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Developing Design Parameters for Constructing Ecologically Functional Marshes Using Dredged Material in Galveston Bay, Texas

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Abstract

The goal of our study was to build a data base from which design parameters could be developed for constructing ecologically functional marshes in Galveston Bay using dredged material. We measured a variety of habitat attributes using field surveys and from aerial photography to characterize three existing marshes (Atkinson Island, Hog Island, and Cedar Point) near a demonstration site. In addition, we compared animal densities among different types of intertidal and shallow subtidal habitats (pond, channel, cove, open bay, and four marsh types) using a 1 m^2 drop sampler to determine which habitat features of existing marshes should be constructed and tested in the demonstration marsh. The density of channels ranged from 0.6/ha at Hog Island to 1.1/ha at Cedar Point. Marsh ponds ranged in size from 60 m^2 to 3.3 ha, and the highest density of ponds (3.1/ha) occurred at Hog Island. The ratio of marsh to open water ranged from 1.9 (Hog Island) to 4.5 (Cedar Point). We identified four major marsh types in the study area, which occurred along an elevation gradient and in which three species (*Spartina alterniflora*, *S. patens*, and *Scirpus maritimus*) dominated the vegetation. In 183 drop samples taken over three seasons (spring, summer, and fall), we collected a total of 28 species of fishes, 12 species of decapod crustaceans, and 11 species

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of molluscs. Of the dominant fishes, only gulf menhaden *Brevoortia patronus* and bay anchovy *Achoa mitchilli* were abundant in the open bay. Most fishes and decapods, which included several important fishery species, were more abundant in the marsh habitats than in the open bay. Based on our results, we recommend constructing marshes with a variety of marsh and shallow subtidal habitats to enhance biodiversity. To maximize fishery habitat, we recommend placing greater emphasis on constructing low marsh edge habitat by creating large areas of *Spartina alterniflora* and *Scirpus maritimus* marsh interspersed with a dense network of shallow channels and interconnected ponds.

Introduction

Texas estuaries support a number of important Gulf coast fisheries. Between 1972 and 1990 almost two billion pounds of seafood products valued at nearly $3 billion were harvested from Texas bays and adjacent Gulf waters and landed in Texas (Campbell et al. 1992). The Galveston Bay system is one of the most productive Texas estuaries, with landings equaling or exceeding other systems for most commercial species, and it is a major site for recreational saltwater angling, which is valued at more that $2 billion statewide in annual direct expenditures (Campbell et al. 1991).

The Galveston Bay estuary supports valuable fisheries by providing habitat for fishery species. One of the primary nursery habitats is the intertidal marsh surface. Zimmerman and Minello (1984) have shown that Galveston Bay marshes are used extensively by the young of several fishery species including brown shrimp *Penaeus aztecus*, which is more valuable than any other Texas fishery species (Campbell et al. 1992). In addition, the marsh is critical for many resident species (e.g., grass shrimps, killifishes), which are eaten by some fishery species, and thus support fishery production through the food chain.

Unfortunately, intertidal marsh habitat along the Gulf coast is being lost at a rapid rate as a result of coastal submergence (Penland and Ramsey 1990). Some of the highest rates of marsh loss in the Gulf area are occurring in the vicinity of Galveston Bay. From the 1950's to 1989 more than 10,500 ha of marsh in the Galveston Bay system were converted to open water as a result of human-induced subsidence caused by withdrawal of underground fluids (White et al. 1993). Natural marsh formation through delta-building processes can offset these losses; however, this is not occurring in Galveston Bay. For estuaries like Galveston Bay, where wetland

loss rates are high and losses are not compensated by natural marsh formation, the use of dredged material to create intertidal marshes is one of the few options available for offsetting wetland losses (Shreffler et al. 1992).

