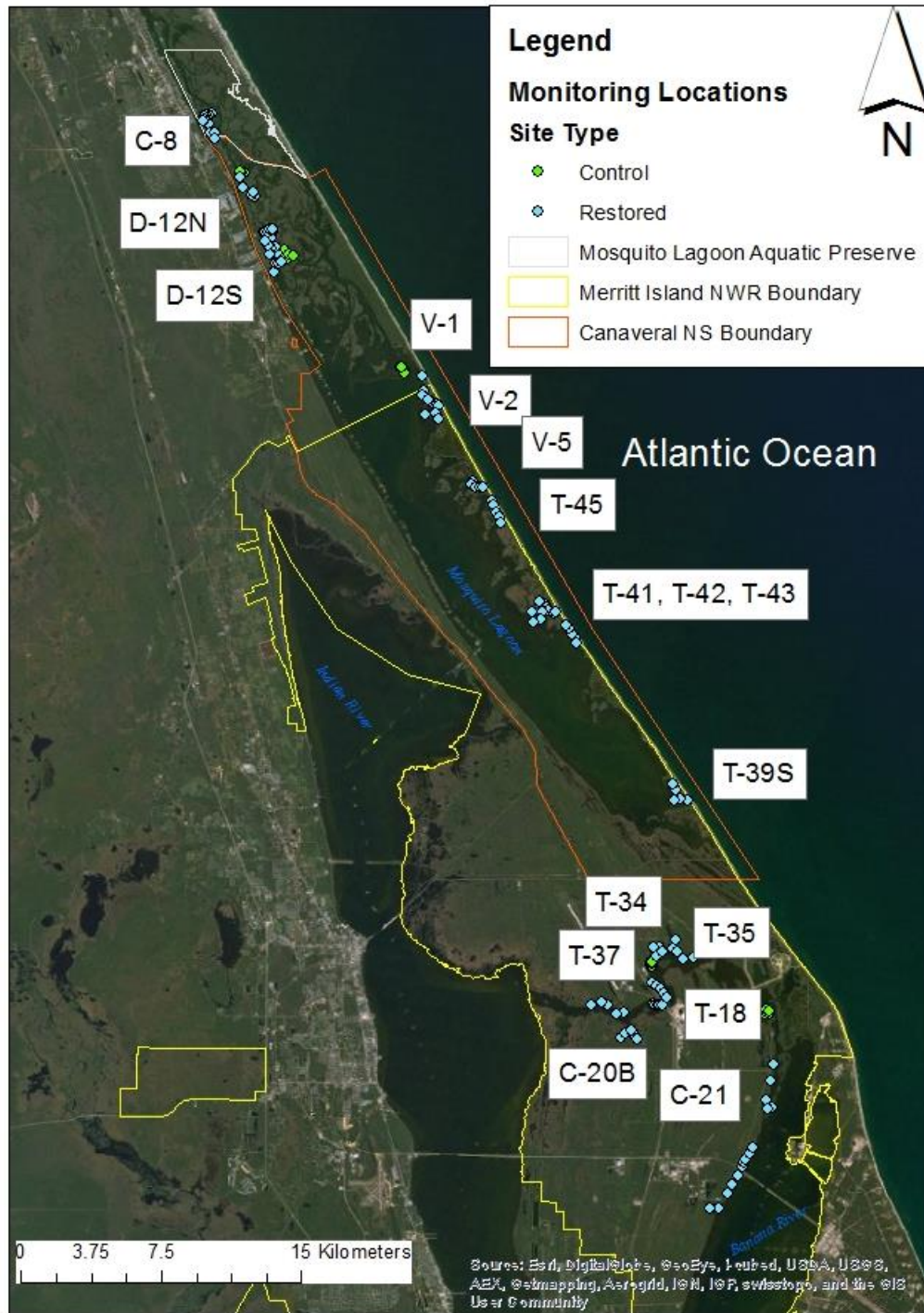


Figure 1: Location of restored and control wetlands in the Indian River Lagoon.

Table 1. Summary of abiotic and biotic variables included in this study.

Shoreline Parameters	Shoreline Variables	Sampling Methods
1. Abiotic	Soil Moisture	Soil moisture meter
	Soil Salinity	Dilution method
	Relative Elevation	Laser level on linear transects
	Substrate Type	Point-intercept in 0.25 m ² quadrats
2. Biotic	Vegetation	Total counts/species in 0.25 m ² quadrats
	Fiddler Crabs/Burrows	Total counts in 0.25 m ² quadrats
	Birds	Seasonal abundance/behavior observations during 1 hr survey

