



Long-Term Development of Planted Mangrove Wetlands in Florida

by Deborah Shafer and Thomas Roberts

PURPOSE: This technical note documents long-term trends in stand development for mangrove mitigation sites in southern and central Florida, and compares structural characteristics of planted and natural mangrove sites.

BACKGROUND: Many areas in Florida have experienced losses of mangrove swamps over the last few decades. Lewis et al. (1985) estimated that approximately 600 km² (23 percent) of the mangrove forests in Florida have been lost, relative to historical levels. However, in some areas, the losses have been more dramatic. For example, in Biscayne Bay, a loss of more than 52,200 ha (82 percent) of mangroves was documented by Lewis (1982a). In Tampa Bay, 4,423 ha (44 percent) have been lost (Lewis 1982a). Recent reports suggest that the rate of mangrove loss is decreasing. In 2004, the total mangrove acreage was estimated at 275,750 ha, a loss of 325 ha since 1998 (Dahl 2006). Mumby et al. (2004) emphasize the interconnectivity of mangroves and other coastal ecosystems such as seagrasses and coral reefs and their importance in maintaining fisheries productivity (Mumby et al. 2004). Because of this habitat connectivity, continued loss of mangrove forests could have widespread deleterious consequences for tropical nearshore ecosystems (Mumby et al. 2004).

The U.S. Army Corps of Engineers and the Florida Department of Environmental Regulation require permits for excavation or fill of certain wetland types, but originally there was no requirement for mitigation (Lewis 1990). In the mid- to late 1980s, mitigation for adverse wetland impacts began to receive increased attention due to the passage of a new wetlands protection act by the Florida legislature (Lewis 1990). As a result, mitigation to offset wetland loss and degradation became a major focus of wetland restoration and creation efforts (Lewis 1990). Success of mitigation sites is typically evaluated based on relatively simple criteria, such as survival of planted stock, measurements of percent cover, etc. over some period of time, usually 4-5 years or less (Mitsch and Wilson 1996). Performance curves or trajectories have been suggested by a number of authors as a way to understand the development of restoration and mitigation sites; however, the development of such tools has been impeded by a lack of appropriate long-term datasets (Simenstad and Thom 1996, Kentula 2000). Although Crewz and Lewis (1991) suggest that monitoring periods of 10-25 years may be required to evaluate mangrove mitigation success based on vegetative structural characteristics, studies that describe long-term trends in site development are rare.

STUDY LOCATIONS: A number of planted wetland sites in central and southern Florida were first sampled in 1988 as part of an earlier project to assess mitigation success (T. Roberts 1988, Tennessee Technical University, Cookeville, TN, unpublished data). In 2005, 18 of these sites were revisited (Figure 1). Ten sites that contained mangroves and were accessible for sampling in 2005

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were selected for subsequent analyses (Table 1). All but the Island Shoppes sites were wetland creation projects at which uplands had been graded to lower elevations. The Island Shoppes project involved planting mangrove seedlings in a portion of an existing wetland from which the trees had been removed. The remaining eight sites were visually examined to determine the presence or absence of mangroves.