Although the technical knowledge for planting marsh vegetation on dredged material is easily applied, the technology for creating marsh characteristics and features that are functionally equivalent to natural marshes is only rudimentarily developed (Zedler, 1988, Moy and Levin 1991, Minello and Zimmerman 1992). One approach to designing marshes with the functional equivalency of natural marshes is to attempt to create marshes with physical attributes (e.g., elevation, geomorphology) that approximate those of existing marshes. One might reasonably expect a high degree of success from this approach for at least two reasons. First, we know that physical attributes of marshes influence the distribution of plants and animals. For example, marsh plants have specific requirements with regard to the elevation at which they can grow. Most plants tolerate only a narrow elevation range. Therefore, to insure that vegetation established in constructed marshes is similar to natural marshes, the dredged material must have the same elevation as nearby existing marshes (Woodhouse et al. 1974). Animals are also influenced by physical features. The presence of channels and open water ponds within marshes is extremely important to creating habitat diversity and increasing access for animals (Rozas et al. 1988, Minello et al. 1994). Secondly, some physical attributes are important in maintaining marsh stability or persistence. For example, fetch and shoreline orientation are characteristics that predict the susceptibility of a marsh to erosion from waves. Marshes by their nature thrive in quiet waters on soft muddy sediments. Marshes facing long stretches of open water can be exposed to high energy waves, and therefore, can experience high erosion rates and poor development.

Our study is an outgrowth of previous research by Zimmerman et al. (1992), which identified potential sites in Galveston Bay for establishing salt marsh on dredged material and was funded by the U.S. Army Corps of Engineers at the request of the Beneficial Uses Group (BUG) for the Houston-Galveston Ship Channel Project. The BUG was formed by the Interagency Coordination Team to recommend a dredged material disposal plan to incorporated beneficial uses. Our study was motivated by concerns of the BUG that any marsh constructed as a result of the project be ecologically functional and additional concerns by the Port of Houston Authority that more information was needed on how to construct functional marshes in a cost-effective manner. The primary goal of our study was to build a data base from which design parameters could be developed for constructing ecologically functional marshes in Galveston Bay. Constructing the demonstration marsh will provide an opportunity to determine the efficacy of these design criteria and the most effective bio-engineering techniques for creating marsh habitats on dredged material. Specific objectives of our study were to (1) characterize existing (reference) marshes near the demonstration site by measuring a variety of habitat attributes from aerial photography and in field surveys, (2) measure and compare animal use patterns among different types of habitats in the reference marshes, and (3) determine which habitat features of the reference marshes should be constructed and tested in the demonstration marsh.

Methods

We identified three reference marshes near a proposed marsh demonstration site in upper Galveston Bay. Reference sites were located at Atkinson Island, Hog Island, and Cedar Point (Rozas et al. 1994). Selected physical and biological attributes were measured and characterized in the reference marshes using aerial photography, transect surveys, *in situ* recordings of instruments placed in the field, and quantitative sampling of animals.

Aerial photography was used to determine two-dimensional site attributes that may be important to both habitat function for animals and persistence of intertidal marshes. We measured site attributes from color-infrared NAPP photography enlarged to a scale of approximately 1:2400 and purchased from the U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota. The photography we used was the most recent available for the three sites. Photography of Atkinson and Hog Islands was taken in February, 1989, whereas that of Cedar Point was shot in March 1989.

Survey transects were established to measure site attributes that could not be obtained from aerial photography. At each reference site we established three transects along an elevation gradient from subtidal open water in the bay, across the shoreline, to the supra littoral upland. We determined elevations along each transect using standard surveying techniques (a) at no more than 50 m intervals, (b) where changes in vegetation occurred, and (c) on both sides and within intersected creeks and other water bodies. Elevation measurements

extended bayward into the subtidal to approximately -0.5m MTL (mean tide level) at sites where the elevation gradient was perpendicular to the bay (i.e., Atkinson Island and Hog Island).