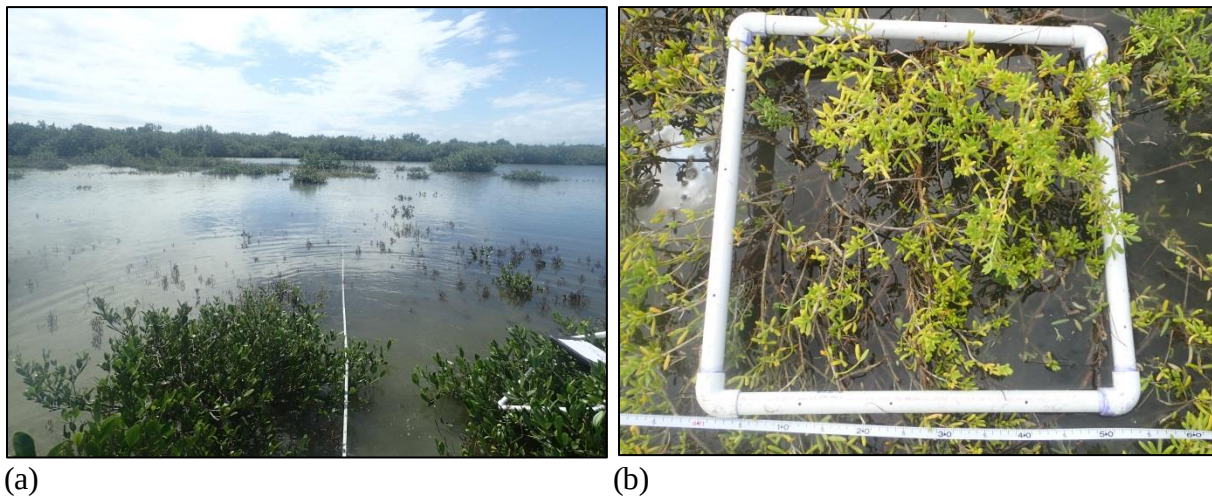


Figure 2. Abiotic and biotic variables were measured along three 20-m transects, running perpendicular to the shoreline, from the subtidal zone towards the interior marsh at each location (a). Percent cover of vegetation was measured using the point-intercept method in 0.25 m² quadrats at 4-m intervals along each transect (b). Plant abundance and diversity, number of fiddler crab burrows, soil moisture, water depth, and soil salinity were also measured within each quadrat.

Table 2. Descriptive statistics and counts for restored mosquito impoundments and natural wetlands monitored between 2015 and 2017. Means and total counts for restored wetlands (RW) were calculated from the data collected at the 4 m to 16 m intervals along transects, representing the area where dike leveling occurred. Means and total counts for interior wetlands (IW) were calculated from the 20 m position of transects. Means for control wetlands were calculated from the same transect intervals for comparison to restored sites. Control wetlands were monitored annually between 2015 and 2017 and values in table below represent the three year mean for each of these sites.

Year	Site	Sub Lagoon	Year of Rest.	Mean Percent Cover $\pm$ SE		Total Plant Species Richness		Mean Density of Fiddler Crab Burrows/ m ² $\pm$ SE		Mean Soil Moisture $\pm$ SE		Mean Soil Salinity $\pm$ SE		Maximum Elevation (cm)
				RW	IW	RW	IW	RW	IW	RW	IW	RW	IW	
2015	V-2	ML	2000	74.5 $\pm$ 39.3	100 $\pm$ 0.0	9	5	0	0	100 $\pm$ 0.0	100 $\pm$ 0.0	22.7 $\pm$ 2.0	25.6 $\pm$ 1.9	6
	V-5	ML	2000	66.6 $\pm$ 40.1	100 $\pm$ 0.0	4	3	0	0	100 $\pm$ 0.0	100 $\pm$ 0.0	23.5 $\pm$ 1.1	18.4 $\pm$ 1.6	11
	T-45	ML	2000	78.6 $\pm$ 35.7	100 $\pm$ 0.0	6	4	0	0	100 $\pm$ 0.0	100 $\pm$ 0.0	27.1 $\pm$ 1.2	21.6 $\pm$ 2.5	13
	D-12S-4	ML	2005	76.9 $\pm$ 32.1	100 $\pm$ 0.0	10	4	15.1 $\pm$ 0.4	4 $\pm$ 0.6	89.5 $\pm$ 1.3	100 $\pm$ 0.0	20.0 $\pm$ 3.2	35.5 $\pm$ 2.0	24
	T-18-A	NIRL	2010	83.5 $\pm$ 23.2	100 $\pm$ 0.0	10	7	40.0 $\pm$ 0.0	60 $\pm$ 0.0	99.0 $\pm$ 0.5	95.8 $\pm$ 1.8	53.9 $\pm$ 10.5	18.4 $\pm$ 6.1	12
	T-34	NIRL	2010	97.2 $\pm$ 7.9	100 $\pm$ 0.0	10	8	0	0	100 $\pm$ 0.0	100 $\pm$ 0.0	36.7 $\pm$ 6.5	20.4 $\pm$ 0.9	15
	T-41	ML	2010	59.6 $\pm$ 38.5	100 $\pm$ 0.0	7	6	0	0	100 $\pm$ 0.0	100 $\pm$ 0.0	26.3 $\pm$ 2.4	19.2 $\pm$ 0.8	15
	T-43	ML	2010	59.8 $\pm$ 42.1	100 $\pm$ 0.0	5	4	0	0	100 $\pm$ 0.0	100 $\pm$ 0.0	24.5 $\pm$ 2.3	19.2 $\pm$ 1.5	11