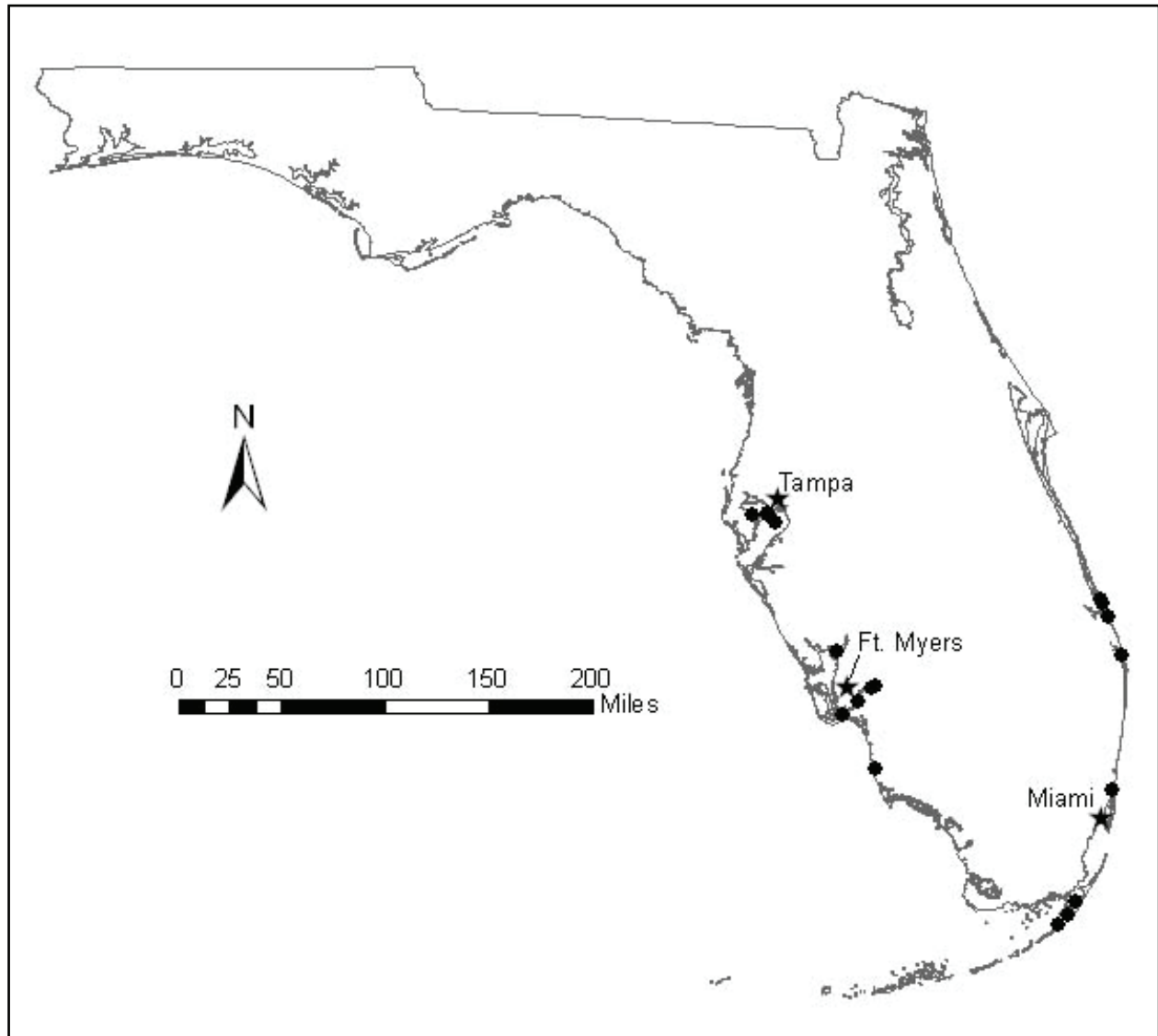


Figure 1. Locations of planted mangrove sites visited in 2005.

Table 1
Locations, planting dates, and ages of sites sampled in 2005.

Site	Latitude	Longitude	County	Year Planted	Age (in 2005)
Admiral's Cove	26° 54.346	80° 05.132	Palm Beach	1980	25
Ft. Myers Wharf	27° 38.729	82° 52.383	Lee	1987	18
Gandy Bridge	27° 53.527	82° 32.074	Hillsborough	1982	23
Island Shoppes	27° 15.389	80° 11.931	St. Lucie	1984	21
Kritzer	25° 04.951	80° 26.605	Monroe	1983	22
MacDill AFB	27° 49.664	82° 28.431	Hillsborough	1986	19
Punta Gorda Isles	26° 55.332	82° 03.126	Charlotte	1983	22
Thunder Bay	27° 52.990	82° 38.367	Pinellas	1986	19
Troutman	26° 29.135	82° 00.268	Lee	1987	18
Windstar	26° 06.660	81° 46.939	Collier	1983	22

METHODS: In Florida, three mangrove species occur: the red mangrove (*Rhizophora mangle*) (Figure 2), black mangrove (*Avicennia germinans*), and the white mangrove (*Laguncularia racemosa*) (Odum et al. 1982). Red mangroves typically occupy the lower elevation zones at the edges of bays, tidal creeks, and rivers, while black and white mangroves occupy the higher elevation zones (Lewis 2005). Mangrove zonation patterns have been described by numerous authors, and appear to be the result of both chemical and physical factors such as salinity and hydroperiod, as well as interspecific competition (Odum et al. 1982).

In 2005, mangrove community composition and structure data were collected from ten sites using the same protocols as in the original 1988 study. Three 2-m by 2-m plots were sampled at each location. All mangroves were identified by species, and the number of stems in each of five size classes (Table 2) was recorded. Mean basal area ($\text{m}^2 \text{ha}^{-1}$) of trees greater than 2.5 cm diameter at breast height (DBH) was calculated for each site according to Cintron and Novelli (1984) using the midpoints of size classes III-V (Table 2). Mean basal area was not calculated for 1988 data, since all except one of the sites contained only trees less than 2.5 cm DBH. Average canopy height was measured for each plot using a



Figure 2. Red mangrove.

