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"Use of Marsh Habitats by Fishery Organisms Along a Salinity Gradient in Galveston Bay"

By

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ABSTRACT

This paper reports on nursery functions of estuarine marshes in Galveston Bay for fishery species. The investigation shows that foods in marshes may greatly explain the distributions of fishery juveniles. Juvenile shrimps, crabs and fishes follow their prey, and environmental factors, such as the long-term effects of freshwater input, may dictate the distribution and abundances of these foods. Since the kind, number and accessibility of prey vary among marshes in Galveston Bay, the nursery value of marshes for fishery juveniles also varies.

Marshes in the upper, middle and lower parts of Galveston Bay differ in their utilization by fishery species in relation to salinity regime and the presence of certain foods. The highest numbers of shrimps, blue crabs and commercial fishes were in drop samples from marshes in the middle and lower bay. These abundances were associated with high abundances of benthic peracarid crustaceans (amphipods and tanaidaceans) which were shown to be used as foods through feeding experiments and gut analyses. Other foods such as annelid worms and bivalve mollusks were less often numerically related to the distribution of fishery juveniles. This finding provides a cause-and-effect relationship that can partly explain differences in utilization of marshes by fishery species.

The foods directly used by fishery juveniles in marshes are modified by influences from freshwater inflow. In upper Galveston Bay where salinities are generally less than 10 ppt, long-term effects from the Trinity and San Jacinto rivers dominate. Marshes and submerged vegetation are characterized here by brackish water plants (<u>Scirpus</u>, <u>Sagittaria</u>, <u>Ruppia</u>, <u>Vallisneria</u>) with highly seasonal growth patterns and complete winter defoliation. This environment is especially stressful to estuarine organisms because of long-term low salinities and high sedimentation rates. The environment is not conducive to development of resident populations of epibenthic invertebrates, that have limited capacity to osmoregulate, or of epiphytic algae. The resident infauna mostly consist of oligochaete worms and bivalve mollusks. Transient fishery species from the bay, including juveniles of fishes, crabs and shrimps, have ready access to these marshes but do not use them extensively, even on the short-term, despite their ability to osmoregulate. This lack of attractiveness is apparently due to the absence of preferred foods, especially epiphytic algae and peracarid crustaceans. Unlike marshes in other parts of Galveston Bay, the value of these upper bay marshes to fisheries is indirect; that is, they provide a large quantity of organic detritus exported to the middle and lower bay.

In the middle of Galveston Bay, the organic detritus from upper bay marshes becomes an important basis for food chains. Here detritus particles, colonized with bacteria and fungi, provide food for epibenthic fauna. Stimulated by food and mesohaline conditions, large numbers of epibenthic organisms develop (as indicated by the numbers of peracarids) that, in turn, provide a rich nursery feeding ground for fishery species. In this mid-bay processing region, foods and immigrating juveniles of commercial and game species were abundant in both the marsh and the nearby subtidal (nonvegetated) mud bottom.

In the lower bay, detritus is also important to food chains, but here, reduced turbidities and moderate salinities foster the development of epiphytic algae as another carbon source. Since Spartina marshes in the lower bay persist year-around and are regularly inundated, they offer perennial substrata for epiphyte colonization. Epifauna and epiflora associated with these marshes are a food resource that we have shown to be used by young penaeid shrimp, blue crabs and small fishes (pinfish and spot croaker) which are eaten by larger fishes (flounder, spotted seatrout and red drum). The difference in abundances of these foods between the marsh and the adjacent nonvegetated bottom is greater in the lower bay than the middle bay, emphasizing the greater direct importance of marshes in the lower system as a feeding ground.

The results demonstrate that interconnections and differing functions among the parts of Galveston Bay are important to fisheries. Low salinity (oligohaline) marshes in the upper subsystem (especially at the Trinity Delta) export large amounts of organic material that becomes a food source in the middle and lower system. The plants of the river delta defoliate each winter and the standing crop is exported by river floods and lunar tides. This creates plant detritus for transport to the middle system that increases the productivity of epibenthic detritus feeders (such as peracarid crustaceans). These, in turn, are foraged by juveniles of commercially valuable fishes, shrimps and crabs. Because of the widespread availibility of forage organisms in the middle system, both the marsh and subtidal bottom are extensively utilized as nursery habitat. This part of the bay is characterized by mesohaline to polyhaline (mid-range) salinities. In the lower subsystem, euryhaline salinities approach those of seawater and productivity appears to be more dependent on algal resources. Marshes and seagrasses in this part of the bay are heavily epiphytized by algae that provides an additional basis for food chains. Nutrients stimulating algal growth are imported from the middle and upper subsystems. In relation to other parts of the bay, the marsh surface in the lower subsystem has more food than nonvegetated subtidal bottom and is subsequently more attractive as a fishery nursery. In conclusion, the subsystems of the bay, as characterized by salinity, are functionally different, but the interdependence of these functions appears to be critical to maintaining overall fishery productivity.

INTRODUCTION

Purpose.

The purpose of this study is to characterize marsh utilization by fishery species in Galveston Bay relative to salinity regime. Several hypotheses have been proposed. The central hypothesis is that marshes in the mid-range salinity regimes are more utilized by the estuarine aquatic fauna than marshes in low or high salinity regimes. Subhypotheses propose that marshes with mid-range salinities have: a) higher densities of fishery organisms, including shrimps, crabs and fishes, and b) greater abundances of epi-and infaunal foods foraged by fishery species.

Galveston Bay Characterization

The Physical Environment. The physical environment of the Trinity-Galveston Bay system has been reviewed by Wermund et. al (1988). Descriptions from surveys are in Reid (1955), Chambers and Sparks (1959), Pullen et al. (1969, 1971), Diener (1975), the Texas Dept. Water Resources (1981), Fisher (1983), and White et al. (1985). In his 1963-66 study, Pullen (1971) reported temperature ranges between 0.4 and 36.0° C, salinity ranges between 0.1 and 36.6 ppt, and dissolved O_2 between 0.2 and 13.6 ml/l. From salinity averages, the 10 ppt isohaline line was placed through the middle of Trinity Bay (north to south), the 15 ppt line crossed through the middle of Galveston Bay (east to west) extending the length of East Bay, and the 20 and 25 ppt lines were confined to lower Galveston Bay near the pass into the Gulf of Mexico at Bolivar Roads. The lower bays West Bay and Christmas Bay were not included in early surveys, but salinities are generally known to be higher than the upper and middle bays (including East Bay) due to proximity to major passes into the Gulf (White et al. 1985).

The greater system has about 600 square miles (1,554 km^2) of open water, intertidal marshes and flats representing 23% of the total estuarine area in Texas (Armstrong 1987). Pullen estimated that the largest bays in the system, Trinity Bay, Galveston Bay, East Bay and West Bay, covered approximately 1,360 km^2. Despite it's relatively large size the system is very shallow with mean depths generally under 2m. Diener (1975) reported on acreage of open water and maximum and mean depth at mean low water for Trinity Bay (83,310 ac\337 km^2; 17 ft\5.2m max. and 5.2 ft\1.6m mean), upper Galveston Bay (69,890 ac\283 km^2; 42 ft\12.8m max. and 5.7 ft\1.7m mean), lower Galveston Bay (89,380 ac\362 km^2; 44 ft\13.4m max. and 6.5 ft\2m mean), East Bay (33,370 ac\135 km^2; 12 ft\3.7m max. and 3.3 ft\1m mean), West Bay (44,390 ac\180 km^2; 25 ft\7.6m max. and 3.9 ft\1.2m) and Christmas-Bastrop Bay (9,690 ac\39.2 km^2; 20 ft\6.1m max. and 3.2 ft\1m mean).

Surface sediments in the Galveston Bay system are described by White et al.(1985) as composed of mud, muddy sand and sandy mud. In general, the upper areas in the system are muddy and the lower areas are sandy. Fine grained mud predominates in Trinity Bay, upper Galveston Bay and East Bay. The Trinity river delta and the passes at either end of Galveston Island are sandy. Bay margins along Bolivar peninsula and Galveston Island are muddy sand. Marsh sediments in the system reflect open bay characteristics; thus Trinity delta marshes are sandy to muddy, upper and middle Galveston Bay and East Bay marshes are muddy, and lower Galveston Bay, West Bay and Christmas Bay marshes are sandy to muddy sand.

The major river inputs in the system are the Trinity and San Jacinto Rivers, contributing 5 million and 1.4 millon ac/ft of freshwater per year respectively. About 2.5 millon ac/ft/yr is added from local rainfall of 50 inches (127 cm) rainfall/yr (Wermund et. al 1988).

The system includes 233 square miles (603 km^2) of wetlands (Texas Dept. Water Resources 1981). Approximately 61 square miles of wetlands are at the Trinity Delta (the largest river delta in Texas), comprised of marshes (21 $mi.^2$; 54 km^2), cypress swamps (26 $mi.^2$; 68 km^2), and shallow fresh to brackish lakes (13 $mi.^2$; 35 km^2). Salt marshes cover 54 square miles (140 km^2) and brackish marshes occupy 89 square miles (230 km^2) of intertidal wetlands throughout the remainder of the system (Fisher et. al 1972). The balance is freshwater and terrestrial marsh.

Normal tides in the system have a relatively low diurnal amplitude (about 30 cm) as compared to a seasonal range of about 1 m (Hicks et. al 1983). However, because of it's shallow nature, meterological forces of wind and barometeric pressure often have a strong overiding effect on tidal height (Smith 1982). Strong weather fronts from the west and northwest, during the winter months, drive water away from the coast and depress bay water-levels. The opposite occurs during warm season months when southeast winds and tropical depressions move water toward the coast and elevate water levels. These forces cause tidal variations that routinely excede the predicted values, often beyond the annual range. Freshwater inflow from high rainfall also has an effect on elevating water-levels. Trinity delta marshes and other marshes in the upper subsystem and in East Bay are inundated for extended periods due to flood events (Borey 1979; Texas Dept. Water Resources 1981; Borey et. al 1983).

<u>Biological Compontents</u>. The biological components of Galveston Bay have been reviewed by Sheridan et. al (1988). The major fisheries have been described generally and their relationships to freshwater inflow modeled by Texas Dept Water Resources (1981). Relationships between benthic invertebrates and sediments in the bay have been characterized by White et. al

(1985). Other descriptions of the biota include marsh vegetation (Fisher et. al 1972), benthic algae (Lowe et. al 1978), phytoplankton (Texas Dept. Water Resources 1981), zooplankton (Holt and Strawn 1983), molluscan distributions (Harry 1976), oyster reefs (Hofstetter 1977 and 1983), penaeid shrimp populations (Chin 1960; Baxter and Renfro 1967; Parker 1970; Zimmerman and Minello 1984), the blue crab population (More and Moffett 1964; More 1969; Hammerschmitt 1985), and the fish community (Parker 1965; Sheridan 1983).

The biota is dominated by estuarine species, in a subtropical to temperate climate, including populations of considerable commercial value. Penaeid shrimp (Penaeus aztecus and P. setiferus) lead these followed by oysters (Crassostrea virginica), blue crabs (Callinectes sapidus) and finfishes (Sheridan et. al 1988). Commercial and recreational fishes in order of kg landed are spotted seatrout (Cynoscion nebulosus), southern flounder (Paralicthys lethostigma), sand seatrout (Cynoscion spp.), atlantic croaker (Micropogonias undulatus), and red drum (Sciaenops ocellatus). All of the commercially important species require the estuary at least as a nursery and many species, commercial and otherwise, are closely associated with marsh habitats. Examples such as grass shrimp (Palaemonetes pugio), mud fish (Fundulus grandis), and the naked goby (Gobiosoma bosci) are marsh residents, and juveniles of brown shrimp (P. aztecus), blue crabs (C. sapidus) and spotted seatrout (C. nebulosus) have been shown to select tidally flooded marsh in preference to nonvegetated mud bottom (Zimmerman and Minello 1984).

Most faunal species occur throughout the system, although abundances may be unevenly distributed depending on location and season. Prior studies indicate a coarse relationship between distributions and salinity. For instance, the clams Rangia cuneata and R. flexuosa are more abundant in the upper and middle subsystem (fresher), oyster reefs are prevalent in the middle subsystem and hard clams (Mercenaria mercenaria and bay scallops (Argopecten) only occur in small populations in the lower subsystem (more saline).

Emergent marshes are the dominant vegetation throughout the system (Fisher et. al 1972). Submerged aquatic vegetation (SAV) is currently limited to small stands mostly in Trinity Bay and Christmas Bay. Sheridan et al. (1988) reports that SAV has declined in the system from about 21 km^2 in 1960 to <1 km^2 in 1979. We report on the present composition and seasonal dynamics of the Trinity delta and Christmas Bay grass beds.

Influences of Freshwater Inflow

Recruitment to the Nursery. Gulf of Mexico species that require estuarine nurseries usually have postlarvae that follow salinity gradients from saline to brackish conditions. Most of these species use freshwater as a cue for directional movement. Planktonic larvae of barnacles and oysters detect salinity differences in water masses and respond behaviorly to effect their transport within estuaries. Swimming behavior by oyster larvae is stimulated by increased salinities and supressed by decreased salinities (Haskin 1964). This helps larvae position themselves for favorable tidal transport on salinity wedges. Likewise megalopa of blue crabs and postlarvae of penaeid shrimps move vertically in the water column responding to salinity changes that signal useful transport in an estuary.

Recruits also depend upon freshwater inflow to sustain the quality of nursery habitat. Since primary production in estuaries is driven by nutrient availability (Nixon 1981), high production depends on nutrients resupplied by freshwater inflow (Flint et. al 1986). A close relationship between estuarine chlorophyll a level and river flow (Bennett et. al 1986) exemplifies this relationship. In northwestern Gulf of Mexico estuaries, nutrients and suspended organic solids are largely imported via riverine flow through freshwater marshes (Stern et. al 1986). In Spartina salt marshes nitrogen levels and soil hydrology interact to determine production levels (Mendelssohn 1979; Conner et. al 1987). Salt marshes are also benefitted by freshwater through moderation of detrimental high soil salinities (Webb 1983). At the consumer level, high numbers of estuarine infauna (useful as food for fishery juveniles) have been attributed to rainfall and floods (Flint 1985). Increased recruitment and survival of red drum in the Laguna Madre has been related to moderation of hypersaline conditions through floods after hurricanes (Matlock 1987). River transported sediments also supply turbidity and soft substrates that are good refuges from predation for juvenile recruits (Minello et. al 1987).

Nurseries are almost always located along the shallow edges of an estuary. Usually the most useful habitats are vegetated, such as emergent marshes, mangroves, seagrasses, and algae beds. In Galveston Bay these nurseries consist of brackish and salt marshes and small areas of submerged vegetation. Parker (1970) established that postlarval brown shrimp in Galveston Bay move directly to the marshes after they immigrate through the passes (Baxter and Renfro 1970). Zimmerman et. al (1984) have shown that juvenile brown shrimp ranging in size from about 15 mm to 60 mm TL are strongly attracted to salt marsh surfaces in West Bay. The selective value of increased abundances of foods (Gleason and Zimmerman 1984; Gleason 1986; Zimmerman et. al 1988) and protective structure of Spartina alterniflora (Minello and Zimmerman 1983) are the apparent reasons for this attraction. Juvenile blue crabs (Callinectes sapidus) have been shown to exhibit a similar strong attraction for marsh and seagrass habitats in West Bay and Christmas Bay, apparently for the same reasons (Thomas et. al 1988; Thomas and Zimmerman 1988). Other important species that use the West Bay salt marsh as a nursery (excluding residents, and in order of abundance) are white shrimp (P. setiferus), pinfish (Lagodon rhomboides), spot croaker (Leiostomus xanthurus), bay anchovy (Anchoa mitchilli), Atlantic croaker (Micropogonias undulatus), Gulf menhaden (Brevoortia patronus), spotted seatrout (Cynoscion nebulosus), southern flounder (Paralicthys lethostigma), striped mullet (Mugil cephalus), and red drum (Sciaenops ocellatus) (Zimmerman and Minello 1984). The only species of commercial interest not found as juveniles in the West Bay salt marsh nursery were sheepshead (Archosargus probatocephalus) and black drum (Pogonias cromis).

Oysters (C. virginica) are recruited throughout Galveston Bay forming reefs in areas with salinities ranging between about 10 and 30 ppt (Hopkins 1931; Hofsetter 1977 and 1983; Sheridan et. al 1988). Salinities above 7 ppt are required for spawning (Loosanoof 1948) and spat grow best in salinities above 12 ppt (Davis and Calabrese 1964). Salinities above 20 ppt in Galveston Bay favor populations of oyster drills (Thais haemastoma), a predator, and a disease (Perkinsus marinus) that reduce oyster numbers (Sheridan et. al, 1988). As a consequence of predation and disease at higher salinities and of physiological limitations at lower salinities, the most productive oyster reefs are in the middle of Galveston Bay and at the mouth of East Bay where salinities are 10 to 20 ppt (Sheridan et. al 1988).

Fishery Yields. Relationships between freshwater flow into estuaries and fishery production are poorly established and not well understood. An overall review of the influence of freshwater inflows on estuarine productivity is provided by Turek et al. (1987) with citations of case studies and previous reviews by Copeland (1966), Baxter (1977), Armitage (1978), Pandian (1980), Benson (1981) and Peters (1982).

Our present concept of relationships between freshwater input and fisheries yields arises from inferences based upon correlations. Estuaries are by definition mixtures of fresh and marine waters (Pritchard, 1967) and 69 percent of all finfish and shellfish landings in the U.S. are from estuarine-dependent species (McHugh, 1966 and 1976). A simplified view of estuarine-dependent productivity is dependence upon the freshwater flow which creates estuaries. In this view, large estuarine areas, supported by freshwater inflow, would produce greater fishery yields. This inference is based upon a few studies that show a positive correlation between fishery yield and estuarine area. The most often cited studies are Turner (1977) and Nixon (1982) .

The estuarine dependency of fisheries in the Gulf of Mexico is about 98 percent (Gunter, 1967). The Texas Department of Water Resources (1981b) has produced 115 significant multiple regressions from models of Texas estuaries relating fishery yields to the amount of freshwater inflow. Most of these are linked to spring and late fall inflows indicating important seasonal relationships. In addition, a major drought in Texas during the 1950s caused low fishery yields and adverse effects on estuarine populations (Powell, 1985). Estuarine-dependent populations apparently recovered quickly after spring and fall rains in 1957 at the end of the drought (Hoese, 1960).

Habitat Modification. The intertidal marsh surface and shallow water without vegetation in northwestern Gulf of Mexico estuaries comprise the principal nursery for immigrating postlarvae of fishery species. These microhabitats occur together in a reticulated pattern with a high degree of interfacing. The mosiac is due to marsh deterioration caused by subsidence, loss of sediment input and other factors (Craig et al. 1980; Reidenbaugh et al. 1983; Hatton et al. 1983). The condition increases both shoreline complexity and the opportunity for habitat selection by recruiting animals. For example, in a previous investigation we reported that small brown shrimp select flooded marsh in preference to nonvegetated subtidal bottom, while white shrimp demonstrate no consistent preference for either habitat (Zimmerman and Minello 1984). In support of our observations, the offshore catch of brown shrimp has been positively correlated with the amount of intertidal marsh area (Turner 1977), shoreline complexity (Faller 1979) and the ratio of marsh to open-water (Browder 1985). However, similar observations have not been made for white shrimp. These investigations suggest differences in habitat usage between two fishery species which may reflect resource partitioning.

Juvenile brown shrimp have been traditionally associated with vegetated estuarine habitats such as marshes and seagrasses (Loesch 1965; Stokes 1974; Christmas et al. 1976; and Zimmerman et al. 1984) and white shrimp have been identified with nonvegetated, muddy bottom, open-water habitats (Loesch 1965; Stokes 1974; and Zimmerman et al. 1984). White shrimp are sometimes associated with detritus rich sediments (Williams 1955). Recent evidence explains these habitat associations through differences in feeding (Zimmerman et al. 1989). The high numbers of small benthic macrofauna sought by carnivorous brown shrimp are most abundantly found in vegetated habitats. In the northwestern Gulf of Mexico, these are predominantly intertidal marshes.

Differences in diets between shrimp species (McTigue and Zimmerman 1989) may greatly determine habitat value. White shrimp exploit plants and possibly planktonic resources that brown shrimp do not. Brown shrimp are highly effective in feeding on benthic infauna and epifauna, while white shrimp are much less so. White shrimp are not growth limited by dietary resources separated by marsh and open-water while brown shrimp were limited by habitat-related abundances of epi- and infauna (Zimmerman et al. 1989). This means that habitat changes affecting one species, such as marsh loss or nutrient enrichment, do not affect species equally.

Marshes in the northwestern Gulf of Mexico are currently accreting less sediment and sustaining more salt water intrusion due to diversion of freshwater riverflow (Craig et al., 1980; and Hatton et al., 1983). Although these processes ultimately destroy marsh habitat, the short-term effect is to make more habitat available for exploitation. Microtidal diurnal amplitudes in the Gulf are dominated by high seasonal tides (Provost. 1976). This effect increases the duration of marsh innundation during spring and fall seasons. A mild climate allows development of high abundances of epifauna and infauna during the winter season (Flint and Younk, 1983). These phenomena cause an abundance of foods to be available for exploitation by spring recruits. The foods are substantially more abundant on the salt marsh surface than in open water. Increased seasonal accessibility of intertidal foods, as determined by marsh geomorphology and tidal innundation pattern, appears to be a key to elevating production of brown shrimp and other estuarine dependent animals that use the marsh surface as a nursery.

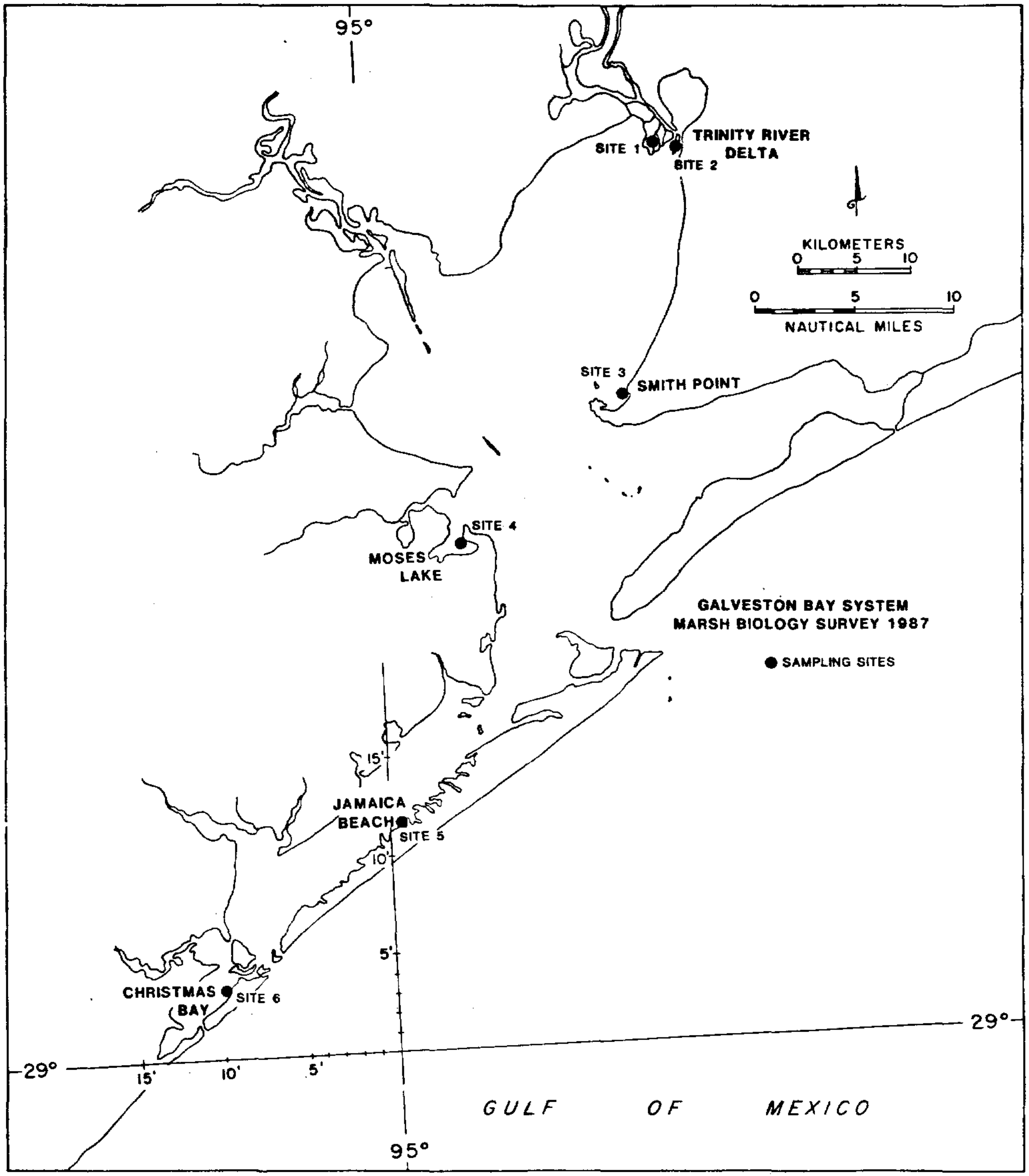
METHODS

Study Sites

Marshes in three regions of the Galveston Bay system were chosen for study based on salinity characteristics Fig.1). The regions were the upper, middle and lower parts of the system and the corresponding salinity regimes based on Cowardin et al. (1979) were oligohaline (0.5 to 5 ppt), mesohaline (5 to 18 ppt) and polyhaline (18 to 30 ppt). Two marsh sites in each region were chosen based on observed similarity to other marshes in the area and on accessibility for sampling. Salinity regimes were characterized using Texas Parks and Wildlife Department (TPWD) records taken over the past 10 years within 1 km of each site, as well as from salinities measured in 1987 during the study. Marshes were compared to open water micro-habitats in the adjacent bay throughout the study. The open water micro-habitats were either nonvegetated mud or sand bottom, or submerged aquatic vegetation (SAV), such as seagrasses, or both.

In the upper bay, two marsh sites (Sites 1 and 2) were studied on the Trinity River delta located at 94° 42' W, 29° 44' 36" N and at 94° 43' 18" W, 29° 45' 30" N (Fig.1). The marshes had mixed emergent vegetation but the dominant plant near the marsh edge was *Scirpus robustus* . Submerged aquatic vegetation (SAV) was present at both sites during the summer and was mostly comprised of *Ruppia maritima*, *Najas* sp. and *Vallisneria* sp. Both marshes were situated along coves that opened into Trinity Bay. The site closest to the bay near the navigation channel was designated the outer site (Site 2; OTD, outer Trinity Delta) and the site farther into the delta near southwest pass was designated the inner site (Site 1; ITD, inner Trinity Delta). Ten year monthly mean salinities from TPWD ranged from 3.0 to 18.9 ppt with an overall mean of 9.2 ppt at the outer site. Mean monthly salinities at the inner marsh site ranged from 1.7 to 14.4 ppt at the inner site with an overall mean of 6.0 ppt. Because of the low salinity occurrences, the inner site was designated as oligohaline. The dominance at the inner site of *Najas* and *Vallisneria*, plants which do not tolerate long-term salinities above 6 ppt, confirm the validity of the classification. Because of its slightly higher salinities, the outer site was classified as a transition from oligohaline to mesohaline.

In the middle of the bay, mesohaline marshes were located at Smith Point (Site 3; SP) and at Moses Lake (Site 4; ML). These sites are at 94° 45' 24" W, 29° 33' 18" N and 94° 55' 30" W, 29° 26' 24" N, respectively, and are on opposing sides of the bay (Fig.1). At Smith Point, the marsh was mostly composed of *Spartina alterniflora* with *Juncus roemerianus* and *Spartina cynosuroides* mixed in . At Moses Lake, the marsh was *Spartina alterniflora*, *Juncus roemerainus* and *Distichlis spicata*. The was no SAV in the area; open water bottoms adjacent to the marsh varied from hard clay and soft mud to muddy sand with broken *Rangia* shell. The ten


95°
TRINITY RIVER
DELTA
SITE 1
SITE 2
KILOMETERS
0 5 10
0 5 10
NAUTICAL MILES
SITE 3
SMITH POINT
SITE 4
MOSES
LAKE
GALVESTON BAY SYSTEM
MARSH BIOLOGY SURVEY 1987
SAMPLING SITES
15'
JAMAICA
BEACH
SITE 5
10'
5'
CHRISTMAS
BAY
SITE 6
29°
29°
15'
10'
5'
GULF OF MEXICO
95°

year mean salinities were 11.7 ppt for Smith Point and 15.7 ppt for Moses Lake.

In the lower system, two polyhaline marsh study sites were located, one each, at Jamaica Beach (Site 5;JB) in West Bay at the Galveston Island State Park and on the peninsula in Christmas Bay (Site 6;CB). They were at 94° 59' W, 29° 12' N and 95° 10' W, 29° 2' 48" N, respectively. The marshes at both sites were composed of nearly monotypic stands of Spartina alterniflora with some Salicornia virginica and Batis maritima mixed in at higher elevations. The subtidal bottom next to the marsh at Jamaica Beach was sandy mud without SAV present; but at Christmas Bay the bottom was sandy and SAV was present throughout the year. The extensive stand of SAV was mostly composed of Halodule wrightii with traces of Ruppia maritima, Halophyla sp. and Thalassia testudinum mixed in. Ten year mean salinities from TPWD were 23.8 ppt at Jamaica Beach and 26.4 ppt at Christmas Bay.

Field Procedures:

The principal method of sampling animal abundances on the marsh surface and in nearby shallow-water subtidal habitats was drop sampling (Fig.2). This version of drop sampling was developed at the Galveston Laboratory of the National Marine Fisheries Service to compare animal densities among a variety of shallow-water habitats. The method employs a large cylinder (1.8 m dia.) dropped from a boom on a boat to entrap organisms within a prescribed area (2.6 m^2). Most of the moblie fauna are captured by using dip nets while water is pumped out of the sampler. When the sampler is drained the remaining animals are picked up by hand. The technique is designed for areas where fishes, crabs and shrimps are difficult to quantify because of environmental limitations. It has been especially useful in marshes, seagrass beds and oyster reefs where other methods such as trawls and seines are ineffective. The technique improves on conventional methods because it measures actual densities (numbers/unit area) of organisms, as opposed to relative abundances; hence, with drop sampling, quantitative comparisions of organism abundances within and between marshes and a variety of other habitats are possible. To date, the technique has been successfully used in water depths up to 1.1 meter in marshes, seagrass beds, oyster reefs, mangroves, and bare sand and mud bottoms. The methodology is described and data are exemplified in Zimmerman, Minello and Zamora (1984) and Zimmerman and Minello (1984). Drop sampling is being used in Texas and Louisiana as a means to establish value of marshes to estuarine dependent fishery species.

In the Galveston Bay study, we employed the drop sampler to assess utilization of marshes and adjacent subtidal bottoms by fishery species among sites along a salinity gradient. Four replicate samples (2.6 m^2 each) of each microhabitat at each site were taken during the spring, summer and fall seasons of 1987.

Figure 2. Drawing of drop-sampler.

Microhabitat sampling always included marsh and bare mud bottom (subtidal open-water at the marsh edge) in sample pairs (4 replicate pairs/site during each sampling foray); 4 SAV replicates were added when that microhabitat was present. Thus, without including SAV, 8 samples of marsh and 8 samples of adjacent mud bottom were taken in each the upper, middle and lower system (48 total) during April, July and November (144 total). These samples constituted a balanced set and the basis for our main comparisons. Since SAV did not occur at all sites (it was only at the Trinity delta and Christmas Bay sites) and varied in its presence seasonally, these samples were treated separately. The main data taken from the drop samplers were densities of fishes and decapod crustaceans. These organisms were collected in the field and preserved with 10% Formalin for identification, enumeration and measurement in the laboratory.

Other materials and observations taken in drop samplers included samples of sediment with infauna and epifauna and of vegetation, and measurements of water depth, temperature, salinity, dissolved oxygen and turbidity. Infauna and epifauna were sieved from a single 10 cm dia. x 5 cm sediment core taken in each drop sample. They were retained on a 500 micron square mesh screen, then placed in zip-lock plastic bags with 10% Formalin with Rose Bengal stain, and stored for sorting at the laboratory. All emergent plants in marsh samples were cut and placed in plastic garbage bags, without preservation, for laboratory processing. Water depth was measured as maximum and minimum depth with a meter rule in each drop sample. Water temperature and dissolved oxygen was measured using a YSI Model 51B meter, and salinity was measured using an AO refractometer. Water samples (500 cm^2) were taken to measure turbidity (HR Instruments Model DRT 15) and to cross check conductivity/salinity (Hydrolab Data Sonde) at the laboratory.

Laboratory Proceedures:

In the laboratory, fishes and crustaceans were sorted to species (using identifications based on guides, keys and taxonomic papers listed in Appendix I), counted and measured. Fish counts were entered in 10 mm size intervals and decapod crustaceans were entered in 5 mm size intervals. Data was recorded on printed forms and entered in dBASE III Plus files using a microcomputer. Infauna and epifauna were processed similarly except these organisms were not measured, and individuals were identified to species only in 1 of each 4 replicates; in the other 3 replicates, they were counted as peracarid crustaceans, annelid worms, mollusks and other fauna. Marsh plants were first weighed wet then air dried for at least two months and weighed dry. After drying, the number of culms in each sample were counted to calculate density and then discarded. All faunal samples were kept on hand in 5% Formalin or 70% ETOH for reference. These will be stored for at least 3 years from the date of collection. All field sheets and laboratory data entry forms are on file and will be kept for at least 5 years.

Analytical Procedures:

We used a one-way ANOVA design to test for differences in observation means between the six sites situated along the apparent salinity gradient. The main observation at each site was density of animals, including each abundant fish and decapod crustacean species and selected groups of species eg., all fishes, all decapods, commercially important fishes, and certain families. The main test was to assess differences in species utilization of marsh microhabitat between sites. To compare these results with utilization of nearby subtidal bottom, identical observations were made in nonvegetated and SAV (when present) subtidal microhabitats that were adjacent to the marsh. Other observations tested between sites, within microhabitats, included physical parameters, densities of forage organisms and vegetational measurements. All raw data were transformed for ANOVAs using log x + 1 since variances were usually proportional to the means (see means and standard errors in Appendices II, III and IV). Differences between observation means among sites were tested at the 0.05 significance level. Because most species were highly seasonal (high numbers confined to one season), large changes in occurrences as well as abundances among species took place seasonally. We felt that this greatly weaked our justification for comparisons across seasons (such as including seasons as another level in the ANOVA design). Therefore, we limited our tests to within seasons. In all ANOVAs, where probabilities were equal to or greater than 0.05, we used LSD multiple range tests to identify where differences between sites occurred. To evaluate differences between sites in upper, middle and lower bay regions (2 sites in each region), we used orthogonal contrast tests.

To compare differences in means between marsh and nonvegetated bottom among sites, we used paired t-tests since these two microhabitats were always sampled as pairs. To compare SAV, marsh and nonvegetated microhabitats, we used a one-way ANOVA at sites were SAV was present (Christmas Bay and the Inner Delta). Raw data was log transformed and each season was analyzed separately. We also used ANOVAs to analyze for differences in microhabitat selection by species between sites, using percent abundance in the marsh (calculated from animal densities in pairs of samples of marsh and nonvegetated bottom) as the observation. The observations in this case were arcsine transformed. All of the t-tests and ANOVAs were executed on a micro-computer using SAS/STAT programs.

Untransformed means and standard errors of species densities were calculated by season/site/habitat and tabulated for Appendices II, III and IV. Tabulations were done with Lotus 1-2-3 and graphics were done with ENERGRAPHICS and Sigma Plot. All data and analytical reductions have been stored on standard 5 1/2 inch magnetic floppy disks.

A direct gradient analysis was used to associate distribution of species within the bay with salinities. As recommended by Gauch (1986), we chose this procedure because at least two factors distinguishing the sites were obvious (salinity regime and position in the bay) and because of its simplicity and ease in interpretation. The aim was to show salinity preferences of species using their distribution patterns in the bay, i.e. abundance patterns among sites could be related to the salinity characteristics of the sites. In the procedure, we used abundances of species to calculate a central position for each species on the gradient. The gradient was ordered 1 through 6, corresponding to site numbers. The position of each species (GP) relative to sites on the gradient was calculated using the equation

$$GP = \frac{(A \times 1) + (B \times 2) + (C \times 3) + (D \times 4) + (E \times 5) + (F \times 6)}{(A + B + C + D + E + F)}$$

where: ~~A =~~ abundance at Site 1, B = abundance ~~at~~ Site 2, C = abundance at Site 3, D = abundance at Site 4, E = abundance at Site 5, and F = abundance at Site 6. Since the ten year historical and the 1987 salinities were known for each site, both could be used in describing the most closely associated salinity regime (preference) of each species (by relating GP to site salinity). When the GP coincided with a site number, the associated salinity of the species was the same as the mean salinity calculated for that site. When the GP of a species fell between sites, as most did, linear interpolation was used to determine the salinity association.

Eliminated

RESULTS

Physical Parameters

Salinity: Salinity measurements taken in Galveston Bay during the 1987 survey are graphically compared to 10 year TPWD averages in Figure 3, and the 1987 salinity means and standard errors are given in Appendix II. Some imprecision in the 10 year historical database from TPWD may be present due to unequal sample sizes and they should be noted. The 10 year means (historical) at the Trinity Delta is based on only 26 measurements at the inner site (Site 1) and 25 measurements at the outer site (Site 2). Since the measurements are few and they were taken randomly over time, not all the monthly means are available (June is missing for the inner site and February is missing for the outer site). The remaininig sites, in the middle and lower bay, are in better shape in terms of numbers of measurements, but they too are unequal; eg., Smith Point (Site 3) has 125; Moses Lakes (Site 4) has 241; Jamaica Beach (Site 5) has 156; Christmas Bay (Site 6) has 87. We are nonetheless using the overall TPWD means at each of these sites as a representation of salinity history.

The salinity gradient is clearly evident (Fig. 3 and Fig. 4), both in 1987 and historically. The 1987 mean values, especially, fall within salinity classification ranges that divide the bay into oligohaline, mesohaline and polyhaline environments that correspond to the upper, middle and lower divisions of the bay. These cross seasonal means, both 1987 and historical, represent the influences of long-term salinity regimes. Seasonal differences are also evident with steeper gradients occurring in the spring and summer due to lower salinities in the upper bay and higher salinities in the lower system (Fig. 3). During the fall, salinities reach their annual peak in the upper system, thus reducing the slope of the gradient. These seasonal variations in salinity impose short-term influences on the environment. In Table 1, the short-term differences in salinity are depicted between sites seasonally and at the same time the overall integrity of the gradient is demonstrated. There was no difference in salinity between marsh and open water micro-habitats (Paired-t tests within sites and seasons, $n = 4$, $P > 0.05$).

Water Depths: Mean water depth at the sites was always less than 1 m and was always deeper in open water (near the edge of the marsh) than on the marsh surface (Appendix II). However, due to variability in water depths (they were changing with the tides) during sampling, differences in depth were not always significant between microhabitats (paired-t tests within sites, $n = 4$, $P > 0.05$). For the same reason, differences between marsh and open water depths among sites were usually not significant (ANOVAs, $df = 5$, $P = 0.05$; Table 2).

Figure 4. Mean salinities.

SALINITIES

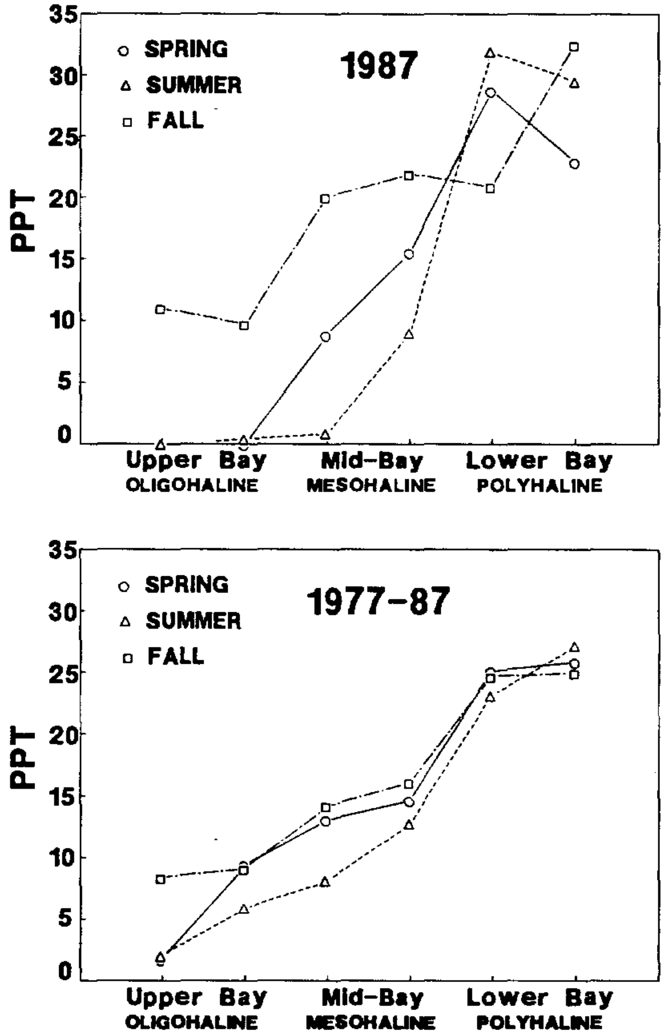

35
30
25
20
15
10
5
0
PPT
SPRING
SUMMER
FALL
1987
Upper Bay
OLIGOHALINE
Mid-Bay
MESOHALINE
Lower Bay
POLYHALINE
35
30
25
20
15
10
5
0
PPT
SPRING
SUMMER
FALL
1977-87
Upper Bay
OLIGOHALINE
Mid-Bay
MESOHALINE
Lower Bay
POLYHALINE

TABLE 1. Mean salinities at sites along an environmental gradient in Galveston Bay during drop sampling 1987. Mean value at each site is from combined measurements in marsh and adjacent open water (n = 8).

SEASON	SITES Salinities in ppt					
Spring (April-May)	OTD 0.01	ITD 0.02	SP 8.5	ML 15.5	CB 22.1	JB 33.3
Summer (July)	ITD 0.0	OTD 0.5	SP 0.8	ML 9.0	JB 27.8	CB 29.4
Fall (November)	OTD 9.6	ITD 10.8	SP 20.0	JB 20.5	ML 22.1	CB 32.1

Sites: ITD = Inner Trinity Delta, OTD = Outer Trinity Delta, SP = Smith Point, ML = Moses Lake, CB = Christmas Bay (see Fig. 1). Underline denotes no significant difference between values (ANOVA, df = 5, P > 0.05; LSD, df = 42). There was no difference in salinities between marsh and open water at each site (paired-t tests, n = 4, P > 0.05), therefore their values were combined within sites (n = 8) for ANOVAs. For exact dates and time of day that measurements were taken refer to Appendix II.

TABLE 2. Mean water depth differences between marsh and adjacent nonvegetated open water micro-habitats at sites along an environmental gradient in Galveston Bay during drop sampling in 1987. Values are means of differences in water depths from pairs of samples (open water - marsh = difference; n = 4 pairs) taken at each site flood tide.

SEASON	SITES Difference in water depth (cm) between marsh and open water.					
Spring (April-May)	OTD 7.1	ML 10.2	SP 18.0	JB 18.5	ITD 30.6	CB 51.0
Summer (July)	OTD 9.4	ITD 10.9	JB 19.9	ML 22.0	CB 24.4	SP 33.5
Fall (November)	CB 4.5	ML 12.0	ITD 16.5	SP 19.1	JB 23.9	OTD 30.1

Sites: (Identified in Table 1, above). Underline denotes no significant difference among values (ANOVA, df = 5, P > 0.05; LSD multiple range test, df = 42). For exact dates and time of day that measurements were taken refer to Appendix II.

Other Parameters: Water temperature, dissolved oxygen and water turbidity values were rarely different between microhabitats within sites (Appendix II; paired t-tests within sites and seasons, $n = 4$, $P > 0.05$), but were often different between sites (Table 3; ANOVA, df = 5, $P > 0.05$; LSD multiple range test, df = 42). However, gradient-related patterns in temperature and dissolved oxygen were not apparent. A weak pattern of higher turbidities at upper bay sites and lower turbitidies at lower bay sites was evident. Mean temperatures were lowest during the fall sampling (18.8 to 25.2 °C) and highest during the summer sampling (27.6 to 32.0 °C). Dissolved oxygen was lowest during fall sampling (4.0 to 9.4 ppm) and highest during spring sampling (7.0 to 12.4 ppm). Turbidities were generally lower during the spring sampling (13.4 to 44.3 ppm) and highest during fall sampling (22.0 to 89.5 ppm). Although these parameters reflect conditions occurring while drop samples were being taken, they do not reflect the strong environmental gradient in the bay indicated by salinity.

Demersal Organisms

All Fishes: Drop sampling in marshes and adjacent nonvegetated open water during 1987 secured 49 species of fishes among 2030 individuals (Appendix III). These came from 4 replicate samples (2.6 m^2 each) X 2 microhabitats X 6 sites X 3 seasons, for a total of 144 samples and 374.4 m^2 covered. The overall number of fishes from marshes was 1,410 (7.5/m^2) compared to 620 (3.3/m^2) from nonvegetated open water. Although the total numbers were higher in marshes, the differences between micro-habitats were usually not significantly different within sites (paired t-tests within sites and seasons, $n = 4$, $P > 0.05$). Lowest densities occurred in the spring and highest in the fall (Fig. 5). Spring densities were not significantly different between sites within either microhabitat (ANOVA, df = 5, $P > 0.05$), but summer densities in both marsh and open water were significantly different between sites and fall densities were significantly different between sites only in the marsh. The pattern, mostly due to summer and fall occurrences, was one of higher abundances at the middle bay sites (Smith Point and Moses Lake) in both microhabitats (Fig. 5).

Commercial and Sports Fishes: Commercial and recreational fishes, comprised of spotted seatrout (*C. nebulosus*), southern flounder (*P. lethostigma*) and red drum (*S. ocellatus*), followed an occurrence pattern somewhat similar to that of all fishes combined. Densities were highest in the summer and fall, and middle bay sites had highest abundances (Fig.6). Mean seasonal occurrences were highest in marsh microhabitat at the outer Trinity Delta and Smith Point, and highest in open water at Smith Point, Christmas Bay and Jamaica Beach (Fig. 6).

TABLE 3. Means of temperature, dissolved oxygen and turbidity at sites along an environmental gradient in Galveston Bay during drop sampling in 1987. Mean value at each site is from combined measurements in marsh and open water (n = 8).

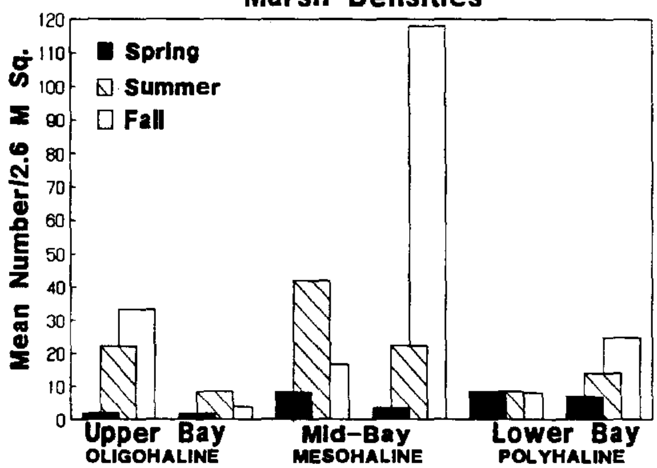
PARAMETER SEASON	SITES					
Temperature (^{o}C)						
Spring	CB	ITD	OTD	JB	ML	SP
(April-May)	23.7	28.0	28.6	28.8	29.5	30.5
Summer	ML	OTD	CB	ITD	SP	JB
(July)	27.6	30.6	30.7	31.2	31.4	32.0
Fall	ITD	JB	ML	OTD	SP	CB
(November)	18.8	20.9	22.4	22.7	22.9	25.2
Dissolved Oxygen (ppm)						
Spring	CB	JB	ITD	OTD	SP	ML
(April-May)	7.0	7.6	8.3	9.5	11.7	12.4
Summer	CB	JB	ML	ITD	SP	OTD
(July)	6.0	7.0	7.1	7.4	8.2	9.4
Fall	ITD	OTD	JB	ML	SP	CB
(November)	4.0	7.9	7.9	8.0	8.4	9.4
Turbidity (FTUs)						
Spring	JB	CB	SP	ML	OTD	ITD
(April-May)	13.4	14.6	17.0	29.3	33.1	44.3
Summer	CB	ML	SP	OTD	JB	ITD
(July)	10.3	26.8	30.5	30.9	32.0	46.4
Fall	CB	JB	ITD	OTD	SP	ML
(November)	22.0	24.4	50.8	51.5	70.9	89.5

Sites: (Identified in Table 1). Underline denotes no significant difference among values (ANOVA, df = 5, P > 0.05; LSD multiple range test, df = 42). For exact dates and time of day that measurements were taken refer to Appendix II.

Figure 5. Densities of all fishes.

