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Increasing the probability of success in the construction of marshes in coastal Virginia

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Final Report

To

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Executive Summary

Habitat functions of a constructed tidal marsh and two adjacent natural tidal marshes were compared between marshes and with similar data collected in the same marshes seven years earlier. The marshes were sampled for fish, blue crabs, benthic infauna, vegetation community type, stem density and cover, salinity, temperature, dissolved oxygen, organic carbon, and bird utilization.

The constructed marsh has reached a general level of function similar to that of nearby natural marshes. Some morphological differences remain such as the differences in community type ratios. Significant differences in habitat function remain in three areas: sediment organic carbon at depth, mature saltbush density, and bird utilization (hypothesized to be related to saltbush density). Data from this study suggests that the addition of an organic soil amendment at the construction phase and the planting of a mature saltbush community would help increase the probability of a success in the construction of artificial marshes to replace the habitat functions of natural marshes.

Differences observed between the constructed and natural marshes over time.

Parameters	Differences observed 1992	Differences observed 1999	
Organic carbon at depth	Y	Y	higher organic carbon in natural marshes
Salinity	Y	N	
Dissolved oxygen	Y	N	
Low marsh stem density	Y	N	
Saltbush stem density	Y	Y	higher stem densities in natural marshes
Saltbush percent cover	Y	Y	higher percent cover in natural marshes
Blue crab abundance	Y	N	
Blue crab size	Y	N	
Total fish abundance	Y	N	
Commercial fish abundance	Y	N	
Fish richness	Y	Y	higher richness value in constructed marsh
Fish diversity	Y	Y	higher diversity value in constructed marsh
Bird richness	Y	Y	higher richness value in natural marshes
Bird diversity	Y	Y	higher diversity value in natural marshes
Bird abundance	Y	Y	higher abundance in natural marshes

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Introduction

The expansion of human populations and the anthropogenic impact on sensitive natural systems, such as wetlands, has spurred increased use of created marshes to offset the loss of developed natural marshes. Mitigation of the loss of valuable marshes has become increasingly important to regulatory agencies and consequently to the development community. The construction of marshes to compensate for permitted impacts to natural marshes is becoming pandemic. Emphasis on the successful construction of marshes has gained increased scrutiny with the recent passage of the Federal Guidance for the Establishment, Use and Operation of Mitigation Banks (CFR Vol. 60, No. 228, 1995) which allows the construction of marshes and the sale of credits to compensate for the destruction of natural marshes. Information on design criteria for the successful construction of marshes is vitally important for mitigation bank creation. Marsh construction, however, is a relatively young science, and the "successful" establishment of a constructed marsh is fraught with many difficulties, variables, and unknowns (Mitch and Wilson 1996). The question of if and how long does it take for a constructed marsh to achieve the same level of function as similar natural marshes remains unanswered. In addition, the ability of constructed marshes to withstand invasion by non-native or aggressive, undesirable plants is questionable (Havens et al 1997).

This study involves the comparison of ecological conditions in a twelve year old artificially created tidal marsh excavated from upland and two nearby natural reference tidal marshes. These marshes were extensively studied in 1992 and baseline data is available for comparison (Havens et al 1995, Varnell and Havens 1995, Varnell et al 1995). The 1992 study was among the first to use the reference wetland concept and to use replicate sampling methods appropriate for robust parametric statistical analyses in the comparison of natural versus constructed marshes. This study builds on the extensive database of the previous study in order to compare the habitat function of a constructed marsh with reference natural marshes over time.

Methods

The study site is located in Sarah's Creek, a tributary to the York River near Gloucester Point, Virginia, USA (37°16'30"N 76°29'40"W) approximately 10 km from the Chesapeake Bay and 40 km from the Atlantic Ocean. The tidal amplitude is 0.75 m.

The same methods and equipment used in the 1992 study were duplicated (Havens et al. 1995). Physical characteristics of the marshes were determined from low altitude aerial photographs of a scale of 1:4200. The vertical aerial imagery was digitized using the vector-based GIS software ARC/INFO. Topcon infrared surveying equipment was used to survey elevations within each marsh. Each marsh was surveyed at transects of 10-m intervals with survey points along each transect every 10 m and at distinct elevation transition zones such as vegetation community margins and channel edges. At least five survey points were included in marsh channels for each transect. The gridded elevation topographies were overlaid with calculated mean high water to determine volume using LI Contour V+ software.