Table 2
Mangrove size classes used in this study.

Size Class	DBH Range (cm)
I	0-1.3
II	1.3-2.5
III	2.5-5.1
IV	5.1-10.2
V	> 10.2

graduated survey rod. Paired t -tests (JMP 5.1) were used to evaluate changes in mean canopy height at seven sites between 1988 and 2005. The 95-percent confidence intervals constructed from the paired t -test analyses were then used to estimate rates of height increase during the first two decades of site development.

Using 2005 data, a mangrove structural complexity index (I_c) was calculated according to the following formula taken from McKee and Faulkner (2000):

$$I_c = \text{number of species} \times \text{mean stem density (stems} > 2.5 \text{ cm DBH ha}^{-1}) \\ \times \text{mean total basal area (m}^2\text{ha}^{-1}) \times \text{mean stand height (m)} \times 10^{-6}$$

The data obtained in the present study were used to compare structural characteristics (e.g. number of mangrove species, mean height, mean basal area, and mean stem density) of the sampled mitigation sites with other planted and natural mangrove wetlands in Florida using data from two previously published reports (Pool et al. 1977, McKee and Faulkner 2000). Data reported by Pool et al. (1977) and McKee and Faulkner (2000) were converted to the same units of measure and the I_c were recalculated. The combined dataset was analyzed by multi-dimensional scaling (MDS) using standardized data and Euclidean distance as the similarity measure (PRIMER 5.1). Standardization is recommended when different parameters are measured by different methods and units (Pielou 1984). Patterns detected in the MDS plot were further analyzed using Analysis of Similarity (ANOSIM) (PRIMER 5.1). Prior to analysis, density data were transformed by multiplying by 10^{-3} to minimize the influence of large numbers on the outcome of the analysis (Clarke and Warwick 2001).

Average canopy height was measured for each plot using a graduated survey rod. Paired t -tests (JMP 5.1) were used to evaluate changes in mean canopy height at each site between 1988 and 2005. The 95-percent confidence intervals constructed from the paired t -test analyses were then used to estimate rates of height increase during the first two decades of site development.

RESULTS:

Mitigation Compliance Success. Of the 18 sites that were revisited in 2005, 13 (72 percent) were dominated by mangroves, and would likely be considered successful mitigation projects based on typical performance criteria in Section 404 permits (Streever 1999). Only two sites, both located on Key Largo, were total failures (no mangroves present). One failed site was adjacent to a large residential tract and was subject to heavy recreational use. It may never have been planted, as no seedlings were present during the first survey in 1988. Alternatively, planted seedlings may not have survived. The other site probably failed because the planting elevation was too low (Crewz and Lewis 1991). Two other sites contained a few isolated mangrove plants, but appeared to have site elevations too high to support extensive mangrove development. Both sites had been extensively invaded by Brazilian pepper (*Schinus terebinthifolius*). The presence of Brazilian pepper was noted at more than 65 percent of the sites; it typically occurred in a narrow fringe along the upland edge. The growth of the mangroves at two other projects, Admiral's Cove and Peace River, had been interrupted by pruning or spraying with herbicides, but it is not known if this had been approved in the original permit.

Three sites that had originally been planted with emergent marsh vegetation had developed into mangrove swamps by 2005. Thunder Bay had initially been planted with *Spartina alterniflora* (and contained no mangroves in 1988), but had subsequently been colonized by volunteer white mangroves and had developed into mangrove swamps. The Gandy Bridge site, which had originally been planted with both *Spartina alterniflora* and red mangroves (Crewz and Lewis 1991), had also converted entirely to swamp forest.

In order to evaluate mitigation compliance success, it is necessary to be able to compare existing site conditions with permit requirements. Unfortunately, the authors were able to obtain permit information for only one of the projects. The difficulty in obtaining permit records for older (> 10 years) wetland mitigation sites was also noted by Crewz and Lewis (1991) and Cole and Shafer (2002). Even if permit records can be located, they frequently contain insufficient information to be able to evaluate project success (Streever 1999). For the one mangrove mitigation project in this study for which the authors were able to obtain copies of the original permit, the permit conditions stated only that “an area of fill ... shall be scraped to 0.8 ft NGVD ($\pm$ 0.5 ft) and revegetated with natural wetland species.” Since this site was dominated by mangroves when visited in 2005, clearly the permit criteria were met. The authors were unable to conclusively evaluate compliance success for the remaining sites.

