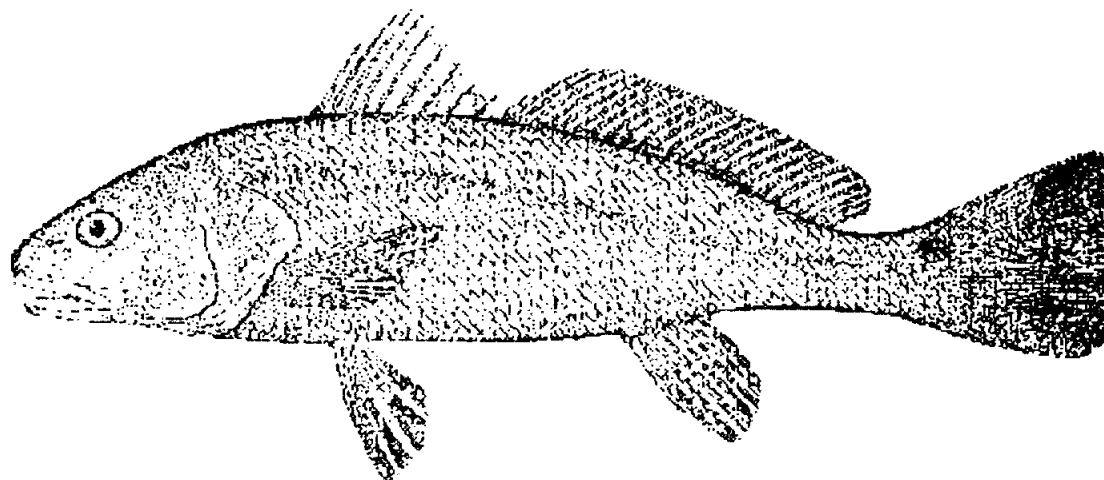




NOAA Technical Memorandum NMFS - SEFC - 236

Habitat-Related Differences in Diets of Small Fishes from Lavaca Bay, Texas, 1985 - 1986



AUGUST 1989

**GALVESTON LABORATORY
SOUTHEAST FISHERIES CENTER
NATIONAL MARINE FISHERIES SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC
ADMINISTRATION
DEPARTMENT OF COMMERCE**

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**Habitat-Related Differences in Diets of Small
Fishes in Lavaca Bay, Texas, 1985-1986**

BY

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ABSTRACT

The stomach contents of fishes collected in drop samples and trawls were examined to determine whether dietary patterns varied in relation to habitats in Lavaca Bay. The diets of fishes collected in delta areas, near the mouth of the Lavaca River, were compared with those collected in coastal areas during October 1985, May 1986, and August 1986. A qualitative analysis of feeding patterns of individual fish species did not reveal any habitat-related differences. In part, this may have been due to small sample sizes for many species. A consistent pattern in the data combined for all fish species examined, however, suggested that the quantity of food eaten at coastal sites was larger than at delta sites. Dominant fish predators on penaeid shrimp included the southern flounder, inshore lizardfish, spotted seatrout, and sand seatrout. Most of the shrimp were eaten at coastal sites even though fish predators and shrimp were abundant at both delta and coastal sites. These data suggest that habitat characteristics at delta sites may offer shrimp more protection from predation.

INTRODUCTION

An examination of the diet of estuarine fishes in conjunction with estimates of prey abundance and distribution can be useful in determining the nutritional capacity of habitats for these fish and the protective nature of habitats for particular prey species. The availability of vegetative structure (Stoner 1979, Coen et. al. 1981, Heck and Thoman 1981), appropriate substrata for burrowing (Stein and Magnuson 1976), and the turbidity of the water (Moore and Moore 1976, Gardner 1981) have all been shown to alter predator-prey interactions. These factors have also been shown to alter feeding rates of estuarine fishes on juvenile penaeid shrimp (Minello and Zimmerman 1983, 1984, Zimmerman and Minello 1984, Minello et. al. 1987). Freshwater inflow and the associated sediment load affects these habitat characteristics, and the proximity of particular locations in an estuary to the source of freshwater can control the vegetation type, sediment characteristics, and perhaps the turbidity.

A major objective of our research program on the effects of freshwater inflow in estuaries is to compare habitats located near sources of freshwater with more marine habitats. In Lavaca Bay, Texas, the abundance of crustaceans and small fishes in nearshore and marsh habitats located near the Lavaca River delta were compared with similar habitats in areas of higher salinity, closer to Matagorda Bay and the Gulf of Mexico. As a part of this project, the stomach contents of small estuarine fishes collected in these upper bay and lower bay areas were examined for possible habitat-related dietary patterns.

METHODS AND MATERIALS

Fishes for dietary analyses were obtained from drop samples collected both in vegetated and nonvegetated shallow shoreline areas. A small trawl was also used to collect additional fish from the shallow waters along these shorelines. The samples were collected at three delta sites near the mouth of the Lavaca River and at three coastal sites in the lower bay nearer the Gulf (Figure 1). Four vegetated and four nonvegetated drop samples (2.6 m² each) were collected at each site along with one or more trawl samples. Trawl samples were taken to obtain an adequate number of fish for stomach analyses, and therefore trawl durations were adjusted in relation to the number of fish collected. Because of this variable sampling effort and the relatively poor catch efficiency of trawls, comparisons of the number of fish collected at the sites were made only from drop-sample data. A complete set of samples was collected in October 1985 and May 1986. During August 1986, low water levels prevented the collection of samples at vegetated delta sites, and therefore only nonvegetated samples from both coastal and delta sites were analyzed for this sampling period. The fish selected for analysis were chosen on the basis of their abundance and on their potential impact on fishery

species i.e. they were known or suspected predators on important commercial or recreational species of prey, mainly juvenile shrimp, crabs and fishes. All fish collected and the species targeted for stomach analyses are listed in Table 1. Fishes were preserved in the field with a 10% Formalin solution. In the laboratory, fish were identified and total length was measured to the nearest 1 mm. Stomach contents were examined from all specimens in a targeted fish species, with the exception of individuals which were mutilated in the collection process. Stomachs were dissected and the contents were identified, counted, and separated into taxa for drying. Annelids were weighed but not counted due to fragmentation in guts. Both prey and predators were dried at 100° C for 24 hours or until a constant dry weight was obtained. Within samples, food items from fish of similar sizes were combined to obtain an overall estimate of dry weight of prey for that particular size group of predator. The data were examined for trends in feeding patterns, but statistical analyses were restricted to some of the summary data due to the large number of missing data points, the small number of fish collected, and the non-normal and heteroscedastic nature of the data. A log transformation of the data was used to reduce the positive relationship between the variance and the mean.

Figure 1. Sampling sites in Lavaca Bay, Texas

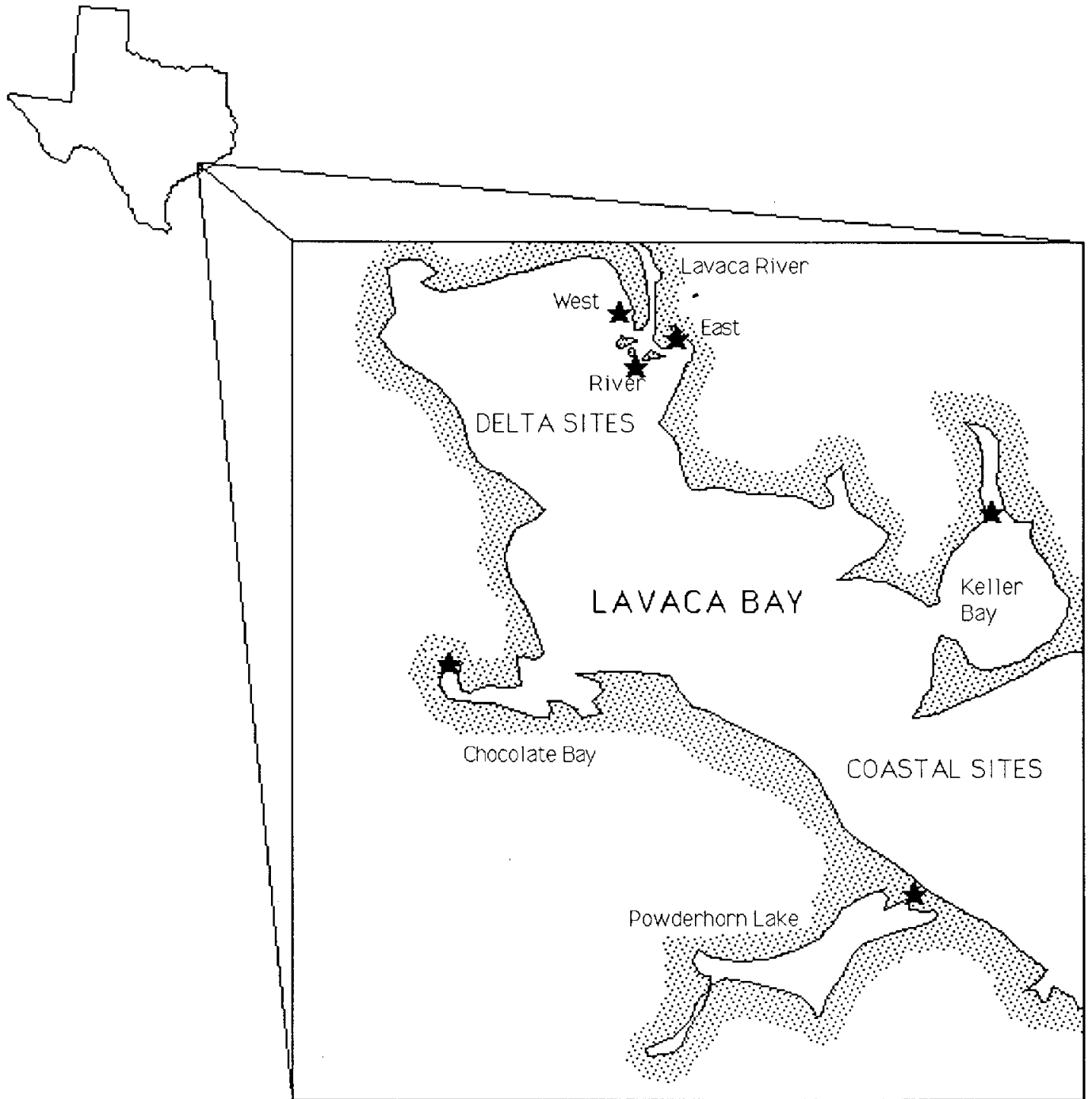


Table 1. Fish collected using the drop sampler and a trawl in Lavaca Bay during 1985-1986. Total number caught is given for Delta and Coastal sites during each sampling period. Fish are ranked according to the total number collected. Asterisks (*) indicate fish predators examined for stomach contents.

Common Name	Scientific Name	OCTOBER			MAY			AUGUST			Year
		Delta	Coastal	Sum	Delta	Coastal	Sum	Delta	Coastal	Sum	
Naked goby	<i>Gobiosoma boscii</i>	400	120	520	51	52	103	54	3	57	680
Bay anchovy	<i>Anchoa mitchilli</i>	267	161	428	66	77	143	0	0	0	571
Gulf menhaden	<i>Brevoortia patronus</i>	0	14	14	263	197	460	0	0	0	474
* Spot	<i>Leiostomus xanthurus</i>	3	49	52	106	182	288	19	46	65	405
* Pinfish	<i>Lagodon rhomboides</i>	0	6	6	57	121	178	16	21	37	221
* Atlantic croaker	<i>Micropogonias undulatus</i>	5	4	9	49	80	129	31	2	33	171
Darter goby	<i>Gobionellus boleosoma</i>	8	94	102	2	12	14	0	17	17	133
Chain pipefish	<i>Syngnathus louisianae</i>	0	6	6	1	1	2	91	5	96	104
* Silver perch	<i>Bairdiella chrysoura</i>	1	2	3	5	59	64	1	2	3	70
* Gulf killifish	<i>Fundulus grandis</i>	37	2	39	8	18	26	0	0	0	65
Inland silverside	<i>Menidia beryllina</i>	0	3	3	17	15	32	23	2	25	60
Blackcheek tonguefish	<i>Symphurus plagiusa</i>	26	17	43	0	2	2	2	6	8	53
Striped mullet	<i>Mugil cephalus</i>	0	5	5	0	2	2	0	30	30	37
Least puffer	<i>Sphoeroides parvus</i>	3	22	25	9	2	11	0	0	0	36
Clown goby	<i>Microgobius gulosus</i>	23	12	35	0	0	0	0	0	0	35
* Southern flounder	<i>Paralichthys lethostigma</i>	0	0	0	13	8	21	4	2	6	27
* Sand seatrout	<i>Cynoscion arenarius</i>	0	0	0	0	1	1	7	16	23	24
* Spotted seatrout	<i>Cynoscion nebulosus</i>	9	10	19	0	1	0	0	3	3	23
Diamond killifish	<i>Adinia xenica</i>	19	0	19	0	1	1	0	0	0	20
Hardhead catfish	<i>Arius felis</i>	3	0	3	9	5	14	0	0	0	17
Gulf toadfish	<i>Opsanus beta</i>	0	0	0	12	1	13	0	0	0	13
Spotfin mojarra	<i>Eucinostomus argenteus</i>	4	8	12	0	0	0	1	0	1	13
* Pigfish	<i>Orthopristis chrysoptera</i>	0	0	0	1	6	7	0	2	2	9
* Inshore lizardfish	<i>Synodus foetens</i>	1	7	8	0	1	1	0	0	0	9
Gulf pipefish	<i>Syngnathus scovelli</i>	0	3	3	0	6	6	0	0	0	9
Speckled Worm eel	<i>Myrophis punctatus</i>	4	0	4	1	0	1	3	0	3	8
Bay whiff	<i>Citharichthys spilopterus</i>	1	1	2	2	3	5	0	0	0	7
Atlantic threadfin	<i>Polydactylus octonemus</i>	0	0	0	1	6	7	0	0	0	7
Sheepshead minnow	<i>Cyprinodon variegatus</i>	1	0	1	2	3	5	0	0	0	6
Lined sole	<i>Achirus lineatus</i>	0	2	2	0	0	0	0	4	4	6
Skilletfish	<i>Gobiesox strumosus</i>	2	0	2	0	3	3	0	0	0	5
* Longnose killifish	<i>Fundulus similis</i>	4	0	4	0	0	0	0	0	0	4
Bayou killifish	<i>Fundulus pulvereus</i>	4	0	4	0	0	0	0	0	0	4
Sheepshead	<i>Archosargus probatocephalus</i>	0	1	1	0	2	2	0	0	0	3
* Red drum	<i>Sciaenops ocellatus</i>	0	0	0	1	1	2	0	1	1	3
Frillfin goby	<i>Bathygobius soporator</i>	0	2	2	0	0	0	0	0	0	2
Threadfin shad	<i>Dorosoma petenense</i>	0	1	1	0	0	0	0	0	0	1
Atlantic spadefish	<i>Chaetodipterus faber</i>	0	0	0	0	1	1	0	0	0	1
Smooth puffer	<i>Lagocephalus laevigatus</i>	0	1	1	0	0	0	0	0	0	1
* Silver seatrout	<i>Cynoscion nothus</i>	0	0	0	0	0	0	0	1	1	1
Dusky pipefish	<i>Syngnathus floridae</i>	0	1	1	0	0	0	0	0	0	1
Crevalle	<i>Caranx hippos</i>	0	0	0	0	1	1	0	0	0	1
Code goby	<i>Gobiosoma robustum</i>	0	0	0	1	0	1	0	0	0	1
Bluntnose jack	<i>Hemicaranx amblyrhynchus</i>	1	0	1	0	0	0	0	0	0	1
Totals		826	554	1380	677	869	1546	252	163	415	3342

RESULTS

Diet of Individual Species

Spot

Most spot were collected during May, and approximately 97% of these fish were caught in the trawl. A total of 317 spot were examined and the predominate food items that could be identified were copepods and annelid worms (Table 2). Spot collected during August had been feeding almost exclusively on copepods. Only three relatively large specimens were collected on the delta in October, and these fish had been feeding on mysids. Juvenile spot have been found to feed on postlarval penaeid shrimp in Galveston Bay (Minello et. al., in press), but no penaeids were found in the fish examined from Lavaca Bay.

Pinfish

Most pinfish were also collected in May. A large portion of their stomach contents consisted of plant material, but these fish also fed upon a variety of invertebrates including relatively large numbers of copepods and amphipods (Table 2). Small numbers of penaeid shrimp and crabs were also found in the stomachs of some fish. There did not appear to be any major differences in the feeding patterns of fish collected at the delta in comparison with fish collected at coastal sites.

Atlantic Croaker

As with the spot and pinfish, most Atlantic croaker were collected in the May samples. A large percentage of the stomach contents of these fishes consisted of unidentifiable animal material (no chloroplasts). The dominant identifiable prey items were annelids, but fish and copepods were also present (Table 2).

Silver Perch

The majority of silver perch (84%) were collected during May in the coastal area with

67% occurring at one site (Keller Bay). Almost all of these fish were early juveniles, and they had been feeding upon a relatively wide variety of crustaceans including amphipods, tanaids, mysids, and copepods (Table 2).

Gulf Killifish

Fundulus grandis showed a strong affinity for vegetated habitats, and all specimens were collected in vegetated drop samples. Killifish are year-round residents of the marsh, and apparently many individuals do not migrate from the marsh surface at low tide but find refuge in small pools and in the burrows of other animals (Kneib 1986). This behavior may explain the lack of any specimens in our August samples, which were collected on nonvegetated bottom at low water levels. Overall, amphipods appeared to be the dominant prey item of this species (Table 2). During May, the fish collected at coastal sites were feeding mainly on amphipods, but over 90% of the food eaten by fish at delta sites consisted of insects.

Southern Flounder

A total of 27 southern flounder were collected, and most of these were juveniles (less than 120 mm, total length) caught during May. Penaeid shrimp were the dominant food of these fish, making up 76% and 92% of the weight of food eaten at delta and coastal sites, respectively (Table 2).

Spotted Seatrout

Most of the 23 spotted seatrout examined were collected in October. At coastal sites, penaeid shrimp were the dominant food item (Table 2), and at delta sites the fish had been feeding on mysids, caridean shrimp, and fish.

Sand Seatrout

Sand seatrout occurred mainly in the August samples, and all but one of the 23 fish examined was caught during this sampling period. These fish had been feeding mostly

on mysids although fish prey made up a relatively large percentage of the weight of stomach contents at delta sites (Table 2). The one specimen caught during May had eaten four penaeid shrimp.

Inshore Lizardfish

The nine specimens of lizardfish were all collected with the trawl, and eight of the nine were caught in October. Although the density of these fish appeared low, they may be dominant predators of penaeid shrimp. The stomach contents of the fish examined consisted almost exclusively of penaeid shrimp and fish (Table 2).

Other species

Stomach contents of red drum, silver seatrout, and pigfish were also examined, but the small number of specimens collected made it difficult to characterize dietary patterns for these fish. A large number of small gobies (mostly under 25 mm, TL) was also collected (Table 1) in the drop samples, and although we did not target these fish for a detailed analysis, we examined stomach contents of 56 specimens from 3 species (naked goby, darter goby, clown goby). These fish had all been feeding on small infaunal and epifaunal organisms including amphipods, tanaids, mysids, copepods, and polychaetes.

Habitat-Related Patterns in the Amount of Food Eaten

Data on the weight of food eaten by individual fish species were highly variable, and this along with the lack of specimens at many sites made it difficult to detect differences between coastal and delta areas (Table 3). There was some indication from the May data that spot caught at coastal sites had been eating more than spot caught at delta sites. There was a consistent difference in the weight of food eaten per gram of fish between these two areas, although the t-test between means

was not significant at the 5% level (Table 3). Combining the data for all the fish species examined reduced some of the problems related to unequal sample size (Table 4). In October the weight of food eaten per fish was significantly greater in the coastal area (31.6 g) compared with the delta area (21.7 g) of the bay. A large portion of this difference, however, appeared to be related to a difference (not significant) in the size of fish collected in the two areas. When the weight of food eaten was corrected for the weight of the fish, mean values were still larger in the coastal area, but the difference was not significant. In May, the mean weight of fish was much lower than at other times of the year indicating the abundance of new recruits during the spring. The weight of food eaten per weight of fish was consistently larger at coastal sites and the t-test approached significance ($P=0.07$). No significant differences were evident in August, but the trend of more food being eaten at coastal sites continued. Overall, the mean weight eaten per weight of fish at the coastal sites was similar for the three sampling periods, ranging from 10.06 mg/g in August to 11.14 mg/g in May, and these coastal values were consistently larger than the values from the delta.

Predation on Penaeid Shrimp

A special effort was made to identify predators of juvenile penaeid shrimp. A total of 47 penaeids (mostly *Penaeus aztecus*) were eaten by the fish examined, and 39 of these (83%) were eaten at coastal sites. Near the delta, the southern flounder was the dominant predator, eating 97% of the shrimp by weight (Table 5). At coastal sites 3 species of fish combined to eat approximately 98% of the shrimp by weight including the inshore lizardfish (65.8%), the spotted seatrout (19.6%), and the southern flounder (12.4%). The combined data from both areas and all sampling times showed that overall, 78% of

Table 2. Comparison of the diet of fishes between delta and coastal sites in Lavaca Bay. The size range (mm, TL) and mean dry weight (g) are given for all fish examined. The total number of each prey item found in the fish stomachs is listed along with the percentage of the total dry weight (mg) of food.

Spot

Location	OCTOBER				MAY				AUGUST			
	DELTA		COASTAL		DELTA		COASTAL		DELTA		COASTAL	
No. examined	3		49		80		123		19		43	
No. with food	3		44		68		122		19		43	
Size Range	114-122		12-130		44-73		47-126		65-105		60-150	
Mean Weight (g)	4.6		2.9		0.5		0.8		1.3		3.0	
PREY ITEMS	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Amphipods		0.0	11	3.5		0.0	14	1.1		0.0	2	0.2
Mysids	207	79.3		0.0		0.0		0.0	4	0.0		0.0
Copepods		0.0	198	5.5	860	19.7	5202	13.3	1783	67.1	3466	72.7
Cumaceans		0.0		0.0		0.0		0.0	5	2.4		0.0
Annelids		0.0		24.5		11.6		2.5		0.0		0.3
Plant Material		0.0		0.0		0.0		0.3		0.0		0.4
Unid. foods		20.7		66.5		68.7		82.7		30.5		26.4
Total weight (mg)	9.2		335.2		85.3		1096		71.4		338.7	

Pinfish

Location	OCTOBER				MAY				AUGUST			
	DELTA		COASTAL		DELTA		COASTAL		DELTA		COASTAL	
No. examined	0		6		57		97		16		21	
No. with food			6		56		97		16		21	
Size Range			96-138		42-88		36-88		71-120		65-118	
Mean Weight (g)			7.4		1.0		1.0		2.9		2.8	
PREY ITEMS	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Penaeus aztecus</i>				0.0		0.0	1	2.2		0.0		0.0
<i>Penaeus spp.</i>			2	0.1		0.0		0.0		0.0		0.0
Amphipods			2	0.0	36	2.5	66	5.3	9	0.3	2	0.1
Tanaids				0.0	2	0.0	1	0.0	7	0.4		0.0
Mysids			4	0.0		0.0	2	0.0		0.0		0.0
Copepods				0.0	376	4.6	428	1.0	6	0.2	116	0.6
Crabs			1	0.3		0.0		0.0		0.0		0.0
Unid. Crustacea				0.0		3.3	20	2.2	2	0.2	3	3.4
Annelids				0.0		4.6		21.6		0.0	1	0.3
Fish				0.0	1	1.8		0.0		0.0		0.0
Plant Material				99.6		44.7		28.7		89.9		92.9
Unid. foods				0.0		38.6		39.0		9.1		2.7
Total weight (mg)			454.6		594.5		910.8		371.5		533.7	

Atlantic croaker

Location	OCTOBER				MAY				AUGUST			
	DELTA		COASTAL		DELTA		COASTAL		DELTA		COASTAL	
No. examined	5		4		49		62		31		2	
No. with food	5		3		47		60		30		2	
Size Range	115-150		14-119		57-107		54-114		98-151		152-155	
Mean Weight (g)	6.1		1.2		1.2		1.3		3.6		9.7	
PREY ITEMS	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Penaeus spp.</i>		0.0		0.0		0.0	1	0.9		0.0		0.0
Amphipods		0.0	1	5.6		0.0	7	0.5		0.0		0.0
Mysids	5	4.3	1	11.1	1	0.0		0.0	32	2.5		0.0
Copepods		0.0		0.0	36	0.1	354	1.1	10	0.4		0.0
Carideans		0.0		0.0		0.0		0.0		0.0	1	8.8
Unid. Crustacea		0.0		0.0	3	0.6		0.0		0.0		0.0
Annelids		58.4		0.0		34.6		13.7		0.0		64.0
Fish		29.2		0.0	4	23.0		0.0		0.0		0.0
Plant Material		0.0		38.9		3.8		0.0		41.6		0.0
Unid. foods		8.1		44.4		37.9		83.7		55.5		27.2
Total weight (mg)	147.7		1.8		357.5		894.7		185.7		40.8	

Table 2. Continued.
Silver Perch

Location	OCTOBER				MAY				AUGUST			
	DELTA		COASTAL		DELTA		COASTAL		DELTA		COASTAL	
No. examined	1		2		5		58		1		2	
No. with food	1		2		4		43		1		1	
Size Range	130		72-110		8-30		9-32		74		68	
Mean Weight (g)	6.2		2.0		0.0		0.0		0.9		9.6	
PREY ITEMS	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Penaeus aztecus</i>		0.0		0.0		0.0	1	1.8	1	14.7		0.0
<i>Penaeus spp.</i>		0.0	1	16.6		0.0		0.0		0.0		0.0
Amphipods		0.0		0.0	9.0	43.2	46.0	34.0		0.0		0.0
Isopods		0.0		0.0		0.0	1.0	0.0		0.0		0.0
Tanaids		0.0	24	66.2	5	27.3	24	9.0		0.0		0.0
Mysids		0.0	52	9.9		0.0	2	1.8		0.0		0.0
Copepods		0.0		0.0		0.0	189	35.6	4	17.3		0.0
Unid. Crustacea		0.0		0.0	3	29.5	12	17.5		0.0	8	100.0
Annelids		0.0		0.0		0.0		0.0		0.0		0.0
Unid. foods		100.0		7.3		0.0		0.3		68.0		0.0
Total weight (mg)		8.6		15.1		4.4		38.8		7.5		4.1

Gulf killifish

Location	OCTOBER				MAY				AUGUST			
	DELTA		COASTAL		DELTA		COASTAL		DELTA		COASTAL	
No. examined	27		0		8		18		0		0	
No. with food	22				7		15					
Size Range	26-43				32-69		20-82					
Mean Weight (g)	0.1				0.2		0.5					
PREY ITEMS	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Amphipods	15	60.0			7	4.0	29	55.2				
Tanaids	4	6.2										
Copepods	24	6.9					1	2.5				
Carideans							1	7.4				
Insects					9	90.5	1	2.0				
Plant Material		19.3										
Unid. foods		7.6				5.5		33.0				
Total weight (mg)		14.5				34.6		20.4				

Southern flounder

Location	OCTOBER				MAY				AUGUST			
	DELTA		COASTAL		DELTA		COASTAL		DELTA		COASTAL	
No. examined	0		0		13		8		4		2	
No. with food					7		7		4		1	
Size Range					50-119		60-117		77-95		169-355	
Mean Weight (g)					0.8		2.8		1.4			
PREY ITEMS	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Penaeus aztecus</i>					7	75.8	7	61.0		0.0		0.0
<i>P. setiferus</i>						0.0	2	31.0		0.0		0.0
<i>Penaeus spp.</i>						0.0	1	1.6		0.0		0.0
Amphipods					1	3.5	3	1.5		0.0		0.0
Mysids					5	15.3	1	0.5	60	100.0		0.0
Carideans						0.0	2	1.3		0.0		0.0
Unid. Crustacea					5.4		6	2.7		0.0		0.0
Fish						0.0		0.0		0.0	2	100.0
Plant Material						0.0		0.5		0.0		0.0
Total weight (mg)						48.3		199.7		24.1		1798

Table 2. Continued.
Spotted seatrout

Location	OCTOBER				MAY				AUGUST			
	DELTA		COASTAL		DELTA		COASTAL		DELTA		COASTAL	
No. examined	9		10		0		1		0		3	
No. with food	9		9				0				2	
Size Range	26-110		7-133				26				13-99	
Mean Weight (g)	0.8		1.0				0.0				0.6	
PREY ITEMS	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Penaeus aztecus</i>		0.0	4	78.7								0.0
Amphipods	3	0.4		0.0								0.0
Mysids	111	23.6	24	4.6					2	3.1		
Carideans	1	25.1	3	9.8					1	96.9		
Fish	1	48.7		0.0								0.0
Plant Material		0.0		6.9								0.0
Unid. foods		2.2		0.0								0.0
Total weight (mg)	226.6		377.6								39.0	

Sand seatrout

Location	OCTOBER				MAY				AUGUST			
	DELTA		COASTAL		DELTA		COASTAL		DELTA		COASTAL	
No. examined	0		0		0		1		7		15	
No. with food							1		6		14	
Size Range							41		62-93		46-83	
Mean Weight (g)							0.1		0.6		0.3	
PREY ITEMS	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Penaeus aztecus</i>						2	7.0		0.0			0.0
<i>Penaeus spp.</i>						2	8.0		0.0	2		0.0
Mysids							0.0	62	24.1	86		93.9
Copepods							0.0		0.0	3		4.3
Unid. Crustacea							85.0		0.0			0.0
Fish							0.0	3	69.7			0.0
Unid. foods							0.0		6.2			1.8
Total weight (mg)							10.0		141.6		27.7	

Inshore lizardfish

Location	OCTOBER				MAY				AUGUST			
	DELTA		COASTAL		DELTA		COASTAL		DELTA		COASTAL	
No. examined	1		7		0		1		0		0	
No. with food	0		7				1					
Size Range	104.0		123-203				174					
Mean Weight (g)	2.1		5.8				8.3					
PREY ITEMS	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Penaeus aztecus</i>			7	73.2				0.0				
<i>Penaeus spp.</i>			6	2.9				0.0				
Fish			6	21.3			1	100.0				
Unid. foods				2.7				0.0				
Total weight (mg)			1309				340.8					

Table 3. Mean weight of food present in the stomachs of fishes collected at three delta sites and three coastal sites in Lavaca Bay. Probability (P) values are from a t-test comparing means between delta and coastal areas (log transformed data); nt = no test performed.

OCTOBER		Delta Sites				Coastal Sites				P value
		East	Channel	West	Mean	Keller	Chocolate	Powderhorn	Mean	
Spot	Number of Fish Examined	3				11	1	37		
	Size Range (mm,TL)	114-122				12-127	94	78-130		
	Mean Wt (g) of Fish	4.63			4.63	4.65	2.22	2.41		3.09
	Wt (mg) Eaten/Fish	3.07			3.07	13.16	4.00	5.04		7.40
	Wt (mg) Eaten/ g Fish	0.66			0.66	2.83	1.80	2.09		2.24
Pinfish	Number of Fish Examined					2	1	3		
	Size Range (mm,TL)					132	138	96-120		
	Mean Wt (g) of Fish					9.37	10.63	4.91		8.30
	Wt (mg) Eaten/Fish					125.30	70.80	44.40		80.17
	Wt (mg) Eaten/ g Fish					13.38	6.66	9.04		9.69
Atlantic Croaker	Number of Fish Examined	1	3	1		2	2			
	Size Range (mm,TL)	136	115-150	150		14-26	95-119			
	Mean Wt (g) of Fish	4.94	6.05	7.50	6.16	0.02	2.34			1.18
	Wt (mg) Eaten/Fish	5.80	46.20	3.30	18.43	0.05	0.85			0.45
	Wt (mg) Eaten/ g Fish	1.17	7.63	0.44	3.08	3.33	0.36			1.85
Spotted Seatrout	Number of Fish Examined	4	3	2		1	4	4		
	Size Range (mm,TL)	26-110	88-100	48-77		65	50-108	73-133		
	Mean Wt (g) of Fish	0.66	1.24	0.45	0.78	0.44	0.09	1.74		0.76
	Wt (mg) Eaten/Fish	31.98	6.17	40.10	26.08	11.80	9.20	82.25		34.42
	Wt (mg) Eaten/ g Fish	48.82	4.97	90.11	47.97	26.82	105.14	47.27		59.74
Lizardfish	Number of Fish Examined				1	1	4	2		
	Size Range (mm,TL)				104	139	123-150	189-203		
	Mean Wt (g) of Fish				2.07	2.07	3.16	3.58		11.45
	Wt (mg) Eaten/Fish				0.00	0.00	162.30	64.78		443.85
	Wt (mg) Eaten/ g Fish				0.00	0.00	51.36	18.08		38.76
Silver Perch	Number of Fish Examined	1				1	1			
	Size Range (mm,TL)	130				110	72			
	Mean Wt (g) of Fish	6.22			6.22	2.96	0.90			1.93
	Wt (mg) Eaten/Fish	8.60			8.60	1.10	14.00			7.55
	Wt (mg) Eaten/ g Fish	1.38			1.38	0.37	15.56			7.96
MAY		Delta Sites				Coastal Sites				P value
		East	Channel	West	Mean	Keller	Chocolate	Powderhorn	Mean	
Spot	Number of Fish Examined	32	10	38		47	40	38		
	Size Range (mm,TL)	44-68	47-70	53-73		51-126	47-92	52-85		
	Mean Wt (g) of Fish	0.43	0.50	0.50	0.48	0.75	0.73	0.86		0.78
	Wt (mg) Eaten/Fish	0.79	1.26	1.25	1.10	3.18	2.56	22.21		9.32
	Wt (mg) Eaten/ g Fish	1.85	2.51	2.48	2.28	4.23	3.52	25.87		11.20
Pinfish	Number of Fish Examined	26	14	14		39	9	49		
	Size Range (mm,TL)	51-83	42-88	58-73		36-79	54-88	56-88		
	Mean Wt (g) of Fish	0.89	1.08	1.03	1.00	0.59	1.68	1.22		1.16
	Wt (mg) Eaten/Fish	8.48	8.91	17.79	11.73	7.87	19.19	8.80		11.95
	Wt (mg) Eaten/ g Fish	9.50	8.28	17.32	11.70	13.36	11.42	7.23		10.67
Atlantic Croaker	Number of Fish Examined	18	6	25		14	40	8		
	Size Range (mm,TL)	57-107	74-98	71-101		75-114	54-99	87-101		
	Mean Wt (g) of Fish	1.06	1.05	1.23	1.11	1.83	1.05	1.98		1.62
	Wt (mg) Eaten/Fish	8.38	8.20	6.30	7.63	9.03	18.32	4.44		10.60
	Wt (mg) Eaten/ g Fish	7.94	7.80	5.14	6.96	4.93	17.48	2.24		8.22

Southern Flounder	Number of Fish Examined	8	5		5	2	1			
	Size Range (mm,TL)	50-119	63-95		73-177	60-67	120			
	Mean Wt (g) of Fish	0.78	0.94	0.86	3.54	0.42	3.52	2.49		
	Wt (mg) Eaten/Fish	2.55	5.58	4.07	31.90	20.10	0.00	17.33	0.70	
	Wt (mg) Eaten/ g Fish	3.29	5.92	4.61	9.00	47.86	0.00	18.95	0.82	
Lizardfish	Number of Fish Examined						1			
	Size Range (mm,TL)						174			
	Mean Wt (g) of Fish						8.33	8.33		
	Wt (mg) Eaten/Fish						340.80	340.80	nt	
	Wt (mg) Eaten/ g Fish						40.91	40.91	nt	
Silver Perch	Number of Fish Examined	3	2		46	7	5			
	Size Range (mm,TL)	8-20	22-30		9-25	20-32	10-17			
	Mean Wt (g) of Fish	0.01	0.03	0.02	0.01	0.05	0.01	0.02		
	Wt (mg) Eaten/Fish	0.87	0.90	0.88	0.75	0.46	0.26	0.49	0.14	
	Wt (mg) Eaten/ g Fish	86.67	36.00	61.33	71.46	8.65	43.33	41.15	0.53	
AUGUST										
		Delta Sites				Coastal Sites				P value
		East	Channel	West	Mean	Keller	Chocolate	Powderhorn	Mean	
Spot	Number of Fish Examined	5	10	4		9		34		
	Size Range (mm,TL)	65-85	67-105	76-96		11-115		60-110		
	Mean Wt (g) of Fish	0.95	1.53	1.35	1.28	7.76		1.72	4.74	
	Wt (mg) Eaten/Fish	2.08	4.67	3.58	3.44	27.13		2.78	14.96	0.35
	Wt (mg) Eaten/ g Fish	2.20	3.05	2.65	2.63	3.50		1.62	2.56	0.83
Pinfish	Number of Fish Examined	5		11		5		16		
	Size Range (mm,TL)	82-96		71-120		65-100		70-118		
	Mean Wt (g) of Fish	2.74		2.94	2.84	2.14		3.06	2.60	
	Wt (mg) Eaten/Fish	20.84		24.30	22.57	13.88		29.02	21.45	0.79
	Wt (mg) Eaten/ g Fish	7.59		8.28	7.94	6.47		9.48	7.98	0.96
Atlantic Croaker	Number of Fish Examined	19	6	6		2				
	Size Range (mm,TL)	98-151	118-145	100-126		152-155				
	Mean Wt (g) of Fish	3.61	4.67	3.38	3.89	9.65			9.65	
	Wt (mg) Eaten/Fish	5.14	5.87	8.80	6.60	20.40			20.40	0.06
	Wt (mg) Eaten/ g Fish	1.42	1.26	2.61	1.76	2.12			2.12	0.67
Sand Seatrout	Number of Fish Examined	6	1					15		
	Size Range (mm,TL)	62-93	74					46-83		
	Mean Wt (g) of Fish	0.64	0.69		0.67			0.35	0.35	
	Wt (mg) Eaten/Fish	22.05	9.30		15.68			1.85	1.85	nt
	Wt (mg) Eaten/ g Fish	34.36	13.48		23.92			5.33	5.33	nt
Spotted Seatrout	Number of Fish Examined							3		
	Size Range (mm,TL)							13-99		
	Mean Wt (g) of Fish							0.57	0.57	
	Wt (mg) Eaten/Fish							13.00	13.00	nt
	Wt (mg) Eaten/ g Fish							22.81	22.81	nt
Southern Flounder	Number of Fish Examined	2	2			1		1		
	Size Range (mm,TL)	77-80	93-95			169		355		
	Mean Wt (g) of Fish	1.01	1.70		1.35	11.34		--	--	
	Wt (mg) Eaten/Fish	6.20	5.85		6.03	0.00		1798.60	899.33	nt
	Wt (mg) Eaten/ g Fish	6.17	3.44		4.81	0.00		--	--	nt
Silver Perch	Number of Fish Examined			1		1	1			
	Size Range (mm,TL)			74		175	68			
	Mean Wt (g) of Fish			0.94	0.94	18.48	0.62		9.55	
	Wt (mg) Eaten/Fish			7.50	7.50	0.00	4.10		2.05	nt
	Wt (mg) Eaten/ g Fish			7.98	7.98	0.00	6.61		3.31	nt

Table 4. Summary data on the weight of food present in the stomachs of selected species of fishes collected in Lavaca Bay. The fish species included in this analysis are listed in Table 3. Probability (P) values are from a t-test comparing means between delta and coastal sites. Both of the variables involving weight of food eaten were log transformed before statistical analysis.