We recorded species composition, stem height, and percent cover of the three dominant plants at all locations where elevation data were collected. Using the elevation and vegetation data, we identified four major vegetation zones and calculated the average elevation of the marsh surface where each vegetation zone occurred. We selected representative sample areas from each major vegetation zone to determine vegetation-elevation associations using the following criteria. Zone 1 was defined as the narrow band of marsh along waterbodies and consisted exclusively of tall (≥1m) *Spartina alterniflora*. The other three zones were dominated (i.e., ≥75% coverage) by short to medium (<1m) *S. alterniflora* (Zone 2), *Scirpus maritimus* (Zone 3) or *Spartina patens* (Zone 4). To calculate a mean elevation at which each vegetation type occurred, we averaged elevations measured within each of these vegetation zones across all transects and sites.

We also used the elevation and vegetation data to estimate the proportion of each reference site occupied by the different habitat types. Estimates were made from transect profiles drawn to scale by plotting elevations and corresponding habitats at the appropriate distance along each surveyed line. Each transect was divided into segments so that each segment contained a single vegetation type or habitat. To estimate the proportion of the site occupied by each habitat, we summed the lengths of segments containing the same habitat across the three transects at each reference site and divided by the total length of the transects. We estimated the representation of habitats across all sites by totaling segment lengths across all transects and dividing by the total length of all nine transects. All values were converted to percentages.

We used tidal data from water level recorders located at Atkinson Island and Morgans Point to calculate marsh flooding duration (percentage of time marsh was submerged) in each intertidal habitat. The Conrad Blucher Institute at Corpus Christi State University supplied us with data collected continuously from January through October 1993 at Morgans Point (NOS Station I.D.=87700613). In addition, we collected data seasonally during three, 1-2 mo periods during 1993 from a water level recorder installed at Atkinson Island.

We collected macrofauna (fishes, crustaceans, and mollusca) with a cylindrical 1.0 m^2 drop sampler using the procedure described by Zimmerman et al. (1984). Briefly, the sampler was dropped from a boom on a boat after being positioned over the sample area, entrapping organisms within the cylinder. We clipped plant stems at ground level and removed them from the cylinder a marsh sites. We captured natant macrofauna trapped in the drop sampler using dip nets and by pumping the water out of the enclosure and through a 1 mm mesh net. Any animals remaining on the bottom of the sampler after it was drained were removed by hand. We preserved samples in formalin with Rose Bengal stain. In the laboratory, we sorted the samples and identified the macrofauna to species or lowest feasible taxon.

We sampled eight major habitats including four marsh types (*S. alterniflora* edge, *S. alterniflora* inner, *S. patens*, and *Scirpus maritimus*) and four subtidal habitats (marsh pond, marsh channel, marsh cove, and unsheltered open bay) at two of the reference sites (Atkinson Island and Hog Island). To sample the *S. Alterniflora* inner marsh, we pushed the boat into the marsh as far as possible so that the sample area was usually 5 to 6 m from the marsh edge (vegetation-water interface). Sample areas of other vegetated habitats were within 1 or 2 m of the marsh edge. We collected a total of 183 macrofaunal samples in three seasons (spring, summer, and fall) in 1993. Most habitats were sampled eight times each season. However, we did not sample *S. patens* habitat in summer due to low water levels, and only seven open bay samples were taken in the fall. We based the number of samples collected at each site (Atkinson Island of Hog Island) in a particular habitat on the ratio of the habitat area at a site to the total area of the habitat (both sites combined). Within each site, replicate sample locations were randomly selected using a random number generator and a grid placed over the potential sample areas. We collected samples during the day when all habitats were inundated and available to aquatic organisms.

