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An Assessment of Wildlife Utilization between a Man-made Marsh, an Adjacent Natural Marsh, and a Nearby Natural Marsh in Virginia

Kirk J. Havens
Virginia Institute of Marine Science

Lyle M. Varnell
Virginia Institute of Marine Science

Julie G. Bradshaw
Virginia Institute of Marine Science

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College of William and Mary

Principal Investigators:

Kirk J. Havens

Lyle M. Varnell

Julie G. Bradshaw

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INTRODUCTION

The expansion of the human population and the subsequent impact on sensitive natural systems, such as wetlands, has spurred increased use and study of created wetlands. As the human population increases within the coastal region, wetland systems come under increasing pressure from developmental, agricultural, and industrial interests. Historically, wetlands were viewed simply as wastelands and mosquito breeding grounds and subjected to significant filling and draining activity. Approximately one third to one half of the wetlands of the coterminous United States have been lost in the past 200 years, and between the mid 1950s and the mid 1970s nine million acres of wetlands were destroyed (Tiner, 1984; Mitchell, 1990). Even more disturbing is that the loss of wetlands is continuing at a rate of approximately 290,000-450,000 acres per year (Dahl, 1990; Kentula and Kusler, 1990; Mitchell, 1990). Virginia lost approximately 42% of its wetlands between 1780 to 1980 (Dahl, 1990).

During the 1970s, an increased awareness of the functions and values of these systems resulted in the enactment of laws protecting wetlands (Hefner and Brown, 1985). Estuarine wetlands now receive the most protection through laws enacted by both the federal government and state governments. As a result, estuarine wetland acreage declined 1% between the mid-1970's and the mid-1980's (Dahl and Johnson, 1991). In Virginia, losses of estuarine wetlands through the permit process is estimated at 20 acres annually (Priest et al. 1990).

Mitigation of the loss of valuable wetlands has accordingly become increasingly important to regulatory agencies and, consequently, to the development community. Attempts to create wetlands on dredge spoil and from graded upland areas have been conducted, but few studies have compared these created wetlands with adjacent natural marshes. Researchers have been plagued by the question of if and how long does it take for a man-made marsh to achieve the same level of maturity as adjacent natural marshes. Different methodologies have been employed to estimate the time needed for a created marsh to equal a natural marsh. However, these studies emphasize mostly the vegetative function of marshes and leave in question the myriad of additional functions considered of value in wetland systems. Sediment carbon content has been used to give estimates of 4 to 25 years for a created marsh to resemble a natural marsh (Seneca et al. 1976). Organic carbon content was used to estimate a time of 3.7 to 4.5 years in one marsh and 22 to 26 years in another marsh (Cammen et al. 1974).

Recently, some studies have compared various functions of man-made and natural marshes. Moy and Levin (1991) showed a significantly lower *Spartina* stem density and *Fundulus* population in a created wetland relative to two adjacent natural wetlands in North Carolina. However, some studies have shown primary production rates to be similar between created wetlands and nearby natural wetlands after several years (Seneca et al.,1976). Nevertheless, the majority of studies reveal lower primary production values for created wetlands compared to natural wetlands.

The present study investigates the functions and values of man-made and natural tidal wetlands. The study is among the first to use simultaneous sampling techniques to investigate animal use preference between man-made and adjacent natural tidal wetlands.

MATERIALS AND METHODS

SITE LOCATION

The study site is located in Sarah's Creek, a tributary to the York River near Gloucester Point, Virginia (37°16'30"/76°29'40") approximately 6 miles from the Chesapeake Bay and 25 miles from the Atlantic Ocean (Figure 1). The average tidal amplitude is 0.67 meters.

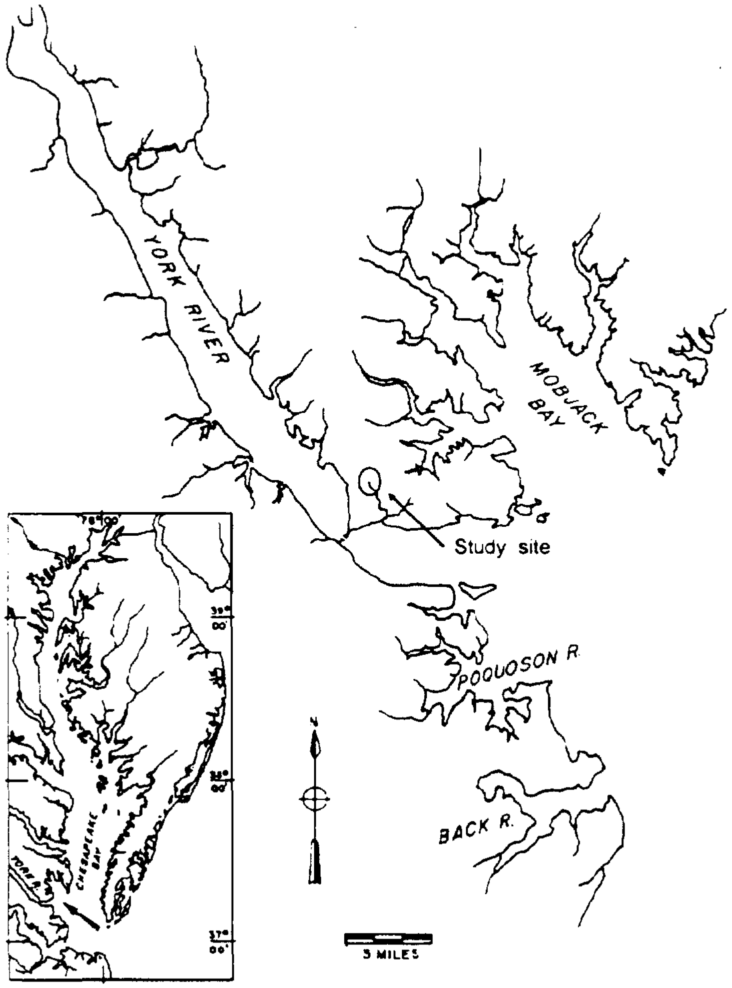


Figure 1 Study site. Sarah's Creek, Gloucester County, Virginia

Physical characteristics of the marshes were determined from low altitude aerial photographs of a scale of 1:4200. The vertical aerial imagery of the marshes was digitized using the vector-based GIS software ARC/INFO. The digitization of coverages was conducted using Dell personal computer work stations interfaced with Numonics 2200 digitizing tablets. Topcon infrared surveying equipment was used to survey elevations within each marsh. Volumetric and tide range data was obtained by comparing marsh elevation data with a tide gauge established on site.

The total area of the man-made wetland (MM) is 1.66 acres. An adjacent natural wetland (ADJ) is located just upstream of the man-made marsh but is separated by a 50 foot wide wooded peninsula and contains 1.29 acres. The other natural wetland (NAT) is located approximately 150 meters downstream from the man-made wetland and is 1.08 acres in size. It is separated from the man-made wetland by approximately 40 acres of wooded upland (Figure 2). The man-made wetland is bordered on the north

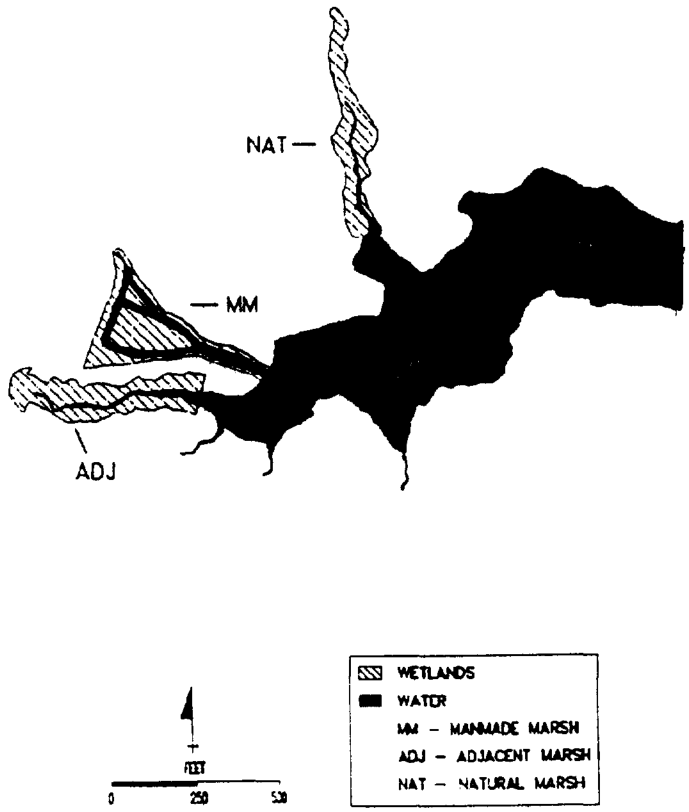


Fig. 2 Relative location of study sites.

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 adjacent natural wetland receives only incidental freshwater input while the downstream natural wetland receives freshwater input through a drainage ditch along the north border.

The MM wetland was constructed in 1985 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 24 to 36 inch centers on the graded land. The channel was excavated to a depth of 3 feet mean low water.

EXPERIMENTAL DESIGN

Our main objective was to determine whether a created tidal wetland could function, over time, as well as a similar natural tidal wetland. In doing so, we chose to evaluate some of the more important functional relationships between a tidal wetland and the adjacent marine environment. Essentially, we followed the important food chain routes from primary production to secondary consumers. These categories included comparisons of vegetation, sediment carbon, benthic fauna, zooplankton, fish abundance, crab abundance and bird utilization.

The uniqueness of our study site allowed for accurate and efficient comparisons between the man-made and similar tidal marshes. Due to the close proximity of the three marshes, variables such as weather, tidal input and access availability by marine and avian fauna could be accurately assumed to affect each marsh equally.

An intensive, two season sampling strategy was chosen above other alternative sampling strategies for statistical purposes. Spring sampling occurred from 12 May to 14 May and summer sampling occurred from 27 July to 29 July. By sampling each marsh for three consecutive days during two seasons (spring and summer), we could account for the natural intrinsic variation of tidal salt marshes within each study component.

STATISTICAL ANALYSIS

By design, each sample category was analyzed by the same statistical methods. Differences between marshes within each sample category were analyzed by analysis of variance. Depending upon the normality and homogeneity of variance of the data, either parametric or nonparametric methods were used. When the data were normal and variances were homogeneous, parametric oneway analysis of variance (ANOVA) was used in conjunction with either Scheffe's or Tukey's multiple range tests, and *a priori* tests. Otherwise, the Kruskall-Wallis test (a nonparametric ANOVA) was used in conjunction with the Mann-Whitney test (a nonparametric test for differences between two means).

Normality testing was done using a Lilliefors modification of the Kolmogorov-Smirnov test. When data points to be tested were greater than 30, the Shapiro-Wilks test was used.

Relationships between length (for spot and blue crabs) and length-weight (for spot only) were done using standard regression techniques. Differences in regression slopes were tested using a parametric analysis of covariance (ANCOVA).

Biodiversity was measured for various populations by calculation of Species Richness and Diversity. Richness (d) was calculated as below:

$$d = \frac{s-1}{\log N}$$

where s= number of species, and
N= number of individuals.

Diversity was calculated using the Shannon-Weaver Index of Diversity.

SAMPLING METHODOLOGY

Random sample plots within each marsh were necessary for the vegetation, benthic fauna, sediment carbon and marsh surface trap net 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 one square meter cells (Figure 3). 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 were numbered and placed at ten meter intervals along the upland-wetland boundaries of each marsh from mouth to head for ease of field identification of the random plots. Specific sample sites were extrapolated from the flagged locations.

Fish and blue crabs from each wetland were sampled by simultaneously establishing a Priest Modified Hoop Net (Priest, per. com.) across the entrance of each marsh. The nets were set at the slack at high tide and emptied periodically until low tide. The two natural marshes drain close to dry at low tide while the man-made marsh maintains a two foot depth at mean low tide. At low tide the man-made marsh was seined to collect remaining fish. Fish and blue 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 nets were set for three consecutive days during May (spring) and July (summer).