OCTOBER	Delta Sites				Coastal Sites				P Value
	Channel	West	East	Mean	Keller	Powderhorn	Chocolate	Mean	
Number of Fish Examined	10	4	5	6.3	18	46	13	25.7	
Mean Wt (g) of Fish	4.20	2.62	1.51	2.78	4.25	2.90	2.55	3.23	0.65
Wt (mg) Eaten/ Fish	17.49	20.88	26.74	21.70	31.71	33.40	29.72	31.61	0.04
Wt (mg) Eaten/ g Fish	4.16	7.98	17.69	9.94	7.47	11.50	11.67	10.21	0.73
MAY									
Number of Fish Examined	35	79	87	67.0	151	102	98	117.0	
Mean Wt (g) of Fish	0.89	0.81	0.71	0.81	0.68	1.18	0.89	0.91	0.50
Wt (mg) Eaten/ Fish	6.13	5.77	4.83	5.57	5.14	16.20	10.73	10.69	0.18
Wt (mg) Eaten/ g Fish	6.89	7.10	6.76	6.92	7.60	13.77	12.04	11.14	0.07
AUGUST									
Number of Fish Examined	19	22	37	26.0	18	54	16	29.3	
Mean Wt (g) of Fish	2.50	2.68	2.51	2.56	7.20	2.02	0.36	3.20	0.78
Wt (mg) Eaten/ Fish	5.42	15.54	9.65	10.20	19.69	44.38	1.99	22.02	0.74
Wt (mg) Eaten/ g Fish	2.17	5.81	3.84	3.94	2.73	21.98	5.46	10.06	0.39

Table 4. Summary data on the weight of food present in the stomachs of selected species of fishes collected in Lavaca Bay. The fish species included in this analysis are listed in Table 3. Probability (P) values are from a t-test comparing means between delta and coastal sites. Both of the variables involving weight of food eaten were log transformed before statistical analysis.

OCTOBER	Delta Sites				Coastal Sites				P Value
	Channel	West	East	Mean	Keller	Powderhorn	Chocolate	Mean	
Number of Fish Examined	10	4	5	6.3	18	46	13	25.7	
Mean Wt (g) of Fish	4.20	2.62	1.51	2.78	4.25	2.90	2.55	3.23	0.65
Wt (mg) Eaten/ Fish	17.49	20.88	26.74	21.70	31.71	33.40	29.72	31.61	0.04
Wt (mg) Eaten/ g Fish	4.16	7.98	17.69	9.94	7.47	11.50	11.67	10.21	0.73
MAY									
Number of Fish Examined	35	79	87	67.0	151	102	98	117.0	
Mean Wt (g) of Fish	0.89	0.81	0.71	0.81	0.68	1.18	0.89	0.91	0.50
Wt (mg) Eaten/ Fish	6.13	5.77	4.83	5.57	5.14	16.20	10.73	10.69	0.18
Wt (mg) Eaten/ g Fish	6.89	7.10	6.76	6.92	7.60	13.77	12.04	11.14	0.07
AUGUST									
Number of Fish Examined	19	22	37	26.0	18	54	16	29.3	
Mean Wt (g) of Fish	2.50	2.68	2.51	2.56	7.20	2.02	0.36	3.20	0.78
Wt (mg) Eaten/ Fish	5.42	15.54	9.65	10.20	19.69	44.38	1.99	22.02	0.74
Wt (mg) Eaten/ g Fish	2.17	5.81	3.84	3.94	2.73	21.98	5.46	10.06	0.39

Table 5. Major fish predators on penaeid shrimp. Total dry weights are given for fish (g) and shrimp (mg).

Species	Fish Examined		Fish with Food		Fish Eating Shrimp		Shrimp Eaten		% of All Shrimp Eaten		% of Fish Eating Shrimp
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	by No.	by Wt.	
Pinfish	73	100.70	72	100.27	0	0.00	0	0.0	0.00	0.00	0.00
Atlantic croaker	85	203.48	82	197.58	0	0.00	0	0.0	0.00	0.00	0.00
Silver perch	7	7.24	6	7.22	1	0.94	1	1.1	12.50	2.92	14.29
Southern flounder	17	16.32	11	8.41	4	2.05	7	36.6	87.50	97.08	23.53
Sand seatrout	7	4.54	6	3.37	0	0.00	0	0.0	0.00	0.00	0.00
Spotted seatrout	9	7.23	9	7.23	0	0.00	0	0.0	0.00	0.00	0.00
Lizardfish	1	2.07	0	0.00	0	0.00	0	0.0	0.00	0.00	0.00
TOTALS	199	341.58	186	324.08	5	2.99	8	37.7			

COASTAL

Species	Fish Examined		Fish with Food		Fish Eating Shrimp		Shrimp Eaten		% of All Shrimp Eaten		% of Fish Eating Shrimp
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	by No.	by Wt.	
Pinfish	124	201.52	124	201.52	3	16.60	3	20.5	7.69	1.35	2.42
Atlantic croaker	68	107.40	65	103.34	1	0.73	1	8.4	2.56	0.55	1.47
Silver perch	62	23.84	46	5.11	2	0.90	2	3.2	5.13	0.21	3.23
Southern flounder	10	22.08	8	18.56	6	17.80	10	186.9	25.64	12.35	60.00
Sand seatrout	16	5.33	15	4.55	2	0.25	6	1.5	15.38	0.10	12.50
Spotted seatrout	14	11.33	11	11.29	3	6.30	4	297.0	10.26	19.62	21.43
Lizardfish	8	48.72	8	48.72	7	40.40	13	996.1	33.33	65.81	87.50
TOTALS	302	420.22	277	393.09	24	82.98	39	1513.6			

DELTA AND COASTAL SITES COMBINED

Species	Fish Examined		Fish with Food		Fish Eating Shrimp		Shrimp Eaten		% of All Shrimp Eaten		% of Fish Eating Shrimp
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	by No.	by Wt.	
Pinfish	197	302.22	196	301.79	3	16.60	3	20.5	6.38	1.32	1.52
Atl. croaker	153	310.88	147	300.92	1	0.73	1	8.4	2.13	0.54	0.65
Silver perch	69	31.08	52	12.33	3	1.84	3	4.3	6.38	0.28	4.35
S. flounder	27	38.40	19	26.97	10	19.85	17	223.5	36.17	14.41	37.04
Sand trout	23	9.87	21	7.92	2	0.25	6	1.5	12.77	0.10	8.70
Spotted trout	23	18.56	20	18.52	3	6.30	4	297.0	8.51	19.15	13.04
Lizardfish	9	50.79	8	48.72	7	40.40	13	996.1	27.66	64.21	77.78
TOTALS	501	761.80	463	717.17	29	85.97	47	1551.3			

1

Fish having eaten at least one penaeid shrimp.

2

Total shrimp eaten by each predator species.

3

Percent of fish examined having eaten at least one penaeid shrimp.

the lizardfish examined contained penaeid shrimp compared with 37% for southern flounder and 13% for spotted seatrout. Only a small percentage of the juvenile pinfish and Atlantic croaker were feeding on penaeids, but these fish were relatively abundant and together their populations were responsible for over 8% of the number of penaeids in fish stomachs.

DISCUSSION

A qualitative comparison of diets for individual fish species did not reveal any large differences between coastal and delta habitats. The most abundant species examined, spot and pinfish, exhibited very little habitat-related variability in their diets. The small apparent differences between coastal and delta sites in diets of other species can probably be attributed to the small sample size and to natural variability in prey selection.

Variability in the amount of food eaten was also high for individual species, but for all fish species combined there appeared to be consistently more food in the stomachs of fish collected at coastal sites compared with fish collected at delta sites. Habitat-related differences in the weight of food eaten by estuarine fishes may indicate differences in the availability of food and the relative quality of these areas for foraging. However, data on the weight of food eaten at different sites should be analyzed carefully, because diel changes in feeding combined with variability in collection times could bias the results. Our samples were generally collected between 0930 and 1700 hrs, and there did not appear to be any relationship between the time of collection and the weight of food eaten or any consistent confounding between the time of collection and the sample sites.

Major predators on the young of commercially-important penaeid shrimp were also identified from the diets of small estuarine fishes. Previous studies, on mostly large fish,

have shown that southern flounder, spotted seatrout, and red drum are frequent predators on shrimp in Texas estuaries (Pearson 1928, Gunter 1945, Miles 1949, Kemp 1950, Seagle 1969, Stokes 1977). Studies in salt marshes of Galveston Bay have shown that small juveniles of these fishes also prey upon penaeid shrimp (Zimmerman et. al. 1984; Minello et al. in press). In general the data collected in Lavaca Bay agree with previously reported results as to the importance of these fish as predators on shrimp. Only a few red drum were collected, however, and none of these had eaten any shrimp. In addition inshore lizardfish and sand seatrout ate a large percentage of the shrimp identified in stomachs. Most of these fish were collected at coastal sites, and all of the shrimp eaten by these two fish species were eaten at coastal sites. Divita et. al. (1983) and Sheridan and Trimm (1983) have reported these fish as predators on penaeid shrimp in nearshore and coastal waters.

There appeared to be a large difference in the overall number of shrimp eaten between areas in the bay, with 83% of the shrimp being eaten at coastal sites. This difference could be due to a number of factors including the presence of larger numbers of shrimp or fish predators in coastal areas. The difference may also be related, however, to differences in the protective nature of habitats related to their location in the bay. A comparison of crustacean densities between the coastal and delta sites revealed few obvious differences (Zimmerman and Minello 1987), and there were no significant differences in penaeid shrimp abundances between the areas. The four major predators on shrimp, southern flounder, inshore lizardfish, sand seatrout, and spotted seatrout were slightly more abundant at coastal sites, but the ratio of the number of shrimp eaten to the number of fish examined in this group was 0.7 at coastal sites in comparison with 0.2 at delta sites. These limited data, therefore, suggest that mortality rates for shrimp may be lower in the

upper portion of the bay, and reduced mortality in this area may not strictly be due to fewer fish predators. Differences in vegetation, substrate, and water turbidity may all be involved in altering predation rates on shrimp, and could be responsible for habitat-related differences in shrimp mortality.

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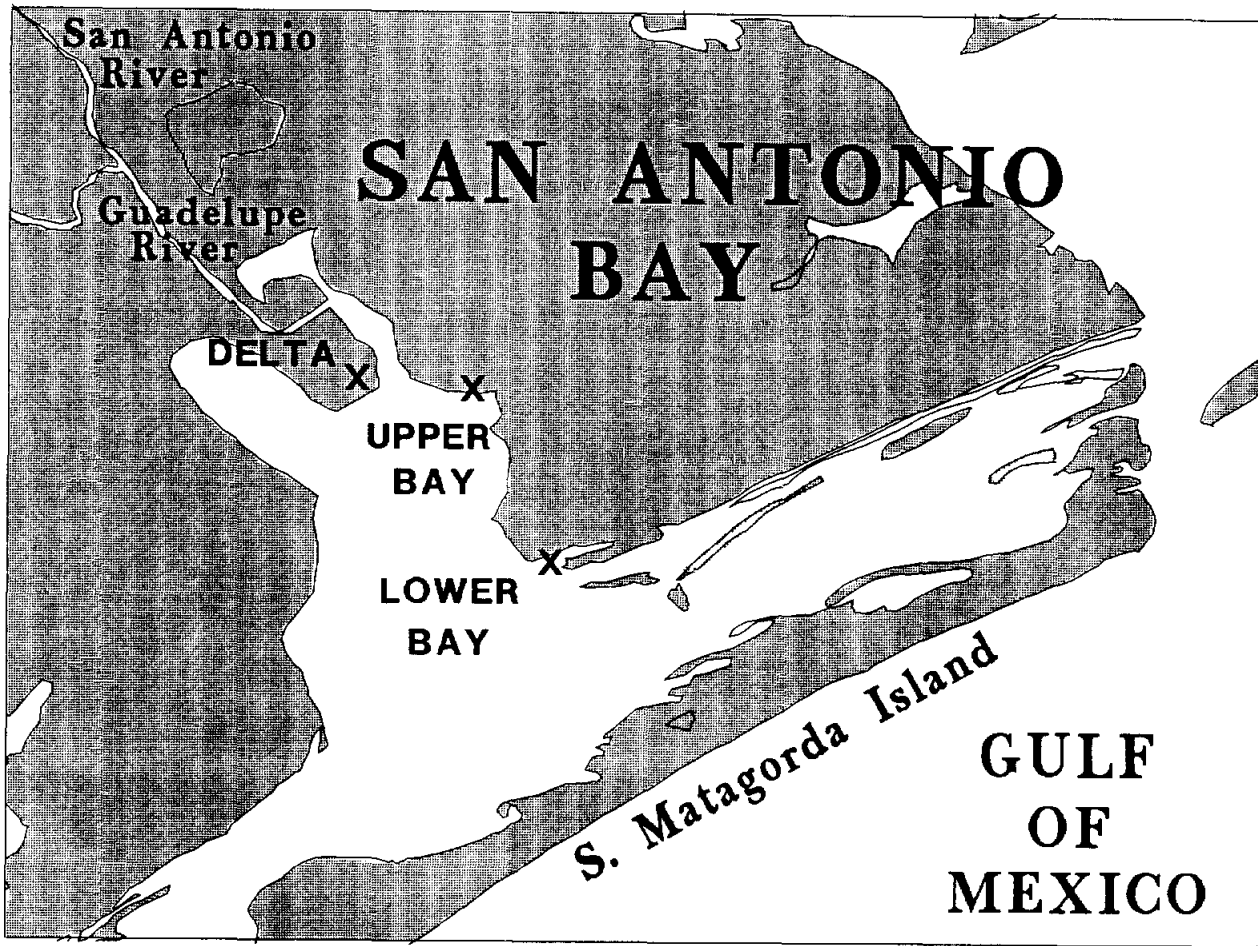
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Utilization of Nursery Habitats in San Antonio Bay in Relation to Annual Salinity Variation.



GALVESTON LABORATORY

SOUTHEAST FISHERIES CENTER

NATIONAL MARINE FISHERIES SERVICE

NATIONAL OCEANIC AND ATMOSPHERIC
ADMINISTRATION

DEPARTMENT OF COMMERCE

MARCH 1990



Utilization of Nursery Habitats in San Antonio Bay in Relation to Annual Salinity Variation.

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Final Report to:

The Texas Parks and Wildlife Department

And

The Texas Water Development Board

Austin, Texas

MARCH 1990

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ABSTRACT

The effect of salinity on utilization of shallow-water nursery habitats by aquatic fauna was assessed in San Antonio Bay, Texas. Juveniles of economically important shrimps, crabs, and fishes were the focal point, but the investigation also included all other small fishes and decapod crustaceans. Animal densities were measured using drop trap sampling at three locations representing the delta (Lucas Lake), the upper bay (mouth of the Victoria Barge Canal) and the lower bay (Lake Islands) areas. Nursery habitats sampled included marsh, submerged aquatic vegetation (SAV) and bare mud bottom. Sampling was conducted from the fall of 1986 through the spring of 1989, during spring and fall seasons.

Salinity in San Antonio Bay differed significantly between locations and years. A salinity gradient was always present, with highest salinities occurring in the lower bay, intermediate salinities in the upper bay, and lowest salinities at the delta. Across years, salinities changed considerably, ranging from 0.1 to 16 ppt at the delta, 1.1 to 21.5 ppt at the upper bay, and 12.1 to 34.5 ppt at the lower bay. These changes in salinity significantly affected the abundances of animals using shallow water habitats.

Overall, salinity level and animal abundances were directly related, and crustacean abundances were more affected by salinity than fish abundances. Also, salinity effects on abundances were greater among locations and over time than among habitats. The magnitude of effect varied among species, and although many residents were less affected than transient species, no particular pattern existed. Species effects contrasted from virtually no response to complete elimination within both resident and transient species.

Vegetated habitats, marsh and SAV, had significantly higher densities of fishes and decapod crustaceans than bare mud habitat. Species composition and abundances of individuals were lowest at the delta and became progressively higher toward the lower bay. Numerically dominant fishes were comprised of several resident species of cyprinodontids, gobiids and silversides, and transient juveniles of bay anchovy, pinfish and spot. Transient juveniles of game fishes occurred in comparatively low densities primarily in the lower bay and were evenly dis-

tributed across all habitats. The predominant decapod crustaceans collected during this study included three species of grass shrimps, a mud crab, blue crab, brown shrimp and white shrimp. Grass shrimps and mud crabs were residents, and penaeid shrimps and the blue crab were transient juveniles. Grass shrimps were significantly more abundant in the marsh than SAV habitat, while penaeid shrimps and blue crab were sometimes in greater abundance in SAV. Brown shrimp, white shrimp, pink shrimp and blue crab were equally abundant between the upper and lower bay, but decapods were scarce on the delta.

Although most aquatic species in San Antonio Bay were able to tolerate relatively low salinities of 2 to 5 ppt, abundances were negatively affected when salinities were persistently lowered. It is unlikely that such responses of the fauna were attributable to the immediate effects of salinity, but rather these responses were prompted by longer term habitat changes caused by the long lasting effects of low salinity.

INTRODUCTION

Background

Much information exists on the effects of salinity on individual estuarine species (Kinne 1967), and many surveys have been done relating distributions of aquatic animals to salinity patterns, but the issue of whether high or low freshwater inflows are beneficial or detrimental to estuarine productivity still remains obscure (see review by Turek et al. 1987). Gunter (1961 and 1967) and Deegan et al. (1986) suggested a direct relationship between productivity of estuarine species and freshwater inflow. Hoese (1960) and Copeland (1966) revealed that drought periods with low inflows and high salinities resulted in changes to community structure and reduced abundances of many common estuarine species. Others have shown that some estuarine species suffer mass mortalities due to the abrupt lowering of salinity (reviewed by Brongersma-Sanders 1957). In lower Texas bays such mortalities may occur when populations acclimated to euhaline conditions (30 to 36 ppt) are exposed to extreme lowering of salinities due to rainfall from tropical depressions. Molluscan bivalves suffered mass mortalities in Redfish Bay after Hurricane Beulah in 1967, when salinities were reduced from 30 ppt to less than 1 ppt within a week (Zimmerman and Chaney 1969). Hedgpeth (1953) reported mortalities after a similar event in Nueces Bay. Moreover, low salinity limitations are known for many estuarine species. Oyster populations are restricted 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). Salinities above 7 ppt are required for spawning of oysters (Loosanoff 1953) and spat grow best in salinities above 12 ppt (Davis and Calabrese 1964). Even among euryhaline species such as red drum, white shrimp,

brown shrimp and blue crab, low salinities that do not restrict juveniles and adults can be limiting to larvae and postlarvae (Costlow and Bookhout 1959; Holt et al. 1981; Zein-Eldin 1989 unpubl.). Among crustaceans, many estuarine species are relatively intolerant to oligohaline conditions (Green 1968; Remane and Schlieper 1958) while others, such as juvenile blue crabs, are quite tolerant (Gifford 1962; Tagatz 1971). Among annelid worms, some capitellids and nereids accommodate extreme changes in salinity with little difficulty (Hammen 1980). Still, the majority of marine species do not easily acclimate to brackish or very low salinity conditions.

For those marine species that have estuarine dependent juvenile stages the question of salinity effect on productivity is paramount. Of special interest are economically important estuarine dependent penaeid shrimps, portunid crabs and game fishes that use specific types of estuarine nursery habitats. For example, juveniles of these species have been associated with estuarine marshes ranging from oligohaline (Rozas and Hackney 1983, 1984; Rogers et al. 1984; Rozas and Odum 1987) to saline (Weinstein 1979; Zimmerman and Minello 1984; Hettler 1989). But comparative utilization of such habitats under changing salinity conditions is not well understood and, as indicated above, conflicting views have been expressed. The problem arises, for the most part, from the apparent lack of long term well focused studies. Usually, field surveys and laboratory experiments are relatively near term (within months or years, rarely over years) and conclusions become short sighted and conflictive.

In order to address both near term and long term effects of salinity change on use of nursery habitats by estuarine organisms the following study was undertaken. As far as we are aware, this is the first study

to examine annual variability in utilization of nursery habitats in Texas bays.

Purpose and hypothesis.

The purpose of this investigation was to compare utilization of emergent marsh, submerged aquatic vegetation (SAV), and bare nonvegetated mud bottom habitats by demersal estuarine species over years and under differing salinity conditions. This was accomplished by measuring densities of fishes and decapod crustaceans in nursery habitats along a salinity gradient in a small bay for a four year period. The central hypothesis was that utilization of nursery habitats by estuarine aquatic fauna is related to long term changes in salinity. The null hypothesis was that faunal densities in nursery habitats would not differ between years with significant differences in salinity.

METHODS

Study Sites.

The study was conducted in San Antonio Bay, a shallow body of water on the middle of the Texas coast in the western Gulf of Mexico (Fig. 1). The bay was separated from Gulf of Mexico waters by a barrier island (south Matagorda Island). Water exchange with the Gulf was principally through two large tidal passes via other bays, Espiritu Santo Bay through Cavallo Pass to the north, and Aransas Bay through Aransas Pass to the south. Cedar Bayou, a minor pass also provided some Gulf water exchange with the bay through the barrier island. However this pass was open only after October 1988 during the latter part of this study. Oyster reefs, salt marshes, delta marshes, seagrasses as well as other submerged vascular rooted vegetation (SAV),

bare sand and bare mud bottoms were the prominent habitats in the bay. Water depths were generally less than 2 meters in the center of the bay and less than 1 meter in most of the area around the perimeter. Three sampling sites along the salinity gradient were selected: in the lower bay (Lake Islands), upper bay (Mouth of the Victoria Barge Canal) and delta (Lucas Lake). Lower bay habitats at the Lake Islands site consisted of intertidal smooth cordgrass (*Spartina alterniflora*), subtidal shoal grass (*Halodule wrightii*), widgeon grass (*Ruppia maritima*) and subtidal bare mud habitat. Upper bay habitats near the mouth of the Victoria Barge Canal were the same as in the lower bay, but SAV was sparse (sometimes absent), and the bare habitat was sand. The delta had the most variable habitats. Delta marsh at the Lucas Lake site was comprised of mixed subdominants, including smooth cordgrass, bulrush (*Scirpus* spp.) and cattails (*Typha* sp.). Submerged aquatic vegetation was rarely present, but when it was, plants ranged from sparse widgeon grass to freshwater naiads and filamentous green algal species. The bare habitat which usually predominated subtidally was soft muddy ooze.

Field Procedures.

To quantify habitat-related abundances of decapod crustaceans and fishes, sets of four drop-trap samples (Zimmerman et al. 1984), were taken in emergent marsh, submerged aquatic vegetation (SAV) and nonvegetated (bare mud or sand) habitats within each site location during Spring (April-May) and fall seasons (September-October) from 1986 through 1989. The drop-trap sampling method, as described by Zimmerman et al. (1984), was highly effective for measuring densities of decapod crustaceans and small fishes in habitats such as marshes and seagrasses, where trawls and seines are ineffective. Drop trap sampling also

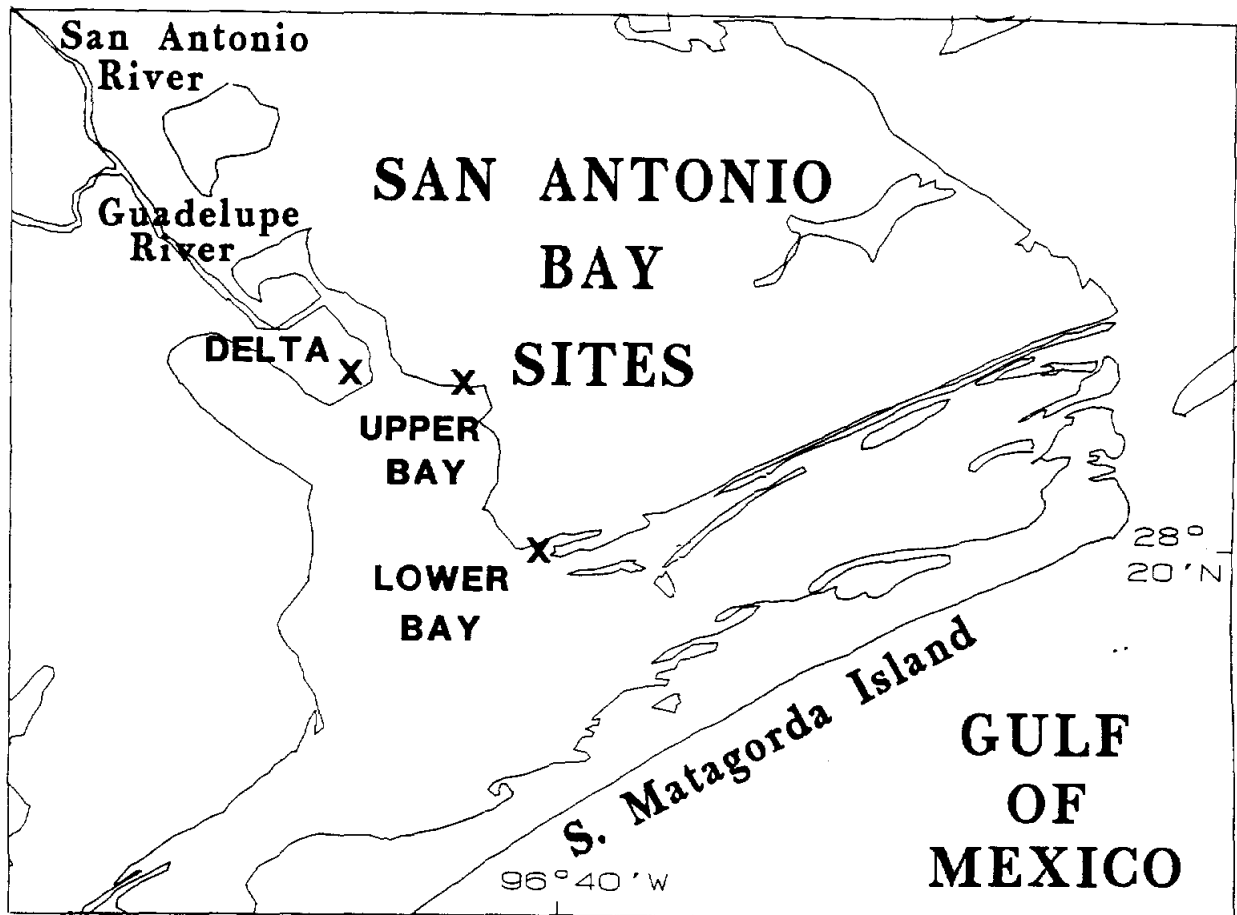


Figure 1. Sampling sites in San Antonio Bay, Texas.

improved on conventional methods (seines and trawls) by quantifying the densities of animals (individuals/unit area) rather than estimating relative abundances. This method employed a large cylindrical sampler (1.8 m dia.), which was dropped from a boom affixed to a small boat to entrap animals in a 2.6 m² area. In marsh samples, all emergent vegetation was clipped and removed for laboratory processing. Most of the fauna were removed with dip nets while water was pumped from the sampler into a 1 mm sq. mesh plankton net. After the sampler was drained, animals remaining on the bottom were picked up by hand. Faunal samples were preserved in the field with 10% Formalin in seawater containing Rose Bengal stain, and then taken to the laboratory for processing.

Laboratory Procedures.

In the laboratory, fishes and crustaceans were sorted to species (using standard taxonomic guides for the Texas Coast), measured and counted. Fish were counted within 10 mm size intervals (1 to 10, 11 to 20, ...etc.) and decapod crustaceans were counted within 5 mm size intervals (1 to 5, 6 to 10, 11 to 15, ...etc). Marsh plants were identified and wet weights (kg) were taken upon returning to the laboratory. Afterwards, plants were air dried for two months and weighed again, dry (kg). In addition, the number of culms in each sample were counted to calculate plant stem densities. The data were written on preprinted standard forms and transcribed to microcomputer files using DBASE III+. Faunal samples were stored in 5% Formalin or 70%

ETOH to be kept for at least 5 years from the date of collection. All field sheets, laboratory data entry forms and electronic data files will be kept at the NMFS Galveston Laboratory for at least 8 years.

Analytical Procedures.

The main analysis was performed using a three-way balanced design analysis of variance (ANOVA) with year, location, and habitat as factors. Only marsh and bare bottom habitats were compared in this analysis since they were always present. Locations were the delta, upper bay and lower bay. Years were 1986, 1987, and 1988 for the fall season, and 1987, 1988, and 1989 for spring season. Thus, each season was analyzed separately. A logarithmic transformation ($\log_{10} x + 1$) was used to correct for heteroscedasticity. Probabilities less than 0.05 were considered significant. The two-way interactions were plotted, and the interaction means and main-effect means were compared using Fisher's LSD procedure (Milliken and Johnson 1984). Limited planned comparisons using this procedure should have a Type I error of 0.05 (comparisonwise error). This protected LSD reduces experimentwise error because comparisons of means are not made without a significant F in the ANOVA. Experimentwise error does increase, however, above the comparisonwise error of 0.05, and care should be taken in making many unplanned comparisons using this analysis. The effect of SAV was secondarily analyzed for the lower bay location where SAV was always present using a two-way ANOVA with habitat and year as factors. As before, seasons were analyzed separately. The main observations were faunal densities among groups of animals, including all fishes, all decapod crustaceans, all game fishes (spotted seatrout, southern flounder, red drum), bait fishes (bay anchovy, pinfish, gulf

menhaden, striped mullet), as well as on selected numerically dominant families (Gobiidae, Cyprinodontidae, Palaemonidae, Penaeidae) and species (brown shrimp, white shrimp, pink shrimp, blue crab). Untransformed means and standard errors of densities were tabulated by species, year, season, location, and habitat (Appendices). All original data were entered in DBASE III+ and were stored on standard 5 1/2 inch microcomputer magnetic disks.

RESULTS

Physical Variation.

The salinity gradient ranged from oligohaline to mesohaline in the delta and upper bay, and from mesohaline to euhaline in the lower bay (Fig. 2). Salinities were not different between habitats within locations in the spring or fall seasons, but significant interactions occurred between years and locations in both seasons (Table 1). However a discernable pattern was apparent. Salinities progressively declined from moderately high levels in fall of 1985 to very low levels by the spring and fall of 1987. This was followed by a return to relatively high salinities by the spring of 1989. Salinities in the lower bay depicted this progression well since all years were significantly different within seasons (Fig. 3). The persistence of lowered salinities (oligohaline) was demonstrated in values from the fall 1986 and 1987 which did not differ within upper bay and delta locations. By the fall of 1988, salinities at both locations had become significantly higher.

Temperatures did not differ between habitats within locations in the spring or fall seasons, and, like salinities, significant interaction occurred between years and locations (Table 1). There was a weak pattern of

SALINITY

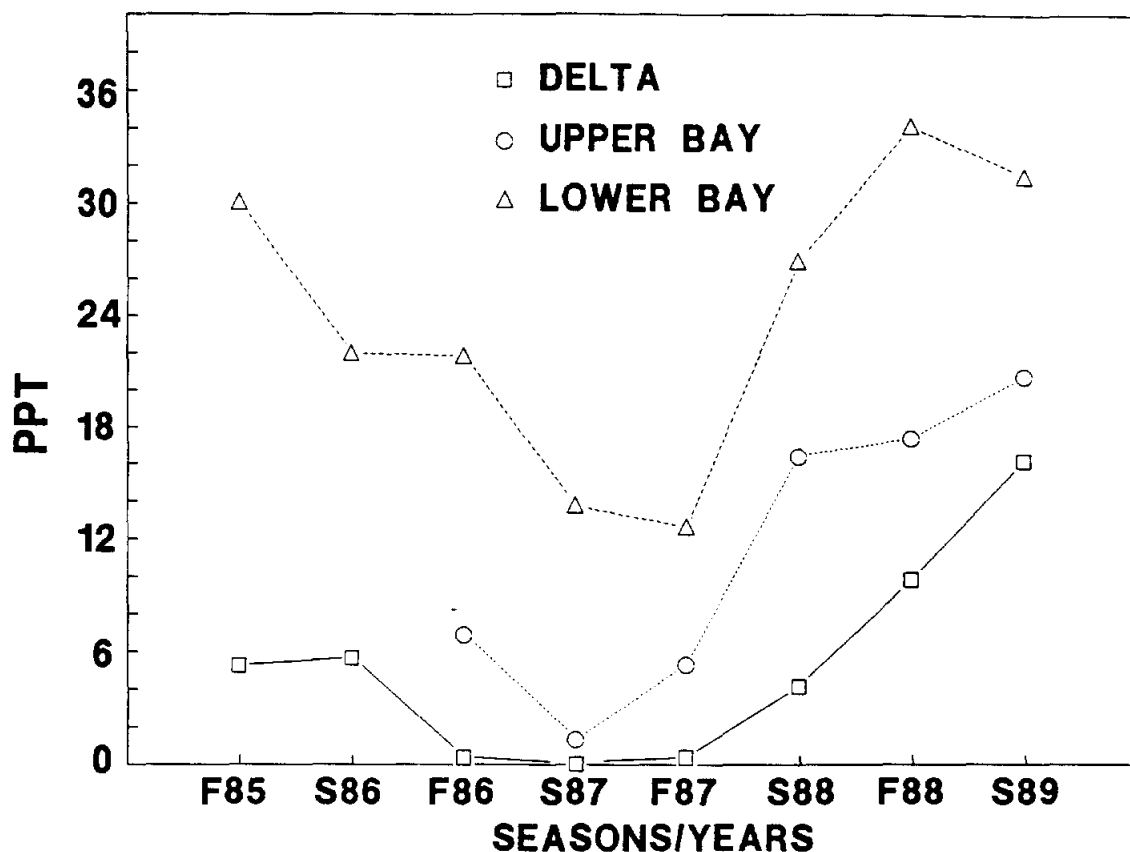


FIGURE 2. Salinities in San Antonio Bay, Texas during drop trap sampling from fall 1985 to spring 1989.

TABLE 1. SUMMARY OF 3-WAY ANOVA (YEAR x LOCATION x HABITAT) ANALYSES OF PHYSICAL MEASUREMENTS IN SAN ANTONIO BAY. FALL YEARS = 1986, 1987, 1988. SPRING YEARS = 1987, 1988, 1989. LOCATIONS = DELTA, UPPER BAY, LOWER BAY. HABITATS = SALT MARSH, BARE BOTTOM. NUMBERS IN BOLD PRINT INDICATE SIGNIFICANT P VALUE.