ALL FISHES

Marsh Densities



Open Water Densities

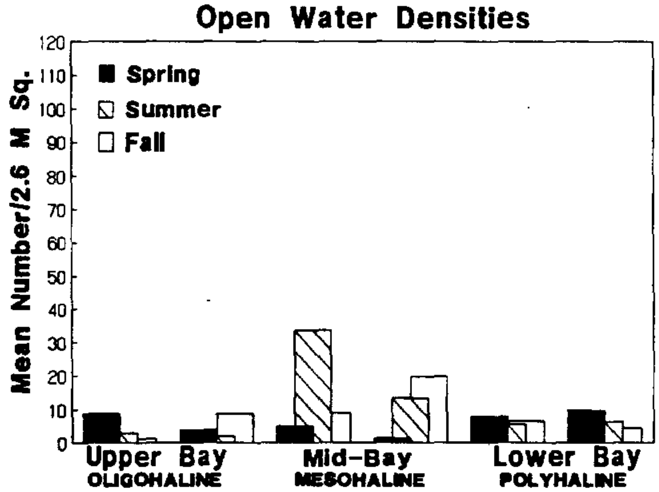
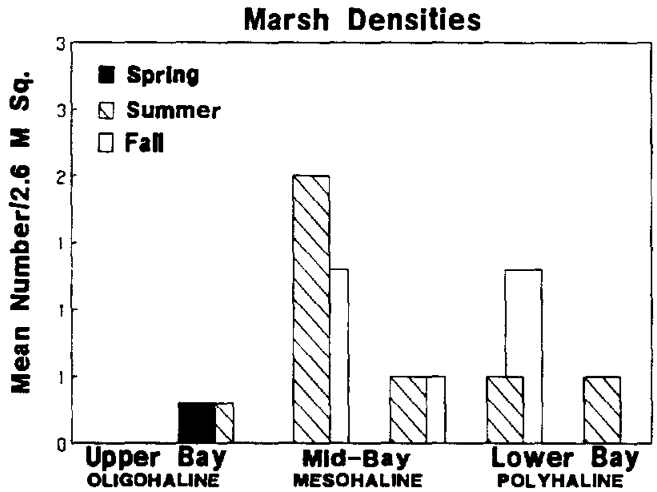
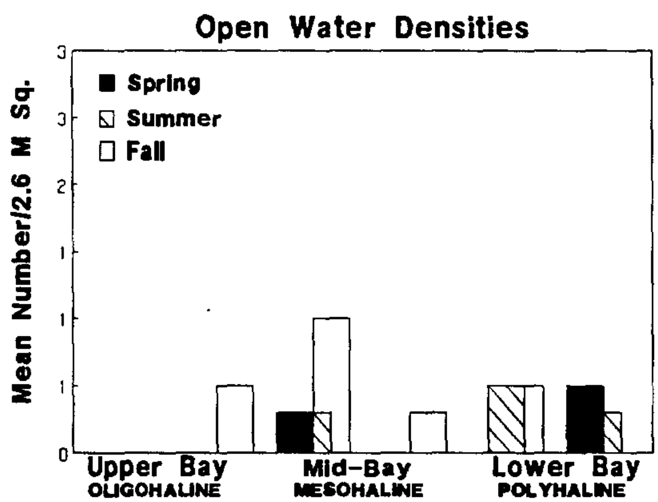


Figure 6. Densities of commercial and sports fish

GAME FISHES



Marsh Densities
Mean Number/2.6 M Sq.
3
3
2
1
1
1
0
Spring
Summer
Fall
Upper Bay
OLIGOHALINE
Mid-Bay
MESOHALINE
Lower Bay
POLYHALINE



Open Water Densities
Mean Number/2.6 M Sq.
3
3
2
1
1
1
0
Spring
Summer
Fall
Upper Bay
OLIGOHALINE
Mid-Bay
MESOHALINE
Lower Bay
POLYHALINE

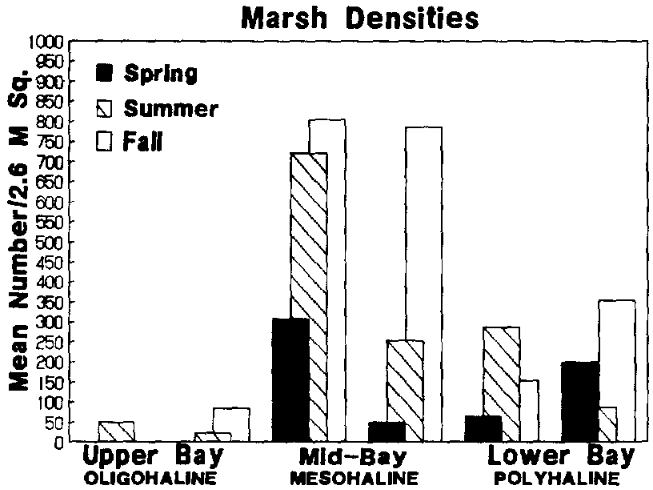
All Decapod Crustaceans: During 1987, 28 species of decapod crustaceans among 18,051 individuals were acquired in 144 drop samples equally divided between marsh and nonvegetated open water microhabitat (Appendix III). Of these, 16,914 individuals ($90/m^2$) were on marsh surface and 1,137 ($6.1/m^2$) were on nonvegetated bottom. Unlike combined fishes, decapod crustaceans within sites were usually significantly higher in marsh microhabitat than in open water (paired t-tests within sites and seasons, $n = 4$, $P > 0.05$). Lowest densities occurred in the spring and highest densities occurred in the summer and fall (Fig. 7). Densities were significantly different between sites within both micro-habitats during all seasons (ANOVA, $df = 5$, $P > 0.05$). The pattern was one of highest abundances at the middle bay sites at Smith Point and Moses Lake and lowest at the upper bay sites at the outer and inner Trinity Delta (Fig. 7). This strong pattern reflects high occurrences of decapod crustaceans in middle bay in all seasons (Fig. 7).

All Penaeid Shrimps: Spring and fall densities of combined penaeid shrimps were highest at lower bay sites declining toward the upper bay. Summer densities were highest in the middle bay (Smith Point) declining sharply to the upper bay and moderately to lower bay sites (Fig. 8). The resulting mean seasonal occurrence pattern among sites indicates higher occurrences in the lower bay and lowest in the upper bay (Fig. 8). Moreover, lower bay sites (Jamaica Beach and Christmas Bay) were the only sites where densities were always significantly higher in the marsh as compared to open water (paired t-tests within sites and seasons, $n = 4$, $P > 0.05$).

Brown Shrimp (*Penaeus aztecus*): Spring and summer densities of brown shrimp were highest and fall densities were lowest (Fig. 9). Densities were significantly different among sites within microhabitats during all seasons (ANOVAs, $df = 5$, $P > 0.05$) Brown shrimp distribution was mostly in the lower bay (Jamaica Beach and Christmas Bay) during the spring, mixed in the middle bay and lower bay in the summer (Smith Point and Jamaica Beach) and throughout the middle and lower bay in the fall (Fig. 9). No brown shrimp occurred at upper bay sites (outer and inner Trinity Delta) during the spring but a few occurred in the summer and fall. The mean seasonal occurrence pattern reflects low occurrences at the upper bay sites and generally high occurrences at middle and lower bay sites (Fig. 9). However, within marsh microhabitat highest mean occurrences were in the lower bay and in nonvegetated open water higher occurrences tended toward the middle bay. Significantly higher densities in marsh compared to open water occurred at Christmas Bay and Jamaica Beach in the spring, at Christmas Bay, Jamaica Beach and Moses Lake in the summer and at Jamaica Beach and Smith Point in the fall (paired t-tests within sites and seasons, $n = 4$, $P > 0.05$).

Figure 7. Densities of all decapods.

ALL DECAPODS



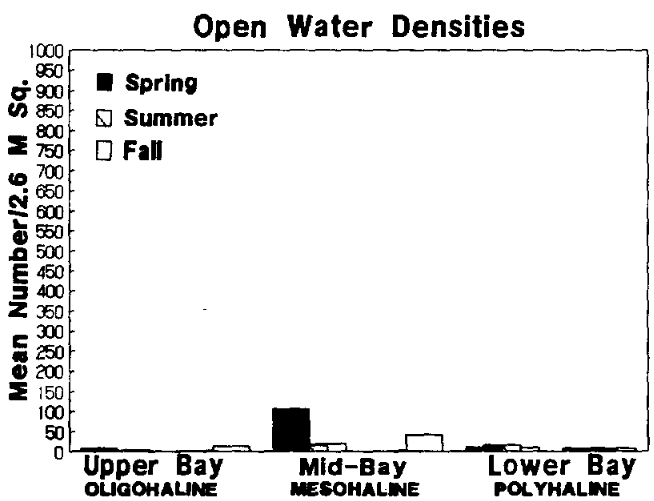
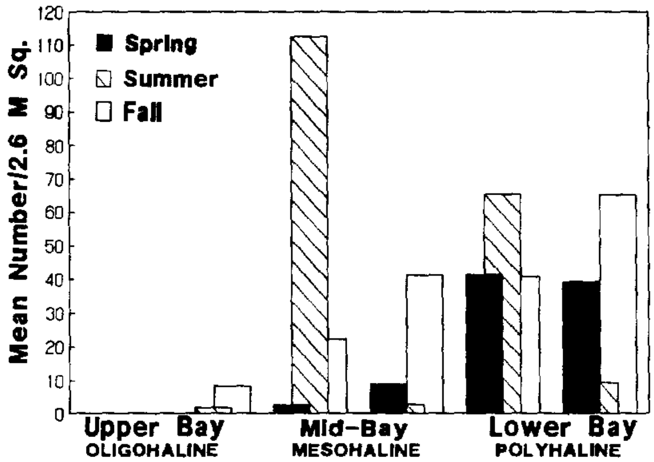


Figure 8. Densities of all penaeids.

ALL SHRIMP

Marsh Densities



Open Water Densities

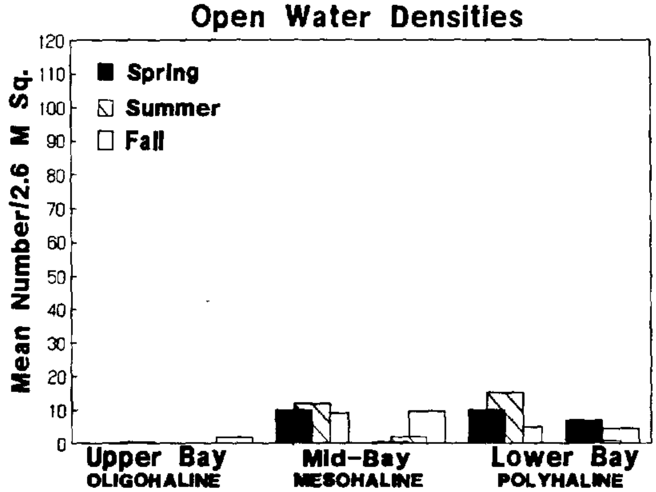
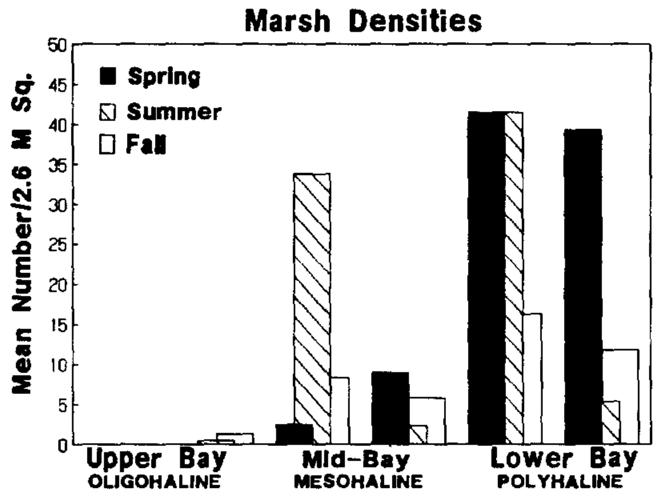
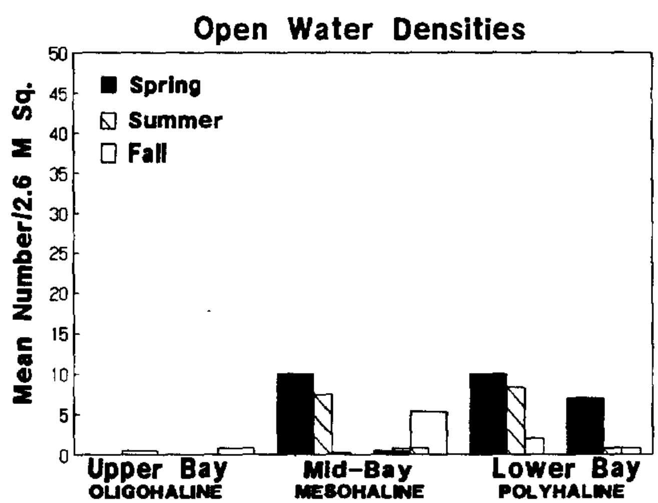


Figure 9. Densities of brown shrimp.

BROWN SHRIMP





White Shrimp (Penaeus setiferus): White shrimp entered the Galveston Bay system in the summer with highest densities in the middle of the bay at Smith Point in the summer and highest densities in the fall in the lower system at Christmas Bay (Fig. 10). In both seasons, densities among sites within habitats were significantly different (ANOVAs, df = 5, $P > 0.05$). The mean seasonal occurrence pattern (only summer and fall) reveals highest occurrence in the system for both marsh and open water at Smith Point in the middle bay and moderately lower levels of occurrence at other sites in the middle and lower bay (Fig. 10). Occurrence at the upper bay sites was sharply reduced. Despite high mean differences between marsh and open water (marsh was often much higher) densities between microhabitats were rarely significantly different. For instance, white shrimp densities between microhabitats with the highest values (Smith Point and Christmas Bay; see Fig. 10) were not significantly different (paired t-tests within sites and seasons, $n = 4$, $P > 0.05$).

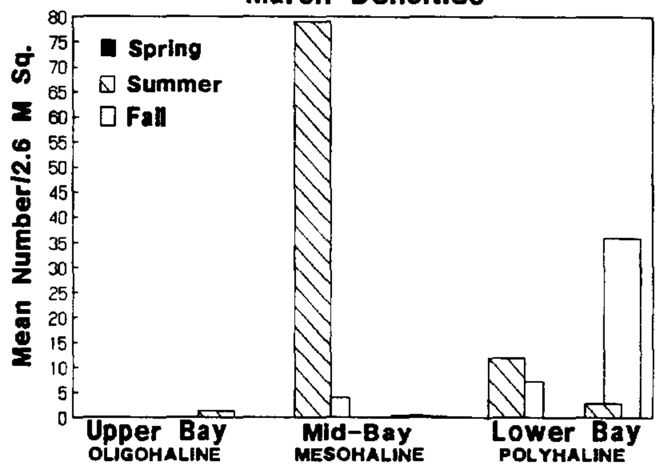
Pink Shrimp (Penaeus duorarum): Like white shrimp, pink shrimp were only in the system during the summer and fall, with highest seasonal densities in the fall (Fig. 11). Summer occurrence was restricted to the lower sites and fall occurrences were throughout the system, with highest fall densities at middle bay (Moses Lake) and lower bay (Jamaica Beach and Christmas Bay) sites. The mean pattern of seasonal occurrence indicates higher occurrences in both microhabitats at lower (Jamaica Beach) and middle (Moses Lake) sites (Fig.11). Density differences between marsh and open water (marsh was always higher) were always significant (paired t-tests within sites and seasons, $n = 4$, $P > 0.05$).

Blue Crab (Callinectes sapidus): Blue crabs occurred in all seasons and were distributed throughout the Galveston Bay system. Seasonal densities were lowest in the spring and highest in the fall (Fig. 12). Highest seasonal densities in marshes at sites were at Smith Point in the spring, at Jamaica Beach in the summer and at Moses Lake in the fall. The mean seasonal pattern for marsh microhabitat indicates highest occurrences at middle bay sites (Smith Point and Moses Lake) and moderate levels of occurrence in the lower system (Jamaica Beach and Christmas Bay) (Fig. 12). In open water microhabitat, the mean seasonal occurrence pattern indicates approximately equivalent levels of occurrence throughout the system (Fig. 12). Blue crabs were usually more abundant in marsh microhabitat, but not always, and often density differences between microhabitats were not significant. For example, in the spring, crab densities were significantly higher in open water than marsh at the inner Trinity Delta site and significantly lower at the Smith Point site, but densities were not different between microhabitats at any other sites (paired t-tests within site and seasons, $n = 4$, $P > 0.05$).

Figure 10. Densities of white shrimp.

WHITE SHRIMP

Marsh Densities



Open Water Densities

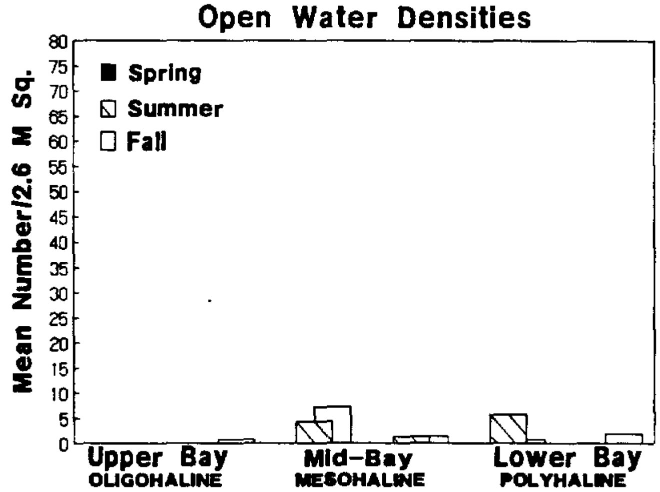
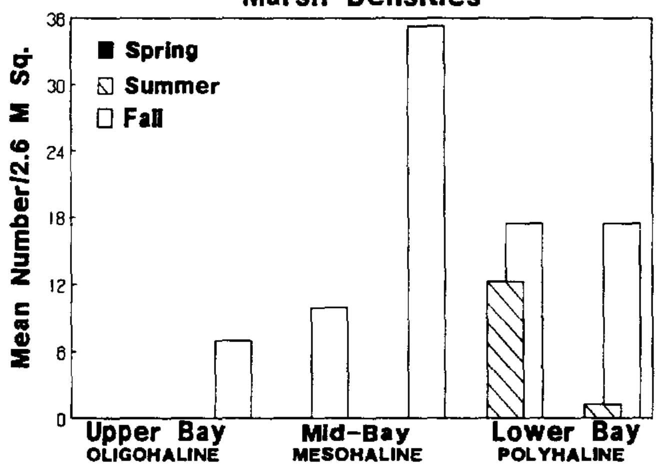


Figure 11. Densities of pink shrimp.

PINK SHRIMP

Marsh Densities



Open Water Densities

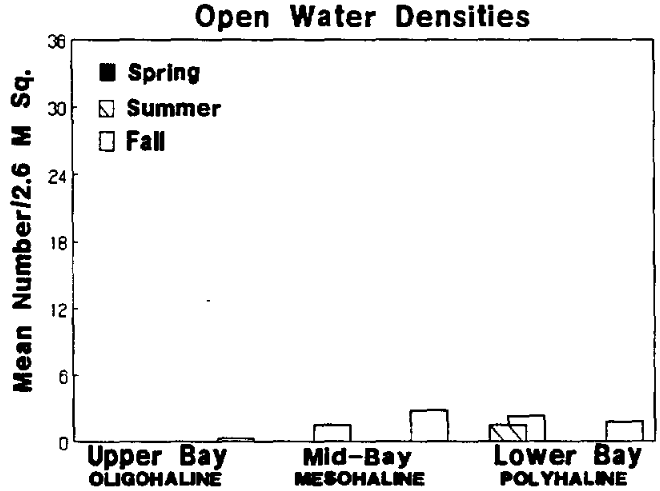
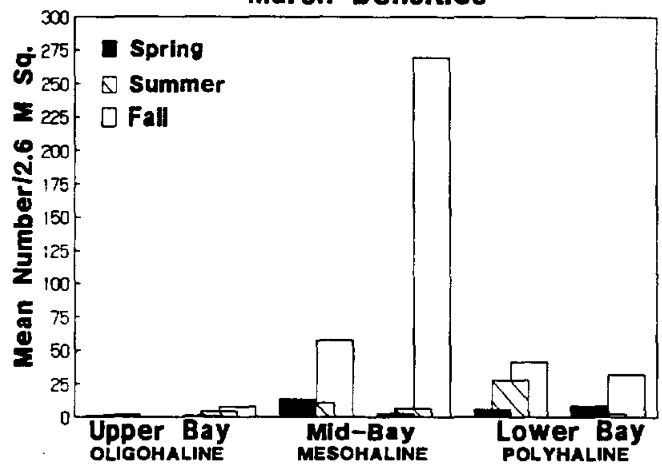


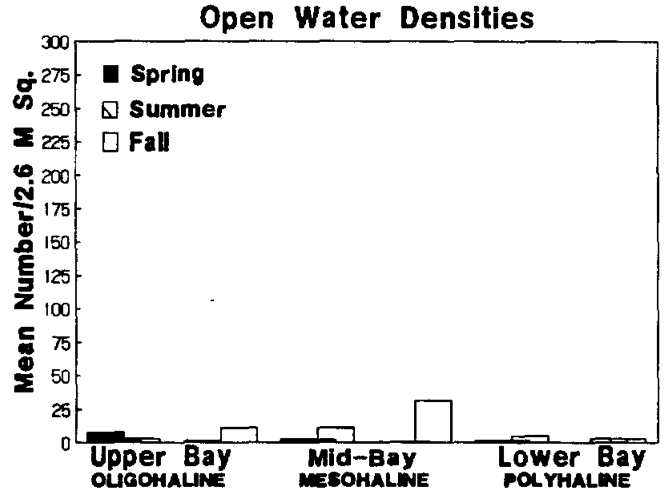
Figure 12. Densities of blue crab.

BLUE CRAB

Marsh Densities



Open Water Densities



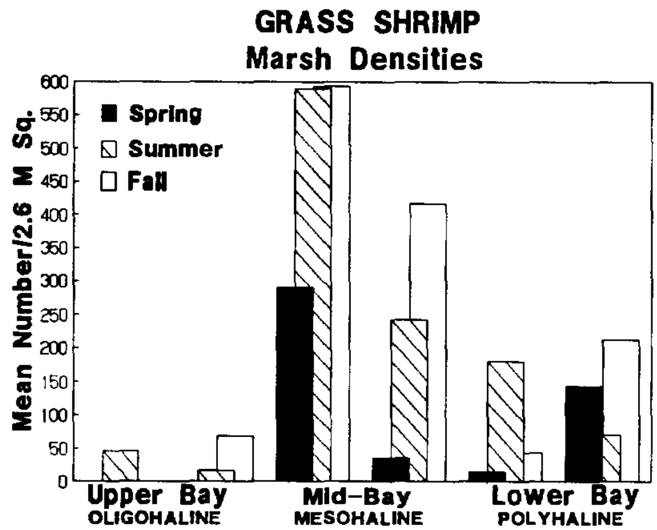
Grass Shrimp (Palaemonetes pugio): Grass shrimp occurred in all seasons and were the most numerous decapod crustacean in the marshes. Peak densities were in the summer and fall and in the middle bay at Smith Point and Moses Lake (Fig. 13). The mean seasonal occurrence pattern demonstrates the high occurrence level of grass shrimp in both marsh and open water at the middle bay sites (Fig. 13). Differences in densities between microhabitats (marsh densities were usually much greater) were nearly always significant (paired t-tests within sites and seasons, $n = 4$, $P > 0.05$).

Forage Organisms

All Epifauna and Infauna: All of the macrofauna taken from sediment cores (10 cm dia.; 78.5 cm^2 each) were considered to be forage organisms for demersal fishes and decapod crustaceans. These taxa mainly included annelid worms, peracarid crustaceans (mostly amphipods and tanaidaceans), and small mollusks. Densities of all these organisms combined were highest seasonally in the spring in the middle (Moses Lake) and lower (Jamaica Beach) Bay (Fig. 14). Within the summer and spring, combined densities were highest at the upper bay sites (Fig. 14). Although marsh microhabitat nearly always had higher combined densities, the mean values were rarely significantly different from open water (paired t-tests within sites and seasons, $n = 4$, $P > 0.05$). The mean seasonal occurrence pattern indicated that two upper bay sites (outer and inner Trinity Delta) had generally higher occurrences and the lower system (Jamaica Beach and Christmas Bay) had generally lower occurrences. The middle of the bay had transitional characteristics with both lowest (Smith Point) and highest (Moses Lake) occurrences.

Annelid Worms: Annelid worms (polychaeta and oligochaeta) were mostly infaunal and were the most uniformly abundant of forage organisms (Appendix IV). The patterns of distribution and abundance (Fig. 15) were similar to those of all epifauna and infauna combined (see Fig.14 and discussion above). Undoubtedly their high numbers are reflected in combined epi/infaunal abundances. Spring densities of annelids were highest seasonally, and like combined abundances, were highest during the spring in the middle bay. Notably, densities increased in the summer and fall at the upper bay sites (outer and inner Trinity Delta) while they decreased at lower and middle bay sites (Fig. 15). Marsh densities were significantly different among sites during all seasons, but for open water only spring densities were significantly different among sites(ANOVAs within seasons, $df = 5$, $P > 0.05$). Rarely were annelid densities significantly different between marsh and open water within sites (paired t-tests within sites and seasons, $n = 4$, $P > 0.05$). Mean seasonal occurrences were generally higher in the upper system and lower in the lower system (Fig. 15).

Figure 13. Densities of grass shrimp.


GRASS SHRIMP
Marsh Densities
Mean Number/2.6 M Sq.
0
50
100
150
200
250
300
350
400
450
500
550
600
Spring
Summer
Fall
Upper Bay
OLIGOHALINE
Mid-Bay
MESOHALINE
Lower Bay
POLYHALINE

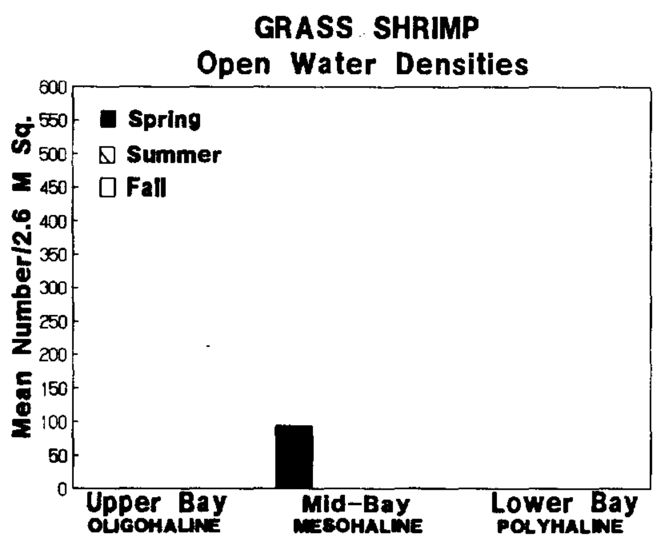
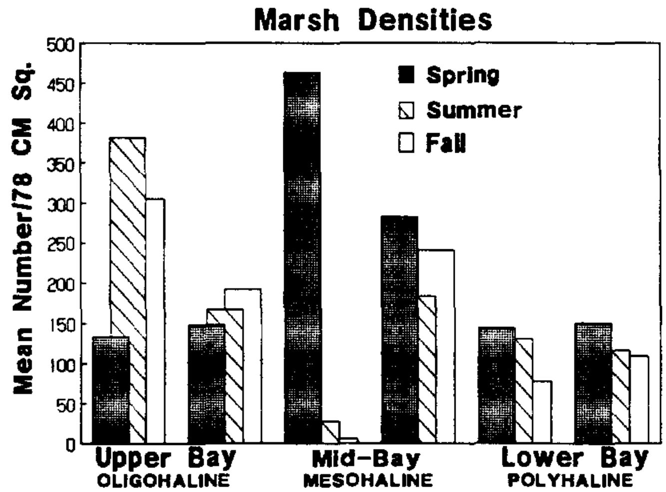

GRASS SHRIMP
Open Water Densities
Mean Number/2.6 M Sq.
0
50
100
150
200
250
300
350
400
450
500
550
600
Spring
Summer
Fall
Upper Bay
OLIGOHALINE
Mid-Bay
MESOHALINE
Lower Bay
POLYHALINE

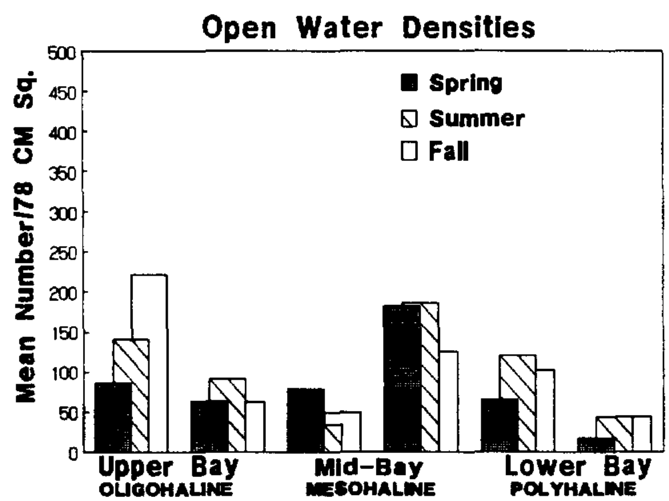
Figure 14. Densities of epi/infaunal

Eliminated

Figure 15. Densities of annelids.

ANNELID WORMS





Amphipods and Tanaidaceans: Amphipods and tanaids (peracaridean crustaceans) were second in abundance to annelid worms as forage organisms (Appendix IV). Like annelids, seasonal densities were highest in the spring declining to lowest levels the fall (Fig. 16). In contrast to annelids, peracarids were virtually absent from the upper system. In the middle system, abundances of pericarids were comparatively high (Fig. 16). This pattern is clearly reflected in mean seasonal occurrences among sites (Fig. 16). Within seasons, densities were always significantly different among sites in either marsh or open water (ANOVAs within seasons, df = 5, $P > 0.05$). Although mean densities in marsh microhabitat were often higher, the values were often not significantly different from open water (paired t-test within sites and seasons, n = 4, $P > 0.05$).

The Environmental Gradient

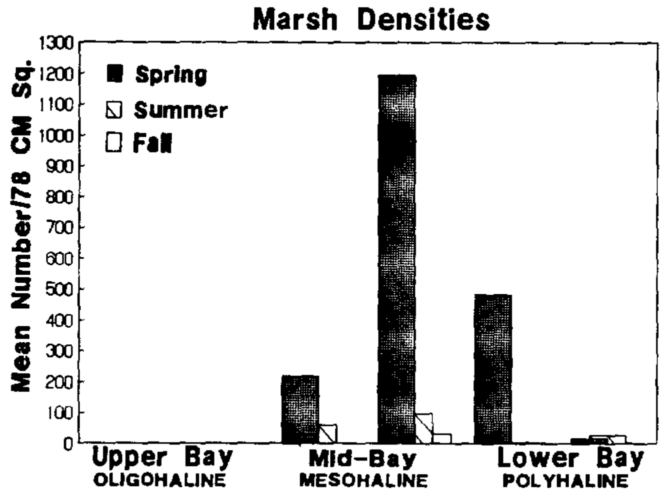
All species were analyzed for position that corresponded to site location and salinity along the environmental gradient. The center of distribution for each species was determined by abundance pattern from marsh and nonvegetated microhabitats across all three seasonal collections. SAV was not included since this microhabitat did not occur at all sites. The distribution center, or gradient position (GP), was used to characterize the most closely associated salinity of each species. These salinity regimes were calculated as 1987 means (our data, taken during drop sampling) and as the ten year salinity historical means at each site (data from random sampling by the Texas Parks and Wildlife Department). The sites and their corresponding salinities (1987 and historical) were: Site 1 - Inner Trinity Delta (3.6 and 6.0 ppt), Site 2 - Outer Trinity Delta (3.4 and 9.2 ppt), Site 3 -Smith Point (9.8 and 11.7 ppt), Site 4 - Moses Lake (15.5 and 15.7 ppt), Site 5 -Jamaica Beach (27.2 and 23.8 ppt) and Site 6 - Christmas Bay (27.9 and 26.4 ppt).

Among 47 species of fishes encountered, 8 species were most closely associated with the upper bay (Sites 1 and 2), 24 species were most closely associated with the middle bay (Sites 3 and 4) and 15 species were most closely associated with the lower system (Sites 5 and 6) (Table 4). Overall abundances of fishes were also highest in the middle bay. Of 2030 individuals, 394 (19.4 %) were in the upper bay, 1168 (57.5 %) were in the middle bay and 468 (23.0 %) were in the lower system (Table 4).

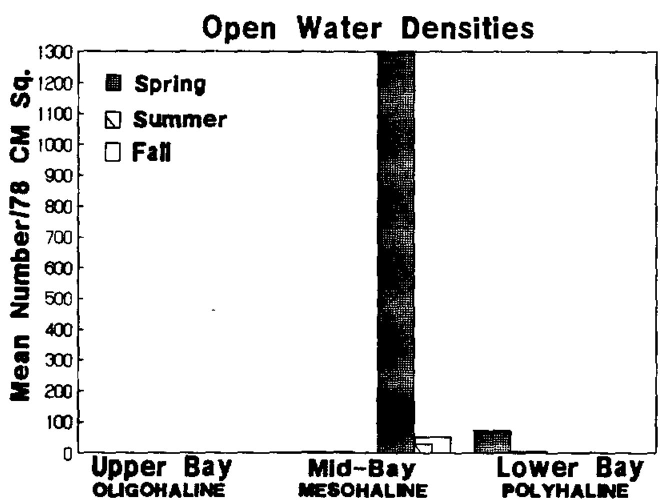
Among 28 species of decapod crustaceans encountered, 1 species was most closely associated with the upper bay (Sites 1 and 2), 14 species were most closely associated with the middle bay (Sites 3 and 4), and 13 were most closely associated with the lower system (Sites 4 and 5) (Table 5). Of 18,051 individuals, 756 (4.2 %) were at upper bay sites, 12433 (68.9 %) were at middle bay sites and 4862 (26.9 %) were at lower system sites (Table 5).

Figure 16. Densities of peracarids.

PERACARIDS



Marsh Densities
Mean Number/78 CM Sq.
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Spring
Summer
Fall
Upper Bay
OLIGOHALINE
Mid-Bay
MESOHALINE
Lower Bay
POLYHALINE



Open Water Densities
Mean Number/78 CM Sq.
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Spring
Summer
Fall
Upper Bay
OLIGOHALINE
Mid-Bay
MESOHALINE
Lower Bay
POLYHALINE

TABLE 4. Relationship between abundances of fishes and salinity regimes in Galveston Bay.

(Former Gradient Analysis)

Overall Abundances in relation to station Location and salinity) — modified.

TABLE 5. Relationship between abundances of decapod crustaceans and salinity regimes in Galveston Bay.

same as previous table

The most closely associated 1987 and historical salinities for each of eleven fishery species (Tables 4 and 5) were:

1) common croaker - 6.6 and 10.4 ppt
2) red drum - 10.6 and 12.2 ppt
3) spotted seatrout - 15.1 and 15.4 ppt
4) blue crab - 15.5 and 15.7 ppt
5) white shrimp - 16.1 and 16.1 ppt
6) southern flounder - 18.1 and 17.5 ppt
7) menhaden - 20.2 and 19.0 ppt
8) pink shrimp - 20.6 and 19.3 ppt
9) brown shrimp - 23.2 and 21.1 ppt
10) sheepshead - 27.2 and 23.8 ppt
11) stone crab - 27.2 and 23.8 ppt

As seen above, the most attractive salinities for fishery species during 1987 were not stricly mesohaline, but ranged from mesohaline (6.6 ppt) to polyhaline (27.2 ppt). Of the 11 fishery species, 6 were mesohaline and 5 were polyhaline.

Of 42 forage species, 6 species were most closely associated with the upper bay (Sites 1 and 2), 19 species were most closely associated with the middle bay (Sites 3 and 4) and 17 species were most closely associated with the lower system (Sites 5 and 6) (Table 6). Of 33,897 individuals, 8,356 (24.7 %) were at upper bay sites, 18,260 (53.9 %) were at middle bay sites and 7,281 (21.5 %) were at lower system sites (Table 6).

<u>Effect of SAV Microhabitat</u>

SAV microhabitat only occurred at Trinity Delta and in Christmas Bay. In both areas, SAV was adjacent to marsh in the low intertidal zone (usually only exosed during extremely low seasonal tides). Nonvegetated muddy sand was subtidal to SAV. In most instances, densities within sites were not significantly different between marsh and seagrass. However, Christmas Bay marsh and seagrass usually had significantly higher animal densities than those at the Trinity Delta (ANOVAs, df = 5, P > 0.05; LSD multiple range tests, spring and fall df = 18, summer df = 20). The outer Trinity Delta site had SAV year-around, but the inner site had SAV only in the summer.

Highest fish densities occurred in seagrasses at Christmas Bay and at the Trinity Delta inner site (Figure 17). In the spring, fish densities among site/microhabitat combinations were highest and significantly different only for Christmas Bay seagrasses; in summer, highest densities and significant differences overlapped between the inner Trinity Delta and Christmas Bay marsh and seagrass; in the fall, highest densities (not different) were in Christmas Bay marsh and seagrass (see Appendix for LSD results).

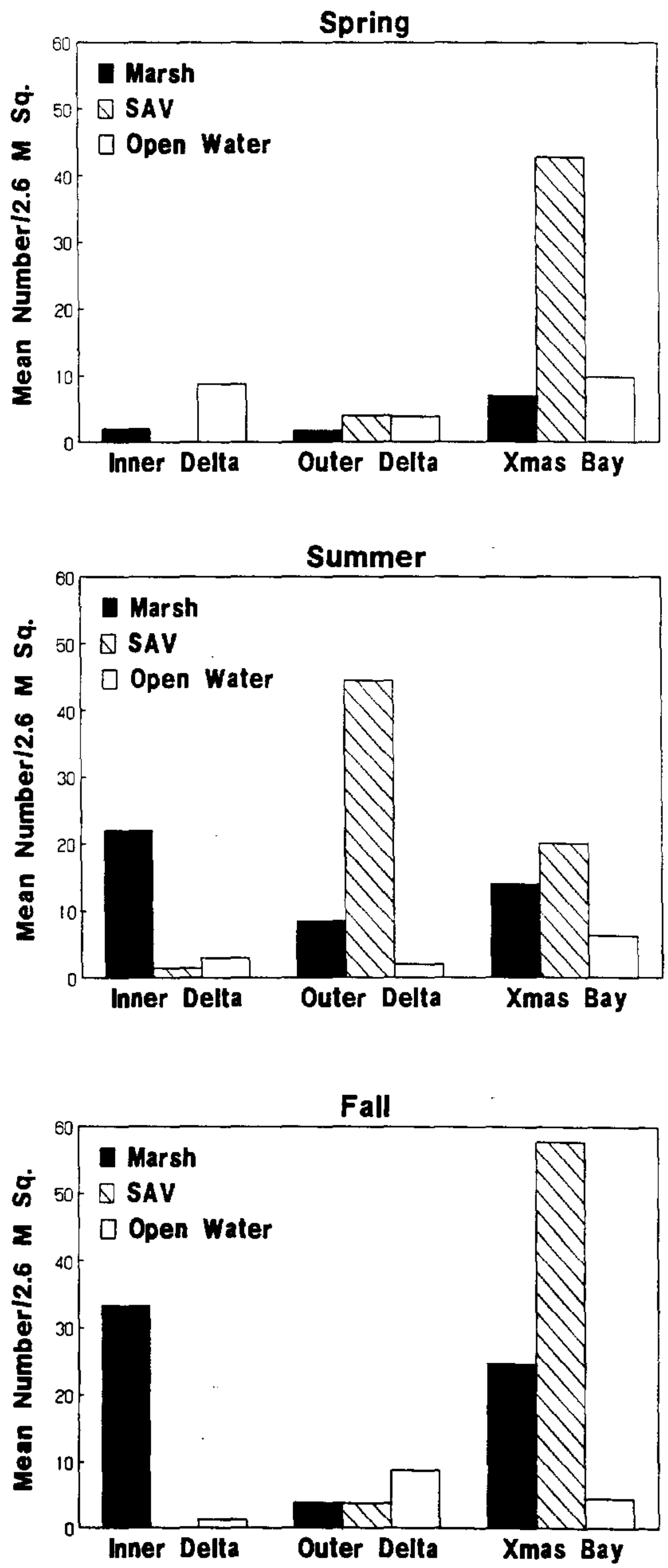
Highest decapod crustacean densities consistantly occurred in

Eliminated

~~TABLE 6. Relationship between abundances of epi/infauna and salinity regimes in Galveston Bay.~~

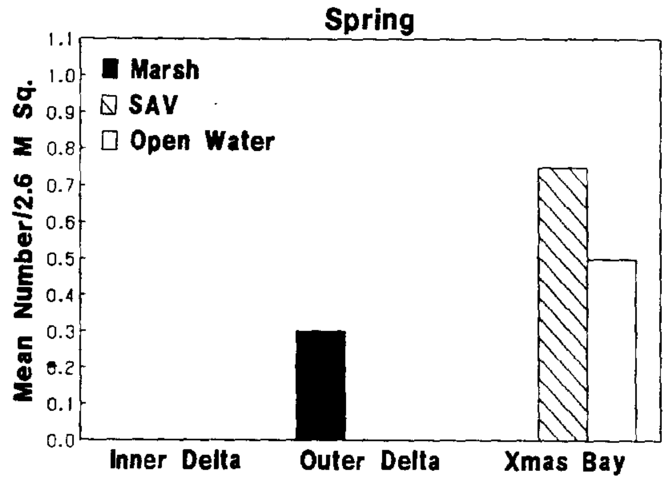
New Figures Follow — to compare marsh, SAV & open water habitats.

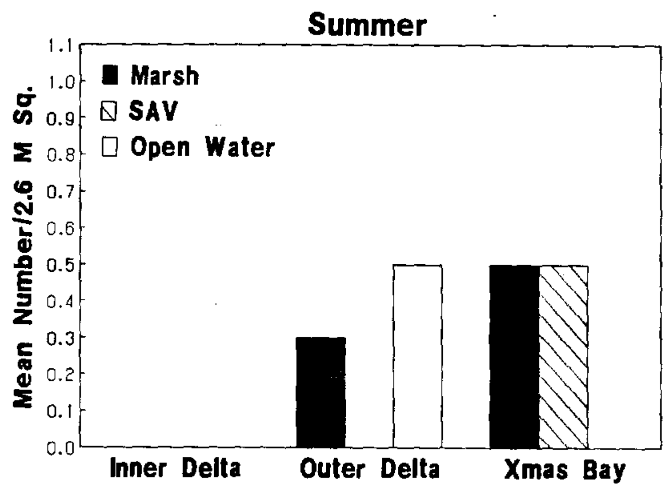
ALL FISHES

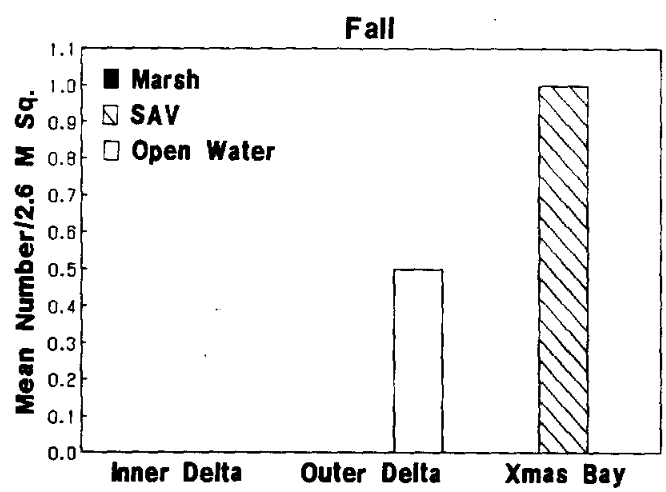


Spring
Summer
Fall
Mean Number/2.6 M Sq.
Marsh
SAV
Open Water
0
10
20
30
40
50
60
Inner Delta
Outer Delta
Xmas Bay

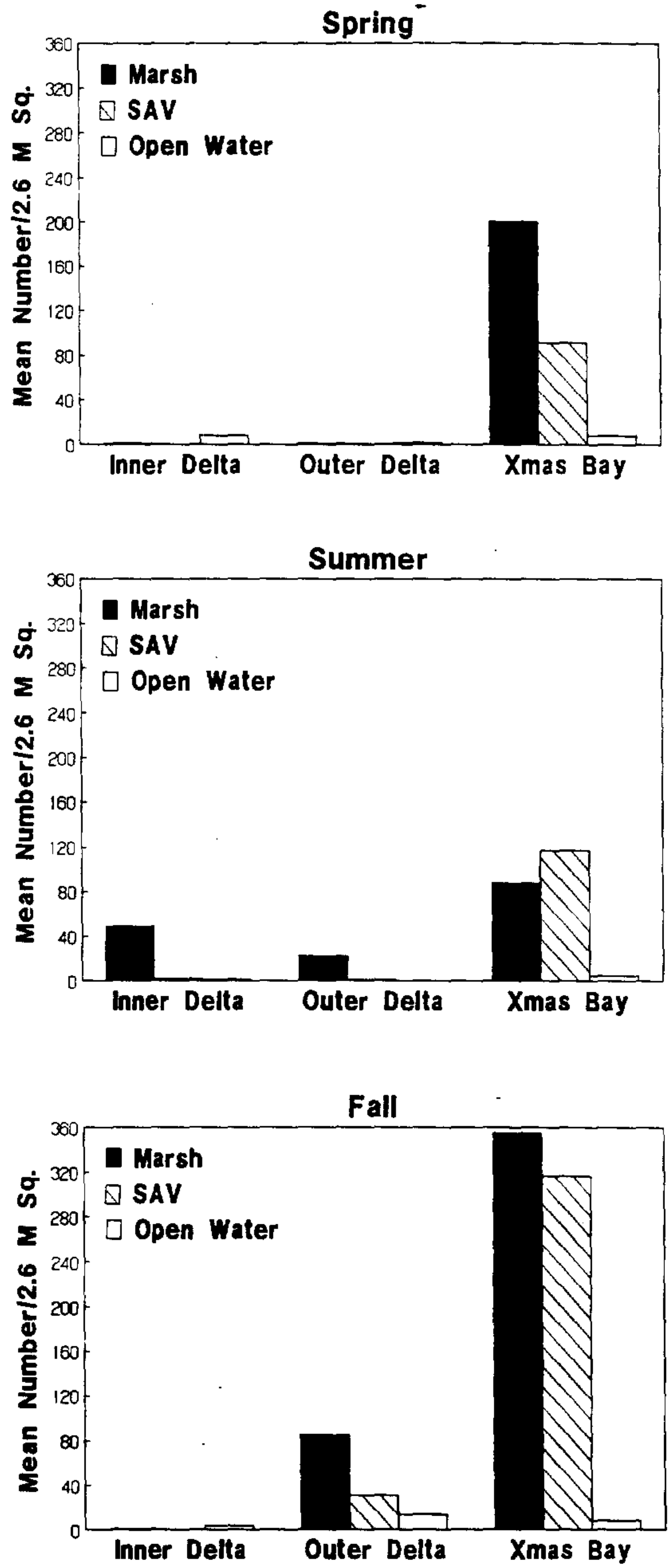
GAME FISHES


Spring
Marsh
SAV
Open Water
Mean Number/2.6 M Sq.
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Inner Delta
Outer Delta
Xmas Bay