Results and Discussion

The salt marsh at Atkinson Island was larger than the combined area of marsh at Hog Island and Cedar Point (Table 1). Open water habitats within and contiguous with the marsh included channels, ponds, and coves. The density of channels (number of marsh channels/total marsh area) ranged from 0.6/ha at Hog Island to 1.1/ha at Cedar Point. Although Hog Island had the smallest channel density of the three sites, it contained the greatest density of marsh ponds (3.1/ha). Ponds ranged in size from about 60 m^2 to 3.3 ha, but most were <500 m^2. All three sites contained large semi-enclosed embayments that

we categorized as coves to differentiate this habitat from the subtidal areas of the open bay which were subjected to greater wave energy. The two largest coves occurred at Atkinson Island (6.4 ha) and Hog Island (2.6 ha); Atkinson Island also had the smallest cove (0.6 ha).

Table 1. Comparison of the three reference sites by environmental attributes measured from aerial photography.

Attribute	Atkinson Island	Site Hog Island	Cedar Point
Total Number of Ponds	33	52	20
Total Pond Perimeter (m)	2,263	3,701	1,703
Total Pond Area (m^2)	18,389	57,780	14,583
Total Number of Channels	28	10	17
Total Channel Length (m)	1,241	1,043	1,037
Total Channel Area (m^2)	4,760	3,728	6,188
Total Cove Number	3	1	1
Total Cove Area (m^2)	79,248	26,377	12,259
Total Length of Shoreline (m)	8,009	6,489	5,491
Total Area of Site (m^2)	454,564	263,193	205,093
Total Area of Upland (m^2)	8,831	9,877	22,427
Total Area of Marsh (m^2)	343,335	165,430	149,636
Total Area of Open Water (m^2)	102,398	87,886	33,030
Marsh: Open Water Ratio	**3.4**	**1.9**	**4.5**
Pond Density (ponds/ha of marsh)	**1.0**	**3.1**	**1.3**
Channel Density (channels/ha of marsh)	**0.8**	**0.6**	**1.1**

The most common plant species in our reference marshes agree with the list of dominant salt marsh plants of Galveston Bay reported by Wermund et al. (1992), and our observations of plant distribution within the marshes are in accordance with their description of plant zonation as it relates to elevation. We identified eleven habitat associations from the survey transects (Table 2). Overall, open water and *Scirpus maritimus* marsh covered the largest area within the reference sites (Table 2). However, marsh dominated by either *Spartina alterniflora* or *S. patens* was also widespread. Differences in habitat coverage differed among the sites as well. *S. alterniflora* marsh was most extensive at Atkinson Island, whereas *S. patens* covered the greatest proportion of Hog Island (Table 2). Most of the site at Cedar Point was vegetated by *Scirpus maritimus*. Of the four major intertidal vegetation zones identified in our study, fringing marshes dominated by tall (≥1 m) *Spartina alterniflora*

Table 2. Percent (%) of the total area occupied by each habitat type at each reference marsh and for all three sites together as estimated from survey transect data.

Habitat Type	Atkinson Island	Hog Island	Cedar Point	Overall
Open Water	22.0	22.0	35.5	26.3
Tall *Spartina alterniflora* marsh	0.7	5.5	0.2	1.7
Spartina alterniflora marsh	25.7	5.9	12.1	16.6
S. alterniflora/ *S. maritumus* marsh	0.0	0.0	8.3	2.6
Scirpus maritimus marsh	23.6	21.1	27.5	24.2
S. maritimus/*D. spicata* marsh	0.0	3.1	0.0	0.8
Distichlis spicata marsh	0.0	0.8	3.6	1.3
S. maritimus/S. patens marsh	6.7	2.6	0.8	3.9
Spartina patens marsh	15.5	37.4	11.5	19.6
Shrub	5.4	0.0	0.3	2.5
Upland	0.3	1.7	0.2	0.6

occupied the lowest elevation (26.5 cm NGVD). The average elevation at which *Scirpus maritimus* occurred (40.5) cm NGVD) was slightly higher than that of inner *Spartina alterniflora* (35.0 cm NGVD), and *Spartina patens* was found at the highest elevation of the intertidal zone (49.1 cm NGVD). Even though elevational differences among intertidal habitats were small, estimated flooding durations differed substantially. *Spartina alterniflora* edge marsh was submerged over 60% of the time on average from January through October 1993, whereas inner *S. alterniflora*, *Scirpus maritimus*, and *S. patens* marsh flooded approximately 45, 34, and 22% of the time during this period, respectively. Successful establishment of salt marsh on dredged material is highly dependent on substrate elevation and flooding regime. Therefore, establishing these species on constructed marshes will require careful attention to the upper and lower limits of each species.