PARAMETERS	SEASON	FACTORS			INTERACTIONS			
		YEAR	SITE	HABITAT	YEAR SITE	YEAR HABITAT	SITE HABITAT	YEAR SITE HABITAT
Temperature	Sp	0.0001	0.0001	0.2400	0.0247	0.8794	0.1934	0.8769
	F	0.0001	0.0001	0.9568	0.0018	0.7384	0.8375	0.9294
Salinity	Sp	0.0001	0.0001	0.2217	0.0001	0.9225	0.1847	0.7062
	F	0.0001	0.0001	0.9006	0.0001	0.9921	0.9469	0.7458
Dissolved Oxygen	Sp	0.0001	0.2122	0.1069	0.0002	0.5588	0.3224	0.1922
	F	0.0001	0.0918	0.8569	0.0305	0.0590	0.9679	0.5281
Turbidity	Sp	0.0001	0.0001	0.3031	0.0001	0.3296	0.9922	0.4018
	F	0.0790	0.0001	0.1103	0.2999	0.0133	0.9173	0.0044
Water Depth	Sp	0.5069	0.8083	0.0001	0.1993	0.6463	0.0577	0.7641
	F	0.0001	0.0029	0.0001	0.0026	0.2395	0.1178	0.8951

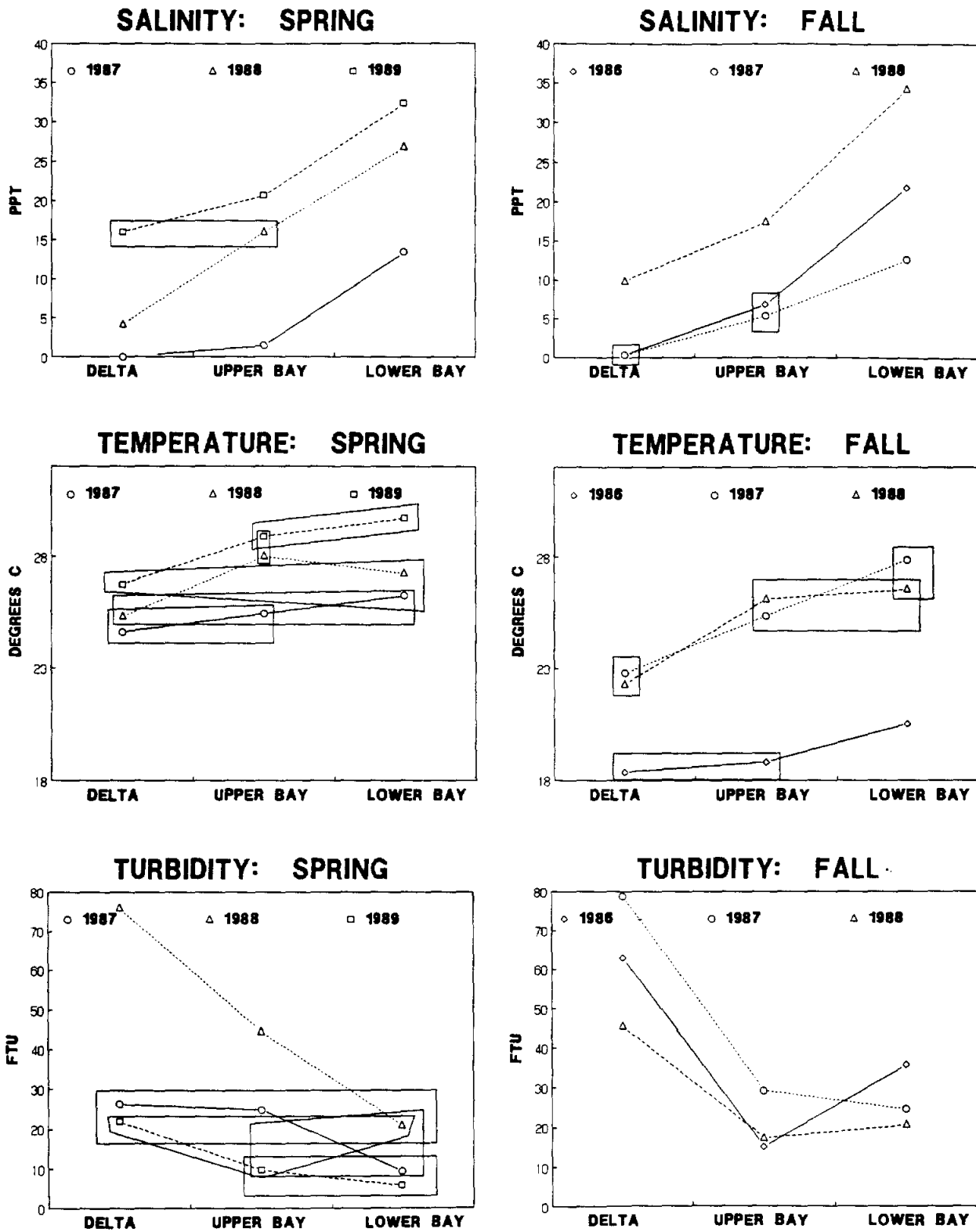


FIGURE 3. Interactions of salinity, temperature and turbidity among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Means within boxes are not significantly different (Fisher's protected LSD-test, $P > 0.05$). If there are no boxes, the ANOVA P for that interaction was not significant at the 0.05 level.

higher 1989 spring temperatures and lower 1987 spring temperatures (Fig. 3) which directly correlated with salinity. In addition, the fall of 1986 was significantly cooler than 1987 or 1988 at all locations. The range of mean temperatures (by location and year) was from 24.6 to 29.8 °C for the spring and from 18.4 to 27.9 °C for the fall.

Dissolved oxygen (DO) and turbidity also did not differ between habitats, but interactions occurred in levels of values between years and locations (Table 1). Mean DO was almost always near saturation or well above, ranging from 5.7 to 10.7 ppm in the spring, and 6.8 to 15.3 ppm in the fall. Mean turbidities ranged from 6 to 76.1 FTUs in the spring, and 15.3 to 78.8 FTUs in the fall. Turbidity was significantly higher at the delta and upper bay in the spring of 1986 than during other years (Fig. 3). This coincided with low salinity and low temperature, reflecting high freshwater inflow. The delta also exhibited significantly higher turbidities than at other locations during the fall of each year.

Water was significantly deeper in bare subtidal habitat than in the marsh, at all locations, during both the spring and fall seasons of each year (Table 1). However, significant interactions among water depths did occur between year and location during the fall season.

Abundance Patterns.

Abundances of estuarine macrofauna (based on densities) were compared between marsh and bare bottom habitats at all three locations in San Antonio Bay from the fall of 1986 to the spring of 1989. The spring and fall seasons were analyzed separately, then compared. SAV habitat was not included here because it was not present at all locations, but it is analyzed in the next section (see Effect of SAV).

All Fishes: Fish abundances were significantly higher in salt marsh compared to bare bottom habitat at all locations during both the spring and fall seasons (Table 2; Fig. 4). Abundances were lower during the spring of 1987, and similar during the fall of all years. In general, fish abundances were similar along the gradient from the delta to the lower bay (Fig. 5).

Abundant Fishes: Members of Cypriodontidae, Gobiidae, silversides, Gulf menhaden and the bay anchovy were the most abundant fishes in the bay (Appendix I). Cypriodontidae, including Gulf and rain-water killifishes and sheepshead minnows were always significantly more abundant in marsh versus bare bottom (Table 2). Gobiidae, mostly the naked goby, were variable in abundances with significant interactions between year and location, year and habitat, and location and habitat (Fig. 6 and 7). Interestingly, spring abundances of gobies in the upper and lower bay were significantly higher during 1989 than during 1987 or 1988. This caused overall fish densities in the spring of 1987 to be significantly lower than in the spring of 1989 (Fig. 7). The fall pattern followed the spring pattern with significantly lower densities of gobies in marsh habitat during 1987 than 1986 or 1988. Bay anchovies also had various interactions between factors (Table 2). Unlike other fishes, Gulf menhaden and bay anchovy abundances increased in response to lowered salinities. Significantly higher anchovy abundances occurred in the upper bay during the fall of 1987 and spring of 1988 (Fig. 8 and 9). Gulf menhaden abundances increased significantly at the delta in the spring seasons of 1987 and 1988 (Fig 10 and 11).

TABLE 2: SUMMARY OF 3-WAY ANOVA (YAR x LOCATION x HABITAT) ANALYSES OF FAUNAL DENSITIES IN SAN ANTONIO BAY. FALL YEARS = 1986, 1987, 1988. SPRING YEARS = 1987, 1988, 1989. LOCATIONS = DELTA, UPPER BAY, LOWER BAY. HABITATS = SALT MARSH, BARE BOTTOM. NUMBERS IN BOLD PRINT INDICATE SIGNIFICANT P VALUES.

	FACTORS				INTERACTIONS			
	SEASON	YEAR	SITE	HABITAT	YEAR SITE	YEAR HABITAT	SITE HABITAT	YEAR SITE HABITAT
All Fishes	Sp	0.0001	0.6812	0.0132	0.0001	0.2559	0.0024	0.0626
	F	0.3603	0.3786	0.0001	0.0167	0.3486	0.4847	0.4388
Cyprinodontidae	Sp	0.0988	0.0583	0.0003	0.4810	0.0988	0.0583	0.4810
	F	0.1759	0.7129	0.0001	0.0925	0.5794	0.1156	0.2109
Gobiidae	Sp	0.0001	0.2227	0.2157	0.0916	0.0002	0.9018	0.2036
	F	0.0001	0.0508	0.0001	0.0018	0.0308	0.6383	0.1989
<i>Anchoa mitchilli</i>	Sp	0.0200	0.0001	0.0731	0.0401	0.7105	0.1506	0.5405
	F	0.0146	0.6411	0.0002	0.0194	0.0111	0.4471	0.0291
Game Fishes	Sp	0.1594	0.9050	0.5298	0.4157	0.5010	0.5010	0.0348
	F	0.2255	0.0597	0.3302	0.0316	0.4282	0.1319	0.7789
All Crustaceans	Sp	0.0002	0.0001	0.0001	0.0060	0.1451	0.0040	0.1102
	F	0.0001	0.0001	0.0001	0.0046	0.0001	0.6340	0.0179
Penaeidae	Sp	0.0001	0.0001	0.0001	0.0001	0.2317	0.3700	0.0076
	F	0.0001	0.0001	0.5744	0.0131	0.9576	0.4216	0.1493
<i>Callinectes sapidus</i>	Sp	0.0001	0.3072	0.0001	0.0001	0.0032	0.5700	0.5333
	F	0.0001	0.1546	0.0001	0.0637	0.0341	0.0083	0.0050
<i>Palaemonetes pugio</i>	Sp	0.0001	0.0007	0.0001	0.0037	0.2190	0.1530	0.0073
	F	0.0001	0.0017	0.0001	0.0008	0.0001	0.0003	0.0098
<i>Palaemonetes vulgaris</i>	Sp	0.7416	0.7416	0.1273	0.2636	0.7416	0.7416	0.2636
	F	0.6093	0.6093	0.1630	0.3010	0.6093	0.6093	0.3010
<i>Penaeus aztecus</i>	Sp	0.0001	0.0001	0.0001	0.0008	0.0739	0.0072	0.0023
	F	0.0001	0.0029	0.0190	0.0444	0.4022	0.7427	0.7868
<i>Penaeus duorarum</i>	Sp	0.0228	0.0228	0.5208	0.0021	0.3557	0.3557	0.5718
	F	0.2245	0.2748	1.0000	0.6208	0.1055	0.9782	0.5616
<i>Penaeus setiferus</i>	Sp	0.5331	0.6968	0.3697	0.3292	0.4466	0.3432	0.3703
	F	0.0001	0.0002	0.0001	0.0420	0.0103	0.0001	0.0008

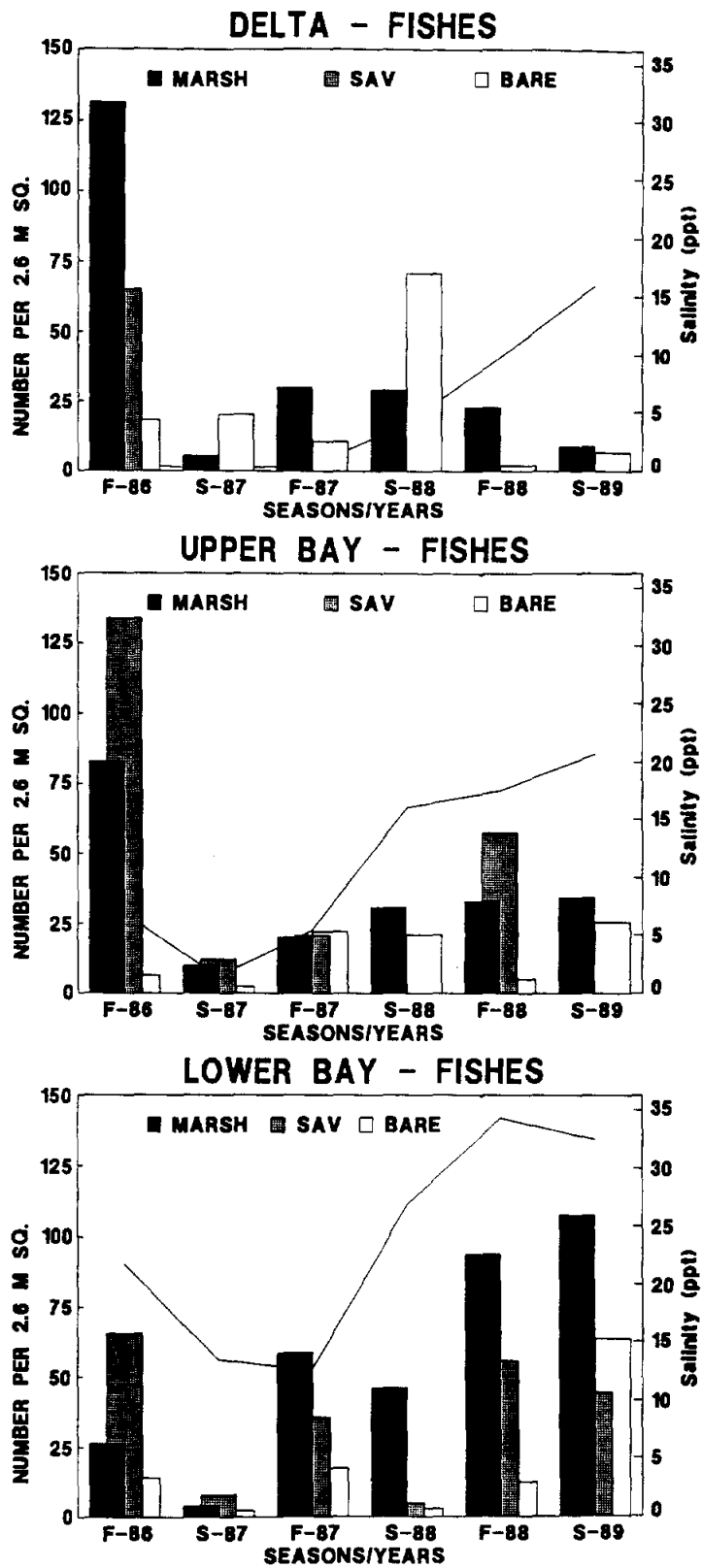


FIGURE 4. Annual variation in densities of fishes among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

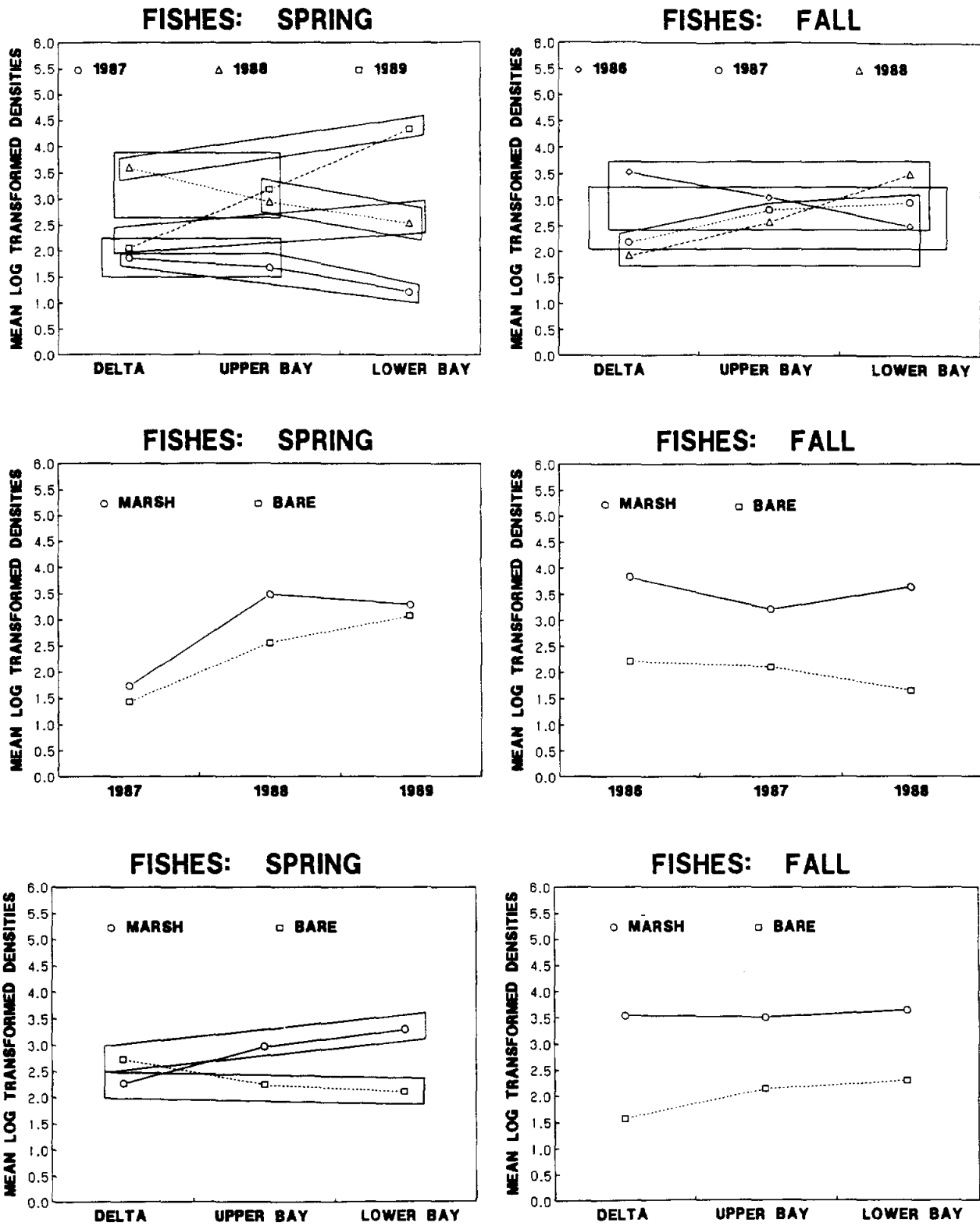


FIGURE 5. Interactions of fish densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

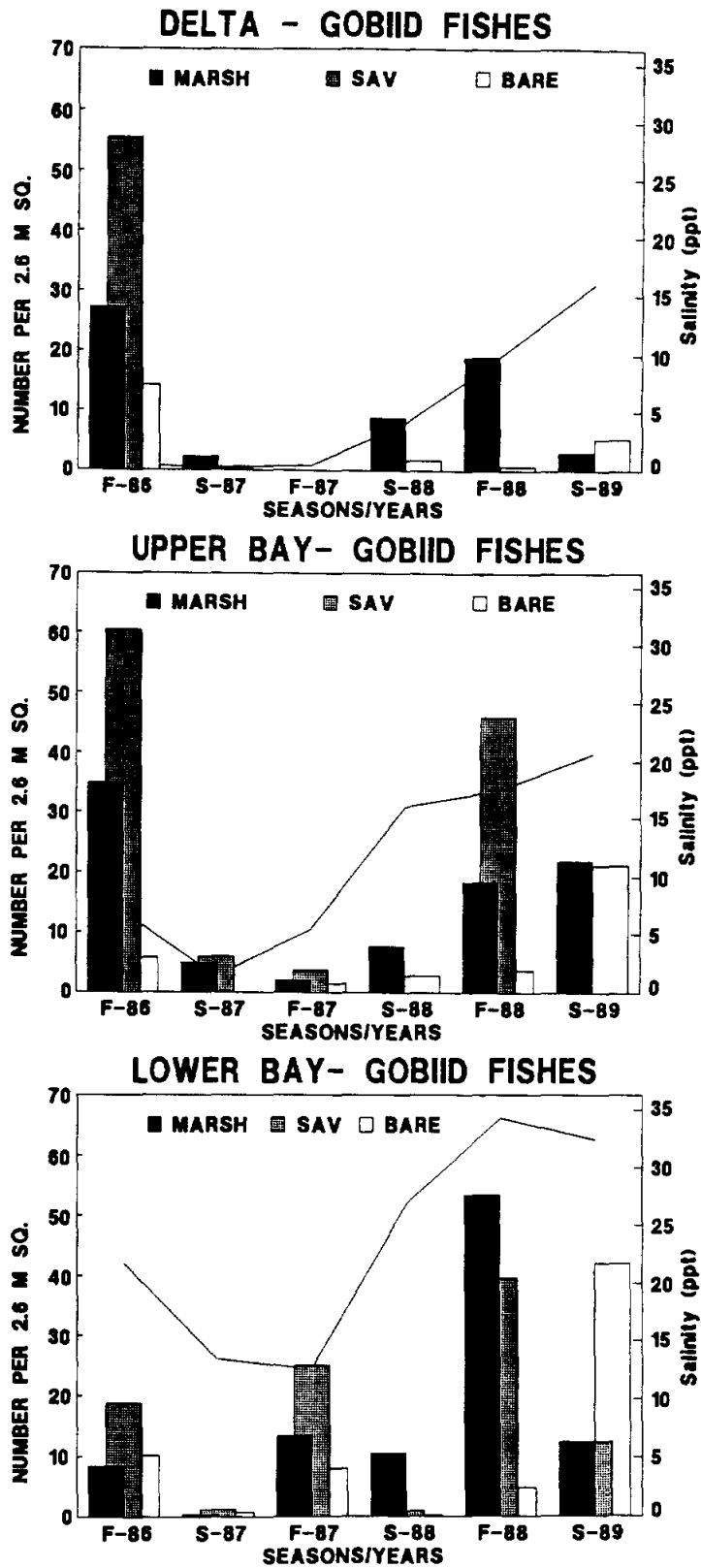


FIGURE 6. Annual variation in densities of gobiid fishes among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

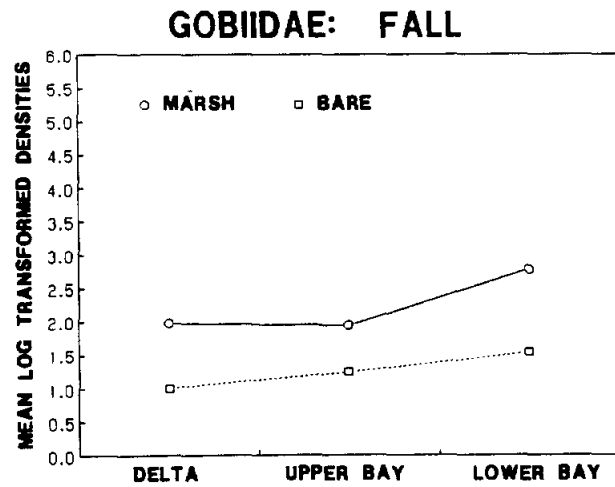
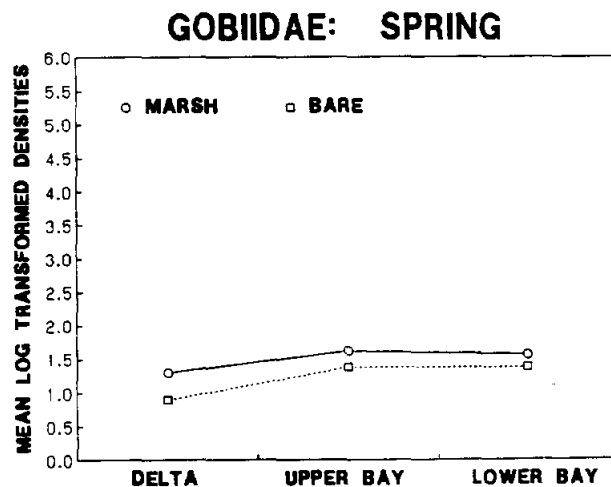
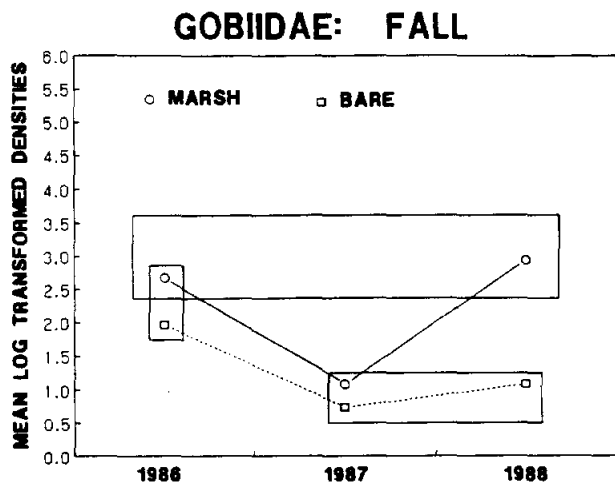
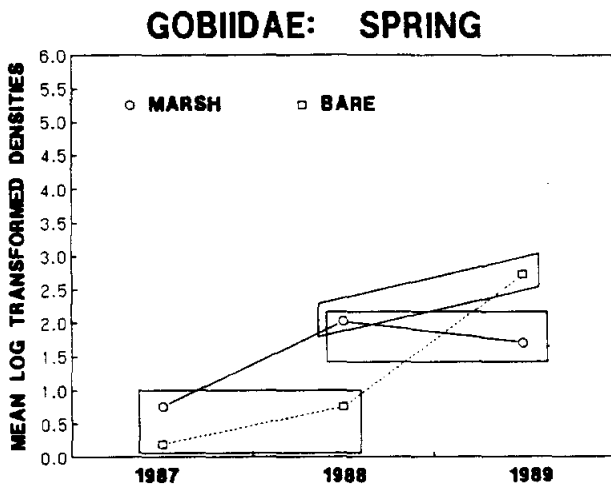
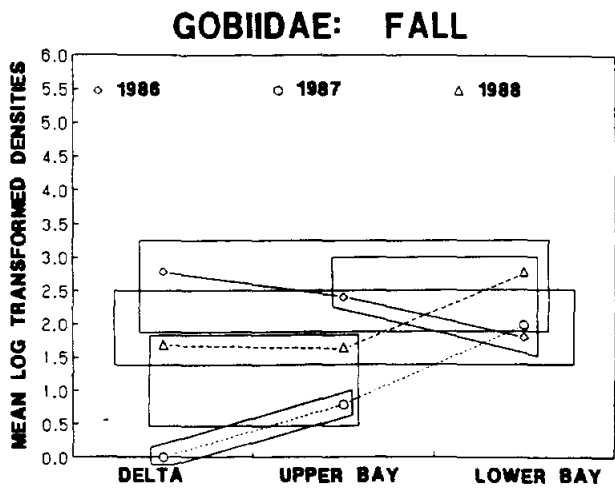
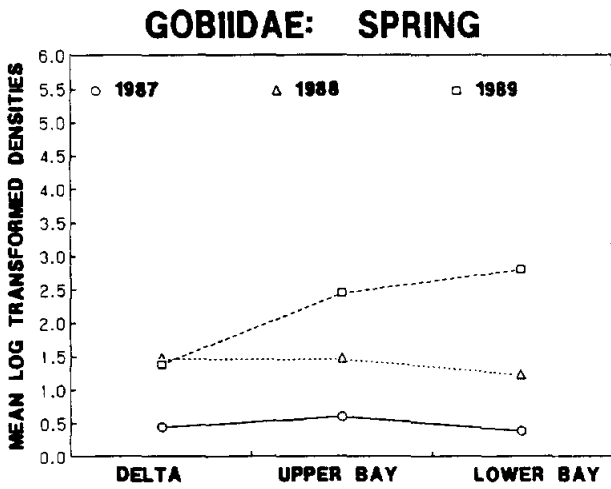


FIGURE 7. Interactions of gobiid fish densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

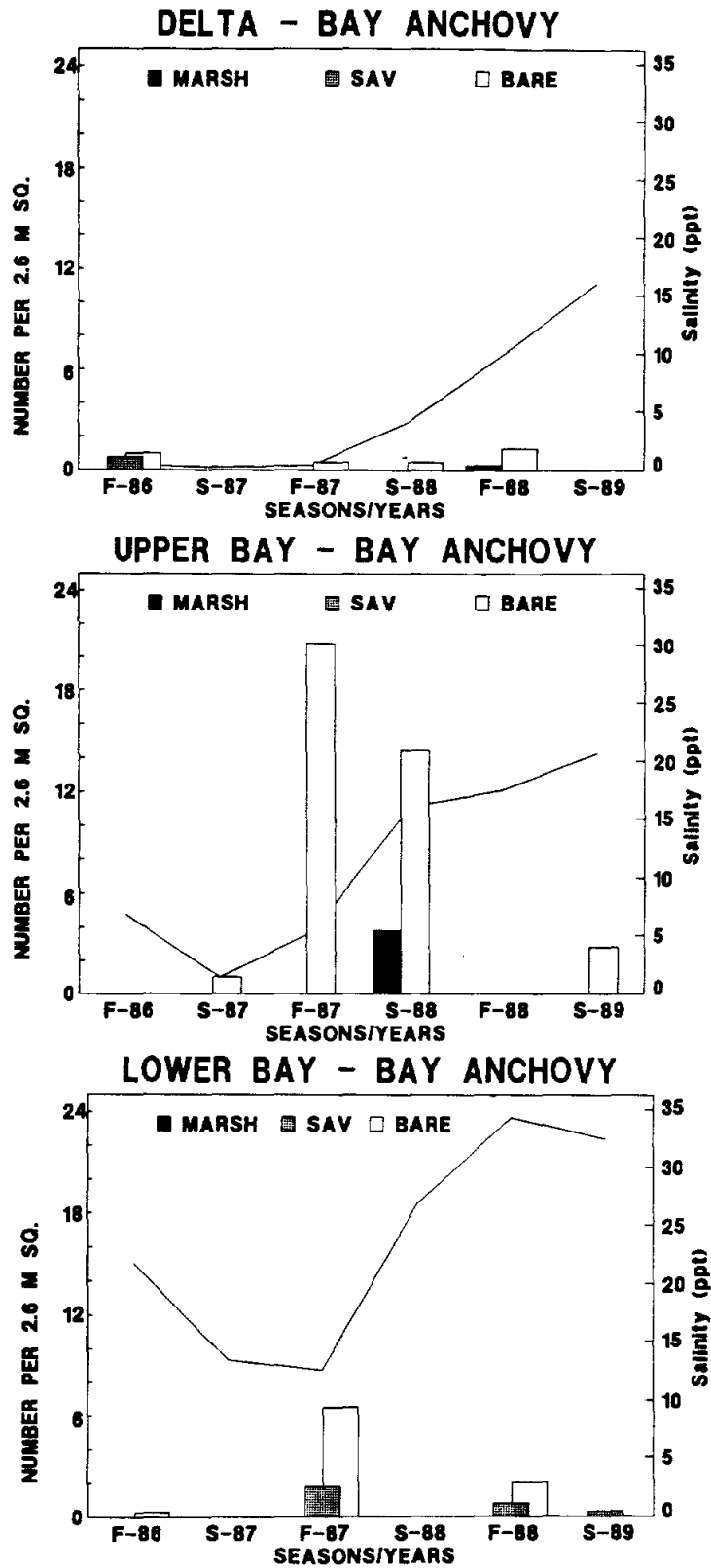


FIGURE 8. Annual variation in densities of bay anchovies among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

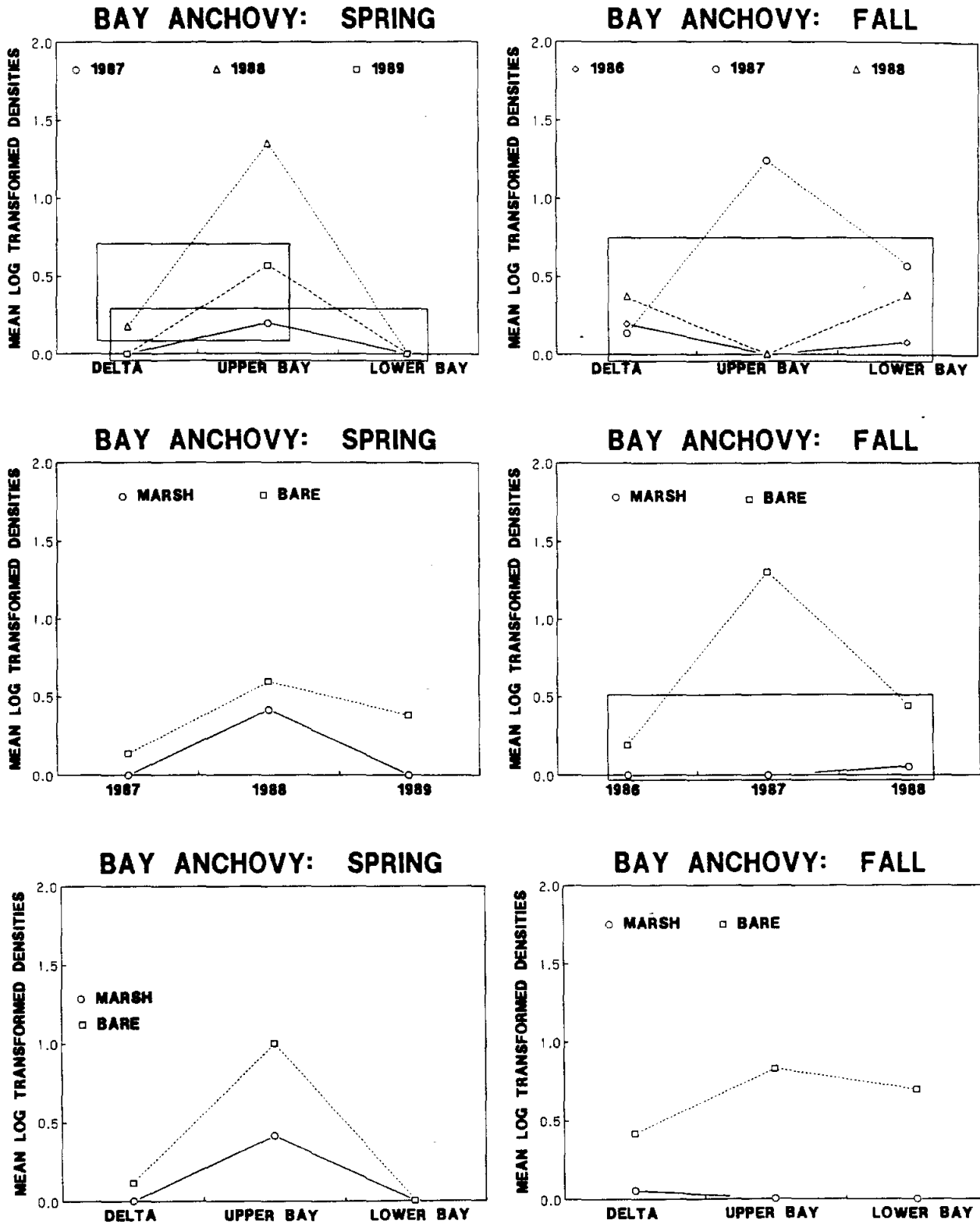


FIGURE 9. Interactions of bay anchovy densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

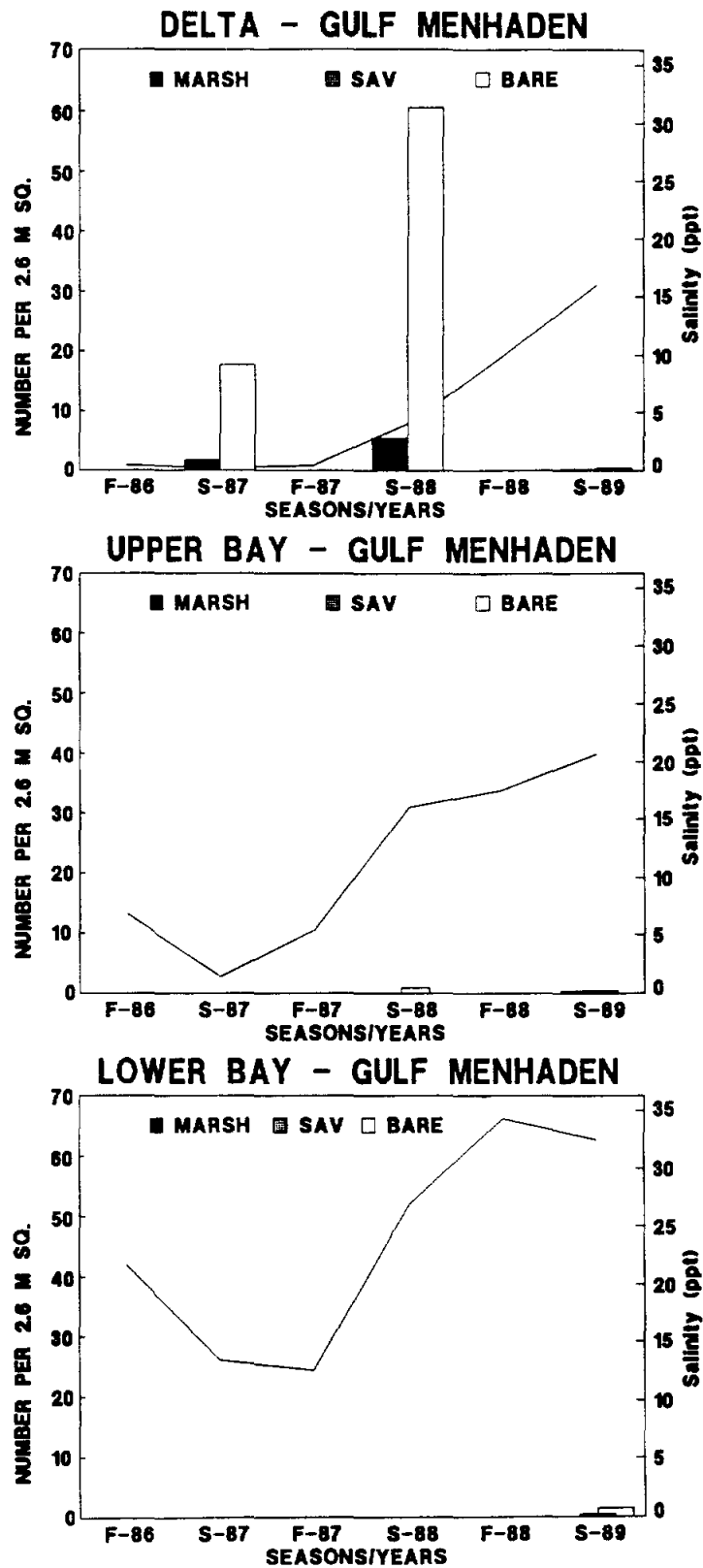


FIGURE 10. Annual variation in densities of Gulf menhaden among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

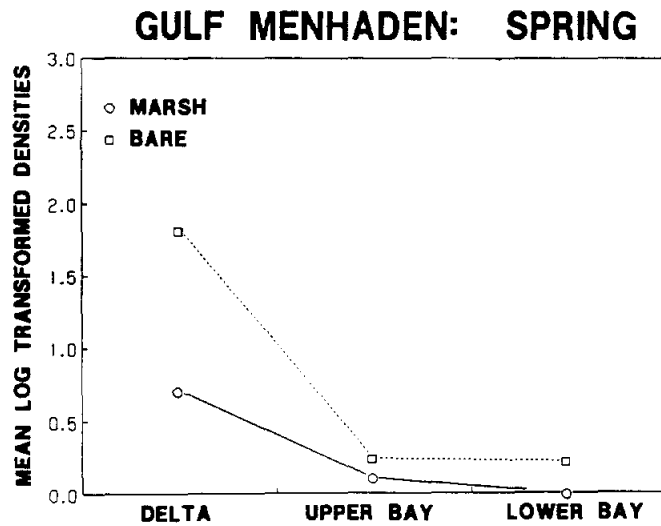
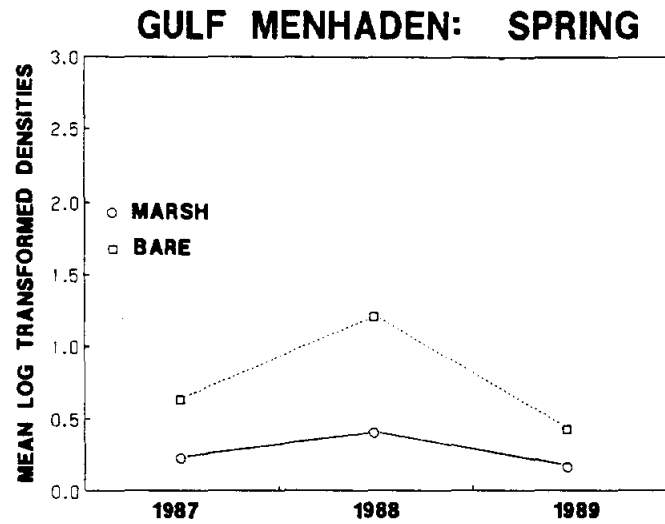
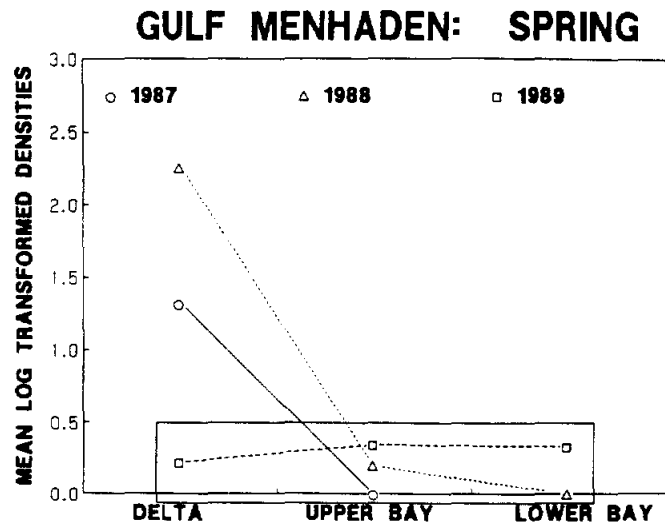


FIGURE 11. Interactions of Gulf menhaden densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

All Decapod Crustaceans: Decapod crustaceans were clearly most abundant in marsh habitat (Fig. 12), but significant interactions among factors occurred (Table 2). During the spring, marsh densities were always significantly higher than bare bottom densities. In 1987, overall decapod densities were significantly lower at the delta than the upper or lower bay. In 1989, densities in the lower bay tended to be higher than those of the delta and upper bay, but not significantly (Fig. 13). Fall densities repeated the spring patterns, except that decapod densities in marsh habitat during the fall of 1987 were exceedingly depressed (corresponding to low salinities).