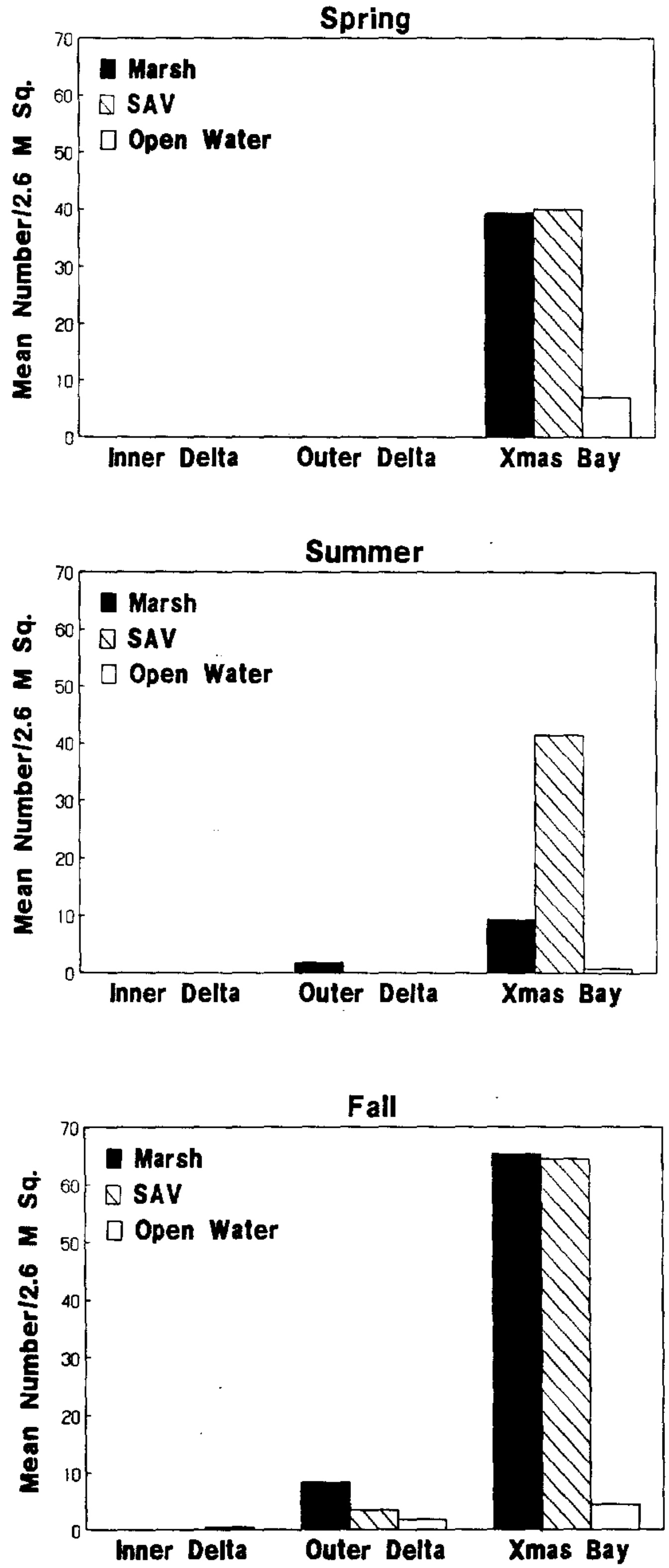

Summer
Marsh
SAV
Open Water
Mean Number/2.6 M Sq.
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Inner Delta
Outer Delta
Xmas Bay


Fall
Marsh
SAV
Open Water
Mean Number/2.6 M Sq.
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Inner Delta
Outer Delta
Xmas Bay

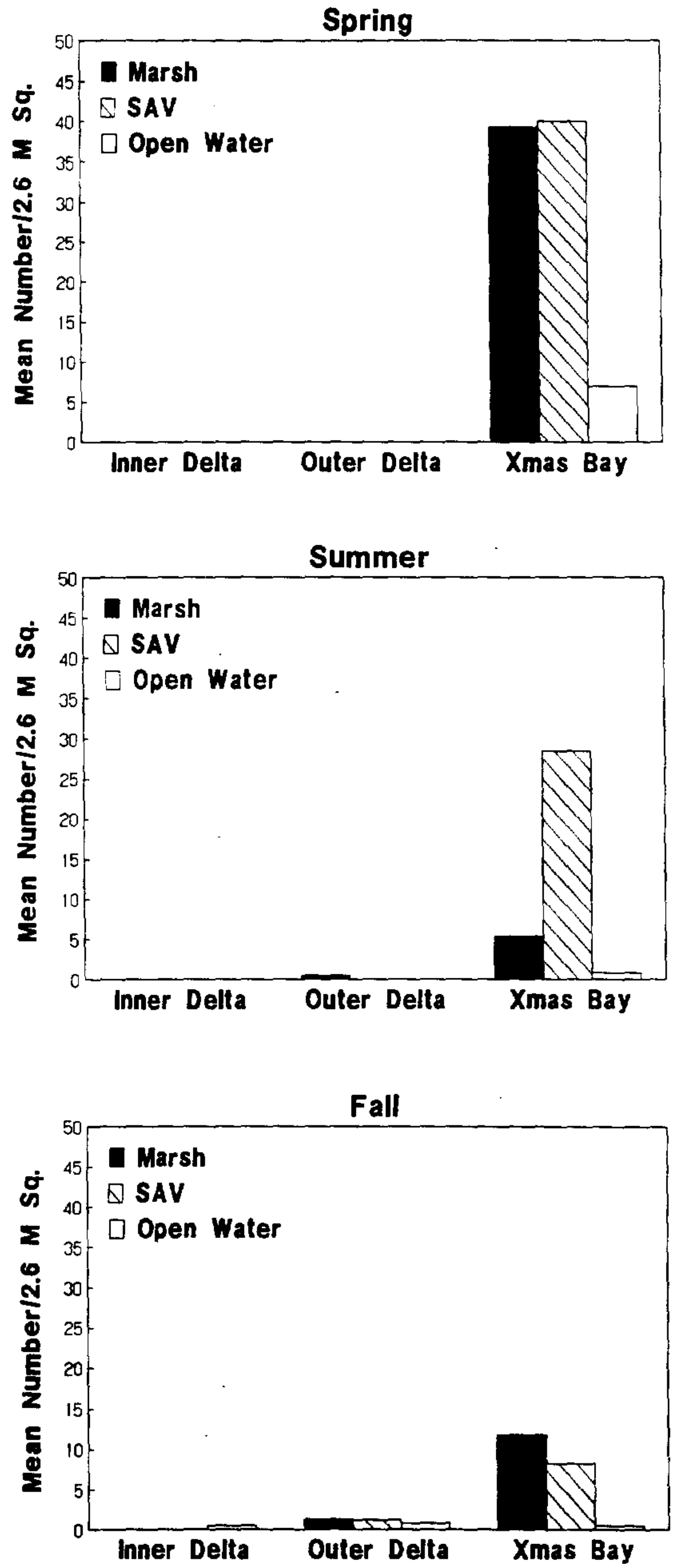
ALL DECAPODS



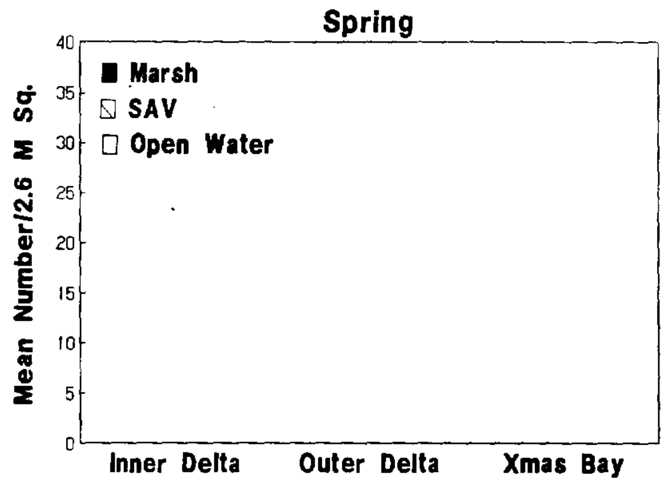
ALL PENAEIDS

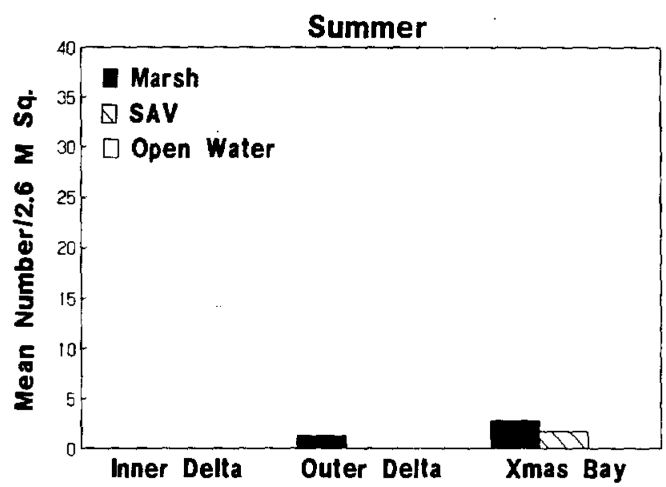


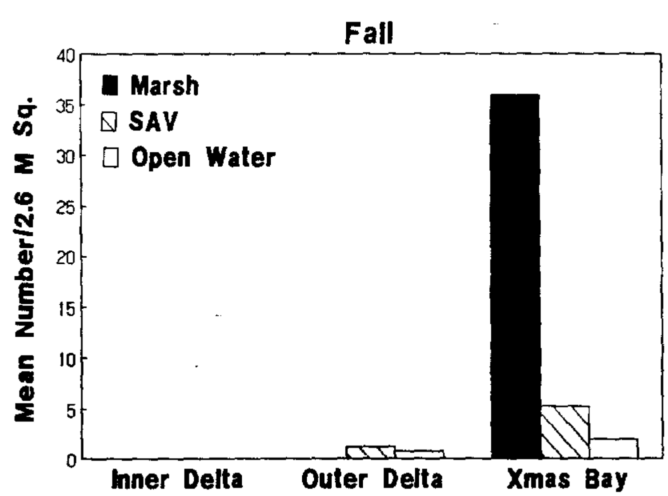
BROWN SHRIMP



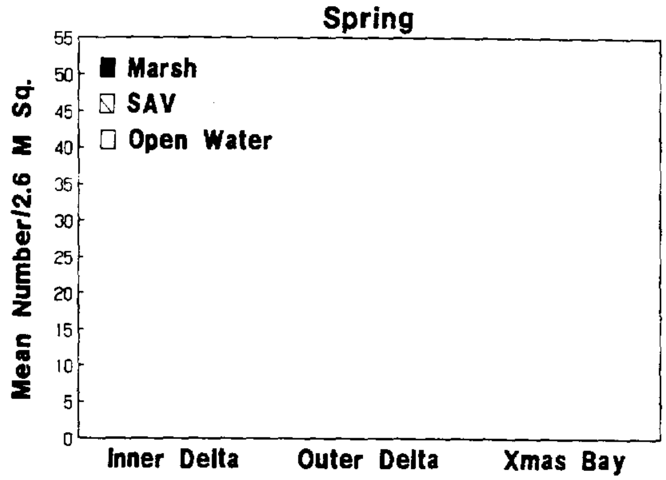
WHITE SHRIMP

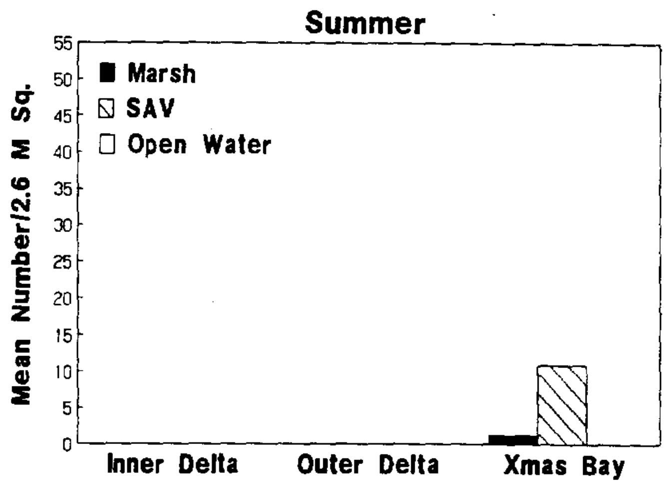


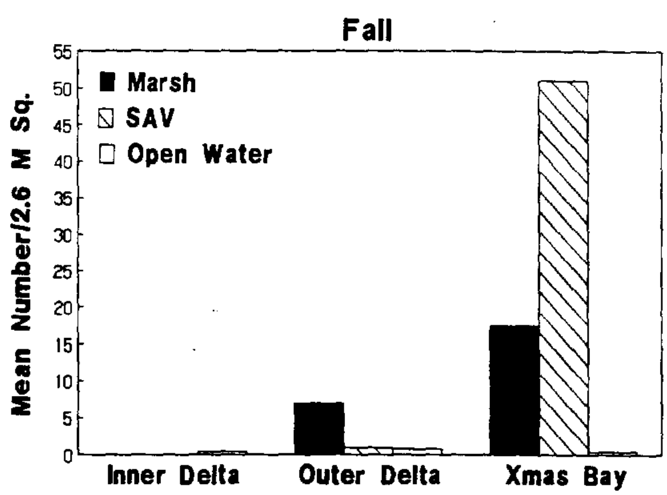




PINK SHRIMP

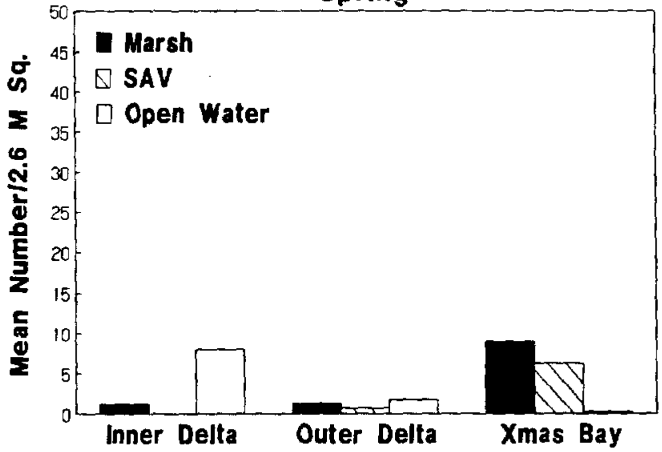

Spring
Marsh
SAV
Open Water
Mean Number/2.6 M Sq.
0
5
10
15
20
25
30
35
40
45
50
55
Inner Delta
Outer Delta
Xmas Bay


Summer
Marsh
SAV
Open Water
Mean Number/2.6 M Sq.
0
5
10
15
20
25
30
35
40
45
50
55
Inner Delta
Outer Delta
Xmas Bay

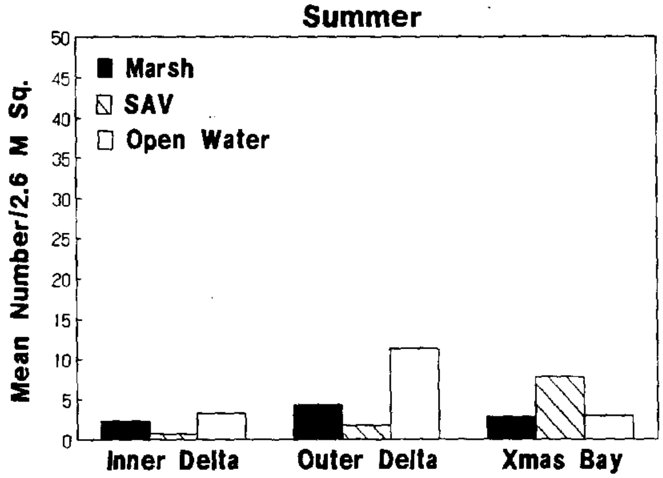

Fall
Marsh
SAV
Open Water
Mean Number/2.6 M Sq.
0
5
10
15
20
25
30
35
40
45
50
55
Inner Delta
Outer Delta
Xmas Bay

BLUE CRAB

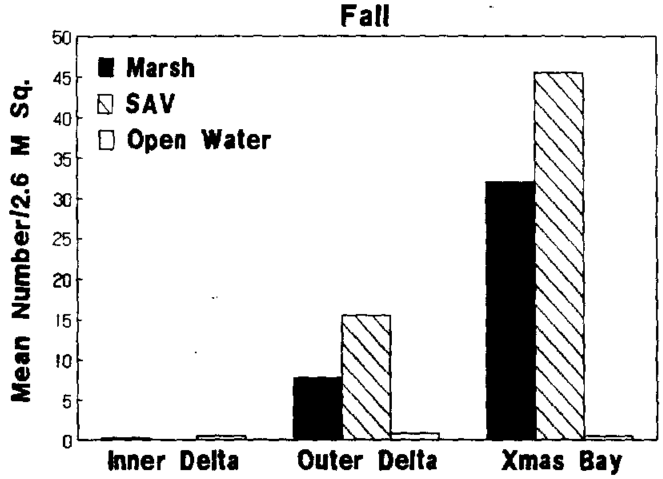
Spring



Summer



Fall



DISCUSSION

The Salinity Gradient in Galveston Bay.

The salinity gradient is clearly apparent in the Galveston Bay system and reflects the dominating influence of freshwater inflow on characteristics of marsh communities in the system. During 1987, the salinity gradient was steeper than usual, as salinities were lower in the upper bay and higher in the lower system than historical means (Fig. 4). The gradient was steepest in the summer (July) when salinities in the upper bay and part of the middle bay approached zero. These low salinities are short term phenomena that are within the range of annual variability; likewise, the higher salinities in marshes of the lower system during 1987 were short term events (within a season) that occurr normally. Data from 1982 through 1988 from a salt marsh in West Bay (the Jamaica Beach site) reveal that short term conditions are often hypersaline in the late summer. Our record shows that during August at the Jamaica Beach marsh salinities were 38 ppt in 1982 (Zimmerman and Minello, 1984) and 41 ppt in 1985 (unpublished) over a period of several weeks. Because of this variability, the gradient within the Galveston Bay system can be expected to range, at least on the short term, from fresh (0 ppt) to hypersaline (40+ ppt). The historical means at the sites along the gradient perhaps best describe salinty regimes in the system. In Figure 3, we have compared different parts of the system using 1987 and historical salinity regimes. These are long term attributes of the environmental gradient. Both long term (annual) and short term (seasonal) variations in salinity influence the responses of organisms.

Effect of Salinity on Organisms.

The deviations in 1987 salinities from historical means and corresponding responses in distributions and abundances of organisms can be viewed as reflections of short term versus long term effects. Short term salinity changes (together with other freshwater inflow attributes such as sedimentation) have immediate and direct effects, even if only temporary, on the community. Under short term low salinity stress, the larger mobile fauna have the option to leave the area or to stay and accommodate. Other less mobile organisms under the same circumstances, such as small epifuana, infauna and plants, cannot leave and thus must accommodate or suffer mortalities.

Many, if not most, estuarine species can temporarily accommodate oligohaline salinities below 5 ppt. Decapod crustaceans, such as brown shrimp, white shrimp and blue crab, are notable for their ability to accommodate low salinities (Zien-Elden 1989; Gifford 1962; Tagatz 1971). For example, we have observed responses of these and other estuarine species to abrupt lowering of salinities from mesohaline (7 to 15 ppt) to oligohaline (less than 1 ppt) during flooding of the Lavaca River delta in June of 1987. Freshwater flooding did not reduce densities of brown shrimp, white shrimp, grass shrimp, blue crabs in the delta marshes. Among fishes, densities of bay anchovies and menhaden actually increased significantly during the flooding. Similar results were achieved in the middle of Galveston Bay in the present study. Euryhaline faunal abundances were not depressed during short term lowering of salinities during the summer.

By contrast, other species are known to suffer mortalities due to abrupt lowering of salinity (reviewed by Brongersma-Sanders 1957). In lower Texas bays mortalities occur when populations acclimated to euhaline conditions (30 to 36 ppt) are exposed to rapid lowering of salinities due to rainfall from tropical depressions. Molluscan bivalves suffered mass mortalities in Redfish Bay after Hurricane Beauhla in 1967 (Zimmerman and Chaney 1968). Salinities, in this instance, were reduced from 30 ppt to less than 1 ppt within about a week. Hedgpeth (1953) reported mortalities after a similar event in Nueces Bay. Low salinity limitations are known for many estuarine species. The restriction of oyster populations to salinities above 5 ppt (reviewed by Van Sickle et al. 1976) and their predator, the oyster drill, to salinities above 15 ppt (Gunter 1979) are well known examples. Even among euryhaline species, such as red drum, white shrimp and brown shrimp, low salinities and temperature extremes that do not restrict juveniles and adults can be limiting to postlarvae (Holt et al. 1981; Zien-Eldin 1989).

There are good physiological reasons for such limitations. In some crustacea, the size of antennal gland is larger in animals that must maintain an internal fluid concentration that is hypotonic relative to the environment. The larger size is due to longer nephridial canals providing more surface area for salt resorption and dilute urine production. This occurrs in crayfish and some shrimp (Barnes 1980) and in freshwater amphipods (Green 1968). In marine, estuarine and terrestrial amphipods, the antennal glands are smaller than in comparable freshwater species (Schlieper 1930; Bousfield 1973;). This restricts many, if not most, estuarine amphipods from oligohaline environments and may account for their paucity at the Trinity delta during 1987. Most decapod crustaceans, like fishes, osmoregulate through their gills (not antennal glands) in brackish waters (Barnes 1980). Adaptation to resident living under oligohaline conditions is difficult in any case. Few aquatic fauna are well adapted to survive and reproduce in this transition zone between rivers and estuaries over the long term (Remane and Schlieper 1958). Those that do, such as some bivalves (Rangia) and annelids (nereids), usually exhibit specialized adaptations (Hopkins et al. 1973; Oglesby 1965a, 1965b). The capitellid and oligochaete infaunal worms that were abundantly found at the Trinity River delta are so adapted.

Marsh Communities in Galveston Bay.

The Upper System: Marshes in the upper system (Trinity Bay) are dominated by influences from the Trinity River and other streams emptying into the estuary. Overall salinities in 1987 were lower than historical averages in the upper system revealing a wet year (Fig.4). Both the inner and outer marsh sites at the Trinity River Delta were strictly oligohaline during the spring and summer of 1987. By fall, salinities had shifted to the low mesohaline range. Responses of the marsh community not only reflected 1987 conditions but indicated more general characteristics of the delta marsh environment.

Plant cover was very spare at the beginning of spring as a result of the winter die-back. Salt marsh bulrush (Scirpus robustus), the dominant marsh plant, began to emerge in April along with subdominants, arrowheads (Sagittaria lancifolia, S. latifolia), alligator weed (Alternanthera philoxeroides), pickerel weed (Pontederia cordata), water hyssop (Bacopa monnerieri), switchgrass (Panicum sp.) and others , but was heavily grazed by nutria (personal observation). Grazing pressure and export of the previous years production by tides and river floods left the intertidal zone virtually bare. The subtidal areas adjacent to the marsh were also barren of vegetation. By July, however, plants had recovered to near maximum biomass and the marsh surface as well as subtidal areas were dramatically changed. Scirpus cover was dense and lush and subtidal areas adjacent to the marsh were mostly covered with submerged aquatic vegetation (SAV). At the inner site, this vegetation changed with depth and extended from the marsh edge to nonvegetated open water about 80 cm deep. The dominant SAV species at the inner site (Site 1) were quillwort (Isotes sp.) and widgeongrass (Ruppia maritima) in shallow water and naiads (Najas spp.) and tapegrass (Vallisneria sp.) in deeper water. Quillwort was limited to very shallow water (less than 20 cm deep and often exposed) next to the marsh edge, forming a dense short turf that was present year-around. Its coverage was more extensive at the outer site (Site 2). Tapegrass was not at the outer site, but was present in large beds (in water about 30 to 80 cm deep) at the inner site. Further examination in 1988 revealed that the Vallisneria beds cover many hectares and extend westward for at least 2 kilometers. They appear to be a vegetational feature of the delta that has not been previously reported. In both 1987 and 1988, most of the vegetation experienced a die-back during the fall (September and October) that was associated with increased salinities; however it is not known whether the cause was salinity related. Most of the plant biomass was exported as detritus into Trinity Bay during ensuing winter months.

Of 8 species of fishes associated with delta marshes, 4 were cyprinodontidae (killifishes), two were freshwater species (crappie and channel catfish) and one was an estuarine species of commercial and recreational value (Atlantic croaker) (Table 4). During the spring, these fishes were mostly found in open water (not much vegetation present), but in the summer they shifted in increasing densities into marsh habitat. During the fall, fishes strongly selected marsh in favor of open water at the inner site and weakly favored open water at the outer site. The movements of fishes between microhabitats corresponded to seasonal changes in plant cover. McIvor and Odum (1988) point out that such differences in selection for the marsh surface may be controlled by the differences in the quality of nearby subtidal habitat that fishes must use when the marsh is drained. Fishes that seek high quality subtidal bottom for food and protection at low tide simply move onto the nearest marsh surface at flood tide. The single estuarine fish of commercial value (Atlantic croaker) associated with the Trinity delta also has been found in abundance under low salinity conditions (0 to 11 ppt) in upper Barataria Bay, Lousiana (Rogers and Herke 1987). This species is apparently one of the few that finds nursery refuge on nonvegetated bottoms and oligohaline conditions.

Although 10 of the 28 species of decapod crustaceans encountered used the upper bay sites at sometime in the year, only 1 (a crab) was closely associated with the sites (Table 5). All 3 species of penaeid shrimp and the blue crab used the delta marshes, but not in large numbers. Baldauf (1970) previously reported from monthly trawl surveys taken in 1967, 1968 and 1969 that brown shrimp, white shrimp and blue crab use the delta as a nursery. He concluded that brown shrimp abundances were less during years when Trinity River flow was high and that white shrimp abundances were not influenced by annual differences in river flow. Comparison of trawl collections in open water channels with marsh net collections on nonvegetated bottom next to the marsh yielded few shrimp found in association with the marsh. These data suggest that the marsh surface f the delta may not be as important as subtidal open water as nursery habitat for shrimps. We concur with his observation, and add that the roles of marsh surface and open water reverse in importance as nursery habitat toward the lower system. Accordingly, the direct utilization of the marsh surface becomes increasingly important toward the lower system.

Small macroinvertebrates, useful as forage organisms, were limited almost entirely to annelids worms at the delta sites during 1987. A nereid polychaete (<u>Laeonereis</u> <u>culveri</u>) and several unidentified oligochaete species comprised the dominant infaunal community (Table 6). Epifaunal peracarid crustaceans (amphipods and tanaidaceans) were essentially absent. Since peracarids are highly utilized and often are preferred (or more available) as food for small fishes and decapod crustaceans, their absence may have affected the distributions of these predators. At least, their absence would have lessened the food value of the delta marsh surface for many species. We propose that the lack of amphipods and tanaids was directly attributable to low salinities, since estuarine aquatic peracarids have poor ability to osmoregulate and cannot accommodate freshwater conditions for very long.

The Middle System: The marshes in the middle part of Galveston Bay are greatly influenced by exchanges between freshwater input from the upper system and seawater from the lower system. This was clearly demonstrated during 1987. Salinities at these sites (Smith Point and Moses Lake) varied more than at any other sites with values ranging between near 0 ppt to above 20 ppt (Fig. 4). Seasonal values were similar to those of the upper system or lower system depending upon circumstances; eg. spring salinities were mid-range (8 to 15 ppt); summer salinities were similar to the upper system (0.8 to 9 ppt) following several months of high freshwater inflow; fall salinities were like those of the lower system (20 to 22 ppt) following reduced freshwater inflow and high equinox tides. Over the long term the middle system was unquestionably mesohaline, despite short-term salinities that varied between oligohaline and polyhaline.

Marshes were mixed occurrences of smooth cordgrass (Spartina alterniflora), black rush (Juncus roemerainus), saltgrass (Distichlis spicata) and marsh hay (Spartina patens), with smooth cordgrass dominating the outer fringe. Submerged aquatic vegetation was not present, possibly due to the extreme variations in salinity. However, due to the presence of expansive oyster reefs in the middle bay, ample shell substrate was available in some areas for algal colonization observed to be mostly periphytic greens and bluegreens. These small algae were dense enough at Smith Point to be seen during aerial surviellance and mistaken for vascular SAV.

In the middle bay, fishes were not only nearly as diverse as those in the lower bay (32 versus 34 of 47 species), but they were more numerous (57.5 % of all individuals) and had more species closely associated with the area (24 of 47 species) than any other part of the bay (Table 4). The list includes the most valuable of the commercial and recreational fishes (menhaden, spotted seatrout, southern flounder and red drum) as well as many of the bait fishes of key importance to food chains (bay anchovy, spot, silversides and mullet). The salinity regimes of highest abundance calculated for these species was from 9.8 to 20.2 ppt in 1987 and from 11.7 to 19.0 ppt historically. This suggests that the mid-bay area, where most of the fishes are found, is an optimal environment for fishes under mid-mesohaline to lower polyhaline salinities.

Decapod crustaceans were less diverse in the middle bay (17 versus 24 of 28 species) than in the lower system, but they were more numerous (68.9 % of all individuals) and had more more closely associated species (14 of 28) (Table 5). Like fishes, the list of shrimps and crabs closely associated with the middle bay included the majority of commercially important (white shrimp, pink shrimp and blue crab) and food chain (grass shrimps and xanthid crabs) species. The 1987 salinity regime for these species ranged from

9.8 to 21.4 ppt, and the historical salinity regime ranged from 11.7 to 19.8 ppt; thus, optimal salinity conditions for most decapod crustaceans of fishery value were mid-mesohaline and lower polyhaline .

More than half of the combined species of annelids, small crustaceans and small mollusks (25 of 42) were found in the middle bay, and of these, 21 were more closely associated with the middle bay than upper or lower parts of the system (Table 6). Moreover, 53.9 % of all individuals were found at middle bay sites. Abundances of amphipods and tanaids were strikingly higher here than elsewhere, and their numerical relationship to higher abundances of larger fauna is likely to indicate food chain connections. Amphipods are a key compotent in the diets of many small estuarine fishes (Stoner 1982; Huh and Kitting 1985; Whitfield 1988). Gut analyses of fishes from Galveston Bay (Sheridan) and other Texas bays (Minello et al. 1987) support this observation. In recent experiments, both small juvenile brown shrimp and post larval blue crabs have been shown to prefer amphipods and tanaids over worms and mollusks (Zimmerman et al. 1989; Thomas and Zimmerman, 1989).

The Lower System: Historical salinity regimes at sites in the lower system (West Bay and Christmas Bay) are polyhaline, but short term factors commonly create mesohaline to hypersaline conditions. The dominant influence is Gulf water via tidal input. Evaporation normally produces a hypersaline environment in lower bay marshes during dry summers; but this condition is often alleviated or abruptly reversed by high rainfall from tropical depressions. In general, the lower system sites are more saline and less variable than those in the middle and upper systems because of moderation from the Gulf.

Lower system marshes are composed almost entirely of smooth cordgrass (*Spartina alterniflora*) at the bayside edge gradually changing to stands of glasswort (*Salicornia* spp.) saltwort and saltwort (*Batis maritima*) on the landward side. A salt pan zone without rooted vegetation, which does not occur in marshes of the middle and upper system, is usually present between the intertidal marsh and terrestrial vegetation. This zone is occuppied by a bluegreen alga mat (Sage and Sullivan 1978; Pulich and Rabalais 1986). In addition, epiphytic algae on *Spartina* (Sullivan 1978, 1981) and macroalgae (Conover 1964; Williams-Cowper 1978) are more abundant in the lower system. These bays commonly have submerged rooted flowering plants (including true seagrasses) as SAV along the bay margins. In Christmas Bay, these plants are shoal grass (*Halodule wrightii*), widgeon grass (*Ruppia maritima*), turtle grass (*Thalassia testudinum*) and *Halophila engelmannii*. At the Jamaica Beach site, large seagrass beds present as late as 1975 (Pullen) have disappeared. This loss of rooted SAV appears to have occurred throughout West Bay.

A similar number of fish species occurred in the lower system compared to the middle system (34 of 47 overall), but abundances were lower (23.0 % of all individuals) resulting in higher diversity. However, a relatively low proportion of those fish were most closely associated with lower system (12 of 34) indicating the transitional nature of the environment. Under most circumstances, the porportion of fully marine species can be expected to rise to 100 % as the salinities become increasingly euhaline. This occurs somewhere between about 20 and 35 ppt depending upon the stability of salinity in the environment (Remane 1934). Although all of the commercial and recreational fishes occurred in the lower system, only the sheepshead (Archosargus probatocephalus) was more closely associated with the lower system than with other systems (Table 4).

Decapod crustaceans were also more diverse in the lower system; eg., 24 of 28 species overall, and 26.9 % of all individuals. Of the 24 species, 13 were more closely associated with the lower system than the upper and middle systems. Among commercially important species in this group were brown shrimp (P. aztecus) and stone crab (Menippe mercenaria) (Table 5).

Of 42 forage species overall, 28 occurred in the lower bay among 21.5 % of all individuals, again indicating higher diversity than the in middle and upper systems. Of the 28 species in the lower system, only 12, a low proportion, were closely associated. Amphipods and tanaids were numerous but not as high in abundance as those encountered in the middle system. Abundances of annelid worms in the lower system were intermediate to those of other the other areas. The stablity of substrates, the presence of algae and seagrasses, and the relative uniformity of salinities afforded more habitat options in the lower system. Two structural and dietary factors are important to forage species in lower system marshes. For one thing, smooth cordgrass culms remain in place throughout the year even though a die back occurs in the winter (dead stems remain erect and it takes several years for them to deteriorate). The culms also provide year-around surface for the development of an epiphytic algal community. Both the algae and dead cordgrass are available as food and shelter for annelids, amphipods and tanaids. This epiphytic community is well developed at Jamaica Beach and, like salt marshes elsewhere, has higher numbers of epifauna among culms than on the surrounding bottom (Rader 1984; Zimmerman et al. 1989). As a consequence, the nursery value of lower system marshes for exploiting estuarine fishes, shrimps and crabs is high.

Marsh Utilization By Fishery Species.

Our hypothesis was that marshes under mid-range salinity regimes are more utilized by fishery species. The test of the null hypothesis is to disprove that utilization at sites in the middle bay, in the middle of the salinity gradient of the overall system, was not different from sites of the upper and lower subsystems. Using abundances, our results showed that fishery species were more associated with the mid-bay than with the other subsystems, thus disproving the null hypothesis. Indeed, most commercial and recreational species, including white shrimp, pink shrimp, blue crab, spotted seatrout, southern flounder, and red drum, had highest overall abundances in the mid-bay. As previously discussed, there was overlap in salinities of the middle bay with both the upper and lower subsystems (especially through seasonal variability). This underscores evidence that it is not salinity alone, but a complex of associated inputs, riverine from above and marine from below, that create this attractive mid-bay environment. It is also safe to say that favorable conditions for utilization of marshes in the middle bay extended more the lower subsystem than the upper subsystem.

Fishery species were not greatly attracted to the oligohaline marshes of the lower Trinity River delta during 1987. Although these delta marshes were not directly utilized, they nonetheless may be of substantial indirect importance to fishery species. Nearly the entire annual production of plants from the delta marshes at our sites is exported into the bay each year. This dead plant material becomes particulate detritus that fuels detritus based food chains in at least the middle subsystem and perhaps the lower subsystem.

Distributions of Foods

Annelid worms and peracarid crustaceans (amphipods and tanaids) constituted the most abundant macrofaunal benthos in sediments in Galveston Bay. Evidence from our feeding experiments (Zimmerman et al. 1990; Thomas, 1989) and gut analyses (Minello et al. 1989) indicate these small animals are the principal foods of small fishes, shrimps and crabs in the estuarary. Moreover, the literature cites numerous examples of the importance of these forage organisms in estuarine food chains (Kikuchi 1974; Young et al.1976; Bell and Coull 1978; Nelson 1981; Stoner 1982; Huh and Kitting 1985; Whitfield 1988).

However, benthic foods (both plant and animal) appeared to be differentially abundant throughout the bay and highly dependent upon location. Among plants, vascular plant detritus appeared more abundant in the upper and middle subsystems, while epiphytic and macro-algae was most abundant in the lower subsystem. Annelid worms were numerous throughout, but most abundant in the upper subsystem. Peracarid crustaceans were most abundant in the middle subsystem and nearly absent in the upper subsystem.

Since larger predators (fishes, crabs and shrimps) were exceptionally numerous in the middle subsystem, a food chain relationship with forage organisms can be inferred. We propose that the relationship is based upon the input of detritus and abundances of peracarids. As detritus from delta marshes is exported down the salinity gradient, it breaks up into smaller particles, is colonized and enriched with nitrogen by microflora, thus becoming ideal food for detritivorous annelids (Tenore 1977; Findlay and Tenore 1982), peracarids (Hargrave 1970; Monk 1977; Zimmerman et al. 1979) and molluscs (Newell 1964). Since very large populations of annelids and peracarids occurred in the middle subsystem, detritus availability and conditioning appears to be most favorable in this area. These small prey are available to support large numbers of small fishes and decapod crustaceans, and many of these, in turn, serve as ready food for larger fishes and crustaceans. Thus, a detritus-based benthic food web (Odum 1975) is created in the middle bay. Among the forage animals, peracarids appear to be more preferred and are more available than annelids (Huh and Kitting 1985; Leber 1985; Luczkovich 1988; Thomas 1989; Zimmerman et al. 1990). The relative absence of peracarids from the delta marshes was striking and we predict it may have been a reason that so few predators were attracted there.

Effect of Salinity on Fishery Habitat

The direct effect of salinity (that is, salinity per se) appears to have little influence on distributions of demersal fishes, crabs and shrimps except under extreme circumstances. Even then, most estuarine species tolerate very low salinities (less than 1 ppt) for short periods of time (days to weeks). Large natant decapods and fishes in Texas estuaries commonly move across salinity gradients into low salinities (Baldauf 1970; Renfro 1960). Their presence or absence in low salinity situations appears to be a behavior of choice. Species such as brown shrimp, white shrimp, blue crab, grass shrimp, menhaden, bay anchovies, striped mullet, red drum, southern flounder and common croaker are often noted in very low salinity waters. For instance, during the summer of 1987, we obtained all of these species and others in mid-bay waters at Smith Point with 0.8 ppt salinity. About 10 kilometers away from this site, the salinity was similar (0.5 ppt) at the delta marsh sites, yet these estuarine species were virtually absent. We submit that the reason for these differences in abundances was not due to the short term effect of salinity itself, but to habitat differences that developed from longer term effects of salinity.

One long term difference we noted was the effect of salinity on distribution of foods. The absence of amphipods and tanaidaceans in the delta marshes and their exceptional abundance in mid-bay marshes suggests that this is at least one cause-and-effect relationship between long term salinity characteristics and abundances of fishes and decapod crustaceans. It has long been known that oligohaline salinity regimes (> 5 ppt) diminish the number of residents of small less mobile estuarine species (Remane and Schlieper 1958). Estuarine amphipods and tanaids are among those whose species are limited to only a few that tolerate oligohaline conditions over the long term. Since they are highly useful forage organisms, their absence diminishes the value of a low salinity marsh for their predators. Since we know so little about these kinds of effects and how they are likely to control the relationships between salinity and fishery productivity, we propose that this is a fertile and necessary area of further research.

CONCLUSIONS

Salinity Characteristics of Galveston Bay Marshes

The environmental gradient in the Galveston Bay system is characterized by a strong salinity gradient. Salinities on the gradient range from fresh (0 ppt) to hypersaline (> 40 ppt) depending upon seasonal and annual rainfall. Normally, the upper system (Trinity Bay) is oligohaline to mesohaline, the middle system (Galveston Bay proper) is mesohaline to polyhaline, and the lower system (West Bay and Christmas Bay) is polyhaline. High rainfall during the spring and summer of 1987 reduced the salinities, causing in oligohaline conditions (< 1 ppt) throughout the upper system and highly variable conditions (< 1 to 15 ppt) in the middle system. Salinities of the lower system (22 to 33 ppt) were relatively unaffected. The resulting summer salinity gradient was the steepest of the year. As freshwater input diminished in the fall and equinox tides caused salinities in the upper system to increase to near 10 ppt, the slope of the gradient lessened across the system. These long term and short term salinity characteristics reflect freshwater inflow effects that determine the nature of marsh communities in the system.

Biological Characteristics of Galveston Bay Marshes

The marsh communities are clearly different between the upper, middle and lower subsystems. Their biological attributes uniquely characterize each subsystem, inferring relationships to salinity. At the same time, the subsystems are interconnected and depend on one another through materials flow. These interrelationships appear to have a larger effect on determining how marshes function for fishery species than salinity itself.

The upper subsystem, represented by the lower Trinity River delta, is oligohaline and strongly reflects freshwater influences. Emergent marsh plants (*Scirpus* and *Sagittaria*) are those commonly associated with active deltaic environments. This is one of the few areas in Galveston Bay supporting large stands of submerged aquatic vegetation (SAV). Part of the deltaic SAV is an extensive area of previously unreported *Vallisneria* habitat. During the winter months most of the emergent marsh and subtidal SAV dies back and is exported. SAV growth is essentially limited to the summer months. Among forage organisms present in the marshes and SAV habitat, peracarid crustaceans are few, but annelid worms are abundant. This pattern corresponds to relatively low useage of deltaic marsh and SAV by fishes and decapod crustaceans (usually not significantly different from useage of nonvegetated open water). As a result, since it is continuously available, nonvegetated subtidal bottom appears to be more directly useful as nursery habitat in the upper subsystem compared to the marsh surface and SAV. Even so, overall abundances of animals are significantly lower in the upper subsystem compared to the middle and lower subsystems.

By contrast, peracarids are exceptionally abundant in the middle subsystem and abundances of fishes and decapods are also high. The relationship exists because the large numbers of peracarids, in both marsh and open water, are useful as food to juveniles of many dermersal species. Consequently, marsh and nonvegetated bottom in the middle subsystem serve equally as nursery habitats that contribute to high production in fishery species. However, this productivity appears to be directly related to organic materials flow from the upper subsystem. We propose that the middle region receives most of its dead plant material, that is highly useful to peracarid detritivores such as amphipods and tanaids, from the deltaic marshes of upper region.

In the lower subsystem, marshes appear to be proportionately more important as nurseries compared to nonvegetated bottom. Forage organisms are significantly more abundant on the marsh surface and the structure of _Spartina_ culms offers stable year-around shelter. In addition, epiphytic algae populations are well developed in lower subsystem marshes. These factors improve the direct value of these marshes to exploiting juveniles of fishes and decapods crustaceans. The salinity regime, however, is not necessarily less stressful than in other parts of the bay, since hypersaline conditions are not uncommon in the lower system.

Relationship Between Salinity and Marsh Utilization

Each subsystem in the Galveston Bay system has characteristics that can cause physiological stress in organisms. Our observation is that most of the higher estuarine animals (such as estuarine dependent fishery juveniles) have evolved to accomodate these stresses and that distributions are due to other factors.

Fishery species were more abundant as species and individuals in mid-range salinities between middle mesohaline and low polyhaline values. These salinity conditions and abundances of animals occurred in the middle subsystem of Galveston Bay. We propose that the reason for this relationship was arises from freshwater inflow, but it is not necessarily due to salinity. The direct cause-and-effect relationships are food chain responses to materials flow. However, salinity reflects freshwater inflow, and areas that most favor utilization by fishery species can be delineated by mid-range salinity regimes.

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APPENDIX I: Principal Keys and References Used to Identify Galveston Bay Aquatic Fauna.

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APPENDIX II: PHYSICAL MEASUREMENTS, SPRING.

GALVESTON BAY STUDY
ENVIRONMENTAL PARAMETERS
SPRING SAMPLING SET

	Site 1 TRINITY RIVER INNER DELTA				Site 2 TRINITY RIVER OUTER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	27.4	0.43	28.5	0.22	28.7	0.93	28.6	1.27
Salinity (ppt)	0	0.02	0	0	0	0	0	0.01
Dissolved Oxygen (ppm)	8.1	0.42	8.5	0.29	9.2	0.51	9.7	0.74
Turbidity (FTU)	45	5.58	43.5	10.44	28	2.04	38.3	3.12
Median Depth (cm)	7.4	0.92	38	13.5	13.6	1.09	20.8	3.68
Maximum Depth (cm)	9.5	0.87	44	15.44	17	1.41	21.3	3.68
Minimum Depth (cm)	5.3	1.03	32	11.61	10.3	3.42	20.3	3.68
Time Interval: (date time)	(April 21: 1835 - 1929 hrs)				(April 20: 1610 - 1854 hrs)			

	Site 3 SMITH POINT				Site 4 MOSES LAKE			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	31.1	0.24	29.8	0.53	29.5	0.67	29.6	0.78
Salinity (ppt)	8.8	0.25	8.3	0.25	15.5	0.29	15.5	0.29
Dissolved Oxygen (ppm)	11.1	0.36	12.3	0.36	12.7	2.1	12.1	2.16
Turbidity (FTU)	13	5.43	21	4.81	31.5	10.99	27	7.55
Median Depth (cm)	22.5	2.61	40.5	3.85	8.5	1.67	18.8	1.61
Maximum Depth (cm)	25	2.52	41.3	3.97	16	3.19	19.5	1.66
Minimum Depth (cm)	20	2.86	39.8	3.75	1	0.71	18	1.58
Time Interval: (date time)	(April 21: 1457 - 1613 hrs)				(April 30: 1440 - 1551 hrs)			

	Site 5 JAMAICA BEACH				Site 6 CHRISTMAS BAY			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	28.8	0.47	28.8	0.23	23.7	0.25	23.6	0.2
Salinity (ppt)	33.3	0.14	33.3	0.32	23	1.35	21.3	0.25
Dissolved Oxygen (ppm)	7.5	0.13	7.7	0.38	7.7	0.23	6.4	0.19
Turbidity (FTU)	12.6	1.75	14.1	1.65	18.3	1.49	11	4.06
Median Depth (cm)	13.4	1.42	31.9	2.23	18.5	3.58	69.5	1.14
Maximum Depth (cm)	18.4	1.14	33.6	2.38	23.5	2.18	70.3	1.11
Minimum Depth (cm)	8.4	1.85	30.3	2.09	13.5	5.12	68.8	1.18
Time Interval: (date time)	(May 1: 1310 - 1725 hrs)				(May 6: 1147 - 1515 hrs)			

Drop samples; 2.6 m sq. each; N = 4;

APPENDIX II (continued): PHYSICAL MEASUREMENTS, SUMMER.

GALVESTON BAY STUDY ENVIRONMENTAL PARAMETERS SUMMER SAMPLING SET	Site 1 TRINITY RIVER INNER DELTA				Site 2 TRINITY RIVER OUTER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	31.4	0.24	31	0.41	30.4	0.69	30.8	0.48
Salinity (ppt)	0	0	0	0	0.4	0.08	0.5	0.03
Dissolved Oxygen (ppm)	7.3	0.41	7.6	0.42	9.2	0.47	9.5	0.27
Turbidity (FTU)	46.8	0.75	46	9.69	30.8	6.52	31	6.67
Median Depth (cm)	28.8	2.79	52.5	14.27	37.8	2.05	47.1	5.3
Maximum Depth (cm)	35.5	4.65	58.5	17.21	40	2.42	48	5.43
Minimum Depth (cm)	22	4.14	46.5	11.65	35.5	2.06	46.3	5.17
Time Interval: (date time)	(July 21: 1425 - 1630 hrs)				(July 21: 1115 - 1333 hrs)			

	Site 3 SMITH POINT				Site 4 MOSES LAKE			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	31.5	0.29	31.3	0.25	26.4	2.79	28.8	0.25
Salinity (ppt)	0.8	0.03	0.7	0.02	9	0	9	0
Dissolved Oxygen (ppm)	8.6	0.46	7.9	0.25	6.8	0.76	7.5	0.42
Turbidity (FTU)	34.8	7.97	26.3	1.11	28	5.58	25.5	2.1
Median Depth (cm)	34.3	4.99	67.8	4.51	40.8	3.5	62.8	3.82
Maximum Depth (cm)	41.5	5.56	69	4.45	49	3.83	64	4.06
Minimum Depth (cm)	27	5.08	66.5	4.57	32.5	4.5	61.5	3.57
Time Interval: (date time)	(July 22: 1320 - 1450 hrs)				(July 20: 0954 - 1113 hrs)			

	Site 5 JAMAICA BEACH				Site 6 CHRISTMAS BAY			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	31.9	0.22	32.2	0.15	31.4	1.55	30	0
Salinity (ppt)	27.9	0.13	27.8	0.14	29.5	0.5	29.3	0.48
Dissolved Oxygen (ppm)	7.3	0.21	6.7	0.32	5.7	0.48	6.3	0.55
Turbidity (FTU)	32.3	3.22	31.8	4.33	13.8	2.93	6.8	1.25
Median Depth (cm)	16.7	1.64	36.6	1.33	32.6	1.6	57	2.46
Maximum Depth (cm)	22.3	1.75	38.8	1.33	34.8	2.5	60	2.8
Minimum Depth (cm)	11.1	1.78	34.5	1.34	30.5	0.87	54	2.45
Time Interval: (date time)	(July 17: 1035 - 1347 hrs)				(July 24: 0946 - 1156 hrs)			

Drop samples; 2.6 m sq. each; N = 4;

APPENDIX II (continued): PHYSICAL MEASUREMENTS, FALL.