Pit traps consisting of 5 gallon plastic tubs were buried flush with the sediment surface to sample marsh surface use by actively mobile fauna. Four pits were established in the *Spartina alterniflora* community and four in the *Spartina patens* community in each wetland. Each pit was emptied at low tide during each sampling period. Contents were enumerated and identified to the lowest taxonomic level.

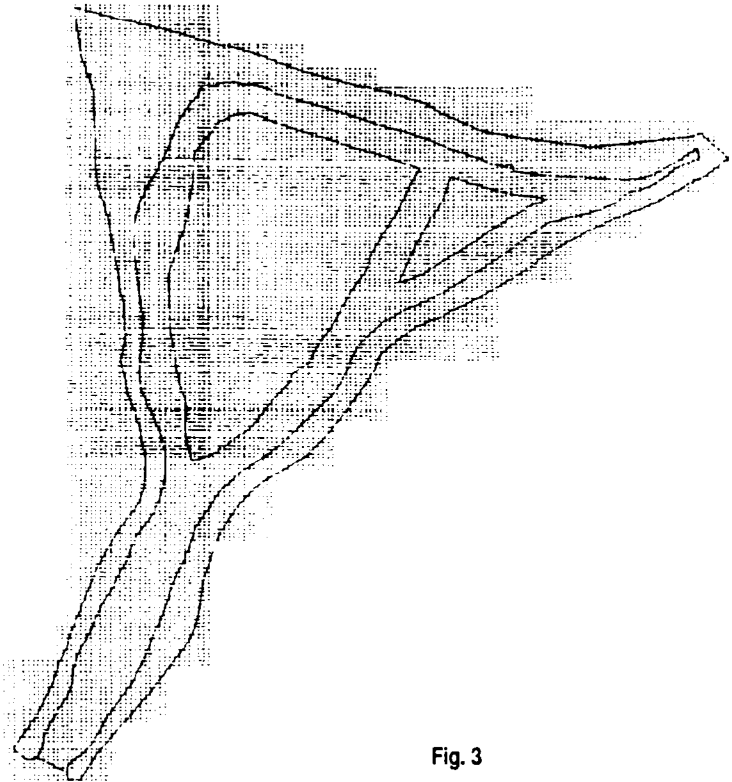


Fig. 3
Grid reduced scale overlay for random plot generation. Example for the created marsh.

Three trap nets (1 meter square) were randomly placed in each wetland at each high tide throughout the sampling period to investigate utilization in different habitat types and to sample for gastropods and *Uca* species.

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 sampled using a 1/4 square meter quadrat. The saltbush community was sampled using a two meter radius plot. Percent cover and stem density data were collected for each sample within each community.

Sediment was sampled in three habitat types within each marsh: high marsh, low marsh, and nonvegetated intertidal. Three sediment cores were 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).

Benthic invertebrates were sampled using a 232.25 square cm benthic grab. Seven samples (with duplicates) were collected from each marsh in June. The samples were sieved through a 0.5mm mesh, stained with rose bengal, and preserved in 10% formalin. Taxonomic identification to species level was determined where possible. The data was analyzed for community structure parameters such as species richness and diversity.

The three marshes were surveyed to determine bird usage during three seasons (winter, spring, summer) and at two tide stages (low and high tide). Marshes were surveyed between 0.5 and 3.0 hours after sunrise and between 2 hours before and 2 hours 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. The marshes were also surveyed for bird nests at the end of the breeding season by walking through each marsh.

Physical water quality data including: salinity, dissolved oxygen, and temperature were measured each morning of the sampling period immediately after setting the block nets. Salinity was measured using a refractometer. Dissolved oxygen and temperature was measured with an *Orbisphere* Portable Meter.

Zooplankton were collected from each marsh using a specially designed net (150 micron mesh) which sampled the top 12 cm of the water column at slack high tide for each day of the sampling period. The design permitted sampling well into the shallow regions of the marshes. A *General Oceanics* propeller-type flowmeter was affixed to the collection device immediately behind the plankton net. Due to the small size of the net aperture, the flowmeter could not be positioned in the net as is customary for zooplankton collection. However, placement of the flowmeter posterior to the collecting net proved beneficial since it allowed less binding of the propeller from floating debris.

Volume of water sampled was calculated from flowmeter readings using the formula:

$$V=FK_iA$$

where $V=$ volume filtered,
$F=$ flowmeter counts,
$A=$ filtering area in m^2 (dimensions of the net aperture),
$K_i=$ net constant.

Net constant was calculated in a high volume flume of constant flow and velocity.

Copepod adults and larval copepods and barnacles were identified, enumerated, and tested statistically by previously described methods. Only adult copepods are presented in this paper.

Examination of zooplankton abundance with various measured physical parameters revealed a possible relationship between zooplankton abundance and salinity. This observation was tested by nonparametric correlation (Spearman's correlation coefficient) since the data was not bivariate normally distributed.

RESULTS AND DISCUSSION

THE PHYSICAL ENVIRONMENT

Table 1 presents average physical water quality parameters measured during the study. Water temperatures were consistent throughout the study; differences between marshes were never greater than 2^0 C. Differences were observed in salinity and dissolved oxygen measurements between man-made and natural systems. Salinity in MM was markedly lower each season, which can be attributed to the freshwater input directed into the wetland. Freshwater input, possibly coupled with the greater depth and open water of the creek channel may also be reasons for dissolved oxygen levels in MM being equal to or higher than dissolved oxygen levels in NAT and ADJ.

Table 1. Average measured physical parameters for each marsh by season (S- salinity in parts per thousand, T- temperature in degrees Celsius, DO- dissolved oxygen in milligrams per liter).

Sampling Season	Marsh	Region of Marsh								
		Head			Middle			Mouth		
		S	T	DO	S	T	DO	S	T	DO
Spring	Adjacent Natural	10.0	19.0	2.36	11.3	19.3	2.88	11.3	19.9	4.37
	Man-made	1.8	19.8	5.03	4.7	20.6	4.73	4.3	20.8	4.98
	Natural	1.8	17.8	3.93	11.0	18.7	4.24	13.7	19.2	4.97
Summer	Adjacent Natural	12.7	26.6	1.74	12.3	27.3	3.35	15.9	28.0	4.10
	Man-made	6.5	26.7	3.10	8.2	27.1	3.48	9.7	26.9	3.79
	Natural	11.3	27.4	2.14	14.7	27.5	3.24	14.7	27.6	4.29

Overall, dissolved oxygen was low in all three marshes as compared to open water areas. Resident fish and crab species are able to tolerate low dissolved oxygen levels for extended time periods, but foodfish are unable to adapt as well as resident species. As discussed later, however, dissolved oxygen levels were not a factor in fish and crab distribution among the three marshes. Data also indicated that salinity seems to influence zooplankton abundance in tidal marsh creeks (also discussed later).

The man-made wetland compared well with the natural wetlands for dissolved oxygen and temperature. The lower salinity levels in MM do not compare well with the surrounding natural system. In terms of salinity (which, of course, is important in marine systems) the man-made wetland seems to create an isolated environmental anomaly which may be responsible for some of the differences found during the study. It must be noted that the original wetland that was filled, and for which the man-made wetland was created, received considerable freshwater input from a large drainage ditch. The extent to which this affected salinity in the original wetland is unknown.

SEDIMENT ANALYSIS

Tidal marsh soils serve as reservoirs of organic matter for estuarine systems and as sinks in the global carbon cycle (Friedman and DeWitt, 1978; Armentano, 1980). The reduced decomposition rate due to the waterlogged soil conditions coupled with the high primary productivity of wetlands results in an accumulation of organic matter. Schlesinger (1977) reported that while wetlands comprise less than 2% of the earth's land surface, they contain approximately 10% of the total nonsubaqueous soil organic carbon.

An important question from both a management and biogeochemical perspective is whether man-made marshes can become an organic carbon sink with a reservoir capacity similar to natural marshes. Craft et al. (1988) in a study along the North Carolina coast found macro-organic matter levels much lower in transplanted versus natural marshes. The one exception was one site that had been established for 14 years. Carbon and nitrogen pools were also found to be much greater in the natural marshes.

Table 2. Organic carbon per marsh at surface and within the root zone ($g/cm^3 \times 10^3$)

	Surface (0-2 cm)	Depth (14-16 cm)
ADJ	16.3	17.4
NAT	12.9	15.3
MM	9.5	5.0

Data from this study supports the hypothesis that created wetlands are lacking in organic matter and organic carbon, especially in the initial stages of development (Table 2). Average values of organic carbon at a depth of 14-16cm (the approximate root zone for vegetated areas) for the ADJ and NAT wetland were 0.0174g/cm^3 and 0.0153g/cm^3, respectively. This differs significantly ($p < .05$) from the man-made wetland value of 0.0050g/cm^3 (Figures 4 & 5).

Differences in surface carbon content among marshes revealed no consistent pattern. Although mean surface carbon content for MM was below that of ADJ and NAT in each zone, significant differences were only apparent between MM and NAT in the high marsh zone, between ADJ and MM, and ADJ and NAT in the low marsh zone, and between ADJ and MM in the nonvegetated intertidal zone.