Vegetative Characteristics.

Species composition: In most cases, the species composition of the original planting was unknown. However, species composition at a majority of the sites changed considerably during the interval between sampling periods. In their early development stages, most sites were dominated by a single mangrove species (Figure 3A). In 1988, three sites were dominated by red mangrove, Fort Myers Wharf (100 percent), Island Shoppes (66 percent), and Kritzer (88 percent) (Figure 3A). The MacDill AFB site was predominantly (> 95 percent) black mangrove; black mangrove was present at only two other sites in 1988, where it represented a very small proportion (<10 percent) of the mangrove community (Figure 3A). The Admiral’s Cove, Punta Gorda Isles, and Troutman sites were predominantly (>75 percent) white mangrove (Figure 3A). Two sites, Gandy Bridge and Thunder Bay, lacked mangroves. Only two sites, Kritzer and Windstar, contained all three mangrove species at the time of sampling in 1988 (Figure 3A). Since these two sites were already five years old in 1988, it is possible that this diversity was due to volunteer recruitment by mangrove seeds or seedlings.

By 2005, white mangrove had become the dominant species at a majority of the sites, including two sites that had lacked mangroves in 1988, and one site that was formerly 100 percent red mangrove (Figure 3B). Black mangrove was present at only six sites, where it generally represented less than 20 percent of the mangrove community (Figure 3B). Mangrove species richness increased in 50 percent of the eight sites that had contained mangroves in 1988. By 2005, all three mangrove species were present at five sites (Figure 3B).

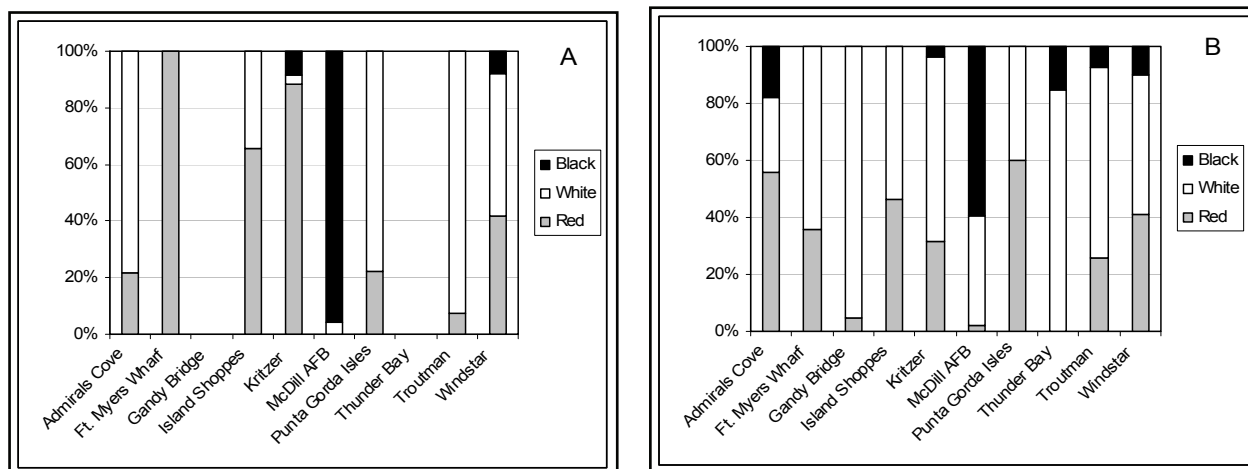


Figure 3. Species composition of planted mangrove sites in 1988 (A) and 2005 (B).

Canopy height. Mean height increased during the interval between sampling periods at all except one of the sites. This site was one in which the planted mangroves are routinely trimmed to maintain a view of the canal system (Figure 4). Excluding this site, the rate of increase in canopy height from 1988 to 2005 ranged between 5.4 and 25 cm/year, with an average of 16.4 cm/year (Table 3). The most rapid rate of increase in canopy height (25.0 cm/yr) was observed at the Island Shoppes site. The fact that these trees were planted in an existing wetland that had been cleared rather than in an excavated site may have been responsible in part for the high rate of growth at this site. The rate of growth at one site (Kritzer) was very slow in comparison with other sites (Table 3). This site, in an area of scrub mangroves located on Key Largo, differed from the others in that the substrate was composed largely of calcareous marl. Based on the 95-percent confidence intervals for canopy height constructed from the paired *t*-test analysis (excluding both the trimmed and scrub sites), the estimated rate of increase in canopy height for planted mangrove wetlands in Florida during the first two decades of site development can be predicted to range from 13-23 cm/year.