GALVESTON BAY STUDY ENVIRONMENTAL PARAMETERS FALL SAMPLING SET	Site 1 TRINITY RIVER INNER DELTA				Site 2 TRINITY RIVER OUTER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	18.5	0.46	19	0.31	23	0.44	22.3	0.35
Salinity (ppt)	11	0	10.5	0.29	9.8	0.25	9.5	0.29
Dissolved Oxygen (ppm)	3.7	0.41	4.3	0.38	7.9	0.56	7.8	0.31
Turbidity (FTU)	68.8	10.08	32.8	8.37	64.8	19.6	38.3	12.56
Median Depth (cm)	8.9	1.88	25.4	8.5	5.6	0.43	35.8	4.62
Maximum Depth (cm)	12.3	2.21	27.8	10.16	9	0.71	39.8	5.07
Minimum Depth (cm)	5.5	2.1	23	6.86	2.3	0.85	31.8	4.23
Time Interval: (date time)	(November 3: 0725 - 0921 hrs)				(November 2: 1017 - 1245 hrs)			

	Site 3 SMITH POINT				Site 4 MOSES LAKE			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	23.1	0.46	22.8	0.29	22.3	0.51	22.4	0.28
Salinity (ppt)	20	0	20	0	22	0.41	22.3	0.48
Dissolved Oxygen (ppm)	8.6	0.13	8.1	0.11	7.6	1.83	8.5	1.86
Turbidity (FTU)	90.5	38.2	51.3	13.44	111.3	18.19	67.8	14.79
Median Depth (cm)	25	3.17	44.1	1.42	18.8	2.92	30.8	2.25
Maximum Depth (cm)	29.5	2.72	45.3	1.6	36.3	5.02	32	2.48
Minimum Depth (cm)	20.5	3.66	43	1.29	1.3	1.25	29.5	2.02
Time Interval: (date time)	(November 3: 1158 - 1315 hrs)				(November 4: 0921 - 1115 hrs)			

	Site 5 JAMAICA BEACH				Site 6 CHRISTMAS BAY			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	20.9	0.06	20.9	0.06	25.3	1.4	25.1	0.66
Salinity (ppt)	20.5	0.29	20.5	0.29	32.5	0.87	31.8	0.25
Dissolved Oxygen (ppm)	8	0.15	7.8	0.18	9.4	0.27	9.4	1.5
Turbidity (FTU)	25.9	4.71	22.9	1.59	18	2.86	26	11.8
Median Depth (cm)	22.1	1.01	46.1	2.9	17.5	2.07	22	5.94
Maximum Depth (cm)	27	0.94	48.8	3.01	18.5	1.85	24.3	5.36
Minimum Depth (cm)	17.3	1.11	43.4	3.4	16.5	2.33	19.8	6.66
Time Interval: (date time)	(October 23: 0823 - 1209 hrs)				(November 5: 1015 - 1240 hrs)			

Drop samples; 2.6 m sq. each; N = 4;

APPENDIX III: FISH AND DECAPOD CRUSTACEAN DENSITIES, UPPER BAY, SPRING.

GALVESTON BAY STUDY UPPER BAY SYSTEM Macrofauna/2.6 m sq. (n=4) April 20-21, 1987		Site 1 TRINITY RIVER INNER DELTA				Site 2 TRINITY RIVER OUTER DELTA			
		VEGETATED		NON-VEGETATED		VEGETATED		NON-VEGETATED	
SPECIES		MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:									
Micropogonias undulatus	S108	0	0	3.5	2.02	0	0	0.8	0.75
Fundulus grandis	S117	0	0	0.3	0.25	1.5	0.87	0	0
Myrophis punctatus	S114	0	0	2.8	1.6	0	0	0.5	0.29
Anchoa mitchilli	S120	0	0	0	0	0	0	2	1.68
Leiostomus xanthurus	S101	0	0	0	0	0	0	0.5	0.5
Fundulus pulvereus	S142	1.8	1.75	0	0	0	0	0	0
Mugil cephalus	S106	0	0	0.8	0.75	0	0	0	0
Elops saurus	S109	0	0	0.5	0.5	0	0	0	0
Brevoortia patronus	S100	0	0	0.3	0.25	0	0	0	0
Citharicthys spilopterus	S115	0	0	0.3	0.25	0	0	0	0
Gambusia affinis	S140	0.3	0.25	0	0	0	0	0	0
Paralichthys lethostigma	S104	0	0	0	0	0.3	0.25	0	0
Symphurus plagiusa	S113	0	0	0.3	0.25	0	0	0	0
Syngnathus floridae	S122	0	0	0.3	0.25	0	0	0	0
Cyprinodontidae		1.8	1.75	0.3	0.25	1.5	0.87	0	0
Sciaenidae		0	0	3.5	2.02	0	0	1.3	0.75
Commercial/Sports Fishes		0	0	0	0	0.3	0.25	0	0
FISH TOTALS:		2	1.68	8.8	3.04	1.8	1.03	3.8	2.46
CRUSTACEANS:									
Callinectes sapidus	S404	1.3	0.48	8	1.58	1.3	0.75	1.8	1.18
Palaemonetes pugio	S403	0	0	0.5	0.29	0	0	0	0
CRUSTACEAN TOTALS:		1.3	0.48	8.5	1.32	1.3	0.75	1.8	1.18

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, MIDDLE BAY, SPRING.

GALVESTON BAY STUDY MID-BAY SYSTEM Macrofauna/2.6 m sq. (n=4) April 21 & 30, 1987		Site 3 SMITH POINT				Site 4 MOSES LAKE			
		Vegetated		Non-vegetated		Vegetated		Non-vegetated	
SPECIES		MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:									
Lagodon rhomboides	S103	3.8	1.7	0	0	1	1	0	0
Gobionellus boleosoma	S116	2.3	0.85	0.8	0.48	0	0	0	0
Myrophis punctatus	S114	0.3	0.25	0	0	1	1	1	0.71
Leiostomus xanthurus	S101	0	0	2	1.08	0	0	0	0
Gobiosoma bosci	S105	1.3	1.25	0.3	0.25	0	0	0	0
Mugil cephalus	S106	0	0	0.3	0.25	1	0.71	0.3	0.25
Fundulus grandis	S117	0.5	0.29	0	0	0.3	0.25	0	0
Symphurus plagiusa	S113	0	0	0.8	0.48	0	0	0	0
Elops saurus	S109	0	0	0.5	0.5	0	0	0	0
Adina xenica	S133	0	0	0	0	0.3	0.25	0	0
Lucania parva	S112	0.3	0.25	0	0	0	0	0	0
Menidia beryllina	S110	0	0	0	0	0	0	0.3	0.25
Micropogonias undulatus	S108	0	0	0.3	0.25	0	0	0	0
Paralichthys lethostigma	S104	0	0	0.3	0.25	0	0	0	0
Cyprinodontidae		0.8	0.48	0	0	0.5	0.29	0	0
Gobiidae		3.5	1.71	1	0.41	0	0	0	0
Sciaenidae		0	0	2.3	0.95	0	0	0	0
Commercial/Sports Fishes		0	0	0.3	0.25	0	0	0	0
FISH TOTALS:		8.3	3.45	5	1.08	3.5	2.02	1.5	1.19
CRUSTACEANS:									
Palaemonetes pugio	S403	290.5	48.05	94.3	93.92	37.5	37.17	0	0
Penaeus aztecus	S400	2.5	1.32	10	2.48	9	9	0.5	0.29
Callinectes sapidus	S404	13.3	2.1	2.8	1.25	2.8	2.43	0.5	0.5
Rhithropanopeus harrisii	S445	1	0.58	0.3	0.25	0	0	0	0
Penaeidae		2.5	1.32	10	2.48	9	9	0.5	0.29
CRUSTACEAN TOTALS:		307.3	51.36	107.3	93.26	49.3	48.58	1	0.41

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, LOWER BAY, SPRING.

GALVESTON BAY STUDY
LOWER BAY SYSTEM
Macrofauna/2.6 m sq. (n=4)
May 1st & 6th, 1987

SPECIES		Site 5 JAMAICA BEACH Vegetated MEAN	S.E.	Non-vegetated MEAN	S.E.	Site 6 CHRISTMAS BAY Vegetated MEAN	S.E.	Non-vegetated MEAN	S.E.
FISHES:									
Lagodon rhomboides	S103	1.3	0.75	0.5	0.29	3	1.68	5	4.02
Menidia beryllina	S110	7.3	6.92	0.5	0.29	0	0	0	0
Brevoortia patronus	S100	0	0	5.8	5.11	0	0	0	0
Gobionellus boleosoma	S116	0	0	0	0	2.3	0.85	0.3	0.25
Leiostomus xanthurus	S101	0	0	0.5	0.29	0	0	1.5	0.65
Micropogonias undulatus	S108	0	0	1	0	0	0	0.5	0.5
Myrophis punctatus	S114	0	0	0.5	0.29	0.5	0.5	0.3	0.25
Fundulus grandis	S117	0	0	0	0	1	0.71	0	0
Mugil cephalus	S106	0	0	0	0	0.3	0.25	0.3	0.25
Paralichthys lethostigma	S104	0	0	0	0	0	0	0.5	0.5
Symphurus plagiusa	S113	0	0	0	0	0	0	0.5	0.5
Citharichthys spilopterus	S115	0	0	0	0	0	0	0.3	0.25
Dasyatis sabina	S157	0	0	0	0	0	0	0.3	0.25
Orthopristis chrysoptera	S123	0	0	0	0	0	0	0.3	0.25
Synodus foetens	S124	0	0	0	0	0	0	0.3	0.25
Cyprinodontidae		0	0	0	0	1	0.71	0	0
Gobiidae		0	0	0	0	2.3	0.85	0.3	0.25
Sciaenidae		0	0	1	0	0	0	2	1.08
Commercial/Sports Fishes		0	0	0	0	0	0	0.5	0.5
FISH TOTALS:		8.5	7.53	7.8	4.82	7	2.65	9.8	6.3
CRUSTACEANS:									
Palaemonetes pugio	S403	15	8.36	0.5	0.29	143.3	63.73	0	0
Penaeus aztecus	S400	41.5	8.37	10	1.15	39.3	8.36	7	1.87
Callinectes sapidus	S404	6	2.38	1.5	0.29	9	2.58	0.3	0.25
Clibanarius vittatus	S408	2.5	1.26	0.5	0.29	4.8	1.7	0	0
Hippolyte zostericola	S432	0	0	0	0	1.3	1.25	0	0
Pagurus spp.	S429	0	0	0	0	0	0	0.5	0.5
Neopanope texana	S435	0	0	0	0	0.3	0.25	0	0
Unknown crustacean species	S431	0	0	0	0	0	0	0.3	0.25
Penaeidae		41.5	8.37	10	1.15	39.3	8.36	7	1.87
CRUSTACEAN TOTALS:		64.8	10.62	11.8	1.32	200.3	70.63	8	1.68

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, UPPER BAY, SUMMER.

GALVESTON BAY STUDY
UPPER BAY SYSTEM
Macrofauna/2.6 m sq. (n=4)
July 21-22, 1987

SPECIES		Site 1 TRINITY DELTA INNER MARSH VEGETATED MEAN	S.E.	NON-VEGETATED MEAN	S.E.	Site 2 TRINITY DELTA OUTER MARSH VEGETATED MEAN	S.E.	NON-VEGETATED MEAN	S.E.
FISHES:									
Fundulus grandis	S117	6.8	2.63	0.3	0.25	2.8	0.25	0	0
Mugil cephalus	S106	3	3	0.3	0.25	3.3	0.85	0.3	0.25
Cyprinodon variegatus	S111	5	4.36	0	0	0	0	0	0
Lucania parva	S112	2.8	2.43	0	0	0	0	0	0
Anchoa mitchilli	S120	0	0	1.8	1.03	0	0	0.5	0.29
Menidia beryllina	S110	1	0.41	0	0	1.3	0.75	0	0
Leiostomus xanthurus	S101	0	0	0.3	0.25	0.3	0.25	0.5	0.29
Conodon nobilis	S174	0.8	0.75	0	0	0	0	0	0
Symphurus plagiusa	S113	0.8	0.75	0	0	0	0	0	0
Myrophis punctatus	S114	0.3	0.25	0.3	0.25	0	0	0	0
Brevoortia patronus	S100	0.5	0.29	0	0	0	0	0	0
Fundulus jenkinsi	S171	0.5	0.29	0	0	0	0	0	0
Fundulus pulvereus	S142	0.3	0.25	0	0	0.3	0.25	0	0
Syngnathus scovelli	S137	0	0	0	0	0.5	0.29	0	0
Citharicthys spilopterus	S115	0	0	0.3	0.25	0	0	0	0
Gobionellus boleosoma	S116	0	0	0	0	0	0	0.3	0.25
Gobiosoma bosci	S105	0	0	0	0	0	0	0.3	0.25
Ictalurus punctatus	S172	0	0	0	0	0	0	0.3	0.25
Lagodon rhomboides	S103	0.3	0.25	0	0	0	0	0	0
Sciaenops ocellatus	S121	0	0	0	0	0.3	0.25	0	0
Unknown fish species	S152	0.3	0.25	0	0	0	0	0	0
Cyprinodontidae		15.3	6.39	0.3	0.25	3	0.41	0	0
Gobiidae		0	0	0	0	0	0	0.5	0.29
Sciaenidae		0	0	0.3	0.25	0.5	0.29	0.5	0.29
Commercial/Sports Fishes		0	0	0	0	0.3	0.25	0	0
FISH TOTALS:		22	5.34	3	1.22	8.5	1.04	2	0.91
CRUSTACEANS:									
Palaemonetes pugio	S403	45.8	24.35	0	0	16.3	8	0	0
Callinectes sapidus	S404	2.3	1.31	1.3	0.75	4	1.47	0	0
Penaeus setiferus	S401	0	0	0	0	1.3	0.75	0	0
Palaemonetes vulgaris	S436	0	0	0	0	0.5	0.5	0	0
Penaeus aztecus	S400	0	0	0	0	0.5	0.29	0	0
Sesarma reticulatum	S407	0.5	0.29	0	0	0	0	0	0
Uca pugnax	S406	0.5	0.5	0	0	0	0	0	0
Neopanope texana	S435	0.3	0.25	0	0	0	0	0	0
Penaeidae		0	0	0	0	1.8	0.75	0	0
CRUSTACEAN TOTALS:		49.3	27.78	1.3	0.75	22.5	7.51	0	0

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, MIDDLE BAY, SUMMER.

GALVESTON BAY STUDY MID-BAY SYSTEM Macrofauna/2.6 m sq. (n=4) July 20 & 22, 1987		Site 3 SMITH POINT				Site 4 MOSES LAKE			
		Vegetated		Non-vegetated		Vegetated		Non-vegetated	
SPECIES		MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:									
Gobiosoma bosci	S105	32.8	9.31	0.8	0.48	9.5	5.84	3.3	2.93
Anchoa mitchilli	S120	1.8	1.75	30.5	13.99	0	0	7	6.04
Myrophis punctatus	S114	0.3	0.25	1.3	0.63	2.8	2.14	0.5	0.29
Mugil cephalus	S106	1	0.58	0	0	2.8	1.31	0	0
Lagodon rhomboides	S103	1.3	0.95	0	0	1.3	0.25	0	0
Brevoortia patronus	S100	0	0	0	0	0	0	2.3	2.25
Fundulus grandis	S117	0.8	0.75	0	0	1.5	0.87	0	0
Cynoscion nebulosus	S125	1.5	0.29	0	0	0.5	0.5	0	0
Menidia beryllina	S110	0.3	0.25	0	0	1.5	1.19	0	0
Syngnathus scovelli	S137	0	0	0	0	1.3	1.25	0	0
Cyprinodon variegatus	S111	0	0	0	0	1	0.71	0	0
Oligoplites saurus	S173	0.8	0.48	0	0	0	0	0	0
Paralichthys lethostigma	S104	0.3	0.25	0.3	0.25	0	0	0	0
Membras martinica	S129	0	0	0.5	0.5	0	0	0	0
Unknown fish species	S152	0.5	0.5	0	0	0	0	0	0
Arius felis	S135	0	0	0.3	0.25	0	0	0	0
Citharicthys spilopterus	S115	0	0	0.3	0.25	0	0	0	0
Gobiesox sturmosus	S159	0.3	0.25	0	0	0	0	0	0
Hyporhamphus unifasciatus	S155	0.3	0.25	0	0	0	0	0	0
Lucania parva	S112	0	0	0	0	0.3	0.25	0	0
Sciaenops ocellatus	S121	0.3	0.25	0	0	0	0	0	0
Sphoeroides parvus	S158	0	0	0	0	0	0	0.3	0.25
Stellifer lanceolatus	S139	0.3	0.25	0	0	0	0	0	0
Cyprinodontidae		0.8	0.75	0	0	2.8	1.11	0	0
Gobiidae		32.8	9.31	0.8	0.48	9.5	5.84	3.3	2.93
Sciaenidae		2	0.41	0	0	0.5	0.5	0	0
Commercial/Sports Fishes		2	0	0.3	0.25	0.5	0.5	0	0
FISH TOTALS:		42	10.97	33.7	13.92	22.3	7.11	13.3	10.97
CRUSTACEANS:									
Palaemonetes pugio	S403	590	167.07	0.3	0.25	242	16.52	0.3	0.25
Penaeus setiferus	S401	79	41.29	4.3	1.75	0.5	0.29	1.3	0.63
Penaeus aztecus	S400	33.8	13.85	7.5	0.5	2.3	0.63	0.8	0.48
Callinectes sapidus	S404	10.8	4.27	2.3	1.31	6.3	1.03	0.8	0.48
Rhithropanopeus harrisii	S445	3.3	1.97	0.5	0.5	0.3	0.25	0	0
Palaemonetes vulgaris	S436	1.3	0.95	0	0	0.5	0.5	0	0
Uca pugnax	S406	1.8	1.75	0	0	0	0	0	0
Neopanope texana	S435	1.3	1.25	0	0	0	0	0	0
Palaemonetes intermedius	S437	0	0	0	0	1	0.41	0	0
Eurypanopeus depressus	S439	0.3	0.25	0	0	0	0	0	0
Penaeidae		112.5	53.16	11.8	2.17	2.8	0.48	2	0.71
CRUSTACEAN TOTALS:		721	183.37	14.8	3.77	252.8	17.76	3	0.58

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, LOWER BAY, SUMMER.

GALVESTON BAY SYSTEM LOWER BAY SYSTEM Macrofauna/2.6 m sq. (n=4) July 17 & 24, 1987		Site 5 JAMAICA BEACH				Site 6 CHRISTMAS BAY			
		Vegetated		Non-vegetated		Vegetated		Non-vegetated	
SPECIES		MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:									
Cyprinodon variegatus	S111	0	0	0	0	8.5	8.5	0	0
Lagodon rhomboides	S103	2	0.91	0.5	0.5	2	1	0.5	0.29
Eucinostomus spp.	S175	0	0	0	0	0	0	4.3	4.25
Gobiosoma bosci	S105	3.5	1.44	0.5	0.29	0.3	0.25	0	0
Anchoa mitchilli	S120	0	0	1.8	0.75	0	0	0	0
Menidia beryllina	S110	0.3	0.25	1.3	0.48	0.3	0.25	0	0
Mugil cephalus	S106	0	0	0.5	0.29	1.3	0.95	0	0
Cynoscion nebulosus	S125	0.5	0.29	0.5	0.29	0.5	0.29	0	0
Symphurus plagiusa	S113	0	0	0.5	0.29	0.3	0.25	0.5	0.5
Adinia xenica	S133	0	0	0	0	1	0.71	0	0
Fundulus grandis	S117	1	0.41	0	0	0	0	0	0
Syngnathus scovelli	S137	1	0.58	0	0	0	0	0	0
Fundulus similis	S107	0.5	0.29	0	0	0	0	0	0
Microgobius thalassinus	S102	0	0	0.5	0.29	0	0	0	0
Opsanus beta	S128	0.5	0.29	0	0	0	0	0	0
Archosargus probatocephalus	S130	0	0	0.3	0.25	0	0	0	0
Chaetodipterus faber	S163	0	0	0.3	0.25	0	0	0	0
Citharichthys spilopterus	S115	0	0	0	0	0	0	0.3	0.25
Eucinostomus argenteus	S151	0	0	0	0	0	0	0.3	0.25
Gambusia affinis	S140	0.3	0.25	0	0	0	0	0	0
Leiostomus xanthurus	S101	0	0	0.3	0.25	0	0	0	0
Myrophis punctatus	S114	0	0	0.3	0.25	0	0	0	0
Paralichthys lethostigma	S104	0	0	0	0	0	0	0.3	0.25
Syngnathus louisianae	S146	0.3	0.25	0	0	0	0	0	0
Unknown fish species	S152	0	0	0	0	0	0	0.3	0.25
Cyprinodontidae		1.3	0.63	0	0	9.5	8.19	0	0
Gobiidae		3.5	1.44	1	0.41	0.3	0.25	0	0
Sciaenidae		0.5	0.29	0.5	0.29	0.5	0.29	0	0
Commercial/Sports Fishes		0.5	0.29	0.5	0.29	0.5	0.29	0.3	0.25
FISH TOTALS:		8.5	2.53	5.5	0.65	14	7.01	6.3	3.92
CRUSTACEANS:									
Palaemonetes pugio	S403	180.3	39.73	0.5	0.29	70.3	16.24	0.5	0.5
Penaeus aztecus	S400	41.5	6.24	8.3	2.02	5.3	2.02	0.8	0.48
Callinectes sapidus	S404	27.8	2.29	1.8	0.63	2.8	1.8	3	0.71
Penaeus setiferus	S401	12	3.49	5.8	2.25	2.8	0.48	0	0
Penaeus duorarum	S402	12.3	3.09	1.5	0.87	1.3	0.63	0	0
Alpheus heterochaelis	S405	6.5	4.63	0	0	0	0	0	0
Clibanarius vittatus	S408	4	1.22	0	0	1	0.58	0.8	0.48
Palaemonetes intermedius	S437	3.3	2.59	0	0	1.8	1.44	0	0
Uca minax	S444	0	0	0	0	1.8	0.85	0	0
Neopanope texana	S435	0.3	0.25	0	0	0.5	0.5	0	0
Petrolisthes armatus	S448	0.8	0.75	0	0	0	0	0	0
Palaemonetes vulgaris	S436	0.3	0.25	0.3	0.25	0	0	0	0
Eurypanopeus abbreviatus	S449	0.5	0.5	0	0	0	0	0	0
Libinia dubia	S438	0.3	0.25	0	0	0	0	0	0
Menippe mercenaria	S409	0	0	0	0	0.3	0.25	0	0
Panopeus herbstii	S440	0	0	0	0	0.3	0.25	0	0
Unknown crustacean species	S431	0.3	0.25	0	0	0	0	0	0
Penaeidae		65.5	6.69	15	3.03	9.3	2.29	0.8	0.48
CRUSTACEAN TOTALS:		287.5	39.89	17	3.08	87.8	20.5	5	1.41

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, UPPER BAY, FALL.

GALVESTON BAY STUDY
UPPER BAY SYSTEM
Macrofauna/2.6 m sq. (n = 4)
November 2-3, 1987

SPECIES		Site 1 TRINITY RIVER INNER DELTA Vegetated MEAN	S.E.	Site 1 Non-vegetated MEAN	S.E.	Site 2 TRINITY RIVER OUTER DELTA Vegetated MEAN	S.E.	Site 2 Non-vegetated MEAN	S.E.
FISHES:									
Cyprinodon variegatus	S111	31.5	31.5	1	0.71	0	0	0	0
Anchoa mitchilli	S120	0	0	0	0	0	0	6.8	6.75
Fundulus grandis	S117	0.8	0.48	0	0	3.5	3.18	1	1
Lucania parva	S112	0.5	0.29	0.3	0.25	0	0	0	0
Cynoscion nebulosus	S125	0	0	0	0	0	0	0.5	0.5
Fundulus jenkinsi	S171	0.5	0.5	0	0	0	0	0	0
Mugil cephalus	S106	0	0	0	0	0	0	0.5	0.5
Fundulus pulvereus	S142	0	0	0	0	0.3	0.25	0	0
Cyprinodontidae		33.3	31.59	1.3	0.63	3.8	3.12	1	1
Sciaenidae		0	0	0	0	0	0	0.5	0.5
Commercial/Sports Fishes		0	0	0	0	0	0	0.5	0.5
FISH TOTALS:		33.3	31.59	1.3	0.63	3.8	3.12	8.8	6.37
CRUSTACEANS:									
Palaemonetes pugio	S403	0.5	0.29	0	0	68.3	18.67	0.3	0.25
Callinectes sapidus	S404	0.3	0.25	3.3	2.29	7.8	2.25	11.3	1.7
Penaeus duorarum	S402	0	0	0	0	7	5.7	0.3	0.25
Penaeus aztecus	S400	0	0	0.5	0.29	1.3	0.95	0.8	0.25
Neopanope texana	S435	0	0	0	0	0.5	0.29	0.5	0.29
Penaeus setiferus	S401	0	0	0	0	0	0	0.8	0.48
Rhithropanopeus harrisii	S445	0	0	0	0	0.3	0.25	0	0
Penaeidae		0	0	0.5	0.29	8.3	6.64	1.8	0.63
CRUSTACEANS TOTALS:		0.8	0.48	3.8	2.5	85	26.71	13.8	1.18

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, MIDDLE BAY, FALL.

GALVESTON BAY STUDY
MIDDLE BAY SYSTEM
Macrofauna/2.6 m sq. (n=4)
November 3-4, 1987

SPECIES		Site 3 SMITH POINT Vegetated MEAN	S.E.	Site 3 Non-vegetated MEAN	S.E.	Site 4 MOSES LAKE Vegetated MEAN	S.E.	Site 4 Non-vegetated MEAN	S.E.
FISHES:									
Gobiosoma bosci	S105	6.3	1.44	0	0	106.8	18.75	1.3	0.75
Symphurus plagiusa	S113	7	2.68	6	2.8	0	0	0	0
Anchoa mitchilli	S120	0	0	0	0	0.8	0.75	9.5	8.51
Menidia beryllina	S110	0	0	0	0	1	1	7.3	6.6
Myrophis punctatus	S114	0	0	0.3	0.25	4.5	0.87	0.5	0.29
Fundulus grandis	S117	0.8	0.48	0	0	3.3	1.38	0	0
Cynoscion nebulosus	S125	1.3	0.63	0	0	0.5	0.5	0	0
Micropogonias undulatus	S108	0.3	0.25	0.8	0.75	0	0	0.5	0.5
Sciaenops ocellatus	S121	0	0	1	0.41	0	0	0	0
Gobionellus boleosoma	S116	0	0	0.8	0.75	0	0	0	0
Gobiesox sturmosus	S159	0.5	0.5	0	0	0	0	0	0
Syngnathus louisianae	S146	0.5	0.5	0	0	0	0	0	0
Gobiosoma robustum	S162	0	0	0	0	0.3	0.25	0.3	0.25
Microgobius thalassinus	S102	0	0	0.3	0.25	0	0	0	0
Mugil cephalus	S106	0	0	0	0	0.3	0.25	0	0
Opsanus beta	S128	0	0	0	0	0.3	0.25	0.3	0.25
Paralichthys lethostigma	S104	0	0	0	0	0	0	0	0
Sphoeroides parvus	S158	0	0	0	0	0	0	0.3	0.25
Syngnathus scovelli	S137	0	0	0	0	0.3	0.25	0	0
Unknown fish species	S152	0	0	0	0	0.3	0.25	0	0
Cyprinodontidae		0.8	0.48	0	0	3.3	1.38	0	0
Gobiidae		6.3	1.44	1	0.71	107	18.57	1.3	0.75
Sciaenidae		1.5	0.5	1.8	0.48	0.5	0.5	0.5	0.5
Commercial/Sports Fishes		1.3	0.63	1	0.41	0.5	0.5	0.3	0.25
FISH TOTALS:		16.5	3.86	9	2.94	118	19.01	19.8	9.46
CRUSTACEANS:									
Palaemonetes pugio	S403	593.8	35.73	0.3	0.25	417	89.09	1.3	0.75
Callinectes sapidus	S404	57.5	9.4	11	3.39	269.3	55.61	31.3	17.63
Palaemonetes vulgaris	S436	88.3	59.49	0	0	32.5	17.96	0	0
Palaemonetes intermedius	S437	32	32	0	0	22	7.82	0	0
Penaeus duorarum	S402	10	4.26	1.5	0.87	35.3	14.64	2.8	0.95
Penaeus aztecus	S400	8.3	4.61	0.3	0.25	5.8	3.84	5.3	1.44
Penaeus setiferus	S401	4	1.68	7.3	1.49	0.3	0.25	1.5	0.87
Neopanope texana	S435	6.5	6.5	0	0	0.5	0.5	0	0
Rhithropanopeus harrisii	S445	3	2.38	0	0	0.8	0.75	0	0
Xanthidae, unknown species	S412	1	1	0	0	0	0	0	0
Eurypanopeus abbreviatus	S449	0	0	0	0	0.5	0.5	0	0
Eurypanopeus depressus	S439	0.5	0.5	0	0	0	0	0	0
Panopeus herbstii	S440	0.5	0.5	0	0	0	0	0	0
Alphaeus heterochaelis	S405	0	0	0	0	0.3	0.25	0	0
Menippe mercenaria	S409	0	0	0	0	0.3	0.25	0	0
Uca rapax	S447	0	0	0	0	0.3	0.25	0	0
Penaeidae		22.3	10.26	9	1.22	41.3	12.51	9.5	2.4
CRUSTACEAN TOTALS:		805.3	108.13	20.3	3.68	784.5	70.91	42	19.73

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, LOWER BAY, FALL.

GALVESTON BAY STUDY LOWER BAY SYSTEM Macrofauna/2.6 m sq. (n=4) October 23 and November 5, 1987		Site 5 JAMAICA BEACH				Site 6 CHRISTMAS BAY			
		Vegetated		Non-vegetated		Vegetated		Non-vegetated	
SPECIES		MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:									
Gobionellus boleosoma	S116	1	0.41	0.3	0.25	19.8	11.88	1.5	0.96
Symphurus plagiusa	S113	2.3	0.75	1.3	0.25	1	0.71	1.5	0.29
Anchoa mitchilli	S120	0	0	4.3	2.21	0.3	0.25	0	0
Gobiosoma bosci	S105	3	1.58	0.3	0.25	0	0	0	0
Fundulus grandis	S117	1.5	0.87	0	0	0.8	0.48	0	0
Syngnathus scovelli	S137	0	0	0	0	1.8	0.75	0	0
Cynoscion nebulosus	S125	1.3	0.25	0	0	0	0	0	0
Cyprinodon variegatus	S111	0	0	0	0	1.3	0.75	0	0
Menidia beryllina	S110	0.3	0.25	0.3	0.25	0	0	0	0
Microgobius thalassinus	S102	0	0	0.5	0.5	0	0	0	0
Mugil cephalus	S106	0	0	0	0	0	0	0.5	0.5
Achirus lineatus	S127	0	0	0	0	0	0	0.3	0.25
Eucinostomus spp.	S175	0	0	0	0	0	0	0.3	0.25
Fundulus pulvereus	S142	0.3	0.25	0	0	0	0	0	0
Lagodon rhomboides	S103	0	0	0	0	0	0	0.3	0.25
Leiostomus xanthurus	S101	0	0	0.3	0.25	0	0	0	0
Paralichthys lethostigma	S104	0	0	0.3	0.25	0	0	0	0
Sciaenops ocellatus	S121	0	0	0.3	0.25	0	0	0	0
Trinectes maculatus	S144	0	0	0	0	0	0	0.3	0.25
Cyprinodontidae		1.5	0.87	0	0	2	1.15	0	0
Gobiidae		3.8	1.55	1	0.71	19.8	11.88	1.5	0.96
Sciaenidae		1.3	0.25	0.3	0.25	0	0	0	0
Commercial/Sports Fishes		1.3	0.25	0.5	0.29	0	0	0	0
FISH TOTALS:		8	1.87	6.5	2.02	24.8	12.75	4.5	1.85
CRUSTACEANS:									
Palaemonetes pugio	S403	42.8	7.36	0	0	212.5	76.32	0.5	0.29
Callinectes sapidus	S404	41.5	6.51	4.8	0.25	32	14.46	3	1.08
Penaeus setiferus	S401	7.3	1.11	0.8	0.48	36	22.87	2	2
Palaemonetes vulgaris	S436	23	12.77	0	0	18.5	18.5	0	0
Penaeus duorarum	S402	17.5	4.84	2.3	0.63	17.5	5.66	1.8	0.25
Penaeus aztecus	S400	16.3	5.07	2	0.71	11.8	9.17	0.8	0.25
Palaemonetes intermedius	S437	2.5	0.87	0	0	11	7.08	0	0
Clibanarius vittatus	S408	2.8	0.48	0.3	0.25	7.5	3.01	0.5	0.5
Alpheus heterochaelis	S405	0.3	0.25	0	0	7.8	7.42	0	0
Sesarma cinereum	S443	0.8	0.75	0	0	0	0	0	0
Petrolisthes armatus	S448	0.5	0.5	0	0	0	0	0	0
Rhithropanopeus harrissi	S445	0	0	0	0	0.5	0.5	0	0
Panopeus herbstii	S440	0	0	0	0	0.3	0.25	0	0
Pinnixa chaetopterana	S451	0.3	0.25	0	0	0	0	0	0
Sesarma reticulatum	S407	0.3	0.25	0	0	0	0	0	0
Uca spp.	S458	0.3	0.25	0	0	0	0	0	0
Penaeidae		40.8	6.84	4.8	1.03	65.3	22.84	4.5	2.18
CRUSTACEANS TOTALS:		153.3	28.25	9.5	1.04	355.3	84.05	8.5	1.19

APPENDIX IV: EPIFAUNA AND INFAUNA DENSITIES, SPRING.

GALVESTON BAY MARSH STUDY Epi-Infauna/78.5 cm sq. (n=4) April 20 - May 6, 1987	SITE/HABITAT				SITE/HABITAT			
UPPER BAY:	Trinity Delta Outer Marsh				Trinity Delta Inner Marsh			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Annelids	148	29.819	63.5	37.529	133.5	57.77	86.25	22.103
Crustaceans	0	0	0	0	0.5	0.5	0.25	0.25
Molluscs	0	0	3.5	2.843	0.5	0.289	1.25	1.25
Others	8.75	2.594	25.5	23.514	4.25	2.016	4.25	3.924
Totals	156.75	31.006	92.5	61.907	138.75	60.401	92	25.72
MIDDLE BAY:	Smith Point				Moses Lake			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Annelids	46	14.071	78.25	32.294	282	39.684	182	36.681
Crustaceans	218.5	85.927	2.25	0.629	1193.5	261.25	1302.25	169.075
Molluscs	3.25	3.25	1.25	0.25	0.75	0.75	0	0
Others	4.5	2.843	3	1.225	48.25	32.281	22.75	7.565
Totals	272.25	96.28	84.75	32.255	1524.5	285.066	1507	190.195
LOWER BAY:	Jamaica Beach				Christmas Bay			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Annelids	144.5	42.822	65.25	17.983	150.5	41.242	17.5	3.329
Crustaceans	483.25	211.775	72.5	18.554	16.5	6.958	3	1.08
Molluscs	0.5	0.5	1	0.707	0.25	0.25	7.25	3.683
Others	23.25	18.346	3.75	2.496	2	1.354	0.25	0.25
Totals	651.5	249.324	142.5	16.983	169.25	49.123	29	4.262

APPENDIX IV (continued): EPIFAUNA AND INFAUNA DENSITIES, SUMMER.

GALVESTON BAY MARSH STUDY
Epi-Infauna/78.5 cm sq. (n=4)
July 17 - 24, 1987

	SITE/HABITAT				SITE/HABITAT			
UPPER BAY:	Trinity Delta Outer Marsh				Trinity Delta Inner Marsh			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Annelids	166.75	43.991	91	19.101	381.75	78.742	140.75	47.776
Crustaceans	1.75	1.75	0	0	0.25	0.25	0	0
Molluscs	0.5	0.5	0.75	0.479	6	3.894	23	22.668
Others	3.5	1.19	2	1.08	36	18.353	5.75	3.449
Totals	172.5	43.963	93.75	18.277	424	99.25	169.5	72.882
MIDDLE BAY:	Smith Point				Moses Lake			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Annelids	28	13.681	34.75	12.652	183.75	133.982	185.75	98.68
Crustaceans	60.5	36.999	4.25	3.591	98	87.358	29.75	17.853
Molluscs	0.5	0.289	1.75	0.75	0.5	0.289	0	0
Others	1.5	0.5	1.25	0.946	15	13.385	3	2.041
Totals	90.5	48.086	42.25	15.971	297.5	234.225	218.5	116.963
LOWER BAY:	Jamaica Beach				Christmas Bay			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Annelids	131	56.254	120.75	55.253	116.5	51.745	43.5	14.086
Crustaceans	4.25	1.25	7.75	2.136	28.25	26.597	0.5	0.5
Molluscs	0	0	1.75	0.25	0	0	1.25	0.946
Others	7	7	3.25	2.926	3.75	3.75	1	0.707
Totals	142.25	53.4	133.5	55.468	148.5	77.881	46.25	15.451

APPENDIX IV (continued): EPIFAUNA AND INFAUNA DENSITIES, FALL.

GALVESTON BAY MARSH STUDY
Epi-Infauna/78.5 cm sq. (n=4)
October 23 - November 5, 1987

	SITE/HABITAT				SITE/HABITAT			
UPPER BAY:	Trinity Delta Outer Marsh				Trinity Delta Inner Marsh			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Annelids	192.25	20.621	63	14.566	305	36.03	221.25	8.938
Crustaceans	0.75	0.479	1.5	0.866	0.5	0.289	0	0
Molluscs	4	3.674	0	0	0.25	0.25	8.25	4.973
Others	3	2.345	1.75	1.031	2	0.816	5.5	3.227
Totals	200	24.742	66.25	13.937	307.75	36.954	235	10.48
MIDDLE BAY:	Smith Point				Moses Lake			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Annelids	6.25	2.056	49.5	7.577	241.5	87.463	125	59.611
Crustaceans	2	1.414	6	3.83	32.75	7.307	52.5	20.234
Molluscs	0	0	1.25	0.479	0.25	0.25	0.5	0.5
Others	0.75	0.479	1.25	1.25	6.5	3.428	2.25	1.652
Totals	9	1.414	58	6.671	281	92.416	180.25	78.715
LOWER BAY:	Jamaica Beach				Christmas Bay			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Annelids	78	32.357	102.25	39.205	109.25	24.178	43.5	11.701
Crustaceans	4	1.581	7	3.674	3.75	1.652	0.75	0.479
Molluscs	0	0	0.25	0.25	0.75	0.479	2	1.225
Others	0.5	0.289	1.5	0.5	0.75	0.479	4.25	3.924
Totals	82.5	33.908	111	40.663	114.5	23.869	50.5	14.192

GALVESTON BAY STUDY
SEAGRASS SAMPLES
Macrofauna/2.8 m sq. (n = 4)

SPECIES	CODE	SPRING				SUMMER						FALL			
		SITE 2 OUTER DELTA		SITE 6 CHRISTMAS BAY		SITE 1 INNER DELTA		SITE 2 OUTER DELTA		SITE 6 CHRISTMAS BAY		SITE 2 OUTER DELTA		SITE 6 CHRISTMAS BAY	
		MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISH:															
Gobionellus boleosoma	S116	0	0	10.5	1.443	0	0	0	0	1	0.707	0	0	42	12.871
Lagodon rhomboides	S103	0	0	27	5.845	0	0	0	0	6.5	1.848	0	0	0.25	0.25
Cyprinodon variegatus	S111	0.25	0.25	0	0	26	3.24	0	0	0	0	0	0	0	0
Lucania parva	S112	0	0	0	0	18	3.028	0	0	0	0	0	0	0	0
Gobiosoma robustum	S162	0	0	1	1	0	0	0	0	1.5	1.5	0	0	7	4.123
Gobiosoma bosci	S105	0	0	2	2	0	0	0.25	0.25	5	2.345	0	0	2	1.08
Symphurus plagiusa	S113	0	0	0.5	0.289	0	0	0	0	1.5	0.957	0	0	2	0.913
Syngnathus scovelli	S137	0	0	0	0	0	0	0	0	1	0.408	0	0	2.5	0.645
Fundulus grandis	S117	0.75	0.75	0	0	0	0	0	0	0	0	2.25	1.315	0	0
Myrophis punctatus	S114	0	0	0.75	0.479	0.5	0.5	1.25	0.479	0	0	0	0	0.25	0.25
Anchoa mitchilli	S120	0.25	0.25	0	0	0	0	0	0	0.75	0.75	1.25	1.25	0	0
Cynoscion nebulosus	S125	0	0	0.75	0.75	0	0	0	0	0.5	0.289	0	0	1	0.707
Micropogonias undulatus	S108	2	0.707	0	0	0	0	0	0	0	0	0	0	0.25	0.25
Bairdiella chrysoura	S131	0	0	0	0	0	0	0	0	1.5	0.645	0	0	0	0
Leiostomus xanthurus	S101	0.75	0.75	0	0	0	0	0	0	0.25	0.25	0	0	0.25	0.25
Adina xenica	S133	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0
Arius felis	S135	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0	0
Menidia beryllina	S110	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25
Opsanus beta	S128	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0	0
Synodus foetens	S124	0	0	0.25	0.25	0	0	0	0	0	0	0	0	0	0
Cyprinodontidae		1	1	0	0	44	3.7193	0	0	0	0	2.5	1.1902	0	0
Gobiidae		0	0	13.5	2.0207	0	0	0.25	0.25	7.5	2.3274	0	0	51	12.062
Sciaenidae		2.75	1.0308	0.75	0.75	0	0	0	0	2.25	0.4787	0	0	1.5	0.5
Bait Fishes		0.25	0.25	27	5.8452	0	0	0	0	7.25	2.1747	1.25	1.25	0.25	0.25
Commercial/Sports Fishes		0	0	0.75	0.75	0	0	0	0	0.5	0.2887	0	0	1	0.7071
TOTAL FISH COUNT:		4		42.75		44.5		1.5		20		3.75		57.75	
CRUSTACEANS:															
Palaemonetes pugio	S403	0.25	0.25	38.25	6.237	0.5	0.289	0.25	0.25	55	16.558	9.5	8.17	139.75	57.469
Callinectes sapidus	S404	0.75	0.25	6.25	1.031	1.75	0.629	0.75	0.25	7.75	2.496	15.5	3.403	45.5	5.545
Penaeus aztecus	S400	0	0	40	5.672	0	0	0	0	28.5	3.884	1.25	0.75	8.25	3.092
Penaeus duorarum	S402	0	0	0	0	0	0	0	0	11	3.808	1	0.408	51	12.537
Palaemonetes vulgaris	S436	0	0	0	0	0	0	0	0	0	0	0	0	33.5	13.865
Hippolyte zostericola	S432	0	0	6.25	2.529	0	0	0	0	5.25	2.72	0	0	8.5	5.545
Alphaeus heterochaelis	S405	0	0	0	0	0	0	0	0	4.5	2.533	0	0	9.75	2.75
Palaemonetes intermedius	S437	0	0	0.5	0.5	0	0	0	0	2.75	2.428	0	0	11	3.189
Penaeus setiferus	S401	0	0	0	0	0	0	0	0	1.75	0.479	1.25	0.75	5.25	3.924
Tozeuma carolinense	S420	0	0	0	0	0	0	0	0	0	0	0	0	2.5	2.179
Rhithropanopeus harrissi	S445	0	0	0.75	0.479	0	0	0.25	0.25	0	0	0.75	0.75	0	0
Clibanarius vittatus	S408	0	0	0	0	0	0	0	0	0	0	0	0	1.25	0.75
Neopanope texana	S435	0	0	0	0	0	0	0	0	0	0	1.25	0.946	0	0
Panopeus turgidus	S441	0	0	0	0	0	0	0	0	0.75	0.75	0	0	0.25	0.25
Panopeus herbstii	S440	0	0	0	0	0	0	0	0	0	0	0.75	0.75	0	0
Grass Shrimp		0.25	0.25	38.75	5.9214	0.5	0.2887	0.25	0.25	57.75	18.922	9.5	8.1701	184.25	66.127
Penaeid Shrimp		0	0	40	5.6716	0	0	0	0	41.25	5.391	3.5	1.0408	64.5	8.5878
TOTAL CRUSTACEAN COUNT:		1	0.4082	92	12.483	2.25	0.8539	1.25	0.25	117.25	22.957	31.25	9.4989	316.5	61.038

NOAA TECHNICAL MEMORANDUM
NMFS-SEFC- 250

Utilization of Marsh and Associated Habitats Along a Salinity Gradient in Galveston Bay.

By

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FEBRUARY 1990

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ABSTRACT

Nursery utilization of estuarine marshes by fishery species was studied in relation to salinity in Galveston Bay. The investigation revealed that effects of salinity on foods may explain distributions of fishery juveniles among marshes. Juvenile shrimp, crab and fish predators follow their prey, and environmental factors, such as the long-term effects of freshwater flows into an estuary, appeared to affect distributions and abundances of prey. Predator and prey abundances varied significantly among marshes in Galveston Bay, thus varying the nursery value of marshes to fishery juveniles.

The highest numbers of penaeid shrimps, blue crab and commercial fishes were in marshes of the middle and lower bay. These abundances were associated with high abundances of benthic peracarid crustaceans (amphipods and tanaidaceans) which have been shown to be used as foods through feeding experiments and gut analyses. Other foods such as annelid worms and bivalve mollusks were less utilized and less related to distributions of fishery juveniles. This cause-and-effect relationship may partly explains differences in utilization of marshes by fishery species.

Habitats in upper Galveston Bay were dominated by long-term effects of low salinity from the Trinity and San Jacinto rivers. Marshes and submerged vegetation at the Trinity River delta were characterized by brackish water plants having highly seasonal growth patterns with complete winter defoliation. This environment was not favorable for development of populations of small estuarine invertebrates, nor to the growth of epiphytic algae. Infauna consisted of a few species of osmoconforming oligochaete worms and bivalve mollusks. Transient species such as juveniles of shrimps, crabs, and fishes had ready access to these marshes but did not use them extensively, despite their own abilities to osmoregulate. This lack of attractiveness was apparently due to the absence of preferred foods, especially epiphytic algae and peracarid crustaceans. Hence the value of upper bay oligohaline marshes was not through direct utilization but was attributed to large quantities of organic detritus exported and utilized downstream.

Organic detritus from the upper bay was an apparent energy source for food chains in the middle bay. Here, vascular plant detritus and reformed particles from dissolved organics, colonized and conditioned by bacteria and fungi, provided a nitrogen rich food resource for epibenthic detritivores. Stimulated by favorable food and salinity conditions, large numbers of epibenthic fauna developed (as indicated by abundances of peracarids and annelids), providing a rich feeding ground in both marsh and subtidal habitats. Importantly, this mid-bay region was the frontal zone where nutrients from the upper bay mixed with immigrating recruits from the lower bay.

Detritus in the lower bay was important, but perhaps to a lesser extent than in the middle bay. Reduced turbidities and marine salinities of the lower bay fostered the development of epiphytic algae and grazers as another carbon source. *Spartina* marshes in the lower bay persisted year-around and were regularly inundated by marine waters, thus offering perennial substrata for epiphyte colonization. Young shrimp, crabs and fishes were more abundant in marsh habitats, compared to bare subtidal habitat, in the lower bay than in the middle and upper bay.

These collective findings revealed how marshes of the Galveston Bay system are utilized by consumers. Low salinity (oligohaline) marshes in the upper bay (especially at the Trinity Delta) exported large amounts of organic material to the middle bay. The plants of the river delta defoliate each winter and the entire standing crop is exported downstream. Enriched plant detritus in the middle system increases the productivity of epibenthic detritus feeders (such as peracarid crustaceans) and these were foraged by juveniles of commercially valuable fishes, shrimps and crabs. Because both the marsh and subtidal bottom in the middle bay had high abundances of forage organisms, the entire area was valuable nursery habitat. The moderate influence of mesohaline to polyhaline salinities in the middle bay also encouraged utilization by consumers. In the lower bay, algal carbon was another base for secondary productivity in marsh and seagrass habitats heavily epiphytized by algae. Finally, the interconnections between the different systems of the bay appeared to be critical to maintaining overall fishery productivity.

INTRODUCTION

Purpose

The purpose of this study was to characterize marsh use by fishery species relative to salinity regime. Several hypotheses were proposed. The central hypothesis was that marshes in the mid-range salinity regimes are more utilized by the estuarine aquatic fauna than marshes in low or high salinity regimes. Subhypotheses proposed, a) that habitats with mid-range salinities have higher densities of fishery organisms, and b) that habitats with mid-range salinities have greater abundances of foods foraged by juveniles of fishery species.

The Galveston Bay System

The Physical Environment. The physical environment of the Trinity-Galveston Bay system has been reviewed by Wermund et. al (1989). Descriptions from surveys are in Reid (1955), Chambers and Sparks (1959), Pullen et al. (1969, 1971), Diener (1975), the Texas Department of Water Resources (TDWR 1981a and b), Fisher (1983), and White et al. (1985). In his 1963-66 study, Pullen (1971) reported temperature ranges between 0.4 and 36.0° C, salinity ranges between 0.1 and 36.6 ppt, and dissolved O_2 between 0.2 and 13.6 ml/l. From salinity averages, the 10 ppt isohaline line was placed through the middle of Trinity Bay (north to south), the 15 ppt line crossed through the middle of Galveston Bay (east to west) extending the length of East Bay, and the 20 and 25 ppt lines were confined to lower Galveston Bay near the pass into the Gulf of Mexico at Bolivar Roads. The lower bays West Bay and Christmas Bay were not included in early surveys, but salinities are generally known to be higher than the upper and middle bays (including East Bay) due to proximity to major passes into the Gulf (White et al. 1985).

The Galveston Bay system has about 1,554 km^2 of open water, intertidal marshes and flats representing 23% of the total estuarine area in Texas (Armstrong 1987). Pullen estimated that the largest bays in the system, Trinity Bay, Galveston Bay, East Bay and West Bay, covered approximately 1,360 km^2. Despite the relatively large size the system is very shallow with mean depths generally under 2m. Diener (1975) reported on acreage of open water and maximum and mean depth at mean low water for Trinity Bay (337 km^2;5.2m max. and 1.6m mean), upper Galveston Bay (283 km^2;12.8m max. and 1.7m mean), lower Galveston Bay (362 km^2; 13.4m max. and 2m mean), East Bay (135 km^2; 3.7m max. and 1m mean), West Bay (180 km^2; 7.6m max. and 1.2m) and Christmas-Bastrop Bay (39.2 km^2; 6.1m max. and 1m mean).