Figure 4

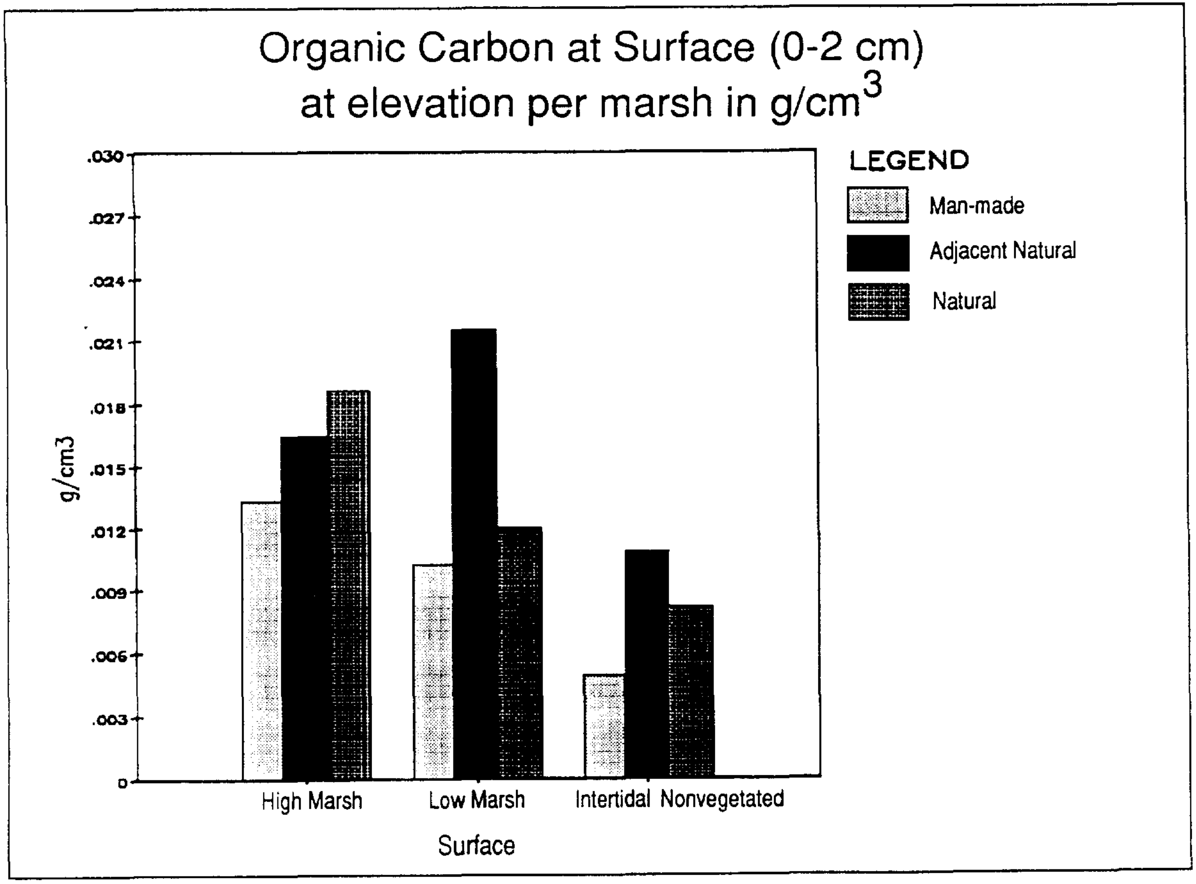
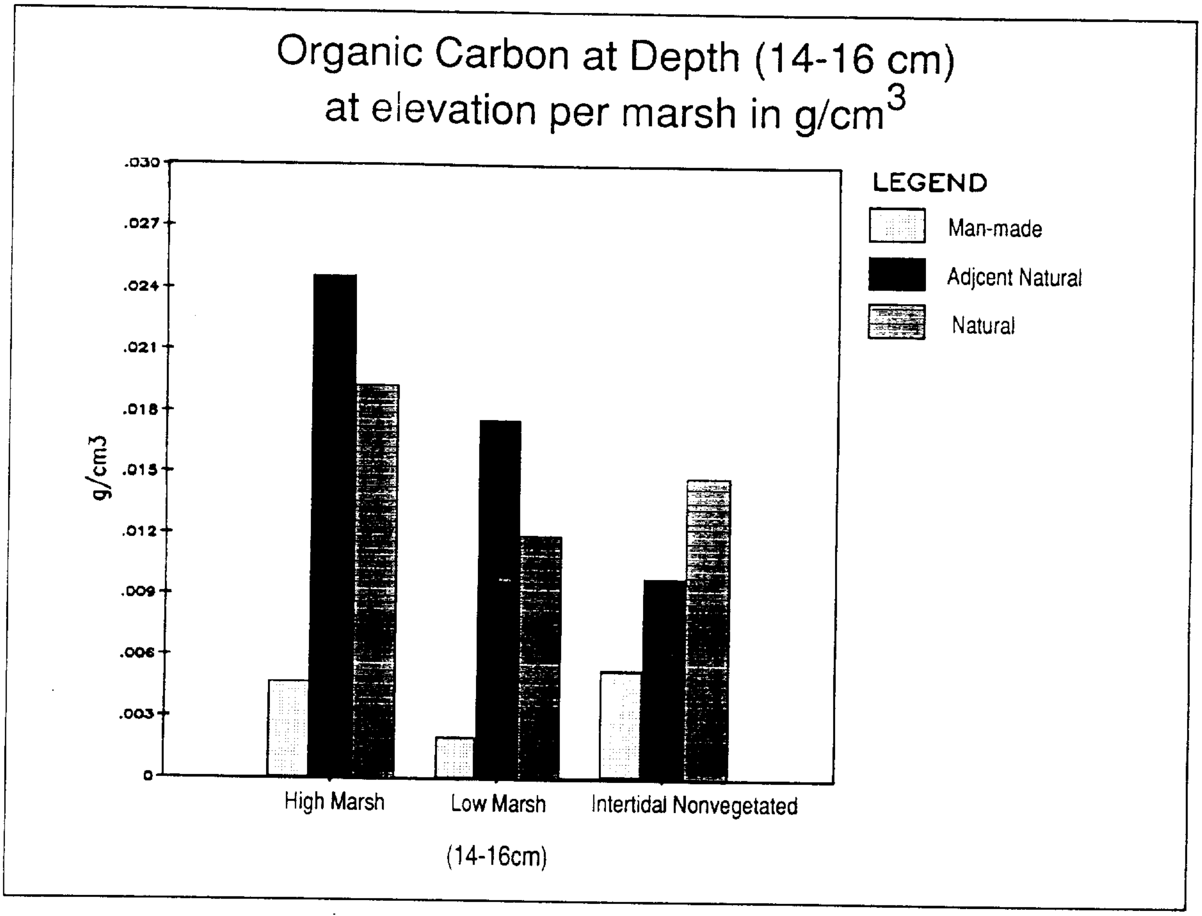


Figure 5



We believe our data show maturation of MM with respect to surface carbon content which will eventually equal natural systems. However, the carbon content in the root zone of vegetated areas in MM may never achieve levels similar to natural systems. Placement of organic rich soil on top of the excavated area and planting with greater initial stem density would possibly have accelerated both processes.

VEGETATION

Figure 6 presents acreages and percentages of physical zones for each marsh. Stem density counts and percent cover estimates in both the natural marshes were higher than in the man-made marsh (Table 3). Our cover estimates of 53% for MM and 66% for ADJ compared well with the estimates of Barnard and Mason (1991) of 47% for MM and 57% for ADJ (these numbers represent high and low marsh vegetation zones combined)(Table 4). Priest (1989) found similar coverage differences between

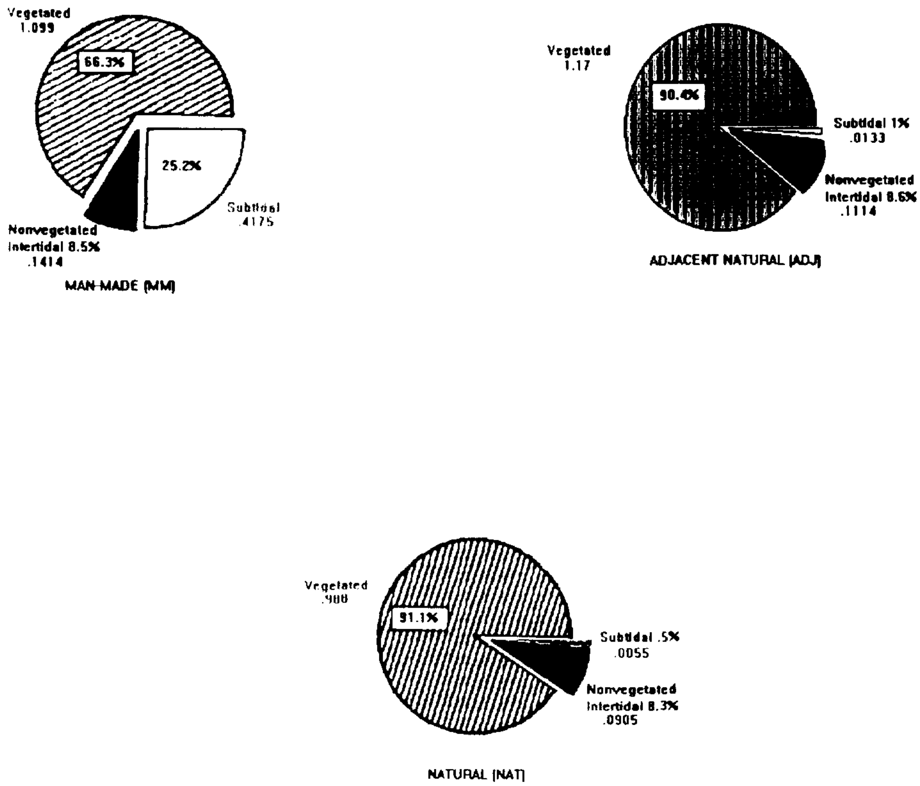


Figure 6. Acreages and Percentages of Physical Zones in the Three Studied Marshes

Table 3. Marsh vegetation survey results. For Vegetation Zone category, high marsh species include *Spartina patens* and *Distichlis spicata*, low marsh species include *Spartina alterniflora*, and saltbush species include *Baccharis halimifolia* and *Iva frutescens*. Average stem density is presented per square meter.

Vegetation Measure	Marsh	Vegetation Zone High Marsh	Low Marsh	Saltbush
Average Stem Density	Adjacent Natural	1,727	365	1.8
	Man-made	1,489	290	0
	Natural	1,916	504	0.8
Average Percent Cover	Adjacent Natural	86	55	74
	Man-made	77	30	0
	Natural	71	68	57

man-made and natural marshes in Norfolk, Virginia with estimates of 46% for the man-made and 58% and 64% for two natural marshes. Cover estimates of two man-made marshes of different ages, four years and eight years, were reported at 51.5% and 47.5%, respectively (LaSalle et al., 1991).

Stem density in natural marshes range from 230-1170/m^2 (Oviatt et al., 1977). LaSalle et al. (1991) reported stem densities of 199/m^2 and 257/m^2 for a four year old and eight year old man-made marsh,

Table 4. Comparison of similar historical salt marsh veg. measures with the present study.

Study Site	Average Percent Cover	Average Stem Density	Reference
Monkey Bottom man-made marsh (Norfolk, VA)- low marsh	46	340	Priest, 1989
Natural marsh (Norfolk, VA)- low marsh	64	308	Priest, 1989
Natural marsh (Norfolk, VA)- low marsh	58	465	Priest, 1989
Man-made marsh (8 years old)- low marsh	48	257	LaSalle et al., 1991
Man-made marsh (4 years old)- low marsh	52	199	LaSalle et al., 1991
Man-made marsh- low marsh	--	707	Broome et al., 1986
Natural marsh- low marsh	--	719	Broome et al., 1986
Various natural marshes- low marshes	--	230 - 1,170	Oviatt et al., 1977
Jamaica natural marsh- low marsh (1978/1979)	--	483/567	Webb & Newling, 1985
Pepper natural marsh- low marsh (1978/1979)	--	192/409	Webb & Newling, 1985
Eight Mile natural marsh- low marsh (1978/1979)	--	302/425	Webb & Newling, 1985
Bolivar man-made marsh- low marsh (1978/1979)	--	221/292	Webb & Newling, 1985
Man-made marsh- low marsh (same as in this study- 1988)	47	--	Barnard & Mason, 1991
Adjacent natural marsh- low marsh (same as in this study- 1988)	57	--	Barnard & Mason, 1991

Table 4 continued

Study Site	Average Percent Cover	Average Stem Density	Reference
Adjacent natural marsh- high marsh	86	1,727	Havens et al., 1992
Man-made marsh- high marsh	77	1,489	Havens et al., 1992
Natural marsh- high marsh	71	1,916	Havens et al., 1992
Adjacent natural marsh- low marsh	55	365	Havens et al., 1992
Man-made marsh- low marsh	30	290	Havens et al., 1992
Natural marsh- low marsh	68	504	Havens et al., 1992

respectively. Priest (1989) recorded stem densities of 308/m^2 and 465/m^2 in two natural marshes and 340/m^2 in a man-made marsh. Broome et al. (1986) found little difference in stem density between a natural marsh (719/m^2) and a man-made marsh (707/m^2). Total stem densities from our study fall within the range reported by Oviatt (1977) with counts of 1209/m^2 for NAT, 1045/m^2 for ADJ, and 889/m^2 for MM which were not significantly different.

Webb and Newling (1985) (Table 4) studied stem density of *Spartina alterniflora* in three natural marshes and one man-made marsh and recorded counts of 567/m^2, 409/m^2, 425/m^2, and 292/m^2 respectively. Stem density measurements of *Spartina alterniflora* in our study compare well with counts for ADJ, NAT, and MM of 365/m^2, 504/m^2, and 290/m^2 respectively. The stem density of *Spartina alterniflora* in the man-made (MM) marsh was significantly lower ($P < .05$) than the two natural marshes ADJ and NAT.

Species composition between marshes is similar with saltmarsh cordgrass, *Spartina alterniflora,* and saltmeadow hay, *Spartina patens,* dominating each marsh. The notable difference between the natural marshes and the man-made marsh is the absence of mature saltbush (*Iva frutescens* and *Baccharis halimifolia*) in the man-made marsh. It should be noted that approximately 60% of the area of the original wetland that was filled consisted of mature saltbush community (Silberhorn, 1986). Mature *Iva frutescens* and *Baccharis halimifolia* comprise 25% and 47% of the vegetation of ADJ and NAT, respectively.