The total area of the constructed marsh is 0.65 ha. An adjacent marsh to the west is 0.58 ha and is located just upstream of the constructed marsh but is separated by a 15-m wide wooded peninsula. The other natural marsh is located approximately 150 m downstream (east) of the constructed marsh and is 0.42 ha in size. It is separated from the constructed marsh by approximately 16 ha of wooded upland. The constructed marsh is bordered on the north side by a shopping center complex and receives drainage from the shopping center parking lot via a sediment detention pond. There is additional freshwater input through a drainage ditch along the northeast border. The west marsh receives only incidental freshwater input while the east marsh receives freshwater input through a drainage ditch along the north border. A multiplex theater has been constructed within 15 m of the west marsh since the original 1992 study (Fig. 1).

The constructed marsh was created in 1987 by excavating an upland area and grading it to intertidal elevations. One-year-old greenhouse-grown *Spartina alterniflora*, *Spartina patens*, and *Distichlis spicata* were planted on 50- to 90-cm centers on the graded land. The channel was excavated to a depth of 1 m below mean low water.

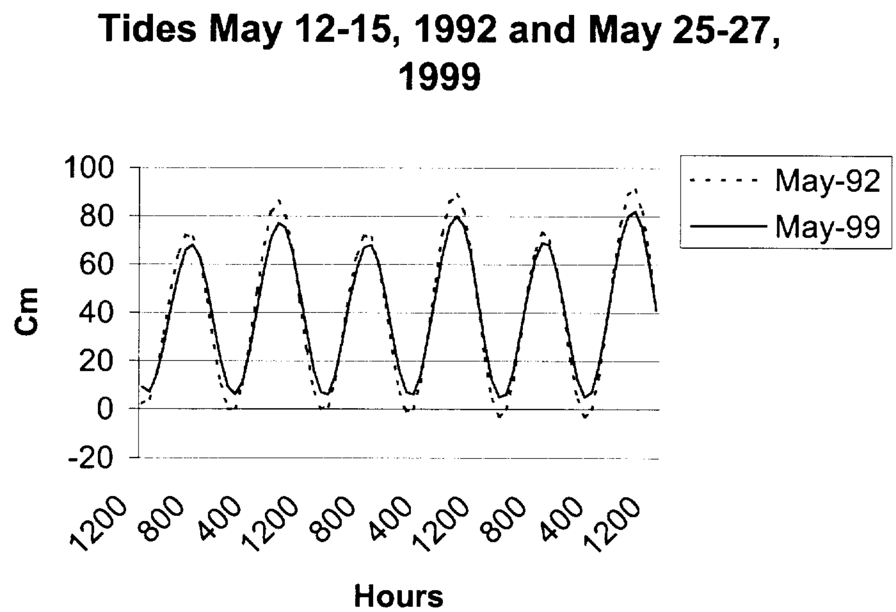
An intensive, two-season sampling strategy was chosen that followed a similar lunar cycle and time frame as the previous 1992 study (Fig. 2). Spring sampling occurred from 25 to 27 May 1999 and summer sampling occurred from 9 to 11 August 1999. By sampling each marsh for three consecutive days during two seasons (spring and summer), we could account for the short-term variability associated with assessing mobile aquatic fauna abundance in estuarine wetlands (Varnell et al. 1995).

Random sample plots within each marsh were selected for analysis of the vegetation, benthic fauna, and sediment carbon study components. The wetland boundaries for each marsh were delineated from aerial photographs and digitized. Each digitized image was computer overlaid by a grid of scaled 1-m^2 cells. Each square meter grid cell was numbered. For each marsh, square meter sample plots were identified by random number generation. Unique sample plots were generated for each study component requiring random sampling. Standard field flags from the previous study were located at 10-m intervals along the upland-wetland boundaries of each marsh from mouth to head and specific sample sites were extrapolated from the flagged locations.