	C-21-CN	BR/NF H	2010	58.7 ± 38.5	100 ± 0.0	9	8	11.6 ± 0.3	20.5 ± 0.9	96. 2 ± 0.9	94.6 ± 1.0	40.8 ± 5.4	60.5 ± 20.8	18
2016	D-12S-3	ML	2006	76.7 ± 29.4	100 ± 0.0	6	4	17.1 ± 0.4	0	95. 6 ± 0.9	100 ± 0.0	35.2 ± 2.5	18.9 ± 0.6	24
	D-12N	ML	2006	93.6 ± 10.2	100 ± 0.0	6	4	31.2 ± 0.6	24.3 ± 0.7	96. 3 ± 1.1	100 ± 0.0	58.3 ± 1.7	59.2 ± 2.2	22
	C-21-CS	BR/NF H	2008	93.7 ± 8.7	100 ± 0.0	7	5	0	0	100 ± 0.0	98.2 ± 0.7	21.5 ± 0.9	17.2 ± 1.7	29
	T-35	NIRL	2009	90.4 ± 16.9	100 ± 0.0	7	4	19.7 ± 0.2	16.0 ± 0.0	100 ± 0.0	95.6 ± 0.8	35.3 ± 2.2	13.3 ± 1.0	17
	C-20-B	NIRL	2009	96.3 ± 7.5	100 ± 0.0	6	4	0	0	100 ± 0.0	100 ± 0.0	18.2 ± 1.1	15.2 ± 1.2	13
	T-18-B	NIRL	2010	87.5 ± 18.6	100 ± 0.0	6	5	0	0	100 ± 0.0	98.5 ± 0.9	19.4 ± 2.1	15.2 ± 1.1	11
	T-42	ML	2010	70.3 ± 26.7	100 ± 0.0	5	4	15.2 ± 0.3	0	95. 7 ± 0.8	100 ± 0.0	55.3 ± 2.5	18.6 ± 0.8	12
2017	V-1	ML	1999	71.3 ± 28.7	100 ± 0.0	9	5	24.6 ± 1.1	18.4 ± 0.9	100 ± 0.0	100 ± 0.0	34.4 ± 1.6	29.8 ± 1.2	9
	D-12S-1	ML	2003	76.9 ± 25.4	100 ± 0.0	5	4	15.6 ± 1.1	10.6 ± 0.4	96. 7 ± 0.7	100 ± 0.0	38.9 ± 1.2	21.3 ± 0.8	18
	D-12S-2	ML	2004	79.8 ± 21.4	100 ± 0.0	6	4	16.9 ± 2.1	9.8 ± 1.0	95. 5 ± 0.9	100 ± 0.0	29.4 ± 1.5	23.2 ± 0.5	25
	C-21-D	BR/NF H	2007	88.7 ± 19.6	100 ± 0.0	5	5	12.5 ± 1.1	15.6 ± 0.5	96. 6 ± 0.5	100 ± 0.0	20.1 ± 1.6	21.3 ± 1.2	20
	T-39-S	ML	2008	83.5 ± 25.7	100 ± 0.0	5	4	18.5 ± 0.7	11.3 ± 0.3	94. 5 ± 0.4	100 ± 0.0	41.2 ± 0.8	22.5 ± 1.8	15

	C-8	ML	2007	94.8 ± 15.4	100 ± 0.0	6	5	10.5 ± 0.3	12.8 ± 1.3	95.9 ± 0.9	100 ± 0.0	40.2 ± 1.3	41.2 ± 2.3	18
	C-8	ML	2008	90.2 ± 17.5	100 ± 0.0	5	4	12.4 ± 1.5	8.6 ± 0.2	94.8 ± 0.8	100 ± 0.0	42.2 ± 1.1	40.9 ± 2.1	16
	T-37-B	NIRL	2009	92.6 ± 22.1	100 ± 0.0	6	5	3.1 ± 0.1	0	93.6 ± 1.2	100 ± 0.0	32.2 ± 1.5	19.8 ± 0.6	16
Control Sites (2015-2017)	V-C	ML	Control	99.7 ± 0.1	99.7 ± 0.1	6	5	13.7 ± 0.3	19.4 ± 0.6	100 ± 0.0	100 ± 0.0	53.7 ± 1.2	57.8 ± 2.3	15
	D-12S C	ML	Control	100 ± 0.0	100 ± 0.0	7	4	5.1 ± 1.1	6.9 ± 1.2	100 ± 0.0	100 ± 0.0	37.1 ± 1.3	41.5 ± 1.5	17
	D-12N C	ML	Control	100 ± 0.0	100 ± 0.0	7	5	10.2 ± 1.2	12.6 ± 0.6	100 ± 0.0	100 ± 0.0	45.5 ± 1.2	42.6 ± 1.4	17
	NIRL-C	NIRL	Control	100 ± 0.0	100 ± 0.0	6	5	12.7 ± 1.1	9.8 ± 0.9	100 ± 0.0	99.8 ± 0.1	24.5 ± 1.7	22.0 ± 1.2	15
	NIRL-C2	NIRL	Control	100 ± 0.0	100 ± 0.0	6	5	6.5 ± 1.0	8.0 ± 0.3	100 ± 0.0	100 ± 0.0	17.5 ± 1.1	16.5 ± 1.5	15