Our results reveal that the condition of the vegetation communities within the man-made wetland are deficient. Although the man-made wetland has achieved total cover estimates similar to the nearby natural wetlands, it is evident that it has yet to achieve comparable saltmarsh cordgrass or saltbush stem densities.

BENTHIC COMMUNITY

Species richness and species diversity were calculated for benthic invertebrates within each marsh and between intertidal and subtidal habitats. Total sampled populations were tested for differences by nonparametric methods.

Table 5. Total numbers of benthic fauna collected for each marsh by taxa.

Taxa	Adjacent Natural	Natural	Man-made	Total
Streblospio benedicti	5	13	94	112
Nereis succinea	35	49	35	119
Gyptis vittata	0	0	3	3
Asabellides oculata	10	35	3	48
Eteone sp.	2	2	0	4
Eteone heteropoda	60	17	19	96
Capitellidae	15	4	4	23
Capitella capitata	103	2	53	158
Heteromastus filiformis	35	79	87	201
Mediomastus ambiseta	0	1	0	1
Syllidae	0	2	2	4
Tubificidae	96	94	95	285
Nemertinea	8	20	20	48
Micrura leidyi	1	0	0	1
Macoma balthica	14	5	28	47
Macoma mitchelli	0	0	3	3
Gammarus sp.	0	1	0	1
Gammarus palustris	0	1	0	1
Corophium sp.	0	0	1	1
Corophium lacustre	0	0	2	2
Orchestia grillus	0	0	1	1
Cyathura polita	0	1	0	1
Mysidacea	0	0	1	1
Chironomidae	5	5	27	37
Totals	389	331	478	1,198

Table 5 presents the species and numbers collected of benthic fauna during the study. The data suggest little difference in species richness or species diversity between sites or between habitats within sites (Table 6). Diversity values are within the range reported for the Hampton Roads area (Diaz and

Table 6. Community Structure for macrobenthos.

	Species Richness			Species Diversity		
	Intertidal	Subtidal	Total	Intertidal	Subtidal	Total
ADJ	2.9	3.8	3.1	1.84	1.87	1.98
NAT	4.4	4.3	4.4	1.86	1.88	1.99
MM	4.9	3.5	4.9	2.10	2.09	2.19

Gapcynski, 1990; Boesch, 1973), though somewhat on the low end, with a slight indication of more diversity in the man-made wetland.

No significant differences in population levels exist between any of the three marshes. Of interest, however, is the apparent greater abundance of benthic fauna within MM. This may be due to the high sand content of upper-intertidal sediment which may facilitate a greater oxygen supply for benthic inhabitants.

The benthic community in MM appears to have matured to the point that it is similar to natural systems. This was expected since it is widely known from dredging studies that benthic communities can become established relatively rapidly (LaSalle et al., 1991).

ZOOPLANKTON

Zooplankton, especially copepods, are important dietary components for various life stages of estuarine fishes (Currin et al., 1984; Smith et al., 1984). Because of their importance in the marine food chain their life histories and ecology has received broad study. However, their presence in intertidal marsh creeks have received only minimal study. Therefore, we consider this component of our study to be unique.

Adult copepods are active swimmers, but are mainly at the mercy of the tides for lateral movement. Therefore, we did not expect to find adult copepods actively "choosing" a particular marsh. We chose to study zooplankton mainly because of the open water area in MM. We hypothesized that a zooplankton population may be high here because the creek does not drain completely dry, i.e. resident zooplankton may not leave. A constant zooplankton population may encourage greater use of MM by nektonic zooplankton feeders. If we found zooplankton populations highest here, we may be able to infer causes to possible differences in fish abundance.

Our results were somewhat unexpected. As expected, adult copepod concentrations were greater in July than in May. However, in each sampling period, MM had the lowest average adult copepod concentration of the three marshes. For MM, these differences were significant only between ADJ in May, but between ADJ and NAT in July. Differences between ADJ and NAT were significant in May but not in July, with ADJ containing the greater concentration.

The differences between MM and the natural marshes may be attributable to MM being an outlet for directed stormwater runoff. Even during flood tide, and during both sampling periods, a noticeable outward surface flow was evident at the mouth of MM. This outward surface flow may inhibit zooplankton from invading the marsh creek. Menhaden and various other members of the herring family (clupeidae), which feed on zooplankton during various stages during their life cycle, were collected from both ADJ and MM. Predation may have played some role in abundance differences between marshes however, the immediate collection of zooplankton after placement of the block nets at high slack tide, the presense of clupeids in both ADJ and MM, plus the relatively low numbers of clupeids collected with respect to total marsh water volume, lead us to believe that predation would have only a minimal effect on measured zooplankton abundance. We contend that the main effects on adult copepod abundance in MM was the continuous surface-water outflow and lower salinity levels.

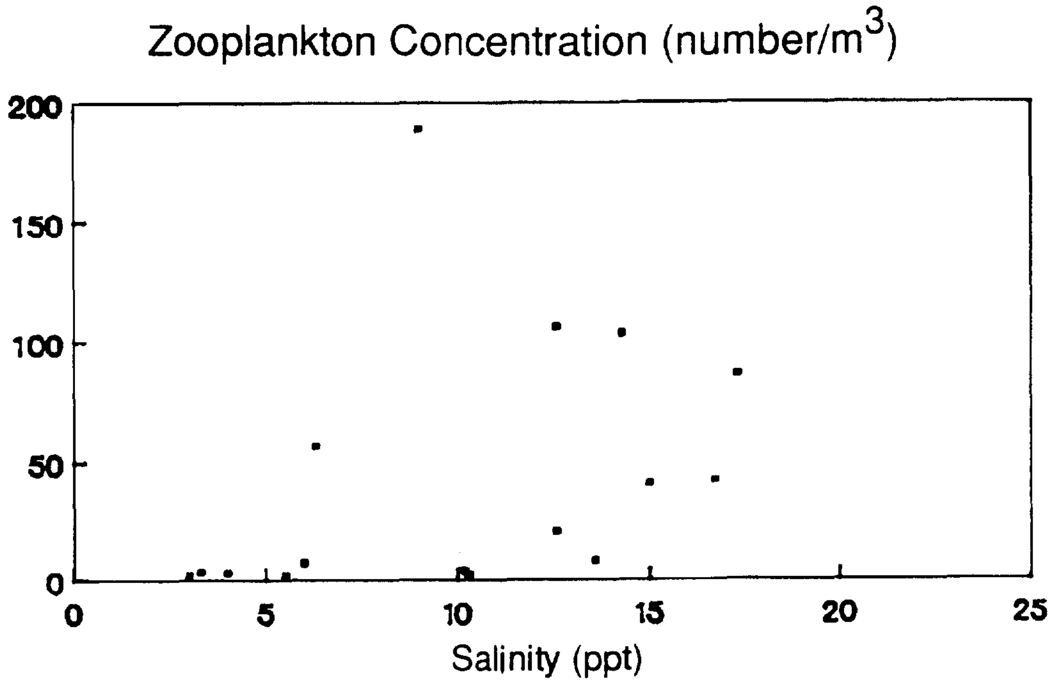


Figure 7. Zooplankton Concentration vs Salinity

Continuous freshwater input has caused lower salinities in MM (reference Table 1), which seems to have had an effect on zooplankton abundance in this study. We tested adult copepod abundance against salinity levels and found a significant correlation (P= 0.010)(Figure 7). Therefore, prohibiting constant freshwater input, which would also aide in the maintenance of surrounding ambient salinities, seems necessary to promote a healthy and "natural" zooplankton population.

MARSH SURFACE UTILIZATION

Tidal marshes and creeks have been shown to be important habitats for the larval stages of marine and estuarine fish (Clark et al., 1969; Weinstein, 1979). Two of the major factors that are considered important in habitat selection by juvenile fish are foraging profitability and risk of predation (Werner and Hall, 1976; Holbrook and Schmitt, 1984; Schmitt and Holbrook, 1985). This, in turn, may be influenced by marsh morphology and microtopography. Creek sinuosity, channel depth, and bank stability may affect fish utilization of a creek system and the adjacent vegetated marsh surface (McIvor and Odum, 1988).

McIvor and Odum (1988) demonstrated that at high tide the predator refuge supplied by shallow, depositional areas no longer exists since larger predatory fish can utilize these areas with the rise in water depth. However, these shallow areas would be exposed to such predation for shorter periods than deeper channel or bank areas.

Juvenile fish may forage the marsh surface because of the higher content of organic matter and to avoid predation by larger fish. There is evidence that dense vegetation inhibits the foraging efficiency of some piscivores (Minello and Zimmerman, 1983). However some studies have shown that some juvenile fish confined exclusively to vegetated habitats reveal reduced growth (Fraser and Cerri, 1982; Werner et al., 1983a). Werner et al. (1983a) showed that juvenile bluegill move out of vegetated areas when predatory fish were removed. This is believed to maximize their energy efficiency by enabling them to feed on zooplankton in the water column.

Rozas et al. (1988) demonstrated the importance of rivulets in marsh topography. These small, shallow drainage areas are the preferred access points for small fish to the marsh surface and provide refuge during low tide.

Our results show significantly greater ($P< .05$) use of the total marsh surface in the natural marshes (ADJ & NAT) than in the man-made marsh (MM) in July and no significant difference in May. While there was no significant difference in usage of the high marsh area during either sampling period, there was significantly ($P< .05$) more usage of the low marsh of both ADJ and NAT than in MM, in July. In May there was no significant difference in use of the low marsh zone between ADJ and MM, but a significantly ($P< .05$) higher use of the MM and ADJ low marsh than the NAT low marsh.

Young, prey size fish and shellfish were more abundant in the summer as compared to the spring, which may explain differences found in July. In the low marsh zone during the spring sampling period, use was approximately half that of the low marsh zone during the summer sampling period. Therefore, differences found in May should be interpreted with caution due to the relatively small amount of data collected.

Data collected by the square meter trap method revealed no significant differences in crab (*Uca sp.*) burrows between either of the marshes at the 5% level. The only significant difference revealed by this method was for the gastropod *Melampus bidentatus* abundance between ADJ and MM during the summer sampling period, with abundance greater in ADJ.

This method produced other data which we were unable to test statistically because of the high variability; however, these data reveal some interesting observations. For example, the ribbed mussel, *Modiolus demissus*, was only observed in ADJ. It has been reported that killifish use the shell of mussels as an egg depository site (Able, 1984). Also, the common periwinkle, *Littorina irrorata*, was observed in ADJ and NAT, but not in MM.

The differences in low marsh surface use revealed during this study show MM not functioning as well as the natural marshes. Since there appears to be little difference between the marshes in surface organic carbon content, this use preference may reflect the presence of rivulets and higher stem densities in the natural marshes which are lacking in the man-made marsh. This could also be due to the physical extent of the low marsh areas (narrow in MM versus wide) in the natural marshes.

BLUE CRAB UTILIZATION

Blue crabs (*Callinectes sapidus*) are commercially and ecologically important in East and Gulf Coast estuarine systems.

Relatively few studies have been done which address blue crab use of tidal marshes. In Virginia, research in this area has emphasized the importance of adjacent eelgrass beds over tidal marsh creeks for feeding and molting (Ryer, 1987; Ryer et al., 1990). Blue crabs are an important component in energy transfer processes in tidal salt marshes and primarily use these areas for predator avoidance and feeding; especially in areas where submerged aquatic vegetation is absent. Predators of blue crabs include Sciaenids such as Atlantic croaker and red drum, striped bass, and other blue crabs (all of which were collected during this study) and various wading birds (which were observed during this study). Blue crabs feed on a myriad of tidal salt marsh inhabitants including fishes, xanthid crabs, mussels, gastropods, other blue crabs and detritus. Feeding by blue crabs frequently occurs in intertidal areas of salt marshes during high tides. Movement into deeper waters occurs during ebb tide.