Figure 4. Trimmed mangrove fringe in Admiral's Cove.

Table 3			
Changes in canopy height from 1988 to 2005.			
Site	Canopy Height (m)		Growth Rate (cm/year)
	1988	2005	
MacDill AFB	0.7	2.4	10.8
Punta Gorda Isles	1.2	5.0	23.8
Ft. Myers Wharf	0.6	3.0	14.9
Troutman	1.0	4.1	19.5
Windstar	2.6	5.5	18.1
Kritzer	0.7	1.6	5.4
Admiral's Cove	1.8	1.7	-0.6
Island Shoppes	2.2	6.2	25.0

Size class distribution. With the exception of the Windstar site, all sites contained only small trees in size classes I and II (< 2.5 cm DBH) when first sampled in 1988 (Figures 6A, 6C, and 6E). Only one site, Island Shoppes, contained large trees in size class V (> 10.2 cm DBH) in 2005. Individuals in size class I were present at all sites in 2005 due to volunteer recruitment. White mangrove had colonized all nine sites, including two sites that had not contained white mangroves in 1988 (Figures 6C and 6D). Red mangrove recruitment was observed at all sites except Lookout Point and MacDill AFB (Figure 6B). Forty to fifty percent of the sites contained red and white mangroves in

size classes I through IV (Figures 6B and 6D), indicating continuous and ongoing recruitment of these species. Colonization by black mangroves was less frequent; of the seven sites not containing any black mangroves in 1988, only three sites subsequently became colonized by that species (Figures 6E and 6F). Only one site contained black mangroves in size classes I through IV, indicating less frequent and more episodic volunteer recruitment patterns by this species. Black mangrove seedlings also were observed less frequently than other species in 2005 (Figure 6F).

