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An Assessment of Aquatic Wildlife Utilization Between Created and Natural Tidal Salt Marshes

Kirk J. Havens
Virginia Institute of Marine Science

Lyle M. Varnell
Virginia Institute of Marine Science

Virginia Institute of Marine Science, Wetlands Program

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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 the fact that the loss of wetlands is continuing at a rate of approximately 290,000-450,000 acres per year (Dahl, 1990; Kusler and Kentula, 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 are estimated at 20 acres annually (Priest et al. 1990).

Compensation 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 anthropogenic marsh to achieve the same level of functional value 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. Comparisons of the 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 produced estimates 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 anthropogenic 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.

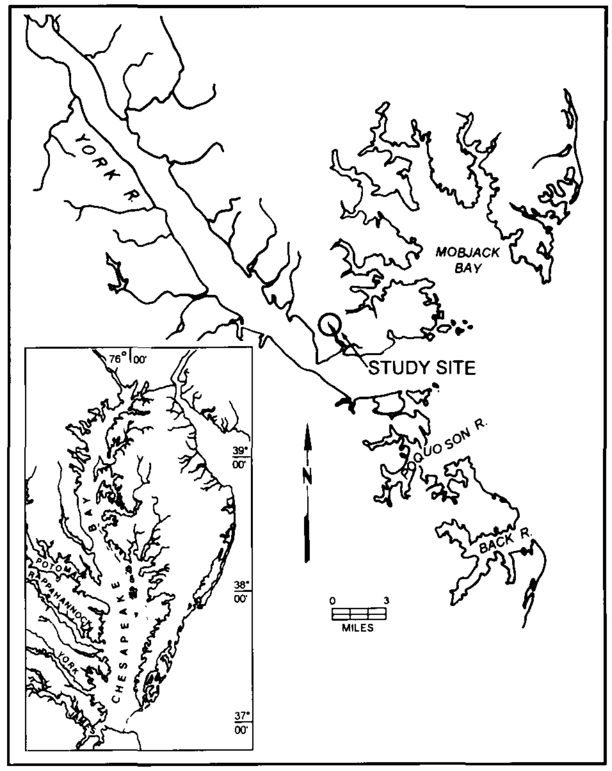

Figure 1. Study site. Sarah's Creek, Gloucester County, Virginia.

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 2.2 feet.

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.

College of William and Mary
Virginia Institute of Marine Science
School of Marine Science
Wetlands Program
Gloucester Point, VA 23062

Dr. Carl Hershner, Program Director
Editors: Thomas A. Barnard, Jr.
Kirk J. Havens
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Commonwealth's Declared Policy:
"to preserve the wetlands and to
prevent their despoliation and destruction . . ."

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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 500 feet 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 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 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 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.

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 meter cells. Each square meter grid cell

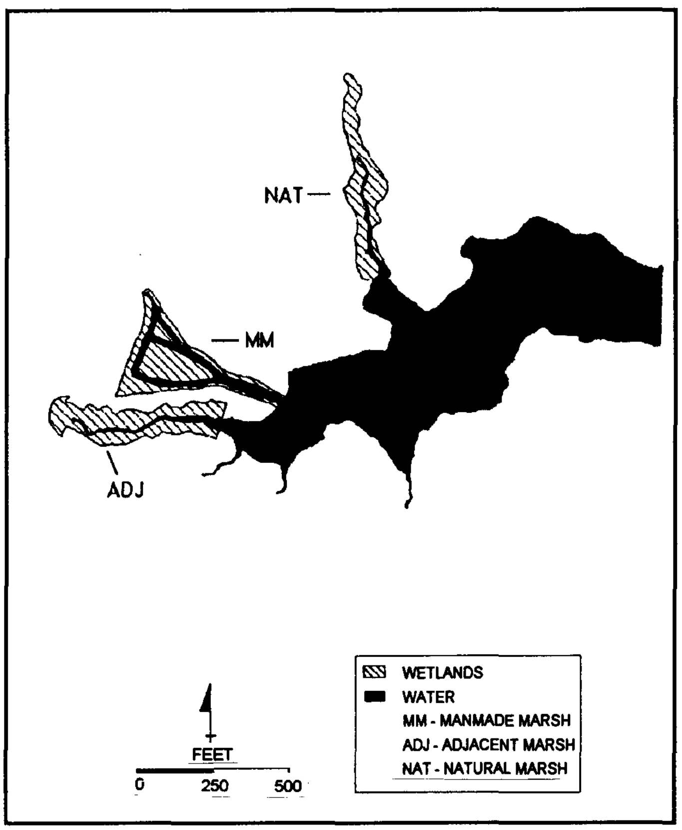

Figure 2. Study site. Sarah's Creek.