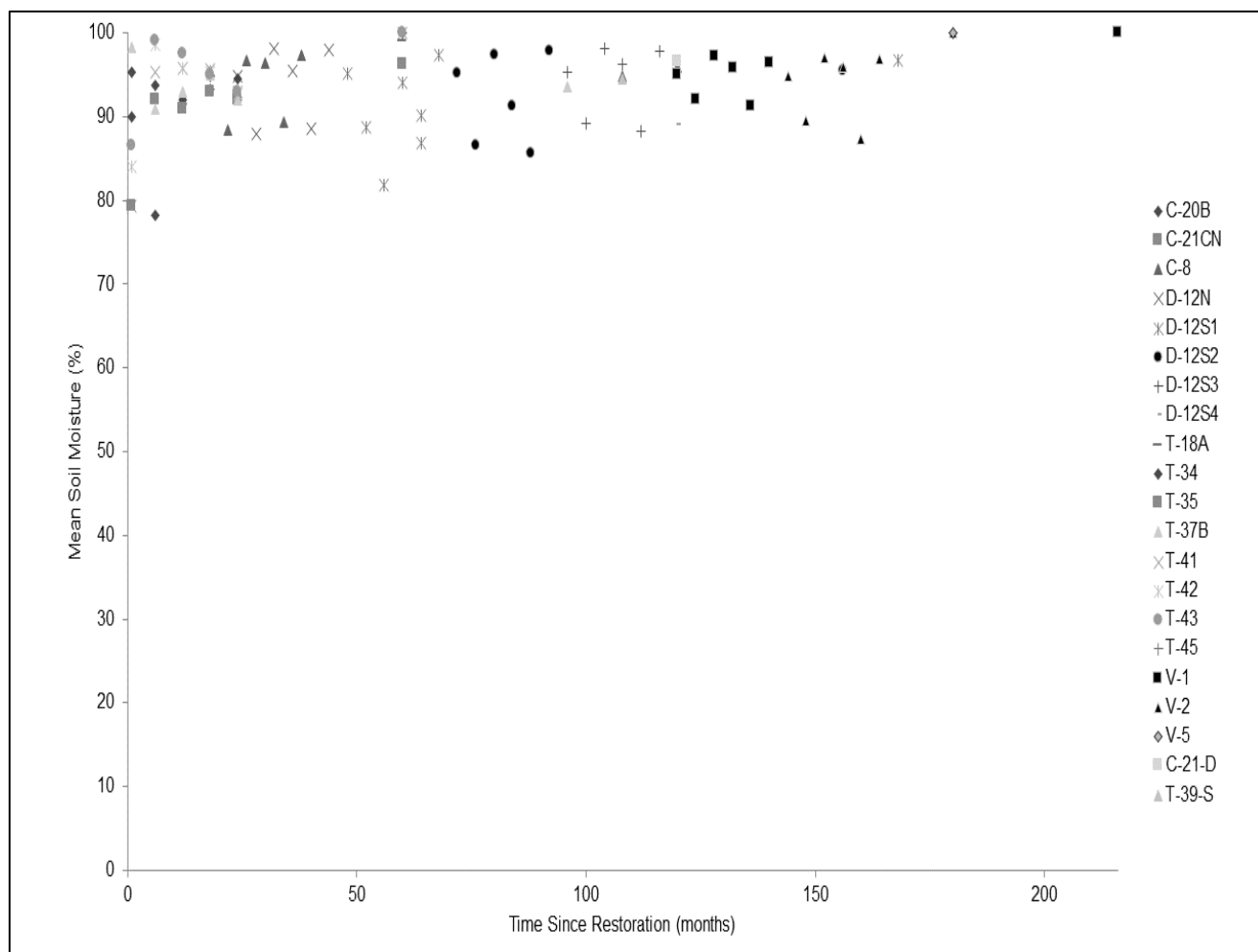


a) C-21CS



b) D-12S2

Figure 3. The overall distribution and abundance of Brazilian pepper at restored mosquito impoundments was low, however, some impoundments (C-21CS (a), D-12S2 (b)) had scattered trees remaining on the restored wetland.