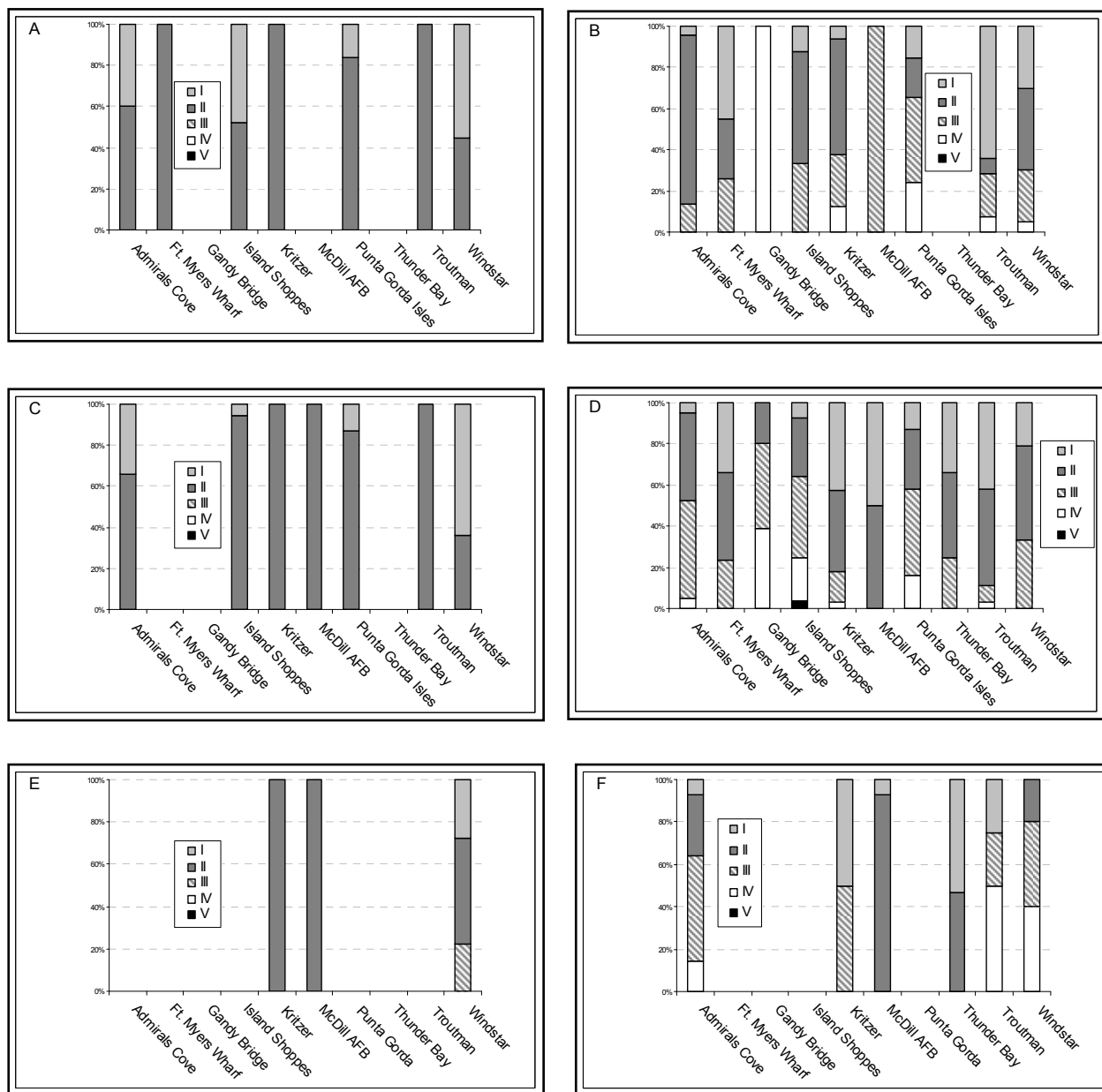


Figure 5. Percent composition by size class for each mangrove species. Red mangroves, 1988 (A) and 2005 (B); white mangroves, 1988 (C) and 2005 (D), and black mangroves, 1988 (E) and 2005 (F).

Comparison with other Florida Mangrove Wetlands. Structural complexity indices (I_c) of planted mangrove wetlands were more variable than those of natural mangrove wetlands, ranging from less than 0.01 to 27.8, with an average of 5.3 (Table 4). I_c values for natural mangrove wetlands ranged from 0.2 to 5.0, with an average of 2.1 (Table 4). The MDS plot (stress = 0.01) indicated that despite some obvious similarities, structural characteristics (e.g. number of mangrove species, mean basal area, mean stem density, and mean canopy height) of 13- to 25-year-old planted sites differed from natural mangrove wetlands (Figure 3). Results of the ANOSIM analysis confirmed that stand structure of planted mangrove wetlands with volunteer recruitment over time was significantly different from natural sites ($p = 0.01$, Global $R = 0.525$). Although the number of mangrove species was similar in both planted and natural sites, planted sites had lower basal area and height than natural sites, but were more dense and complex than natural sites (Table 4).

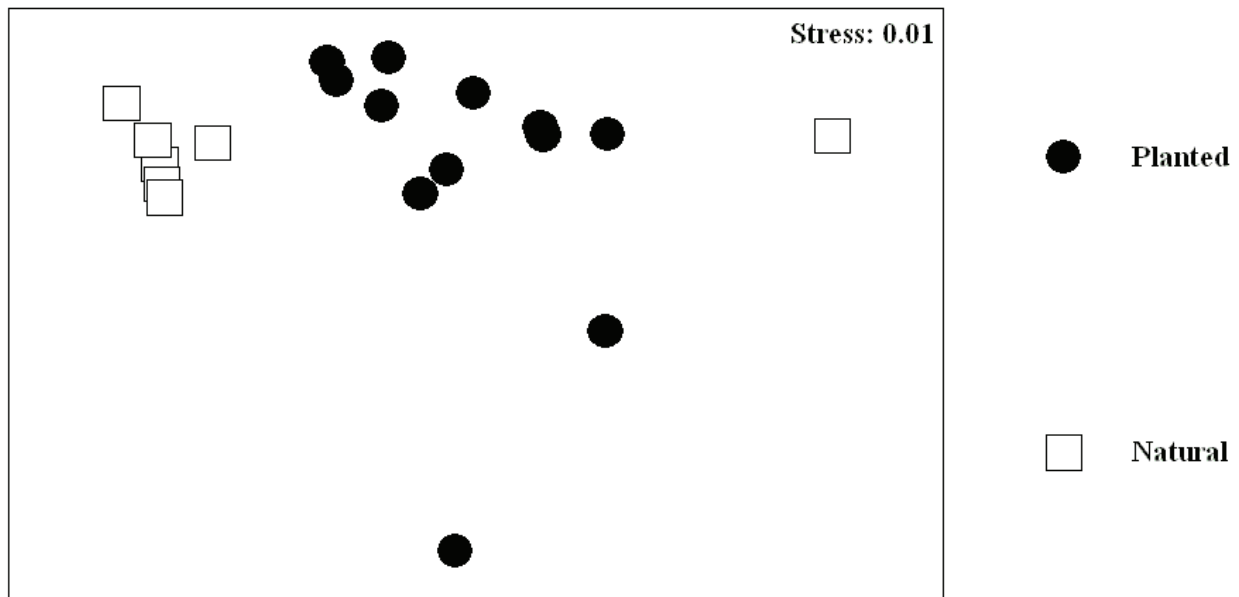


Figure 6. MDS plot of mangrove structural characteristics in planted and natural sites in Florida.