Salinity, dissolved oxygen, and temperature were measured each morning of the sampling period immediately after setting the block nets using a YSI 85 Temperature, Conductivity, Salinity, and Dissolved Oxygen meter.

Sediment was sampled in three habitat types within each marsh: high marsh, low marsh, and nonvegetated intertidal. Three sediment cores were randomly collected within each habitat type and divided into two fractions: 0-2 cm and 14-16 cm. Total organic matter and organic carbon were calculated for each habitat type and by depth. Organic matter was measured by loss on ignition at 450°C and converted into organic carbon by multiplying by 0.45 (Craft et al. 1988).

Figure 1. Study marshes in Sarah's Creek, Virginia, USA



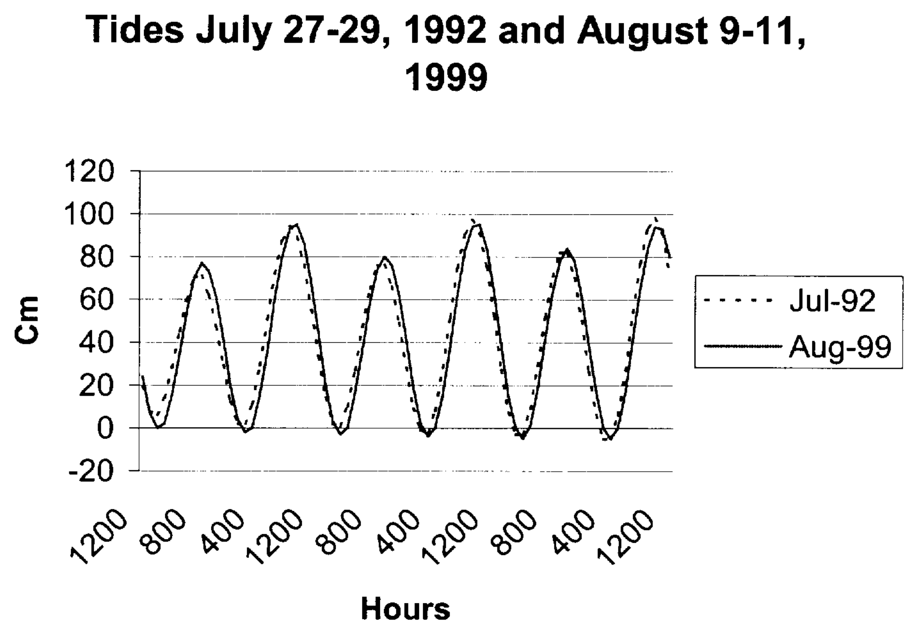


Figure 2. Tidal cycle comparison between 1992 and 1999 sampe dates

Vegetation in each marsh was divided into community types: saltmarsh cordgrass (dominated by *Spartina alterniflora*), saltmeadow hay (dominated by *Spartina patens*), and saltbushes (dominated by *Iva frutescens* and *Baccharis halimifolia*). The saltmarsh cordgrass community was randomly sampled using a square meter quadrat. The saltmeadow hay community was randomly sampled using a 1/4 square meter quadrat. The saltbush community was randomly sampled using a 2-m radius plot. Percent cover and stem density data were collected for each sample within each community.

Benthic invertebrates were sampled using a 232.25-cm^2 benthic grab. Seven samples (with duplicates) were collected from each marsh in June. The samples were sieved through a 0.5-mm mesh, stained with rose bengal, and preserved in 10% formalin. Taxonomic identification to species level was determined where possible. The data were analyzed for community structure parameters such as species richness, diversity, and equitability using Shannon-Weaver analysis. Total sampled populations were tested for differences by nonparametric methods.

Fish and blue crabs from each wetland were sampled by simultaneously setting a Priest Modified Hoop Net (Havens et al. 1995). The nets were set at the slack at high tide and emptied on the hour until low tide. The two natural marshes drain close to dry at low tide while the constructed marsh maintains less than 0.5-m depth in some places at mean low tide. At low tide the constructed marsh was seined to collect remaining fish and shellfish. Fish and crabs were identified, counted, measured and released. Sciaenids and other food fish (those commercially exploited) were separated and returned to the lab for further analysis.