We collected a total of 28 species of fishes, 12 species of decapod crustaceans, and 11 species of molluscs in 183 drop samples. Most molluscs were not quantitatively sampled using our methodology. Therefore, this taxonomic group is discussed no further. Fishes and decapod crustaceans were collected in all the habitats we sampled, and average densities of animals varies with season and habitat (Fig. 1). Most fishes were collected in the spring (Fig. 1A), and the most abundant species at this time were gulf menhaden *Brevoortia patronus*, striped mullet *Mugil cephalus*, spot *Leiostomus xanthurus*, and gulf killifish *Fundulus grandis*. With the exception of spot, these species also dominated the catch in summer as did bay anchovy *Anchoa mitchilli* and diamond killifish *Adinia xenica*. The most abundant species in the fall were gulf killifish, bay anchovy, blackcheek tonguefish *Symphurus plagiusa*, and sheepshead minnow *Cyprinodon variegatus*. Average densities of fishes taken in marsh system habitats (pond channel, cove, and four intertidal marsh habitats) were not significantly different from average densities collected in the open bay habitat (ANOVA Contrasts: all p's>0.05). However, few of the dominant species collected in our study were abundant in open bay habitat. The fish assemblage of the open bay habitat was composed almost entirely of two species, gulf menhaden and bay anchovy.

Decapod crustaceans, unlike fishes, were much more abundant in the summer and fall than in spring (Fig. 1B). Daggerblade grass shrimp *Palaemonetes pugio*, brown shrimp, white shrimp *Penaeus setiferus*, and blue crab *Callinectes sapidus* accounted for most of the decapod crustaceans taken in our macrofaunal samples. These species, with the exception of white shrimp, which was