During the spring sampling period 18 blue crabs were collected from MM, compared with 87 from ADJ and 108 from NAT. During the summer sampling period 165 blue crabs were collected from MM, compared with 362 from ADJ and 258 from NAT. None of these was significantly different at the 5% level. Taking into account abundance by total marsh area, differences were still not significant. However, since we assumed that we were sampling the total population, reliable conclusions can be made from the raw data.

The data suggests that MM is not as suitable a habitat for blue crabs as the natural marshes. This could be due to reduced food availability in MM or the physical structure of MM as compared to ADJ and NAT. Both of the natural marshes contain rivulets and vegetation hammocks that are not present in the man-made marsh. These structures are important as micro-habitats used for predator avoidance and as foraging areas. Lack of these areas would be disadvantageous for blue crabs.

Length-frequencies of blue crabs for each marsh and sampling period (Figures 8-13) show larger crabs (those less vulnerable to predation) inhabiting MM during the spring. By summer, differences in sizes of blue crabs in all three marshes were similar. Overall, larger crabs were collected in the spring than in the summer for all marshes combined (Figures 14-15).

We are of the opinion that the man-made marsh is not functioning as well as the natural marshes as a blue crab habitat. We believe that this can be attributed to the lack of rivulets and vegetation hammocks in MM.

NEKTON UTILIZATION

Tidal marsh creek systems have long been recognized as an important resource for juvenile fish of commercial and recreational value (Clark et al., 1969; Bozeman and Dean, 1980).

Bozeman and Dean (1980) sampled a 1.7 hectare marsh in South Carolina and obtained absolute abundances ranging from 271 to 144,503 fish per sample date. Dominant fish species were *Leiostomus xanthurus* (spot), *Lagodon rhomboides* (pinfish), *Brevoortia tyrannus* (menhaden), *Micropogon undulatus* (croaker), and *Myrophis punctatus* (speckled worm eel). Warlen and Burke (1990) sampled the Newport River estuary in North Carolina using paired 60cm bongo nets. The most abundant species recorded were spot, croaker, menhaden, pinfish, and speckled worm eel. Peak recruitment appeared to coincide with the spring zooplankton bloom. Hettler (1989) sampled the marsh surface of a creek in North Carolina using modified 10 meter block nets set perpendicular to the creek channel. *Fundulus heteroclitus* (a killifish) dominated the catch in both average biomass and average numbers. Pinfish ranked second in biomass, while spot ranked second in number.

Figure 8

```
Count     Midpoint    One symbol equals approximately   .40 occurrences

    0       1.25 |
    0       1.75 |
    0       2.25 |
    0       2.75 |
    0       3.25 |
    0       3.75 |
    0       4.25 |
    1       4.75 |***
    0       5.25 |
    2       5.75 |*****
    6       6.25 |***************
    2       6.75 |*****
   11       7.25 |****************************
   12       7.75 |******************************
   10       8.25 |*************************
   11       8.75 |****************************
    7       9.25 |******************
    7       9.75 |******************
    5      10.25 |*************
    3      10.75 |********
    4      11.25 |**********
    2      11.75 |*****
    2      12.25 |*****
    0      12.75 |
    2      13.25 |*****
    0      13.75 |
    0      14.25 |
    0      14.75 |
    0      15.25 |
    0      15.75 |
    0      16.25 |
    0      16.75 |
    0      17.25 |
    0      17.75 |
    0      18.25 |
    0      18.75 |
    0      19.25 |
    0      19.75 |
                 +----+----+----+----+----+----+----+----+----+----+
                 0         4         8         12        16        20
                           Histogram frequency
```

Mean = 8.5368   Median = 8.4000

Std Err = 0.1809

Figure 8. Blue Crab Length-Frequency - Adjacent (Spring)
Length From Point to Point in Centimeters

Figure 9

```
Count   Midpoint    One symbol equals approximately   .10 occurrences

   0       1.25 |
   0       1.75 |
   0       2.25 |
   0       2.75 |
   0       3.25 |
   0       3.75 |
   0       4.25 |
   0       4.75 |
   0       5.25 |
   0       5.75 |
   0       6.25 |
   1       6.75 |**********
   1       7.25 |**********
   0       7.75 |
   3       8.25 |******************************
   3       8.75 |******************************
   1       9.25 |**********
   3       9.75 |******************************
   1      10.25 |**********
   2      10.75 |********************
   0      11.25 |
   0      11.75 |
   1      12.25 |**********
   0      12.75 |
   0      13.25 |
   0      13.75 |
   1      14.25 |**********
   0      14.75 |
   0      15.25 |
   0      15.75 |
   0      16.25 |
   0      16.75 |
   0      17.25 |
   0      17.75 |
   0      18.25 |
   1      18.75 |**********
   0      19.25 |
   0      19.75 |
                +----+----+----+----+----+----+----+----+----+----+
                0         1         2         3         4         5
                         Histogram frequency
```

```
Mean = 9.9778          Median = 9.5500
Std Err = 0.6456
```

Figure 9. Blue Crab Length-Frequency - Man-Made (Spring)
Length From Point to Point in Centimeters

Figure 10

```
Count    Midpoint    One symbol equals approximately   .40 occurrences

   0        1.25  |
   0        1.75  |
   0        2.25  |
   0        2.75  |
   0        3.25  |
   0        3.75  |
   1        4.25  |***
   2        4.75  |*****
   6        5.25  |***************
   9        5.75  |***********************
  13        6.25  |*********************************
  13        6.75  |*********************************
  16        7.25  |****************************************
   9        7.75  |***********************
  14        8.25  |***********************************
   5        8.75  |*************
   4        9.25  |**********
   0        9.75  |
   7       10.25  |******************
   3       10.75  |********
   2       11.25  |*****
   3       11.75  |********
   2       12.25  |*****
   0       12.75  |
   0       13.25  |
   0       13.75  |
   0       14.25  |
   0       14.75  |
   0       15.25  |
   0       15.75  |
   0       16.25  |
   0       16.75  |
   0       17.25  |
   0       17.75  |
   0       18.25  |
   0       18.75  |
   0       19.25  |
   0       19.75  |
                  +----+----+----+----+----+----+----+----+----+----+
                  0         4         8         12        16        20
                            Histogram frequency

                     Mean = 7.5193           Median = 7.1000
                     Std Err = 0.1729
```

Figure 10. Blue Crab Length-Frequency - Natural (Spring)
Length From Point to Point in Centimeters

Figure 11

```
Count   Midpoint   One symbol equals approximately  1.20 occurrences

   0      1.25  |
   2      1.75  |**
   2      2.25  |**
   4      2.75  |***
   5      3.25  |****
   7      3.75  |******
  17      4.25  |**************
  30      4.75  |*************************
  34      5.25  |****************************
  41      5.75  |**********************************
  55      6.25  |**********************************************
  23      6.75  |*******************
  29      7.25  |************************
  22      7.75  |******************
  18      8.25  |***************
  13      8.75  |***********
  16      9.25  |*************
   8      9.75  |*******
   6     10.25  |*****
   9     10.75  |********
   5     11.25  |****
   4     11.75  |***
   4     12.25  |***
   4     12.75  |***
   2     13.25  |**
   0     13.75  |
   0     14.25  |
   0     14.75  |
   0     15.25  |
   0     15.75  |
   0     16.25  |
   0     16.75  |
   0     17.25  |
   0     17.75  |
   0     18.25  |
   0     18.75  |
   0     19.25  |
   0     19.75  |
                +----+----+----+----+----+----+----+----+----+----+
                0         12        24        36        48        60
                          Histogram frequency


             Mean = 6.7169          Median = 6.2000
             Std Err = 0.1138
```

Figure 11. Blue Crab Length-Frequency - Adjacent (Summer)
Length From Point to Point in Centimeters

Figure 12

```
Count    Midpoint    One symbol equals approximately   .60 occurrences

    0        1.25 |
    1        1.75 |**
    5        2.25 |********
   14        2.75 |***********************
   19        3.25 |********************************
   27        3.75 |*********************************************
   17        4.25 |****************************
    9        4.75 |***************
    5        5.25 |********
    3        5.75 |*****
    1        6.25 |**
    3        6.75 |*****
    4        7.25 |*******
    2        7.75 |***
    7        8.25 |************
    2        8.75 |***
    6        9.25 |**********
    5        9.75 |********
    9       10.25 |***************
    8       10.75 |*************
    7       11.25 |************
    3       11.75 |*****
    2       12.25 |***
    3       12.75 |*****
    2       13.25 |***
    0       13.75 |
    1       14.25 |**
    0       14.75 |
    0       15.25 |
    0       15.75 |
    0       16.25 |
    0       16.75 |
    0       17.25 |
    0       17.75 |
    0       18.25 |
    0       18.75 |
    0       19.25 |
    0       19.75 |
                  +----+----+----+----+----+----+----+----+----+----+
                  0         6         12        18        24        30
                            Histogram frequency

                     Mean = 6.1000          Median = 4.4000
                     Std Err = 0.2558
```

Figure 12. Blue Crab Length-Frequency - Man-Made (Summer)
Length From Point to Point in Centimeters

Figure 13

```
Count   Midpoint    One symbol equals approximately   .80 occurrences

   0       1.25 |
   0       1.75 |
   0       2.25 |
   1       2.75 |*
   4       3.25 |*****
   5       3.75 |******
  16       4.25 |********************
  21       4.75 |**************************
  33       5.25 |*****************************************
  37       5.75 |**********************************************
  23       6.25 |*****************************
  17       6.75 |*********************
  19       7.25 |************************
  10       7.75 |*************
  11       8.25 |**************
   5       8.75 |******
   8       9.25 |**********
   7       9.75 |*********
  12      10.25 |***************
  12      10.75 |***************
   7      11.25 |*********
   4      11.75 |*****
   2      12.25 |***
   0      12.75 |
   1      13.25 |*
   0      13.75 |
   1      14.25 |*
   0      14.75 |
   0      15.25 |
   0      15.75 |
   3      16.25 |****
   0      16.75 |
   0      17.25 |
   0      17.75 |
   0      18.25 |
   0      18.75 |
   0      19.25 |
   0      19.75 |
                +----+----+----+----+----+----+----+----+----+----+
                0         8        16        24        32        40
                          Histogram frequency


                Mean = 6.9471            Median = 6.2000
                Std Err = 0.1528
```

Figure 13. Blue Crab Length-Frequency - Natural (Summer)
Length From Point to Point in Centimeters

Figure 14

```
Count   Midpoint    One symbol equals approximately   .60 occurrences

   0       1.25 |
   0       1.75 |
   0       2.25 |
   0       2.75 |
   0       3.25 |
   0       3.75 |
   1       4.25 |**
   3       4.75 |*****
   6       5.25 |**********
  11       5.75 |******************
  19       6.25 |********************************
  16       6.75 |***************************
  28       7.25 |***********************************************
  21       7.75 |***********************************
  27       8.25 |*********************************************
  19       8.75 |********************************
  12       9.25 |********************
  10       9.75 |*****************
  13      10.25 |**********************
   8      10.75 |*************
   6      11.25 |**********
   5      11.75 |********
   5      12.25 |********
   0      12.75 |
   2      13.25 |***
   0      13.75 |
   1      14.25 |**
   0      14.75 |
   0      15.25 |
   0      15.75 |
   0      16.25 |
   0      16.75 |
   0      17.25 |
   0      17.75 |
   0      18.25 |
   1      18.75 |**
   0      19.25 |
   0      19.75 |
                +----+----+----+----+----+----+----+----+----+----+
                0         6         12        18        24        30
                          Histogram frequency

                  Mean = 8.1397          Median = 8.0000
                  Std Err = 0.1358
```

Figure 14. Blue Crab Length-Frequency - Total All Marshes (Spring)
Length From Point to Point in Centimeters

Figure 15

```
Count   Midpoint    One symbol equals approximately  2.00 occurrences
   0       1.25  |
   3       1.75  |**
   7       2.25  |****
  19       2.75  |**********
  28       3.25  |**************
  39       3.75  |********************
  50       4.25  |*************************
  60       4.75  |******************************
  72       5.25  |************************************
  81       5.75  |*****************************************
  79       6.25  |****************************************
  43       6.75  |**********************
  52       7.25  |**************************
  34       7.75  |*****************
  36       8.25  |******************
  20       8.75  |**********
  30       9.25  |***************
  20       9.75  |**********
  27      10.25  |**************
  29      10.75  |***************
  19      11.25  |**********
  11      11.75  |******
   8      12.25  |****
   7      12.75  |****
   5      13.25  |***
   0      13.75  |
   2      14.25  |*
   0      14.75  |
   0      15.25  |
   0      15.75  |
   3      16.25  |**
   0      16.75  |
   0      17.25  |
   0      17.75  |
   0      18.25  |
   0      18.75  |
   0      19.25  |
   0      19.75  |
                 +----+----+----+----+----+----+----+----+----+----+
                 0        20        40        60        80       100
                           Histogram frequency

                   Mean = 6.6631          Median = 6.1000
                   Std Err = 0.0909
```

Figure 15. Blue Crab Length-Frequency - Total All Marshes (Summer)
Length From Point to Point in Centimeters

Killifish have been identified as important to energy transformations in marshes. Killifish feed on small crustaceans, insects, annelids, algae, detritus, and fecal pellets on the marsh surface and at low tide return to the deeper waters of the creek channel where they are preyed upon by larger fish as the tide rises (Kneib and Stiven, 1978; Kneib, 1986; Hettler, 1989).