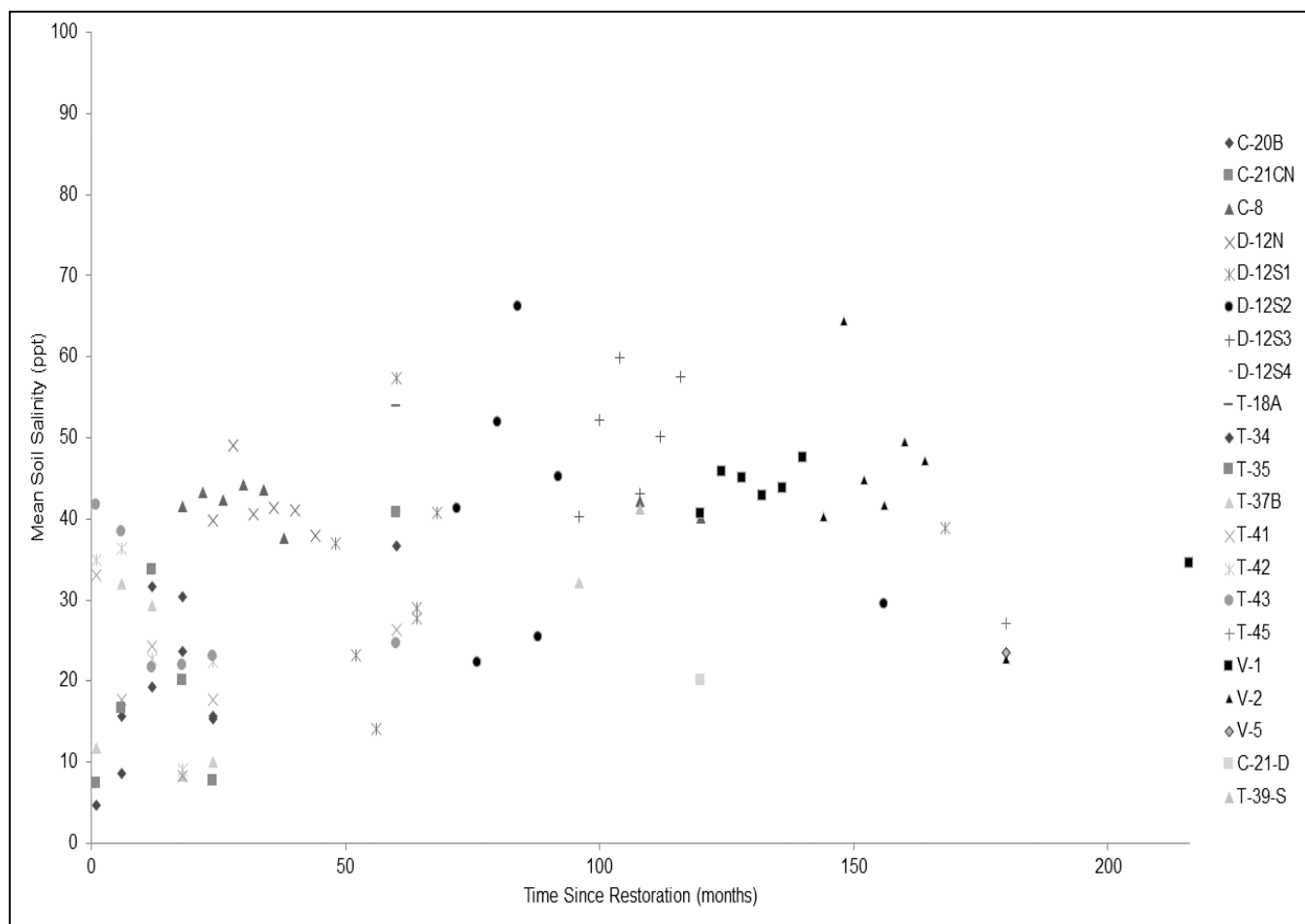


Figure 5. The mean soil salinity (ppt) of restored mosquito impoundments over time since restoration (months).



a) Seagrass near T-39S



b) Oysters attached to mangrove roots along shoreline of C-8

Figure 6. Mosquito impoundment restoration has also benefitted habitats adjacent to wetlands, including seagrass (a) in the southern region of our monitoring area and oysters (b) in the northern region.

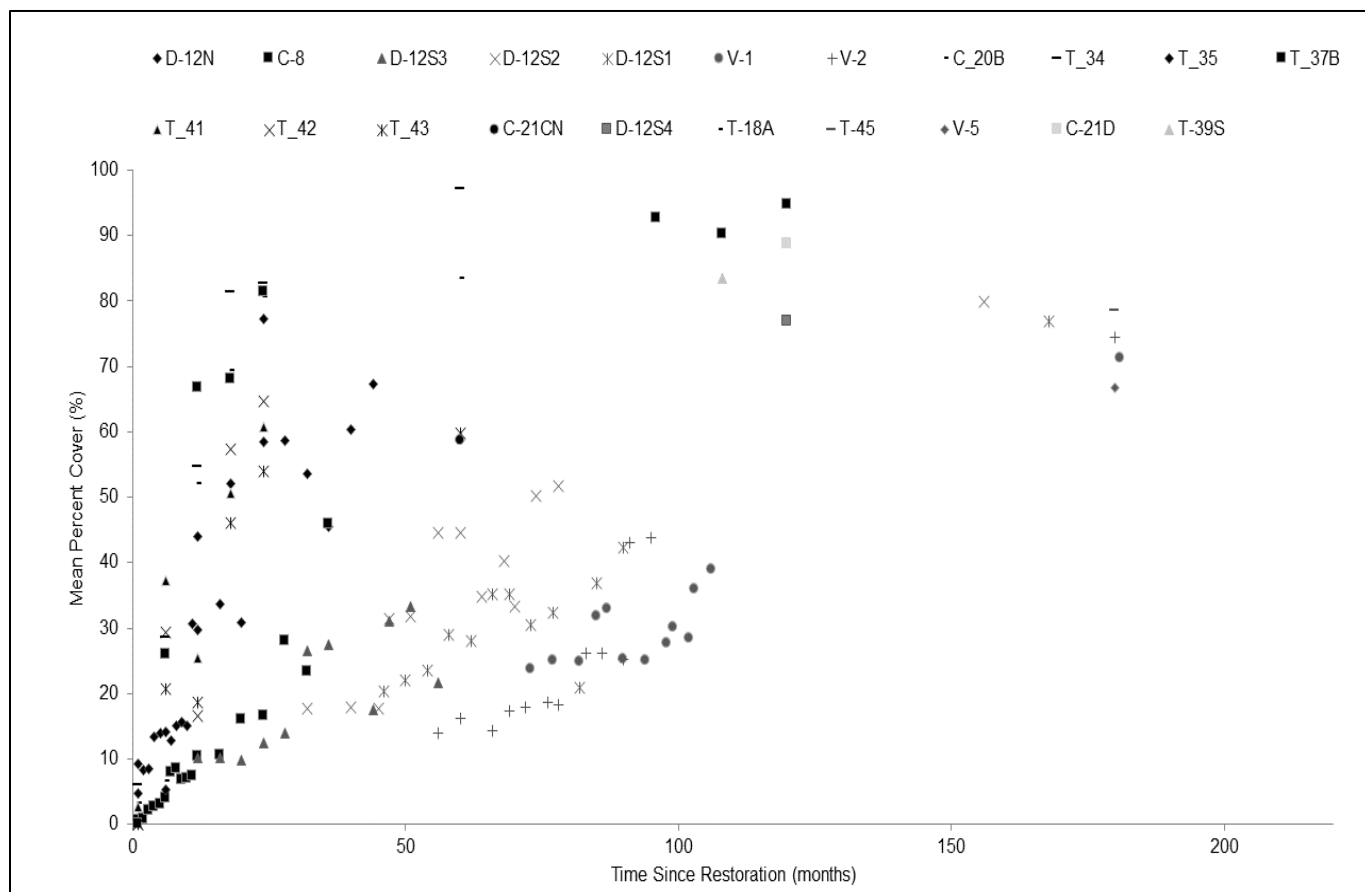


Figure 7. The mean percent cover (%) of restored mosquito impoundments over time since restoration (months). Impoundments denoted with a black symbol represent impoundments where shoreline vegetation was left intact during dike leveling and gray symbols represent impoundments where all vegetation was removed.