Grass Shrimps: The grass shrimp *Palaemonetes pugio*, was the most abundant shrimp in the bay, and not surprisingly the abundance patterns were the same as those of all decapods (Table 2; Fig. 14). Marsh densities in the spring and fall were always significantly higher; overall, lowest densities occurred at the delta and upper bay (Fig. 15). Another species, *Palaemonetes vulgaris*, was present at low densities throughout marsh and bare bottom habitats, but was not different in abundance between them (Table 2).

All Penaeid Shrimps: As a group, penaeid shrimps were significantly more dense in the marsh than on bare bottom during the spring, but not different between habitats during the fall (Table 2; Fig. 16). Interactions occurred between years and locations. Lowest overall densities occurred in the spring of 1987 (significantly lower at the delta) and fall of 1986 (significantly lower throughout the bay) (Fig. 17).

Brown Shrimp: Brown shrimp were the most abundant commercial shrimp in San Antonio Bay (Fig. 18). Brown shrimp had significantly higher densities in marsh

habitat, and interactions occurred between years and locations (Table 2). During the fall of 1986 throughout the bay, and fall of 1987 at the delta, browns were significantly lower than at other locations in 1987 and all locations in 1988 (Fig. 18 and 19). Overall spring densities were significantly lower in the delta and upper bay, and on bare bottom habitat for 1987.

White Shrimp: White shrimp were most abundant in the fall with generally higher numbers occurring on bare bottom (Fig. 20). No significant differences occurred between factors during the spring (mostly attributable to low densities), whereas in fall seasons interactions occurred among all factors (Table 2). Densities became significantly higher in the lower bay by the fall of 1988 (Fig. 21). Moreover, marsh densities in 1987, and marsh and bare bottom in 1988, were significantly higher than either habitat in 1986 or bare bottom habitat in 1987.

Pink Shrimp: Pink shrimp were scarce in marsh and bare bottom habitats in San Antonio Bay (Fig. 22). Pink shrimp were not significantly different between factors during the fall, but in the spring, their abundances were higher in the marsh habitat. Interactions occurred between year and location (Table 2; Fig. 23).

Blue Crab: Blue crab juveniles occurred in densities higher than any other economically important species in San Antonio Bay (Fig. 24). Significant interactions occurred in blue crab abundances among all factors studied (Table 2). However, during the spring, overall abundances were significantly higher in marsh than on bare bottom (Fig. 25). Habitat related abundances followed the same pattern in the fall, but with fewer significant differences. Among years, blue crab numbers remained about the same (e.g., no difference over time).

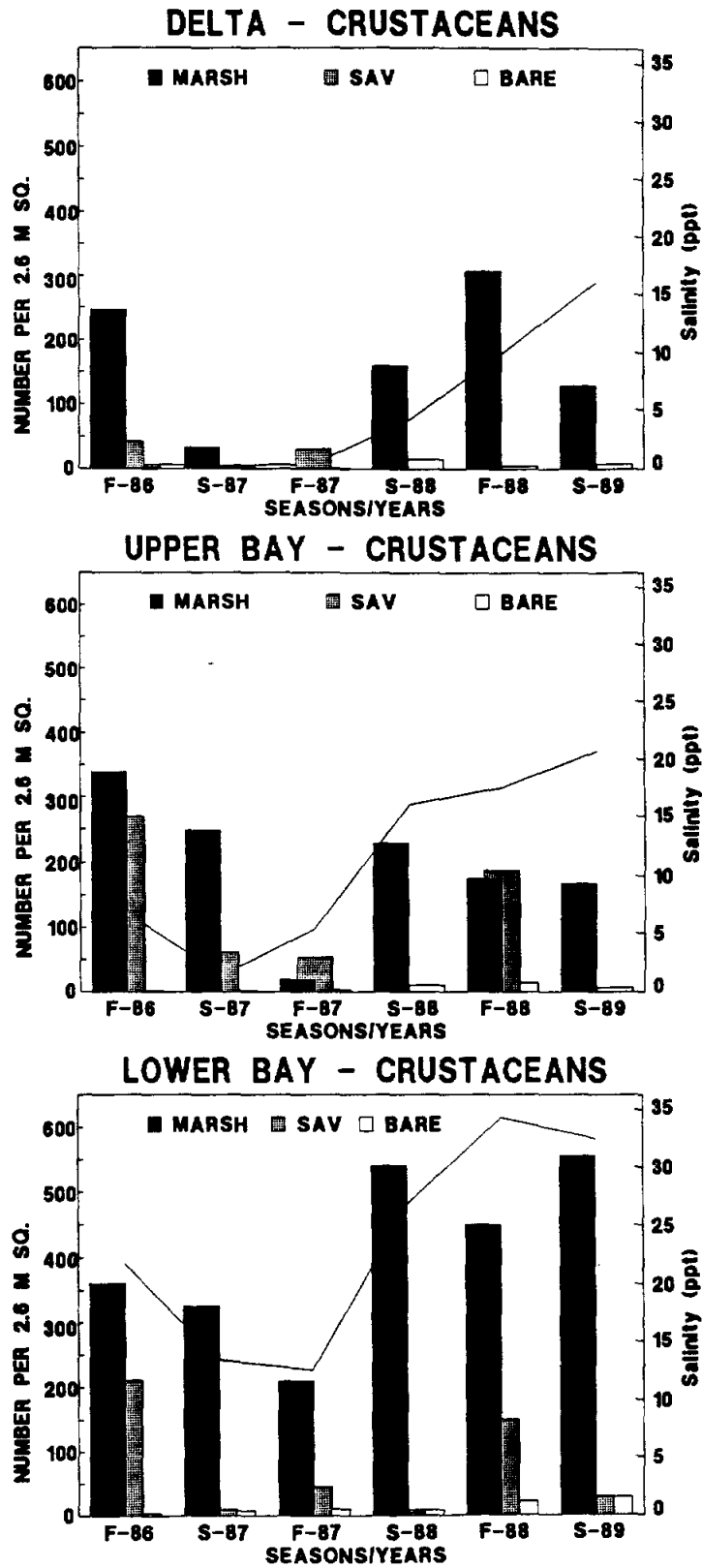


FIGURE 12. Annual variation in densities of crustaceans among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

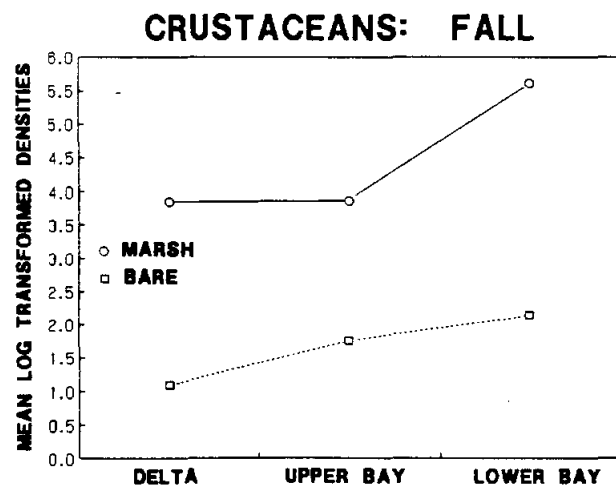
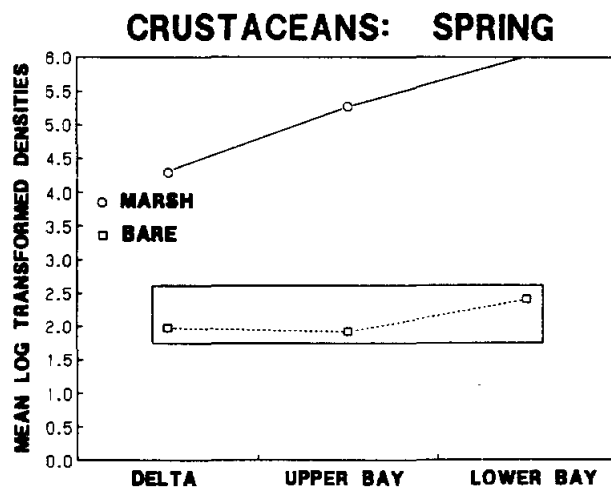
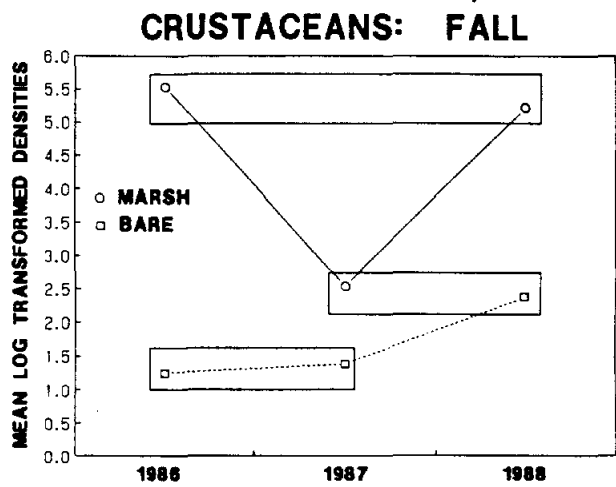
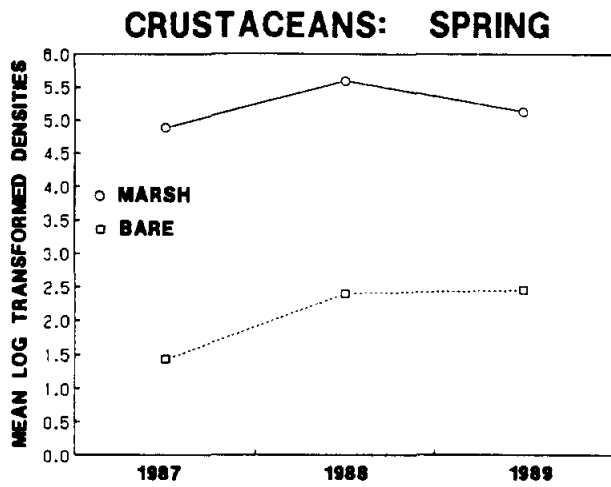
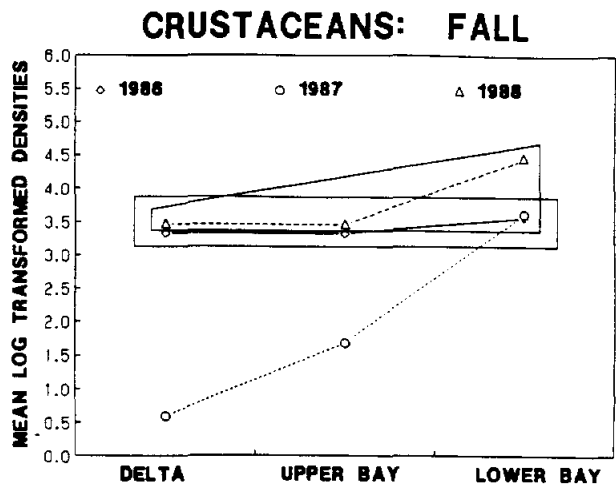
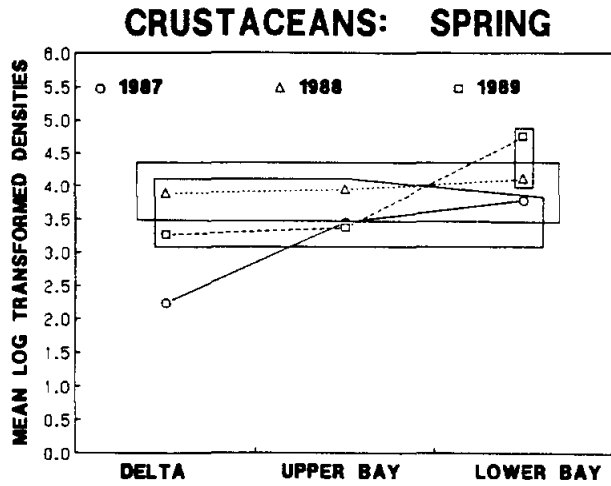


FIGURE 13. Interactions of crustacean densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

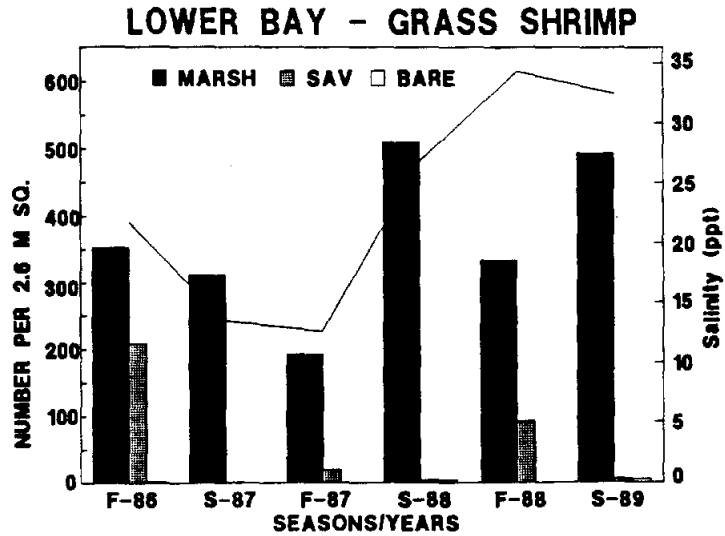
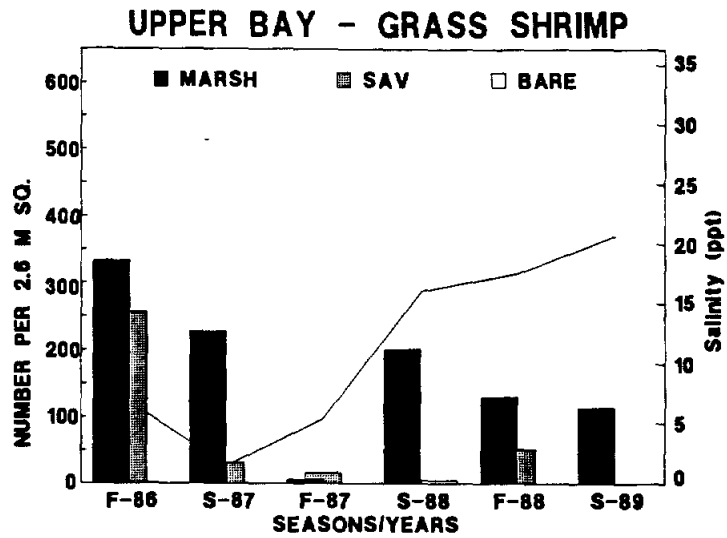
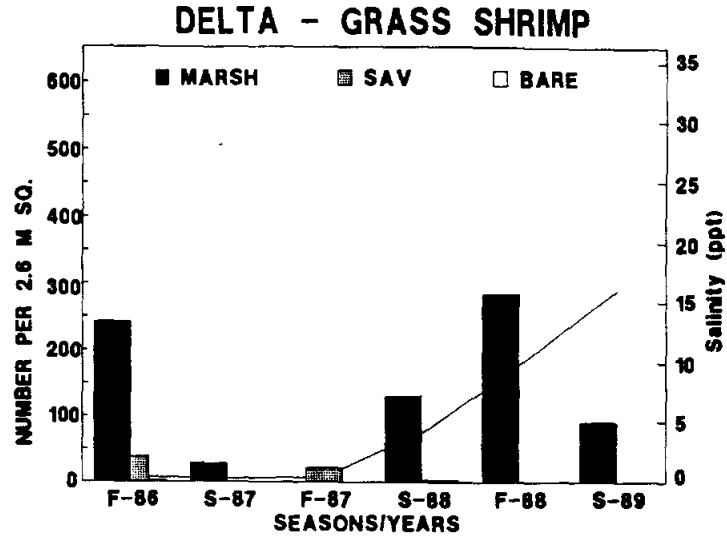


FIGURE 14. Annual variation in densities of grass shrimp among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

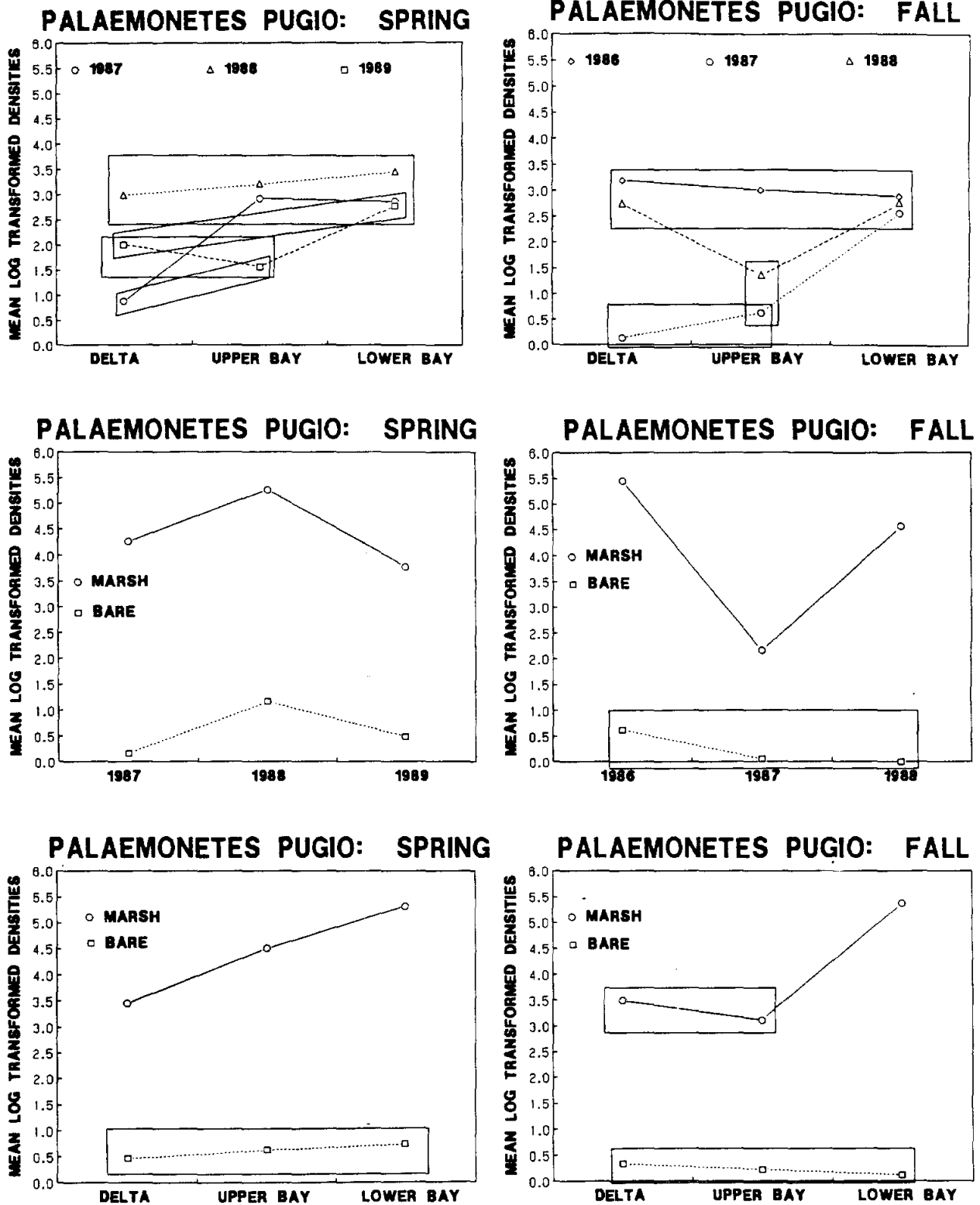


FIGURE 15. Interactions of *Palaemonetes pugio* densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

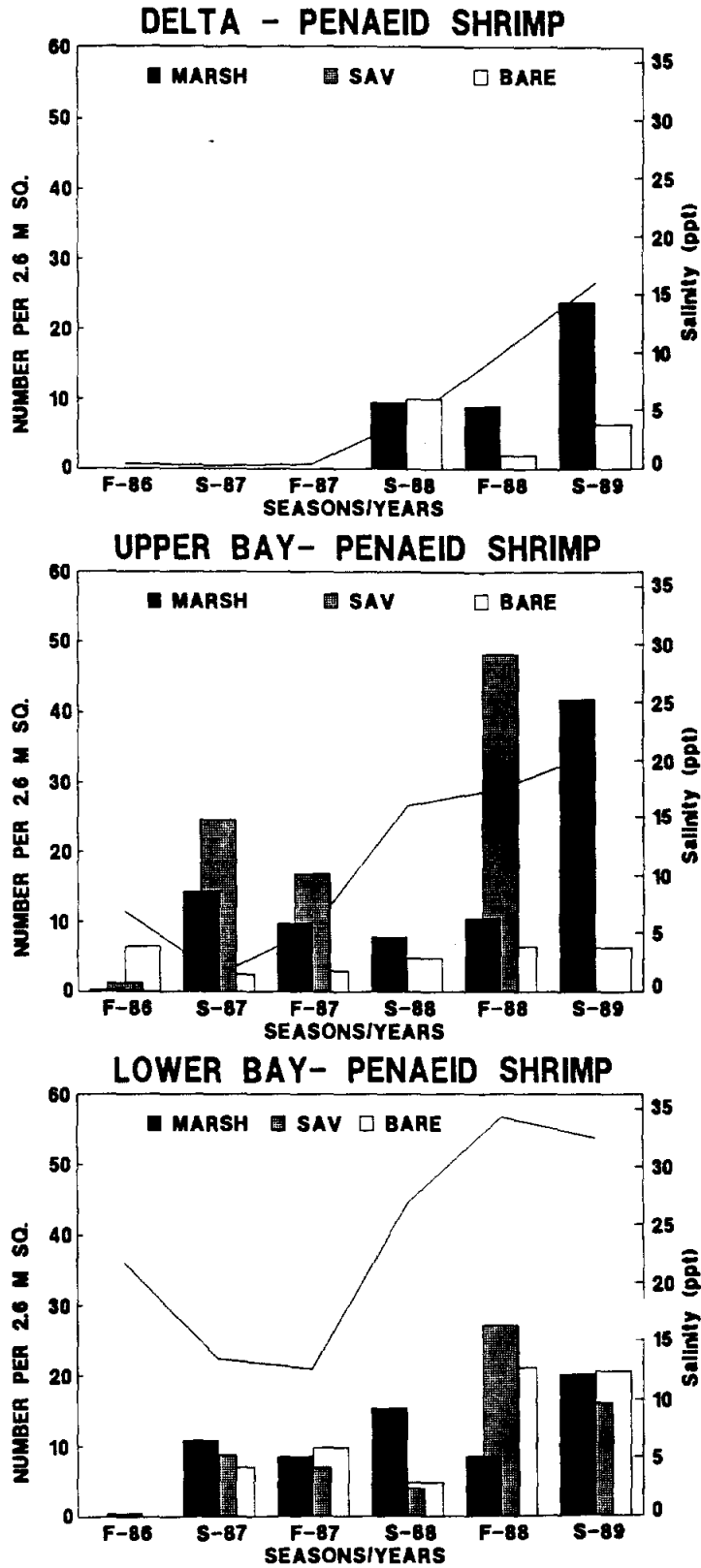


FIGURE 16. Annual variation in densities of penaeid shrimp among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

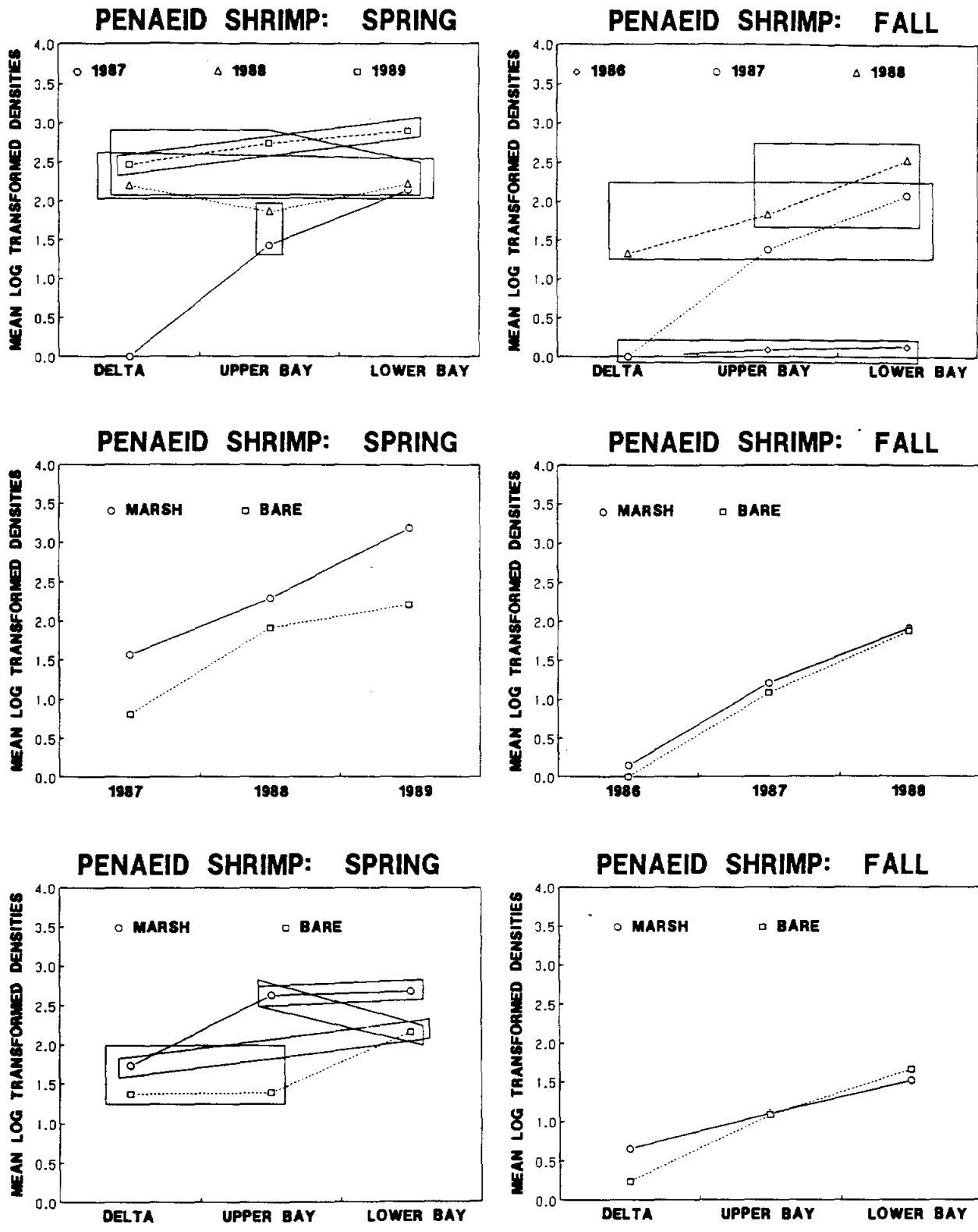


FIGURE 17. Interactions of penaeid shrimp densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

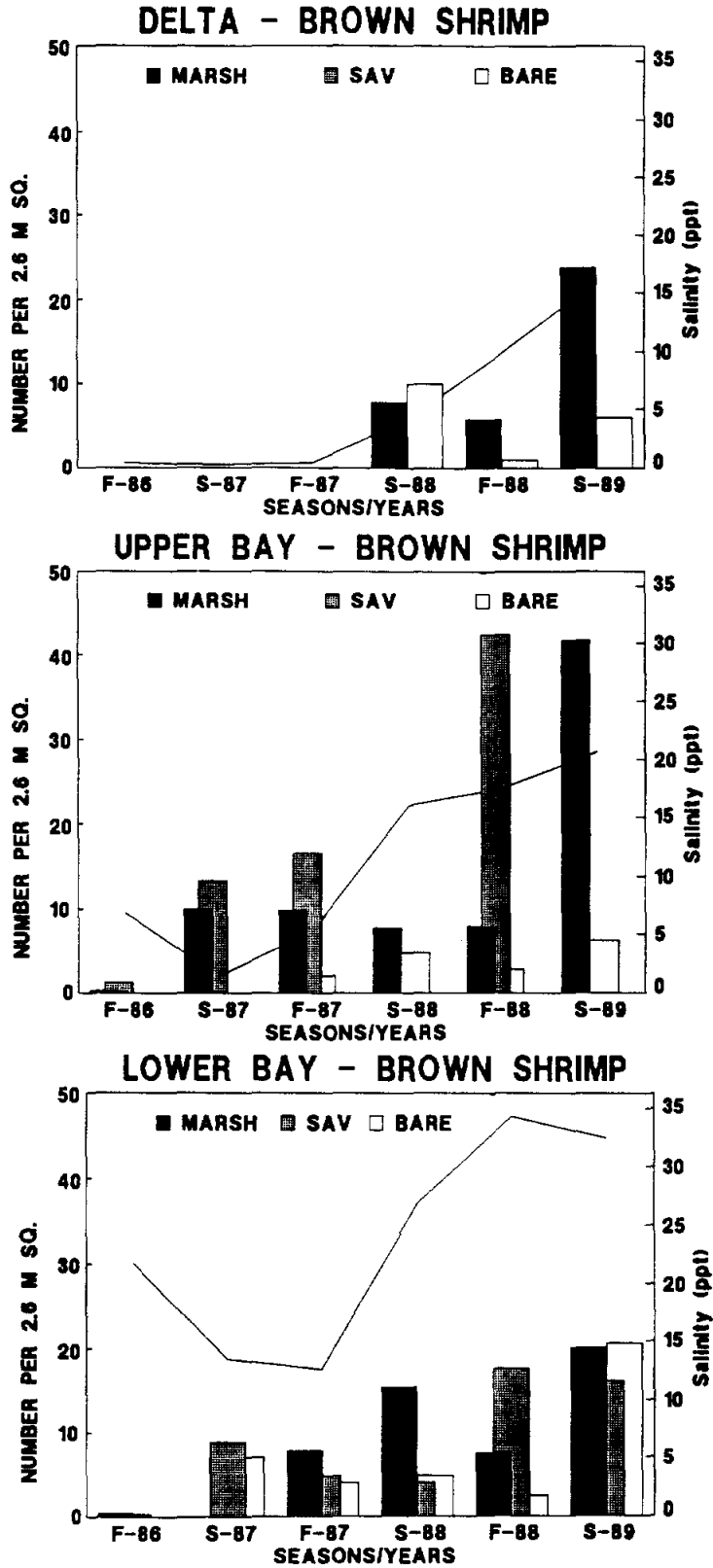


FIGURE 18. Annual variation in densities of brown shrimp among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

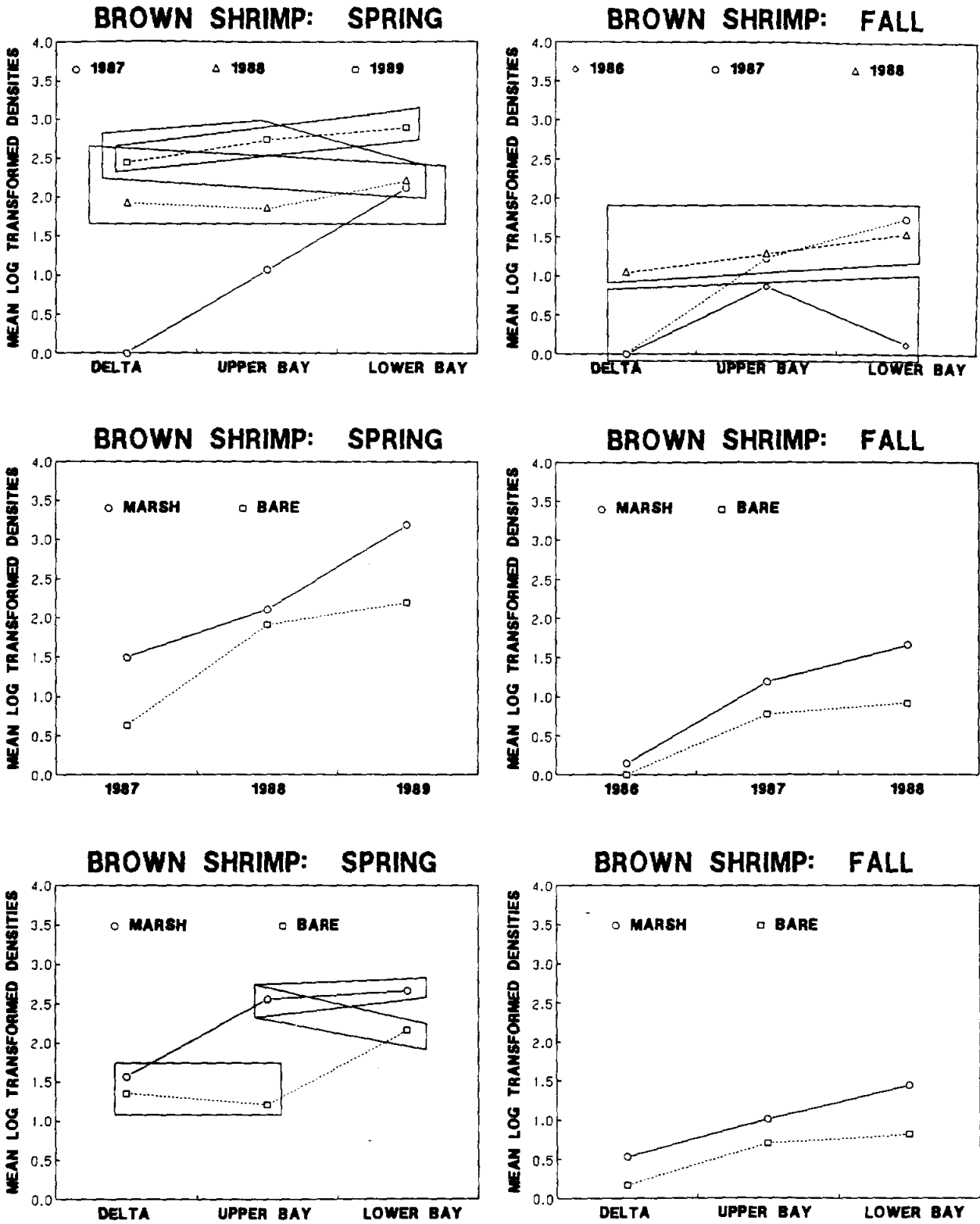


FIGURE 19. Interactions of brown shrimp densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