Surface sediments in the Galveston Bay system were described by White et al.(1985) as composed of mud, muddy sand and sandy mud. In general, the upper areas in the system are muddy and the lower areas are sandy. Fine grained mud predominates in Trinity Bay, upper Galveston Bay and East Bay. The Trinity river delta and the passes at either end of Galveston Island are sandy. Bay margins along Bolivar peninsula and Galveston Island are muddy sand. Marsh sediments in the system reflect open bay characteristics; thus Trinity delta marshes are sandy to muddy, upper and middle Galveston Bay and East Bay marshes are muddy, and lower Galveston Bay, West Bay and Christmas Bay marshes are sandy to muddy sand.

The major river inputs in the system are the Trinity and San Jacinto Rivers, contributing 5 million and 1.4 millon ac/ft of freshwater per year respectively. About 2.5 millon ac/ft/yr is added from local rainfall of 50 inches (127 cm) rainfall/yr (Wermund et. al 1988).

The system includes 603 km^2 of wetlands (TDWR 1981a). The Trinity River delta is the largest river delta in Texas, comprised of 54 km^2 of marshes, 68 km^2 of cypress swamps, and 35 km^2 of shallow fresh to brackish lakes. Salt marshes cover 140 km^2 and brackish marshes occupy 230 km^2 of intertidal wetlands throughout the remainder of the system (Fisher et. al 1972). The balance is freshwater and terrestrial marsh.

Normal tides in the system have a relatively low diurnal amplitude (about 30 cm) as compared to a seasonal range of about 1 m (Hicks et. al 1983). However, because the bay is shallow, meterological forces of wind and barometeric pressure often overide tidal forces (Smith 1982). Strong weather fronts from the west and northwest, during the winter months, drive water away from the coast thus lowering water-level in the bay. The opposite effect occurs during the warm season when southeast winds and tropical depressions move water toward the coast and elevate water levels. These forces cause tidal variations that routinely excede the predicted values, often beyond the annual range. Freshwater inflow from high rainfall also has an effect on elevating water-levels. Trinity delta marshes and other marshes in the upper bay and in East Bay (lower bay) are inundated for extended periods due to flood events (Borey 1979; Texas Dept. Water Resources 1981a; Borey et. al 1983).

Biological Components. The biological components of Galveston Bay have been reviewed by Sheridan et. al (1988). The major fisheries have been described generally and their relationships to freshwater inflow modeled by TDWR (1981a and b). Relationships between benthic invertebrates and sediments in the bay have been characterized by White et. al (1985). Other descriptions of the biota include marsh vegetation (Fisher et. al 1972), benthic algae (Lowe et. al 1978), phytoplankton (TDWR 1981a), zooplankton (Holt and Strawn 1983), molluscan distributions (Harry 1976), oyster reefs (Hofstetter 1977 and 1983), penaeid shrimp populations (Chin 1960; Baxter and Renfro 1967; Parker 1970; Zimmerman and Minello 1984), the blue crab population (More and Moffett 1964; More 1969; Hammerschmitt 1985), and the fish community (Parker 1965; Sheridan 1983).

The biota is dominated by subtropical to temperate estuarine species, including populations of considerable economic value. Penaeid shrimp (*Penaeus aztecus* and *P. setiferus*) lead the economically important species followed by oysters (*Crassostrea virginica*), blue crabs (*Callinectes sapidus*) and finfishes (Sheridan et. al 1988). Commercial and recreational fishes in order of kg landed are spotted seatrout (*Cynoscion nebulosus*), southern flounder (*Paralichthys lethostigma*), sand seatrout (*Cynoscion* spp.), Atlantic croaker (*Micropogonias undulatus*), and red drum (*Sciaenops ocellatus*). All of the commercially important species require the estuary at least as a nursery and many species, commercial and otherwise, are closely associated with marsh habitats. Examples such as grass shrimp (*Palaemonetes pugio*), mud fish (*Fundulus grandis*), and the naked goby (*Gobiosoma bosci*) are marsh residents, and juveniles of brown shrimp, blue crabs and spotted seatrout have been shown to select tidally flooded marsh in preference to non-vegetated mud bottom (Zimmerman and Minello 1984).

Most faunal species occur throughout the system, although abundances may be unevenly distributed depending on location and season. Prior studies indicate a coarse relationship between distributions and salinity. For instance, the clams *Rangia cuneata* and *R. flexuosa* are more abundant in the upper and middle subsystem (fresher), oyster reefs are prevalent in the middle subsystem and hard clams *(Mercenaria mercenaria*)and bay scallops (*Argopecten*) only occur in small populations in the lower subsystem (more saline).

Emergent marshes are the dominant vegetation throughout the system (Fisher et. al 1972). Submerged aquatic vegetation (SAV) is currently limited to small stands mostly in Trinity Bay and Christmas Bay (West 1972). Sheridan et al. (1988) reports that SAV has declined in the system from about 21 km^2 in 1960 to <1 km^2 in 1979. We report on the present composition and seasonal dynamics of the Trinity delta and Christmas Bay grass beds.

Influences of Freshwater Inflow

Recruitment to the Nursery.
Gulf of Mexico species that require estuarine nurseries usually have postlarvae that follow salinity gradients from saline to brackish conditions. Most of these species use freshwater as a cue for directional movement. Planktonic larvae of barnacles and oysters detect salinity differences in water masses and respond behaviorly to effect their transport within estuaries. Swimming behavior by oyster larvae is stimulated by increased salinities and supressed by decreased salinities (Haskin 1964). This helps larvae position themselves for favorable tidal transport on salinity wedges. Likewise, megalopae of blue crabs and postlarvae of penaeid shrimps move vertically in the water column responding to salinity changes that signal transport into an estuary.

Recruits also depend upon freshwater inflow to sustain the quality of nursery habitat. Since primary production in estuaries is driven by nutrient availability (Nixon 1981), high production depends on nutrients resupplied by freshwater inflow (Flint et. al 1983). A close relationship between estuarine chlorophyll a level and river flow (Bennett et. al 1986) exemplifies this relationship. In northwestern Gulf of Mexico estuaries, nutrients and suspended organic solids are largely imported via riverine flow through freshwater marshes (Stern et. al 1986). In *Spartina* salt marshes nitrogen levels and soil hydrology interact to determine production levels (Mendelssohn 1979; Conner et. al 1987). Salt marshes are also benefited by freshwater through moderation of detrimental high soil salinities (Webb 1983). At the consumer level, high numbers of estuarine infauna (useful as food for fishery juveniles) have been attributed to rainfall and floods (Flint 1985). Increased recruitment and survival of red drum in the Laguna Madre has been related to moderation of hypersaline conditions through floods after hurricanes (Matlock 1987). River transported sediments also supply turbidity and soft substrates that are good refuges from predation for juvenile recruits (Minello et. al 1987).

Nurseries are usually located along the shallow edges of an estuary. The most effective nurseries are vegetated, such as emergent marshes, mangroves, seagrasses, and algae beds. In Galveston Bay, nursery habitat consists of extensive areas of brackish and salt marshes and limited areas of submerged vegetation. Parker (1970) reported that postlarval brown shrimp in Galveston Bay move directly to the marshes after they immigrate through the passes (Baxter and Renfro 1967). Zimmerman et. al (1984) showed that juvenile brown shrimp, from 15 mm to 60 mm total length (TL), were strongly attracted to salt marsh habitat in West Bay. The selective value of the attraction was increased abundances of foods (Gleason and Zimmerman 1984; Gleason 1986; Zimmerman et. al) and greater protective cover from *Spartina alterniflora* (Minello and Zimmerman 1983). Juvenile blue crabs exhibited a similar strong attraction for marsh and seagrass habitats, in West Bay and Christmas Bay, apparently for the same reasons (Thomas 1989; Thomas et. al 1990).

Other important transient species using the West Bay salt marsh as a nursery (in order of abundances) were white shrimp, pinfish, spot (*Leiostomus xanthurus*), bay anchovy (*Anchoa mitchilli*), Atlantic croaker, Gulf menhaden (*Brevoortia patronus*), spotted seatrout, southern flounder, striped mullet (*Mugil cephalus*), and red drum (Zimmerman and Minello 1984). The only estuarine fishes of commercial interest not found as juveniles in the West Bay salt marsh nursery were sheepshead (*Archosargus probatocephalus)* and black drum (*Pogonias cromis*).

Oysters are recruited throughout Galveston Bay forming reefs in areas with salinities ranging between about 10 and 30 ppt (Hopkins 1931; Hofsetter 1977 and 1983; Sheridan et. al 1988). Salinities above 7 ppt are required for spawning (Loosanoof 1953) and spat grow best in salinities above 12 ppt (Davis and Calabrese 1964). Salinities above 20 ppt in Galveston Bay favor populations of oyster drills (*Thais haemastoma*), a predator, and a disease (*Perkinsus marinus*) that reduces oyster numbers (Sheridan et. al, 1988). As a consequence of predation and disease at higher salinities and of physiological limitations at lower salinities, the most productive oyster reefs are in the middle of Galveston Bay where salinities are 10 to 20 ppt (Sheridan et. al 1988).

Fishery Yields. Relationships between freshwater flow into estuaries and fishery production are poorly established and not well understood. An overall review of the influence of freshwater inflows on estuarine productivity is provided by Turek et al. (1987) with citations of case studies and previous reviews by Copeland (1966), Baxter (1977), Armitage (1978), Pandian (1980), Benson (1981) and Peters (1982).

Our present concept of relationships between freshwater input and fisheries yields arises from inferences based upon correlations. Estuaries are by definition mixtures of fresh and marine waters (Pritchard, 1967) and 69 percent of all finfish and shellfish landings in the U.S. are from estuarine-dependent species (McHugh, 1966 and 1976). A simplified view of estuarine-dependent productivity is dependence upon the freshwater flow which creates estuaries. In this view, large estuarine areas, supported by freshwater inflow, would produce greater fishery yields. This inference is based upon a few studies that show a positive correlation between fishery yield and estuarine area. The most often cited studies are Turner (1977) and Nixon (1982).

The estuarine dependency of fisheries in the Gulf of Mexico is about 98 percent (Gunter, 1967). The Texas Department of Water Resources (1981b) has produced 115 significant multiple regressions from models of Texas estuaries relating fishery yields to the amount of freshwater inflow. Most of these are linked to spring and late fall inflows indicating important seasonal relationships. In addition, a major drought in Texas during the 1950s caused low fishery yields and adverse effects on estuarine populations (Powell, 1985). Estuarine-dependent populations apparently recovered quickly after spring and fall rains in 1957 at the end of the drought (Hoese, 1960).

Habitat Modification. The intertidal marsh surface and shallow water without vegetation (bare bottom) in northwestern Gulf of Mexico estuaries comprise the principal nursery habitats for immigrating postlarvae of fishery species. In the NW Gulf, these habitats occur together in a reticulated pattern with a high degree of interfacing. This habitat mosiac is caused by marsh deterioration resulting from subsidence, loss of sediment input and saltwater intrusion (Craig et al. 1980; Reidenbaugh et al. 1983; Hatton et al. 1983). The condition increases both shoreline complexity and the opportunity for habitat selection by recruiting animals. This benefits species like brown shrimp whose juveniles select flooded marsh in preference to non-vegetated subtidal bottom (Zimmerman and Minello 1984). In support of this observation, the offshore catch of brown shrimp has been positively correlated with the amount of intertidal marsh area (Turner 1977), shoreline complexity (Faller 1979) and the ratio of marsh to open-water (Browder 1985). However, similar observations have not been made for white shrimp. Young white shrimp demonstrate no consistent preference between marsh surface and bare bottom habitats. The findings suggest differences in the usage and value of marsh for the principal two fishery species in the Gulf of Mexico.

Juvenile brown shrimp are frequently associated with vegetated habitats such as marshes and seagrasses and young white shrimp are commonly identified with open-water, nonvegetated, muddy bottom habitats (Loesch 1965; Christmas et al. 1976; Stokes 1974; and Zimmerman et al. 1984). White shrimp have also been associated with detritus rich sediments (Williams 1955). Recent evidence may explain these different habitat associations through feeding (Zimmerman et al.). Brown shrimp are highly effective in feeding on benthic infauna and epifauna, while white shrimp are much less so. The high numbers of small benthic macrofauna sought by carnivorous brown shrimp are most abundant in vegetated habitats. In the NW Gulf, these habitats are predominantly intertidal marshes. White shrimp have been shown to exploit epiphytes and possibly planktonic resources that brown shrimp do not (McTigue and Zimmerman, in prep). Growth of white shrimp was not different when held in separate cages in marsh and nonvegetated habitats. By contrast, brown shrimp grew more slowly on nonvegetated bottom than in marsh (Zimmerman et al.). Apparently, habitat requirements differ for each species, and habitat changes, such as marsh loss or nutrient enrichment, do not equally affect both species.

Marshes in the NW Gulf are currently not accreting enough sediment to offset subsidence and are sustaining increased salt water intrusion due to diversion of freshwater riverflow (Craig et al., 1980; and Hatton et al., 1983). Although these processes ultimately destroy marsh habitat, the short-term effect may make more habitat available for exploitation. Microtidal diurnal amplitudes in the Gulf are dominated by high seasonal tides (Provost 1976). This effect increases the duration of marsh innundation during spring and fall seasons. A mild climate allows development of high abundances of epifauna and infauna during the winter season (Flint and Younk, 1983). These phenomena provide an abundance of foods, available for spring exploitation, to incoming brown shrimp recruits. Increased accessibility to intertidal habitats appears to be the key to production in brown shrimp and other estuarine-dependent animals that use the marsh surface as a nursery.

METHODS

Study Sites

Marshes in three parts of the Galveston Bay system were chosen for study based on salinity characteristics (Fig.1). The upper, middle and lower parts of the system corresponded to oligohaline (0.5 to 5 ppt), mesohaline (5 to 18 ppt) and polyhaline (18 to 30 ppt) salinity regimes based on classification by Cowardin et al. (1979). Two marsh sites were chosen in each regime based on observed similarity to other marshes in the area and on accessibility for sampling. The salinity regimes were characterized using Texas Parks and Wildlife Department (TPWD) records taken over the past 10 years within 1 km of each site, as well as from salinities measured in 1987 during the study. Marshes were

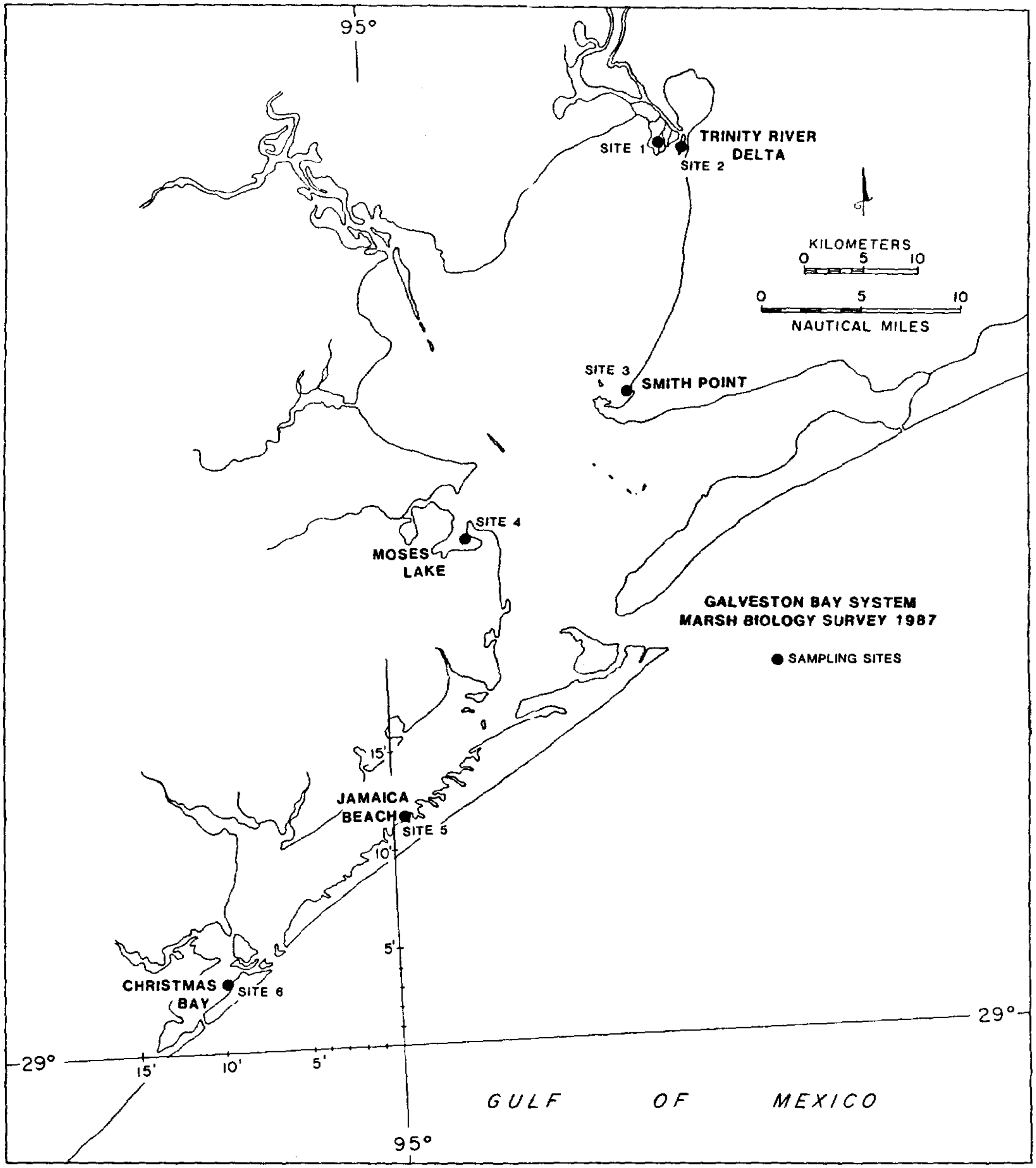

FIGURE 1. Map of sites.

compared to open water habitats in the adjacent bay throughout the study. The open water habitats were either nonvegetated (barren) mud or sand bottom, or submerged aquatic vegetation (SAV), such as seagrasses, or both.

In the upper bay, two marsh sites (Sites 1 and 2) were studied on the Trinity River delta located at 94° 42' W, 29° 44' 36" N and at 94° 43' 18" W, 29° 45' 30" N (Fig.1). The marshes had mixed emergent vegetation but the dominant plant near the marsh edge was *Scirpus* spp.. Submerged aquatic vegetation (SAV) was present at both sites during the summer and was mostly comprised of *Ruppia maritima*, *Najas* sp. and *Vallisneria americana*. Both marshes were situated along coves that opened into Trinity Bay. The site closest to the bay near the navigation channel was designated the outer site (Site 2; OTD, outer Trinity Delta) and the inland delta site, near southwest pass, was designated the inner site (Site 1; ITD, inner Trinity Delta). Ten year monthly mean salinities from TPWD ranged from 3.0 to 18.9 ppt with an overall mean of 9.2 ppt at the outer site. Mean monthly salinities at the inner marsh site ranged from 1.7 to 14.4 ppt at the inner site with an overall mean of 6.0 ppt. Because of the low salinity occurrences, the inner site was designated as oligohaline. The dominance at the inner site of *Najas* and *Vallisneria*, plants which do not tolerate long-term salinities above 6 ppt, confirm the validity of the classification. Because of its slightly higher salinities, the outer site was classified as a transition from oligohaline to mesohaline.

In the middle of the bay, mesohaline marshes were selected at Smith Point (Site 3; SP) and at Moses Lake (Site 4; ML) at 94°45' 24" W, 29° 33' 18" N and 94° 55' 30" W, 29°26' 24" N, respectively. At Smith Point, the marsh was mostly composed of *Spartina alterniflora* with *Juncus roemerianus* and *Spartina cynosuroides* mixed in. At Moses Lake, the marsh was *Spartina alterniflora*, *Juncus roemerainus* and *Distichlis spicata*. The was no SAV in the area; open water bottoms adjacent to the marsh varied from hard clay and soft mud to muddy sand with broken *Rangia* shell. The ten year mean of salinities was 11.7 ppt for Smith Point and 15.7 ppt for Moses Lake.

In the lower bay, polyhaline marsh sites were selected in West Bay, at the Galveston Island State Park, (Site 5;WB) and in Christmas Bay (Site 6;CB). They were located at 94° 59' W, 29° 12' N and 95° 10' W, 29° 2' 48" N, respectively. These marshes were composed of monotypic stands of *Spartina alterniflora* with some *Salicornia virginica* and *Batis maritima* at higher elevations. The subtidal bottom next to the marsh in West Bay was sandy mud without SAV habitat present; but at Christmas Bay the bottom was sandy and SAV habitat was present. The stand of SAV was mostly *Halodule wrightii* with traces of *Ruppia maritima*, *Halophila engelmannii* and *Thalassia testudinum*. Ten year mean salinities from TPWD were 23.8 ppt in West Bay and 26.4 ppt in Christmas Bay.

Field Procedures:

The principal method of sampling animal abundances on the marsh surface and in nearby shallow-water subtidal habitats was drop trap sampling (Fig.2). Drop trap sampling was developed to compare animal densities among a variety of shallow-water habitats. The method employs a large cylinder (1.8 m dia.) dropped from a boom on a boat to entrap organisms within a prescribed area (2.6 m^2). Most of the mobile fauna are captured by using dip nets while the water is pumped out of the sampler. When the sampler is completely drained, animals remaining on the bottom are picked up by hand. The technique is designed to sample fishes, crabs and shrimps in marshes, seagrass beds and

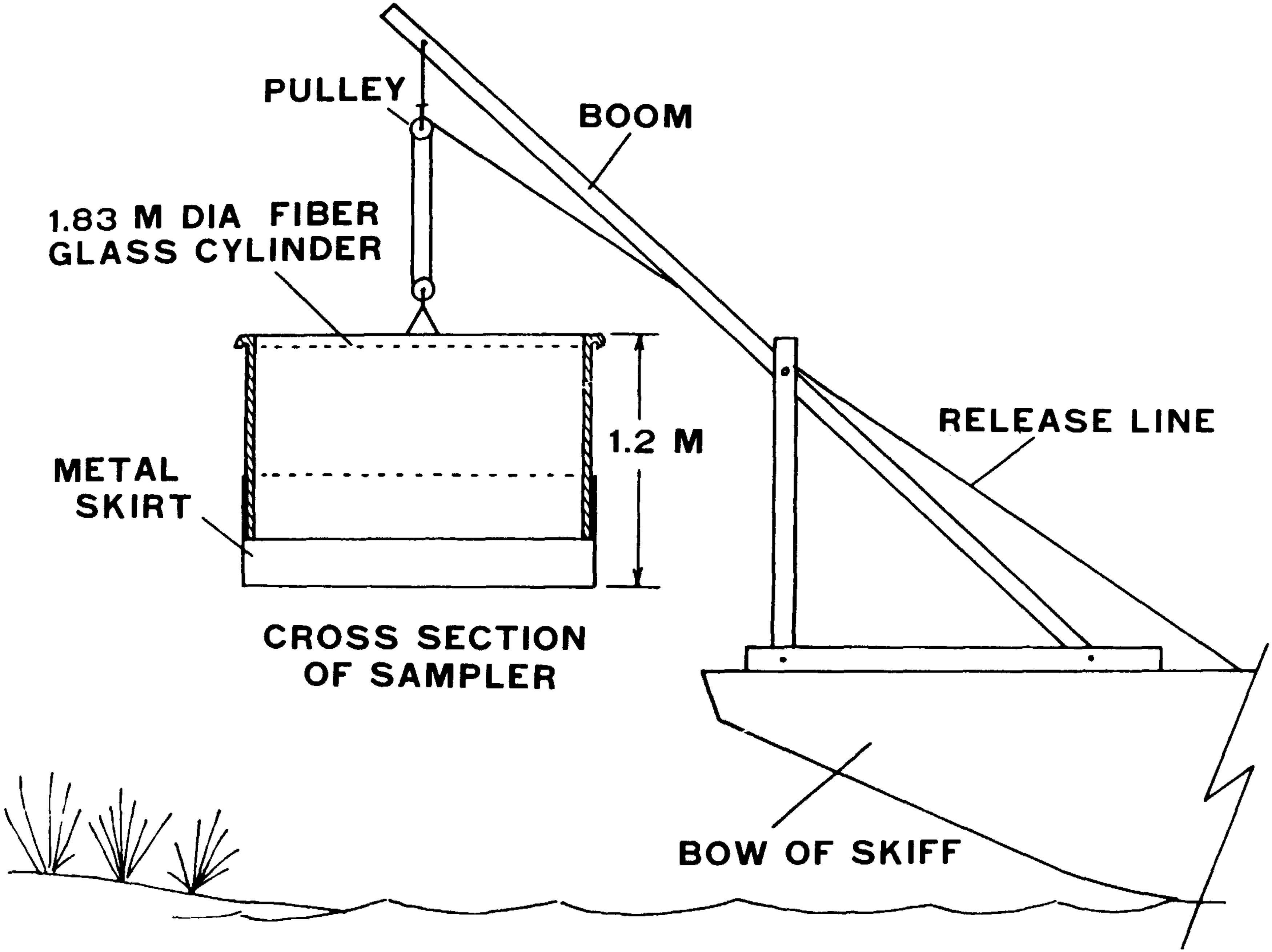

FIGURE 2. Drawing of the drop trap sampler.

oyster reefs where methods such as trawls and seines are ineffective. The technique improves on conventional methods because catch efficiency is very high (85 to 100 %) and measurements approach actual densities (numbers/unit area) of target organisms; hence, with drop trap sampling, quantitative comparisions of organism abundances within and between marshes and among a variety of other habitats are possible. The technique has been used in water depths up to 1.1 meter in marshes, SAV beds, mangroves, oyster reefs, and bare sand and mud bottoms. The methodology was described by Zimmerman et al. (1984).

In Galveston Bay, drop trap sampling was employed to assess utilization of intertidal marshes and subtidal bottoms by fishery species along a salinity gradient. Four replicate samples (2.6 m^2 each) of each habitat type at each site were taken during the spring, summer and fall seasons of 1987. Sampling always included marsh and bare mud bottom habitats (subtidal open-water adjacent to the marsh edge) in sample pairs (4 replicate pairs per site) and SAV habitat (4 additional replicates) when present. Thus, withhout SAV, 8 samples of marsh and 8 samples of adjacent mud bottom were taken in each the upper, middle and lower system (48 total) during April, July and November (144 overall total). This balanced set of replicates among habitats and season constituted the basis for our main comparisons. Since SAV was only at the Trinity delta and Christmas Bay sites and was seasonally present, this habitat was compared between sites and with other habitats separately. The main observations from drop trap samples were fish and decapod crustacean densities. The organisms were collected in the field and preserved with 10% Formalin, then taken to the laboratory for identification, measurement and enumeration.

Other observations included densities of infauna and epifauna, vegetation type and biomass, and measurements of water depth, temperature, salinity, dissolved oxygen and turbidity. Infauna and epifauna were sieved from a single 10 cm dia. x 5 cm sediment core taken within each drop trap. These small macrofauna were retained on a 500 micron square mesh screen, then placed in zip-lock plastic bags with 10% Formalin with Rose Bengal stain, and stored for sorting at the laboratory. All emergent plants in marsh samples were cut and placed in plastic garbage bags, without preservation, for laboratory processing. Maximum and minimum water depth was measured in each drop trap with a meter rule. Water temperature and dissolved oxygen was measured using a YSI Model 51B meter, and salinity was measured using an American Optical refractometer. Water samples (500 cm^2) were taken to measure turbidity (HR Instruments Model DRT 15) and to check conductivity/salinity with a Hydrolab Data Sonde at the laboratory.

Laboratory Proceedures:

In the laboratory, fishes and crustaceans were sorted to species (using identifications based on guides, keys and taxonomic papers listed in Appendix I). Fish were measured to nearest mm total length and counted in groups of 10 mm size intervals (1 to 10 mm, 11 to 20 mm, etc.). Decapod crustaceans were measured to nearest mm total length for shrimps and carapace width for crabs and counted in groups of 5 mm size intervals (1 to 5 mm, 6 to 10 mm, etc.). The data were recorded on printed forms and entered in DBASE III Plus files using a microcomputer. Infauna and epifauna were processed similarly except they were not measured, and individuals were identified to species only in 1 of each 4 replicates; in the other 3 replicates, they were counted as peracarid crustaceans, annelid worms, mollusks or other fauna. Marsh plants were first weighed wet, then air dried for two months and weighed dry. After drying, the number of culms in each sample were counted to calculate density, then discarded. All faunal samples were stored in 5% Formalin (with seawater) or 70% ETOH for reference. These will be kept for at least 3 years from the date of collection. All field sheets and data entry forms are on file and will be kept for at least 5 years.

Analytical Procedures:

We used analysis of variance (ANOVA) to test for significance of observations among habitats, areas of the bay, and seasons. In the main design, marsh and nonvegetated habitats were considered subsamples since they were always sampled togeather. Sites were combined within upper, middle, and lower areas of the bay to test for effect of location. Seasons were the spring, summer, and fall. Data were transformed using log x + 1 since variances were usually proportional to the means (see means and standard errors in Appendices II through V). Differences between observation means were tested at the 0.05 significance level. The main observations were densities of selected faunal groups and taxa, including all fishes, all decapods, game fishes, bait fishes, penaeid shrimp, economically important and most abundant species. The game fish were comprised of southern flounder, spotted seatrout and red drum. Bait fish were bay anchovy, pinfish, and striped mullet. Economically important decapods, analyzed as individual species, were brown shrimp, white shrimp, pink shrimp, and blue crab. Other observations included physical parameters, densities of forage organisms (annelid worms and peracarid crustaceans) and vegetational parameters. SAV, marsh, and nonvegetated habitats were compared only between the two sites where SAV was always present (Christmas Bay and the Inner Trinity Delta). Because most species were transient and highly seasonal, occurrences or high abundances within species were often confined to one or two seasons. This weaked our justification for testing across all seasons (including seasons as a level in the ANOVA design) in all taxa. It also increased interaction of season with habitat and bay area. Therefore, many tests at the family or species level were limited to within seasons. In all ANOVAs, where probabilities were equal to or greater than 0.05, and interactions were not significant, we used LSD multiple range tests to identify differences. In some cases where season, area of the bay and habitat interacted significantly, we used paired t-tests to independently analyze for difference between habitats. We also analyzed for differences in selection of marsh versus nonvegetated habitat between sites, using percent abundance in the marsh (calculated from animal densities in pairs of samples of marsh and nonvegetated bottom) as the observation. The observations in this case were arcsine transformed. All analyses were executed on a micro-computer using SAS/STAT programs. The untransformed means and standard errors of species densities were calculated by season/site/habitat and are tabulated in Appendices II through V.

Total abundances within species were tabulated for each site. Since sites were located within characteristic salinity regimes, abundances within species at each site roughly corresponded to relationship with salinity. Total from marsh and nonvegetated habitats were combined, but SAV was not included since it did not occur at all sites. The distribution center was used to characterize the most closely associated salinity regime for each species. Salinity regimes at each site were calculated as 1987 mean (our data, taken during drop trap sampling) and as the ten year historical mean (data from random sampling by the Texas Parks and Wildlife Department within 1 km of each site). The sites and their corresponding salinities (1987 and historical, respectively) were: Site 1 - Inner Trinity Delta (3.6 and 6.0 ppt), Site 2 - Outer Trinity Delta (3.4 and 9.2 ppt), Site 3 - Smith Point (9.8 and 11.7 ppt), Site 4 - Moses Lake (15.5 and 15.7

ppt), Site 5 - West Bay (27.2 and 23.8 ppt) and Site 6 - Christmas Bay (27.9 and 26.4 ppt).

RESULTS

Physical Parameters

Salinity: Salinities in Galveston Bay during the 1987 survey are graphically compared to 10 year TPWD averages in Figure 3, with means and standard errors are given in Appendix II. The unequal sample sizes among sites for the TPWD 10 year historical database should be noted. The 10 year (historical) mean at the Trinity Delta inner site (Site 1) is based on 26 measurements and 25 measurements at the outer site (Site 2). Since the measurements are few and they were taken randomly over time, not all the monthly means are available (June is missing for the inner site and February is missing for the outer site). The remaininig sites, in the middle and lower bay, were based on more observations; eg., Smith Point (Site 3), 125; Moses Lakes (Site 4), 241; West Bay (Site 5), 156; Christmas Bay (Site 6), 87. Withstanding some imprecision for the upper bay, the TPWD record represents mean salinities in different parts of the bay.

The salinity gradient was evident both in 1987 and historically (Fig. 3). The salinity values classify the bay into oligohaline, mesohaline and polyhaline environments that correspond to the upper, middle and lower divisions of the bay (Fig. 4). Seasonal differences are evident with steeper gradients occurring in the spring and summer due to lower salinities in the upper bay and higher salinities in the lower system (Fig. 3). During the fall, salinities reach their annual peak in the upper system, thus reducing the slope of the gradient. These seasonal variations in salinity impose short-term influences on the environment. During 1987, in particular, short term influence of lowering of salinity was observed in the middle bay. In Table 1, the short-term differences in salinity are depicted between sites seasonally and at the same time the overall integrity of the gradient is demonstrated. There was no difference in salinity between marsh and open water habitats (paired-t tests within sites and seasons, n = 4, P > 0.05).

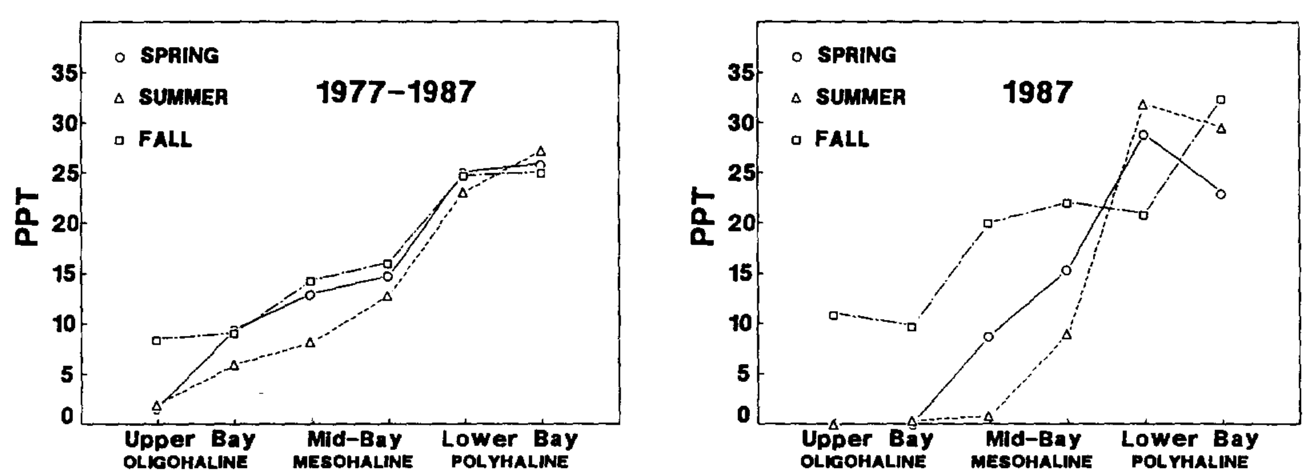

FIGURE 3. Salinities in marsh and adjacent nonvegetated open water at sites in Galveston Bay during a drop trap sampling survey in 1987, and TPWD sampling within 1 km of each site between 1977-87.

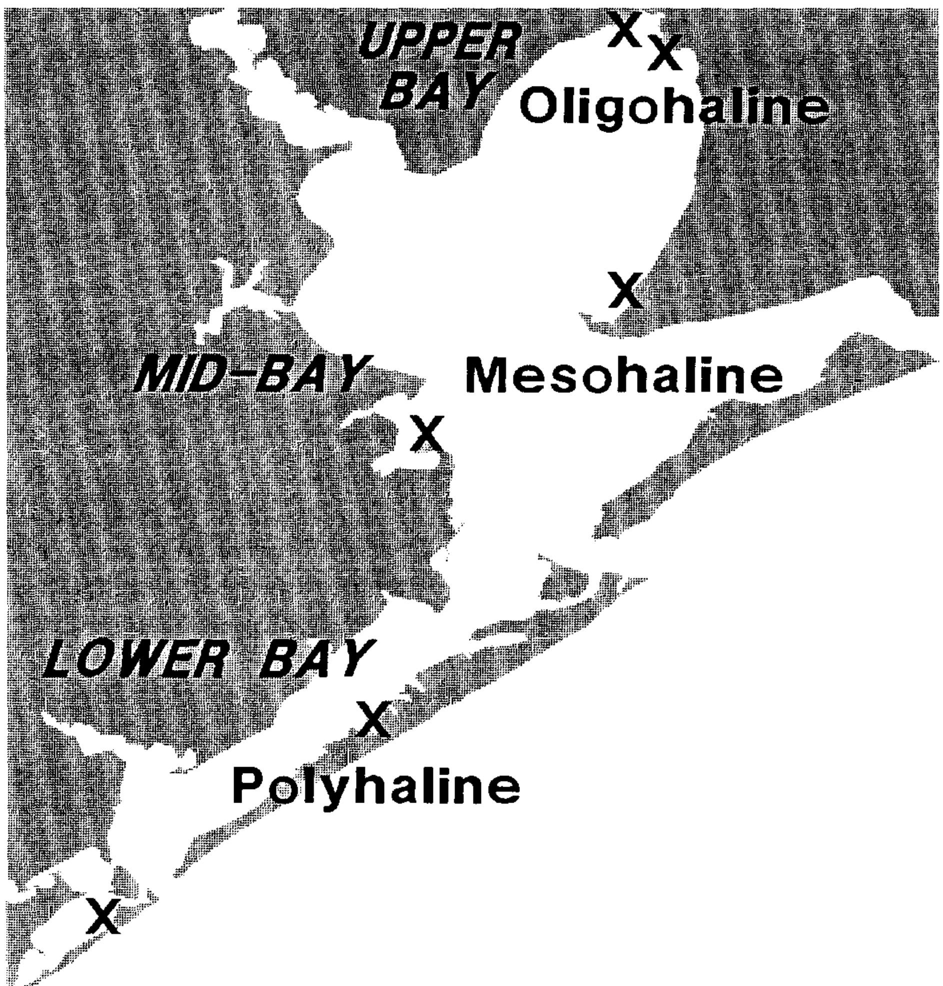

Figure 4. Salinity regimes in Galveston Bay.

TABLE 1. Mean salinities (ppt salinity) in upper, middle, and lower Galveston Bay during 1987. Underline denotes no significant difference between values (ANOVA, df = 5, P > 0.05; LSD, df = 42).

SEASON	UPPER BAY		MIDDLE BAY		LOWER BAY	
Spring	Site 2	Site 1	Site 3	Site 4	Site 6	Site 5
(April-May)	0.01	0.02	8.5	15.5	22.1	33.3
Summer	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
(July)	0.0	0.5	0.8	9.0	27.8	29.4
Fall	Site 2	Site 1	Site 3	Site 5	Site 4	Site 6
(November)	9.6	10.8	20.0	20.5	22.1	32.1

Sites: Site 1 = Inner Trinity Delta; Site 2 = Outer Trinity Delta; Site 3 = Smith Point; Site 4 = Moses Lake; Site 5 = West Bay; Site 6 = Christmas Bay (see Fig. 1). For dates and time of day refer to Appendix II.

Water Depths: Mean water depth at all sites was always less than 1 m and was always deeper in open water (near the edge of the marsh) than on the marsh surface (Appendix II). However, due to variability in water depths (they were changing with the tides) during sampling, differences in depth were not always significant between habitats (paired-t tests within sites, $n = 4$, $P > 0.05$). For the same reason, differences between marsh and open water depths among sites were usually not significantly different (ANOVAs, $df = 5$, $P > 0.05$; Table 2).

Other Parameters: Water temperature, dissolved oxygen and water turbidity values rarely differed between habitats within sites (paired t-tests within sites, $n = 4$, $P > 0.05$), but often differed between sites (Table 3; ANOVA, $df = 5$, $P < 0.05$; LSD multiple range test, $df = 42$). However, gradient-related patterns in temperature and dissolved oxygen were not apparent. A weak pattern of higher turbidities at upper bay sites and lower turbitidies at lower bay sites was evident. Mean temperatures were lowest during the fall sampling (18.8 to 25.2° C) and highest during the summer sampling (27.6 to 32.0° C). Dissolved oxygen was lowest during fall sampling (4.0 to 9.4 ppm) and highest during spring sampling (7.0 to 12.4 ppm). Turbidities were generally lower during the spring sampling (13.4 to 44.3 ppm) and highest during fall sampling (22.0 to 89.5 ppm).

Demersal Organisms

All Fishes: During 1987, 49 species of fishes among 2030 individuals were captured in 144 drop trap samples (2.6 m^2 each) from marsh and adjacent nonvegetated open water habitats in Galveston Bay (Appendix III). The number of fishes from marshes was 1,410 (7.5/ m^2) compared to 620 (3.3/m^2) from nonvegetated open water. Abundances were significantly higher in marshes across all areas of the bay in all seasons (ANOVA, $df = 108$, $P < 0.05$). Densities were significantly different between seasons with lowest densities in the spring and highest in the fall (Fig. 5). Over all seasons, sites in the middle bay had significantly higher fish densities than the upper or lower bay. Within seasons, spring densities were not significantly different between sites in either habitat, summer densities were significantly different between sites in both marsh and open water, and fall densities were significantly different between sites only in the marsh (ANOVA, $df = 5$, $P < 0.05$). The main pattern, mostly due to summer and fall occurrences, was one of higher abundances at the middle bay sites (Smith Point and Moses Lake)(Fig. 5).

TABLE 2. Difference in water depth (cm difference between habitats) bettween marsh and adjacent subtidal nonvegetated habitats at sites in upper, middle and lower Galveston Bay during 1987. Values are means marsh depths minus adjacent open water depth from 4 pairs of samples at each site during flood tide. Underline denotes no significant difference among values (ANOVA, df = 5, P > 0.05; LSD multiple range test, df = 42).

SEASON	SITES					
Spring	Site 1	Site 4	Site 3	Site 5	Site 1	Site 6
(April-May)	7.1	10.2	18.0	18.5	30.6	51.0
Summer	Site 2	Site 1	Site 5	Site 4	Site 5	Site 3
(July)	9.4	10.9	19.9	22.0	24.4	33.5
Fall	Site 5	Site 4	Site 1	Site 3	Site 5	Site 2
(November)	4.5	12.0	16.5	19.1	23.9	30.1

Sites are identified in Table 1. For exact dates and time of day refer to Appendix II.

TABLE 3. Means of temperature, dissolved oxygen and turbidity at sites along an environmental gradidnt in Galveston Bay during drop sampling in 1987. Mean value at each site is from combined measurements in marsh and open water (n = 8).

PARAMETER SEASON	SITES					
TEMPERATURE (°C)						
Spring	Site 6	Site 1	Site 2	Site 5	Site 4	Site 3
(April-May)	23.7	28.0	28.6	28.8	29.5	30.5
Summer	Site 4	Site 2	Site 6	Site 1	Site 3	Site 5
(July)	27.6	30.6	30.7	31.2	31.4	32.0
Fall	Site 1	Site 5	Site 4	Site 2	Site 3	Site 6
(November)	18.8	20.9	22.4	22.7	22.9	25.2
DISSOLVED OXYGEN (ppm)						
Spring	Site 6	Site 5	Site 1	Site 2	Site 3	Site 4
(April-May)	7.0	7.6	8.3	9.5	11.7	12.4
Summer	Site 6	Site 5	Site 4	Site 1	Site 3	Site 2
(July)	6.0	7.0	7.1	7.4	8.2	9.4
Fall	Site 1	Site 2	Site 5	Site 4	Site 3	Site 6
(November)	4.0	7.9	7.9	8.0	8.4	9.4
TURBIDITY (FTUs)						
Spring	Site 5	Site 6	Site 3	Site 4	Site 2	Site 1
(April-May)	13.4	14.6	17.0	29.3	33.1	44.3
Summer	Site 5	Site 4	Site 3	Site 2	Site 5	Site 1
(July)	10.3	26.8	30.5	30.9	32.0	46.4
Fall	Site 6	Site 5	Site 1	Site 2	Site 3	Site 4
(November)	22.0	24.4	50.8	51.5	70.9	89.5

Sites: (Identified in Table 1). Underline denotes no significant difference among values (ANOVA, df = 5, P > 0.05; LSD multiple raange test, df = 42).

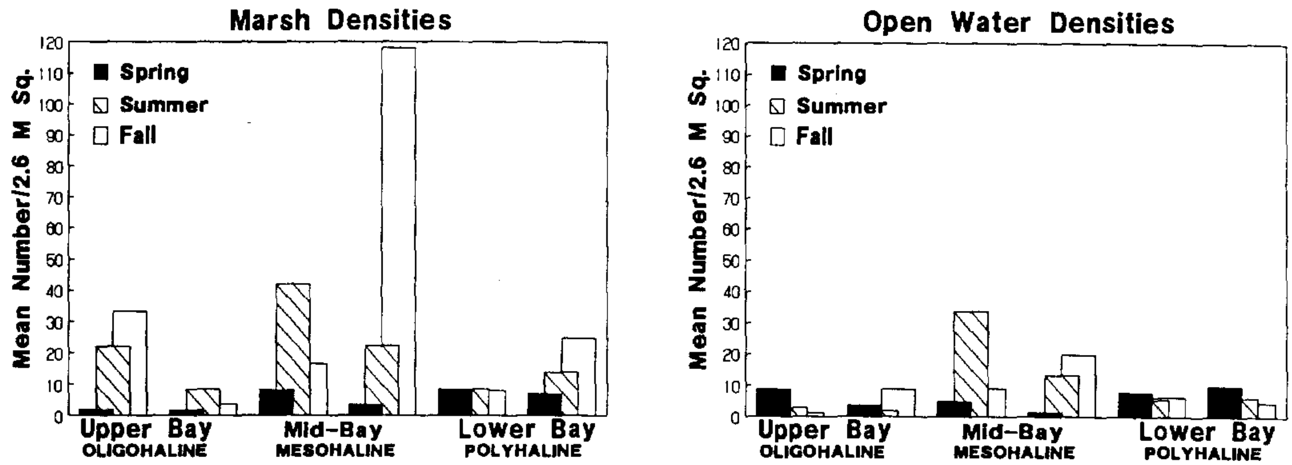

FIGURE 5. Densities of fishes in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

Game Fishes: Spotted seatrout, southern flounder, and red drum followed occurred in a pattern similar to that of all fishes, but abundances were not significantly different between habitats, areas of the bay and seasons (ANOVA, df = 108, $P > 0.05$). Nevertheless, peak abundances occurred in the summer and fall, and at middle bay sites (Fig.6). Within habitats, peak densities were in marsh habitat at the outer Trinity Delta and Smith Point, and in open water at Smith Point, Christmas Bay and West Bay.

All Decapod Crustaceans: During 1987, 18,051 decapod crustaceans among 28 species were caught in 144 drop trap samples from marsh and nonvegetated open water (subtidal) habitats in Galveston Bay (Appendix III). Of these, 16,914 individuals ($90/m^2$) were on marsh surface and 1,137 ($6.1/m^2$) were on nonvegetated bottom. Like fishes, decapod abundances were significantly higher in marshes than open water across all areas of the bay in all seasons (ANOVA, df = 108, $P > 0.05$). The pattern was one of highest abundances at the middle bay sites (Smith Point and Moses Lake) and lowest abundances at the two upper bay sites (Trinity Delta) (Fig. 7). Lowest densities occurred in the spring and highest densities occurred in the summer and fall (Fig. 7). Densities were significantly different among sites within both habitats within all seasons (ANOVAs, df = 5, $P < 0.05$).

All Penaeid Shrimps: Shrimp densities were significantly higher in marshes than open water across all areas of the bay in all seasons (ANOVA, df = 108, $P < 0.05$). The middle and lower bay did not differ in abundances, but the upper bay was significantly lower. Spring and fall densities of penaeid shrimps were highest at lower bay sites (West Bay and Christmas Bay) declining toward the upper bay (Fig. 8). Summer densities were highest in the middle bay (Smith Point), declined sharply in the upper bay, and were intermediate in the lower bay. The overall pattern indicates highest abundances in the lower bay and lowest abundances in the upper bay. Moreover, the lower bay sites (West Bay and Christmas Bay) were the only sites where densities were always significantly higher in the marsh as compared to nonvegetated open water (paired t-tests, n = 4, $P < 0.05$).