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.) (Figure 3) across the entrance of each marsh. The nets were set at slack high tide and emptied periodically until slack 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.

Three trap nets (10.76 feet square) were randomly placed in each wetland at each high tide throughout the sampling period to investigate fish and shellfish utilization in different habitat types and to sample for gastropods and *Uca* species.

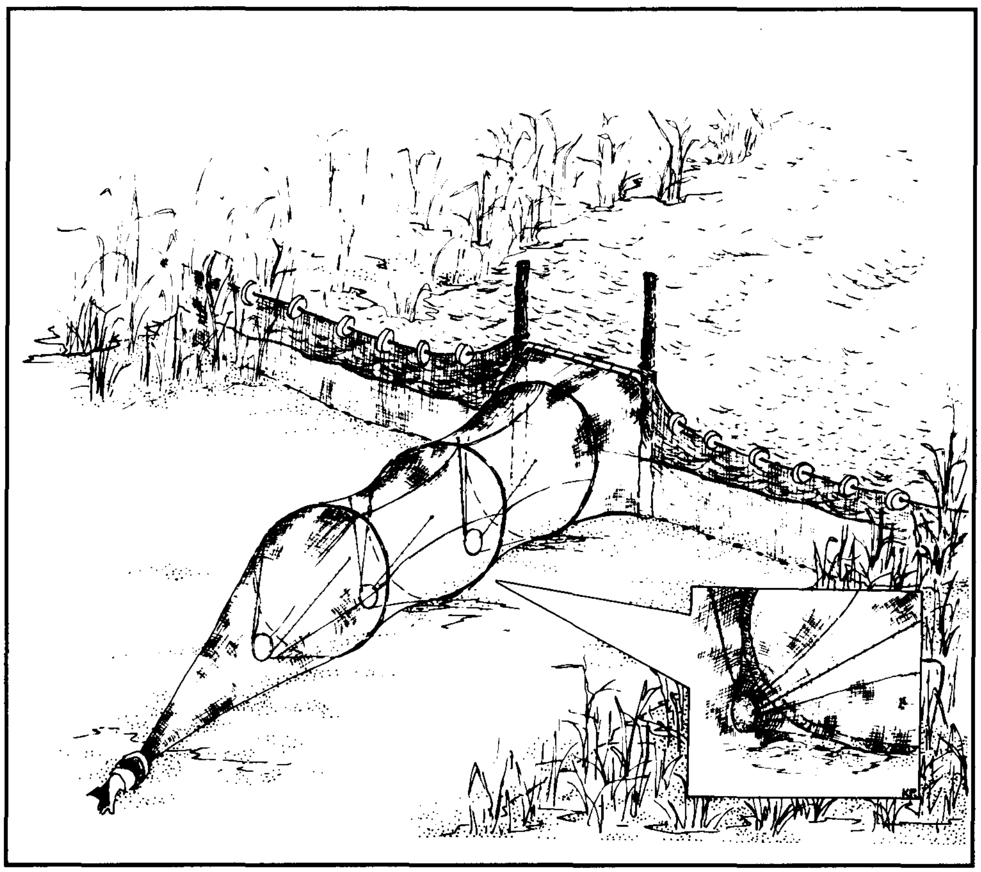

Figure 3. Priest Modified Hoop Net. Downstream water deleted to show detailed net design. Funnel holes 4 inches from bottom to allow continuous fishing at low tide.

Vegetation in each marsh was identified by community type: 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 10.76 square foot quadrat. The Saltmeadow Hay community was sampled using a 1/4 square foot quadrat. The Saltbush community was sampled using a 21.52 foot 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: 0-0.8 inches and 5.6-6.3 inches. 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 36 square inch benthic grab. Seven samples (with duplicates) were collected from each marsh in June. The samples were sieved through a 0.02 inch 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 species richness and diversity.

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 (Figure 4) (0.0004 inch mesh) which sampled the top 5 inches 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 aperature, 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.

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.