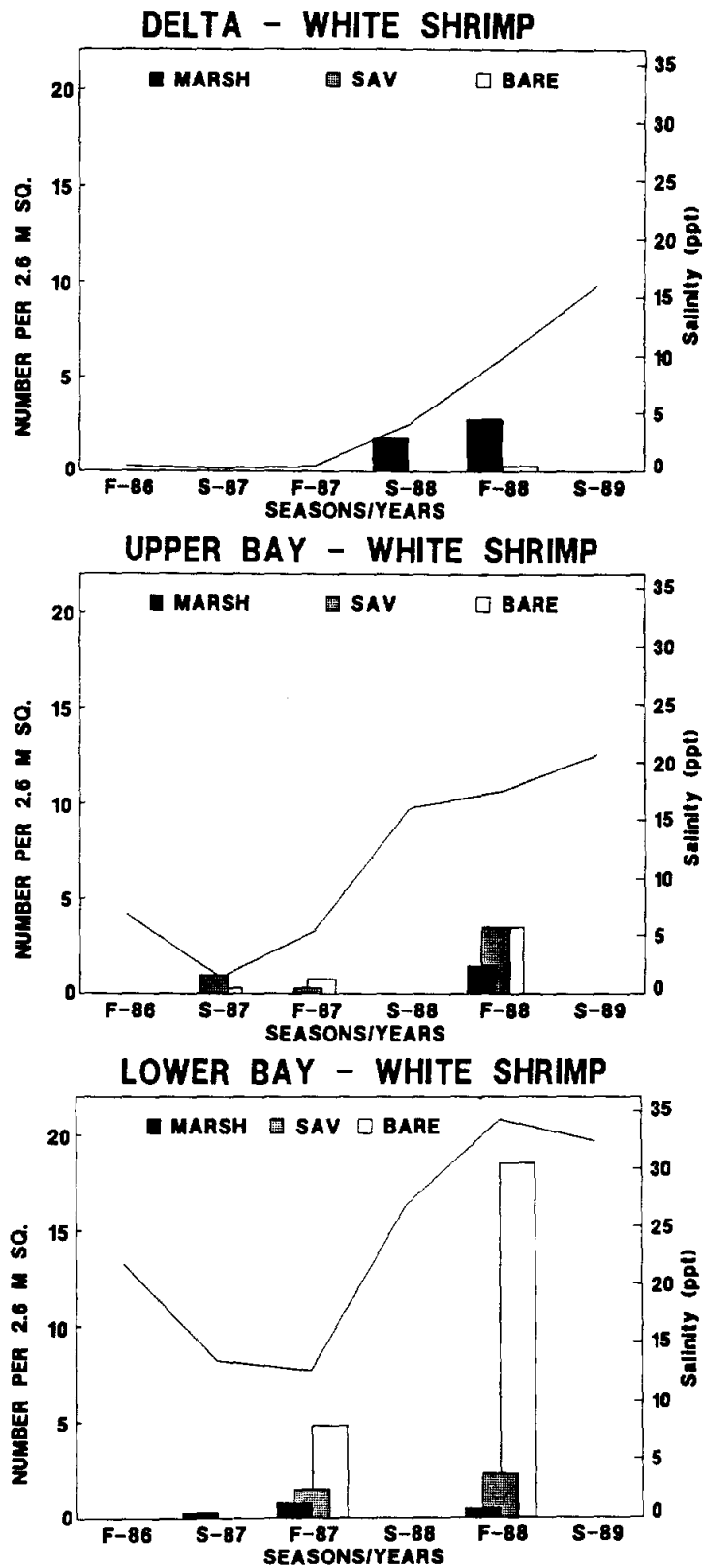


FIGURE 20. Annual variation in densities of white shrimp among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

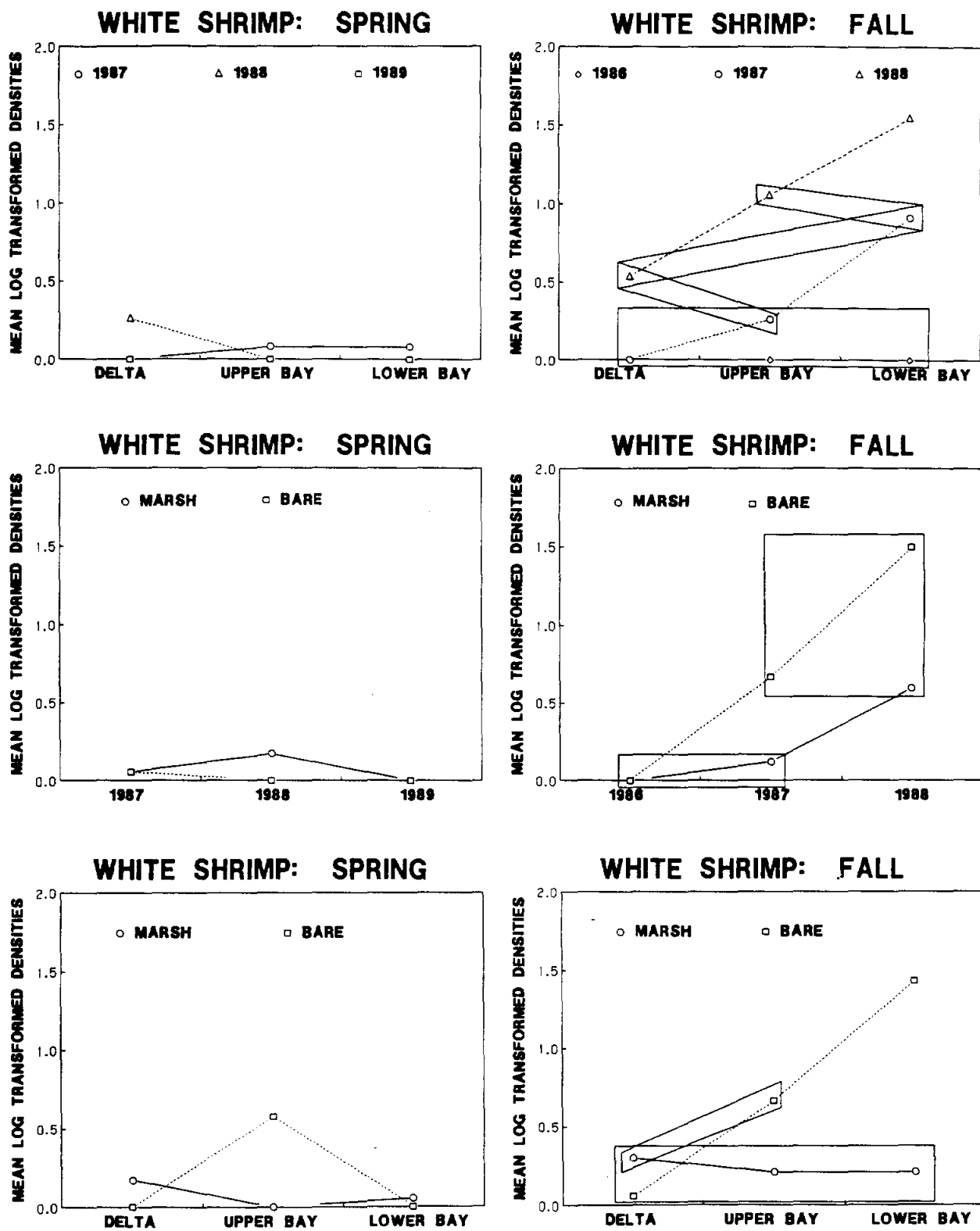


FIGURE 21 . Interactions of white shrimp densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

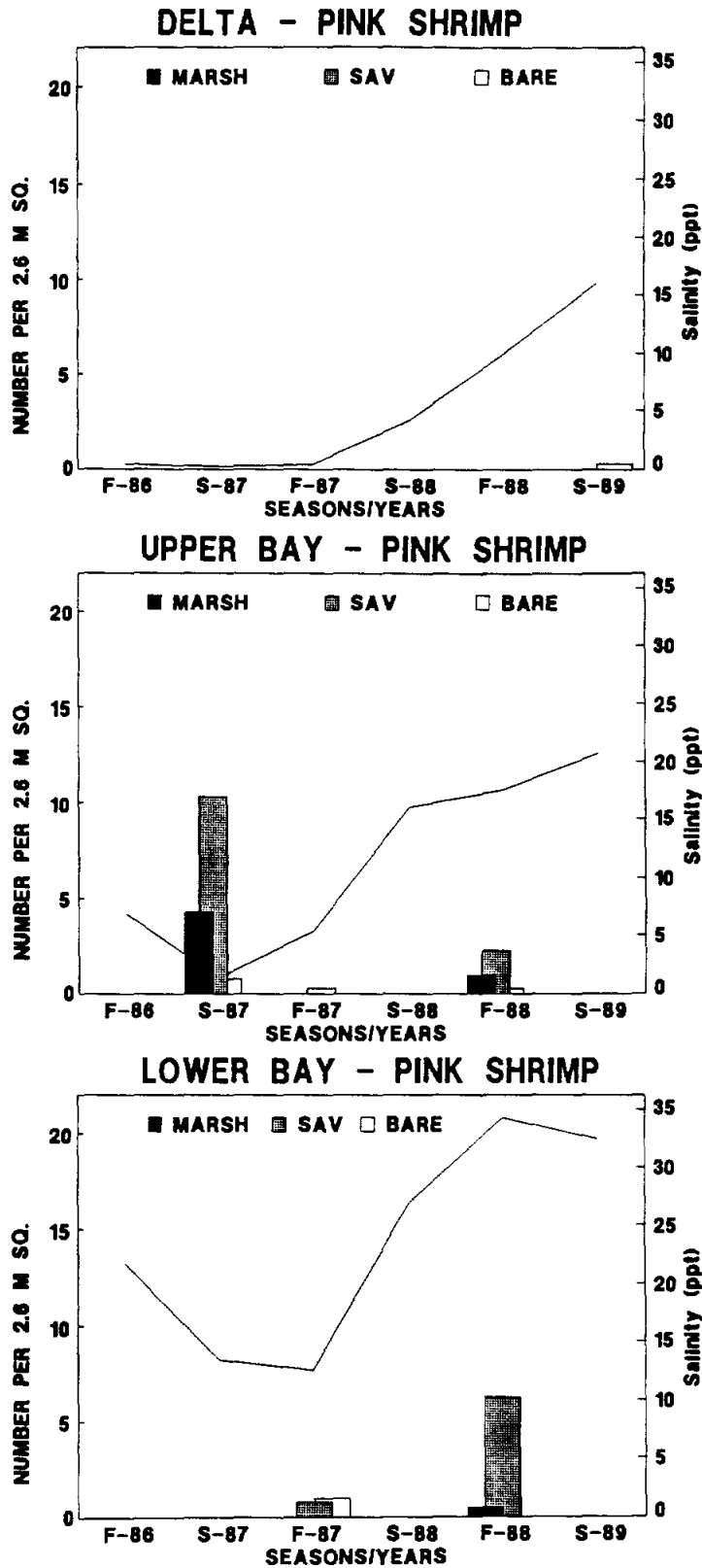


FIGURE 22. Annual variation in densities of pink shrimp among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

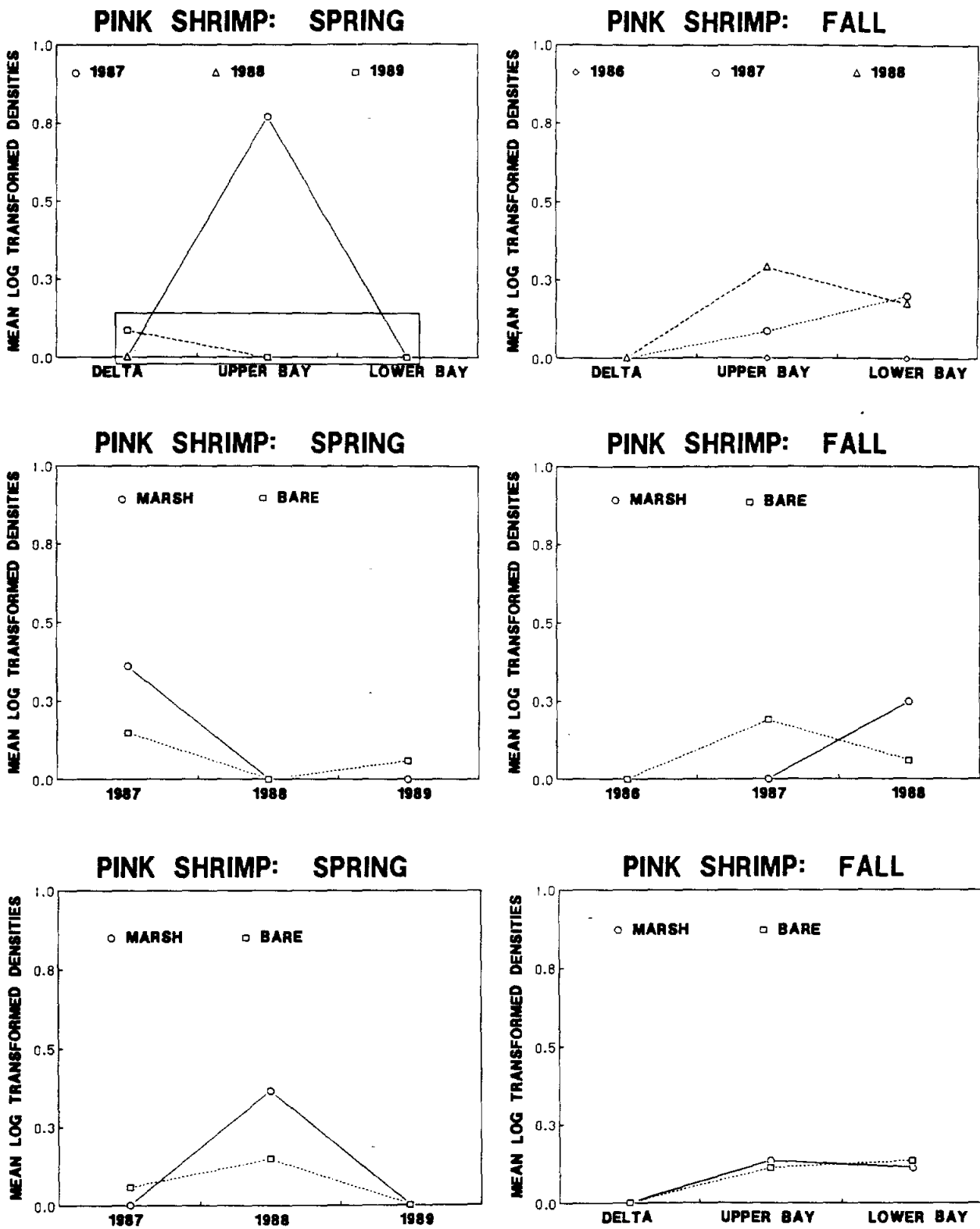


FIGURE 23. Interaction of pink shrimp densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

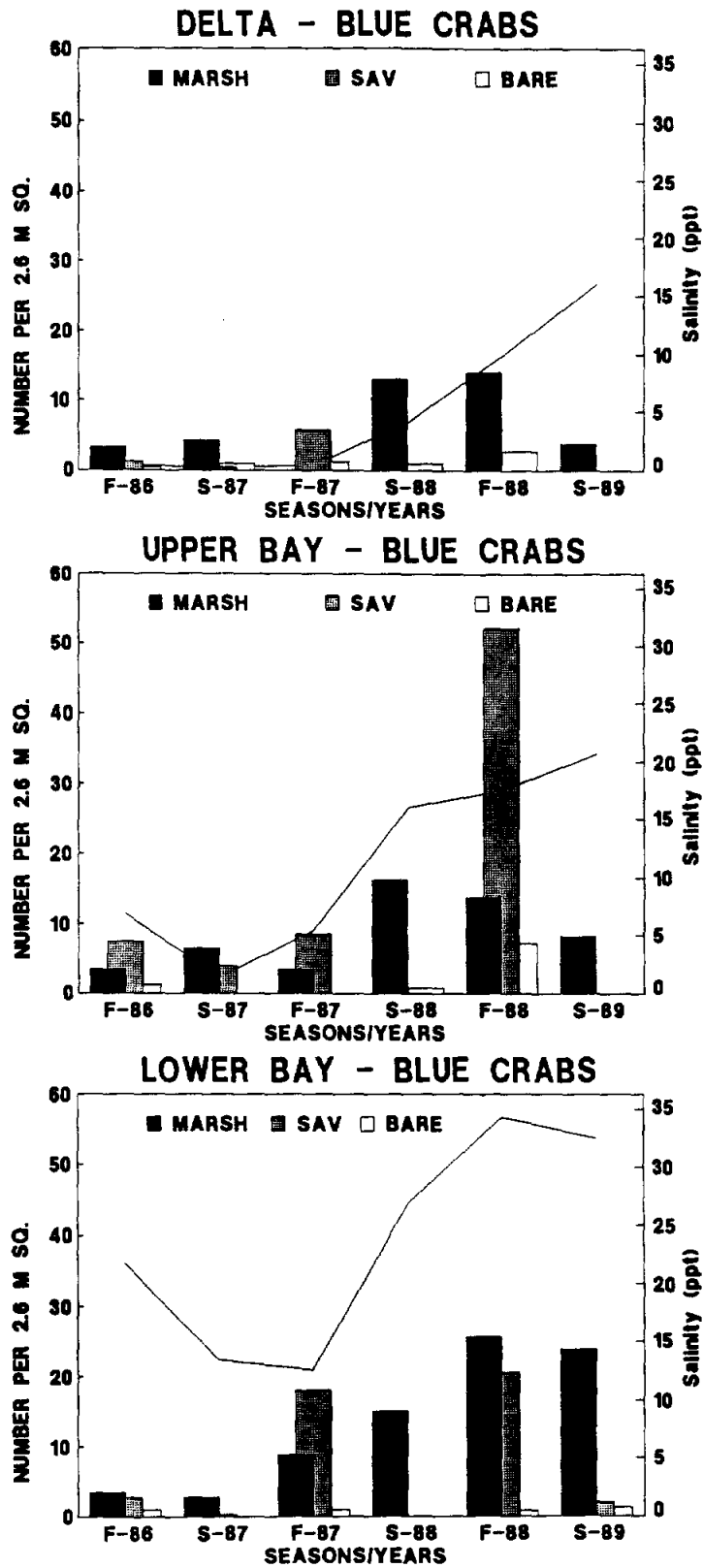


FIGURE 24. Annual variation in densities of blue crab among marsh, SAV and bare mud habitats in San Antonio Bay during spring and fall periods from 1986 to 1989.

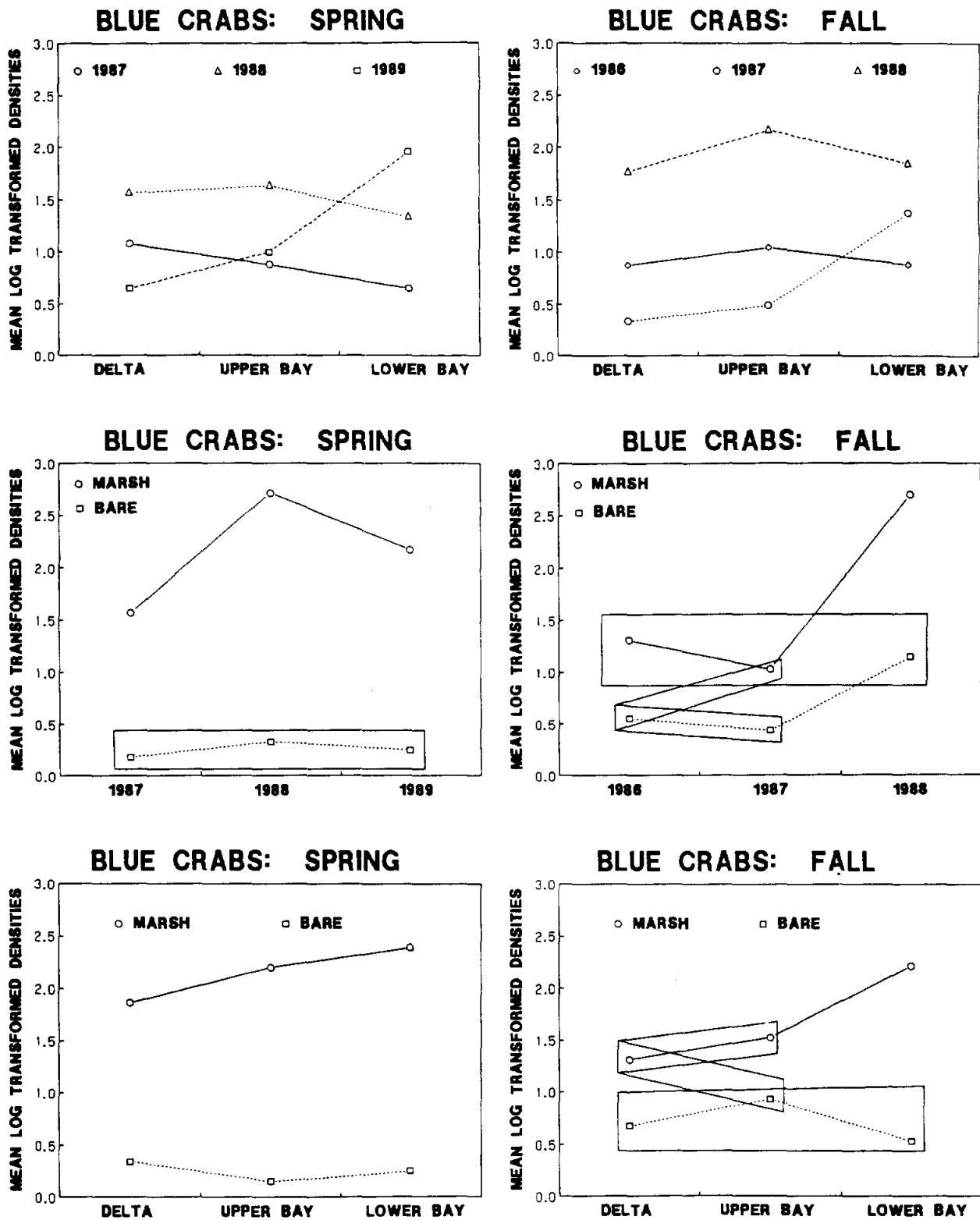


FIGURE 25. Interactions of blue crab densities among year, bay location and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

Effect of SAV.

Submerged aquatic vegetation (SAV) only occurred intermittently at the delta and in the upper bay, but it was always present in the lower bay. Consequently, faunal abundances in SAV were analyzed for comparison to other habitats only from the lower bay (Table 3). Nevertheless, densities were reported when and where SAV occurred (see Figs. 4, 6, 10, 12, 14, 16, 18, 20, 22, and 24).

Fishes: Spring abundances of fishes had significant interactions between years and habitats (Table 3). Importantly, abundances in all three habitats were significantly higher during the spring of 1989 than the spring of 1987. In the spring of 1988, both SAV and bare habitats had very low abundances, while abundances in marsh habitat were high (Fig. 26). During fall seasons, marsh and SAV did not differ in fish abundances, but both differed significantly from bare bottom. Among dominant fish families, Cyprinodontidae were significantly more abundant in marsh habitat during the spring, and in marsh and SAV during the fall (Table 3); the prevalence of Gobiidae not only reflected but probably determined the pattern of all fishes combined (Fig. 26).

Decapod Crustaceans: Decapod crustaceans, as a group, were significantly more abundant in marsh habitat than SAV both in the spring and fall (Table 3, Fig. 26). Generally, SAV had decapod abundances which were intermediate between marsh and bare bottom habitats (Fig. 12). During the spring, the grass shrimp *P. pugio* was significantly more dense in the marsh than in SAV or bare bottom (Fig. 27). The pattern was repeated in fall abundances, except in 1988 when grass shrimp were unusually dense in SAV (Fig. 27).

Economically Important Species:

Penaeids, as a group, did not differ among marsh, SAV, and bare bottom habitats in the lower bay during spring or fall seasons (Table 3). Brown shrimp did not differ between marsh, SAV, and bare bottom in the spring, but by the fall, marsh and SAV (not different from each other) had significantly higher densities than on bare bottom habitat (Table 3). White shrimp were essentially not present in the lower bay during the spring. During the fall, significant interactions in abundances occurred among years and habitats (Table 3). A fall pattern of progressive increases in white shrimp abundances on bare bottom, from 1987 to 1989, was evident. Accordingly, within the lower bay, white shrimp on bare bottom habitat during 1988 were significantly more abundant than at any other time in any other habitat (Fig. 27). Pink shrimp were not present in the lower bay during the spring. Their abundance relationships were similar to those of white shrimp, except they were significantly more abundant in SAV than in other habitats (Fig. 27). Abundances of blue crab had significant interaction between years and habitats (Table 3). Nevertheless, patterns were apparent (Fig. 27). During the spring, blue crab densities were significantly greater in the marsh than SAV or bare bottom. In the fall of 1986, densities did not differ across habitats, but by 1987 and 1988 fall densities in marsh and SAV (not different from each other) had increased and were significantly greater than on bare bottom (Fig. 27).

Habitat Utilization.

A variety of shallow water habitats are available as nurseries and feeding grounds for important fishery species in San Antonio Bay. Our study of animal utilization of these habitats included emergent marshes, submerged aquatic vegetation, and nonvegetated bottom, under conditions ranging from riverine to saline.

TABLE 3: SUMMARY OF 2-WAY ANOVA (YEAR x HABITAT) ANALYSES OF FAUNAL DENSITIES IN LOWER SAN ANTONIO BAY. FALL YEARS = 1986, 1987, 1988. SPRING YEARS = 1987, 1988, 1989. HABITATS = SALT MARSH, SAV, BARE BOTTOM. NUMBERS IN BOLD PRINT INDICATE SIGNIFICANT P VALUES. NOTE: --- = NOT PRESENT

FAUNA	SEASON	FACTORS		INTERACTION
		YEAR	HABITAT	YEAR HABITAT
All Fishes	Sp	0.0001	0.0009	0.0010
	F	0.3265	0.0079	0.4447
Cyprinodontidae	Sp	0.2774	0.0005	0.2789
	F	0.8966	0.0016	0.3918
Gobiidae	Sp	0.0001	0.5818	0.0008
	F	0.1100	0.0038	0.3418
<i>Anchoa mitchilli</i>	Sp	0.3811	0.3811	0.4247
	F	0.1950	0.0781	0.7460
Game Fishes	Sp	0.2639	0.8199	0.9362
	F	0.1065	0.3436	0.4964
All Crustaceans	Sp	0.0049	0.0001	0.1163
	F	0.0294	0.0001	0.4063
Penaeidae	Sp	0.0031	0.0516	0.1400
	F	0.0001	0.7354	0.2480
<i>Callinectes sapidus</i>	Sp	0.0001	0.0001	0.0001
	F	0.0005	0.0001	0.0322
<i>Palaemonetes pugio</i>	Sp	0.5596	0.0001	0.1353
	F	0.0223	0.0001	0.0123
<i>Palaemonetes vulgaris</i>	Sp	0.3811	0.3811	0.4247
	F	0.8629	0.2366	0.5733
<i>Penaeus aztecus</i>	Sp	0.0033	0.0619	0.1402
	F	0.0001	0.0311	0.1803
<i>Penaeus duorarum</i>	Sp	--	--	--
	F	0.0185	0.0302	0.0200
<i>Penaeus setiferus</i>	Sp	0.3811	0.3811	0.4247
	F	0.0002	0.0003	0.0097

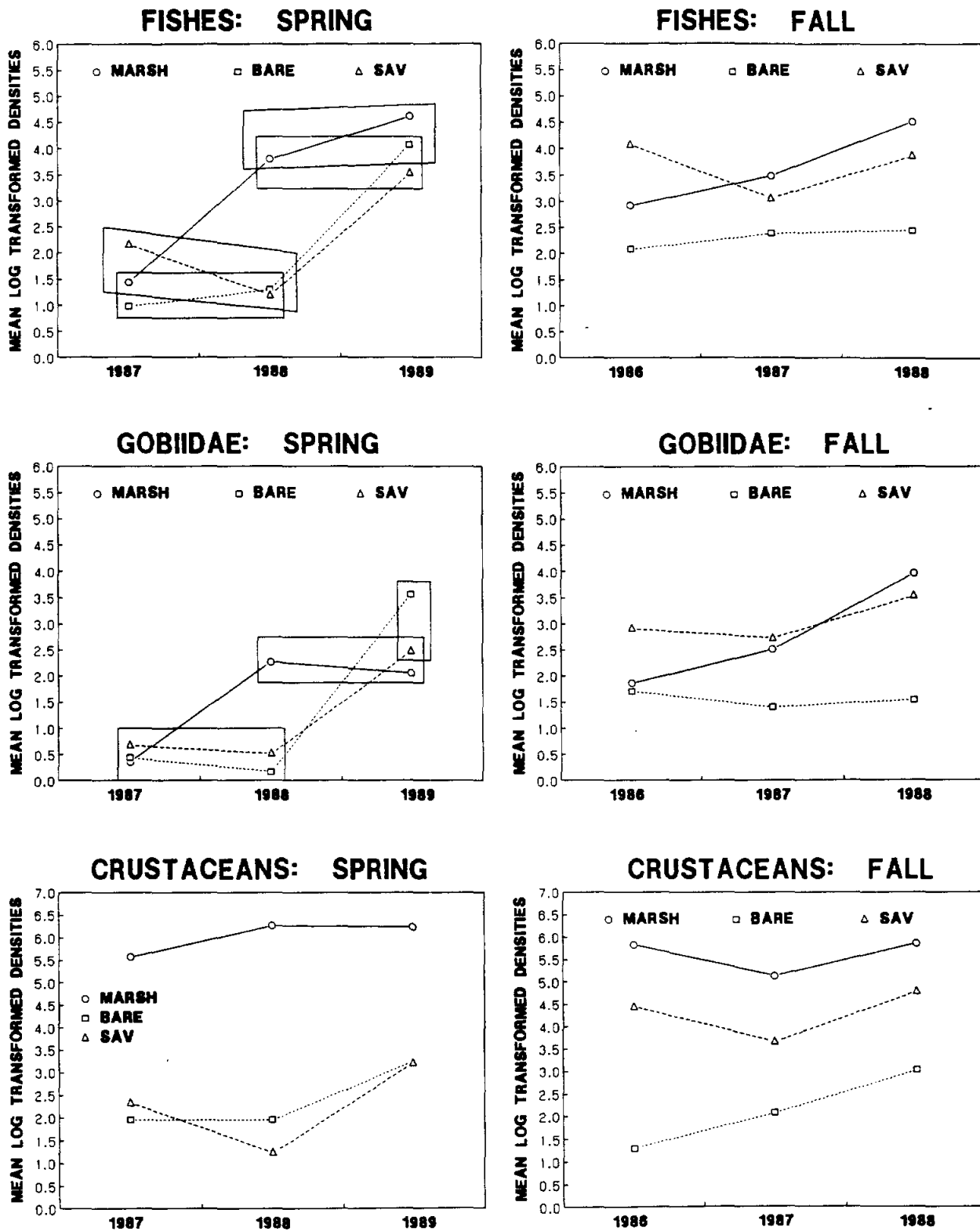


FIGURE 26. Interactions of all fish and all decapod crustacean species densities among year and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

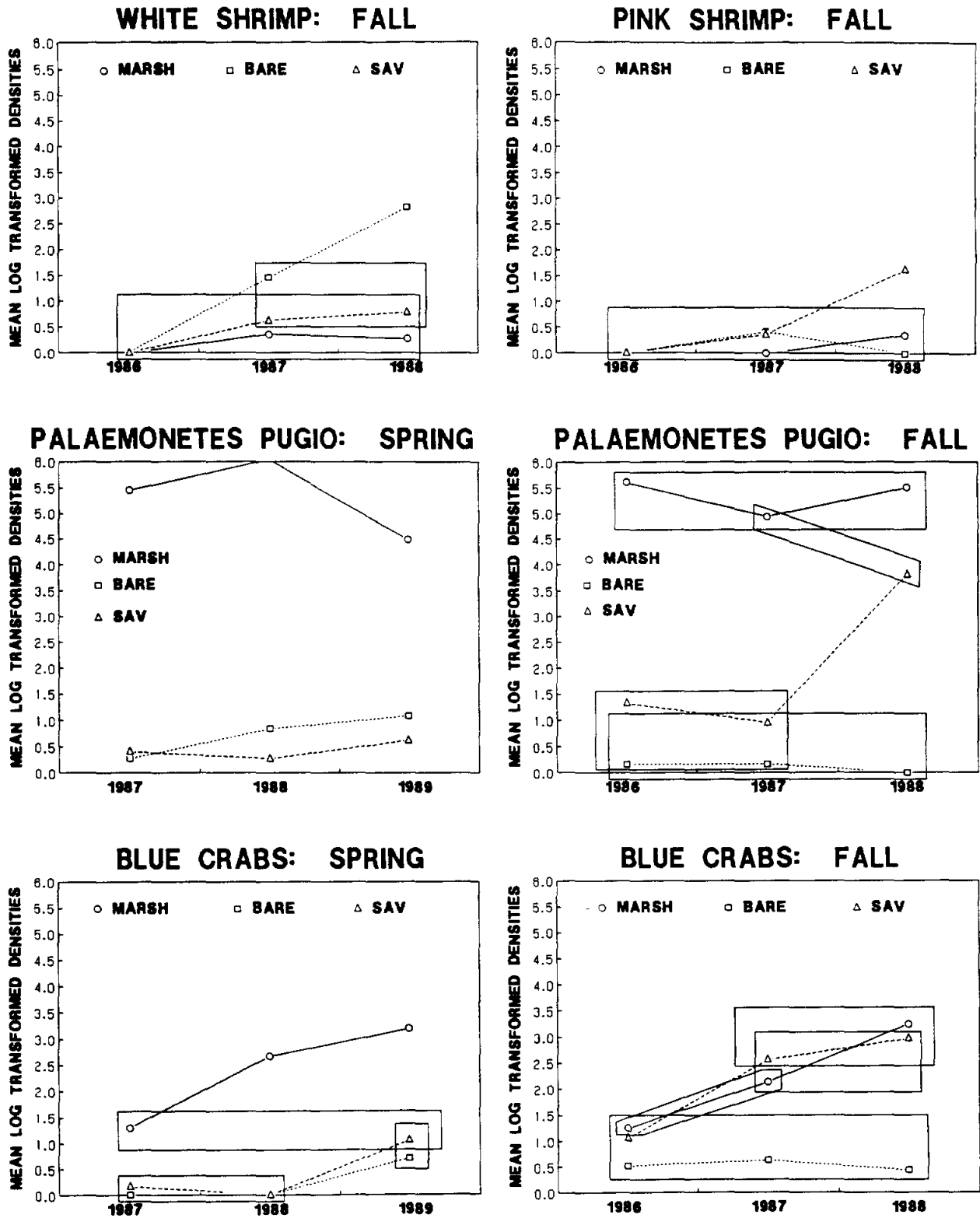


FIGURE 27. Interactions of all decapod crustacean species densities among year and habitat type in San Antonio Bay from 1986 to 1989. Graphed as in FIGURE 3.