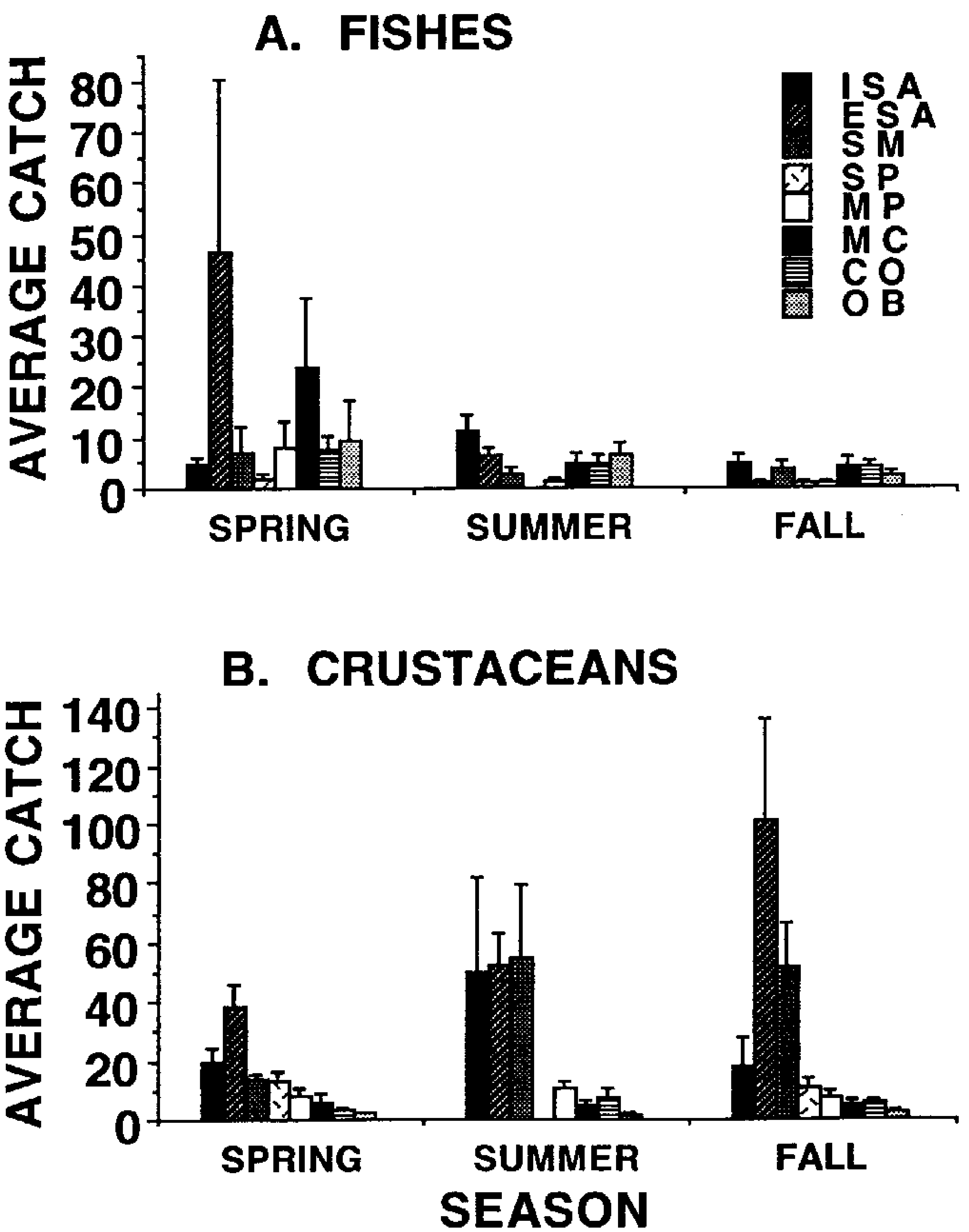

Figure 1. Average catch (animals/m^2) of total fishes (A) and total decapod crustaceans (B) collected in inner *Spartina alterniflora* (ISA), edge *S. alterniflora* (ESA), *Scirpus maritimus* (SM), and *S. patens* (SP) marshes and marsh ponds (MP), marsh channels (MC), coves (CO), and the open bay (OB) in the spring, summer, and fall of 1993. Error bars = 1SE.

absent from the spring samples, dominated the decapod assemblage during all three seasons. Unlike fishes, decapod crustaceans, which included several important fishery species, were significantly more abundant in marsh habitats than in the open bay (ANOVA Contrasts: spring: 1,56 d.f.; F=62.31; p=0.0001; summer: 1,49 d.f.; F=42.10; p=0.0001; fall: 1,55 d.f.; F=23.96; p=0.0001).

In summary, none of the marsh or subtidal habitats was preferred by all species. However, intertidal and subtidal habitats within the marsh system contained much higher densities of most species of nekton than the open bay. Therefore, replacing some open bay bottoms with marsh habitat should have a positive effect on most species that were dominant in our study. Even though some open bay habitat will be lost by creating new marsh, the remaining open water areas ensure that species that use this habitat will likely find suitable habitat near constructed marshes. Therefore, if marshes that are functionally equivalent to natural marshes can be constructed, the increased benefit of enlarging the habitat area for fishery and forage species that use marsh systems should outweigh the loss of open bay habitat. The best approach to constructing marshes that are functionally equivalent to natural marshes in upper Galveston Bay may be to create a variety of marsh and shallow subtidal habitats. To maximize fishery habitat, however, we recommend that within this mix of habitats greater emphasis be given to constructing low marsh edge habitat by creating large areas of *S. alterniflora* and *Scirpus maritimus* marsh interspersed with a dense network of shallow channels and interconnected ponds.

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