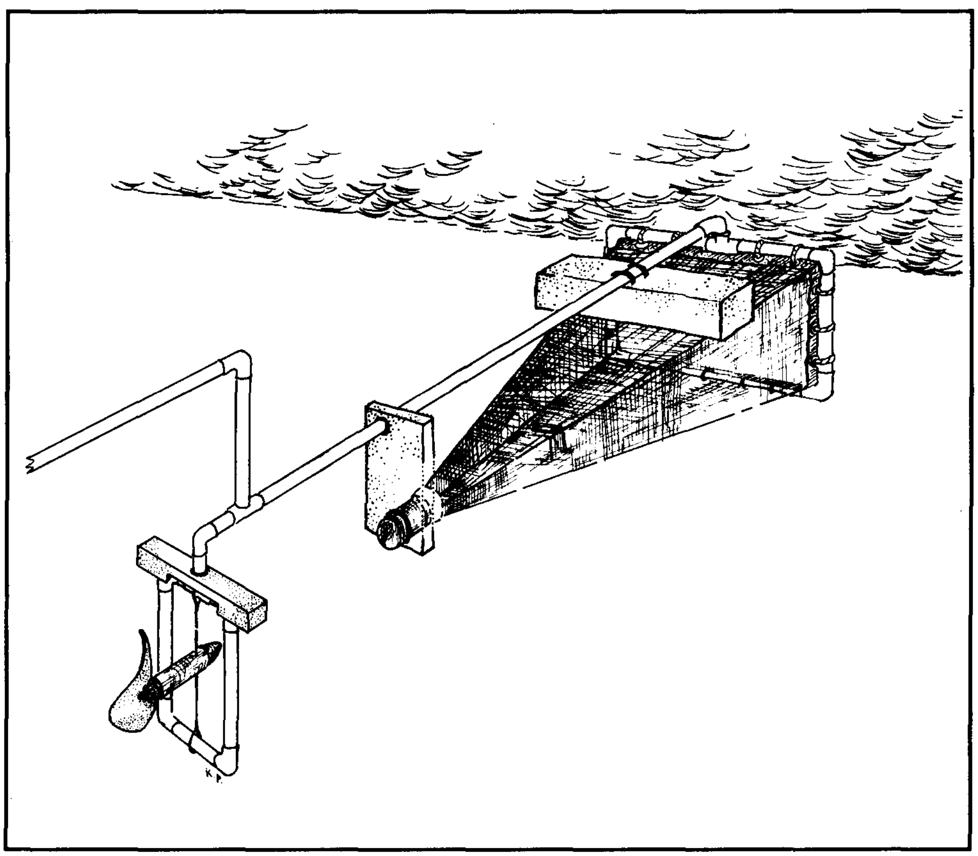

Figure 4. Intertidal creek. Zooplankton collection device for sampling top 5 inches of water column. Water deleted to show specific design features.

Results And Discussion

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. 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.

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, compared with the adjacent natural wetlands, 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 anthropogenic marshes can become an organic carbon sink with a reservoir capacity similar to natural marshes.

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. Average values of organic carbon at a depth of 5.6-6.3 inches (the approximate root zone for vegetated areas) for the ADJ and NAT wetland were 0.0174g/cm3 and 0.0153g/cm3, respectively. This differs significantly ($p < .05$) from the man-made wetland value of 0.0050g/cm^3.

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.

We believe our data show maturation of MM with respect to surface carbon content which will eventually equal natural systems. However, compared to the sandy soil characteristics, 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

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. 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.

Benthic Macrofauna Community

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 and Miller., 1984; Smith et al., 1984). Because of their importance in the marine food chain their life histories and ecology have received broad study. However, their presence in intertidal marsh creeks have received little attention. 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 of 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.

Continuous freshwater input has caused lower salinities in MM 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 ($P = 0.010$). 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 (Holbrook and Schmitt, 1984; Schmitt and Holbrook, 1985). This, in turn, may be influenced by marsh morphology and microtopography. In addition, 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).

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 revealed reduced growth in some juvenile fish confined exclusively to vegetated habitats (Fraser and Cerri, 1982; Werner et al., 1983a). Werner et al. (1983a) showed that juvenile bluegill move out of vegetated areas when predatory fish are removed. This is believed to maximize their energy efficiency by enabling them to feed on zooplankton in the water column.

Our results demonstrate 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 fush and shellfish were more abundant in the summer as compared to 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, *Geukensia demissa*, 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 158 from NAT. Length-frequencies of blue crabs for each marsh and sampling period 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.

The data suggest 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.

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).

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).

In our study the killifish, *Fundulus* spp. and *Gambusia* spp., and spot were the dominant fish in each of the sampled marshes. 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.

We tested for differences between numbers of fish per cubic feet in each marsh. 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.

Species richness was greatest in MM. 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 15.5 foodfish/ft^3 whereas MM's average was ten times lower (1.4 foodfish/ft^3).

Spot dominated foodfish populations in each marsh during the study. Spot were further analyzed for population distribution and length-weight relationships. 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.

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 show 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.

Conclusions and Recommendations

Certain attributes of the man-made marsh resembled the natural marshes, such as temperature, dissolved oxygen, 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, 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 preferably 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. 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. 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.

4. 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.

5. 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.

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College of William and Mary
Virginia Institute of Marine Science
School of Marine Science
Gloucester Point, VA 23062

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