The three marshes were surveyed to determine bird use during three seasons (winter, spring, summer) and at two tide stages (low and high tide). Marshes were surveyed between 0.5 and 3.0 h after sunrise and between 2 h before and 2 h after predicted low or high tide. Each of the 18 surveys (3 marshes x 3 seasons x 2 tide stages) was replicated three times within the same tide series. Each survey consisted of walking the perimeter of the marsh and recording all birds seen or heard within the marsh. Each marsh took approximately 20 minutes to survey. All three marshes were surveyed on each sampling day. This sampling effort was similar to that used by Burger et al. (1982) and identical to the method used in the previous study (Havens et al. 1995).

Results

Physical and vegetative structure

Table 1 presents comparative marsh physiographies and average physical water quality parameters measured during the study between marshes and between years. Whereas significant differences in salinity and dissolved oxygen levels were observed between the constructed marsh and the natural marshes in 1992, comparisons in 1999 showed no significant differences in physical water quality parameters between the constructed marsh and the natural marshes.

Table 1

Comparison of the physiography and water quality of the study marshes by year 1999 (*1992*)

	West natural marsh	Constructed marsh	East natural marsh
Area (hectares)			
total marsh	0.58 (*0.58*)	0.61 (*0.65*)	0.52 (*0.42*)
mean high tide	0.33 (0.33)	0.38 (0.38)	0.18 (0.18)
Volume (m^3)			
total marsh	2,513 (*2,856*)	3,376 (*4,117*)	1,546 (*1,762*)
mean high tide	696 (*882*)	1,746 (*2,123*)	385 (*394*)
Physical marsh zones (as percent of total area)			
vegetated	85.5 (*90.4*)	54.4 (*66.3*)	92.0 (*91.1*)
nonvegetated	13.4 (*8.6*)	17.8 (*8.5*)	7.7 (*8.3*)
subtidal	1.1 (*1.0*)	27.8 (*25.2*)	0.3 (*0.6*)
Physical parameters			
Spring			
Head			
Salinity (‰)	15.5 (*10.0*)	16.3 (*1.8*)	16.7 (*1.8*)
Temperature (°C)	18.7 (*19.0*)	21.1 (*19.8*)	18.8 (*17.8*)
Dissolved oxygen (mg/l)	1.48 (*2.36*)	3.10 (*5.03*)	2.51 (*3.93*)
Middle			
Salinity	16.2 (*11.3*)	16.4 (*4.7*)	16.9 (*11.0*)
Temperature	19.9 (*19.3*)	20.7 (*20.6*)	19.3 (*18.7*)
Dissolved oxygen	2.00 (*2.88*)	2.86 (*4.73*)	2.74 (*4.24*)
Mouth			
Salinity	16.8 (*11.3*)	16.3 (*4.3*)	17.2 (*13.7*)
Temperature	20.9 (*19.9*)	20.8 (*20.8*)	20.1 (*19.2*)
Dissolved oxygen	3.02 (*4.37*)	3.17 (*4.98*)	3.55 (*4.97*)
Summer			
Head			
Salinity	21.5 (*12.7*)	18.3 (*6.5*)	22.2 (*11.3*)
Temperature	26.5 (*26.6*)	27.1 (*26.7*)	26.9 (*27.4*)
Dissolved oxygen	0.57 (*1.74*)	1.44 (*3.10*)	1.75 (*2.14*)
Middle			
Salinity	21.5 (*12.3*)	21.0 (*8.2*)	21.8 (*14.7*)
Temperature	27.0 (*27.3*)	27.3 (*27.1*)	27.4 (*27.5*)
Dissolved oxygen	1.02 (3.35)	1.98 (3.48)	2.51 (3.24)
Mouth			
Salinity	22.0 (*15.9*)	21.9 (*9.7*)	22.3 (*14.7*)
Temperature	27.6 (*28.0*)	27.3 (*26.9*)	27.5 (*27.6*)
Dissolved oxygen	2.35 (*4.10*)	2.80 (*3.79*)	2.57 (*4.29*)

Table 2 presents organic carbon content, area, and percentages of physical zones for each marsh. Similar to the 1992 study average values of organic carbon at depth and stem density and cover estimates for saltbush remain low in the constructed marsh compared with the natural marshes. Stem density and cover estimates were not significantly different for the saltmarsh cordgrass or saltmeadow hay communities. Differences remain regarding physical marsh zone percentages. The constructed marsh ratio of vegetated versus nonvegetated area of approximately 1:1 is lower than the west and east marshes, 6:1 and 11:1 respectively.