The importance of direct utilization of marsh surfaces by estuarine consumers has only recently been recognized. Earlier investigations showed heavy predation on marsh prey (Bell and Coull 1978), but transient estuarine predators were only implicated as a cause and were not specifically identified nor measured in their abundance (Montague et al. 1981). The only known predators were resident species such as *Fundulus* spp. (Kneib and Stiven 1982). Likewise, positive relationships between yield in shrimp fisheries and the area of marshes were noted (Turner 1977), but the magnitude of direct utilization of marsh surfaces by shrimp or any other fishery species was unknown. This changed with the application of drop trap (Zimmerman et al. 1984) and flume (McIvor and Odum 1986) techniques which measured predator densities in marshes. Ensuing investigations have revealed that non-resident animals often extensively utilize tidal marshes during flood tides (Zimmerman and Minello 1984; McIvor and Odum 1988; Rozas et al. 1988; Hettler 1989; Mense and Wenner 1989). Interestingly, the pattern appears to be one of comparatively less exploitation (fewer consumers per unit area) in East Coast marshes (Hettler 1989; Mense and Wenner 1989) than Gulf Coast salt marshes (Zimmerman and Minello 1984; Thomas et al. 1990). The reasons for these regional differences are unclear, but hydroperiod patterns may be involved. East coast marshes generally have larger tides (mesotidal versus microtidal) and more slope than Gulf Coast marshes, causing differences in amplitude, frequency, and duration of tides that inundate marshes (Provost 1976; Hicks et al. 1983). Many northwestern Gulf marshes are subsiding rapidly, which further increases the duration of inundation (Baumann 1987). Hence, the amount of time available for consumer exploitation differs between marshes and between regions. This, together with other differences

related to hydroperiod, may result in fundamental dissimilarities in how marshes are utilized.

Another distinction between East Coast and Gulf Coast marshes can be related to carbon sources and food chain pathways. The traditional East Coast view has been that salt marshes are valued for their outwelling of organic materials which fuel downstream estuarine food chains (Teal 1962; Odum 1980). But tracing the carbon derived from marshes in food chains has been difficult, and to date, evidence that large energetic contributions of salt marsh detritus support estuarine food chains is not convincing (Pomeroy 1989). Stable isotope ratios have revealed that algal carbon is at least equal to the carbon of vascular plant detritus in food chains in East Coast salt marshes (Haines and Montague 1979; Peterson et al. 1986; Peterson and Howarth 1987). Sullivan and Moncrief (1988a), also show that production of edaphic algae is high in Gulf Coast salt marshes and propose that relatively more algal carbon is incorporated into food chains associated with Gulf Coast than East Coast marshes (Sullivan and Moncrief 1988b). Such algae and their grazers are the foods of intermediate size predatory shrimps and crabs (Gleason 1986; Thomas 1989) that are common in the Gulf. Thus production among secondary consumers could be modified and possibly enhanced through greater accessibility to algal based food resources on marsh surfaces.

Primary consumers like peracarid crustaceans (amphipods and tanaidaceans) and annelid worms are the principal prey components of salt marshes (Thomas 1976; Kneib and Stiven 1982; Rader 1984). (In oligohaline marshes aquatic insect larvae are abundant (LaSalle and Bishop 1987) and may also serve as prey). These prey apparently thrive in marshes under the

microtidal regimes of the Gulf and predation on their populations is evidently high. Predator-prey relationships at a marsh on Galveston Island have demonstrated these characteristics. Findings revealed that peracarid and annelid populations increase during the winter months (under seasonally reduced predation) to very high levels. During spring months, coincident with seasonally high tides, heavy predation pressure (Minello et al. 1989b) significantly reduces all prey populations (Zimmerman et al. in prep). Predator populations such as brown shrimp respond in turn with significantly greater growth rates when given access to these prey (Zimmerman et al. in prep). While feeding, these intermediate size predators utilize plant structure associated with salt marsh surfaces as refuge from larger predators (Minello and Zimmerman 1983). Hence, the high abundances of resident species and transient juveniles (especially of fisheries species) found in San Antonio Bay marshes agree with the hypothesis that estuarine species of the western Gulf are greatly benefited by direct utilization of marsh surfaces. The relatively small area of San Antonio Bay marshes compared to subtidal habitats confers additional importance to this relationship.

Submerged aquatic vegetation (SAV) habitats such as seagrasses are also especially valuable to juveniles of fishery species. The value of SAV as refuge from predators is well documented (Stoner 1979; Coen et al. 1981; Heck and Thoman 1981). Less known but equally important is the feeding ground value of SAV habitats. As an example, small predatory penaeid shrimp, blue crabs and certain fishes immigrating into estuaries seek SAV to find cover and feed on peracarid populations that are evidently preferred foods (Stoner, 1979; Leber, 1985; Minello et al. 1989a; Thomas 1989; Thomas et al. 1990; Zimmerman et al. in prep.). Accordingly, Texas saline SAV

beds are intensively utilized by fishes (Huh and Kitting 1985) and decapod crustaceans (Stokes 1974) compared to non-vegetated bottom. Fish production has been related to the amount of seagrass area (Hellier 1962) as it has been for marshes. Carbon source pathways in seagrass beds also appear to be more based on epiphytic algae than vascular plant detritus (Kitting et al., 1984; Fry et al. 1987). Given these similar relationships between SAV and marshes, it is not surprising that overall utilization by consumers does not differ significantly between marsh and SAV habitats in the lower parts of San Antonio Bay.

Salinity Effects.

Annual changes in salinity substantially modified habitat utilization by consumers in San Antonio Bay. The main salinity effect (a significant decline from previous levels) began in the fall of 1986 and persisted for more than a year, until the spring of 1988. Therefore, the responses of consumers should be viewed in a long term (months to years) rather than short term (days to weeks) context. Most estuarine animals are euryhaline and are adapted to survive short term lowering of salinities. This has been shown in our work in other bays. In the delta marshes of Lavaca Bay, for example, river flooding caused salinities to lower to near zero for almost two weeks but densities of penaeid shrimps, grass shrimp and crabs did not change (Zimmerman, et al. 1990b). A similar result occurred in Galveston Bay when relatively high densities of fauna remained in a normally mesohaline marsh site after salinities plummeted to near zero (Zimmerman, et al. 1990a). These were short term events, however, and although they were large scale rapid declines, the salinities began to return to higher levels within a month. The relative effect on habitat change in these instances appeared to be minor. By contrast, the

persistence of low salinities in San Antonio Bay was long lasting. This apparently caused long term changes that resulted in significant modification of habitats and subsequent utilization by consumers.

Even though overall animal abundances were lowered in San Antonio Bay during persistently low salinities of 1987 not all the effects were detrimental. As we found in delta marshes of Lavaca Bay, the abundances of Gulf menhaden and bay anchovy in San Antonio Bay increased in response to lower salinities associated with high riverflow. Such floods may generate long term beneficial effects. Red drum have been known to seek low salinity areas as early juveniles (Peters and McMichael 1987), and had high recruitment success a year after flooding from a hurricane had reduced salinities in the Laguna Madre (Matlock 1987). Increased production of white shrimp has also been associated with high rainfall and riverflow resulting in increased freshwater inflow to estuaries (Gunter and Hildebrand 1954; Mueller and Matthews 1987). White shrimp in Louisiana are often noted in oligohaline and freshwater habitat conditions (Felley, 1987).

Distributions of estuarine animals have long been based on salinities (Hedgepeth 1953; Gunter 1961) and changes in community structure have often been related to freshwater inflow (Hoese 1960; Copeland 1966). Still, we do not understand the cause-effect relationships between salinity and abundances of estuarine animals. From our observations, long term habitat modification factors as well as short-term physiological effects must both be considered.

Salinity Relationships to Fisheries Production.

Gulf fisheries are highly estuarine

dependent (Gunter 1961) and positive relationships have been cited between Gulf fisheries and freshwater inflow to estuaries (Deegan et al. 1986). As explained above, the causative factors and their interactions are complex. However, a study in Galveston Bay (Zimmerman, et al. 1990a), of animal abundances in relation to the salinity gradient, sheds light on the relationship. The study revealed that highest numbers of juveniles of fisheries species were in mesohaline marshes. Evidently, the attraction was partly due to greater infaunal and epifaunal food abundances in mesohaline habitats than elsewhere in the bay. Mid-bay populations of these benthic foods (mainly annelid worms and peracarid crustaceans) were potentially stimulated by organic material exported from freshwater and oligohaline marshes of the upper bay. In a relatively large open system such as Galveston Bay, high riverflow facilitates export of materials that increases the production of primary consumers over an expanded mesohaline area. Larger prey populations increase the value of the feeding grounds through faster growth rates in juveniles of fisheries species, and thus increase fisheries yields. In a small relatively closed system such as San Antonio Bay, high freshwater inflow may create a disproportionately large oligohaline environment which is physiologically stressful to many of these food organisms. If low salinity conditions continue for a long interval of time, preferred benthic foods may diminish and the affected habitats may become less useful to productivity of secondary consumers. We propose that this occurred in San Antonio Bay during the high riverflow period of 1987. However, as mesohaline conditions return, as they did in San Antonio Bay during 1988, desirable food populations rebound and secondary consumers are benefited.

SUMMARY

Salinity in San Antonio Bay differed significantly between locations and years. Within years, a salinity gradient was always present, with highest salinities occurring in the lower bay, intermediate salinities in the upper bay, and lowest salinities at the delta. Across years, salinities changed considerably, ranging from 0.1 to 16 ppt at the delta, 1.1 to 21.5 ppt at the upper bay, and 12.1 to 34.5 ppt at the lower bay. A general decline of salinity began during 1986, which became lowest in the spring and fall of 1987 (0.1 to 14.2 ppt), and recovered in the fall of 1988 and spring of 1989 (9.8 to 34.5 ppt).

Marsh and SAV habitats had similar abundances of fishes and decapod crustaceans. Both habitats usually had significantly higher numbers of animals than bare mud habitat. Species composition and abundances of individuals were lowest at the delta and became progressively higher toward the lower bay. Numerically dominant fishes were comprised of several resident species of cyprinodontids, gobiids and silversides, and transient juveniles of bay anchovy, pinfish and spot. Cyprinodontids and gobiids primarily occurred in the marsh; silversides and pinfish were in the marsh and SAV; spot were in SAV and bare mud; and the bay anchovy was usually over bare mud habitat. Game fishes occurred in comparatively low densities as transient juveniles. Although they were distributed across all habitats, they were primarily in the lower bay. Accordingly, game fishes in the upper bay and the delta were two-thirds and one-third as abundant, respectively, as those in the lower bay. Numerically dominant decapod crustaceans consisted of three species of grass shrimps, a mud crab, blue crab, brown shrimp and white shrimp. Grass shrimps and mud crabs were residents, but penaeid shrimps and the blue crab were transient juveniles. Decapods were gener-

ally as abundant in marsh as SAV habitat, but specific differences did occur. Grass shrimps were significantly more abundant in the marsh than SAV habitat, while penaeid shrimps and blue crab were sometimes in greater abundance in SAV. Economically important decapods (brown shrimp, white shrimp, pink shrimp and blue crab) were equally abundant between the upper and lower bay, but on the delta decapods were scarce. Other decapods (mostly grass shrimps), like fishes, were more abundant in the lower bay.

Overall, salinity level and animal abundances were directly related, and crustacean abundances were more affected by salinity than fish abundances. Also, salinity effects on abundances were greater among locations and over time than among habitats. The magnitude of effect varied among species, and although many residents were less affected than transient species, no overlying pattern existed. Among residents, species contrasted from virtually no responses to salinity in the Cyprinodontidae to high responses in the Gobiidae and Palaemonidae. Likewise, responses of transient species were graded from low to high, in order, from bay anchovy, white shrimp, spot, pinfish, blue crab to brown shrimp.

Despite the separate influences of habitat, bay location, and season on animal abundances, general patterns related to salinity regime were evident. Important threshold levels of salinity affecting faunal abundances were observed at the delta and in the upper bay. Abundances among most species in this area were significantly reduced or eliminated entirely when salinities declined below 2 ppt. At 2 to 5 ppt, some species became abundant but many others were not. When salinities were elevated above 5 ppt most of the common species became abundant. In the lower bay, salini-

ties were always above 10 ppt, but faunal abundances did decline when salinities were below 20 ppt. However this may have been related to overall declines in the bay rather than a specific local effect of salinity.

Most aquatic species in San Antonio Bay were able to tolerate relatively low salinities of 2 to 5 ppt, yet abundances were negatively affected when salinities were persistently lowered. It is unlikely that such responses of the fauna were attributable to the immediate effects of salinity, but rather these responses were prompted by longer term habitat changes caused by long lasting effects of low salinity.

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APPENDIX IA: OVERALL ABUNDANCES AMONG SPECIES IN SAN ANTONIO BAY-
DELTA HABITATS.

Fall 1986 thru Spring 1989

(2.6 m sq. samples, marsh n = 24, SAV n = 12, bare n = 24)

SPECIES	MARSH	SAV	BARE	TOTAL
1 <i>Gobiosoma boscii</i>	240	209	81	530
2 <i>Brevoortia patronus</i>	30	--	315	345
3 <i>Menidia beryllina</i>	282	3	8	293
4 <i>Lucania parva</i>	62	35	10	107
5 <i>Cyprinodon variegatus</i>	55	4	40	99
6 <i>Gambusia affinis</i>	89	8	--	97
7 <i>Bairdiella chrysoura</i>	53	--	22	75
8 <i>Fundulus pulvereus</i>	23	8	--	31
9 <i>Fundulus grandis</i>	22	--	--	22
10 <i>Leiostomus xanthurus</i>	8	--	12	20
11 <i>Poecilia latipinna</i>	18	--	--	18
12 <i>Anchoa mitchilli</i>	1	3	13	17
13 <i>Microgobius gulosus</i>	--	7	8	15
14 <i>Lagodon rhomboides</i>	11	--	--	11
15 <i>Gobiosoma robustum</i>	1	7	--	8
16 <i>Syngnathus scovelli</i>	5	1	1	7
17 <i>Micropogonias undulatus</i>	1	--	3	4
18 <i>Cynoscion nebulosus</i>	1	--	1	2
19 <i>Gobiesox strumosus</i>	2	--	--	2
20 <i>Gobionellus boleosoma</i>	--	2	--	2
21 <i>Mugil cephalus</i>	2	--	--	2
22 <i>Sciaenops ocellatus</i>	1	--	1	2
23 <i>Paralichthys lethostigma</i>	1	--	--	1
24 <i>Strongylura marina</i>	1	--	--	1
25 Unknown fish species	1	--	--	1
26 <i>Palaemonetes pugio</i>	2968	163	25	3156
27 <i>Penaeus aztecus</i>	149	--	68	217
28 <i>Callinectes sapidus</i>	153	30	26	209
29 <i>Palaemonetes intermedius</i>	129	75	--	204
30 <i>Rhithropanopeus harrissi</i>	51	27	23	101
31 <i>Macrobrachium ohione</i>	25	--	--	25
32 <i>Penaeus setiferus</i>	18	--	1	19
33 <i>Penaeus sp.</i>	2	--	3	5
34 <i>Macrobrachium sp.</i>	--	3	--	3
35 <i>Callinectes ornatus</i>	--	2	--	2
36 <i>Callinectes similis</i>	1	--	--	1
37 <i>Palaemonetes vulgaris</i>	1	--	--	1
38 <i>Penaeus duorarum</i>	--	--	1	1
39 <i>Thalassinidea sp.</i>	1	--	--	1

-- = Not Present

APPENDIX IB: OVERALL ABUNDANCES AMONG SPECIES IN SAN ANTONIO BAY-
UPPER BAY HABITATS.

Fall 1986 thru Spring 1989

(2.6 m sq. samples, marsh n = 24, SAV n = 16, bare n = 24)

SPECIES	MARSH	SAV	BARE	TOTAL
1 <i>Gobiosoma boscii</i>	358	466	139	963
2 <i>Fundulus grandis</i>	120	206	--	326
3 <i>Lucania parva</i>	155	105	--	260
4 <i>Anchoa mitchilli</i>	15	--	156	171
5 <i>Syngnathus scovelli</i>	10	72	1	83
6 <i>Lagodon rhomboides</i>	50	14	7	71
7 <i>Menidia beryllina</i>	37	4	7	48
8 <i>Cyprinodon variegatus</i>	35	2	--	37
9 <i>Bairdiella chrysoura</i>	29	--	--	29
10 <i>Leiostomus xanthurus</i>	--	8	7	15
11 <i>Fundulus pulvereus</i>	6	4	--	10
12 <i>Myrophis punctatus</i>	1	7	2	10
13 <i>Brevoortia patronus</i>	2	1	6	9
13 <i>Cynoscion nebulosus</i>	1	5	2	8
14 <i>Gambusia affinis</i>	5	--	--	5
15 <i>Symphurus plagiusa</i>	--	5	--	5
16 Unknown fish species	4	--	1	5
17 <i>Gobiosoma robustum</i>	2	1	--	3
18 <i>Paralichthys lethostigma</i>	3	--	--	3
19 <i>Citharichthys spilopterus</i>	--	1	1	2
20 <i>Dormitator maculatus</i>	--	2	--	2
21 <i>Gobiesox strumosus</i>	2	--	--	2
22 <i>Gobionellus boleosoma</i>	1	--	1	2
23 <i>Mugil cephalus</i>	2	--	--	2
24 <i>Poecilia latipinna</i>	2	--	--	2
25 <i>Elops saurus</i>	1	--	--	1
26 <i>Eucinostomus argenteus</i>	1	--	--	1
27 <i>Ictalurus punctatus</i>	1	--	--	1
28 <i>Lepomis cyanella</i>	1	--	--	1
29 <i>Pomoxis annularis</i>	--	1	--	1
30 <i>Sciaenops ocellatus</i>	--	--	1	1
31 <i>Sphoeroides parvus</i>	--	--	1	1
32 <i>Strongylura marina</i>	1	--	--	1
33 <i>Palaemonetes pugio</i>	4075	1395	25	5495
34 <i>Penaeus aztecus</i>	310	294	63	667
35 <i>Callinectes sapidus</i>	207	289	37	533
36 <i>Palaemonetes intermedius</i>	335	33	2	370
37 <i>Rhithropanopeus harrissi</i>	72	118	25	215
38 <i>Palaemonetes paludosus</i>	52	106	--	158
39 <i>Penaeus duorarum</i>	21	50	5	76
40 <i>Penaeus setiferus</i>	6	19	18	43
41 Unknown <i>Palaemonetes</i>	11	--	--	11
42 <i>Neopanope texana</i>	1	5	--	6
43 <i>Palaemonetes vulgaris</i>	6	--	--	6
44 <i>Hippolyte zostericola</i>	--	4	--	4
45 <i>Alpheus sp.</i>	--	2	--	2
46 <i>Callinassa spp.</i>	--	1	--	1
47 <i>Palaemonetes transversus</i>	--	1	--	1

-- = Not Present

APPENDIX IC: OVERALL ABUNDANCES AMONG SPECIES IN SAN ANTONIO BAY-
LOWER BAY HABITATS.

FALL 1986 THRU SPRING 1989

(2.6 . sq. samples, marsh n = 24, SAV n = 24, bare n = 24.)

SPECIES	MARSH	SAV	BARE	TOTAL
1 <i>Gobiosoma boscii</i>	372	340	230	942
2 <i>Menidia beryllina</i>	261	79	74	414
3 <i>Lagodon rhomboides</i>	234	66	14	314
4 <i>Lucania parva</i>	166	121	--	287
5 <i>Syngnathus scovelli</i>	44	124	8	176
6 <i>Cyprinodon variegatus</i>	149	--	--	149
7 <i>Gobiosoma robustum</i>	27	40	13	80
8 <i>Anchoa mitchilli</i>	--	11	35	46
9 <i>Myrophis punctatus</i>	13	8	5	26
10 <i>Fundulus grandis</i>	19	6	--	25
11 <i>Gobionellus boleosoma</i>	3	7	15	25
12 <i>Bairdiella chrysoura</i>	8	10	--	18
13 <i>Leiostomus xanthurus</i>	1	7	8	16
14 <i>Citharichthys spilopterus</i>	3	4	5	12
15 <i>Opsanus beta</i>	7	4	1	12
16 <i>Symphurus plagiosa</i>	--	4	8	12
17 <i>Cynoscion nebulosus</i>	1	4	6	11
18 <i>Poecilia latipinna</i>	11	--	--	11
19 <i>Brevoortia patronus</i>	--	2	6	8
20 <i>Gobiesox strumosus</i>	7	1	--	8
21 <i>Orthopristis chrysoptera</i>	3	4	1	8
22 Unknown fish species	1	4	1	6
23 <i>Microgobius thalassinus</i>	--	--	5	5
24 <i>Microgobius gulosus</i>	--	3	1	4
25 <i>Micropogonias undulatus</i>	1	--	3	4
26 <i>Sciaenops ocellatus</i>	2	--	2	4
27 <i>Achirus lineatus</i>	--	--	3	3
28 <i>Fundulus pulvereus</i>	2	--	1	3
29 <i>Paralichthys lethostigma</i>	1	1	1	3
30 <i>Adinia xenica</i>	2	--	--	2
31 <i>Archosargus probatocephalus</i>	1	--	1	2
32 <i>Strongylura marina</i>	2	--	--	2
33 <i>Fundulus similis</i>	1	--	--	1
34 <i>Gobionellus hastatus</i>	--	1	--	1
35 <i>Mugil cephalus</i>	--	1	--	1
36 <i>Sphaeroides parvus</i>	--	--	1	1
37 <i>Palaemonetes pugio</i>	6834	324	32	7190
38 <i>Palaemonetes intermedius</i>	1917	972	23	2912
39 <i>Penaeus aztecus</i>	246	206	155	607
40 <i>Callinectes sapidus</i>	316	175	16	507
41 <i>Palaemonetes paludosus</i>	370	26	--	396
42 <i>Penaeus setiferus</i>	6	15	93	114
43 <i>Rhithropanopeus harrissi</i>	36	7	2	45
44 <i>Penaeus duorarum</i>	2	28	4	34
45 <i>Palaemonetes vulgaris</i>	18	8	--	26
46 <i>Alpheus heterochaelis</i>	17	6	1	24
47 <i>Hippolyte zostericola</i>	--	11	1	12
48 <i>Clibanarius vittatus</i>	9	--	--	9
49 <i>Alpheus sp.</i>	1	7	--	8
50 <i>Macrobranchium ohione</i>	1	4	--	5
51 <i>Penaeus sp.</i>	--	5	--	5
52 <i>Neopanope texana</i>	--	4	--	4
53 <i>Callinectes similis</i>	2	--	--	2
54 <i>Eurypanopeus depressus</i>	--	2	--	2
55 <i>Palaemonetes sp. (postlarval)</i>	--	2	--	2
56 <i>Processa sp.</i>	--	1	--	1

-- = Not Present

APPENDIX II. Physical data from drop trap sampling in San Antonio Bay during spring and fall seasons, 1986 to 1989.

SAN ANTONIO BAY STUDY Environmental Data	DELTA (Lucas Lake)						UPPER BAY (Barge Canal)						LOWER BAY (Lake Island)					
	MARSH		SAV		BARE		MARSH		SAV		BARE		MARSH		SAV		BARE	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
SALINITY (ppt)																		
FALL 86	0.5	0.29	0.5	0.29	0.25	0.14	7.0	0.00	7.0	0.00	6.9	0.13	21.8	0.48	21.8	0.48	21.8	0.48
SPRING 87	0.1	0.03	0.1	#N/A	0.1	0.00	1.3	0.57	1.1	0.62	1.7	0.87	13.5	0.29	14.2	0.19	13.6	0.38
FALL 87	0.5	0.13	0.3	0.13	0.5	0.07	4.9	0.18	5.4	0.22	6.0	0.11	13.2	0.60	12.5	0.45	12.1	0.71
SPRING 88	4.2	0.25			4.2	0.25	15.5	0.65			16.5	0.29	26.8	0.48	27.0	0.41	27.0	0.41
FALL 88	10.0	1.35			9.8	1.11	17.8	0.63	17.3	0.75	17.3	0.75	33.7	2.17	33.7	2.17	34.5	2.02
SPRING 89	16.0	0.00			16.3	0.25	20.0	0.82			21.5	0.29	32.7	0.75	29.3	0.48	32.0	1.15
TEMPERATURE (degrees C)																		
FALL 86	18.5	0.17	18.2	0.11	18.3	0.11	18.9	0.23	19.0	0.17	18.8	0.33	20.5	0.89	21.6	0.60	20.6	0.35
SPRING 87	24.6	0.31	24.5	#N/A	24.6	0.47	25.8	1.08	25.5	0.65	25.1	0.52	26.1	0.66	26.0	0.17	26.4	0.08
FALL 87	22.8	1.00	23.1	0.86	22.8	0.73	25.9	0.22	25.4	0.42	24.9	0.29	27.7	0.16	27.9	0.47	28.0	0.46
SPRING 88	25.4	0.24			25.3	0.43	28.4	0.55			27.6	0.24	27.3	0.60	27.4	0.47	27.2	0.47
FALL 88	22.1	0.55			22.5	0.65	26.0	0.33	25.8	0.45	26.3	0.28	26.5	1.19	27.1	1.31	26.7	1.50
SPRING 89	26.5	0.29			27.0	0.00	29.5	0.29			28.3	0.25	30.0	0.71	28.9	0.31	29.5	0.65
OXYGEN (ppm)																		
FALL 86	5.8	0.78	7.8	0.42	8.2	0.38	6.6	0.60	8.2	0.68	7.0	0.37	8.3	0.19	8.7	0.39	8.1	0.19
SPRING 87	10.6	0.69	11.0	#N/A	11.0	1.33	11.6	1.61	11.4	1.30	9.3	0.71	8.2	0.71	9.0	0.51	8.8	0.37
FALL 87	15.1	1.63	15.4	1.58	12.9	1.01	12.4	3.85	18.2	0.77	8.2	0.86	15.7	1.56	15.9	2.40	14.9	2.51
SPRING 88	7.7	0.21			7.6	0.59	10.1	0.82			9.3	0.06	10.1	0.88	11.3	0.68	10.5	0.57
FALL 88	7.8	0.37			7.9	0.40	8.6	2.30	12.7	0.77	11.4	0.31	8.6	0.90	9.4	0.67	9.4	0.99
SPRING 89	5.7	0.13			5.7	0.09	6.3	0.29			5.7	0.03	8.7	1.38	5.7	0.11	6.0	0.30
TURBIDITY (ftu)																		
FALL 86	30.8	10.80	50.7	6.37	95.2	15.41	12.5	2.18	10.3	1.93	18.0	6.75	18.8	2.72	19.8	2.29	52.5	18.88
SPRING 87	26.5	7.10	77.2	21.75	26.0	3.81	21.0	4.12	16.8	2.14	29.0	5.70	10.5	0.87	15.8	3.28	8.3	1.44
FALL 87	102.5	26.26	30.0	4.08	55.0	23.12	12.3	3.97	17.8	3.17	46.5	7.89	27.0	12.81	19.0	6.75	21.8	3.79
SPRING 88	71.3	2.85			95.0	17.69	42.3	13.78			39.7	6.17	15.5	3.48	35.5	8.50	29.0	10.44
FALL 88	43.7	6.71			47.0	11.27	23.8	15.54	7.2	1.44	11.3	0.48	15.8	3.79	20.8	7.16	25.3	9.84
SPRING 89	25.5	4.84			18.3	5.54	9.0	1.29			10.5	2.90	5.5	1.19	9.8	0.85	6.5	1.19
DEPTH (cm)																		
FALL 86	35.8	6.06	39.0	1.02	55.0	9.63	34.0	2.20	45.4	3.00	42.5	5.14	39.4	5.37	52.9	1.08	55.1	1.73
SPRING 87	24.5	2.58	15.5	0.50	32.9	1.49	21.4	1.95	26.8	2.18	49.1	1.79	21.4	1.81	40.2	2.88	38.1	9.14
FALL 87	11.6	1.10	23.0	1.31	25.0	2.78	23.8	3.10	38.0	1.58	47.6	3.51	25.9	3.28	32.1	4.55	43.6	5.26
SPRING 88	26.4	3.40			38.6	4.19	16.8	1.24			32.2	2.59	25.3	2.23	40.1	1.12	36.4	0.56
FALL 88	23.5	1.93			28.3	2.87	15.0	2.44	30.9	1.32	27.6	1.72	16.9	2.01	24.8	1.29	35.0	3.29
SPRING 89	23.8	3.40			32.1	2.02	13.9	1.44			38.4	1.16	21.8	1.77	49.6	0.80	39.1	3.30

APPENDIX III. Faunal densities from drop trap sampling in San Antonio Bay during the fall of 1986.

SAN ANTONIO BAY STUDY Macrofauna/2.6 m sq. (n=4) November 5-7, 1986	DELTA (Lucas Lake)						UPPER BAY (Barge Canal)						LOWER BAY (Lake Island)					
	MARSH		SAV		BARE		MARSH		SAV		BARE		MARSH		SAV		BARE	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:																		
<i>Gobiosoma boscii</i>	27	9.08	52	6.01	12.3	6.02	35	14.48	60.5	20.11	5.8	2.14	8.3	2.78	11.3	5.12	7	4.18
<i>Lucania parva</i>	11	4.67	6.8	6.42	2.5	2.5	22.3	19.37	9.8	6.38	0	0	5	4.67	24.8	16.99	0	0
<i>Fundulus grandis</i>	3.5	2.18	0	0	0	0	20.8	10.63	51.3	47.65	0	0	1	1	0.5	0.5	0	0
<i>Menidia beryllina</i>	68.3	64.61	0.5	0.29	0.5	0.5	0	0	0	0	0	0	5	4.67	0.5	0.29	0.3	0.25
<i>Syngnathus scovelli</i>	0	0	0	0	0	0	1.3	1.25	11	5.28	0	0	4	1.22	20.3	4.13	1	1
<i>Cyprinodon variegatus</i>	13.5	7.58	1	0.71	0	0	2.5	1.5	0.5	0.29	0	0	1.3	0.95	0	0	0	0
<i>Gobiosoma robustum</i>	0.3	0.25	1.8	1.03	0	0	0	0	0	0	0	0	0.3	0.25	7	6.35	2.5	2.5
<i>Fundulus pulvereus</i>	3.3	2.93	0.5	0.29	0	0	0	0	0.5	0.29	0	0	0	0	0	0	0.3	0.25
<i>Microgobius gulosus</i>	0	0	1.8	0.85	2	0.71	0	0	0	0	0	0	0	0	0.5	0.5	0	0
<i>Poecilia latipinna</i>	4.3	2.46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lagodon rhomboides</i>	0	0	0	0	0	0	0	0	0.5	0.29	0.5	0.5	0.5	0.29	0.3	0.25	1	0.41
<i>Anchoa mitchilli</i>	0	0	0.8	0.48	1	1	0	0	0	0	0	0	0	0	0	0	0.3	0.25
<i>Gambusia affinis</i>	0	0	0	0	0	0	1.3	1.25	0	0	0	0	0	0	0	0	0	0
<i>Micropogonias undulatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0.8	0.75
<i>Opsanus beta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.75	0	0	0.3	0.25
<i>Microgobius thalassinus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.75
Unknown fish species	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0.3	0.25	0	0
<i>Cynoscion nebulosus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0
<i>Sciaenops ocellatus</i>	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyprinodontidae	31.3	12.26	8.3	7.25	2.5	2.5	45.5	22.98	62	45.04	0	0	7.3	5.3	25.3	16.75	0.3	0.25
Gobiidae	27.3	9.28	55.5	5.69	14.3	5.79	35	14.48	60.5	20.11	5.8	2.14	8.5	2.87	18.8	3.68	10.3	5.65
Sciaenidae	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0.3	0.25	0.8	0.75
Bait Fish	0	0	0.8	0.48	1	1	0	0	0.5	0.29	0.5	0.5	0.5	0.29	0.3	0.25	1.3	0.63
Commercial/Sports Fish	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0
FISH TOTALS:	131.3	79.01	65	7.99	18.3	9.03	83	28.42	134	56.49	6.5	2.02	26.3	12.09	65.5	20.29	14	6.79
CRUSTACEANS:																		
<i>Palaemonetes pugio</i>	240.8	55.37	37.5	14.13	2.8	1.8	327	174.21	253.5	100.83	1.3	0.63	312.5	68.72	9.8	8.17	0.3	0.25
<i>Palaemonetes intermedius</i>	0.5	0.5	0.3	0.25	0	0	2.8	2.75	2.8	1.7	0	0	40.3	25.46	197	108.34	2.5	1.55
<i>Callinectes sapidus</i>	3.3	0.63	1.3	0.48	0.5	0.29	3.5	1.32	7.5	2.47	1.3	0.25	3.5	1.5	2.8	1.49	1	0.71
<i>Rhithropanopeus harrissi</i>	2	0.82	4	1.47	0.5	0.5	2.3	0.85	3	2.12	0.3	0.25	0	0	0	0	0	0
<i>Alpheus heterochaelis</i>	0	0	0	0	0	0	0	0	0	0	0	0	3.5	2.6	0	0	0.3	0.25
Unknown <i>Palaemonetes</i>	0	0	0	0	0	0	2.8	2.75	0	0	0	0	0	0	0	0	0	0
<i>Panopeus aztecus</i>	0	0	0	0	0	0	0.3	0.25	1.3	0.95	0	0	0.5	0.5	0.3	0.25	0	0
<i>Palaemonetes vulgaris</i>	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	1	1	0	0
<i>Neopanope texana</i>	0	0	0	0	0	0	0	0	1.3	1.25	0	0	0	0	0	0	0	0
<i>Callinectes similis</i>	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0
<i>Callinassa</i> spp.	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0
<i>Panopeus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0
Grass Shrimp	241.3	55.32	37.8	14.21	2.8	1.8	332.8	175.33	256.3	100.2	1.3	0.63	352.8	70.61	208	116.08	2.8	1.49
Penaeidae	0	0	0	0	0	0	0.3	0.25	1.3	0.95	0	0	0.5	0.5	0.5	0.29	0	0
CRUSTACEAN TOTALS:	246.8	56.25	43	14.75	3.8	2.17	338.8	176.73	269.5	104.6	2.8	0.85	360.5	69.07	211	115.61	4	2.12

APPENDIX III (continued). Faunal densities from drop trap sampling in San Antonio Bay during the spring of 1987.

SAN ANTONIO BAY STUDY Macrofauna/2.6 m sq. (n=4) May 4-6, 1987	DELTA (Lucas Lake)						UPPER BAY (Barge Canal)						LOWER BAY (Lake Island)								
	MARSH		SAV		BARE		MARSH		SAV		BARE		MARSH		SAV		BARE				
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.			
SPECIES																					
FISHES:																					
<i>Brevoortia patronus</i>	1.8	1.18	0	0	17.8	14.46	0	0	0	0	0	0	0	0	0	0	0	0	0		
<i>Gobiosoma boscii</i>	2.3	1.93	0	0	0.3	0.25	5	2.92	6	3.56	0	0	0.5	0.29	0.3	0.25	0.3	0.25	0.3	0.25	
<i>Lagodon rhomboides</i>	0.5	0.5	0	0	0	0	1.5	0.87	2	1.08	0	0	0.8	0.75	2.5	0.96	0.5	0.5	0.5	0.5	
<i>Leiostomus xanthurus</i>	0	0	0	0	1.3	0.75	0	0	1.3	0.75	1	1	0	0	1.5	1.5	0.3	0.25	0.3	0.25	
<i>Citharichthys spilopterus</i>	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0.8	0.48	0.5	0.29	0.8	0.48	0.8	0.48	
<i>Fundulus grandis</i>	0.5	0.29	0	0	0	0	1.5	0.96	0	0	0	0	0.3	0.25	0	0	0	0	0	0	
<i>Menidia beryllina</i>	0	0	0	0	0.3	0.25	1	0.71	1	1	0	0	0	0	0	0	0	0	0	0	
<i>Myrophis punctatus</i>	0	0	0	0	0	0	0	0	1	0.58	0.3	0.25	0	0	0.3	0.25	0	0	0	0	
<i>Micropogonias undulatus</i>	0.3	0.25	0	0	0.8	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Anchoa mitchilli</i>	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	
<i>Lucania parva</i>	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0.5	0.29	0	0	0	0	0	0	
<i>Symphurus plagiusa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.71	0	0	0	0	
<i>Cyprinodon variegatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.75	0	0	0	0	0	0	
<i>Fundulus pulvereus</i>	0	0	0	0	0	0	0.8	0.75	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Microgobius gulosus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0.3	0.25	0.3	0.25	
<i>Strongylura marina</i>	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	
<i>Syngnathus scovelli</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0.3	0.25	0	0	0	0	
<i>Bairdiella chrysoura</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	
<i>Gobionellus boleosoma</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	
<i>Gobionellus hastatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	
<i>Gobiosoma robustum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	
<i>Microgobius thalassinus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0.3	0.25
<i>Mugil cephalus</i>	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Pomoxis annularis</i>	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0	0	0	
<i>Sciaenops ocellatus</i>	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0	
Cyprinodontidae	0.5	0.29	0	0	0	0	2.3	1.65	0.5	0.5	0	0	1.5	0.87	0	0	0	0	0	0	
Gobiidae	2.3	1.93	0	0	0.3	0.25	5	2.92	6	3.56	0	0	0.5	0.29	1.3	0.63	0.8	0.48	0.8	0.48	
Sciaenidae	0.3	0.25	0	0	2	0.82	0	0	1.3	0.75	1.3	0.95	0	0	2	1.41	0.3	0.25	0.3	0.25	
Bait Fish	0.5	0.5	0	0	0	0	1.8	0.75	2	1.08	1	1	0.8	0.75	2.5	0.96	0.5	0.5	0.5	0.5	
Commercial/Sports Fish	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0	
FISH TOTALS:	5.5	3.1	0	0	20.3	15	10	2.16	12.3	5.33	2.5	1.19	4	1.58	7.8	0.85	2.3	1.03			
CRUSTACEANS:																					
<i>Palaemonetes pugio</i>	5.3	1.31	0	0	0	0	222.8	111.72	30.8	23.69	0.5	0.5	299.8	95.29	1	1	0.5	0.5			
<i>Penaeus aztecus</i>	0	0	0	0	0	0	10	4.83	13.3	5.51	0	0	10.5	2.5	8.8	1.65	7	2			
<i>Palaemonetes intermedius</i>	22.5	9.24	0	0	0	0	3.8	3.75	0.5	0.5	0	0	12.3	3.71	0	0	0.3	0.25			
<i>Callinectes sapidus</i>	4.3	0.48	0.5	0.5	1	0.71	6.5	2.99	4	1.58	0	0	2.8	0.48	0.3	0.25	0	0			
<i>Penaeus duorarum</i>	0	0	0	0	0	0	4.3	2.84	10.3	1.55	0.8	0.48	0	0	0	0	0	0			
<i>Rhithropanopeus harrissi</i>	0.8	0.48	0	0	1.5	0.65	0	0	2.3	1.31	0.5	0.5	0	0	0.3	0.25	0	0			
<i>Penaeus setiferus</i>	0	0	0	0	0	0	0	0	1	1	0.3	0.25	0.3	0.25	0	0	0	0			
<i>Palaemonetes vulgaris</i>	0	0	0	0	0	0	1.3	1.25	0	0	0	0	0	0	0	0	0	0			
<i>Macrobrachium ohione</i>	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0			
<i>Neopanope texana</i>	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0	0	0			
Grass Shrimp	27.8	9.04	0	0	0	0	227.8	113.17	31.3	23.6	0.5	0.5	312	98.27	1	1	0.8	0.48			
Penaeidae	0	0	0	0	0	0	14.3	7.6	24.5	6.3	1	0.71	10.8	2.29	8.8	1.65	7	2			
CRUSTACEAN TOTALS:	33	8.9	0.5	0.5	2.5	1.19	248.8	115.97	62	28.45	2	0.91	325.8	98.98	10.3	2.39	7.8	2.29			

APPENDIX III (continued). Faunal densities from drop trap sampling in San Antonio Bay during the fall of 1987.