Table 7. Fish species list and total numbers per marsh per season.

Species	**Spring**			**Summer**		
	ADJ	**MM**	**NAT**	**ADJ**	**MM**	**NAT**
Killifish (*Fundulus sp.* and *Gambusia sp.*)	26548	3533	12593	14006	4573	581
Spot (*Leiostomus xanthurus*)	1439	465	1493	291	590	71
Menhaden (*Brevoortia tyrannus*)	393	483	0	0	0	0
Croaker (*Micropogon undulatus*)	100	9	7	4	3	1
Anchovy (*Anchoa mitchilli*)	206	23	2	0	0	0
Striped Mullet (*Mugil cephalus*)	28	126	0	1	1	0
Atlantic Silverside (*Menidia menidia*)	20	42	36	0	0	0
Threadfin Shad (*Dorosoma petenense*)	2	46	2	0	0	0
Gizzard Shad (*Dorosoma cepedianum*)	1	0	0	0	0	0
Red Drum (*Sciaenops ocellatus*)	3	3	4	0	1	0
Striped Bass (*Morone saxatilis*)	0	0	4	0	0	0
Ladyfish (*Elops saurus*)	0	0	0	0	2	0
White Perch (*Morone americana*)	0	1	0	0	0	0
Speckled Trout (*Cynoscion regalis*)	0	0	0	0	1	4
TOTALS	28740	4731	14141	14302	5171	657

In our study the killifish, *Fundulus* spp. and *Gambusia* spp., and spot were the dominant fish in each of the sampled marshes (Table 7). Menhaden, bay anchovy (*Anchoa mitchilli*), croaker, and striped mullet (*Mugil cephalus*) dominated the rest of the catch. Red drum (*Sciaenops ocellatus*) were caught in all three marshes during the May sampling period and four striped bass (*Morone saxatilis*) were recorded in the NAT marsh in May. Some of these striped bass were recaptured fish which were tagged by VIMS in the Mattaponi River as part of another study. These data were provided for use by that study.

Figures 16 and 17 present total fish data by marsh. For statistical testing, the data were normalized for volume. Thus, we tested for differences between numbers of fish per cubic meter in each marsh.

Figure 16

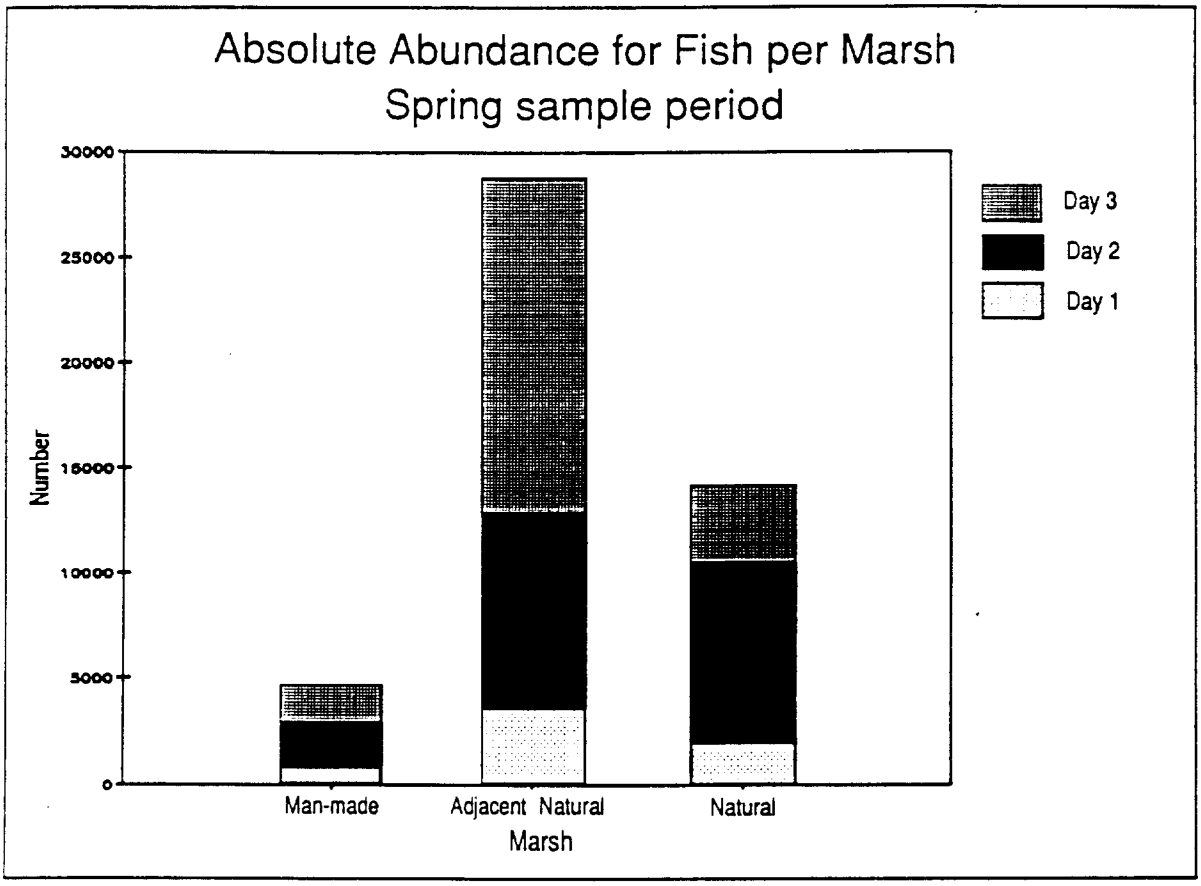
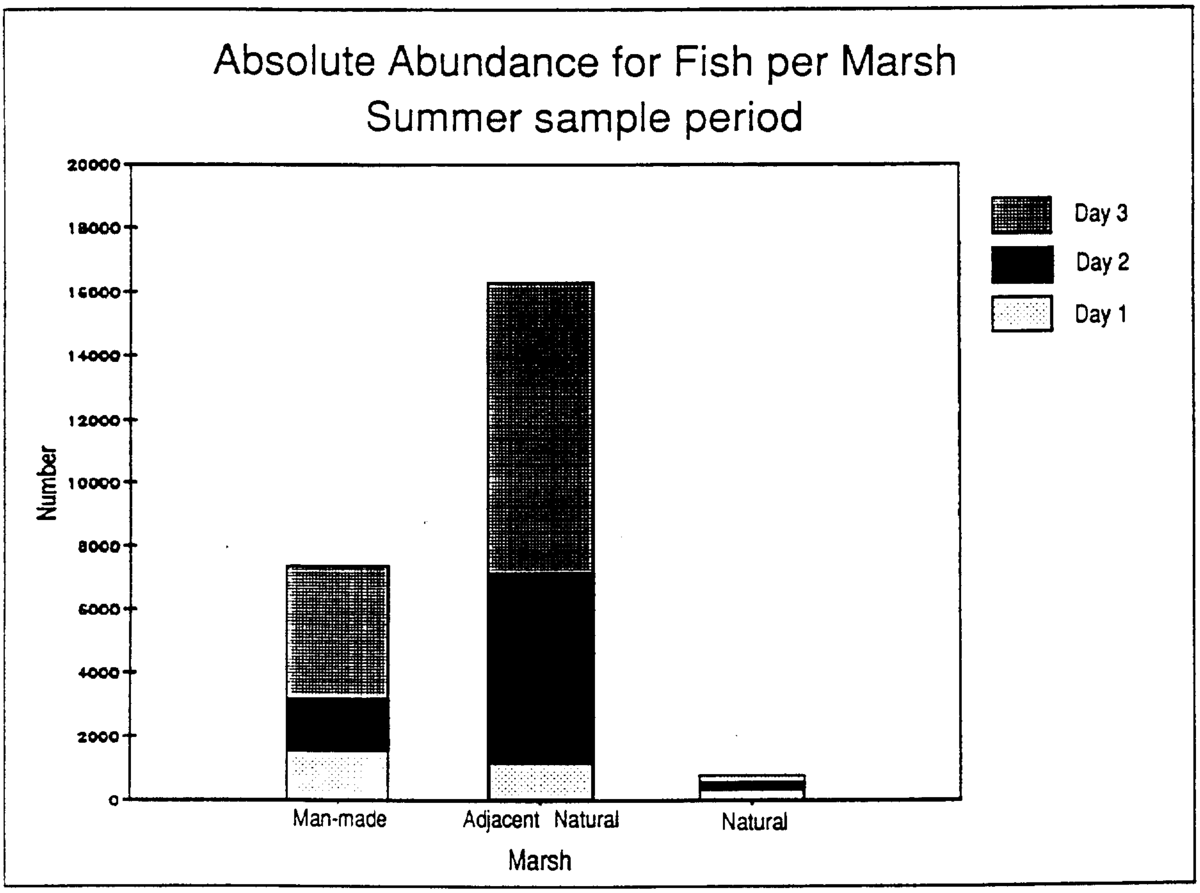


Figure 17



Significant differences were found only during the July sampling period. During the summer sampling period ADJ had a significantly greater amount of total fish than either MM or NAT. MM and NAT were statistically equal for the summer sampling period.

Table 8. Fish species richness and diversity for each season and marsh.

	Diversity		Richness		
Marsh	May	July	May	July	Total
ADJ	0.35	0.10	2.02	0.72	1.94
MM	0.90	0.37	2.45	1.62	2.75
NAT	0.37	0.39	1.69	1.06	1.92

Species richness was greatest in MM (Table 8). ADJ and NAT had similar total species richness levels, but seasonal differences were observed. MM also had the greatest diversity of the three marshes in May, and approximately equal to NAT in July. Diversity and richness were greater in MM probably due to the differences in salinity from ADJ and NAT.

Foodfish species were statistically equal for all three marshes in both seasons; however, during the spring sampling period, both ADJ and NAT averaged 0.44 foodfish/m^3 whereas MM's average was ten times lower (0.04 foodfish/m^3).

Spot dominated foodfish populations in each marsh during the study. Spot were further analyzed for population distribution and length-weight relationships. Length-frequencies are presented in Figures 18-23. All sampled populations were normally distributed with the exception of NAT for the summer sampling period. Slightly larger spot visited ADJ and MM in May as compared to NAT. Conversely, ADJ contained smaller spot than either MM or NAT in July.