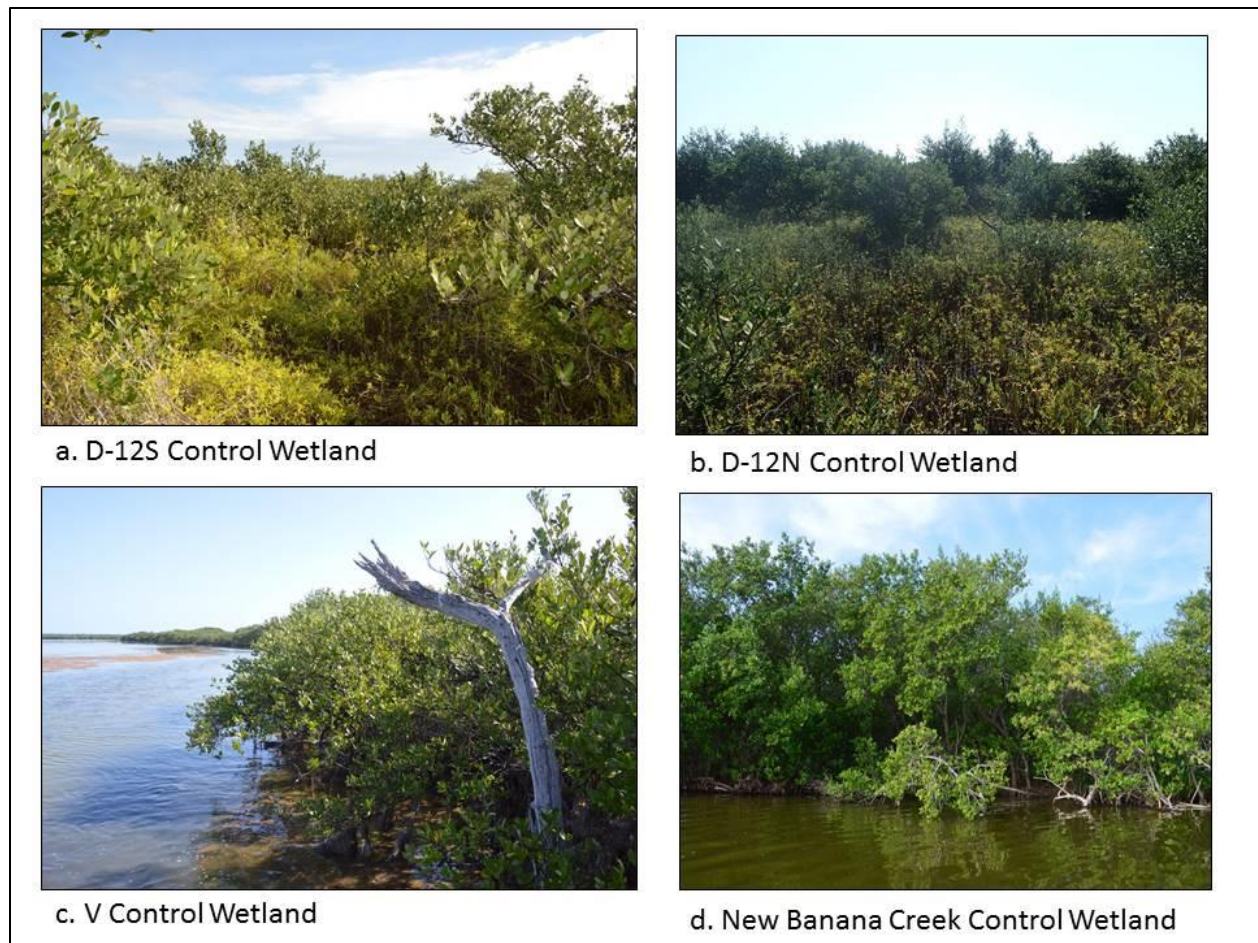


Figure 8. Percent cover was 100% at natural wetlands used as controls in this study.