SAN ANTONIO BAY STUDY Macrofauna/2.6 m sq. (n=4) September 30 - October 1, 1987	DELTA (Lucas Lake)						UPPER BAY (Barge Canal)						LOWER BAY (Lake Island)						
	MARSH		SAV		BARE		MARSH		SAV		BARE		MARSH		SAV		BARE		
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	
FISHES:																			
<i>Gobiosoma boeci</i>	0	0	0	0	0	0	1.5	0.96	3.5	1.5	1.5	0.65	12.5	3.71	23.8	13.34	3.8	2.17	
<i>Cyprinodon variegatus</i>	0.3	0.25	0	0	1.0	1.0	2.3	1.93	0	0	0	0	33.8	32.43	0	0	0	0	
<i>Lucania parva</i>	4.5	2.06	0	0	0	0	11.3	2.84	14.3	4.61	0	0	3.8	2.17	1.5	1.19	0	0	
<i>Anchoa mitchilli</i>	0	0	0	0	0.5	0.5	0	0	0	0	20.8	7.76	0	0	1.8	1.44	6.5	5.55	
<i>Gambusia affinis</i>	22.3	10.87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Lagodon rhomboides</i>	0	0	0	0	0	0	0	0	1	0.58	0	0	2.5	1.32	4.3	3.07	0	0	
<i>Gobionellus boleosoma</i>	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0.8	0.75	1.3	0.48	3.5	2.06	
<i>Fundulus grandis</i>	0	0	0	0	0	0	2.3	2.25	0	0	0	0	0.8	0.48	1	1	0	0	
<i>Fundulus pulvereus</i>	2.3	1.11	0	0	0	0	0.8	0.48	0.5	0.5	0	0	0.3	0.25	0	0	0	0	
<i>Myrophis punctatus</i>	0	0	0	0	0	0	0	0	0.5	0.29	0	0	1	1	1	1	0	0	
<i>Cyanoecion nebulosus</i>	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0.3	0.25	0.3	0.25	1	1	
<i>Opsanus beta</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.5	0.5	0	0	
<i>Gobiosoma robustum</i>	0	0	0	0	0	0	0.3	0.25	0.3	0.25	0	0	0	0	0	0	0.8	0.48	
Unknown fish species	0.3	0.25	0	0	0	0	0.8	0.75	0	0	0	0	0	0	0	0	0.3	0.25	
<i>Syngnathus scovelli</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0.41	0.3	0.25	0	0	
<i>Menidia beryllina</i>	0.5	0.29	0	0	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Sciaenops ocellatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0.5	0.5	
<i>Achirus lineatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	
<i>Adinia xenica</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	
<i>Dormitator maculatus</i>	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	
<i>Poecilia latipinna</i>	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0	
<i>Symphurus plagusia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.29	
<i>Fundulus similis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	
<i>Ictalurus punctatus</i>	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0	0	0	
<i>Lepomis cyanella</i>	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0	0	0	
Cyprinodontidae	7	1.83	0	0	1.0	1.0	16.5	5.89	14.8	4.4	0	0	39.3	34.63	2.5	1.44	0	0	
Gobiidae	0	0	0	0	0	0	2	1.41	3.8	1.31	1.5	0.65	13.3	3.68	2.5	12.99	8	4.64	
Sciaenidae	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0.5	0.29	0.3	0.25	1.5	0.96	
Bait Fish	0	0	0	0	0.5	0.5	0	0	1	0.58	20.8	7.76	2.5	1.32	8	3.24	6.5	5.55	
Commercial/Sports Fish	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0.5	0.29	0.3	0.25	1.5	0.96	
FISH TOTALS:	30	12.37	0	0	10.8	10.09	20.3	5.27	20.8	5.02	22.3	8.08	58.5	35.18	35.5	18.23	17.3	5.92	
CRUSTACEANS:																			
<i>Palaemonetes pugio</i>	0.5	0.5	3.3	1.65	0	0	5.8	3.47	12	7.12	0	0	183.8	83.96	3.3	2.36	0.3	0.25	
<i>Callinectes sapidus</i>	0	0	5.8	1.93	1.3	0.63	3.5	2.6	8.5	2.4	0	0	8.8	2.5	18	9.6	1	0.41	
<i>Palaemonetes intermedius</i>	0	0	18.5	6.98	0	0	0	0	4.5	2.4	0	0	7.5	4.5	15.5	9.28	0	0	
<i>Penaeus aztecus</i>	0	0	0	0	0	0	9.8	6.41	16.5	5.69	2	1	7.8	2.43	4.8	1.65	4	1.47	
<i>Rhithropanopeus harrissi</i>	0.3	0.25	2.8	1.11	0	0	0.5	0.29	12.5	6.01	0.5	0.5	0.3	0.25	0	0	0	0	
<i>Penaeus setiferus</i>	0	0	0	0	0	0	0	0	0.3	0.25	0.8	0.25	0.8	0.75	1.5	1.19	4.8	1.84	
<i>Penaeus duorarum</i>	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0.8	0.75	1	1	
<i>Alpheus heterochaelis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0.5	0.5	0	0	
<i>Macrobrachium</i> sp.	0	0	0.8	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Hippolyte zostericola</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0.3	0.25	
<i>Callinectes ornatus</i>	0	0	0.5	0.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Palaemonetes</i> sp. (postlarval)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0	
<i>Palaemonetes vulgaris</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	
<i>Thalassinidea</i> sp.	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Grass Shrimp	0.5	0.5	21.8	8.55	0	0	5.8	3.47	16.5	7.33	0	0	191.5	82.3	19.3	9.68	0.3	0.25	
Penaeidae	0	0	0	0	0	0	9.8	6.41	16.8	5.72	3	1.08	8.5	2.36	7	3.39	9.8	3.28	
CRUSTACEAN TOTALS:	1	0.71	31.5	9.74	1.3	0.63	19.5	11.51	54.3	15.92	3.5	1.55	209.3	83.03	45	16.04	11.3	3.82	

APPENDIX III (continued). Faunal densities from drop trap sampling in San Antonio Bay during the spring of 1988.

SAN ANTONIO BAY STUDY Macrofauna/2.6 m sq. (n=4) May 9-10, 1988	D E L T A (Lucas Lake)				U P P E R B A Y (Barge Canal)				L O W E R B A Y (Lake Island)					
	MARSH		BARE		MARSH		BARE		MARSH		SAV		BARE	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:														
<i>Brevoortia patronus</i>	5.5	3.2	60.5	29.92	0	0	1	1	0	0	0	0	0	0
<i>Lagodon rhomboides</i>	1	0.71	0	0	9	1.96	1.3	1.25	26.8	8.47	2.3	1.31	1.3	0.25
<i>Gobiosoma boscii</i>	8.8	2.93	1.8	0.85	7.8	3.66	2.8	0.75	10.5	3.57	1	0.71	0.3	0.25
<i>Bairdiella chrysoura</i>	12	3.11	5.3	1.11	6.5	6.5	0	0	2	2	0.3	0.25	0	0
<i>Anchoa mitchilli</i>	0	0	0.5	0.29	3.8	2.43	14.5	13.51	0	0	0	0	0	0
<i>Lucania parva</i>	0	0	0	0	0	0	0	0	4.3	2.72	0	0	0	0
<i>Leiostomus xanthurus</i>	0.5	0.5	1.8	0.85	0	0	0.8	0.25	0.3	0.25	0	0	0.3	0.25
<i>Menidia beryllina</i>	0.3	0.25	1	0.71	1.8	1.44	0.3	0.25	0	0	0	0	0	0
<i>Syngnathus scovelli</i>	0.3	0.25	0	0	0.5	0.5	0	0	1	0.71	0.3	0.25	0	0
<i>Orthopristis chrysoptera</i>	0	0	0	0	0	0	0	0	0.5	0.29	0.5	0.5	0.3	0.25
<i>Myrophis punctatus</i>	0	0	0	0	0.3	0.25	0	0	0	0	0.5	0.29	0.3	0.25
<i>Citharichthys spilopterus</i>	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0.5	0.29
<i>Fundulus grandis</i>	0	0	0	0	0.8	0.75	0	0	0	0	0	0	0	0
<i>Paralichthys lethostigma</i>	0	0	0	0	0	0	0	0	0.3	0.25	0.3	0.25	0.3	0.25
<i>Strongylura marina</i>	0	0	0	0	0.3	0.25	0	0	0.3	0.25	0	0	0	0
<i>Gobiosox strumosus</i>	0.5	0.29	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cynoscion nebulosus</i>	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0	0
<i>Elops saurus</i>	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0
<i>Sphoeroides parvus</i>	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0
Cyprinodontidae	0	0	0	0	0.8	0.75	0	0	4.3	2.72	0	0	0	0
Gobiidae	8.8	2.93	1.8	0.85	7.8	3.66	2.8	0.75	10.5	3.57	1	0.71	0.3	0.25
Sciaenidae	12.8	3.07	7	1	6.5	6.5	0.8	0.25	2.3	1.93	0.3	0.25	0.3	0.25
Bait Fish	1	0.71	0.5	0.29	12.8	2.56	15.8	13.14	26.8	8.47	2.3	1.31	1.3	0.25
Commercial/Sport Fish	0.3	0.25	0	0	0	0	0	0	0.3	0.25	0.3	0.25	0.3	0.25
FISH TOTALS:	29	7.31	70.8	29.08	30.8	8.5	21	13.31	45.8	7.28	5	2.89	3	0.91
CRUSTACEANS:														
<i>Palaemonetes pugio</i>	125.5	19.79	3.3	1.49	150	25.22	4.3	1.97	427.8	51.91	0.5	0.5	3.8	3.42
<i>Palaemonetes intermedius</i>	5	2.04	0	0	51.8	7.63	0.5	0.5	82	34.77	1	0.71	0.5	0.5
<i>Penaeus aztecus</i>	7.8	5.48	10	2.16	7.8	2.53	4.8	0.85	15.3	2.39	4	2.31	4.8	1.25
<i>Callinectes sapidus</i>	13	1.22	1	0.71	16.3	2.14	0.8	0.48	15	4.26	0	0	0	0
<i>Rhithropanopeus harrissi</i>	0.8	0.48	1.3	0.95	3.3	1.7	0.5	0.29	0	0	0	0	0	0
<i>Macrobrachium ohlone</i>	5.3	1.7	0	0	0	0	0	0	0	0	0	0	0	0
<i>Penaeus setiferus</i>	1.8	1.75	0	0	0	0	0	0	0	0	0	0	0	0
<i>Palaemonetes vulgaris</i>	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0	0
Grass Shrimp	130.8	18.6	3.3	1.49	201.8	26.13	4.8	2.46	509.8	86.24	1.5	0.87	4.3	3.92
Penaeidae	9.5	4.91	10	2.16	7.8	2.53	4.8	0.85	15.3	2.39	4	2.31	4.8	1.25
CRUSTACEAN TOTALS:	159.3	18.53	15.5	2.87	229	28.81	10.8	1.75	540	85.38	5.5	3.18	9	5.07

APPENDIX III (continued). Faunal densities from drop trap sampling in San Antonio Bay during the fall of 1988.

SPECIES	DELTA (Lucas Lake)				UPPER BAY (Barge Canal)				LOWER BAY (Lake Island)							
	MARSH		BARE		MARSH		SAV		BARE		MARSH		SAV		BARE	
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
FISHES:																
<i>Gobiosoma boscii</i>	19	4.56	0.8	0.48	18.5	10.4	46	17.33	3.5	1.55	53.3	7.09	39.5	13.44	4.3	2.29
<i>Lucania parva</i>	0	0	0	0	5.3	3.54	1.8	1.44	0	0	27.8	14.37	4	3.67	0	0
<i>Syngnathus scovelli</i>	0.3	0.25	0	0	0.3	0.25	7	3.58	0.3	0.25	3.8	2.25	9.8	4.48	0.5	0.5
<i>Fundulus grandis</i>	1.5	0.96	0	0	4.8	2.59	0.3	0.25	0	0	2.5	1.5	0	0	0	0
<i>Cyprinodon variegatus</i>	0	0	0	0	4	3.37	0	0	0	0	1.5	1.5	0	0	0	0
<i>Anchoa mitchilli</i>	0.3	0.25	1.3	0.95	0	0	0	0	0	0	0	0	0.8	0.75	2	1.41
<i>Menidia beryllina</i>	0.5	0.29	0	0	0	0	0	0	0.8	0.75	0	0	0	0	2.8	2.43
<i>Poecilia latipinna</i>	0.3	0.25	0	0	0	0	0	0	0	0	2.8	2.75	0	0	0	0
<i>Symphurus plagiosa</i>	0	0	0	0	0	0	1.3	0.95	0	0	0	0	0	0	1.5	0.87
<i>Cynoscion nebulosus</i>	0	0	0	0	0	0	1	0.41	0.5	0.5	0	0	0.3	0.25	0.5	0.29
<i>Myrophis punctatus</i>	0	0	0	0	0	0	0.3	0.25	0	0	1.3	0.48	0	0	0	0
Unknown fish species	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0.5	0.5	0	0
<i>Fundulus pulvereus</i>	0.3	0.25	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0
<i>Gobionellus boleosoma</i>	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0.3	0.25
<i>Mugil cephalus</i>	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Achirus lineatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25
<i>Eucinostomus argenteus</i>	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0	0	0
<i>Gobiesox strumosus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0
<i>Lagodon rhomboides</i>	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0
<i>Microgobius thalassinus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25
<i>Opsanus beta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0
<i>Paralichthys lethostigma</i>	0.3	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyprinodontidae	1.8	1.18	0	0	14	6.54	2	1.35	0	0	32	16.75	4	3.67	0	0
Gobiidae	19	4.56	0.8	0.48	18.5	10.4	46	17.33	3.8	1.75	53.3	7.09	39.5	13.44	4.8	2.17
Sciaenidae	0	0	0	0	0	0	1	0.41	0.5	0.5	0	0	0.3	0.25	0.5	0.29
Bait Fish	0.8	0.48	1.3	0.95	0	0	0	0	0	0	0.3	0.25	0.8	0.75	2	1.41
Commercial/Sports Fish	0.3	0.25	0	0	0	0	1	0.41	0.5	0.5	0	0	0.3	0.25	0.5	0.29
FISH TOTALS:	22.8	5.94	2	1.22	33	8.8	57.5	17.77	5.3	1.25	93.5	14.45	55.3	15.77	12.3	3.9
CRUSTACEANS:																
<i>Palaemonetes pugio</i>	281.5	74.58	0	0	130.3	87.69	52	25.04	0	0	331	162.44	65.5	27.68	0	0
<i>Callinectes sapidus</i>	14	4.53	2.8	1.8	13.8	7.19	52.3	23.29	7.3	2.02	25.3	2.66	20.5	5.91	0.8	0.48
<i>Palaemonetes peltodosus</i>	0	0	0	0	13	7.9	26.5	12.84	0	0	77.3	40.72	6.5	3.12	0	0
<i>Penaeus aztecus</i>	5.8	3.2	1	0.71	8	4.69	42.5	11.49	2.8	0.95	7.5	2.96	17.5	8.39	2.5	0.96
<i>Penaeus setiferus</i>	2.8	1.89	0.3	0.25	1.5	1.19	3.5	2.87	3.5	0.5	0.5	0.5	2.3	1.65	18.5	4.52
<i>Palaemonetes intermedius</i>	2.5	2.5	0	0	0	0	0.5	0.5	0	0	1.8	1.03	24.5	7.5	0.3	0.25
<i>Rhithropanopeus harrissi</i>	0	0	0.5	0.5	8.5	5.69	7.3	3.15	1.5	0.87	5	3.08	1.3	0.75	0	0
<i>Penaeus duorarum</i>	0	0	0	0	1	1	2.3	1.44	0.3	0.25	0.5	0.29	6.3	2.66	0	0
<i>Alpheus sp.</i>	0	0	0	0	0	0	0.5	0.29	0	0	0	0	1.8	1.75	0	0
<i>Penaeus sp.</i>	0.5	0.5	0.8	0.48	0	0	0	0	0	0	0	0	1	0.71	0	0
<i>Hippolyte zostericola</i>	0	0	0	0	0	0	1	0.71	0	0	0	0	0.8	0.75	0	0
<i>Palaemonetes vulgaris</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
<i>Eurypanopeus depressus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0
<i>Callinectes similis</i>	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0
<i>Palaemonetes transversus</i>	0	0	0	0	0	0	0.3	0.25	0	0	0	0	0	0	0	0
Grass Shrimp	284	74.98	0	0	130.3	87.69	52.5	25.5	0	0	332.8	161.93	91	35.41	0.3	0.25
Penaeidae	9	3.76	2	1.08	10.5	6.36	48.3	9.31	6.5	1.26	8.5	3.33	2.7	8.44	2.1	4.71
CRUSTACEAN TOTALS:	307	77.34	5.3	3.28	76	100.86	188.5	54.1	15.3	3.5	449	206.15	149.3	50.34	2.2	5.05

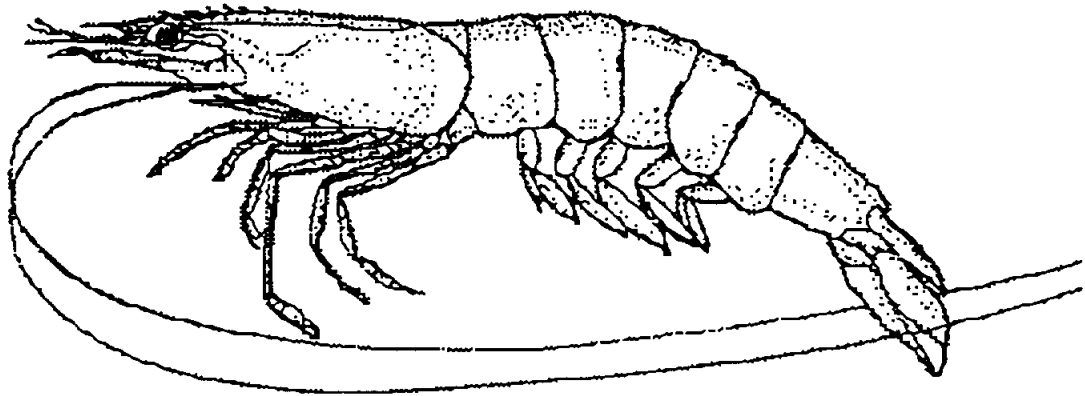
APPENDIX III (continued). Faunal densities from drop trap sampling in San Antonio Bay during the spring of 1989.

SPECIES	DELTA (Lucas Lake)				UPPER BAY (Barge Canal)				LOWER BAY (Lake Island)					
	MARSH		BARE		MARSH		BARE		SAV		BARE			
	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.		
FISHES:														
<i>Gobiosoma boscii</i>	3	1.78	5.3	1.75	21.8	18.53	21.3	7.69	8	7.34	9.3	3.97	4.2	13.93
<i>Menidia beryllina</i>	1	0.58	0	0	6.5	1.18	0.8	0.48	60.3	20.1	19.3	8.65	15.5	6.9
<i>Lagodon rhomboides</i>	1.3	0.25	0	0	2	1.41	0	0	27.8	4.75	7.3	3.3	0.8	0.25
<i>Gobiosoma robustum</i>	0	0	0	0	0.3	0.25	0	0	6.5	2.4	2.8	1.49	0	0
<i>Bairdiella chrysoura</i>	1.3	1.25	0.3	0.25	0.8	0.75	0	0	0	0	1.8	1.03	0	0
<i>Brevoortia patronus</i>	0.3	0.25	0.5	0.5	0.5	0.28	0.5	0.29	0	0	0.5	0.5	1.5	0.96
<i>Syngnathus scovelli</i>	0.8	0.48	0.3	0.25	0.5	0.5	0	0	1	0.41	0.3	0.25	0.5	0.29
<i>Leiostomus xanthurus</i>	1.5	1.5	0	0	0	0	0	0	0	0	0.3	0.25	1.5	0.65
<i>Anchoa mitchilli</i>	0	0	0	0	0	0	2.8	1.03	0	0	0.3	0.25	0	0
<i>Myrophis punctatus</i>	0	0	0	0	0	0	0.3	0.25	1	0.71	0.3	0.25	1	0.71
<i>Gobiosox strumosus</i>	0	0	0	0	0.5	0.29	0	0	1.8	1.44	0	0	0	0
<i>Cynoscion nebulosus</i>	0	0	0.3	0.25	0.3	0.25	0	0	0	0	0.3	0.25	0	0
<i>Orthopristis chrysoptera</i>	0	0	0	0	0	0	0	0	0.3	0.25	0.5	0.5	0	0
<i>Paralichthys lethostigma</i>	0	0	0	0	0.8	0.75	0	0	0	0	0	0	0	0
<i>Archosargus probatocephalus</i>	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0.3	0.25
<i>Mugil cephalus</i>	0	0	0	0	0.3	0.25	0	0	0	0	0.3	0.25	0	0
<i>Sciaenops ocellatus</i>	0	0	0.3	0.25	0	0	0	0	0.3	0.25	0	0	0	0
Unknown fish species	0	0	0	0	0.3	0.25	0	0	0	0	0.3	0.25	0	0
<i>Citharichthys spilopterus</i>	0	0	0	0	0	0	0	0	0	0	0.5	0.29	0	0
<i>Fundulus grandis</i>	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0
<i>Gobionellus boleosoma</i>	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0
<i>Lucania parva</i>	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0
<i>Opsanus beta</i>	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0
<i>Sphoeroides parvus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0.25
Cyprinodontidae	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0
Gobiidae	3	1.78	5.3	1.75	22	18.43	21.3	7.69	14.5	9.08	12.3	3.2	4.2	13.93
Sciaenidae	2.8	1.6	0.8	0.48	1	1	0	0	0.3	0.25	2.3	1.31	1.5	0.65
Bait Fish	1.3	0.25	0	0	2.3	1.44	2.8	1.03	27.8	4.75	7.8	3.12	0.8	0.25
Commercial/Sports Fish	0	0	0.5	0.29	1	0.71	0	0	0.3	0.25	0.3	0.25	0	0
FISH TOTALS:	9	3.94	6.8	0.85	34.3	18.36	25.5	7.59	107.5	23.41	44	16.48	63.3	15.99
CRUSTACEANS:														
<i>Palaemonetes intermedius</i>	1.8	1.75	0	0	25.5	13.89	0	0	335.5	85.2	5	3.32	2.3	0.63
<i>Palaemonetes pugio</i>	88.5	45.59	0.3	0.25	89.3	79.32	0.3	0.25	153.8	80.53	1	0.41	3.3	2.02
<i>Penaeus aztecus</i>	23.8	5.25	6	2.08	41.8	17.02	6.3	1.31	20	5.97	16	3.7	20.5	6.51
<i>Callinectes sapidus</i>	3.8	1.49	0	0	8.3	3.22	0	0	23.8	2.1	2	0.41	1.3	0.48
<i>Rhithropanopeus harrisi</i>	9	3.74	2	1.08	3	1.47	1	0.58	0	0	0.3	0.25	0.5	0.5
<i>Palaemonetes paldosus</i>	0	0	0	0	0	0	0	0	15.3	10.18	0	0	0	0
<i>Palaemonetes vulgaris</i>	0	0	0	0	0	0	0	0	4.3	4.25	0	0	0	0
<i>Clibanarius vittatus</i>	0	0	0	0	0	0	0	0	2.3	0.63	0	0	0	0
<i>Macrobranchium ohione</i>	0.8	0.48	0	0	0	0	0	0	0	0	1	1	0	0
<i>Hippolyte zostericola</i>	0	0	0	0	0	0	0	0	0	0	1.8	1.44	0	0
<i>Alpheus heterochaelis</i>	0	0	0	0	0	0	0	0	0.5	0.29	1	1	0	0
<i>Neopanope texana</i>	0	0	0	0	0	0	0	0	0	0	1	1	0	0
<i>Alpheus sp.</i>	0	0	0	0	0	0	0	0	0.3	0.25	0	0	0	0
<i>Penaeus duorarum</i>	0	0	0.3	0.25	0	0	0	0	0	0	0	0	0	0
<i>Procaesa sp.</i>	0	0	0	0	0	0	0	0	0	0	0.3	0.25	0	0
Grass Shrimp	90.3	46.14	0.3	0.25	114.8	76.35	0.3	0.25	493.5	98.63	6	3.67	5.5	1.85
Peneidae	23.8	5.25	6.3	2.14	41.8	17.02	6.3	1.31	20	5.97	16	3.7	20.5	6.51
CRUSTACEAN TOTALS:	127.5	54.14	8.5	2.9	167.8	91.6	7.5	1.85	555.5	106.07	29.3	9.64	27.8	7.6



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EXPERIMENTAL STUDIES ON SELECTION FOR VEGETATIVE STRUCTURE BY PENAEID SHRIMP



MARCH 1990

GALVESTON LABORATORY
SOUTHEAST FISHERIES CENTER
NATIONAL MARINE FISHERIES SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC
ADMINISTRATION
DEPARTMENT OF COMMERCE

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**NOAA TECHNICAL MEMORANDUM
NMFS-SEFC-237**

**Experimental Studies on Selection for
Vegetative Structure by Penaeid Shrimp**

BY

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	ii
TABLE OF CONTENTS	iv
EXECUTIVE SUMMARY	v
INTRODUCTION	1
METHODS.....	1
General	1
Salinity and a Simulated Freshwater Event	2
Turbidity	2
Food.....	3
Substrate	3
Day Length	3
Light	3
Predators	3
RESULTS	4
Salinity	4
Simulated Freshwater Event	4
Turbidity	11
Food.....	11
Substrate	15
Size	18
Day Length and Light	18
Shrimp Density	18
Predators	24
Control Variability and Within Tank Error	24
DISCUSSION	26
Selection for Structure by Brown Shrimp	26
Selection for Structure by White Shrimp	27
Relationships between Activity and Selection for Structure	27
LITERATURE CITED.....	29

EXECUTIVE SUMMARY

Variability in selection for vegetated habitats by juvenile brown shrimp, *Penaeus aztecus*, and white shrimp, *P. setiferus*, as evidenced by distributions in estuaries, suggests that the value of these habitats is not constant. Previous laboratory work indicates that selection for structure itself is one component of habitat selection, but environmental conditions and other habitat characteristics undoubtedly affect the utilization of vegetated estuarine habitats. This study was designed to examine the effect of environmental variables on selection for structure in the laboratory in an effort to increase our understanding of the way habitats are utilized by penaeid shrimp.

Brown shrimp are generally found in association with estuarine vegetation, and they selected for vegetative structure in the laboratory. An average of 81% of brown shrimp were distributed in the vegetated half of control tanks. Reductions in salinity to oligohaline levels, used to simulate flood events in estuaries, significantly reduced selection for structure. The reduction of light, either through the manipulation of lighting or through turbidity, had a similar effect on brown shrimp distributions. Neither reduced salinity or light, however, reduced the mean percentage of shrimp in the grass below 50%. The overall presence or absence of food or of an appropriate substrate for burrowing, did not alter selection for structure, but the distribution of these habitat characteristics had a dramatic effect on shrimp distributions. Attraction to food or to a substrate for burrowing can override the inherent selection for structure normally exhibited by brown shrimp. Other variables examined including day length and shrimp size did not significantly affect selection.

White shrimp distributions in relation to estuarine vegetation are more variable. In our experiments, white shrimp also showed an inherent selection for the vegetated half of the control tanks (75% of shrimp in the vegetation), but none of our experimental variables appeared to influence this selection to any great extent. There was a strong correlation between white shrimp activity and selection for structure, and this relationship may have contributed to the relatively large variability in selection by this species.

INTRODUCTION

Distributions of juvenile brown shrimp, *Penaeus aztecus*, and white shrimp, *P. setiferus* in estuaries, suggest that habitat selection and perhaps habitat value vary with environmental conditions. Young brown shrimp are often found in association with estuarine vegetation (Loesch 1965, Stokes 1974), and in Galveston Bay, Texas, they are generally concentrated in available salt marsh habitats (Zimmerman et al. 1984). During early spring, however, juvenile brown shrimp are more abundant on nonvegetated bottom (Zimmerman and Minello 1984), suggesting that the relative value of salt marshes for this species may not be constant. In contrast, white shrimp select for salt marsh vegetation sporadically, and exhibit an overall inconsistent distribution pattern in relation to vegetated habitats (Loesch 1965, Stokes 1974, Zimmerman and Minello 1984, Minello and Zimmerman 1985). Exploitation of the salt marsh surface appears to be beneficial to brown shrimp, providing increased food for growth (Zimmerman et al. in press) and protection from fish predators (Minello and Zimmerman 1983, Minello et al. 1989). Although relatively little is known of estuarine habitat value for white shrimp, this species does not appear to obtain the same benefits from vegetated habitats as brown shrimp. Assuming that distributional patterns are related to habitat value, environmental characteristics affecting habitat selection may be related to habitat functions.

An understanding of the factors controlling selection for vegetative structure, should be useful in determining how habitats are utilized. Therefore, we examined the effect of environmental variables on selection for structure by brown shrimp and white shrimp in a series of laboratory experiments. These variables included salinity, a simulated freshwater event (rapid salinity reduction), turbidity, food availability, substrate type, day length, light, and the presence of predators. The effects of shrimp size and density were also examined.

METHODS

General

Experimental animals were collected with trawls in West Galveston Bay, held in a laboratory with an artificial day/night light cycle of 12 hr, and fed each evening with pelleted food. Salinities were slowly altered (over several hours) from collection levels to 20 ‰ in holding tanks, and this salinity was used in all experiments except those where salinity was an experimental factor. Water temperatures in holding and experimental tanks were maintained near 25 to 27 °C.

The 16 rectangular experimental tanks (1.5 m x 0.6 m) were filled with seawater to a depth of 25 cm, and illumination was provided by daylight fluorescent bulbs. Light was measured just above the water's surface using a LICOR integrating quantum meter (Model LI-188B) and ranged between 22 and 27 microeinsteins (μE) $s^{-1} m^{-2}$. To provide a substrate which prevented shrimp from burrowing and facilitated observations, we placed black plastic mesh (6.4 mm) over washed beach sand and then added enough additional sand to cover the mesh. Green plastic drinking straws were used to simulate vegetation and were placed over one half the bottom of each tank in evenly spaced clumps of four straws each. Clumps were spaced 5.5 cm apart, resulting in a density of 670 straws/ m^2 in the vegetated half of the tank (0.75 m x 0.6 m area). Curtains were hung around each tank to reduce disturbances.

Tanks were randomly assigned to experimental treatments, and ten juvenile shrimp (45-60 mm, total length) were placed in each tank the evening before an experiment. Lights came on at 0700 hrs, and observations were made through small openings in the curtains every 2 hrs throughout the day beginning at 0900 hrs and ending at 1700 hrs. The number of shrimp in the vegetated and nonvegetated halves of each tank was recorded, and the activity level of the shrimp was classified as sedentary or active (crawling and swimming).

The percentage of shrimp in the vegetated half of each tank was used as the observation in an ANOVA after an arcsin transformation. The multiple observations taken in each tank throughout the day (generally 5) were treated as subsamples which provided a within tank error term in the analysis. All main effects were tested over the among tank error. The percentage of active shrimp in each tank was analyzed in a similar manner. If the experiment was repeated on a second day, day was treated as a blocking variable in the analysis.

Salinity and a Simulated Freshwater Event

Before each experiment, shrimp were placed in acclimation tanks, and salinities were adjusted to experimental levels of 3 ‰, 20 ‰, and 38 ‰ over a 5-day period using dechlorinated tap water or seawater mixed with artificial sea salts. Initial daily changes were 5 ‰ followed by changes of 2-3 ‰ per day as experimental salinities were approached. Shrimp were then held at these salinities for at least 2 days before an experiment was initiated.

The two treatments with initial salinities of 38 ‰ and 20 ‰ were both assigned six experimental tanks and the 3 ‰ treatment contained four tanks. The effect of salinity itself was determined from observations made during the first day that shrimp were subjected to these experimental conditions. That evening, shrimp were fed with a small amount of pelleted food distributed evenly between vegetated and nonvegetated sides of each experimental tank. The following morning, half of the six tanks with 38 ‰ and 20 ‰ were subjected to a simulated freshwater event. Beginning at 0830 hrs, salinities were lowered in these tanks from 38 to 20 ‰ and from 20 to 3 ‰ over a 3-hr period at a rate of 3 ‰ every half hour. Salinities were reduced by lowering water levels with a small electric pump and incrementally replacing water with dechlorinated freshwater. Airstones provided vertical mixing. Water levels in all other tanks were also lowered and replaced with water of the original

salinity to control for the disturbance effect of water removal and addition. Salinity reductions were completed by 1200 hrs, and observations on the distribution and activity level of shrimp in the tanks were recorded at 1300, 1500, and 1700 hrs.

To maintain a balanced design, data from four tanks per treatment level were used in the analysis of overall salinity effects, while three tanks per treatment level (five levels) were analyzed to determine the effect of a freshwater event. The entire experiment was repeated on a second day. In the ANOVAs on salinity reduction, combinations of the five treatment levels were examined through contrasts. In Contrast A, the three treatments with no salinity change were contrasted with the two treatments where salinity was lowered (38 to 20 ‰ and 20 to 3 ‰), and in Contrast B, the two treatments with a final salinity of 3 ‰ were contrasted with the remaining three treatments.

Turbidity

A slurry of bentonite and seawater was used to create turbid water, and selection for structure was measured at four turbidity levels (0, 10, 25, 50 FTUs). Clay was added to the tanks during the dark cycle on the morning of an experiment, and periodically throughout the morning to maintain treatment turbidity levels. Turbidities were measured with a nephelometric turbidimeter (H-F Instruments Model DRT-15) using a formazin standard and recorded as Formazin Turbidity Units (FTUs). Effects of disturbance due to adding the clay mixture were controlled by adding clear water to the 0 FTU treatment. Because direct observations on the distribution of shrimp could not be made in all treatments, the number of shrimp in each half of the tank was determined by draining the tanks (around 1200 hrs) after a mesh wall was placed at the edge of the vegetation dividing the tank in half. Before draining, but after the wall was in place, light intensity was measured at the water's surface and 13 cm off the bottom in the center of the

nonvegetated half of each tank. Underwater light readings were taken with the sensor directed both towards the surface and horizontally towards the wall of the tank. The experiment was repeated on a second day.

Food

The effect of food distribution was examined using rings of squid (1.0-1.3 g each) attached to small lead weights. Observations on the distribution of shrimp with no food in the tanks were made at 0900 and 1100 hrs; food was then added at 1200 hrs. The four treatment levels were: no food present, food in both vegetated and nonvegetated halves of the tank, food only in the vegetated half, and food only in the nonvegetated half. Three squid rings were placed in each tank half, and lead weights without squid were placed in the non-food treatments. Shrimp distribution and activity and the number of shrimp feeding were recorded at 1300, 1500, and 1700 hrs. The effect of food on selection for structure was also examined at night following the brown shrimp experiment. Food was removed after the 1700 hr observations, and replaced at midnight. The distribution of the shrimp was recorded at 0100 hrs using a small red light.

Substrate

In experiments on the effect of substrate, approximately 5 cm of washed beach sand was compared with the sand/plastic mesh (no sand) used in all other experiments. Shrimp readily burrowed in the beach sand. The four treatment levels examined were: no sand throughout the tank, sand throughout the tank, sand only in the vegetated half, and sand only in the nonvegetated half. Observations on shrimp distribution and activity were made every 2 hrs throughout the day and at midnight following the experiment. Observations were also made on burrowing frequency; a shrimp was considered burrowed if more than 1/2 of its body was beneath the substrate surface.