Figure 18

```
Count    Midpoint    One symbol equals approximately 10.00 occurrences

   9       35.00 |*
 108       45.00 |***********
 449       55.00 |*********************************************
 425       65.00 |*******************************************
 346       75.00 |***********************************
  84       85.00 |********
   1       95.00 |
   0      105.00 |
   1      115.00 |
   6      125.00 |*
   9      135.00 |*
   1      145.00 |
                 +----+----+----+----+----+----+----+----+----+----+
                 0        100       200       300       400       500
                           Histogram frequency


                   Mean = 63.9771            Median = 64.0000
                   Std Err = 0.3289
```

Figure 18. Spot Length-Frequency - Adjacent (Spring)

Figure 19

```
Count    Midpoint    One symbol equals approximately  4.00 occurrences

   0       35.00 |
  50       45.00 |*************
 165       55.00 |*****************************************
 155       65.00 |***************************************
  80       75.00 |********************
   9       85.00 |**
   0       95.00 |
   0      105.00 |
   0      115.00 |
   1      125.00 |
   3      135.00 |*
   1      145.00 |
                 +----+----+----+----+----+----+----+----+----+----+
                 0         40        80       120       160       200
                           Histogram frequency


                   Mean = 62.0516            Median = 60.0000
                   Std Err = 0.5837
```

Figure 19. Spot Length-Frequency - Man-Made (Spring)

Figure 20

```
Count    Midpoint    One symbol equals approximately 12.00 occurrences

    3       35.00  |
  327       45.00  |***************************
  573       55.00  |************************************************
  304       65.00  |*************************
  219       75.00  |******************
   47       85.00  |****
    0       95.00  |
    0      105.00  |
    2      115.00  |
    5      125.00  |
   10      135.00  |*
    3      145.00  |
                   +----+----+----+----+----+----+----+----+----+----+
                   0        120       240       360       480       600
                             Histogram frequency

                     Mean = 59.3423           Median = 56.0000
                     Std Err = 0.3436
```

Figure 20. Spot Length-Frequency - Natural (Spring)

Figure 21

```
Count    Midpoint    One symbol equals approximately  4.00 occurrences

    0       35.00  |
    0       45.00  |
    4       55.00  |*
   14       65.00  |****
   29       75.00  |*******
   68       85.00  |*****************
  108       95.00  |***************************
   48      105.00  |************
   14      115.00  |****
    4      125.00  |*
    1      135.00  |
    1      145.00  |
                   +----+----+----+----+----+----+----+----+----+----+
                   0        40        80        120       160       200
                             Histogram frequency

                     Mean = 91.4502           Median = 93.0000
                     Std Err = 0.7660
```

Figure 21. Spot Length-Frequency - Adjacent (Summer)

Figure 22

```
Count    Midpoint    One symbol equals approximately  8.00 occurrences

    0       35.00  |
    0       45.00  |
    1       55.00  |
   16       65.00  |**
   33       75.00  |****
   76       85.00  |**********
  230       95.00  |*****************************
  184      105.00  |***********************
   30      115.00  |****
    8      125.00  |*
    3      135.00  |
    3      145.00  |
                   +----+----+----+----+----+----+----+----+----+----+
                   0         80        160       240       320       400
                                  Histogram frequency


                     Mean = 96.9814            Median = 97.0000
                     Std Err = 0.5571
```

Figure 22. Spot Length-Frequency - Man-Made (Summer)

Figure 23

```
Count    Midpoint    One symbol equals approximately   .60 occurrences

    0       35.00  |
    0       45.00  |
    0       55.00  |
    0       65.00  |
    4       75.00  |*******
   17       85.00  |****************************
   17       95.00  |****************************
   26      105.00  |*******************************************
    5      115.00  |********
    2      125.00  |***
    0      135.00  |
    0      145.00  |
                   +----+----+----+----+----+----+----+----+----+----+
                   0         6         12        18        24        30
                                  Histogram frequency

                     Mean = 96.4225            Median = 97.0000
                     Std Err = 1.3374
```

Figure 23. Spot Length-Frequency - Natural (Summer)

Spot length-weight regressions are presented in Table 9. All regression equation's slopes were found to be significant. From 38 to 78 percent of the variation in the data can be explained from these regressions, depending upon data grouping (Table below, R^2). The data did not lend itself for comparison of regression lines because slopes are significantly different.

Table 9. Length-weight regressions for Spot.

Sample Period	Marsh	R^2	Intercept	Slope
Combined	All	0.65150	-14.45	0.28575
Spring	All	0.40945	-11.54	0.23904
	ADJ	0.75370 .97	-10.75	0.22177
	MM	0.37777 .97	-14.20	0.28530
	NAT	0.74195 .97	-11.98	0.24951
Summer	All	0.71435	-31.74	0.46582
	ADJ	0.78375 .98	-21.40	0.35173
	MM	0.63250 .98	-29.97	0.44727
	NAT	0.65241 .97	-20.16	0.33833

The man-made marsh's function as a habitat for fish seems inconsistent. In a majority of instances during the study, MM's total fish and foodfish populations were below those of the natural wetland's. During no separate sampling day of our study did MM contain the greatest number of fish per cubic meter, and only half of the sampling days did MM contain the second greatest number of fish per cubic meter. Our data shows MM functioning well as a habitat for fish, but not as well as natural wetlands in all circumstances. Because of the differences in salinity between MM and the natural marshes, this trend may continue indefinitely.

AVIAN UTILIZATION

During the 56 sampling times (3 marshes x 2 tide stages x 3 seasons x 3 replicates), 169 observations were made of 15 bird species. Species observed are shown on Table 10. None of the species observed was unique to the MM (i.e., seen in the MM and not in the ADJ or NAT). However, 7 of the 15 species seen during the study were seen only in one or both of the natural marshes and not in the MM. Of the 169 observations of birds made, 25 were in the MM, 70 in the ADJ, and 74 in the NAT. Species richness was greatest in the ADJ (d=5.96), followed by MM (d=5.00), and the NAT (d=4.28). Similarly, diversity was greatest in the ADJ (H=2.00), followed by the MM (H=1.83), and the NAT (H=1.52). A oneway analysis of variance (i.e., without regard to season, tide stage, or bird species) showed no significant difference between the three marshes in terms of number of bird observations made.

Table 10. Bird species observed in the study marshes.

Species	MM	ADJ	NAT
great blue heron	x	x	
great egret	x		x
green-backed heron	x	x	x
yellow-crowned night heron		x	
spotted sandpiper	x	x	
laughing gull		x	
kingfisher	x	x	
marsh wren		x	
white-eyed vireo			x
yellow warbler			x
myrtle warbler		x	x
common yellowthroat		x	x
swamp sparrow	x	x	x
red-winged blackbird	x	x	x
common grackle	x	x	x

Wading birds appeared to show a preference for the MM (12 observations, versus 7 and 3 for the ADJ and NAT). Most of these observations were at low tide, so a preference for the MM may be explained by the lack of water (and therefore lack of prey) in the ADJ and NM during low tide. Also, the length of marsh/water interface was greater in the MM than in the two natural marshes, providing more of an important foraging habitat component.

Four species of migrant songbirds (white-eyed vireo, yellow warbler, myrtle warbler, and common yellowthroat) were seen only in the two natural marshes during spring. They were using the saltbush habitat in the natural marshes. Since the MM had no mature saltbush habitat, these species would not have been expected in that marsh.

A summer resident, the common grackle, also seemed to prefer the saltbush habitat, and used the natural marshes more heavily (MM=3 observations, ADJ=14 observations, NAT=27 observations).

Winter use of all marshes was sparing (5 of 169 observations) and included 3 species: a kingfisher was resident during the entire study; myrtle warblers and swamp sparrows apparently used the marshes for wintering and migration habitat.

Spring use of the MM (7 observations) was less than either of the natural marshes (42 and 44 observations). Most of the additional observations in the natural marshes were migrant songbirds which, as previously discussed, were found only in the mature saltbush habitat.

Use of the MM was greater at low tide than at high tide (16 and 9 observations, respectively). However, for the natural marshes, use was greater at high tide than at low tide (46 and 24 observations in the ADJ; 54 and 16 observations in the NAT). Again, a large number of these high tide ADJ and NAT observations were of migrant songbirds and grackles, which preferred the mature saltbush habitat which did not exist in the MM.

Nests of 2 species were found: red-winged blackbird and marsh wren. The finding of marsh wren nests was somewhat surprising, since only one observation of a marsh wren was made, and that was during the spring survey. There were 24 wren nests in the ADJ, 1 in the MM, and 7 in the NAT. The lone nest in the MM was found at the back end of the marsh near the freshwater input from behind the shopping center in a patch of tall *Spartina alterniflora*. The nests in the natural marshes were found in *S. alterniflora* of at least 1 meter in height. All nests were found fairly close to the marsh creeks; if a line were drawn perpendicular to the marsh creek through each nest to the upland, the nest was always on the creek side of the midpoint of that line. In all marshes, the wren nests were found where the *S. alterniflora* was in a fairly wide fringe. Since *S. alterniflora* in the MM constituted a fairly narrow fringe (approximately 2-3 meters in width), it was not surprising to find so few nests in the MM.

Migrating male marsh wrens generally arrive at the marsh prior to the females, build several nests or nest shells in the marsh and then sing and display to attract a female mate. The female then either finishes building one of the male's nests or builds its own prior to egg laying. If marsh wrens actually bred in the study marshes, we would have expected to hear them during the summer surveys. Since we heard only one during the spring survey, we suspect that they may not have bred, and that the nests were built by males who were then unsuccessful at attracting females.

Red-winged blackbirds built 4 nests in the ADJ, 1 in the NAT, and none in the MM. Two of the nests in the ADJ were known to have failed; at least one of the other two was successful. All red-winged blackbird nests were found in saltbush. Again, since no mature saltbush community occurred in the MM, it is not surprising that nests are absent from that marsh. Nearly all observations of red-winged blackbirds were of foraging by the pair or just the male from the ADJ.

A recent breeding season study of the relationship between marsh size and bird usage showed that very few species used marshes as small as 0.25 acres in size. The number of species increased as marsh size increased, with a large increase in species between the 2.5 acre and 12 acre study marshes (Bryan Watts, pers. comm.). Since the marshes in the current study were all smaller than 2 acres, it is not surprising to have found little breeding season use of these marshes.

The study marshes are probably too small or too distant from the main waterways (i.e., at the upper end of the tidal creek) to attract or support a large number of birds. However, if a small marsh is created, it would be more productive in terms of bird usage if a mature saltbush community is included. This could be accomplished either at the time of marsh creation by planting mature specimens or, if the created marsh is mitigation for impacts to an existing marsh, the impact to the existing marsh could be allowed only after a saltbush community in the created marsh matures. A mature saltbush community would allow greater use of the marsh by migrating songbirds, by nesting red-winged blackbirds, and by other species which require the cover, foraging, and nesting habitat that the saltbush provides.

If a created marsh of this type is to provide habitat for marsh wrens, a greater proportion of the marsh should be dedicated to larger homogeneous patches of appropriate nesting vegetation, such as *Spartina alterniflora*.

The greater length of marsh/water interface and existence of water in the marsh creek during low tide in the MM may have been responsible for greater use of that marsh by wading birds. However, greater length of marsh/water interface also means that the area of any contiguous marsh patch is smaller than it would be for a marsh of the same area and shape with less marsh/water interface. As mentioned previously, this may have implications for use of the marsh by other species such as marsh wrens.

CONCLUSIONS AND RECOMMENDATIONS

Certain attributes of the man-made marsh resembled the natural marshes, such as temperature, dissolved oxygen, bird visitation, benthic macrofauna and fish diversity. However, data from this study revealed some important differences between the man-made marsh and the natural marshes. The natural marshes were observed to function more effectively in a majority of the categories which are basic and primary structural components of the physical environment unique to tidal salt marshes. These include organic carbon content, salinity and vegetation. Other categories for which differences were observed included zooplankton abundance, marsh surface utilization, bird nesting sites, and use of the marshes by total fish, food fish and blue crabs. Some of these observed differences were seasonal.