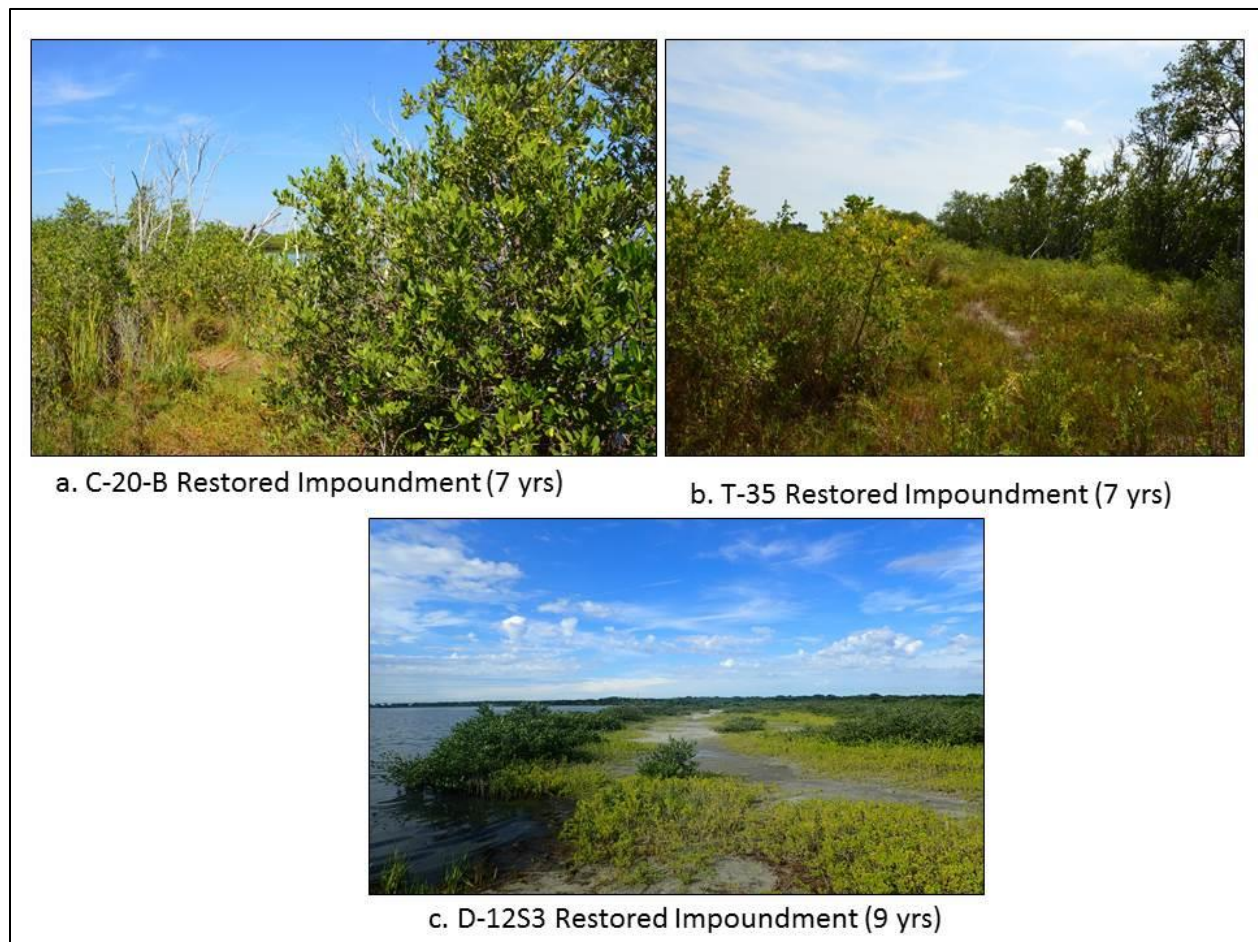


Figure 9. Increases in percent cover of vegetation occurred at faster rates at restored impoundments where shoreline vegetation was left intact (a, b). Abundance and size of *Avicennia germinans* and other mangrove species has increased at older restored impoundments (c).