Table 2

Comparison of the vegetated zones of the study marshes by year 1999 (*1992*)

	West Marsh	Constructed Marsh	East Marsh
Organic carbon per marsh (g/cm^2)			
Surface (0-2 cm)	0.0137 (*0.0163*)	0.0120 (*0.0095*)	0.0145 (*0.0129*)
Depth (14-16 cm)	0.0146 (*0.0174*)	0.0053 (*0.0050*)	0.0149 (*0.0153*)
Physical marsh zones (as percent of total area)			
vegetated	85.5 (*90.4*)	54.4 (*66.3*)	92.0 (*91.1*)
nonvegetated	13.4 (*8.6*)	17.8 (*8.5*)	7.7 (*8.3*)
subtidal	1.1 (*1.0*)	27.8 (*25.2*)	0.3 (*0.6*)
Average stem density			
low marsh (no./m^2)	173 (*365*)	144 (*290*)	82 (*504*)
high marsh (no./m^2)	570 (*1727*)	1655 (*1489*)	2591 (*1916*)
saltbush (no./2-m radius plot)	54 (*181*)	6 (*0*)	40 (*75*)
Average percent cover			
low marsh	73 (*55*)	48 (*30*)	30 (*68*)
high marsh	72 (*86*)	97 (*77*)	88 (*71*)
saltbush	57 (*74*)	20 (*0*)	67 (*57*)

Species composition between marshes is similar with saltmarsh cordgrass, *Spartina alterniflora*, and saltmeadow hay, *Spartina patens*, dominating each marsh. The notable difference between the constructed and the natural marshes remains the low amount of mature saltbush (*Iva frutecsens* and *Baccharis halimifolia*) in the constructed marsh.

Benthic Community Structure

Preliminary review of the community structure for benthic infauna within each marsh and between intertidal and subtidal habitats suggests that the pattern from the 1992 study remains the same. No apparent differences were observed in the benthic infauna population levels between any of the three marshes. Diversity values are within the range reported for the Hampton Roads area (Boesch 1973, Diaz and Gapcynski 1990).

Blue crabs and fish

The 1992 study showed seasonal differences of blue crab and fish abundance between the constructed and natural marshes and a higher species diversity and richness in the constructed marsh. This study showed no significant difference between blue crab (Fig. 3) and fish abundance between marshes (Table 3) but a continued higher diversity and richness in the constructed marsh (Table 4).

Table 3.
Fish species list and total numbers per season and by year 1999 (*1992*)