Table 4 Vegetative characteristics of 19 planted and natural mangrove sites in Florida.							
Site	Type*	# Species	Canopy Height (m)	Basal Area (m ² /ha)	Density (stems ≥ 2.5 cm DBH ha ⁻¹)	I _c	Source
Admiral's Cove	P (24)	3	1.7	26.44	21,666	2.9	this study
Ft. Myers	P (17)	2	3.0	15.76	17,500	1.6	this study
Gandy Bridge	P (23)	2	6.4	67.60	29,167	25.04	this study
Island Shoppes	P (20)	2	6.2	47.34	21,666	12.7	this study
Kritzer	P (21)	3	1.6	19.77	10,833	1.0	this study
MacDill AFB	P (18)	3	2.4	1.29	833	0.01	this study
Punta Gorda	P (21)	2	5.0	69.46	40,000	27.8	this study
Thunder Bay	P (19)	1	3.7	15.10	16,667	0.93	this study
Troutman	P (17)	3	4.1	13.80	9,166	1.6	this study
Windstar	P (21)	3	5.5	20.11	15,000	5.0	this study
Windstar	P (13)	3	3.6	3.2	6,830	0.2	McKee and Faulkner 2000
Henderson Creek	P (6)	2	4.8	18.4	27,700	4.9	McKee and Faulkner 2000
Ten Thousand Islands A	N	2	6.3	26.0	2,400	0.8	Pool et al. 1977
Ten Thousand Islands B	N	2	7.3	35.9	3,600	1.9	Pool et al. 1977
Ten Thousand Islands C	N	2	9.0	60.2	4,600	5.0	Pool et al. 1977
Rookery Bay	N	3	6.5	34.7	6,560	4.4	Pool et al. 1977
Turkey Point	N	1	1.0	6.0	25,030	0.2	Pool et al. 1977
Henderson Creek	N	3	7.5	26.3	1,840	1.1	McKee and Faulkner 2000
Windstar	N	2	7.4	28.2	2,131	1.3	McKee and Faulkner 2000
Mean Values							
Planted	N=12	2.4	4.0	26.52	18,086	7.0	All
Natural	N=7	2.2	6.4	31.0	6,594	2.1	All
* N = Natural, P = Planted; Age of planted sites at time of sampling shown in ().							

DISCUSSION:

Factors Limiting Site Development. Factors limiting successful site development included incorrect site elevation and hydrology, invasion by exotic species, human activity, and conflicting land uses. Three sites were apparently unsuccessful due to inappropriate planting elevation (either too low or too high). The importance of correct planting elevation has been noted by numerous authors (Lewis 2005 and references cited therein). Since all except one of the sites in this study involved excavation of uplands to achieve final planting elevation, careful surveys of site topography in comparison to nearby natural mangrove stands would have increased overall mitigation success of these sites.

Human activity had dramatically altered two sites and highlights the importance of site location in the ultimate success of mitigation projects. The importance of site location relative to ultimate success of mitigation projects was also noted by Roberts (1991) for marsh projects. Several sites

where wetland presence conflicted with intended property uses resulted in the wetlands either being destroyed or dramatically altered. The Peace River site adjacent to Interstate Highway 75 had apparently been mowed or sprayed with herbicide (presumably by the highway department), whereas the Admiral's Cove site mentioned previously had been trimmed to maintain a view. Mangrove trimming is regulated by the 1996 Mangrove Trimming and Preservation Act in sections 403.9321-403.9334 of the Florida Statutes. In general, mangroves may not be trimmed to a height less than 2 m; however, there are exemptions, including maintenance trimming of a previously authorized configuration. Activities such as these obviously prevent mitigation sites from obtaining the structural complexity they otherwise would. Reducing vertical complexity likely has adverse effects on birds that might use the mangroves for roosting as well as reducing the amount of organic material exported to the adjacent water body. The likelihood that such degradation might occur should be considered by regulatory agencies prior to issuance of permits.