Many factors need to be evaluated when the construction of a marsh is contemplated. What is the resource that is being lost? What functions and subsequent values are to be replaced? Should just those functions that are to be lost be replaced or should as many functions as possible be incorporated into the replacement design? Many questions remain concerning the ability of man-made marshes to mimic the functions and values of natural marshes. There will always be an inherent delay in functional effectiveness even if the created wetland can obtain functional equivalency with natural marshes. Accordingly, creating wetlands to replace natural wetlands should only be used as a last resort.

Since in many cases the exact functions and values of the impacted wetland are not known, it is prudent to attempt to accommodate as many functions as possible in the design of the compensatory wetland. Data from this study suggest the following should be included in the created wetland.

1. The substrate from the existing wetland should be excavated and used as the soil in the created wetland. The lack of peat substrate significantly extends the time required for a man-made wetland to reach a substrate composition equivalent to a natural wetland. This could be addressed by supplying the man-made wetland with a highly organic substrate in the construction phase. The substrate would preferable be obtained from the wetland to be impacted. This would supply the newly created wetland with a peat soil complete with high organic carbon, an inherent seed bank, and a flourishing micro-organism population.

2. Herbaceous vegetation should be initially established with higher stem densities and wide (at least 40 feet) fringes. Utilization of the lower elevation wetland vegetation by juvenile fish and resident killifish is enhanced by higher stem densities. In addition, some bird species (i.e. marsh wren) appear to prefer higher stem density and wider vegetated fringes for nesting sites. Stem densities and cover estimates for man-made marshes are usually significantly lower than natural wetlands. Sprigging on centers of one foot or less should be considered.

3. Mature shrub growth should be established. Mature scrub/shrub growth facilitates usage by birds especially as nesting and perching sites.

4. A mix of different habitat types should be incorporated in the design. This should include channel habitat, intertidal nonvegetated habitat, different wetland vegetated communities, and upland buffer areas for birds and terrestrial macrofauna which utilize salt marshes.

5. Marsh microtopography such as rivulets should be constructed. These areas facilitate use of the vegetated wetland surface by juvenile fish and shellfish and provide refuge for juvenile fish during low tides.

6. Direct routing of drainage ditches to the head of created wetlands should be evaluated carefully. Data from this study suggest that high freshwater flows may inhibit zooplankton movement into wetland systems, possibly by significantly reducing salinity and establishing a constant surface outflow.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. Expand upon the intensive sampling procedure used in this study and develop a formal method for comparison of mitigated areas with natural areas.

2. Investigate the importance of upland forested buffer areas adjacent to natural wetlands. Such areas may be important as an alternative, or primary, habitat for important macrofauna which utilize wetlands. In addition, forested buffer areas may function as a water quality filter for upland runoff entering wetlands.

3. Investigate the importance of these and other wetlands as settlement and nursery areas for blue crabs. If tidal marsh creeks are used during this life stage of the blue crab, then enhancement of a created wetlands ability to perform this function should be considered.

4. Investigate total dissolved organic matter versus utilizable dissolved organic matter in man-made and natural wetland systems. Many studies, including this one, have investigated total organic carbon or total organic matter as one criteria for successful establishment of a created wetland. Recent work by Munster and Chrost (1990) suggests that released dissolved organic matter or utilizable organic matter may be a more appropriate measure of the translocation of organic matter through the trophic levels. Much of the total organic matter frequently measured may be refractory and not easily accessible to most organisms.

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Literature Cited

Able, K.W. 1984. Variation in spawning site selection of the mummichog, *Fundulus heteroclitus*. Copeia 1984(2): 522-525.

Armentano, T.V. 1980. Drainage of organic soils as a factor in the world carbon cycle. Bioscience 30: 825-830.

Barnard, T.A., Jr. and P.A. Mason. 1990. A Survey of Compensatory Mitigation within the tidal wetlands of Virginia- submitted to the Virginia Council on the Environment. Virginia Institute of Marine Science. College of William and Mary. 40 pp.

Boesch, D.F. 1973. Classification and Community Structure of Macrobenthos in the Hampton Roads area, Virginia. Marine Biology 21: 226-244.

Bozeman, E.L., Jr. and J.M. Dean. 1980. The abundance of estuarine larval and juvenile fish in a South Carolina intertidal creek. Estuaries 3: 89-97.

Broome, S.W., E.D. Seneca, and W.W. Woodhouse, Jr. 1986. Long-term growth and development of transplants of the salt marsh grass *Spartina alterniflora*. Estuaries 9: 62-73.

Cammen, L.M., E.D. Seneca, and B.J. Copeland. 1974. Animal colonization of salt marshes artificially established on dredge spoil. University of North Carolina Sea Grant Program Publ. UNC-SG-74-15, Chapel Hill, North Carolina 67 p.

Clark, J., W.G. Smith, A.W. Kendall, Jr., and M.P. Fahay. 1969. Studies of estuarine dependence of Atlantic coastal fishes. U.S. Bureau of Sport Fish. Wildl. Tech. Pap. 28, 132pp.

Craft, C.B., S.W. Broome and E.D. Seneca. 1988. Soil Nitrogen, Phosphorus and organic carbon in transplanted estuarine marshes. In D.D. Hook (ed) The Ecology and Management of Wetlands. Timber Press.

Currin, B.J. and J. Miller. 1984. Growth, production, food consumption and mortality of juvenile spot and croaker: a comparison of tidal and nontidal nursery areas. Estuaries 7(4A): 451-459.

Dahl, T.E. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 21pp.

Dahl, T.E. and C.E. Johnson. 1991. Status and trends of wetlands in the coterminous United States, Mid-1970's to Mid-1980's. U.S. Department of the Interior, Fish and Wildlife Service. Washington, D.C. 28pp.

Diaz, R. and P. Gapcynski. 1990. Benthic Sampling report, Fall 1989, COMNAVBASE Wetlands Project. Virginia Institute of Marine Science. College of William and Mary. 100pp.

Fraser, D.F. and R.D. Cerri. 1982. Experimental evaluation of predator-prey relationships in a patchy environment: Consequences for habitat use patterns in minnows. Ecology 63: 307-313.

Friedman, R.M. and C.B. DeWitt. 1978. Wetlands as carbon and Nutrient reservoirs: A spatial, historical, and societal perspective. In P.E. Greeson, Jr., J. Clark and J.E. Clark (eds), Wetland Functions and Values: The State of our Understanding. American Water Resources Association, Minneapolis, MN, pp. 175-185.

Hefner, J.M. and J.D. Brown. 1985. Wetland trends in the southeastern United States. Wetlands 4: 1-11.

Hettler, W.F., Jr. 1989. Nekton use of regularly-flooded saltmarsh cordgrass habitat in North Carolina, USA. Marine Ecology Progress Series 56: 111-118.

Holbrook, S.J. and R.J. Schmitt. 1984. Experimental analysis of patch selection by foraging black surfperch (*Embiotoca jacksoni* Agazzi). Journal of Experimental Marine Biology and Ecology 79: 39-64.

Kneib, R.T. 1986. The role of *Fundulus heteroclitus* in salt marsh trophic dynamics. Amer. Zool. 26: 259-269.

Kneib, R.T. and A.E. Stiven. 1978. Growth, reproduction, and feeding of *Fundulus heteroclitus* (L.) on a North Carolina salt marsh. J. Exp. Mar. Biol. Ecol. 31: 121-140.

Kusler, J.A. and M.E. Kentula. 1990. Wetland Creation and Restoration: The Status of the Science. Island Press, Washington D.C. 594 p.

LaSalle, M.W., M.C. Landin, and J.G. Sims. 1991. Evaluation of the flora and fauna of a *Spartina alterniflora* marsh established on dredged material in Winyah Bay, South Carolina. Wetlands vol. 11(2): 101-208.

McIvor, C.C. and W.E. Odum. 1988. Food, predation risk, and microhabitat selection in a marsh fish assemblage. Ecology 69(5) 1341-1351.

Minello, T.J. and R.J. Zimmerman. 1983. Fish predation on juvenile brown shrimp, *Penaeus aztecus*(Ives): The effect of simulated *Spartina* structure on predation rates. Journal of Experimental Marine Biology and Ecology. 72: 211-231.

Mitchell, G.J. 1990. Foreword In: Wetland Creation and Restoration: The Status of the Science. J.A. Kusler and M.E. Kentula (eds). Island Press, Washington D.C.

Moy, L.D. and L.A. Levin. 1991. Are *Spartina* marshes a replaceable resource? A functional approach to evaluation of marsh creation efforts. Estuaries vol. 14(1): 1-16.

Munster, U. and R.J. Chrost. 1990. Origin, composition, and microbial utilization of dissolved organic matter. In: Aquatic Microbial Ecology J. Overbeck and R.J. Chrost (eds) Springer-Verlag, New York pp. 8-46.

Oviatt, C.A., S.W. Nixon, and J. Garber. 1977. Variation and evaluation of coastal marshes. Environmental Management 1(3): 201-211.

Priest, W.I., III. 1989. Wetlands mitigation evaluation vegetation studies: Monkey Bottom disposal area final report. Virginia Institute of Marine Science, College of William and Mary. Gloucester Pt., VA. 20pp.

Priest, W.I., III, K.J. Havens, T.A. Barnard, Jr., J.G. Bradshaw, and M. Wohlgemuth. 1990. Cumulative Impacts of Shoreline Construction Activity on Tidal Wetlands in Virginia. College of William and Mary. Virginia Institute of Marine Science, Technical Report 90-3. Gloucester Pt., VA. 8pp.

Rozas, L.P., C.C. McIvor, and W.E. Odum. 1988. Intertidal rivulets and creek banks: corridors between tidal creeks and marshes. Marine Ecology Progress Series 47: 303-307.

Ryer, C.H. 1987. Temporal patterns of feeding by blue crabs (*Callinectes sapidus*) in a tidal-marsh creek and adjacent seagrass meadow in the lower Chesapeake Bay. Estuaries 10(2): 136-140.

Ryer, C.H., J. van Montfrans and R.J. Orth. 1990. Utilization of a seagrass meadow and tidal marsh creek by blue crabs *Callinectes sapidus*. II. Spatial and temporal patterns of molting. Bull. Mar. Sci. 46(1): 95-104.

Schlesinger, W.H. 1977. Carbon balance in terrestrial detritus. Am. Rev. Ecol. Syst. 8: 51-81.

Schmitt, R.J. and S.J. Holbrook. 1985. Patch selection by juvenile black surfperch (Embiotocidae) under variable risk: interactive influence of food quality and structural complexity. Journal of Experimental Biology and Ecology 85: 269-285.

Seneca, E.D., S.W. Broome, W.W. Woodhouse, L.M. Cammen, and J.T. Lyon. 1976. Establishing *Spartina alterniflora* marsh in North Carolina. Environmental Conservation 3: 185-188.

Silberhorn, G.M. 1986. Shoreline permit application reports. 86-1583-4. Virginia Institute of Marine Science. College of William and Mary.

Smith, S.M., J.G. Hoff, S.P. O'Neil, and M.P. Weinstein. 1984. Community and trophic organization of nekton utilizing shallow marsh habitats, York River, Virginia. Fishery Bulletin 82(3): 455-467.

Tiner, R.W., Jr. 1984. Wetlands of the United States: current status and recent trends. U.S. Department of the Interior, Fish and Wildlife Service. Washington, D.C. 59pp.

Warlen, S.M. and J.S. Burke. 1990. Immigration of larvae of fall/winter spawning marine fishes into a North Carolina estuary. Estuaries 13(4): 453-461.

Webb, J.W. and C.J. Newling. 1985. Comparison of Natural and man-made salt marshes in Galveston Bay Complex, Texas. Wetlands vol. 4: 75-86.

Weinstein, M.P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fishery Bulletin 77(2): 339-357.

Werner, E.E. and D.J. Hall. 1976. Niche shifts in sunfishes: experimental evidence and significance. Science 191: 404-406.

Werner, E.E., J.F. Gilliam, D.J. Hall, and G.G. Mittelbach. 1983a. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64: 1540-1548.