	Spring			Summer		
	West	Constructed	East	West	Constructed	East
Killifish (*Fundulus* sp. and *Gambusia* sp.)	33136(*26600*)	3616(*3533*)	2830(*13097*)	10957(*14006*)	2207(*4573*)	10661(*581*)
Spot (*Leiostomus xanthurus*)	212(*1439*)	770(*465*)	71(*1493*)	78(*291*)	974(*590*)	222(*71*)
Menhaden (*Brevoortia tyrannus*)	539(394)	56(*483*)	7(*0*)	68(*1993*)	4318(*1976*)	0(*130*)
Croaker (*Micropogon undulatus*)	8(*100*)	18(*9*)	0(*7*)	0(*4*)	1(*3*)	1(*1*)
Anchovy (*Anchoa mitchilli*)	6(*206*)	261(*23*)	0(*2*)	0(*0*)	0(2)	0(*0*)
Striped mullet (*Mugil cephalus*)	18(*28*)	52(*126*)	0(*0*)	1(*1*)	1(*1*)	1(*0*)
Atlantic silverside (*Menidia menidia*)	30(*20*)	255(*42*)	0(*36*)	9(*10*)	2256(*226*)	52(*1*)
Gizzard shad (*Dorosoma cepedianum*)	1(*3*)	126(*46*)	0(*4*)	1(*7*)	18(*17*)	0(*2*)
Red drum (*Sciaenops ocellatus*)	0(*3*)	2(*3*)	0(*4*)	0(*0*)	0(*1*)	0(*0*)
Striped bass (*Morone saxatilis*)	0(*0*)	0(*0*)	0(*4*)	0(*0*)	0(*0*)	0(*0*)
Ladyfish (*Elops saurus*)	0(*0*)	0(*0*)	0(*0*)	2(*0*)	2(2)	0(*0*)
White perch (*Morone americana*)	0(*0*)	1(*1*)	0(*0*)	0(*0*)	0(*0*)	0(*0*)
Speckled trout (*Cynoscion regalis*)	0(*0*)	0(*0*)	0(*0*)	0(*0*)	0(*1*)	0(*4*)
White mullet (*Mugil curema*)	1(*52*)	10(*0*)	0(*104*)	0(*1*)	0(*0*)	0(*0*)
Hogchoker (*Trinectes maculatus*)	0(*0*)	15(*0*)	0(*0*)	0(*1*)	0(*4*)	0(*0*)
Eel (*Anguilla rostrata*)	0(*0*)	1(*0*)	0(*0*)	0(*0*)	0(*1*)	0(*0*)
Total by season	33951(*28845*)	5183(*4731*)	2908(*14751*)	11116(*16314*)	9777(*7397*)	10937(*790*)
Total by year	West 45,067 (*45,159*)			Constructed 14,960 (*12,128*)		East 13,845 (*15,541*)
Grand Total	West 90,226			Constructed 27,088		East 29,386

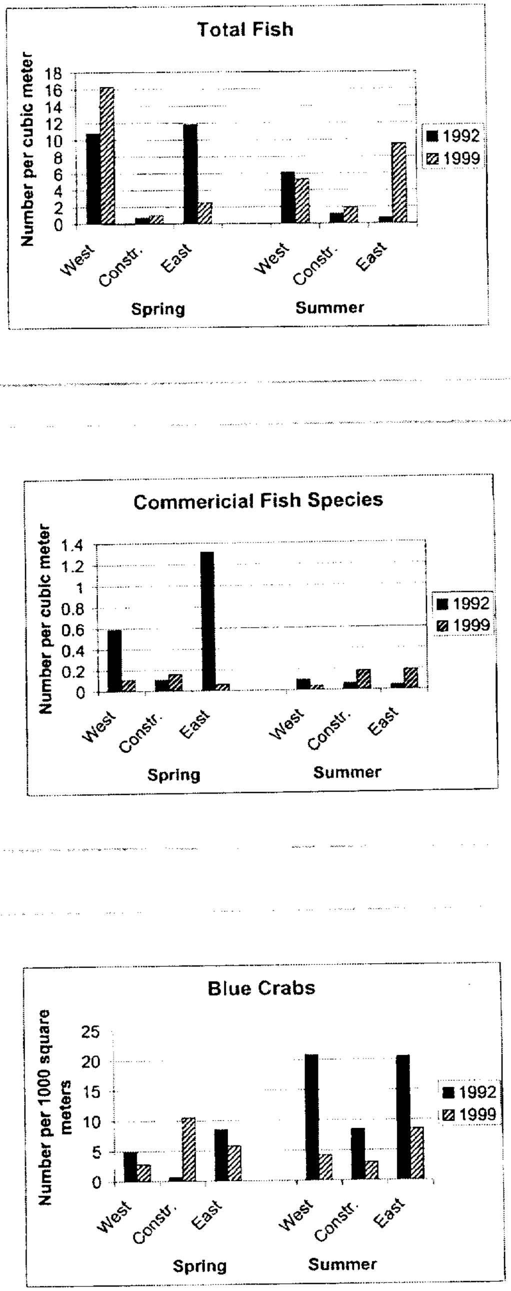


Figure 3. Normalized abundance for total fish, commercial fish and blue crabs By marsh, season, and year.