Brown Shrimp: Spring and summer densities of brown shrimp were highest, and fall densities were lowest (Fig. 9). Densities were usually greater in the marsh than in nonvegetated open water. Densities were significantly different among areas of the bay

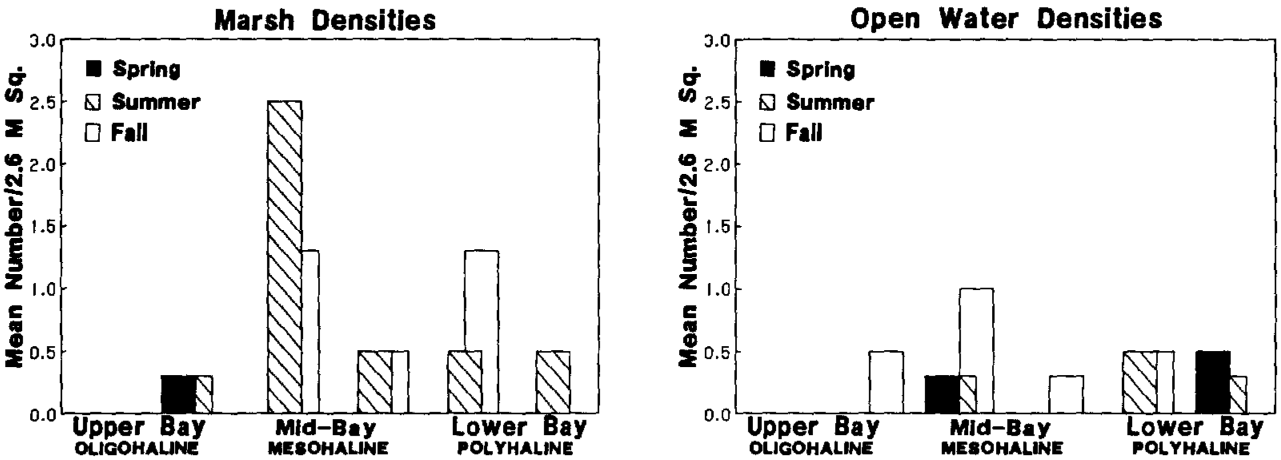

FIGURE 6. Densities of game fishes in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

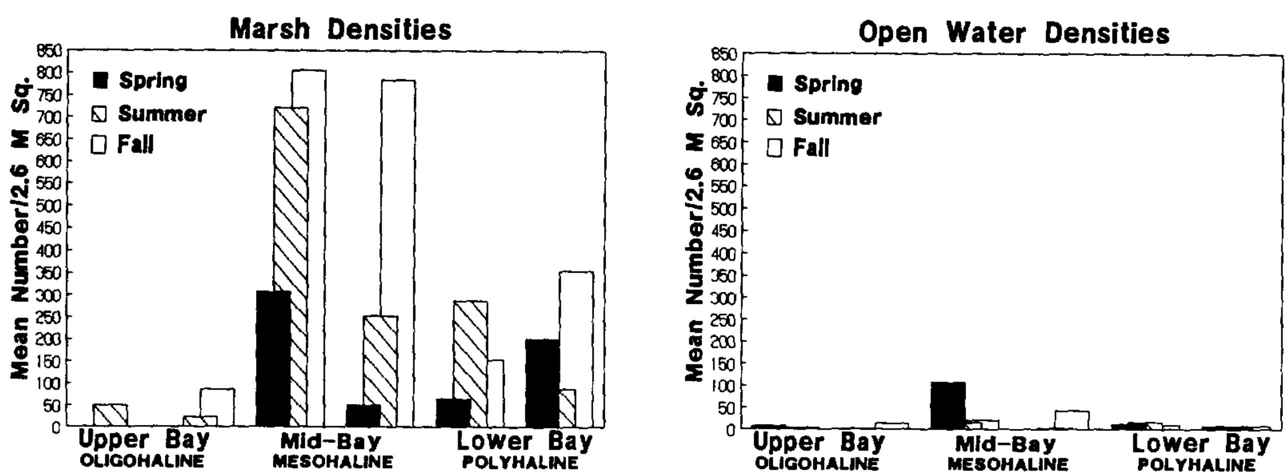

FIGURE 7. Densities of decapod crustaceans in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

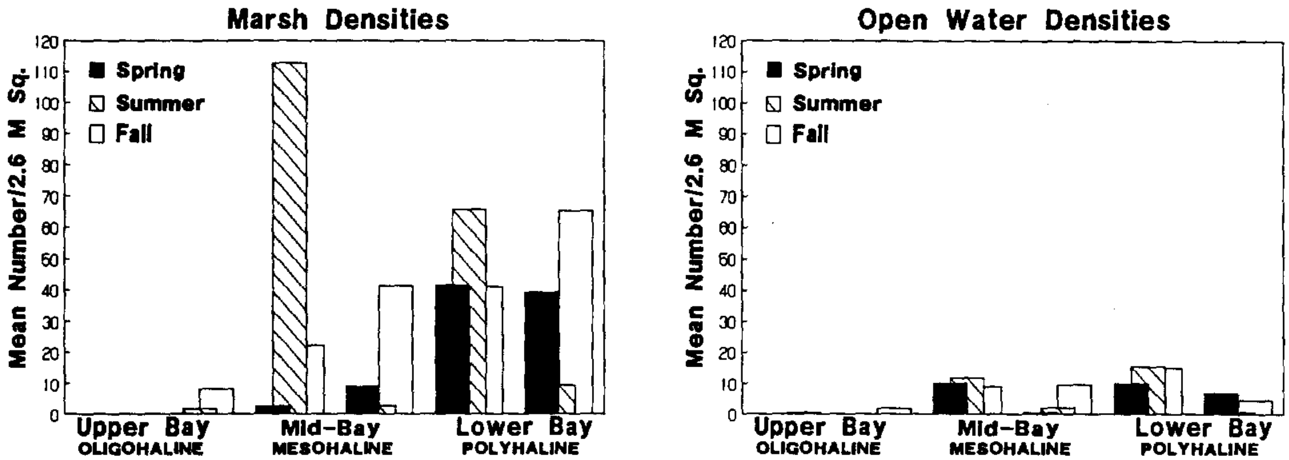

FIGURE 8. Densities of all penaeid shrimps in marsh and adjacent nonvegetated habitats at all sites along a salinity gradient in Galveston Bay.

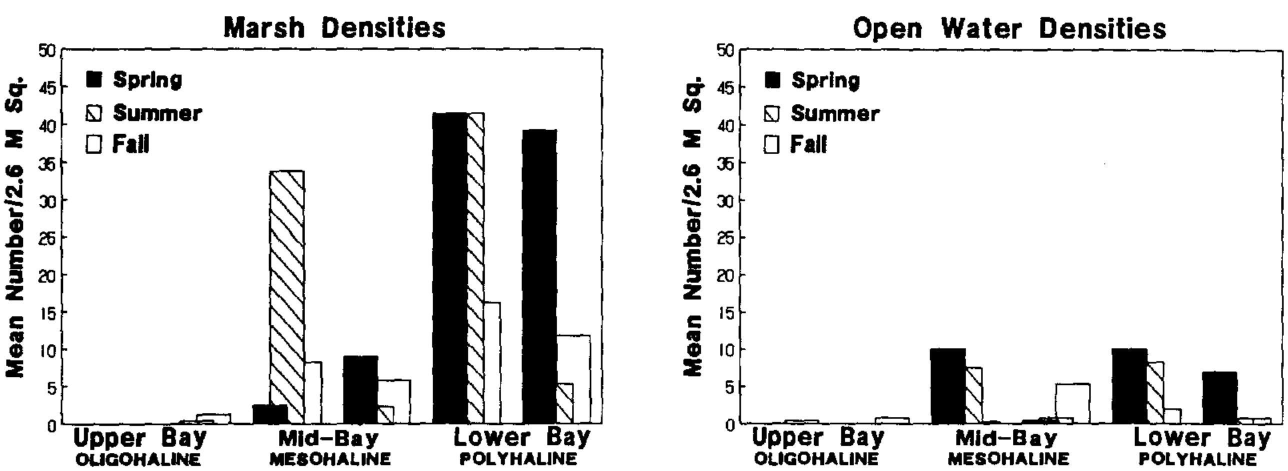

FIGURE 9. Densities of brown shrimp (*Penaeus aztecus*) in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

and habitats but not between seasons (ANOVA, df = 108, $P < 0.05$). Densities were significantly higher in the lower bay than the middle or upper bay. Accordingly, brown shrimp were mostly in the lower bay (West Bay and Christmas Bay) during the spring, and in the middle bay and lower bay during the summer and the fall (Smith Point and West Bay) (Fig. 9). Brown shrimp were absent from upper bay Trinity Delta sites during the spring (the period of peak seasonal abundance) and only a few were present at these sites during the summer and fall. Within marsh habitat highest abundances were also in the lower bay (Fig. 9).

White Shrimp: White shrimp were not present during the spring. Peak annual densities occurred in the summer the middle bay (Smith Point), and highest fall densities occurred in the lower bay (Christmas Bay) (Fig. 10). Densities were significantly different between seasons and areas of the bay, although the lower and middle bay did not differ (ANOVA, df = 108, $P < 0.05$). Like brown shrimp, abundances of white shrimp were sharply (significantly) reduced in the upper bay. Mean densities in the marsh were often much higher than in nonvegetated open water (Fig. 10), but differences were not significant. This occurred because of aggregation behavior (clumping) in white shrimp.

Pink Shrimp: Pink shrimp were only present during the summer and fall, and peak annual densities occurred in the fall (Fig. 11). In the summer pink shrimp were only in the lower bay, but in the fall they occurred throughout the system. The highest fall densities were in the middle and lower bay (Moses Lake, West Bay, and Christmas Bay). Densities were always greater in the marsh than in nonvegetated open water, but significant interaction occurred between habitat and season (ANOVA, df = 108, $P < 0.05$) primarily because of low densities in the summer. For the same reason, significant interaction occurred between area and season. Analysis of the fall season alone revealed significant differences between habitats and areas of the bay (ANOVA, df = 18, $P < 0.05$).

Blue Crab: Blue crabs were distributed throughout the Galveston Bay system in all seasons. Densities were lowest in the spring and highest in the fall (Fig. 12) and significantly different among seasons (ANOVA, df = 108, $P < 0.05$). The overall pattern in marsh habitat indicated highest abundances in the middle bay, intermediate abundances in the lower bay, and lowest abundances in the upper bay (Fig. 12). Densities of open water were approximately equivalent throughout the bay, except during the fall when densities were higher in the middle bay (Fig. 12). However, significant interaction occurred between area and habitat. This was primarily due to habitat selection differences between different parts of the bay. Blue crabs were always more abundant in marsh in the lower and middle bay, but in the upper bay densities were often higher in open water. For instance, during the spring, crabs were significantly higher in open water at the inner Trinity Delta site, significantly higher in marsh at the Smith Point site, and not different between habitats at any of the other sites (paired t-tests within sites, $n = 4$, $P > 0.05$).

Grass Shrimp: Grass shrimp occurred in all seasons as the most abundant decapod crustacean in marsh habitat. Densities peaked during the summer and fall, in the middle bay (Smith Point and Moses Lake) (Fig. 13). Densities were consistently higher in marsh compared to nonvegetated open water, but significant interactions occurred between habitat and season, and between habitat and area of the bay (ANOVA, df = 108, $P < 0.05$). The interaction effect was due to the extremely low numbers, approaching zero, of nearly all the nonvegetated habitat samples (Fig. 13; Appendix II).

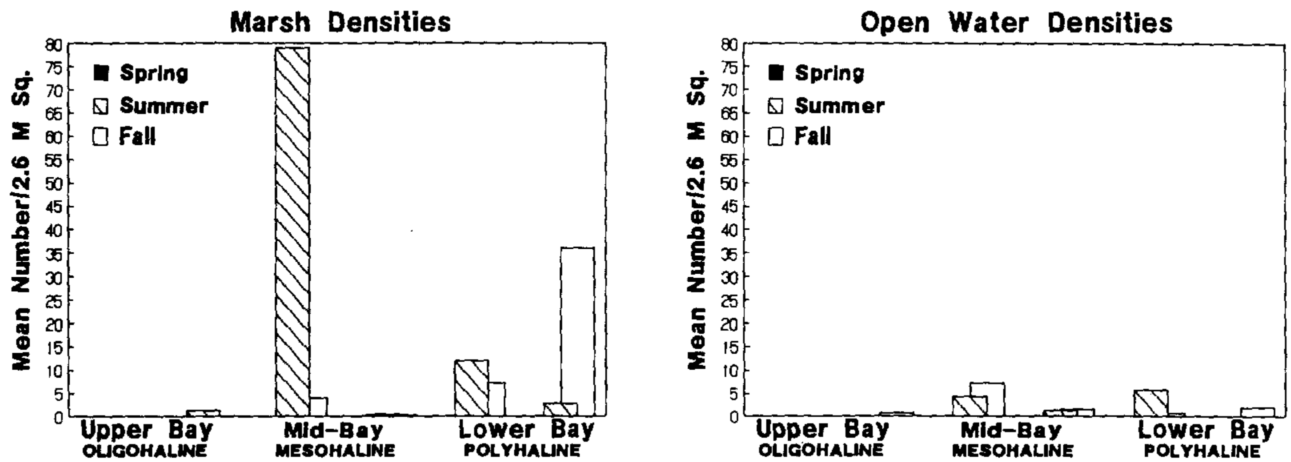

FIGURE 10. Densities of white shrimp (*Penaeus setiferus*) in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

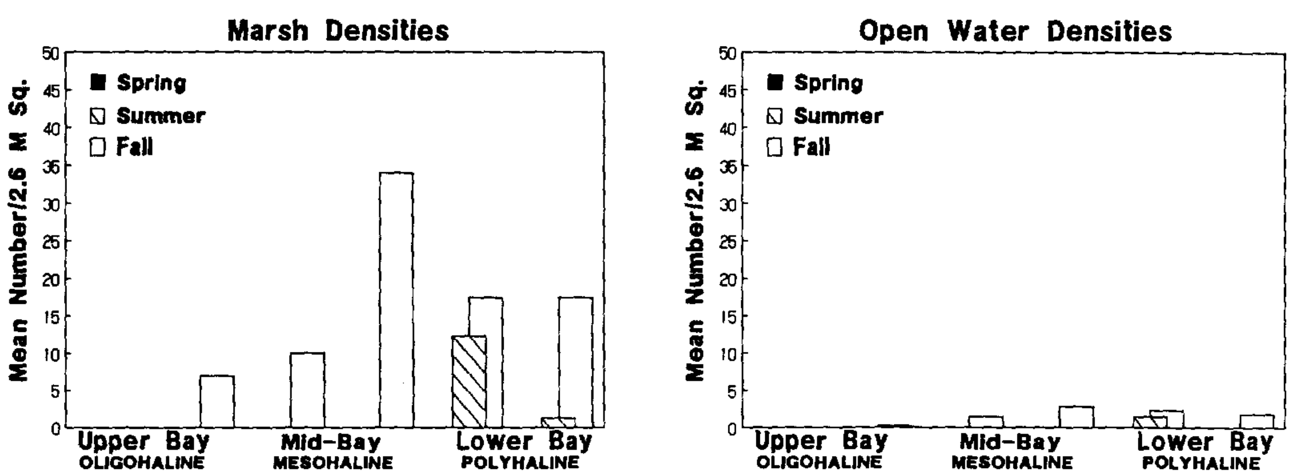

FIGURE 11. Densities of pink shrimp (*Penaeus duorarum*) in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

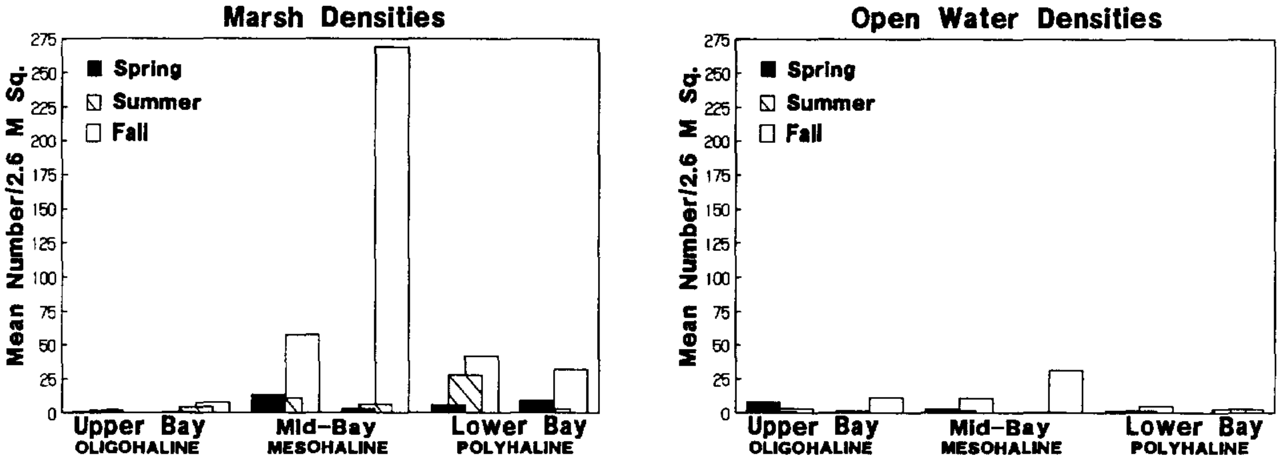

FIGURE 12. Densities of blue crab (*Callinectes sapidus*) in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

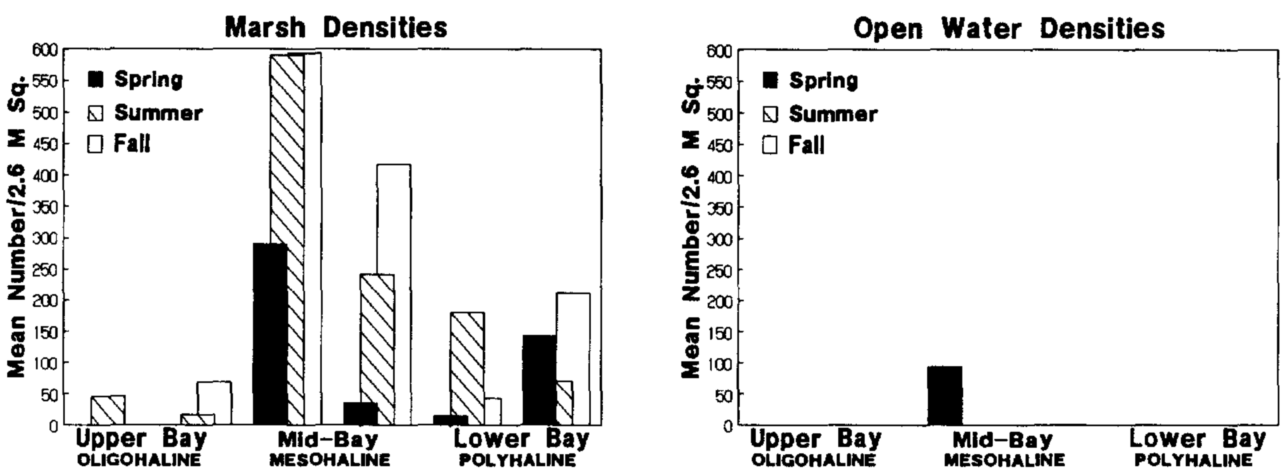

FIGURE 13. Densities of grass shrimp (*Palaemonetes pugio*) in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

Forage Animals

All Epifauna and Infauna: All macrofauna taken from sediment cores (10 cm dia.; 78.5 cm^2 each) were considered to be potential forage organisms (prey) for demersal fishes and decapod crustaceans. In order of abundance, the main taxa included annelid worms, peracarid crustaceans (mostly amphipods and tanaidaceans), and small mollusks. Densities of forage taxa were highest in the middle and lower bay (particularly, Moses Lake and West Bay) during the spring, and highest in the upper bay during the summer (Fig. 14). Marsh always had higher forage densities, but means were not significantly different from open water (ANOVA, df = 108, P > 0.05). Densities were highly dependent on variations in abundances of annelid worms and peracarid crustaceans.

Annelid Worms: Infaunal annelid worms (polychaeta and oligochaeta) were the most abundant group among the forage taxa (Appendix IV). Densities of annelids were highest during the spring in the middle bay, and during the summer and fall in the upper bay (Fig.15). Middle bay abundances declined from spring to summer, but the upper bay abundances increased. Densities were not significantly different among seasons, habitats, or areas of the bay (ANOVAs, df = 108, P > 0.05). Overall, however, highest abundances occurred in the upper bay (Fig. 15).

Peracarid crustaceans: Peracarideans (amphipods and tanaids) were second in abundance to annelid worms as forage animals (Appendix IV). Like annelids, seasonal densities were highest during the spring declining to lowest levels the fall (Fig. 16). In contrast to annelids, peracarids were virtually absent from the upper system in all seasons. Also, in the middle system peracarid abundances were comparatively high (Fig. 16). Overall, densities were significantly different among seasons and areas of the bay (ANOVA, df = 108, P > 0.05), but not between habitats.

Overall Distributions

Among 47 species of fishes, 8 species were mostly in the upper bay (Sites 1 and 2),

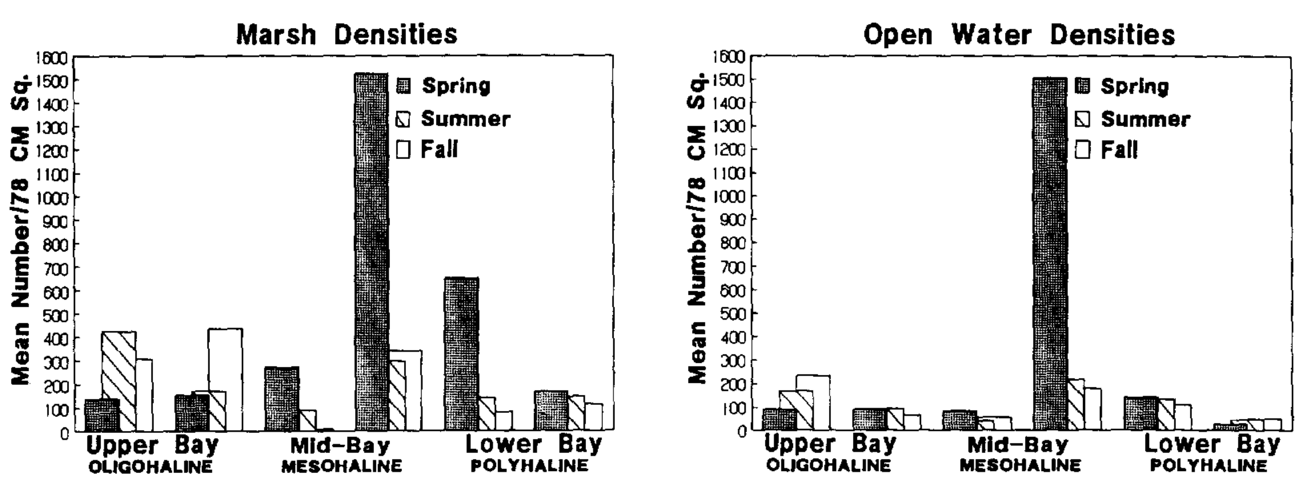

FIGURE 14. Densities of forage taxa for small fishes and decapod crustaceans in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

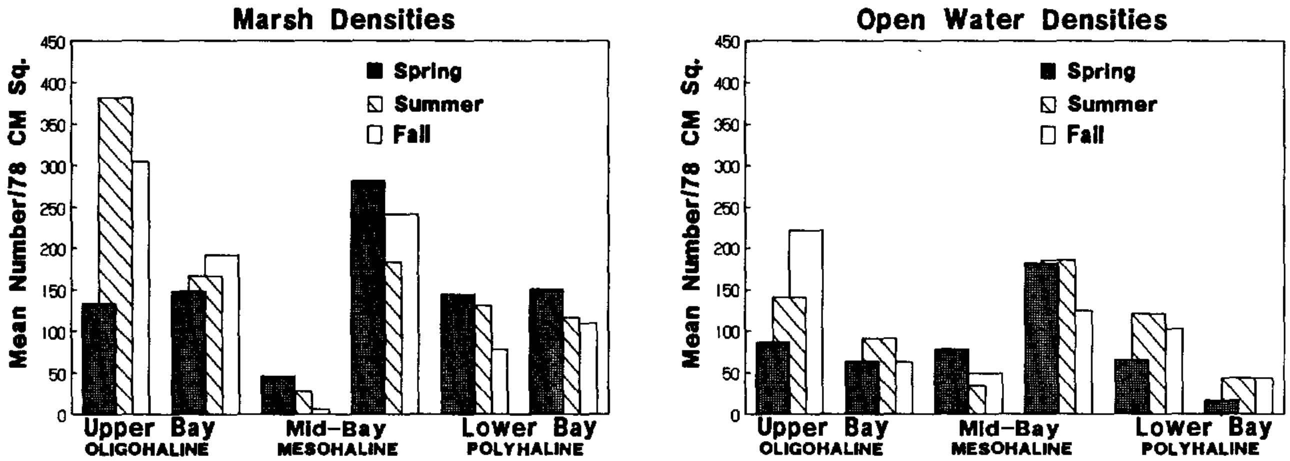

FIGURE 15. Densities of annelid worms in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

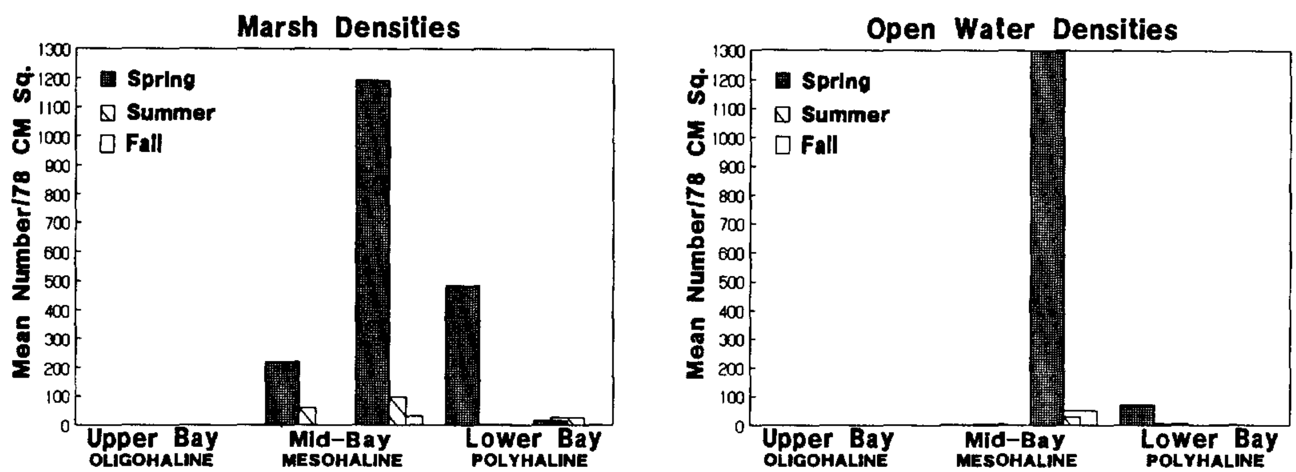

FIGURE 16. Densities of peracarid crustaceans in marsh and adjacent nonvegetated habitats at sites along a salinity gradient in Galveston Bay.

24 species were mostly in the middle bay (Sites 3 and 4) and 15 species were mostly in the lower system (Sites 5 and 6) (Table 4). Overall abundances of fishes were highest in the middle bay. Of 2030 individuals, 394 (19.4 %) were in the upper bay, 1168 (57.5 %) were in the middle bay and 468 (23.0 %) were in the lower system (Table 4).

Among 28 species of decapod crustaceans, 1 species was mostly in the upper bay (Sites 1 and 2), 14 species were mostly in the middle bay (Sites 3 and 4), and 13 were mostly in the lower bay (Sites 4 and 5) (Table 5). Of 18,051 individuals, 756 (4.2 %) were in the upper bay, 12433 (68.9 %) were in the middle bay, and 4862 (26.9 %) were in the lower bay (Table 5).

The abundance centers for each of the eleven fishery species, as related to 1987 and historical salinities, respectively, were:

1) common croaker - 6.6 and 10.4 ppt
2) red drum - 10.6 and 12.2 ppt
3) spotted seatrout - 15.1 and 15.4 ppt
4) blue crab - 15.5 and 15.7 ppt
5) white shrimp - 16.1 and 16.1 ppt
6) southern flounder - 18.1 and 17.5 ppt
7) menhaden - 20.2 and 19.0 ppt
8) pink shrimp - 20.6 and 19.3 ppt
9) brown shrimp - 23.2 and 21.1 ppt
10) sheepshead - 27.2 and 23.8 ppt
11) stone crab - 27.2 and 23.8 ppt

The most common salinity regimes for fishery species during 1987 ranged from mesohaline (6.6 ppt) to polyhaline (27.2 ppt); moreover, of the 11 fishery species, 6 were mesohaline and 5 were polyhaline.

Among 42 forage species, 6 species were mostly in the upper bay (Sites 1 and 2), 19 species were mostly in the middle bay (Sites 3 and 4) and 17 species were mostly in the lower bay (Sites 5 and 6) (Table 6). Of 33,897 individuals, 8,356 (24.7 %) were in upper bay, 18,260 (53.9 %) were in the middle bay and 7,281 (21.5 %) were in the lower bay (Table 6).

Effect of SAV Habitat

SAV habitat occurred only at Trinity Delta and in Christmas Bay. In both areas, SAV was in the low intertidal zone, exposed only during extremely low winter tides, adjacent to marsh. Bayward was subtidal nonvegetated sand. Animal densities within Trinity Delta and Christmas Bay sites were usually not different between marsh and SAV habitats. But, marsh and SAV habitats at Christmas Bay nearly always had higher animal densities than those at the Trinity Delta (Figs. 17 through 23). The outer Trinity Delta site had some, albeit sparse, SAV year-around, while the inner site had SAV only during the summer.

Highest fish densities occurred in the SAV habitats, at Christmas Bay during the spring and fall, and at the Trinity Delta outer site during the summer (Figure 17). In the spring, fish densities were significantly higher in SAV at Christmas Bay than in any other habitat, including those of the outer Trinity Delta (ANOVA, df = 18, $P < 0.05$). During the summer and fall, marsh and SAV fish densities did not differ. Game fishes were consistently more abundant in Christmas Bay, but as a group did not differ among sites in densities between marsh, SAV or nonvegetated habitats (Fig. 18).

Decapod crustacean densities were significantly higher in Christmas Bay marsh and/or SAV habitats (ANOVA, df = 18, $P < 0.05$), than habitats at the Trinity Delta (Figure 19). Moreover, decapod densities did not differ significantly in Christmas Bay between marsh and SAV in any season (ANOVA, df = 18, $P > 0.05$). Penaeid shrimps, as a group, did not differ in density between marsh and SAV habitats, but densities between sites

TABLE 4. Total fishes by site and in relation to salinity in Galveston Bay.

GALVESTON BAY STUDY
TOTAL ABUNDANCES OF FISHES
ALL SEASONS AND HABITATS COMBINED

2.6 m sq. Drop samples	OLIGOHALINE		MESOHALINE		POLYHALINE			
n = 24 per site							1987	HISTORICAL
SPECIES	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SALINITY	SALINITY
1 *Fundulus jenkinsi*	4	0	0	0	0	0	3.6	6.0
2 *Pomoxis annularis*	3	0	0	0	0	0	3.6	6.0
3 *Lucania parva*	14	0	1	1	0	0	3.5	7.0
4 *Fundulus pulvereus*	8	2	0	0	1	0	3.5	7.8
5 *Elops saurus*	2	0	2	0	0	0	3.4	9.2
6 *Ictalurus punctatus*	0	1	0	0	0	0	3.4	9.2
7 *Cyprinodon variegatus*	150	0	0	4	0	39	3.8	9.4
8 *Micropogonias undulatus*	14	3	5	2	4	2	6.6	10.4
9 *Fundulus grandis*	32	35	8	20	10	7	7.6	10.8
10 *Gambusia affinis*	1	0	0	0	1	0	9.8	11.7
11 *Gobiesox strumosus*	0	0	3	0	0	0	9.8	11.7
12 *Oligoplites saurus*	0	0	3	0	0	0	9.8	11.7
13 *Membras martinica*	0	0	2	0	0	0	9.8	11.7
14 *Syngnathus louisianae*	1	0	2	0	1	0	9.8	11.7
15 *Arius felis*	0	0	1	0	0	0	9.8	11.7
16 *Hyporhamphus unifasciatus*	0	0	1	0	0	0	9.8	11.7
17 *Stellifer lanceolatus*	0	0	1	0	0	0	9.8	11.7
18 *Mugil cephalus*	16	16	5	17	2	9	9.8	11.7
19 *Sciaenops ocellatus*	0	1	5	0	1	0	10.6	12.2
20 *Anchoa mitchilli*	7	37	129	69	24	1	11.3	12.7
21 *Myrophis punctatus*	13	2	8	41	3	3	12.1	13.3
22 *Citharichthys spilopterus*	2	0	1	0	0	2	12.1	13.3
23 *Symphurus plagiusa*	4	0	55	0	16	15	14.2	14.8
24 *Leiostomus xanthurus*	1	5	8	0	4	6	14.3	14.8
25 *Gobiosoma bosci*	0	1	165	483	29	1	14.4	14.9
26 *Cynoscion nebulosus*	0	2	11	4	9	2	15.1	15.4
27 *Gobiosoma robustum*	0	0	0	2	0	0	15.5	15.7
28 *Sphoeroides parvus*	0	0	0	2	0	0	15.5	15.7
29 *Menidia beryllina*	4	5	1	40	39	1	17.8	17.3
30 *Paralichthys lethostigma*	0	1	3	1	1	3	18.1	17.5
31 *Brevoortia patronus*	3	0	0	9	23	0	20.2	19.0
32 *Microgobius thalassinus*	0	0	1	0	4	0	22.5	20.6
33 *Opsanus beta*	0	0	0	1	2	0	23.3	21.1
34 *Syngnathus scovelli*	0	2	0	6	4	7	24.2	21.7
35 *Lagodon rhomboides*	1	0	20	9	17	43	25.9	22.9
36 *Archosargus probatocepha*	0	0	0	0	1	0	27.2	23.8
37 *Chaetodipterus faber*	0	0	0	0	1	0	27.2	23.8
38 *Fundulus similis*	0	0	0	0	2	0	27.2	23.8
39 *Gobionellus boleosoma*	0	1	15	0	5	95	27.6	25.2
40 *Adinia xenica*	0	0	0	1	0	4	27.6	25.4
41 *Achirus lineatus*	0	0	0	0	0	1	27.9	26.4
42 *Dasyatis sabina*	0	0	0	0	0	1	27.9	26.4
43 *Eucinostomus argenteus*	0	0	0	0	0	1	27.9	26.4
44 *Orthopristis chrysoptera*	0	0	0	0	0	1	27.9	26.4
45 *Synodus foetens*	0	0	0	0	0	1	27.9	26.4
46 *Trinectes maculatus*	0	0	0	0	0	1	27.9	26.4
47 *Eucinostomus spp.*	0	0	0	0	0	18	27.9	26.4
FISH TOTALS:	280	114	456	712	204	264		

TABLE 5. Total decapod crustaceans by site and in relation to salinity in Galveston Bay.

GALVESTON BAY STUDY
TOTAL ABUNDANCES OF DECAPOD CRUSTACEANS
ALL SEASONS AND HABITATS COMBINED

2.6 m sq. Drop samples n = 24 SPECIES	OLIGOHALINE SITE 1	 SITE 2	MESOHALINE SITE 3	 SITE 4	POLYHALINE SITE 5	 SITE 6	1987 SALINITY	HISTORICAL SALINITY
1 *Sesarma reticulatum*	2	0	0	0	1	0	5.5	10.0
2 *Uca pugnax*	2	0	7	0	0	0	7	10.6
3 *Xanthidae, unknown species*	0	0	4	0	0	0	9.8	11.7
4 *Eurypanopeus depressus*	0	0	3	0	0	0	9.8	11.7
5 *Neopanope texana*	1	4	31	2	1	3	10.8	12.4
6 *Rhithropanopeus harrissi*	0	1	32	4	0	2	11.1	12.6
7 *Palaemonetes pugio*	187	339	6276	2792	956	1708	14	14.6
8 *Palaemonetes vulgaris*	0	2	358	132	94	74	14.5	15.0
9 *Callinectes sapidus*	65	104	390	1243	333	200	15.3	15.6
10 *Uca rapax*	0	0	0	1	0	0	15.5	15.7
11 *Palaemonetes intermedius*	0	0	128	92	24	58	16	16.0
12 *Penaeus setiferus*	0	8	378	14	103	163	16.1	16.1
13 *Penaeus duorarum*	0	29	46	152	134	82	20.6	19.3
14 *Eurypanopeus abbreviatus*	0	0	0	2	2	0	21.4	19.8
15 *Panopeus herbstii*	0	0	2	0	0	2	21.4	19.8
16 *Penaeus aztecus*	2	10	248	94	478	259	23.2	21.1
17 *Libinia dubia*	0	0	0	0	1	0	27.2	23.8
18 *Pinnixa chaetopterana*	0	0	0	0	1	0	27.2	23.8
19 *Uca spp.*	0	0	0	0	1	0	27.2	23.8
20 *Menippe mercenaria*	0	0	0	1	0	1	27.2	23.8
21 *Sesarma cinereum*	0	0	0	0	3	0	27.2	23.8
22 *Petrolisthes armatus*	0	0	0	0	5	0	27.2	23.8
23 *Alpheus heterochaelis*	0	0	0	1	27	31	27.6	25.2
24 *Clibanarius vittatus*	0	0	0	0	40	58	27.6	25.4
25 *Pagurus spp.*	0	0	0	0	0	2	27.9	26.4
26 *Panopeus turgidus*	0	0	0	0	0	3	27.9	26.4
27 *Hippolyte zostericola*	0	0	0	0	0	5	27.9	26.4
28 *Uca minax*	0	0	0	0	0	7	27.9	26.4
CRUSTACEAN TOTALS:	259	497	7903	4530	2204	2658		

TABLE 6. Total epifauna and infauna by site and in relation to salinity in Galveston Bay.

GALVESTON BAY STUDY TOTAL ABUNDANCES OF EPI-INFAUNA ALL SEASONS AND HABITATS COMBINED	OLIGOHALINE		MESOHALINE		POLYHALINE			
78.5 cm sq. cores n = 6 per site			SAMPLING SITES				1987	HISTORICAL
SPECIES	1	2	3	4	5	6	SALINITY	SALINITY
ANNELIDS								
1 *Laeonereis culveri*	285	134	5	1	0	20	3.5	7.8
2 *Oligochaete spp.*	580	396	39	154	13	39	3.4	9.1
3 *Nereidae sp.*	0	1	0	0	0	0	3.4	9.2
4 *Parandalia fauveli*	0	0	1	0	0	0	9.8	11.7
5 *Hobsonia gunneri*	6	21	4	28	7	1	10.8	12.4
6 *Polydora ligni*	0	9	19	33	3	0	11.6	12.9
7 *Marphysa sanguinea*	0	0	0	1	0	0	15.5	15.7
8 *Steninonereis martini*	0	0	0	3	0	0	15.5	15.7
9 *Mediomastus spp.*	0	0	0	6	0	0	15.5	15.7
10 *Mediomastus ambiseta*	0	0	0	9	0	0	15.5	15.7
11 *Eteone lactea*	0	0	0	17	2	0	16.8	16.6
12 *Streblospio benedicti*	3	29	15	769	316	47	18.8	18
13 *Nereis (Neanthes) succinea*	0	0	4	1	2	4	21.9	20.2
14 *Capitella capitata*	0	0	30	49	81	72	25.3	22.5
15 *Asychis elongatus*	0	0	0	0	1	0	27.2	23.8
16 *Scolelepis sp.*	0	0	0	0	1	0	27.2	23.8
17 *Glycera dibranchiata*	0	0	0	0	3	0	27.2	23.8
18 *Mediomastus californiensis*	0	0	0	0	3	1	27.4	24.5
19 *Tharyx setigera*	0	0	0	0	14	6	27.4	24.6
20 *Scoloplos fragilis*	0	0	0	0	1	3	27.7	25.8
21 *Heteromastis filiformis*	0	0	0	1	6	44	27.8	26.1
22 *Aricidea (Acmira) philbinae*	0	0	0	0	1	6	27.8	26.1
23 *Axiothella mucosa*	0	0	0	0	0	1	27.9	26.4
24 *Capitellidae sp.*	0	0	0	0	0	1	27.9	26.4
25 Melinna maculata	0	0	0	0	0	1	27.9	26.4
ANNELID TOTALS: Identified (n = 6):	874	590	117	1072	454	246		
Not Identified (n = 24):	5074	2663	971	4800	2567	1923		
CRUSTACEANS								
1 *Corophium sp. B*	0	1	0	0	0	0	3.4	9.2
2 *Callinectes sapidus*	0	0	1	0	0	0	9.8	11.7
3 *Xanthidae sp.*	0	0	1	0	0	0	9.8	11.7
4 *Gammarus mucronatus*	0	0	24	2	3	0	11.4	15.7
5 *Hargeria rapax*	0	0	281	603	99	12	14.6	15.1
6 *Corophium sp.*	0	6	7	1065	0	0	15.4	15.6
7 *Grandidierella bonneroides*	0	0	14	37	13	0	15.4	15.6
8 *Ampelisca abdita*	1	0	16	598	43	0	16	16
9 *Mysidopsis bahia*	0	0	0	0	3	0	27.2	23.8
10 *Edotea montosa*	0	0	0	0	4	0	27.2	23.8
CRUSTACEAN TOTALS: Identified (n = 6):	1	7	344	2305	165	12		
Not Identified (n = 24):	6	16	1174	10835	2315	211		
MOLLUSKS:								
1 *Amygdalum papyrium*	0	0	1	0	0	0	9.8	11.7
2 *Odostomia sp.*	0	0	0	1	0	0	15.5	15.7
3 *Tellina sp.*	0	0	1	0	0	1	21.4	19.8
4 *Mulinia lateralis*	0	0	0	0	2	0	27.2	27.2
5 *Acteocina canaliculata*	0	0	0	0	5	0	27.2	27.2
6 *Pandora (Clidophora) trilineata*	0	0	0	0	0	1	27.9	26.4
7 *Gastropod sp. A*	0	0	0	0	0	3	27.9	26.4
MOLLUSCAN TOTALS: Identifed (n = 6):			2	1	7	5		
Not Identified (n = 24):	157	35	32	8	14	46		
OTHERS:								
1 *Odonata sp. A*	2	0	0	0	0	0	3.6	6
2 *Odonata sp. B*	1	0	0	0	0	0	3.6	6
3 *Chironomid sp.*	1	24	2	12	0	0	5.7	10.8
4 *Nemertean sp.*	0	0	0	2	0	0	15.5	15.7
OTHER TOTALS: Categorized (n = 6):	4	24	2	14				
Not Catergorized (n = 24):	231	174	49	391	157	48		

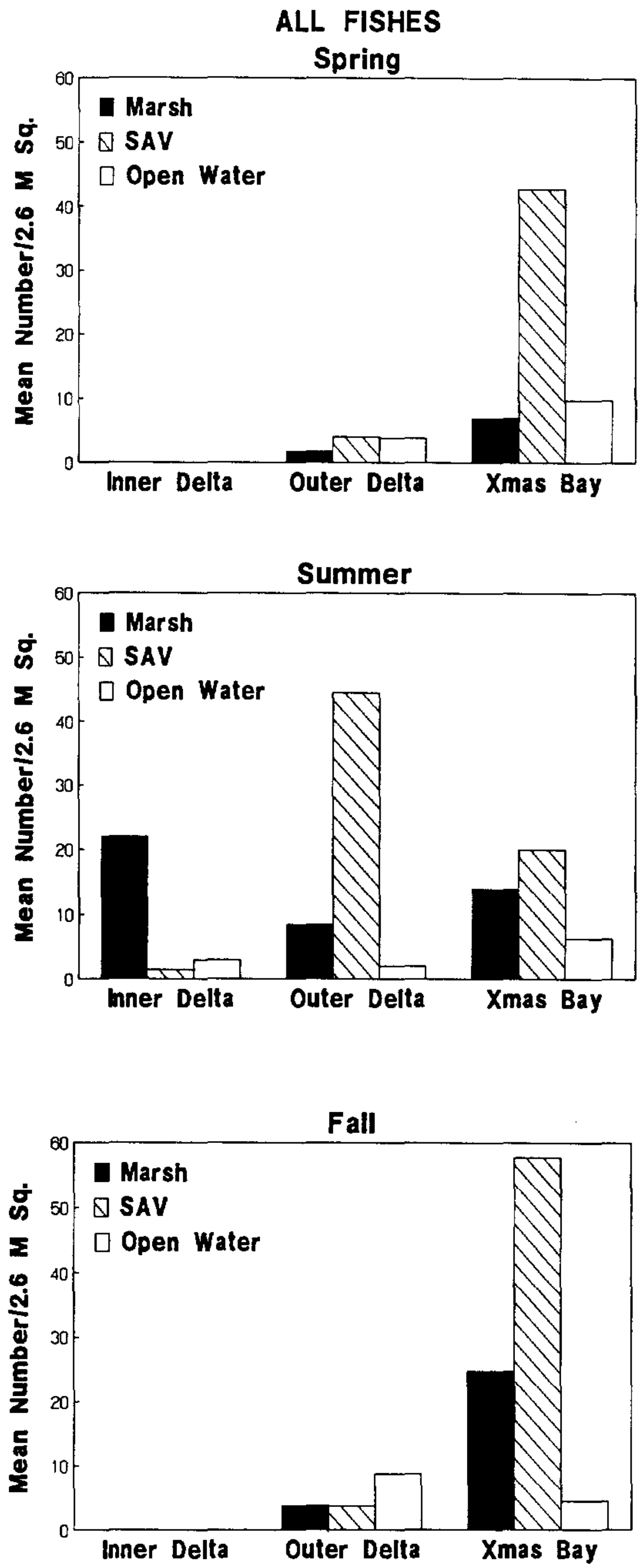

FIGURE 17. Comparative densities of fishes in marsh, submerged aquatic vegetation (SAV), and nonvegetated open water between the upper (Trinity River delta) and lower (Christmas Bay) parts of the Galveston Bay system, during 1987.

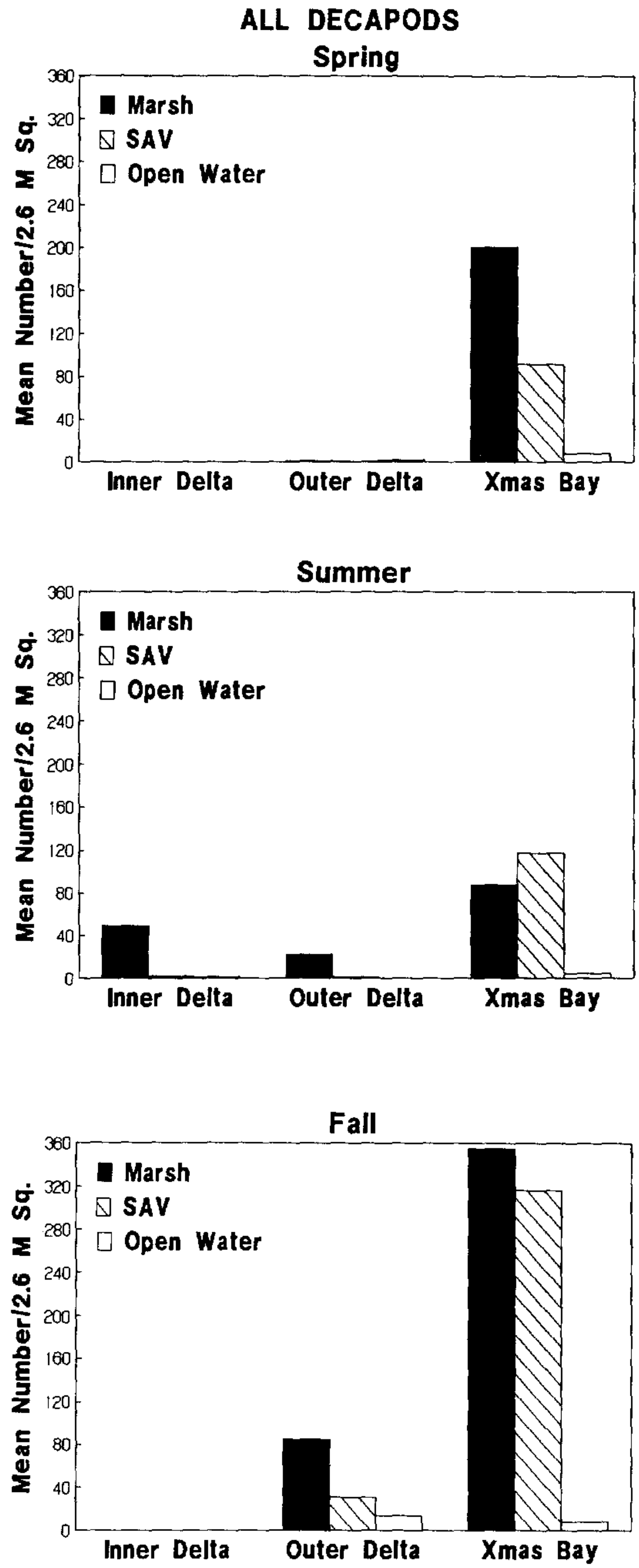

FIGURE 18. Comparative densities of decapod crustaceans in marsh, submerged aquatic vegetation (SAV), and nonvegetated open water between the upper (Trinity River delta) and lower (Christmas Bay) parts of the Galveston Bay system, during 1987.