Facilitation by Marsh Species. The use of the marsh grass *Spartina alterniflora* as a “nurse” plant for natural mangrove colonization was first promoted by Lewis and Dunstan (1976). *Spartina* plantings are able to stabilize bare sediments much more rapidly than mangrove plantings, at significant cost savings (Lewis 1982b). Once established, stands of *Spartina* provide a barrier that effectively traps and holds mangrove propagules, facilitating mangrove establishment (Lewis 1982a). The conversion of three sites visited in this study originally planted with marsh vegetation to mangrove swamps suggests that this approach is a viable option.

Rates of Height Increase. One of the most notable differences observed between natural and planted mangrove wetlands was in canopy height. This study provides generalized estimates of expected increases in canopy height of planted mangrove wetlands during the first 15-20 years of site development, but it is important to recognize the limitations of estimating growth from data collected at only two points in time. As such, the linear growth estimates presented in this study may not be valid for very young sites, or sites older than those in this study (i.e. 21 years at the time of sampling). However, since the estimates of growth reported here were obtained from a number of sites that varied widely in soil type, hydrology, and species composition, the data should be adequate to provide general estimates of potential growth which could be used in the development of realistic performance standards for mitigation and restoration sites.

The slowest rates of increase in height in this study were observed at the Kritzer site on Key Largo. The substrate at this site was largely calcareous marl and planted mangroves at this site had attained a height of only 1.6 m after 23 years. This site was similar to the descriptions of natural stands of scrub mangroves in the Florida Keys provided by Lugo and Snedaker (1974) and Pool et al. (1977). Due to their dwarf stature, these sites will never develop the structural complexity typical of other mangrove forest types. This should be taken into consideration when establishing performance standards for planted mangrove wetlands in these areas.

Measurement of Structural Attributes. If DBH or basal area is to be used as a performance measure, some consideration needs to be given to the unique structural characteristics of mangroves in measurement of these parameters. Although DBH is typically measured on the main trunk of a tree at a height of 1.2 m, branching of prop roots in red mangroves may be evident at heights of up to several meters. Others have addressed this problem by measuring DBH of red mangroves just above the intersection of the main trunk and the prop roots, irrespective of the height at which this occurs

(e.g. Pool et al. 1977). If multiple sites are to be compared, or growth estimates over time are needed, it is critical that the measures be consistently applied.

Differences in methods used to calculate complexity indices (I_c) made it difficult to directly compare values obtained in this study with those reported by different authors. For example, Pool et al. (1977) reported I_c values based on 0.1 ha plot size, multiplied by 10^{-3} . In contrast, McKee and Faulkner (2000) calculated I_c values based on 1.0-ha plot size, multiplied by 10^{-6} . A lack of recognition of such differences in methods could lead to erroneous interpretations.

TO PLANT OR NOT TO PLANT? Understanding natural patterns of recruitment and succession in a given area could lead to significant improvements and cost savings in design and implementation of restoration and mitigation projects. Assuming that site elevations are suitable, planting may be unnecessary in some areas with an abundance of mangrove propagules. It was noteworthy that the mangrove species composition at many of the sites visited in this study had changed considerably during the period between 1988 and 2005. The most common pattern was an increase in volunteer white mangroves at sites at which red mangrove had been the primary species planted. In contrast, recruitment and colonization by black mangroves was observed less frequently. Therefore, future restoration and mitigation efforts could consider placing greater emphasis on the planting of this species, or facilitation of its natural colonization by broadcasting collected seeds, depending on the local variations in natural mangrove forest succession patterns.

SUMMARY: The continued persistence and development of the majority of planted mangrove wetlands sites revisited 17 years after they were initially sampled indicated that the mitigation process can be successful, at least in terms of compliance with the intent of the permit requirements. As expected, basal area and height had increased at most sites, and some were difficult to visually distinguish from adjacent natural stands of mangroves. Although attaining structural complexity does not necessarily equate to functional equivalency, measures of plant structure continue to be the most easily measured and widely used metric of evaluating success in restoration and mitigation sites. However, the results of this study indicate that even 17-25 years after planting, stand structure at planted sites still differed from that of natural sites. Lugo (1980) stated that mangroves are capable of reaching full maturity within 20-30 years, but it appears that some planted mangrove sites may require longer periods to develop the structure characteristic of natural systems.

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<http://el.erdc.usace.army.mil/>

For additional information and a bibliography of mangrove restoration literature, see the web site: www.mangroverestoration.com

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