Table 4.
Fish species richness and diversity using Shannon-Weaver analysis by year 1999 *(1992)*

Marsh	Spring		Summer	
	Diversity	Richness	Diversity	Richness
West	0.13 *(0.36)*	1.77 *(2.02)*	0.09 *(0.33)*	1.48 *(1.89)*
Constructed	1.08 *(0.91)*	3.23 *(2.45)*	1.30 *(0.95)*	1.75 *(3.10)*
East	0.13 *(0.33)*	0.58 *(1.90)*	0.13 *(0.82)*	0.99 *(2.07)*

Birds

During the 54 sampling times (3 marshes x 2 tide stages x 3 seasons x 3 replicates), 306 observations were made of 31 bird species. None of the species were unique to the constructed marsh (i.e. seen in the constructed marsh but not in the natural marshes). However, 20 of the 31 species seen during the study were seen only in one or both of the natural marshes and not in the constructed marsh which is similar to the pattern observed in the 1992 study (Table 5). Of the 306 observations of birds made, 162 were in the west marsh, 49 in the constructed marsh and 95 in the east marsh. Species richness and diversity were greatest in the natural marshes (Table 6). The number of species and number of observations of neotropical migrants were higher in the natural marshes (west 6 and 11, east 7 and 22) than in the constructed marsh (2 and 8). Evidence of breeding was observed in both the west marsh (mallard broods, red-winged blackbird and northern cardinal nests) and the east marsh (gray catbird nest). No evidence of breeding was observed in the constructed marsh.

Table 5.
Bird species observed in the study marshes by year 1999 *(1992)*

Marsh	West		Constructed		East	
Species	1999	*1992*	1999	*1992*	1999	*1992*
American robin (*Turdus migratorius*)					X	
Barn swallow (*Hirundo rustica*)	X		X		X	
Belted kingfisher (*Megaceryle alcyon*)	X	*X*		*X*	X	
Blue gray gnatcatcher (*Polioptila coerulea*)					X	
Blue jay (*Cyanocitta cristata*)					X	
Brown thrasher (*Toxostoma rufum*)	X					
Carolina Chickadee (*Parus carolinensis*)	X				X	
Carolina wren (*Thryothorus ludovicianus*)	X		X			
Common grackle (*Quiscalus quiscula*)	X	*X*	X	*X*	X	*X*
Common tern (*Sterna hirundo*)	X				X	
Common yellowthroat (*Geothlypis trichas*)	X	*X*			X	*X*
Downy woodpecker (*Picoides pubescens*)					X	
Eastern kingbird (*Tyrannus tryrannus*)	X		X		X	
Eastern towhee (*Pipilo erythrophthalmus*)	X				X	
Fish crow (*Corvus ossifragus*)	X		X		X	
Gray catbird (*Dumetella carolinensis*)					X	
Great blue heron (*Ardea herodias*)	X	*X*	X	*X*	X	

Great egret (*Casmerodius albus*)	X		X	*X*	X	*X*
Green heron (*Butorides striatus*)		*X*		*X*		*X*
House finch (*Carpodacus mexicanus*)	X					
Indigo bunting (*Passerina cyanea*)					X	
Laughing gull (*Larus atricilla*)		*X*				
Mallard (*Anas platyrhynchos*)	X		X		X	
Marsh wren (*Cistothorus palustris*)		*X*				
Northern cardinal (*Cardinalis cardinalis*)	X		X		X	
Osprey (Pandion halioetus)	X					
Red winged blackbird (*Agelaius phoeniceus*)	X	*X*	X	*X*	X	*X*
Ringbilled gull (*Larus delawarensis*)	X		X			
Song sparrow (*Melospiza melodia*)	X				X	
Spotted sandpiper (*Actitus macularia*)		*X*		*X*		
Swamp sparrow (*Melospiza georgiana*)	X	*X*		*X*		*X*
Tufted titmouse (*Parus bicolor*)	X					
White eyed vireo (*Vireo griseus*)	X					*X*
White throated sparrow (*Zonotrichia albiocollis*)	X				X	
Yellow crowned night heron (*Nycticorax violacea*)		*X*				
Yellow rumped warbler (*Dendroica coronata*)	X	*X*			X	*X*
Yellow warbler (*Dendroica petechia*)						*X*