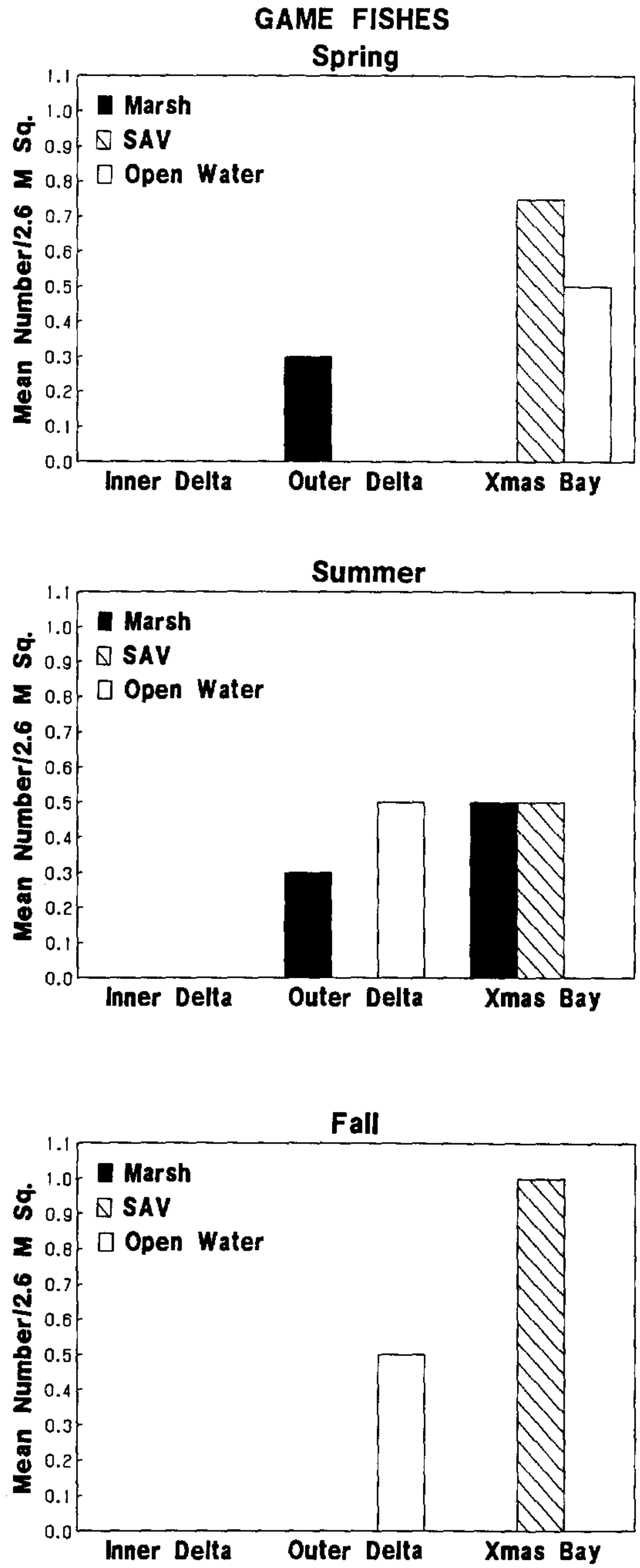

FIGURE 19. Comparative densities of game fishes in marsh, submerged aquatic vegetation (SAV), and nonvegetated open water between the upper (Trinity River delta) and lower (Christmas Bay) parts of the Galveston Bay system, during 1987.

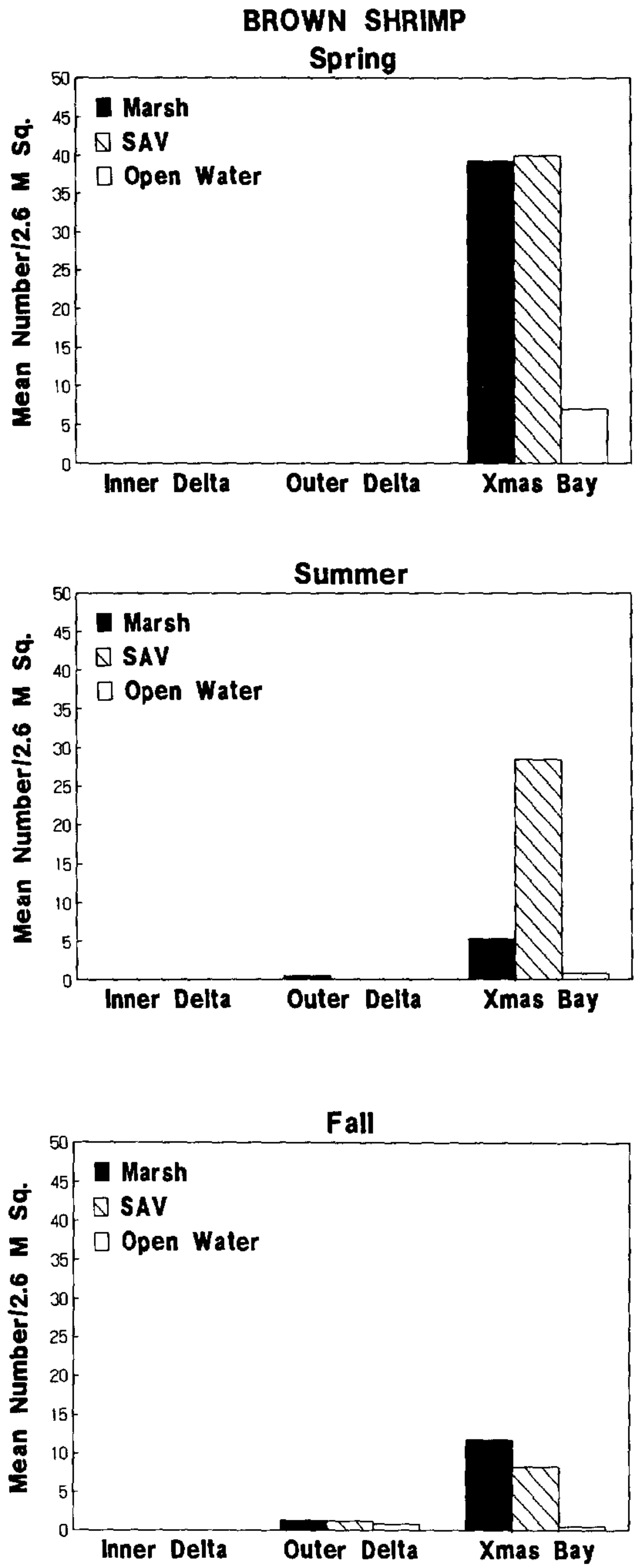

FIGURE 20. Comparative densities of brown shrimp in marsh, submerged aquatic vegetation (SAV), and nonvegetated open water between the upper (Trinity River delta) and lower (Christmas Bay) parts of the Galveston Bay system, during 1987.

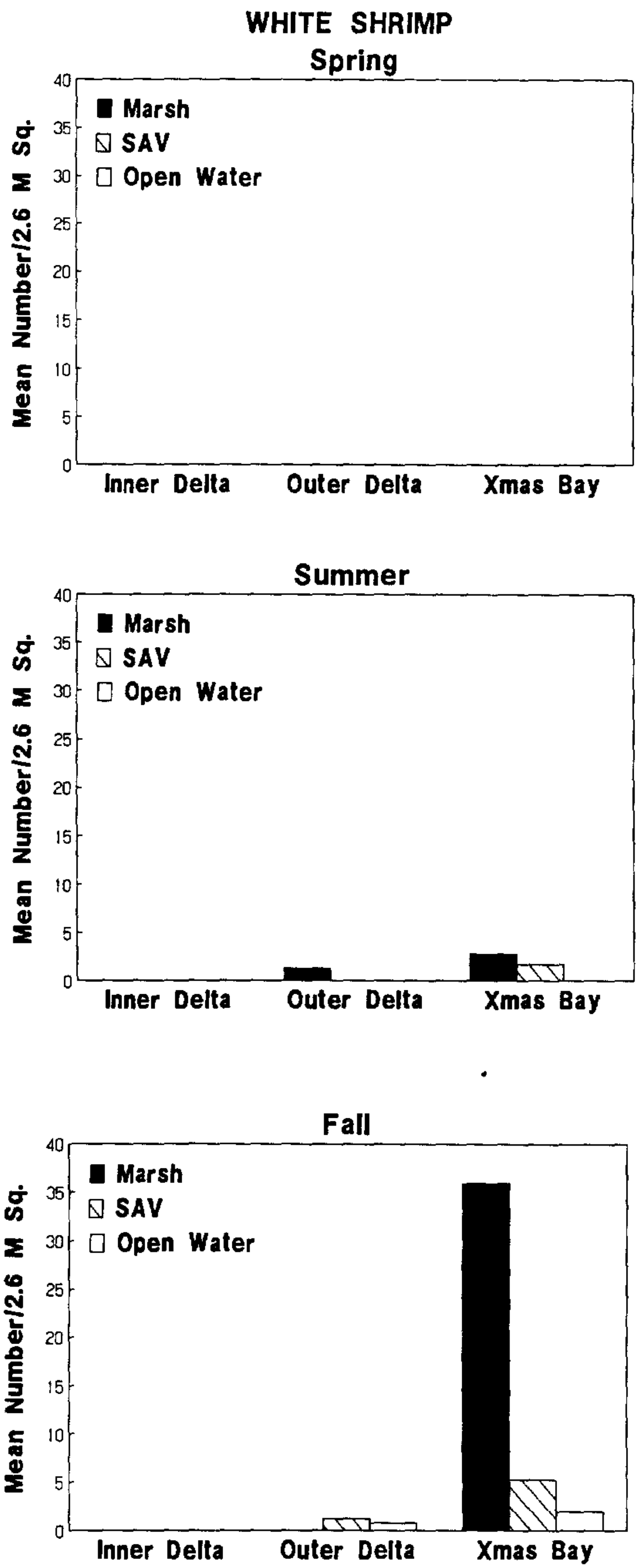

FIGURE 21. Comparative densities of white shrimp in marsh, submerged aquatic vegetation (SAV), and nonvegetated open water between the upper (Trinity River delta) and lower (Christmas Bay) parts of the Galveston Bay system, during 1987.

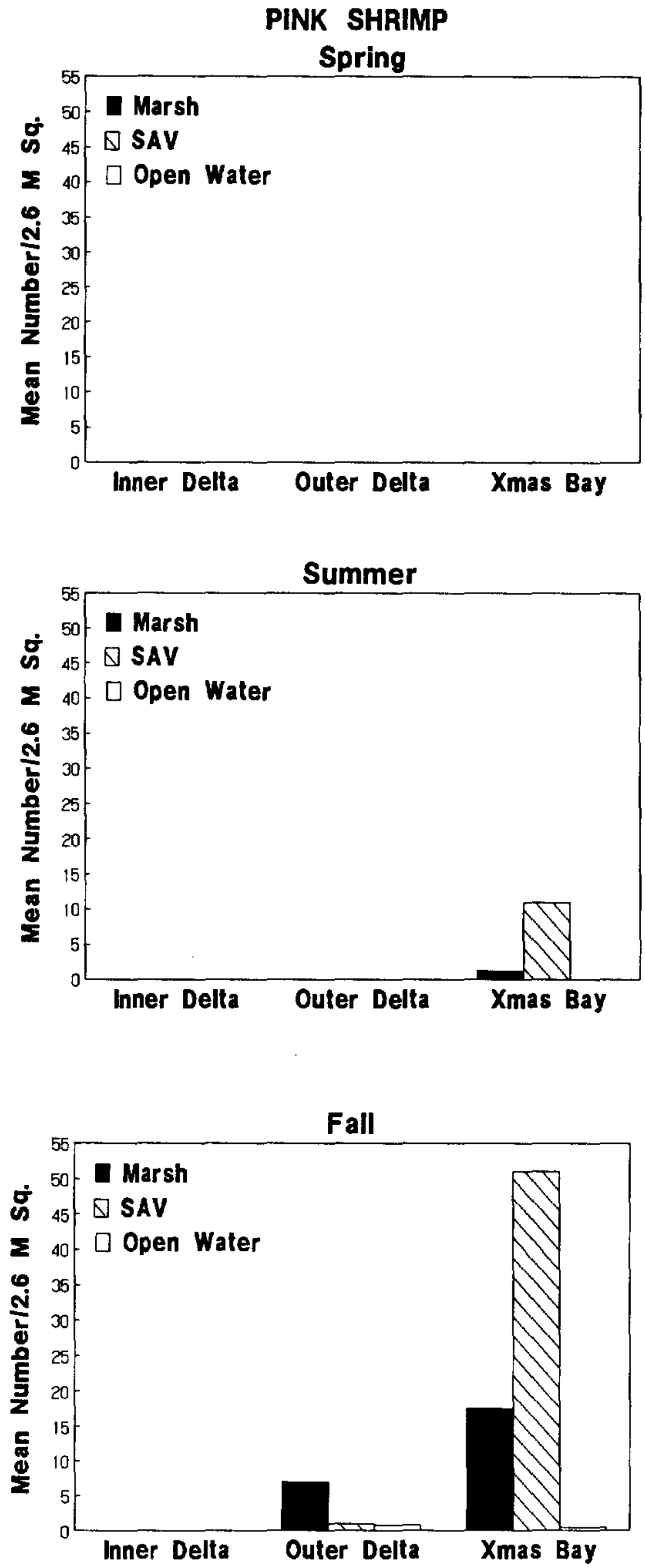

FIGURE 22. Comparative densities of pink shrimp in marsh, submerged aquatic vegetation (SAV), and non-vegetated open water between the upper (Trinity River delta) and lower (Christmas Bay) parts of the Galveston Bay system, during 1987.

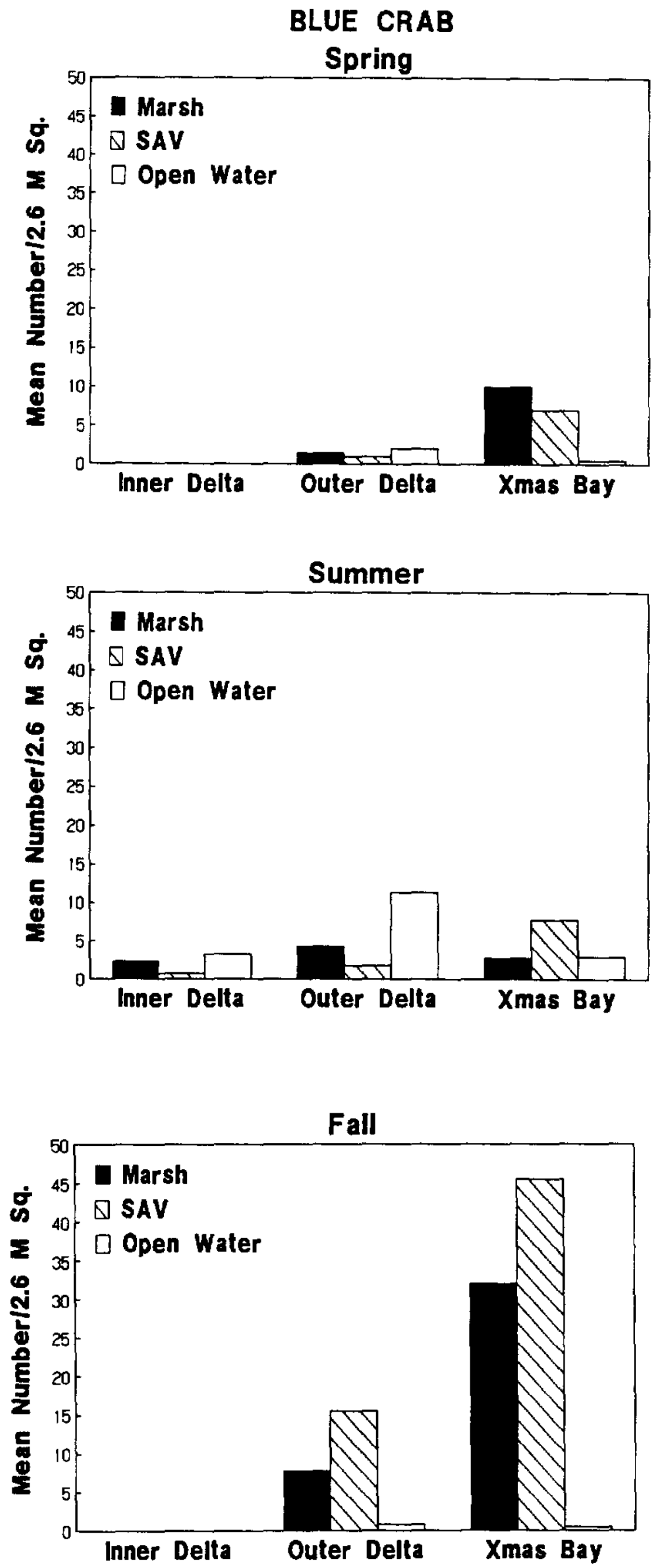

FIGURE 23. Comparative densities of blue crab in marsh, submerged aquatic vegetation (SAV), and non-vegetated open water between the upper (Trinity River delta) and lower (Christmas Bay) parts of the Galveston Bay system, during 1987.

were always significantly higher in Christmas Bay (ANOVA, df = 18, $P < 0.05$) (Fig. 20). This pattern was similarly repeated in brown shrimp (Fig. 21) and pink shrimp (Fig. 22). Blue crab did not differ between habitats except in the fall (ANOVA, df = 18, $P < 0.05$) (Fig. 23).

Characterization of Marshes

The Upper Bay: Marshes in the upper system (Trinity Bay) were dominated by the Trinity River and other streams flowing into the estuary. Overall salinities in 1987 were lower than historical averages in the upper system revealing a wet year (Fig.4). Both the inner and outer marsh at the Trinity River Delta were strictly oligohaline during the spring and summer of 1987. By fall, salinities had increased to low mesohaline range. Responses of the marsh community reflected both the 1987 conditions and the general characteristics of the delta environment.

Plant cover was very sparse at the beginning of spring as a result of the previous winter die-back. Marsh bulrush (*Scirpus* spp.), the dominant plant, emerged in April along with the subdominants, arrowheads (*Sagittaria lancifolia*, *S. latifolia*), alligator weed (*Alternanthera philoxeroides*), pickerel weed (*Pontederia cordata*), water hyssop (*Bacopa monnieri*), and switchgrass (*Panicum* sp.). All were under heavy grazing pressure by nutria (personal observation). Grazing and tidal and floodwater export previous production left the intertidal zone virtually bare. Subtidal areas adjacent to the marsh were also barren. By July, the plants had recovered to near maximum annual biomass on the marsh surface as well as in subtidal areas. Bulrush cover in the marsh was dense and lush, and subtidal areas were covered with submerged aquatic vegetation (SAV) to a water depth of about 80 cm deep. The dominant SAV species at the inner site (Site 1) were quillwort *(Isoetes* sp.) and widgeongrass (*Ruppia maritima*) in shallow water, with naiads (*Najas* spp.) and tapegrass in deeper water. Quillwort was only in very shallow water (less than 20 cm deep and often exposed) next to the marsh edge. It formed a dense short turf year-around, and at the outer site (Site 2) coverage was more extensive. Large beds of tapegrass were present in water 30 to 80 cm deep at the inner site but not at the outer site. Further examination revealed that tapegrass beds covered many hectares extending westward for at least 2 kilometers. Tapegrass beds appeared to be a seasonally persistent vegetational feature that has not been previously reported for the delta. Most of the vegetation experienced a die-back during the fall (September and October) that was associated with increased salinities; but, it was not known whether salinity caused the die-back. Almost all of the fall standing crop of plants was exported as detritus into Trinity Bay during the ensuing winter months.

Of 8 species of fishes in delta marshes, 4 were cyprinodontidae (killifishes), two were freshwater species (crappie and channel catfish) and one was an estuarine species of commercial and recreational value (Atlantic croaker) (Table 4). During the spring, these fishes were mostly found in open water (not much vegetation present), but in the summer and fall they shifted into marsh habitat. Hence, the movements of fishes between habitats corresponded to seasonal changes in plant cover. McIvor and Odum (1988) point out that such differences in selection for the marsh surface may be controlled by the differences in the quality of nearby subtidal habitat that fishes must use when the marsh is drained. Fishes that seek high quality subtidal bottom for food and protection at low tide simply move onto the nearest marsh surface at flood tide. The single estuarine fish of commercial value (Atlantic croaker) associated with Trinity delta marshes also has been reported in abundance under low salinity conditions (0 to 11 ppt) in upper Barataria Bay, Lousiana (Rogers and Herke 1987). This species was apparently one of the few commercial species able to use oligohaline, nonvegetated bottom as a nursery habitat.

Only one decapod crustacean (a crab) was more abundant at the upper bay sites than other areas, although 10 of the 28 species in the bay used the upper bay at sometime during the year (Table 5). All 3 penaeid shrimps and the blue crab used the delta marshes, but not in large numbers. Baldauf (1970) also noted, from monthly trawl surveys taken in 1967, 1968 and 1969, that brown shrimp, white shrimp and blue crab use the delta as a nursery. He concluded that brown shrimp abundances were less during years when Trinity River flow was high and that white shrimp abundances were not influenced by differences in annual river flow. His comparison of catches in open water deep channels with shallow water yielded fewer shrimp next to the the marsh. These data suggest that the delta marsh surface may not be as important as shrimp habitat as the deeper water in the upper bay. We might add that the nursery roles of marsh surface and open water appeared to reverse in importance from the upper to the lower bay. Therefore, direct utilization of the marsh surface became increasingly evident toward the lower system.

Small macroinvertebrates, useful as forage organisms, were comprised almost entirely of annelids worms at the delta during 1987. A nereid polychaete (*Laeonereis culveri*) and several unidentified oligochaete species were the dominant infauna (Table 6). Nereids and oligochaetes are reported detritivores (Tenore et al. 1977; Tenore 1977). Epifaunal peracarid crustaceans were essentially absent. Since peracarids are highly utilized and often are preferred (or more available) as prey by small fishes and decapod crustaceans, their absence may have affected the distributions of these predators. A least the absence of peracarids would have lessened the feeding value of delta marshes for exploiting predators. We propose that the lack of peracarids was directly attributable to low salinities, since estuarine peracarids have poor ability to osmoregulate and cannot accommodate freshwater conditions for very long.

The Middle Bay: The marshes in the middle part of Galveston Bay were greatly influenced by mixing of freshwater from the upper system and seawater from the lower system. This was clearly demonstrated during 1987. Salinities in the middle bay (Smith Point and Moses Lake sites) varied more than any other part of the system, with values from near 0 ppt to above 20 ppt (Fig. 4). Seasonal values were similar to either those of the upper system or lower system depending upon circumstances; eg. spring salinities were mid-range (8 to 15 ppt); summer salinities were similar to the upper system (0.8 to 9 ppt) following several months of high freshwater inflow; fall salinities were like those of the lower system (20 to 22 ppt) following reduced freshwater inflow and high equinox tides. Over the long term, the middle system was unquestionably mesohaline, despite short-term salinities that varied between oligohaline and polyhaline.

Marshes in the middle bay were mixed stands of smooth cordgrass (*Spartina alterniflora*), black rush (*Juncus roemerianus*), saltgrass (*Distichlis spicata*) and marsh hay (*Spartina patens*). Smooth cordgrass dominated the outer fringe (low zone). Subtidal SAV was not present, possibly due to the extreme variations in salinity. But the presence of expansive subtidal oyster reefs provided ample shell for periphytic green and bluegreen algal colonization. These small algae were dense enough at Smith Point to be seen during aerial surveillance and initially mistaken for SAV beds.

In the middle bay, fishes were more numerous (57.5 % of all individuals) and had more species with higher abundances (24 of 47 species) than any other part of the bay (Table 4). Moreover, they were nearly as diverse as those in the lower bay (32 versus 34 of 47 species). The most abundant species included the most valuable of the commercial and recreational fishes in the bay, menhaden, spotted seatrout, southern flounder, and red drum, as well as, many fishes important in food chains (bait fishes), bay anchovy, spot, silversides and mullet. The salinity regimes of these species were 9.8 to 20.2 ppt in 1987 and from 11.7 to 19.0 ppt historically. This suggested that the bay area with mid-mesohaline to low polyhaline salinities was an optimal environment for fishes.

Decapod crustaceans were less diverse in the middle bay (17 versus 24 of 28 species) than in the lower system, but they were more numerous (68.9 % of all individuals) and had more of the most abundant species (14 of 28) (Table 5). Like fishes, the list of most abundant decapods in the middle bay included important commercial species, white shrimp, pink shrimp and blue crab, and food chain species, grass shrimps and xanthid crabs. The 1987 salinity regime of these species ranged from 9.8 to 21.4 ppt, and the historical salinity regime ranged from 11.7 to 19.8 ppt. Thus, optimal conditions for these decapod crustaceans of fishery value were mid-mesohaline to low polyhaline regimes.

Most of the forage species (25 of 42) occurred in the middle bay, and of these, 21 were more abundant in the middle bay than elsewhere (Table 6). Moreover, 53.9 % of all individuals occurred at the middle bay sites. Abundances of peracarid crustaceans were strikingly higher in the middle bay, and this association with high abundances fish and decapod predators strongly suggested a food chain connection. It has been well established that peracarids are a key component in the diets of many small estuarine fishes (Stoner 1982; Huh and Kitting 1985; Whitfield 1988). Gut analyses of fishes from Galveston Bay (Sheridan 1983) and other Texas bays (Minello et al. 1987) support this observation. Furthermore, small juveniles of brown shrimp, pink shrimp, and blue crab have been shown to prefer amphipods and tanaids over other benthos (Leber 1979; Thomas 1989, Zimmerman et al).

The Lower Bay: Historical and 1987 salinity regimes in the lower bay marshes (West Bay and Christmas Bay) were polyhaline, with short term incursions of mesohaline to hypersaline conditions. Gulf water normally dominates through tides. But evaporation often produces a hypersaline environment during dry summers, and this condition can be alleviated or abruptly reversed by high rainfall caused by tropical depressions. In general, however, the lower bay was more saline and less variable than the middle and upper bay due to moderation from the Gulf.

Lower bay marshes were almost entirely smooth cordgrass in the lower zone which gradually changed to mixed stands of smooth cordgrass, glasswort (*Salicornia* spp.), and saltwort (*Batis maritima*) in the upper zone. A salt pan, without rooted vegetation but a bluegreen algal mat (Sage and Sullivan 1978; Pulich and Rabalais 1986), occurred between the marsh and terrestrial environment. Epiphytic algae on smooth cordgrass (Sullivan 1978, 1981) and macroalgae (Conover 1964; Williams-Cowper 1978) were more abundant in the lower bay than elsewhere. SAV occurred in Christmas Bay including, shoal grass (*Halodule wrightii)*, widgeon grass (*Ruppia maritima*), turtle grass (*Thalassia testudinum*) and *Halophila engelmannii.* In West Bay, SAV beds were present as late as 1975, but have since disappeared.

A similar number of fish species occurred in the lower bay as compared to the middle bay (34 of 47 overall), but abundances were lower (23.0 % of all individuals). A relatively low proportion of fish species occurring in the lower bay were most abundant there (12 of 34). Of commercial and recreational fishes, only the sheepshead (*Archosargus probatocephalus)* was more abundant in the lower bay (Table 4). Under most circumstances, the proportion of fully marine species could be expected to dominate as the salinities become increasingly euhaline, somewhere between about 20 and 35 ppt (Remane 1934). This was not evident, thus indicating the polyhaline nature of the the lower system.

Decapod crustaceans were most diverse in lower bay marshes (24 of 28 species), but with only 26.9 % of all individuals. Of the 24 species, 13 were more abundant than in the upper and middle bay. Among commercially important species that were most abundant in the lower bay were brown shrimp and stone crab (Table 5).

Of 42 forage species, 28 occurred in the lower bay among 21.5 % of all individuals, again indicating relatively higher diversity than the middle and upper bay. Of 28 species in the lower bay, only 12, a low proportion, were more abundant there than elsewhere. Peracarids were numerous but not as abundant as in the middle bay. Annelid worm abundances were intermediate to those of the other areas. The presence of algae and seagrasses provided additional food and structure, and less variable estuarine salinities afforded more stability to forage species in the lower system. In addition, smooth cordgrass remained in place throughout the year even though a die back occurred in the winter (dead stems remain erected for several years before they deteriorated). The grass culms provided a year-around surface for an epiphytic algal community. Both epiphytic algae and dead cordgrass are available as food and shelter for annelids, amphipods, tanaids and other organisms. This epiphytic community was well developed at West Bay and, like barrier island salt marshes elsewhere, had significantly higher numbers of epifauna among grass culms than on the surrounding bottom (Rader 1984; Zimmerman et al.). This greatly increased the nursery value of lower bay marshes for foraging estuarine fishes, shrimps and crabs.

DISCUSSION

The Salinity Gradient in Galveston Bay

The salinity gradient is clearly apparent in the Galveston Bay system and reflects the dominating influence of freshwater inflow on characteristics of marsh communities in the system. During 1987, the salinity gradient was steeper than usual, as salinities were lower in the upper bay and higher in the lower bay than historical means (see Fig. 4). The gradient was steepest in the summer (July) when salinities in the upper bay and part of the middle bay approached zero. These low salinities are short-term phenomena that are within the range of annual variability; likewise, the higher salinities in marshes of the lower system during 1987 were short term events (within a season) that occurr normally. Data from 1982 through 1988 from a salt marsh in West Bay (the Jamaica Beach site) reveal that short term conditions are often hypersaline in the late summer. Our record shows that during August at the Jamaica Beach marsh salinities were 38 ppt in 1982 (Zimmerman and Minello, 1984) and 41 ppt in 1985 (unpublished) over a period of several weeks. Because of this variability, the gradient within the Galveston Bay system can be expected to range, at least on the short term, from fresh (0 ppt) to hypersaline (40+ ppt). The historical means at the sites along the gradient perhaps best describe salinty regimes in the system. In Figure 3, we have compared different parts of the system using 1987 and historical salinity regimes. These are long term attributes of the environmental gradient. Both long term (annual) and short term (seasonal) variations in salinity influence the responses of organisms.

Effect of Salinity on Organisms

Deviation in 1987 salinities from the historical means together with distributional responses of organisms provided insight into the short term versus long term effects of salinity. Under short term low salinity stress, the larger mobile fauna have the option to leave an area or to stay and accommodate. Less mobile organisms under the same circumstances, such as small epifuana, infauna and plants, cannot leave and thus must accommodate, at least temporarily, or suffer mortalities.

Many, if not most, estuarine species can temporarily accommodate oligohaline salinities below 5 ppt. Decapod crustaceans, such as brown shrimp, white shrimp and blue crab, are notable for their ability to accommodate low salinities (Zein-Elden 1989; Gifford 1962; Tagatz 1971). For example, we have observed responses of these and other estuarine species to abrupt lowering of salinities from mesohaline (7 to 15 ppt) to oligohaline (less than 1 ppt) during flooding of the Lavaca River delta in June of 1987. Freshwater flooding did not reduce densities of brown shrimp, white shrimp, grass shrimp, blue crabs in the delta marshes. Of fishes, bay anchovies and menhaden actually significantly increased their densities during the flooding. Similar results were observed in the middle of Galveston Bay in 1987 where faunal abundances were not depressed during short term lowering of salinities (a few days to several weeks, but less than a month) during the summer.

By contrast, species are known to suffer mortalities due to abrupt lowering of salinity (reviewed by Brongersma-Sanders 1957). In lower Texas bays mortalities occur when populations acclimated to euhaline conditions (30 to 36 ppt) are exposed to rapid lowering of salinities due to rainfall from tropical depressions. Molluscan bivalves suffered mass mortalities in Redfish Bay after Hurricane Beulah in 1967 (Zimmerman and Chaney 1969). Salinities, in this instance, were reduced from 30 ppt to less than 1 ppt within about a week. Hedgpeth (1953) reported mortalities after a similar event in Nueces Bay. Low salinity limitations are known for many estuarine species. The restriction of oyster populations to salinities above 5 ppt (reviewed by Van Sickle et al. 1976) and their predator, the oyster drill, to salinities above 15 ppt (Gunter 1979) are well known examples. Even among euryhaline species, such as red drum, white shrimp and brown shrimp, low salinities and temperature extremes that do not restrict juveniles and adults can be limiting to postlarvae (Holt et al. 1981; Zein-Eldin 1989).

There are good physiological reasons for such limitations. In some crustacea, the size of antennal gland is larger in animals that must maintain an internal fluid concentration that is hypotonic relative to the environment. The larger size is due to longer nephridial canals providing more surface area for salt resorption and dilute urine production. This occurrs in crayfish and some shrimp (Barnes 1980) and in freshwater amphipods (Green 1968). In marine, estuarine and terrestrial amphipods, the antennal glands are smaller than in comparable freshwater species (Schlieper 1930; Bousfield 1973). This restricts many, if not most, estuarine amphipods from oligohaline environments and may account for their paucity at the Trinity delta during 1987. Most decapod crustaceans, like fishes, osmoregulate through their gills (not antennal glands) in brackish waters (Barnes 1980). Adaptation to resident living under oligohaline conditions is difficult in any case. Few aquatic fauna are well adapted to survive and reproduce in this transition zone between rivers and estuaries over the long term (Remane and Schlieper 1958). Those that do, such as some bivalves (*Rangia*) and annelids (nereids), usually exhibit specialized adaptations (Hopkins et al. 1973; Oglesby 1965a, 1965b). The capitellid and oligochaete infaunal worms that were abundantly found at the Trinity River delta are so adapted.

Marsh Utilization By Fishery Species

Our hypothesis was that marshes under mid-range salinity regimes are more utilized by fishery species. The test of the null hypothesis was to disprove that utilization at sites in the middle bay, in the middle of the salinity gradient, was not different from sites of the upper and lower subsystems. Using abundances, our results showed that fishery species were more abundant overall in the middle bay than in the other parts of the bay, thus disproving the null hypothesis. Indeed, most commercial and recreational species, including white shrimp, pink shrimp, blue crab, spotted seatrout, southern flounder, and red drum, had highest overall abundances in the middle bay. As previously discussed and expected, salinities of the middle bay overlapped extensively with those of the upper and lower bay (especially for short periods of time). This underscores the evidence that it is not salinity alone, but a complex of associated factors that create this attractive mid-bay environment. It is safe to say that the favorable conditions in marshes of the middle bay are influenced by or derived from the inputs of the upper and the lower bay.

Fishery species were not greatly attracted to the oligohaline marshes of the lower Trinity River delta during 1987. Although these delta marshes were not directly utilized, they nonetheless may be of substantial indirect importance to fishery species. Nearly the entire annual production of plants from the delta marshes at our sites is exported into the bay each year. This dead plant material becomes particulate detritus that fuels detritus based food chains in at least the middle subsystem and perhaps the lower subsystem.

Distributions of Foods

Annelid worms and peracarid crustaceans (amphipods and tanaids) constituted the most abundant macrofaunal benthos in sediments in Galveston Bay. Evidence from our feeding experiments (Thomas 1989; Zimmerman et al.) and gut analyses (Minello et al. 1989) indicate these small animals are the principal foods of small fishes, shrimps and crabs in the estuarary. Moreover, the literature cites numerous examples of the importance of these forage organisms in estuarine food chains (Kikuchi 1974; Young et al.1976; Bell and Coull 1978; Nelson 1981; Stoner 1982; Huh and Kitting 1985; Whitfield 1988).

However, benthic foods (both plant and animal) appeared to be differentially abundant throughout the bay and highly dependent upon location. Among plants, vascular plant detritus appeared more abundant in the upper and middle subsystems, while epiphytic and macro-algae was most abundant in the lower subsystem. Annelid worms were numerous throughout, but most abundant in the upper subsystem. Peracarid crustaceans were most abundant in the middle subsystem and nearly absent in the upper subsystem.

Since larger predators (fishes, crabs and shrimps) were exceptionally numerous in the middle subsystem, a food chain relationship with forage organisms can be inferred. We propose that the relationship is based upon the input of detritus and abundances of peracarids. As detritus from delta marshes is exported down the salinity gradient, it breaks up into smaller particles, is colonized and enriched with nitrogen by microflora, thus becoming ideal food for detritivorous annelids

(Tenore 1977; Findlay and Tenore 1982), peracarids (Hargrave 1970; Monk 1977; Zimmerman et al. 1979) and molluscs (Newell 1964). Since very large populations of annelids and peracarids occurred in the middle subsystem, detritus availability and conditioning appears to be most favorable in this area. These small prey are available to support large numbers of small fishes and decapod crustaceans, and many of these, in turn, serve as ready food for larger fishes and crustaceans. Thus, a classical detritus-based benthic food web (Odum and Heald 1975; Odum 1980) is created in the middle bay. Among the forage animals, peracarids appear to be more preferred and are more available than annelids (Huh and Kitting 1985; Leber 1985; Luczkovich 1988; Thomas 1989; Zimmerman et al.). The relative absence of peracarids from the delta marshes was striking and we predict it may have been a reason that so few predators were attracted there.

Effect of Salinity on Fishery Habitat

The direct effect of salinity (that is, salinity per se) appears to have little influence on distributions of demersal fishes, crabs and shrimps except under extreme circumstances. Even then, most estuarine species tolerate very low salinities (less than 1 ppt) for short periods of time (days to weeks). Large natant decapods and fishes in Texas estuaries commonly move across salinity gradients into low salinities (Baldauf 1970; Renfro 1960). Their presence or absence in low salinity situations appears to be a behavior of choice. Species such as brown shrimp, white shrimp, blue crab, grass shrimp, menhaden, bay anchovies, striped mullet, red drum, southern flounder and Atlantic croaker are often noted in very low salinity waters. During the summer of 1987, we obtained all of these species in the mid-bay marsh at Smith Point with salinity of 0.8 ppt. The salinity was similar (0.5 ppt) at the delta marsh sites, yet these estuarine species were virtually absent. We submit that the reason for these differences in abundances was not due to the short term effect of salinity itself, but to habitat differences that developed from long term exposure to low salinity.

One difference we noted was the effect of salinity on distribution of forage organisms. The absence of amphipods and tanaidaceans in the delta marshes compared to their exceptional abundances in mid-bay marshes suggests that this is at least one long term salinity effect. It has been known that oligohaline salinity regimes (< 5 ppt) diminish the number of residents of small less mobile estuarine species (Remane and Schlieper 1958). Estuarine amphipods and tanaids are among fauna whose species are limited to only a few adapted to tolerate oligohaline conditions for long periods of time. Since they are highly useful forage organisms, their absence diminishes the value of a low salinity marsh for predators. However, we know little about these kinds of effects and how they may control the relationships between salinity and fishery productivity. This is a fertile and necessary area of further research.

CONCLUSIONS

Salinity Characteristics of Galveston Bay Marshes

The environment in the Galveston Bay system is characterized by a strong salinity gradient. Salinities along the gradient range from fresh (0 ppt) to hypersaline (> 40 ppt) depending upon seasonal and annual rainfall. Normally, the upper system (Trinity Bay) is oligohaline to mesohaline, the middle system (Galveston Bay proper) is mesohaline to polyhaline, and the lower system (West Bay and Christmas Bay) is polyhaline. High rainfall during the spring and summer of 1987 reduced the salinities, causing in oligohaline conditions (< 1 ppt) throughout the upper conditions (< 1 ppt) throughout the upper system and highly variable conditions (< 1 to 15 ppt) in the middle system. Salinities of the lower system (22 to 33 ppt) were relatively unaffected. The resulting summer salinity gradient was the steepest of the year. As freshwater input diminished in the fall and equinox tides caused salinities in the upper system to increase to near 10 ppt, the slope of the gradient lessened across the system. These long term and short term salinity characteristics reflect freshwater inflow effects that determine the nature of marsh communities in the system.

Biological Characteristics of Galveston Bay Marshes

Marsh communities are clearly different between the upper, middle and lower subsystems in Galveston Bay. Biological attributes uniquely characterize each subsystem, inferring relationships to salinity. At the same time, the subsystems are interconnected and depend on one another through materials flow. These interrelationships appear to have a large effect on determining how the different marshes function for fishery species.

The upper subsystem, represented by the lower Trinity River delta, is oligohaline and strongly reflects freshwater influences. Emergent marsh plants (*Scirpus* and *Sagittaria*) are those commonly associated with active deltaic environments. This is one of the few areas in Galveston Bay supporting large stands of submerged aquatic vegetation (SAV). Part of the deltaic SAV is an extensive area of previously unreported *Vallisneria* habitat. During the winter months most of the emergent marsh and subtidal SAV dies back and is exported. SAV growth is essentially limited to the summer months. Among forage organisms present in the marshes and SAV habitat, peracarid crustaceans are few, but annelid worms are abundant. This pattern corresponds to relatively low useage of deltaic marsh and SAV by fishes and decapod crustaceans (usually not significantly different from useage of nonvegetated open water). As a result, since it is continuously available, nonvegetated subtidal bottom appears to be more directly useful as nursery habitat in the upper subsystem compared to the marsh surface and SAV. Even so, overall abundances of animals are significantly lower in the upper subsystem compared to the middle and lower subsystems.

By contrast, peracarids are exceptionally abundant in the middle subsystem and abundances of fishes and decapods are also high. The relationship exists because the large numbers of peracarids, in both marsh and open water, are useful as food to juveniles of many dermersal species. Consequently, marsh and nonvegetated bottom in the middle subsystem serve equally as nursery habitats that contribute to high production in fishery species. However, this productivity appears to be directly related to organic materials flow from the upper subsystem. We propose that the middle region receives most of its dead plant material, that is highly useful to peracarid detritivores such as amphipods and tanaids, from the deltaic marshes of upper region.

In the lower subsystem, marshes appear to be proportionately more important as nurseries compared to nonvegetated bottom. Forage organisms are significantly more abundant on the marsh surface and the structure of *Spartina* culms offers stable yeararound shelter. In addition, epiphytic algae populations are well developed in lower subsystem marshes. These factors improve the direct value of these marshes to exploiting juveniles of fishes and decapods crustaceans. The salinity regime, however, is not necessarily less stressful than in other parts of the bay, since hypersaline conditions are not uncommon in the lower system.

The Relationship Between Salinity and Marsh Utilization

Over time, each part of the Galveston Bay system incurrs salinities that may cause physiological stress to organisms. However most of the higher estuarine animals (such as fishery juveniles) are adapted to accomodate these stresses, and therefore, most distributions are probably due to other factors.

Fishery species were more abundant as species and individuals in marshes with mesohaline to polyhaline salinity regimes. This occurred primarily in the middle area of Galveston Bay where freshwater and saltwater mixing characteristics were strong. Material imports and physical mixing processes here stimulated food chain responses. Thus, cause-and-effect relationships leading to high utilization were related to salinity, but not necessarily controlled by salinity. Nevertheless, salinity parameters may be viewed as an indicator of physical mixing and marsh utilization characteristics.

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APPENDIX II: PHYSICAL MEASUREMENTS, SPRING.

GALVESTON BAY STUDY ENVIRONMENTAL PARAMETERS SPRING SAMPLING SET	Site 1 TRINITY RIVER INNER DELTA				Site 2 TRINITY RIVER OUTER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	27.4	0.43	28.5	0.22	28.7	0.93	28.6	1.27
Salinity (ppt)	0	0.02	0	0	0	0	0	0.01
Dissolved Oxygen (ppm)	8.1	0.42	8.5	0.29	9.2	0.51	9.7	0.74
Turbidity (FTU)	45	5.58	43.5	10.44	28	2.04	38.3	3.12
Median Depth (cm)	7.4	0.92	38	13.5	13.6	1.09	20.8	3.68
Maximum Depth (cm)	9.5	0.87	44	15.44	17	1.41	21.3	3.68
Minimum Depth (cm)	5.3	1.03	32	11.61	10.3	3.42	20.3	3.68
Time Interval: (date time)	(April 21: 1835 - 1929 hrs)				(April 20: 1610 - 1854 hrs)			

	Site 3 SMITH POINT				Site 4 MOSES LAKE			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	31.1	0.24	29.8	0.53	29.5	0.67	29.6	0.78
Salinity (ppt)	8.8	0.25	8.3	0.25	15.5	0.29	15.5	0.29
Dissolved Oxygen (ppm)	11.1	0.36	12.3	0.36	12.7	2.1	12.1	2.16
Turbidity (FTU)	13	5.43	21	4.81	31.5	10.99	27	7.55
Median Depth (cm)	22.5	2.61	40.5	3.85	8.5	1.67	18.8	1.61
Maximum Depth (cm)	25	2.52	41.3	3.97	16	3.19	19.5	1.66
Minimum Depth (cm)	20	2.86	39.8	3.75	1	0.71	18	1.58
Time Interval: (date time)	(April 21: 1457 - 1613 hrs)				(April 30: 1440 -1551 hrs.)			

	Site 5 JAMAICA BEACH				Site 6 CHRISTMAS BAY			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	28.8	0.47	28.8	0.23	23.7	0.25	23.6	0.2
Salinity (ppt)	33.3	0.14	33.3	0.32	23	1.35	21.3	0.25
Dissolved Oxygen (ppm)	7.5	0.13	7.7	0.38	7.7	0.23	6.4	0.19
Turbidity (FTU)	12.6	1.75	14.1	1.65	18.3	1.49	11	4.06
Median Depth (cm)	13.4	1.42	31.9	2.23	18.5	3.58	69.5	1.14
Maximum Depth (cm)	18.4	1.14	33.6	2.38	23.5	2.18	70.3	1.11
Minimum Depth (cm)	8.4	1.85	30.3	2.09	13.5	5.12	68.8	1.18
Time Interval: (date time)	(May 1: 1310 - 1725 hrs)				(May 6: 1147 - 1515 hrs)			

Drop samples; 2.6 m sq. each; N = 4;

APPENDIX II (continued): PHYSICAL MEASUREMENTS, SUMMER.

GALVESTON BAY STUDY ENVIRONMENTAL PARAMETERS SUMMER SAMPLING SET	Site 1 TRINITY RIVER INNER DELTA				Site 2 TRINITY RIVER OUTER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	31.4	0.24	31	0.41	30.4	0.69	30.8	0.48
Salinity (ppt)	0	0	0	0	0.4	0.08	0.5	0.03
Dissolved Oxygen (ppm)	7.3	0.41	7.6	0.42	9.2	0.47	9.5	0.27
Turbidity (FTU)	46.8	0.75	46	9.69	30.8	6.52	31	6.67
Median Depth (cm)	28.8	2.79	52.5	14.27	37.8	2.05	47.1	5.3
Maximum Depth (cm)	35.5	4.65	58.5	17.21	40	2.42	48	5.43
Minimum Depth (cm)	22	4.14	46.5	11.65	35.5	2.06	46.3	5.17
Time Interval: (date time)	(July 21: 1425 - 1630 hrs)				(July 21: 1115 - 1333 hrs)			

	Site 3 SMITH POINT				Site 4 MOSES LAKE			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	31.5	0.29	31.3	0.25	26.4	2.79	28.8	0.25
Salinity (ppt)	0.8	0.03	0.7	0.02	9	0	9	0
Dissolved Oxygen (ppm)	8.6	0.46	7.9	0.25	6.8	0.76	7.5	0.42
Turbidity (FTU)	34.8	7.97	26.3	1.11	28	5.58	25.5	2.1
Median Depth (cm)	34.3	4.99	67.8	4.51	40.8	3.5	62.8	3.82
Maximum Depth (cm)	41.5	5.56	69	4.45	49	3.83	64	4.06
Minimum Depth (cm)	27	5.08	66.5	4.57	32.5	4.5	61.5	3.57
Time Interval: (date time)	(July 22: 1320 - 1450 hrs)				(July 20: 0954 - 1113 hrs)			

	Site 5 JAMAICA BEACH				Site 6 CHRISTMAS BAY			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	31.9	0.22	32.2	0.15	31.4	1.55	30	0
Salinity (ppt)	27.9	0.13	27.8	0.14	29.5	0.5	29.3	0.48
Dissolved Oxygen (ppm)	7.3	0.21	6.7	0.32	5.7	0.48	6.3	0.55
Turbidity (FTU)	32.3	3.22	31.8	4.33	13.8	2.93	6.8	1.25
Median Depth (cm)	16.7	1.64	36.6	1.33	32.6	1.6	57	2.46
Maximum Depth (cm)	22.3	1.75	38.8	1.33	34.8	2.5	60	2.8
Minimum Depth (cm)	11.1	1.78	34.5	1.34	30.5	0.87	54	2.45
Time Interval: (date time)	(July 17: 1035 - 1347 hrs)				(July 24: 0946 - 1156 hrs)			

Drop samples; 2.6 m sq. each; N = 4;

APPENDIX II (continued): PHYSICAL MEASUREMENTS, FALL.