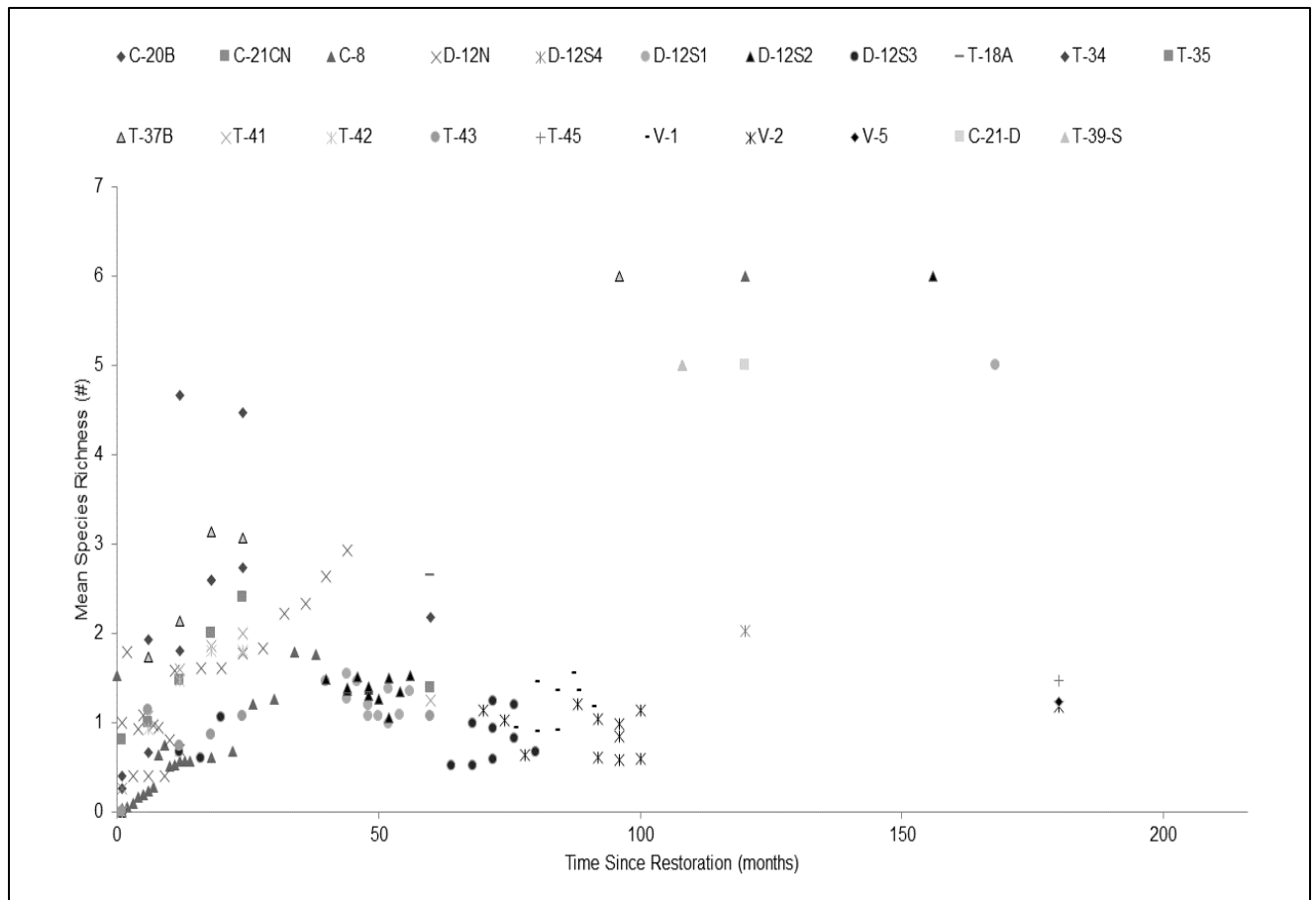


Figure 10. Mean species richness per 0.25 m² at restored mosquito impoundments over time since restoration (months).

Task 2: SET Monitoring Associated with Restoration Sites.

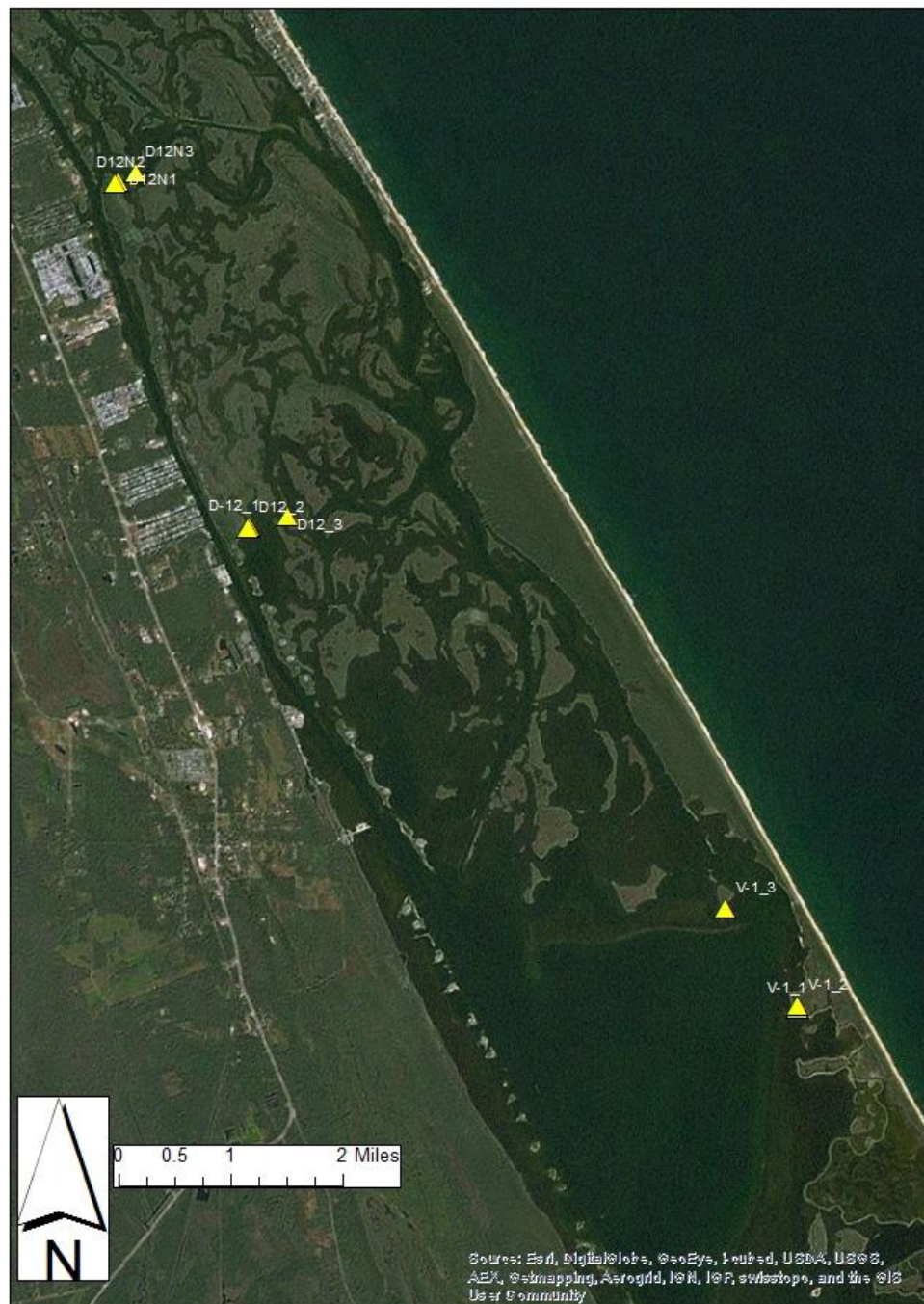


Figure 11: Location of SET stations in Mosquito Lagoon. SET stations 1 and 2 for each impoundment are located on the restored wetland and interior wetland, respectively. Station 3 is located in a nearby control wetland.



Figure 12. New SET stations were installed in the Marine Discovery Center restored wetland and in adjacent natural wetlands.

Task 3: Higher Trophic Level Monitoring.



a. Osprey



b. Great White Egret



c. Great Blue Heron



d. Reddish Egret

Figure 13. The four most common species observed foraging and loafing at restored mosquito impoundments were osprey (a), great white egrets (b), great blue herons (c), and reddish egrets (d).



Figure 14. A mating pair of Wilson's plovers standing guard of their nest at D-12S1 impoundment in April 2016.