Table 6.
Bird species richness and diversity using Shannon-Weaver analysis by year 1999 (*1992*)

Marsh	Diversity	Richness
West	2.53 (*2.00*)	10.86 (*5.96*)
Constructed	2.12 (*1.83*)	5.32 (*5.00*)
East	2.72 (*1.52*)	11.12 (*4.28*)

Discussion

The uniqueness of our study site and data from the study 7 years earlier allowed for accurate and efficient comparisons between the constructed and similar natural marshes across time. The constructed marsh has obtained a general level of function such that data associated with most of the habitat parameters fell within the range of variability expressed by the natural reference marshes. Exceptions included low saltbush density, sediment organic carbon at depth, and bird utilization when compared to the natural marshes (Table 7).

Table 7.
Differences observed between the constructed and natural marshes over time.

Parameters	Differences observed 1992	1999	
Organic carbon at surface	N	N	
Organic carbon at depth	Y	Y	higher organic carbon in natural marshes
Water temperature	N	N	
Salinity	Y	N	
Dissolved oxygen	Y	N	
Low marsh stem density	Y	N	
High marsh stem density	N	N	
Saltbush stem density	Y	Y	higher stem densities in natural marshes
Low marsh percent cover	N	N	
High marsh percent cover	N	N	
Saltbush percent cover	Y	Y	higher percent cover in natural marshes
Benthic infauna abundance	N	N	
Benthic infauna richness	N	N	
Benthic infauna diversity	N	N	
Blue crab abundance	Y	N	
Blue crab size	Y	N	
Total fish abundance	Y	N	
Commercial fish abundance	Y	N	
Spot length-weight relationship	N	N	
Fish richness	Y	Y	higher richness value in constructed marsh
Fish diversity	Y	Y	higher diversity value in constructed marsh
Bird richness	Y	Y	higher richness value in natural marshes
Bird diversity	Y	Y	higher diversity value in natural marshes
Bird abundance	Y	Y	higher abundance in natural marshes

As of the summer of 1999, the constructed marsh was 12 years old. The previous study revealed that organic carbon levels at depth were significantly lower in the constructed marsh when compared to the natural marshes. This is due, in part, to the excavation of the upland to create the marsh site. During the excavation process the organic top layer of soil is usually removed in order to reach a depth that will allow a tidal connection. It has been assumed that as the marsh matures organic matter will accumulate. This process is important to the overall function of the marsh since organic matter supplies the base for higher trophic levels. Organic matter levels at the surface of the marshes are similar, however the constructed marsh still contains significantly less organic matter at depth. While some parameters such as the formation of microtopography within the constructed marsh may be affected by the significant lack of organic matter in the soil, the abundance of fish, blue crabs and benthic infauna appears not to be affected. Amending the site with organic substrate at the time of construction could have helped speed the development of a sediment profile similar to the natural marshes.

The existence of mature saltbush habitat in the natural marshes, and its low abundance in the constructed marsh continues to explain the variation in bird use between the constructed and natural marshes. Of the 162 observations of bird activity in the west marsh, 60% were recorded in the saltbush habitat. In the east marsh, 37% of the observations of bird activity were in the saltbush habitat. In the constructed marsh, which has very little saltbush community, 24% of the observations were recorded in the saltbush or dead saltbush. In the three marshes, all the neotropical migrant songbird activity was recorded in the saltbush community (dead saltbush community in the constructed marsh). Planting sections of the constructed marsh with mature saltbush species could have increased the attractiveness of the marsh to birds by providing nesting, perching and foraging sites for temperate and neotropical migrant species.

Conclusion

The constructed marsh has reached a general level of habitat function similar to that of nearby natural marshes. Some morphological differences remain such as the differences in community type ratios. Significant differences in habitat function remain in three areas: sediment organic carbon at depth, mature saltbush density, and bird utilization (hypothesized to be related to saltbush density).

Data from this study suggests that the addition of an organic soil amendment at the construction phase and the planting of a mature saltbush community would help increase the probability of a success in the construction of artificial marshes to replace the habitat functions of natural marshes.

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