GALVESTON BAY STUDY ENVIRONMENTAL PARAMETERS FALL SAMPLING SET	Site 1 TRINITY RIVER INNER DELTA				Site 2 TRINITY RIVER OUTER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E	MEAN	S.E.
Temperature (Deg. C)	18.5	0.46	19	0.31	23	0.44	22.3	0.35
Salinity (ppt)	11	0	10.5	0.29	9.8	0.25	9.5	0.29
Dissolved Oxygen (ppm)	3.7	0.41	4.3	0.38	7.9	0.56	7.8	0.31
Turbidity (FTU)	68.8	10.08	32.8	8.37	64.8	19.6	38.3	12.56
Median Depth (cm)	8.9	1.88	25.4	8.5	5.6	0.43	35.8	4.62
Maximum Depth (cm)	12.3	2.21	27.8	10.16	9	0.71	39.8	5.07
Minimum Depth (cm)	5.5	2.1	23	6.86	2.3	0.85	31.8	4.23
Time Interval: (date time)	(November 3: 0725 - 0921 hrs)				(November 2: 1017 - 1245 hrs)			

	Site 3 SMITH POINT				Site 4 MOSES LAKE			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	23.1	0.46	22.8	0.29	22.3	0.51	22.4	0.28
Salinity (ppt)	20	0	20	0	22	0.41	22.3	0.48
Dissolved Oxygen (ppm)	8.6	0.13	8.1	0.11	7.6	1.83	8.5	1.86
Turbidity (FTU)	90.5	38.2	51.3	13.44	111.3	18.19	67.8	14.79
Median Depth (cm)	25	3.17	44.1	1.42	18.8	2.92	30.8	2.25
Maximum Depth (cm)	29.5	2.72	45.3	1.6	36.3	5.02	32	2.48
Minimum Depth (cm)	20.5	3.66	43	1.29	1.3	1.25	29.5	2.02
Time Interval: (date time)	(November 3: 1158 - 1315 hrs)				(November 4: 0921 - 1115 hrs)			

	Site 5 JAMAICA BEACH				Site 6 CHRISTMAS BAY			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Temperature (Deg. C)	20.9	0.06	20.9	0.06	25.3	1.4	25.1	0.66
Salinity (ppt)	20.5	0.29	20.5	0.29	32.5	0.87	31.8	0.25
Dissolved Oxygen (ppm)	8	0.15	7.8	0.18	9.4	0.27	9.4	1.5
Turbidity (FTU)	25.9	4.71	22.9	1.59	18	2.86	26	11.8
Median Depth (cm)	22.1	1.01	46.1	2.9	17.5	2.07	22	5.94
Maximum Depth (cm)	27	0.94	48.8	3.01	18.5	1.85	24.3	5.36
Minimum Depth (cm)	17.3	1.11	43.4	3.4	16.5	2.33	19.8	6.66
Time Interval: (date time)	(October 23: 0823 - 1209 hrs)				(November 5: 1015 - 1240 hrs)			

Drop samples; 2.6 m sq. each; N = 4;

APPENDIX III: FISH AND DECAPOD CRUSTACEAN DENSITIES, UPPER BAY, SPRING.

GALVESTON BAY STUDY	Site 1				Site 2			
UPPER BAY SYSTEM	TRINITY RIVER				TRINITY RIVER			
Macrofauna/2.6 m sq. (n=4)	INNER DELTA				OUTER DELTA			
April 20-21, 1987	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:								
Micropogonias undulatus	0	0	3.5	2.02	0	0	0.8	0.75
Fundulus grandis	0	0	0.3	0.25	1.5	0.87	0	0
Myrophis punctatus	0	0	2.8	1.6	0	0	0.5	0.29
Anchoa mitchilli	0	0	0	0	0	0	2	1.68
Leiostomus xanthurus	0	0	0	0	0	0	0.5	0.5
Fundulus pulvereus	1.8	1.75	0	0	0	0	0	0
Mugil cephalus	0	0	0.8	0.75	0	0	0	0
Elops saurus	0	0	0.5	0.5	0	0	0	0
Brevoortia patronus	0	0	0.3	0.25	0	0	0	0
Citharicthys spilopterus	0	0	0.3	0.25	0	0	0	0
Gambusia affinis	0.3	0.25	0	0	0	0	0	0
Paralichthys lethostigma	0	0	0	0	0.3	0.25	0	0
Symphurus plagiusa	0	0	0.3	0.25	0	0	0	0
Syngnathus floridae	0	0	0.3	0.25	0	0	0	0
Cyprinodontidae	1.8	1.75	0.3	0.25	1.5	0.87	0	0
Sciaenidae	0	0	3.5	2.02	0	0	1.3	0.75
Commercial/Sports Fishes	0	0	0	0	0.3	0.25	0	0
FISH TOTALS:	2	1.68	8.8	3.04	1.8	1.03	3.8	2.46
CRUSTACEANS:								
Callinectes sapidus	1.3	0.48	8	1.58	1.3	0.75	1.8	1.18
Palaemonetes pugio	0	0	0.5	0.29	0	0	0	0
CRUSTACEAN TOTALS:	1.3	0.48	8.5	1.32	1.3	0.75	1.8	1.18

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, MIDDLE BAY, SPRING.

GALVESTON BAY STUDY	Site 3				Site 4			
MID-BAY SYSTEM	SMITH POINT				MOSES LAKE			
Macrofauna/2.6 m sq. (n=4)	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
April 21 & 30, 1987								
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:								
Lagodon rhomboides	3.8	1.7	0	0	1	1	0	0
Gobionellus boleosoma	2.3	0.85	0.8	0.48	0	0	0	0
Myrophis punctatus	0.3	0.25	0	0	1	1	1	0.71
Leiostomus xanthurus	0	0	2	1.08	0	0	0	0
Gobiosoma bosci	1.3	1.25	0.3	0.25	0	0	0	0
Mugil cephalus	0	0	0.3	0.25	1	0.71	0.3	0.25
Fundulus grandis	0.5	0.29	0	0	0.3	0.25	0	0
Symphurus plagiusa	0	0	0.8	0.48	0	0	0	0
Elops saurus	0	0	0.5	0.5	0	0	0	0
Adina xenica	0	0	0	0	0.3	0.25	0	0
Lucania parva	0.3	0.25	0	0	0	0	0	0
Menidia beryllina	0	0	0	0	0	0	0.3	0.25
Micropogonias undulatus	0	0	0.3	0.25	0	0	0	0
Paralichthys lethostigma	0	0	0.3	0.25	0	0	0	0
Cyprinodontidae	0.8	0.48	0	0	0.5	0.29	0	0
Gobiidae	3.5	1.71	1	0.41	0	0	0	0
Sciaenidae	0	0	2.3	0.95	0	0	0	0
Commercial/Sports Fishes	0	0	0.3	0.25	0	0	0	0
FISH TOTALS:	8.3	3.45	5	1.08	3.5	2.02	1.5	1.19
CRUSTACEANS:								
Palaemonetes pugio	290.5	48.05	94.3	93.92	37.5	37.17	0	0
Penaeus aztecus	2.5	1.32	10	2.48	9	9	0.5	0.29
Callinectes sapidus	13.3	2.1	2.8	1.25	2.8	2.43	0.5	0.5
Rhithropanopeus harrisii	1	0.58	0.3	0.25	0	0	0	0
Penaeidae	2.5	1.32	10	2.48	9	9	0.5	0.29
CRUSTACEAN TOTALS:	307.3	51.36	107.3	93.26	49.3	48.58	1	0.41

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, LOWER BAY, SPRING.

GALVESTON BAY STUDY	Site 5				Site 6			
LOWER BAY SYSTEM	JAMAICA BEACH				CHRISTMAS BAY			
Macrofauna/2.6 m sq. (n=4)	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
May 1st & 6th, 1987								
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:								
Lagodon rhomboides	1.3	0.75	0.5	0.29	3	1.68	5	4.02
Menidia beryllina	7.3	6.92	0.5	0.29	0	0	0	0
Brevoortia patronus	0	0	5.8	5.11	0	0	0	0
Gobionellus boleosoma	0	0	0	0	2.3	0.85	0.3	0.25
Leiostomus xanthurus	0	0	0.5	0.29	0	0	1.5	0.65
Micropogonias undulatus	0	0	1	0	0	0	0.5	0.5
Myrophis punctatus	0	0	0.5	0.29	0.5	0.5	0.3	0.25
Fundulus grandis	0	0	0	0	1	0.71	0	0
Mugil cephalus	0	0	0	0	0.3	0.25	0.3	0.25
Paralichthys lethostigma	0	0	0	0	0	0	0.5	0.5
Symphurus plagiusa	0	0	0	0	0	0	0.5	0.5
Citharichthys spilopterus	0	0	0	0	0	0	0.3	0.25
Dasyatis sabina	0	0	0	0	0	0	0.3	0.25
Orthopristis chrysoptera	0	0	0	0	0	0	0.3	0.25
Synodus foetens	0	0	0	0	0	0	0.3	0.25
Cyprinodontidae	0	0	0	0	1	0.71	0	0
Gobiidae	0	0	0	0	2.3	0.85	0.3	0.25
Sciaenidae	0	0	1	0	0	0	2	1.08
Commercial/Sports Fishes	0	0	0	0	0	0	0.5	0.5
FISH TOTALS:	8.5	7.53	7.8	4.82	7	2.65	9.8	6.3
CRUSTACEANS:								
Palaemonetes pugio	15	8.36	0.5	0.29	143.3	63.73	0	0
Penaeus aztecus	41.5	8.37	10	1.15	39.3	8.36	7	1.87
Callinectes sapidus	6	2.38	1.5	0.29	9	2.58	0.3	0.25
Clibanarius vittatus	2.5	1.26	0.5	0.29	4.8	1.7	0	0
Hippolyte zostericola	0	0	0	0	1.3	1.25	0	0
Pagurus spp.	0	0	0	0	0	0	0.5	0.5
Neopanope texana	0	0	0	0	0.3	0.25	0	0
Unknown crustacean species	0	0	0	0	0	0	0.3	0.25
Penaeidae	41.5	8.37	10	1.15	39.3	8.36	7	1.87
CRUSTACEAN TOTALS:	64.8	10.62	11.8	1.32	200.3	70.63	8	1.68

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, UPPER BAY, SUMMER.

GALVESTON BAY STUDY	Site 1				Site 2			
UPPER BAY SYSTEM	TRINITY RIVER				TRINITY RIVER			
Macrofauna/2.6 m sq. (n=4)	INNER DELTA				OUTER DELTA			
July 21-22, 1987	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:								
Fundulus grandis	6.8	2.63	0.3	0.25	2.8	0.25	0	0
Mugil cephalus	3	3	0.3	0.25	3.3	0.85	0.3	0.25
Cyprinodon variegatus	5	4.36	0	0	0	0	0	0
Lucania parva	2.8	2.43	0	0	0	0	0	0
Anchoa mitchilli	0	0	1.8	1.03	0	0	0.5	0.29
Menidia beryllina	1	0.41	0	0	1.3	0.75	0	0
Leiostomus xanthurus	0	0	0.3	0.25	0.3	0.25	0.5	0.29
Conodon nobilis	0.8	0.75	0	0	0	0	0	0
Symphurus plagiusa	0.8	0.75	0	0	0	0	0	0
Myrophis punctatus	0.3	0.25	0.3	0.25	0	0	0	0
Brevoortia patronus	0.5	0.29	0	0	0	0	0	0
Fundulus jenkinsi	0.5	0.29	0	0	0	0	0	0
Fundulus pulvereus	0.3	0.25	0	0	0.3	0.25	0	0
Syngnathus scovelli	0	0	0	0	0.5	0.29	0	0
Citharicthys spilopterus	0	0	0.3	0.25	0	0	0	0
Gobionellus boleosoma	0	0	0	0	0	0	0.3	0.25
Gobiosoma bosci	0	0	0	0	0	0	0.3	0.25
Ictalurus punctatus	0	0	0	0	0	0	0.3	0.25
Lagodon rhomboides	0.3	0.25	0	0	0	0	0	0
Sciaenops ocellatus	0	0	0	0	0.3	0.25	0	0
Unknown fish species	0.3	0.25	0	0	0	0	0	0
Cyprinodontidae	15.3	6.39	0.3	0.25	3	0.41	0	0
Gobiidae	0	0	0	0	0	0	0.5	0.29
Sciaenidae	0	0	0.3	0.25	0.5	0.29	0.5	0.29
Commercial/Sports Fishes	0	0	0	0	0.3	0.25	0	0
FISH TOTALS:	22	5.34	3	1.22	8.5	1.04	2	0.91
CRUSTACEANS:								
Palaemonetes pugio	45.8	24.35	0	0	16.3	8	0	0
Callinectes sapidus	2.3	1.31	1.3	0.75	4	1.47	0	0
Penaeus setiferus	0	0	0	0	1.3	0.75	0	0
Palaemonetes vulgaris	0	0	0	0	0.5	0.5	0	0
Penaeus aztecus	0	0	0	0	0.5	0.29	0	0
Sesarma reticulatum	0.5	0.29	0	0	0	0	0	0
Uca pugnax	0.5	0.5	0	0	0	0	0	0
Neopanope texana	0.3	0.25	0	0	0	0	0	0
Penaeidae	0	0	0	0	1.8	0.75	0	0
CRUSTACEAN TOTALS:	49.3	27.78	1.3	0.75	22.5	7.51	0	0

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, MIDDLE BAY, SUMMER.

GALVESTON BAY STUDY	Site 3				Site 4			
MID-BAY SYSTEM	SMITH POINT				MOSES LAKE			
Macrofauna/2.6 m sq. (n=4)	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
July 20 & 22, 1987								
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:								
Gobiosoma bosci	32.8	9.31	0.8	0.48	9.5	5.84	3.3	2.93
Anchoa mitchilli	1.8	1.75	30.5	13.99	0	0	7	6.04
Myrophis punctatus	0.3	0.25	1.3	0.63	2.8	2.14	0.5	0.29
Mugil cephalus	1	0.58	0	0	2.8	1.31	0	0
Lagodon rhomboides	1.3	0.95	0	0	1.3	0.25	0	0
Brevoortia patronus	0	0	0	0	0	0	2.3	2.25
Fundulus grandis	0.8	0.75	0	0	1.5	0.87	0	0
Cynoscion nebulosus	1.5	0.29	0	0	0.5	0.5	0	0
Menidia beryllina	0.3	0.25	0	0	1.5	1.19	0	0
Syngnathus scovelli	0	0	0	0	1.3	1.25	0	0
Cyprinodon variegatus	0	0	0	0	1	0.71	0	0
Oligoplites saurus	0.8	0.48	0	0	0	0	0	0
Paralichthys lethostigma	0.3	0.25	0.3	0.25	0	0	0	0
Membras martinica	0	0	0.5	0.5	0	0	0	0
Unknown fish species	0.5	0.5	0	0	0	0	0	0
Arius felis	0	0	0.3	0.25	0	0	0	0
Citharicthys spilopterus	0	0	0.3	0.25	0	0	0	0
Gobiesox strumosus	0.3	0.25	0	0	0	0	0	0
Hyporhamphus unifasciatus	0.3	0.25	0	0	0	0	0	0
Lucania parva	0	0	0	0	0.3	0.25	0	0
Sciaenops ocellatus	0.3	0.25	0	0	0	0	0	0
Sphoeroides parvus	0	0	0	0	0	0	0.3	0.25
Stellifer lanceolatus	0.3	0.25	0	0	0	0	0	0
Cyprinodontidae	0.8	0.75	0	0	2.8	1.11	0	0
Gobiidae	32.8	9.31	0.8	0.48	9.5	5.84	3.3	2.93
Sciaenidae	2	0.41	0	0	0.5	0.5	0	0
Commercial/Sports Fishes	2	0	0.3	0.25	0.5	0.5	0	0
FISH TOTALS:	42	10.97	33.7	13.92	22.3	7.11	13.3	10.97
CRUSTACEANS:								
Palaemonetes pugio	590	167.07	0.3	0.25	242	16.52	0.3	0.25
Penaeus setiferus	79	41.29	4.3	1.75	0.5	0.29	1.3	0.63
Penaeus aztecus	33.8	13.85	7.5	0.5	2.3	0.63	0.8	0.48
Callinectes sapidus	10.8	4.27	2.3	1.31	6.3	1.03	0.8	0.48
Rhithropanopeus harrisii	3.3	1.97	0.5	0.5	0.3	0.25	0	0
Palaemonetes vulgaris	1.3	0.95	0	0	0.5	0.5	0	0
Uca pugnax	1.8	1.75	0	0	0	0	0	0
Neopanope texana	1.3	1.25	0	0	0	0	0	0
Palaemonetes intermedius	0	0	0	0	1	0.41	0	0
Eurypanopeus depressus	0.3	0.25	0	0	0	0	0	0
Penaeidae	112.5	53.16	11.8	2.17	2.8	0.48	2	0.71
CRUSTACEAN TOTALS:	721	183.37	14.8	3.77	252.8	17.76	3	0.58

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, LOWER BAY, SUMMER.

GALVESTON BAY SYSTEM	Site 5				Site 6			
LOWER BAY SYSTEM	JAMAICA BEACH				CHRISTMAS BAY			
Macrofauna/2.6 m sq. (n=4)	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
July 17 & 24, 1987								
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:								
Cyprinodon variegatus	0	0	0	0	8.5	8.5	0	0
Lagodon rhomboides	2	0.91	0.5	0.5	2	1	0.5	0.29
Eucinostomus spp.	0	0	0	0	0	0	4.3	4.25
Gobiosoma bosci	3.5	1.44	0.5	0.29	0.3	0.25	0	0
Anchoa mitchilli	0	0	1.8	0.75	0	0	0	0
Menidia beryllina	0.3	0.25	1.3	0.48	0.3	0.25	0	0
Mugil cephalus	0	0	0.5	0.29	1.3	0.95	0	0
Cynoscion nebulosus	0.5	0.29	0.5	0.29	0.5	0.29	0	0
Symphurus plagiusa	0	0	0.5	0.29	0.3	0.25	0.5	0.5
Adinia xenica	0	0	0	0	1	0.71	0	0
Fundulus grandis	1	0.41	0	0	0	0	0	0
Syngnathus scovelli	1	0.58	0	0	0	0	0	0
Fundulus similis	0.5	0.29	0	0	0	0	0	0
Microgobius thalassinus	0	0	0.5	0.29	0	0	0	0
Opsanus beta	0.5	0.29	0	0	0	0	0	0
Archosargus probatocephalus	0	0	0.3	0.25	0	0	0	0
Chaetodipterus faber	0	0	0.3	0.25	0	0	0	0
Citharichthys spilopterus	0	0	0	0	0	0	0.3	0.25
Eucinostomus argenteus	0	0	0	0	0	0	0.3	0.25
Gambusia affinis	0.3	0.25	0	0	0	0	0	0
Leiostomus xanthurus	0	0	0.3	0.25	0	0	0	0
Myrophis punctatus	0	0	0.3	0.25	0	0	0	0
Paralichthys lethostigma	0	0	0	0	0	0	0.3	0.25
Syngnathus louisianae	0.3	0.25	0	0	0	0	0	0
Unknown fish species	0	0	0	0	0	0	0.3	0.25
Cyprinodontidae	1.3	0.63	0	0	9.5	8.19	0	0
Gobiidae	3.5	1.44	1	0.41	0.3	0.25	0	0
Sciaenidae	0.5	0.29	0.5	0.29	0.5	0.29	0	0
Commercial/Sports Fishes	0.5	0.29	0.5	0.29	0.5	0.29	0.3	0.25
FISH TOTALS:	8.5	2.53	5.5	0.65	14	7.01	6.3	3.92
CRUSTACEANS:								
Palaemonetes pugio	180.3	39.73	0.5	0.29	70.3	16.24	0.5	0.5
Penaeus aztecus	41.5	6.24	8.3	2.02	5.3	2.02	0.8	0.48
Callinectes sapidus	27.8	2.29	1.8	0.63	2.8	1.8	3	0.71
Penaeus setiferus	12	3.49	5.8	2.25	2.8	0.48	0	0
Penaeus duorarum	12.3	3.09	1.5	0.87	1.3	0.63	0	0
Alpheus heterochaelis	6.5	4.63	0	0	0	0	0	0
Clibanarius vittatus	4	1.22	0	0	1	0.58	0.8	0.48
Palaemonetes intermedius	3.3	2.59	0	0	1.8	1.44	0	0
Uca minax	0	0	0	0	1.8	0.85	0	0
Neopanope texana	0.3	0.25	0	0	0.5	0.5	0	0
Petrolisthes armatus	0.8	0.75	0	0	0	0	0	0
Palaemonetes vulgaris	0.3	0.25	0.3	0.25	0	0	0	0
Eurypanopeus abbreviatus	0.5	0.5	0	0	0	0	0	0
Libinia dubia	0.3	0.25	0	0	0	0	0	0
Menippe mercenaria	0	0	0	0	0.3	0.25	0	0
Panopeus herbstii	0	0	0	0	0.3	0.25	0	0
Unknown crustacean species	0.3	0.25	0	0	0	0	0	0
Penaeidae	65.5	6.69	15	3.03	9.3	2.29	0.8	0.48
CRUSTACEAN TOTALS:	287.5	39.89	17	3.08	87.8	20.5	5	1.41

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, UPPER BAY, FALL

GALVESTON BAY STUDY UPPER BAY SYSTEM Macrofauna/2.6 m sq. (n = 4) November 2-3, 1987	Site 1 TRINITY RIVER INNER DELTA				Site 2 TRINITY RIVER OUTER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:								
Cyprinodon variegatus	31.5	31.5	1	0.71	0	0	0	0
Anchoa mitchilli	0	0	0	0	0	0	6.8	6.75
Fundulus grandis	0.8	0.48	0	0	3.5	3.18	1	1
Lucania parva	0.5	0.29	0.3	0.25	0	0	0	0
Cynoscion nebulosus	0	0	0	0	0	0	0.5	0.5
Fundulus jenkinsi	0.5	0.5	0	0	0	0	0	0
Mugil cephalus	0	0	0	0	0	0	0.5	0.5
Fundulus pulvereus	0	0	0	0	0.3	0.25	0	0
Cyprinodontidae	33.3	31.59	1.3	0.63	3.8	3.12	1	1
Sciaenidae	0	0	0	0	0	0	0.5	0.5
Commercial/Sports Fishes	0	0	0	0	0	0	0.5	0.5
FISH TOTALS:	33.3	31.59	1.3	0.63	3.8	3.12	8.8	6.37
CRUSTACEANS:								
Palaemonetes pugio	0.5	0.29	0	0	68.3	18.67	0.3	0.25
Callinectes sapidus	0.3	0.25	3.3	2.29	7.8	2.25	11.3	1.7
Penaeus duorarum	0	0	0	0	7	5.7	0.3	0.25
Penaeus aztecus	0	0	0.5	0.29	1.3	0.95	0.8	0.25
Neopanope texana	0	0	0	0	0.5	0.29	0.5	0.29
Penaeus setiferus	0	0	0	0	0	0	0.8	0.48
Rhithropanopeus harrisii	0	0	0	0	0.3	0.25	0	0
Penaeidae	0	0	0.5	0.29	8.3	6.64	1.8	0.63
CRUSTACEANS TOTALS:	0.8	0.48	3.8	2.5	85	26.71	13.8	1.18

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, MIDDLE BAY, FALL

GALVESTON BAY STUDY	Site 3				Site 4			
MIDDLE BAY SYSTEM	SMITH POINT				MOSES LAKE			
Macrofauna/2.6 m sq. (n=4)	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
November 3-4, 1987								
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:								
Gobiosoma bosci	6.3	1.44	0	0	106.8	18.75	1.3	0.75
Symphurus plagiusa	7	2.68	6	2.8	0	0	0	0
Anchoa mitchilli	0	0	0	0	0.8	0.75	9.5	8.51
Menidia beryllina	0	0	0	0	1	1	7.3	6.6
Myrophis punctatus	0	0	0.3	0.25	4.5	0.87	0.5	0.29
Fundulus grandis	0.8	0.48	0	0	3.3	1.38	0	0
Cynoscion nebulosus	1.3	0.63	0	0	0.5	0.5	0	0
Micropogonias undulatus	0.3	0.25	0.8	0.75	0	0	0.5	0.5
Sciaenops ocellatus	0	0	1	0.41	0	0	0	0
Gobionellus boleosoma	0	0	0.8	0.75	0	0	0	0
Gobiesox strumosus	0.5	0.5	0	0	0	0	0	0
Syngnathus louisianae	0.5	0.5	0	0	0	0	0	0
Gobiosoma robustum	0	0	0	0	0.3	0.25	0.3	0.25
Microgobius thalassinus	0	0	0.3	0.25	0	0	0	0
Mugil cephalus	0	0	0	0	0.3	0.25	0	0
Opsanus beta	0	0	0	0	0.3	0.25	0.3	0.25
Paralichthys lethostigma	0	0	0	0	0	0	0	0
Sphoeroides parvus	0	0	0	0	0	0	0.3	0.25
Syngnathus scovelli	0	0	0	0	0.3	0.25	0	0
Unknown fish species	0	0	0	0	0.3	0.25	0	0
Cyprinodontidae	0.8	0.48	0	0	3.3	1.38	0	0
Gobiidae	6.3	1.44	1	0.71	107	18.57	1.3	0.75
Sciaenidae	1.5	0.5	1.8	0.48	0.5	0.5	0.5	0.5
Commercial/Sports Fishes	1.3	0.63	1	0.41	0.5	0.5	0.3	0.25
FISH TOTALS:	16.5	3.86	9	2.94	118	19.01	19.8	9.46
CRUSTACEANS:								
Palaemonetes pugio	593.8	35.73	0.3	0.25	417	89.09	1.3	0.75
Callinectes sapidus	57.5	9.4	11	3.39	269.3	55.61	31.3	17.63
Palaemonetes vulgaris	88.3	59.49	0	0	32.5	17.96	0	0
Palaemonetes intermedius	32	32	0	0	22	7.82	0	0
Penaeus duorarum	10	4.26	1.5	0.87	35.3	14.64	2.8	0.95
Penaeus aztecus	8.3	4.61	0.3	0.25	5.8	3.84	5.3	1.44
Penaeus setiferus	4	1.68	7.3	1.49	0.3	0.25	1.5	0.87
Neopanope texana	6.5	6.5	0	0	0.5	0.5	0	0
Rhithropanopeus harrisii	3	2.38	0	0	0.8	0.75	0	0
Xanthidae, unknown species	1	1	0	0	0	0	0	0
Eurypanopeus abbreviatus	0	0	0	0	0.5	0.5	0	0
Eurypanopeus depressus	0.5	0.5	0	0	0	0	0	0
Panopeus herbstii	0.5	0.5	0	0	0	0	0	0
Alphaeus heterochaelis	0	0	0	0	0.3	0.25	0	0
Menippe mercenaria	0	0	0	0	0.3	0.25	0	0
Uca rapax	0	0	0	0	0.3	0.25	0	0
Penaeidae	22.3	10.26	9	1.22	41.3	12.51	9.5	2.4
CRUSTACEAN TOTALS:	805.3	108.13	20.3	3.68	784.5	70.91	42	19.73

APPENDIX III (continued): FISH AND DECAPOD CRUSTACEAN DENSITIES, LOWER BAY, FALL

GALVESTON BAY STUDY	Site 5				Site 6			
LOWER BAY SYSTEM	JAMAICA BEACH				CHRISTMAS BAY			
Macrofauna/2.6 m sq. (n=4)	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
October 23 and November 5, 1987								
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:								
Gobionellus boleosoma	1	0.41	0.3	0.25	19.8	11.88	1.5	0.96
Symphurus plagiusa	2.3	0.75	1.3	0.25	1	0.71	1.5	0.29
Anchoa mitchilli	0	0	4.3	2.21	0.3	0.25	0	0
Gobiosoma bosci	3	1.58	0.3	0.25	0	0	0	0
Fundulus grandis	1.5	0.87	0	0	0.8	0.48	0	0
Syngnathus scovelli	0	0	0	0	1.8	0.75	0	0
Cynoscion nebulosus	1.3	0.25	0	0	0	0	0	0
Cyprinodon variegatus	0	0	0	0	1.3	0.75	0	0
Menidia beryllina	0.3	0.25	0.3	0.25	0	0	0	0
Microgobius thalassinus	0	0	0.5	0.5	0	0	0	0
Mugil cephalus	0	0	0	0	0	0	0.5	0.5
Achirus lineatus	0	0	0	0	0	0	0.3	0.25
Eucinostomus spp.	0	0	0	0	0	0	0.3	0.25
Fundulus pulvereus	0.3	0.25	0	0	0	0	0	0
Lagodon rhomboides	0	0	0	0	0	0	0.3	0.25
Leiostomus xanthurus	0	0	0.3	0.25	0	0	0	0
Paralichthys lethostigma	0	0	0.3	0.25	0	0	0	0
Sciaenops ocellatus	0	0	0.3	0.25	0	0	0	0
Trinectes maculatus	0	0	0	0	0	0	0.3	0.25
Cyprinodontidae	1.5	0.87	0	0	2	1.15	0	0
Gobiidae	3.8	1.55	1	0.71	19.8	11.88	1.5	0.96
Sciaenidae	1.3	0.25	0.3	0.25	0	0	0	0
Commercial/Sports Fishes	1.3	0.25	0.5	0.29	0	0	0	0
FISH TOTALS:	8	1.87	6.5	2.02	24.8	12.75	4.5	1.85
CRUSTACEANS:								
Palaemonetes pugio	42.8	7.36	0	0	212.5	76.32	0.5	0.29
Callinectes sapidus	41.5	6.51	4.8	0.25	32	14.46	3	1.08
Penaeus setiferus	7.3	1.11	0.8	0.48	36	22.87	2	2
Palaemonetes vulgaris	23	12.77	0	0	18.5	18.5	0	0
Penaeus duorarum	17.5	4.84	2.3	0.63	17.5	5.66	1.8	0.25
Penaeus aztecus	16.3	5.07	2	0.71	11.8	9.17	0.8	0.25
Palaemonetes intermedius	2.5	0.87	0	0	11	7.08	0	0
Clibanarius vittatus	2.8	0.48	0.3	0.25	7.5	3.01	0.5	0.5
Alpheus heterochaelis	0.3	0.25	0	0	7.8	7.42	0	0
Sesarma cinereum	0.8	0.75	0	0	0	0	0	0
Petrolisthes armatus	0.5	0.5	0	0	0	0	0	0
Rhithropanopeus harrissi	0	0	0	0	0.5	0.5	0	0
Panopeus herbstii	0	0	0	0	0.3	0.25	0	0
Pinnixa chaetopterana	0.3	0.25	0	0	0	0	0	0
Sesarma reticulatum	0.3	0.25	0	0	0	0	0	0
Uca spp.	0.3	0.25	0	0	0	0	0	0
Penaeidae	40.8	6.84	4.8	1.03	65.3	22.84	4.5	2.18
CRUSTACEANS TOTALS:	153.3	28.25	9.5	1.04	355.3	84.05	8.5	1.19

APPENDIX IV: EPIFAUNA AND INFAUNA DENSITIES, SPRING.

GALVESTON BAY MARSH STUDY

Epi-Infauna/78.5 cm sq. (n=4)

April 20 - May 6, 1987

UPPER BAY:	TRINITY RIVER OUTER DELTA				TRINITY RIVER INNER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Annelids	148	29.819	63.5	37.529	133.5	57.77	86.25	22.103
Crustaceans	0	0	0	0	0.5	0.5	0.25	0.25
Molluscs	0	0	3.5	2.843	0.5	0.289	1.25	1.25
Others	8.75	2.594	25.5	23.514	4.25	2.016	4.25	3.924
Totals	156.75	31.006	92.5	61.907	138.75	60.401	92	25.72

MIDDLE BAY:	SMITH POINT				MOSES LAKE			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Annelids	46	14.071	78.25	32.294	282	39.684	182	36.681
Crustaceans	218.5	85.927	2.25	0.629	1193.5	261.25	1302.25	169.075
Molluscs	3.25	3.25	1.25	0.25	0.75	0.75	0	0
Others	4.5	2.843	3	1.225	48.25	32.281	22.75	7.565
Totals	272.25	96.28	84.75	32.255	1524.5	285.066	1507	190.195

LOWER BAY:	JAMAICA BEACH				CHRISTMAS BAY			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Annelids	144.5	42.822	65.25	17.983	150.5	41.242	17.5	3.329
Crustaceans	483.25	211.775	72.5	18.554	16.5	6.958	3	1.08
Molluscs	0.5	0.5	1	0.707	0.25	0.25	7.25	3.683
Others	23.25	18.346	3.75	2.496	2	1.354	0.25	0.25
Totals	651.5	249.324	142.5	16.983	169.25	49.123	29	4.262

APPENDIX IV (continued): EPIFAUNA AND INFAUNA DENSITIES, SUMMER.

GALVESTON BAY MARSH STUDY
Epi-Infauna/78.5 cm sq. (n=4)
July 17 - 24, 1987

UPPER BAY:	TRINITY RIVER OUTER DELTA				TRINITY RIVER INNER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Annelids	166.75	43.991	91	19.101	381.75	78.742	140.75	47.776
Crustaceans	1.75	1.75	0	0	0.25	0.25	0	0
Molluscs	0.5	0.5	0.75	0.479	6	3.894	23	22.668
Others	3.5	1.19	2	1.08	36	18.353	5.75	3.449
Totals	172.5	43.963	93.75	18.277	424	99.25	169.5	72.882

MIDDLE BAY:	SMITH POINT				MOSES LAKE			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Annelids	28	13.681	34.75	12.652	183.75	133.982	185.75	98.68
Crustaceans	60.5	36.999	4.25	3.591	98	87.358	29.75	17.853
Molluscs	0.5	0.289	1.75	0.75	0.5	0.289	0	0
Others	1.5	0.5	1.25	0.946	15	13.385	3	2.041
Totals	90.5	48.086	42.25	15.971	297.5	234.225	218.5	116.963

LOWER BAY:	JAMAICA BEACH				CHRISTMAS BAY			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Annelids	131	56.254	120.75	55.253	116.5	51.745	43.5	14.086
Crustaceans	4.25	1.25	7.75	2.136	28.25	26.597	0.5	0.5
Molluscs	0	0	1.75	0.25	0	0	1.25	0.946
Others	7	7	3.25	2.926	3.75	3.75	1	0.707
Totals	142.25	53.4	133.5	55.468	148.5	77.881	46.25	15.451

APPENDIX IV (continued): EPIFAUNA AND INFAUNA DENSITIES, FALL

GALVESTON BAY MARSH STUDY — SITE/HABITAT — SITE/HABITAT

Epi-Infauna/78.5 cm sq. (n=4)

October 23 - November 5, 1987

UPPER BAY:	TRINITY RIVER OUTER DELTA				TRINITY RIVER INNER DELTA			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Annelids	192.25	20.621	63	14.566	305	36.03	221.25	8.938
Crustaceans	0.75	0.479	1.5	0.866	0.5	0.289	0	0
Molluscs	4	3.674	0	0	0.25	0.25	8.25	4.973
Others	3	2.345	1.75	1.031	2	0.816	5.5	3.227
Totals	200	24.742	66.25	13.937	307.75	36.954	235	10.48

MIDDLE BAY:	SMITH POINT				MOSES LAKE			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Annelids	6.25	2.056	49.5	7.577	241.5	87.463	125	59.611
Crustaceans	2	1.414	6	3.83	32.75	7.307	52.5	20.234
Molluscs	0	0	1.25	0.479	0.25	0.25	0.5	0.5
Others	0.75	0.479	1.25	1.25	6.5	3.428	2.25	1.652
Totals	9	1.414	58	6.671	281	92.416	180.25	78.715

LOWER BAY:	JAMAICA BEACH				CHRISTMAS BAY			
	Vegetated		Non-vegetated		Vegetated		Non-vegetated	
Taxonomic Group	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
Annelids	78	32.357	102.25	39.205	109.25	24.178	43.5	11.701
Crustaceans	4	1.581	7	3.674	3.75	1.652	0.75	0.479
Molluscs	0	0	0.25	0.25	0.75	0.479	2	1.225
Others	0.5	0.289	1.5	0.5	0.75	0.479	4.25	3.924
Totals	82.5	33.908	111	40.663	114.5	23.869	50.5	14.192

APPENDIX V: FISH AND DECAPOD CRUSTACEAN DENSITIES AT SITES WITH SAV HABITAT.

GALVESTON BAY STUDY	SPRING				SUMMER						FALL			
Macrofauna/2.8 m sq. (n = 4)	SITE 2 OUTER DELTA		SITE 6 CHRISTMAS BAY		SITE 1 INNER DELTA		SITE 2 OUTER DELTA		SITE 6 CHRISTMAS BAY		SITE 2 OUTER DELTA		SITE 6 CHRISTMAS BAY	
SPECIES	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E	MEAN	S.E.
FISH:														
Gobionellus boleosoma	0	0	10.5	1.443	0	0	0	0	1	0.707	0	0	42	12.871
Lagodon rhomboides	0	0	27	5.845	0	0	0	0	6.5	1.848	0	0	0.25	0.25
Cyprinodon variegatus	0.25	0.25	0	0	26	3.24	0	0	0	0	0	0	0	0
Lucania parva	0	0	0	0	18	3.028	0	0	0	0	0	0	0	0
Gobiosoma robustum	0	0	1	1	0	0	0	0	1.5	1.5	0	0	7	4.123
Gobiosoma bosci	0	0	2	2	0	0	0.25	0.25	5	2.345	0	0	2	1.08
Symphurus plagiusa	0	0	0.5	0.289	0	0	0	0	1.5	0.957	0	0	2	0.913
Syngnathus scovelli	0	0	0	0	0	0	0	0	1	0.408	0	0	2.5	0.645
Fundulus grandis	0.75	0.75	0	0	0	0	0	0	0	0	2.25	1.315	0	0
Myrophis punctatus	0	0	0.75	0.479	0.5	0.5	1.25	0.479	0	0	0	0	0.25	0.25
Anchoa mitchilli	0.25	0.25	0	0	0	0	0	0	0.75	0.75	1.25	1.25	0	0
Cynoscion nebulosus	0	0	0.75	0.75	0	0	0	0	0.5	0.289	0	0	1	0.707
Micropogonias undulatus	2	0.707	0	0	0	0	0	0	0	0	0	0	0.25	0.25
Bairdiella chrysoura	0	0	0	0	0	0	0	0	1.5	0.645	0	0	0	0
Leiostomus xanthurus	0.75	0.75	0	0	0	0	0	0	0.25	0.25	0	0	0.25	0.25
Adina xenica	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0
Arius felis	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0	0
Menidia beryllina	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25
Opsanus beta	0	0	0	0	0	0	0	0	0.25	0.25	0	0	0	0
Synodus foetens	0	0	0.25	0.25	0	0	0	0	0	0	0	0	0	0
Cyprinodontidae	1	1	0	0	44	3.7193	0	0	0	0	2.5	1.1902	0	0
Gobiidae	0	0	13.5	2.0207	0	0	0.25	0.25	7.5	2.3274	0	0	51	12.0623
Sciaenidae	2.75	1.0308	0.75	0.75	0	0	0	0	2.25	0.4787	0	0	1.5	0.5
Bait Fishes	0.25	0.25	27	5.8452	0	0	0	0	7.25	2.1747	1.25	1.25	0.25	0.25
Commercial/Sports Fishes	0	0	0.75	0.75	0	0	0	0	0.5	0.2887	0	0	1	0.7071
FISH TOTALS:	4		42.75		44.5		1.5		20		3.75		57.75	
CRUSTACEANS:														
Palaemonetes pugio	0.25	0.25	38.25	6.237	0.5	0.289	0.25	0.25	55	16.558	9.5	8.17	139.75	57.469
Callinectes sapidus	0.75	0.25	6.25	1.031	1.75	0.629	0.75	0.25	7.75	2.496	15.5	3.403	45.5	5.545
Penaeus aztecus	0	0	40	5.672	0	0	0	0	28.5	3.884	1.25	0.75	8.25	3.092
Penaeus duorarum	0	0	0	0	0	0	0	0	11	3.808	1	0.408	51	12.537
Palaemonetes vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	33.5	13.865
Hippolyte zostericola	0	0	6.25	2.529	0	0	0	0	5.25	2.72	0	0	8.5	5.545
Alphaeus heterochaelis	0	0	0	0	0	0	0	0	4.5	2.533	0	0	9.75	2.75
Palaemonetes intermedius	0	0	0.5	0.5	0	0	0	0	2.75	2.428	0	0	11	3.189
Penaeus setiferus	0	0	0	0	0	0	0	0	1.75	0.479	1.25	0.75	5.25	3.924
Tozeuma carolinense	0	0	0	0	0	0	0	0	0	0	0	0	2.5	2.179
Rhithropanopeus harrissi	0	0	0.75	0.479	0	0	0.25	0.25	0	0	0.75	0.75	0	0
Clibanarius vittatus	0	0	0	0	0	0	0	0	0	0	0	0	1.25	0.75
Neopanope texana	0	0	0	0	0	0	0	0	0	0	1.25	0.946	0	0
Panopeus turgidus	0	0	0	0	0	0	0	0	0.75	0.75	0	0	0.25	0.25
Panopeus herbstii	0	0	0	0	0	0	0	0	0	0	0.75	0.75	0	0
Grass Shrimp	0.25	0.25	38.75	5.9214	0.5	0.2887	0.25	0.25	57.75	18.9225	9.5	8.1701	184.25	66.1279
Penaeid Shrimp	0	0	40	5.6716	0	0	0	0	41.25	5.391	3.5	1.0408	64.5	8.5878
CRUSTACEAN TOTALS:	1	0.4082	92	12.4833	2.25	0.8539	1.25	0.25	117.25	22.9578	31.25	9.4989	316.5	61.0389

LARVAL RECRUITMENT

OF

ESTUARINE RELATED FISHES AND INVERTEBRATES

OF THE

TEXAS COAST

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The present study was designed to provide information concerning the physical factors responsible for the transport of larval shrimp, crabs, and fishes from the spawning grounds in the Gulf of Mexico into Matagorda Bay and between Matagorda and Espiritu Santo Bays. Field studies were carried out during the spring and summer months of 1987. These resulted in the collection of 378 plankton samples, each accompanied by appropriate physical environmental data. In the laboratory the plankton samples were sorted, and the organisms were identified to the lowest feasible taxonomic levels. The counts were recorded in terms of density, i.e., the number of individuals of each taxonomic unit per cubic meter of water sampled. The information was entered into a computer data file and subjected to a series of statistical treatments.

Analysis of Methodology

Comparison of paired samples made by the same gear type revealed a high level of internal variability in the data base. Comparison of catches by different gear types indicated that any bias due to gear types is masked by the high internal variability of the data base itself. Regression analysis revealed that the data set from each collecting station is so distinct that it would not be statistically reasonable to combine the data from any pair of stations. Thus, it has been necessary to analyze the data from each station separately.

Regression analysis of biological abundance vs. the various physical factors was carried out by two methods (with zero occurrence values included and with zero values omitted). Comparison of the results obtained by the two methods support the conclusion that the method of analysis with zero values omitted provides the most sound basis for judging the relationships of biological abundance with the physical parameters. Therefore, all conclusions are based upon regressions employing this method of analysis.

Relationship of Each Physical Factor with Biological Abundance

Determination of the overall relationship of the several physical factors with biological abundance has involved averaging the relationships from the four collecting stations. Biological abundance includes the six major biological groups (see below) which account for all the species and life history stages taken. Each physical factor is considered separately.

Current. In 79.2 percent of the cases upchannel current is correlated with biological abundance, and this pattern is consistent through all station locations. The data support the contention that upchannel current is the primary factor involved in the transport of larvae from the continental shelf to the estuary and from one estuary to another.

Wind. In 66.7 percent of the cases upchannel wind is correlated with biological abundance.. This pattern is consistent through three of the stations, but in Pass Cavallo the correlation is with down-channel wind. The Pass Cavallo station is anomalous in that no bottom samples were taken, fewer samples were taken, and during one cruise samples were taken during a strong north wind ("norther"). Omitting the Pass Cavallo data, the relationship would have been 83.3 percent, strongly in favor of upchannel wind. There can be no doubt that, under normal conditions, upchannel wind is a major factor associated with larval transport through the passes.

Tidal height. In 55.6 percent of the cases higher tidal height is correlated with biological abundance, and this pattern is consistent at all three stations for which tidal height information is available. Thus, the analysis based upon major biological group data suggest that higher tidal height is of secondary importance in transport of the larvae. However, examination of the relationships using data from individual species and particular larval stages (rather than major groups) shows that higher tidal height is correlated with biological abundance in 77.8 percent of the cases, indicating that it may play a substantial role in the transport of larvae through the passes.

Water depth. Biological abundance is correlated with deeper water in 50.0 percent of the cases. Some species and life history stages favor the bottom and others the surface waters, and the proportion of the two appears to be about equal. in either event, depth *per se* is not a factor responsible for larval transport.

Temperature. In 58.3 percent of the cases higher temperature is correlated with biological abundance. This may relate to the fact that the majority of the samples were taken during the summer months or that larvae from summer spawners were numerically more abundant. However, temperature itself does not appear to be a factor important in relation to larval transport.

Salinity. In only 45.8 percent of the cases was higher salinity correlated with biological abundance. From the data on hand, there is no evidence that salinity has anything to do with the mechanisms of larval transport through the passes.

Light. Since night-time collections were made only in the Ship Channel, this is the only location for which a day/night comparison can be made. Here, daytime collections are correlated with biological abundance in only 33.3 percent of the cases. In the Ship Channel larval densities are higher at night in the majority of the cases.

From the above discussion it is clear that the physical factors most frequently correlated with larval abundance in the passes include upchannel current, upchannel wind, and higher tidal height. The factors of water depth, temperature, and salinity exhibit mixed correlations since about half the cases are correlated with a higher value and half are correlated with a lower value of the particular factor. In two-thirds of the cases the larvae were more abundant at night.

Analysis of Biological Groups, Larval Stages, and Individual Species

Major Biological Groups

The data were first analyzed by major biological group to determine correlation patterns associated with the multi-species groups. The groups included shrimp larvae, crab larvae, fish eggs, estuarine fish larvae, marine fish larvae, and marine sciaenid larvae. For each group the physical factor correlations with biological abundance will be presented as primary (most frequent correlations) and secondary (less frequent correlations).

Shrimp larvae. Factors primarily correlated with biological abundance include upchannel current, upchannel wind, lower temperature, and lower salinity. Factors secondarily correlated with biological abundance include higher tidal height, shallower depth, and daytime conditions.

Crab larvae. Primary factors include upchannel current, upchannel wind, lower tidal height, shallower depth, and higher temperature. A secondary factor is daytime conditions.

Fish eggs. Primary factors include higher temperature and higher salinity. Secondary factors include higher tidal height, shallower depth, and night-time conditions.

Estuarine fish larvae. Primary factors include upchannel current, greater depth, higher temperature, and higher salinity. Secondary factors include higher tidal height and night-time conditions.

Marine sciaenid larvae. Primary factors include upchannel wind, lower temperature, and lower salinity. Secondary factors include lower tidal height, shallower depth, and night-time conditions.

Shrimp Larval Stages

Penaeidae - protozoea. Primary factors include upchannel current and higher temperature. Secondary factors include higher tidal height, shallower depth, and daytime conditions.

Penaeid - mysis. Primary factors include upchannel wind, higher tidal height, higher temperature, and lower salinity. A secondary factor is daytime conditions.

Penaeus aztecus -postlarvae. Primary factors include down-channel current, shallower depth, and lower temperature. Secondary factors include higher tidal height and daytime conditions.

Penaeus spp. - postlarvae. Primary factors include upchannel current, higher temperature, and lower salinity. Secondary factors include higher tidal height, greater depth, and night-time conditions.

Crab Larval Stages

Portunid - zoea. Primary factors include upchannel current, upchannel wind, lower tidal height, and shallower depth. A secondary factor is daytime conditions.

Callinectes - megalops. Primary factors include upchannel current, down-channel wind, higher tidal height, and lower temperature. Secondary factors include greater depth and daytime conditions.

Portunid - juveniles. A primary factor is greater depth. Secondary factors include upchannel current, upchannel wind, greater tidal height, lower temperature, higher salinity, and night-time conditions.

Individual Fish Species

Of the fifteen target fish species the larvae of only five were taken with sufficient frequency for use in regression analysis.

Bairdiella chrysoura (silver perch). A primary factor is higher salinity. Secondary factors include higher tidal height and daytime conditions.

Cynoscion arenarius (Sand seatrout). Primary factors include upchannel current, upchannel wind, greater depth, and lower salinity. Secondary factors include higher tidal height and night-time conditions.

Cynoscion nebulosus (spotted seatrout). In the case of this species there are no primary factors. Secondary factors include upchannel current, down-channel wind, greater depth, lower temperature, lower salinity, and daytime conditions.

Pogonias cromis (black drum). Primary factors include upchannel wind, higher tidal height, lower temperature, and lower salinity. A secondary factor is night-time conditions.

Stellifer lanceolatus (star drum). Primary factors include down-channel current, upchannel wind, higher tidal height, greater depth, lower temperature, lower salinity, and night-time conditions. For this species there are no secondary factors.

Concluding Remarks

For each major biological group, life history stage, and individual species listed above there is provided a mathematical model expressing the relationships of biological abundance with the various physical factors, and each regression equation is accompanied by a measure of the reliability of the estimates of the relationships. Suggestions are provided concerning the design of future studies dealing with the problem of larval transport through the passes. The problem of larval transport across the continental shelf to the passes has not been addressed. Nor has attention been given to the matter of larval behavior which may be important, particularly in the older larval and early juvenile stages.

As in other ecological systems each species has had to develop its own unique life history strategy in order to achieve long term survival under the prevailing environmental conditions. Therefore, the coastal invertebrates and fishes display a great diversity of spawning seasons, spawning locations, and relations with depth, temperature, salinity, and light conditions. However, the major life history bottleneck for all the estuary related species which spawn in the gulf is the problem of traversing the passes, and here we observe a commonality in the adaptions of the various species. Upchannel current, upchannel wind, and increased tidal height all appear to be involved in a major way in moving the larvae through the passes. There is no evidence from the present study that the factor of salinity plays a significant role in larval transport, and this finding has a bearing upon the question of the importance of freshwater release from streams entering the upper reaches of the estuaries.