Day Length

The effect of day length was experimentally examined with brown shrimp to determine whether seasonal changes in day length might alter selection for vegetation. The shrimp were collected on July 28 when the natural day length is approximately 13.5 hrs in Galveston, Tx. Shrimp were placed in holding tanks under two laboratory day/night cycles, our standard 12 hr day/night cycle (similar to early spring conditions in Texas) and a 14 hr day/10 hr night cycle. Lights in both treatments were synchronized to come on at 0700 hrs each morning. During the dark cycle on August 12, we transferred shrimp from holding tanks to seven experimental tanks per treatment. Observations on shrimp distribution and activity were recorded throughout the following day.

Light

We also examined whether the presence or absence of light affected selection for structure by brown shrimp. At 0900 hrs the distribution and activity of shrimp was recorded in 12 lighted tanks (standard illumination of 22-27 $\mu\text{E s}^{-1} \text{m}^{-2}$). We turned the lights off over 6 of the 12 tanks at 0930 hrs. Light in these dark tanks was below the sensitivity of our meter (0.001 $\mu\text{E s}^{-1} \text{m}^{-2}$). Observations on the distribution and activity of shrimp in both light and dark tanks were recorded at 1100 and 1300 hrs.

Predators

Southern flounder, *Paralichthys lethostigma*, were used to examine the effect of a predator on selection for structure by white shrimp. Fish ranged in size from 135 to 266 mm (TL), and they were starved for 24 hrs before the experiment. Initial shrimp density in this experiment was 12/tank, and the distribution and the number of shrimp in the experimental tanks was recorded throughout the day. We used five tanks without fish and five tanks containing one southern flounder, and repeated the entire experiment on a second day.

RESULTS

Salinity

The mean percentage of brown shrimp in the vegetated half of the tanks was lowest at a salinity of 3 ‰ (Table 1, Figure 1), and the effect of salinity on selection for structure was marginally significant ($P=0.052$). The overall difference, however, in the percentage of shrimp in the grass at 3 ‰ (86% in the grass) compared to 38 ‰ (94%) was only 8% and may be of little biological significance. Selection for structure by white shrimp was not significantly affected by salinity (Table 1, Figure 2).

Activity levels (shrimp swimming or crawling) of brown shrimp were low, and overall only 3% of the shrimp were active (Figure 1). In the white shrimp experiment, overall activity was around 33% (Figure 2). There was no significant effect of salinity on activity of either species (Table 1).

Simulated Freshwater Event

The overall treatment effect in the salinity-reduction experiment was highly significant for brown shrimp (Table 2), but a comparison of the two salinity reduction treatments with the three constant salinity treatments (3 ‰, 20 ‰, and 38 ‰) was not significant (Con-

trast A). The reduction in salinity from 38 to 20 ‰ had no significant effect on selection for structure, but the reduction from 20 to 3 ‰ was significantly different from all other treatment levels, reducing the percentage of brown shrimp in the grass to 62% (Table 3). In general, low salinity resulted in relatively low numbers of shrimp in the grass, and salinity reduction to a final low salinity had the greatest effect. The two treatments with final salinities of 3 ‰ were significantly different from the other treatment levels (Contrast B). The effect of reducing salinity from 20 ‰ to 3 ‰ appeared greatest just after the reduction (at 1300 hrs), and the percentage of brown shrimp in the grass in this treatment increased with time following the addition of fresh water (Figure 3). Salinity reduction to 3 ‰ also caused shrimp mortality (observations on distribution were made only on survivors), and mean survival (out of 10 shrimp) in these tanks was 9.6 shrimp at 1300 hrs, 7.6 shrimp at 1500 hrs, and 6.0 shrimp at 1700 hrs. No mortality was observed in other treatments.

Salinity reduction did not appear to have the same strong effect on white shrimp, and the main effect of salinity reduction in the ANOVA was only marginally significant ($P=0.055$, Table 4). However, the trend of reduced numbers in the grass at low salinity

Table 1. The effect of salinity on the percentage of shrimp in the grass and the percentage of active shrimp. The probability value (P) listed is from an ANOVA comparing all treatment means (8 replicate tanks/mean) using an arcsin transformation. Individual means cannot be statistically distinguished at the 0.05 level if they are connected by a line (LSD multiple range test).

Percent in the Grass	P	Salinity		
		38 ppt	20 ppt	3 ppt
Brown shrimp	0.052	94%	89%	86%
White shrimp	0.35	82%	76%	78%
Percent Active				
Brown shrimp	0.78	2%	4%	4%
White shrimp	0.90	33%	35%	30%

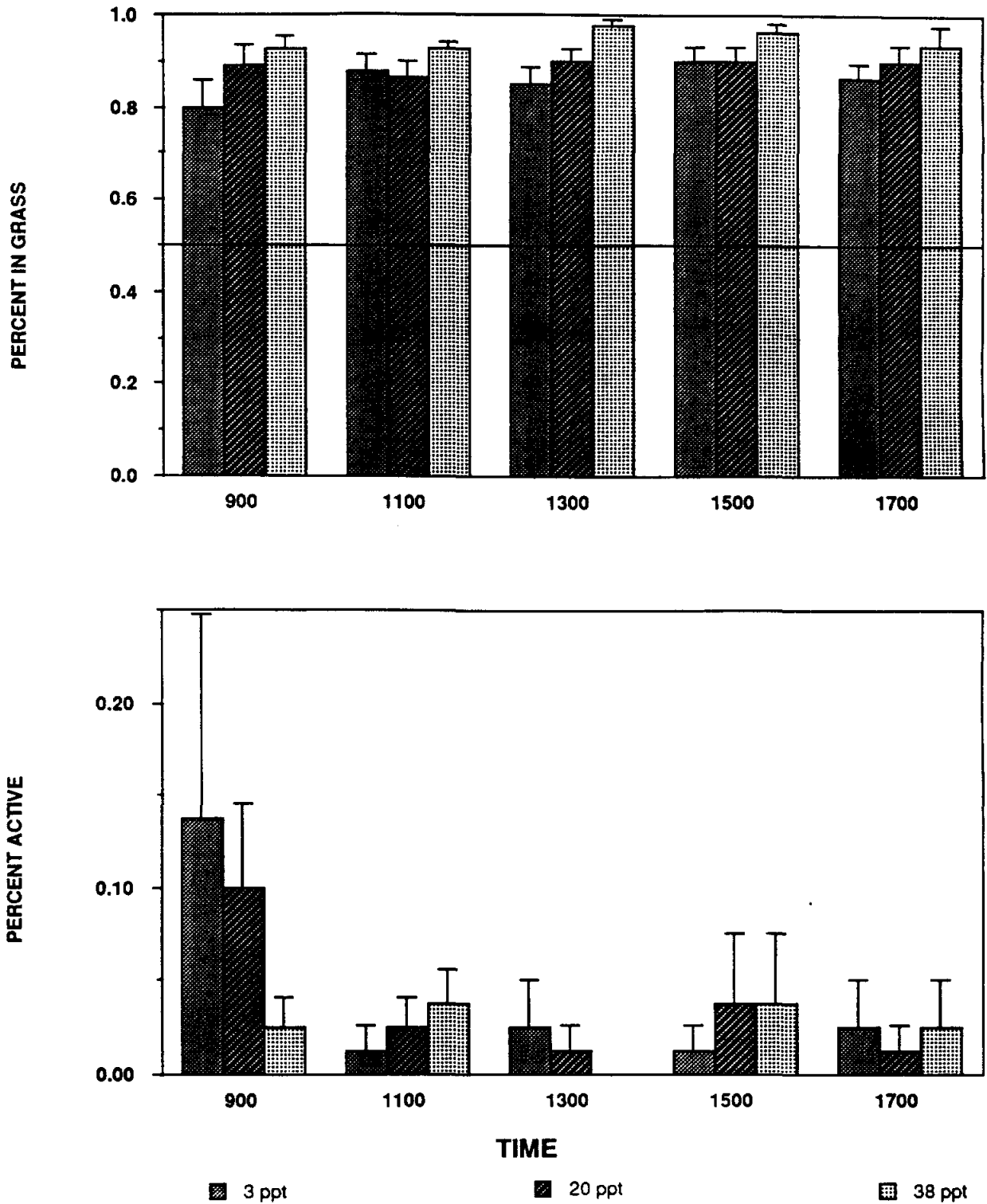


Figure 1. The effect of salinity on selection for structure and activity of brown shrimp. Each bar is a mean percentage from 8 replicate tanks; error bars represent 1 SE from untransformed data.

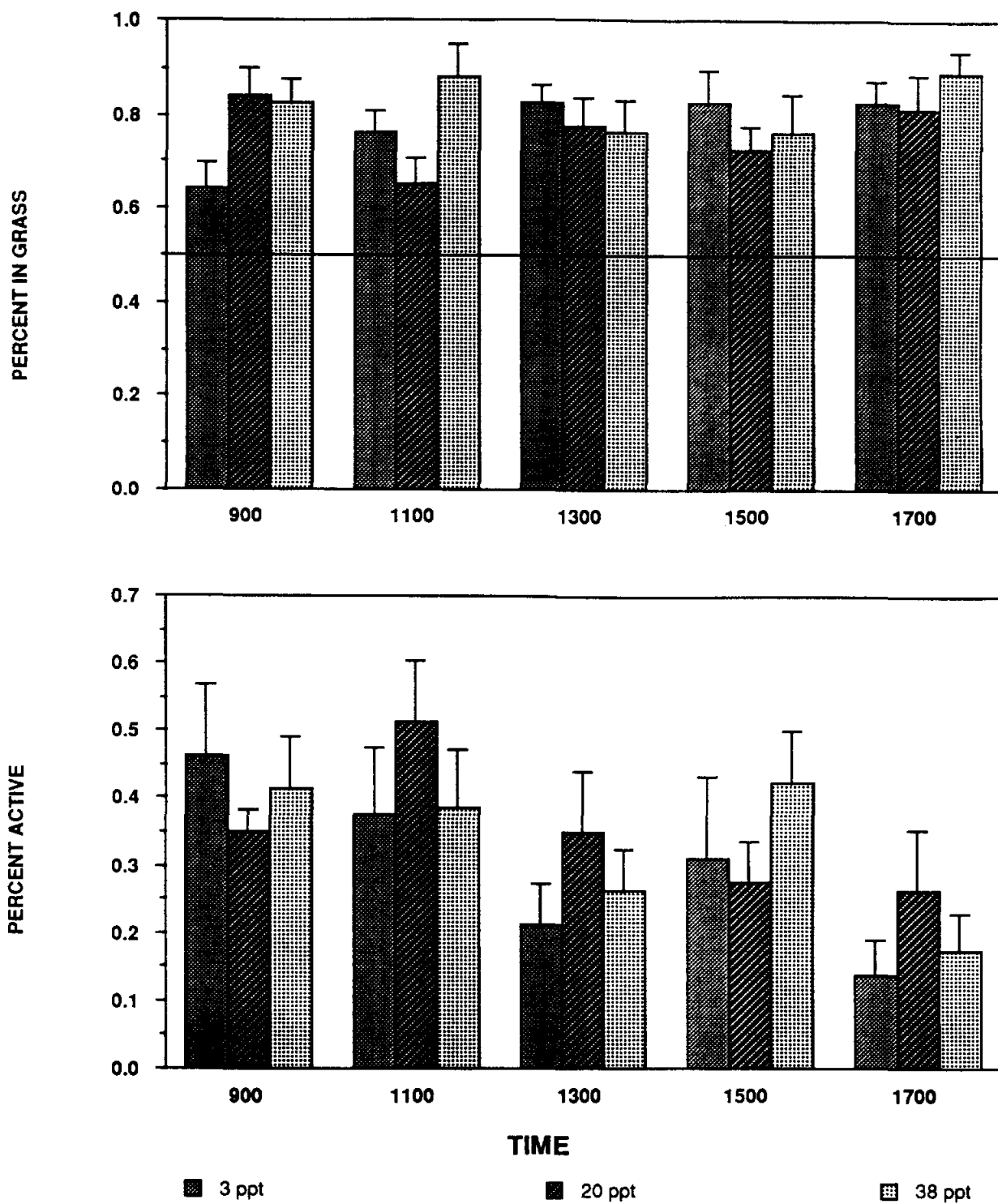


Figure 2. The effect of salinity on selection for structure and activity of white shrimp. Each bar is a mean percentage from 8 replicate tanks; error bars represent 1 SE from untransformed data.

Table 2. Analysis of variance results showing the effect of salinity reduction on the percentage of brown shrimp in the grass and the percentage of active shrimp. An arcsin transformation was used on the percentages. All main effects were tested using the Among Tank error term.

Percent in the Grass

Treatment	df	SS	F	P
Salinity Reduction	4	5.68	8.46	< 0.001
Contrasts				
A. No change vs Reduction	1	0.49	2.91	0.10
B. With 3 ppt vs Without 3 ppt	1	4.17	24.82	< 0.001
Day (Block)	1	0.50	2.99	0.10
Among Tank Error	19	3.19	2.78	0.002
Within Tank Error	50	3.02		

Percent Active

Treatment	df	SS	F	P
Salinity Reduction	4	1.00	1.35	0.29
Contrasts				
A. No change vs Reduction	1	0.00	0.00	0.98
B. With 3 ppt vs Without 3 ppt	1	0.82	4.37	0.050
Day (Block)	1	0.00	0.00	0.97
Among Tank Error	19	3.55	2.96	0.001
Within Tank Error	50	3.15		

Table 3. The effect of salinity reduction on the percent age of shrimp in the grass and the percentage of active shrimp. The probability (P) value listed is from an ANOVA comparing all treatment means (5-6 replicate tanks/mean) using an arcsin transformation (see Tables 2 and 4). Individual means cannot be statistically distinguished at the 0.05 level if they are connected by a line (LSD multiple range test).

	P	Salinity Change (ppt)				
		38-38	38-20	20-20	3-3	20-3
Percent in the Grass						
Brown shrimp	< 0.001	97%	97%	88%	83%	62%
White shrimp	0.055	86%	75%	70%	70%	64%
Percent Active						
Brown shrimp	0.29	3%	4%	13%	24%	28%
White shrimp	0.21	19%	25%	36%	36%	23%

for white shrimp was similar to that for brown shrimp (Table 3, Figure 4). The change from 20 ‰ to 3 ‰ also did not appear as stressful for white shrimp, and relatively few mortalities were observed for this species. The mean survival for white shrimp in this treatment was 10 shrimp (100%) at 1300 hrs, 9.5 shrimp at 1500 hrs, and 9.0 shrimp at 1700 hrs.

Activity levels of brown shrimp were again generally lower than those for white shrimp, and there was a trend of increased activity for brown shrimp with reduced salinity (Table 3). Brown shrimp in treatments with final salinities

of 3 ‰ had significantly higher activity levels than shrimp in other treatments (Contrast B, Table 2). Salinity or salinity reduction did not significantly affect activity of white shrimp (Table 4). For both species, mean activity levels in the treatment with salinity reduced to 3 ‰ declined with time following the salinity change (Figures 3 and 4). Similar declines were also apparent in treatments without a salinity reduction, however, and these trends may be related to the disruption of removing and adding water to the experimental tanks.

Table 4. Analysis of variance results showing the effect of salinity reduction on the percentage of white shrimp in the grass and the percentage of active shrimp. An arcsin transformation was used on the percentages. All main effects were tested using the Among Tank error term.

Percent In the Grass

Treatment	df	SS	F	P
Salinity Reduction	4	1.67	2.70	0.055
Contrasts				
A. No change vs Reduction	1	0.31	1.99	0.17
B. With 3 ppt vs Without 3 ppt	1	0.53	3.45	0.076
Day (Block)	1	0.01	0.05	0.83
Among Tank Error	24	3.70	1.68	0.054
Within Tank Error	60	5.52		

Percent Active

Treatment	df	SS	F	P
Salinity Reduction	4	0.56	1.59	0.21
Contrasts				
A. No change vs Reduction	1	0.12	1.39	0.25
B. With 3 ppt vs Without 3 ppt	1	0.04	0.40	0.53
Day (Block)	1	1.05	11.84	0.002
Among Tank Error	24	2.13	2.32	0.004
Within Tank Error	60	2.30		

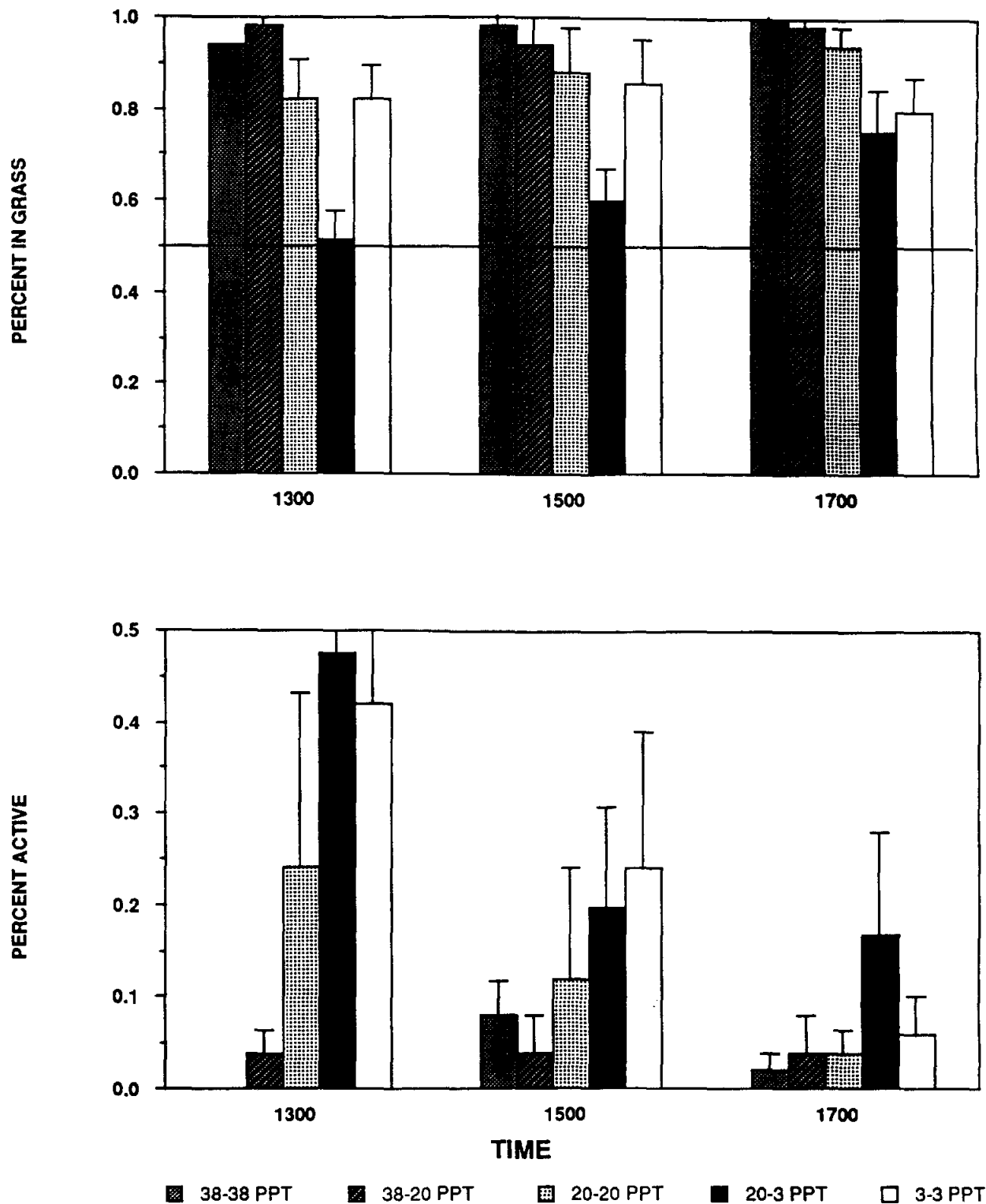


Figure 3. The effect of salinity reduction on selection for structure and activity of brown shrimp. Each bar is a mean percentage from 5 replicate tanks; error bars represent 1 SE from untransformed data.

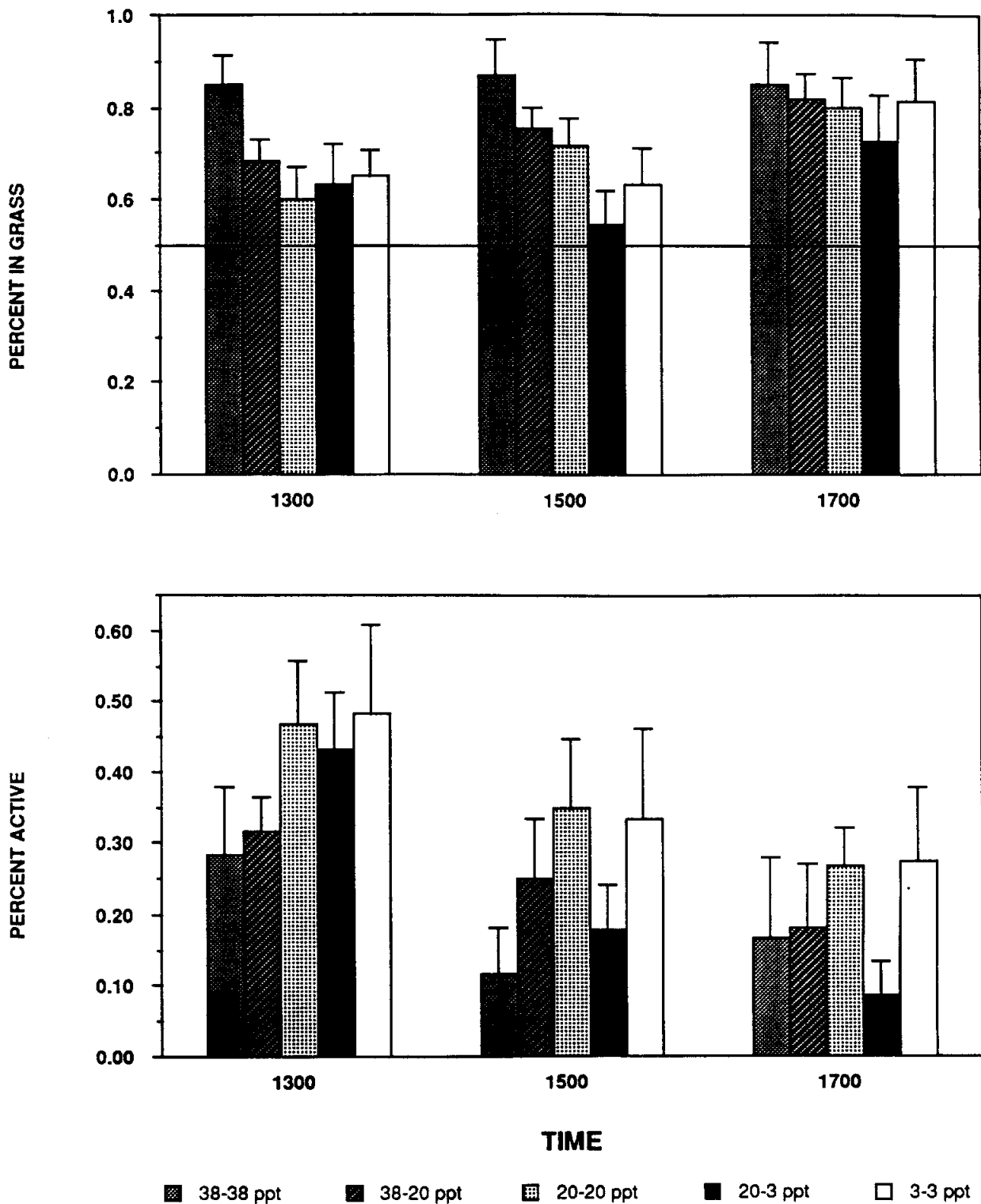


Figure 4. The effect of salinity reduction on selection for structure and activity of white shrimp. Each bar is a mean percentage from 6 replicate tanks; error bars represent 1 SE from untransformed data.

Turbidity

Water turbidity strongly affected selection for structure by brown shrimp, but did not affect selection by white shrimp (Table 5). The percentage of brown shrimp in the grass was highest at the intermediate turbidity of 10 FTUs, and the clear water treatment could not be statistically distinguished from the higher turbidity levels of 25 and 50 FTUs. This response was the same during both days of the experiment.

Sensor orientation had a dramatic effect on light attenuation readings in the experimental tanks. The sensor measures light in a 180° hemisphere, and when it was pointing towards the light source (vertically), light was not significantly reduced from 0 to 10 FTUs, but significant reductions occurred at higher turbidities (Table 5). When the sensor was pointed horizontally towards the wall of the tank, light significantly increased as turbidity increased. A comparison of light penetration between the 0 and 10 FTU treatments, therefore, indicated no significant difference in vertically penetrating light, but a significantly higher horizontal light reading at 10 FTUs.

Food

The distribution of food in the tanks strongly affected the distribution of brown shrimp in relation to structure (Table 6). The overall presence or absence of food did not significantly affect the percentage of shrimp in the grass ($\bar{x} = 67.5\%$), but the presence of food only in the vegetated half of the tanks increased the percentage of shrimp in the grass to 89% (a 32% increase in number), and the presence of food only in the nonvegetated half of the tanks decreased the percentage of shrimp in the grass to 45% (a 33% decrease in number). Separation among treatment effects was greatest just after food was added to the tanks (1300 hrs, Table 6, Figure 5). At night, the results for brown shrimp were similar, although statistically we could not distinguish any of the treatment levels except for food presence in the nonvegetated half of the tank which again had the lowest selection for structure (25% in the grass, Table 6). Night observations were taken only at one time, and the power of the ANOVA to detect significant differences at night was relatively low. In the white shrimp experiment, shrimp distribution

Table 5. The effect of turbidity on the percentage of shrimp in the grass and on light in the water column. Light was measured both with the sensor pointing towards the surface (Vertical) and pointing parallel to the tank substrate (Horizontal). The probability value (P) listed is from an ANOVA comparing all treatment means (8 replicate tanks/mean); an arcsin transformation was used on percentage data. Individual means cannot be statistically distinguished at the 0.05 level if they are connected by a line (LSD multiple range test).

Percent in the Grass	P	Turbidity			
		10 FTU	0 FTU	25 FTU	50 FTU
Brown shrimp	< 0.001	90%	76%	66%	58%
White shrimp	0.39	77%	80%	69%	68%
Light					
Vertical	< 0.001	20.9	21.8	18.6	16.6
Horizontal	< 0.001	6.3	4.0	7.5	8.6

was not significantly affected by the presence or distribution of food (Table 6, Figure 6). The percentage of shrimp in the vegetated half of the tanks was high in all experimental treatments, ranging between 80% and 94%.

Squid may have been inappropriate as food for the white shrimp in this experiment because differences in feeding rates were apparent between species. Brown shrimp were feeding during 43% of the observations compared with only 5% for white shrimp. Hunger levels should have been similar in the experiments, because both species were held in the

lab for 3-5 days before an experiment and fed daily with the same pelleted shrimp food.

Activity levels for both species of shrimp were not significantly affected by the distribution or presence of food (Table 6). Brown shrimp in this experiment were relatively active compared with those in other experiments, and white shrimp were relatively inactive (Table 6). The unusually low activity levels for white shrimp combined with low feeding levels may indicate that this group of animals was dissimilar to animals used in other experiments.

Table 6. The effect of food on the percentage of shrimp in the grass and the percentage of active shrimp. The probability (P) value listed is from an ANOVA comparing all treatment means (4 replicate tanks/mean) using an arcsin transformation. Individual means cannot be statistically distinguished at the 0.05 level if they are connected by a line (LSD multiple range test).

	P	Food Distribution			
		FOOD GRASS	NO FOOD	FOOD BOTH	FOOD NONVEG
Percent in the Grass					
Brown shrimp					
1300, 1500 and 1700 Hrs	< 0.001	89%	74%	61%	45%
1300 Hrs	< 0.001	90%	70%	68%	40%
NIGHT	< 0.001	70%	60%	58%	25%
White shrimp					
1300, 1500 and 1700 Hrs	0.62	94%	90%	91%	80%
1300 Hrs	0.49	98%	90%	88%	78%
Percent Active					
Brown shrimp					
1300, 1500 and 1700 Hrs	0.28	10%	39%	15%	22%
1300 Hrs	0.28	5%	32%	10%	22%
NIGHT	0.18	25%	35%	42%	38%
White shrimp					
1300, 1500 and 1700 Hrs	0.90	1%	1%	1%	2%
1300 Hrs	0.43	0%	2%	0%	0%

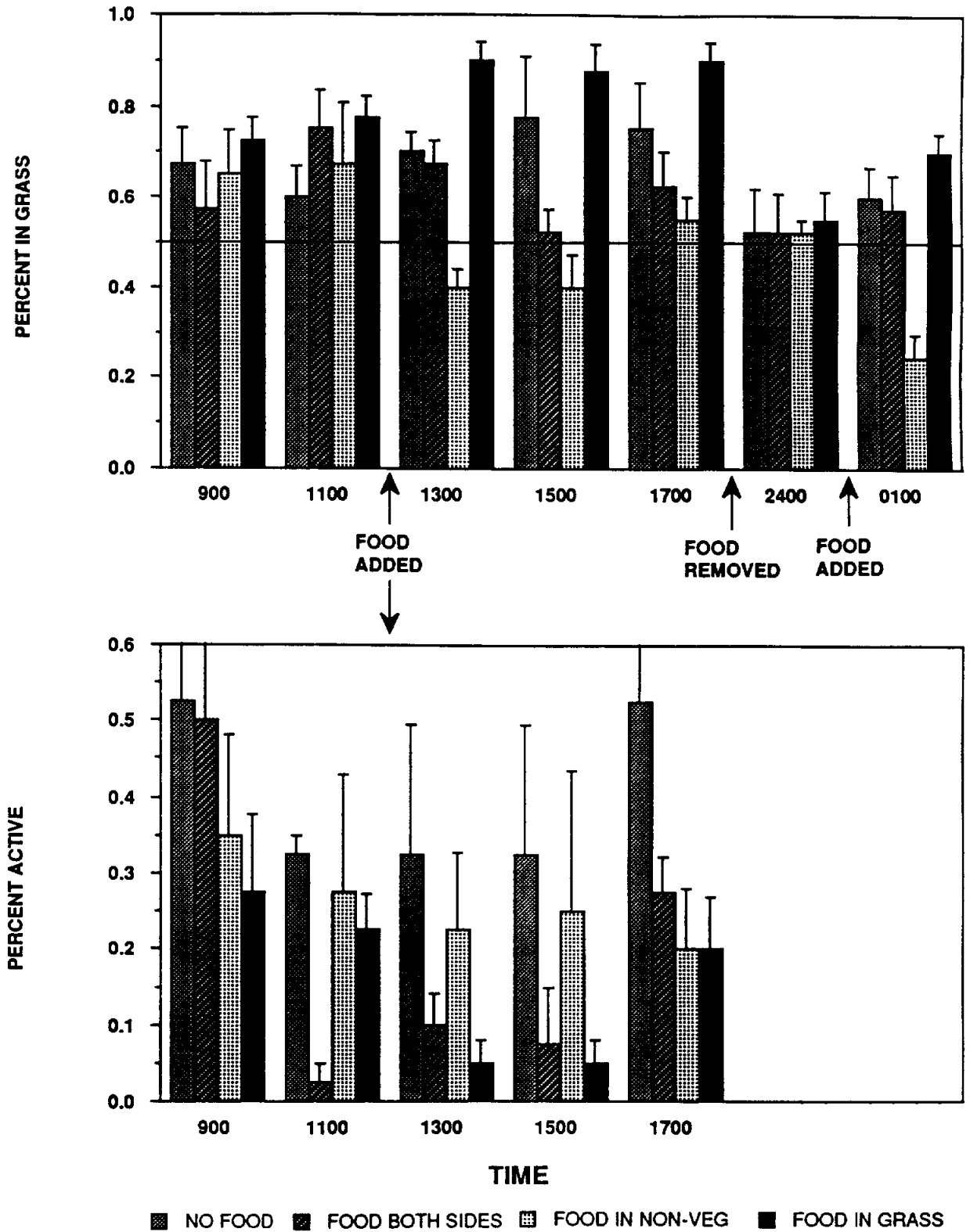


Figure 5. The effect of food on selection for structure and activity of brown shrimp. Each bar is a mean percentage from 4 replicate tanks; error bars represent 1 SE from untransformed data.

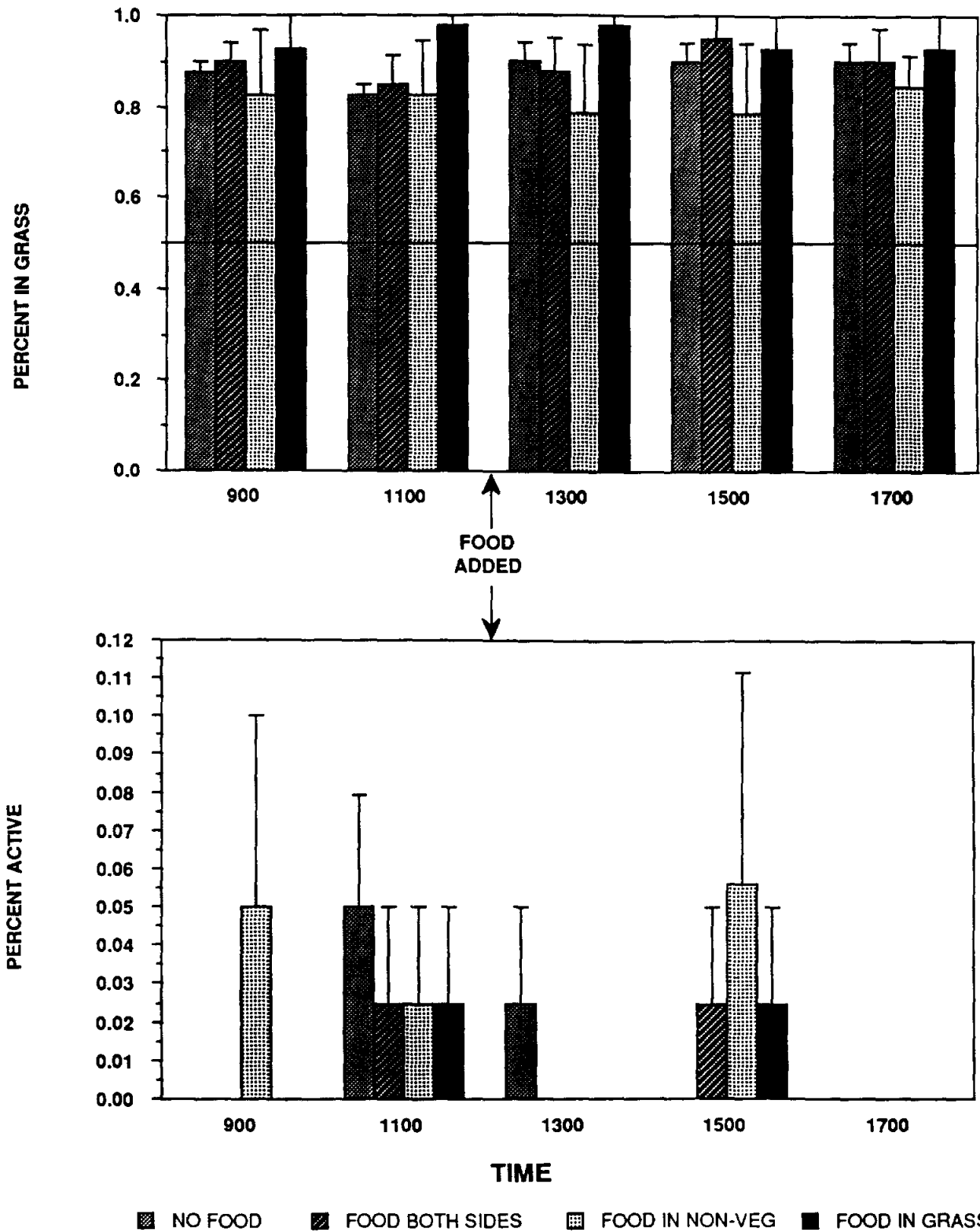


Figure 6. The effect of food on selection for structure and activity of white shrimp. Each bar is a mean percentage from 4 replicate tanks; error bars represent 1 SE from untransformed data.

Substrate

The effect of substrate on the distribution of brown shrimp during the day paralleled the effect of food (Table 7, Figure 7). The overall presence or absence of a substrate for burrowing did not affect selection for structure, but the distribution of the sand was important. When sand was present only in the vegetated half of the tank, 94% of the shrimp were in the grass. When sand was present only in the nonvegetated half of the tank, overall attraction for structure was eliminated, and 67% of the shrimp were on nonvegetated bottom. At night, there was no significant effect of substrate on the distribution of brown shrimp (Table 7), and the average percentage in the grass for all treatments was 61%. Brown shrimp frequently burrowed in the sand substrate during the day, and in treatments where some sand was present, 54% to 77% of brown

shrimp were burrowed (Table 7). In tanks with sand only on nonvegetated bottom, 78% of the shrimp in the nonvegetated half of the tank were burrowed. At night, brown shrimp did not burrow in the substrate, coincident with the lack of a substrate effect on selection for structure.

White shrimp distribution in relation to structure was not affected by the presence or distribution of the substrate (Table 7, Figure 8). Burrowing activity by white shrimp was also low in comparison with brown shrimp (Table 7), and in treatments with some sand present, only 4% to 8% of white shrimp were burrowed. Overall activity levels were low (5-11%) for brown shrimp and relatively high for white shrimp (30-45%). The presence and distribution of the substrate, however, had no significant effect on activity for either species (Table 7).

Table 7. The effect of substrate on the percentage of shrimp in the grass, active, and burrowed. The probability (P) value listed is from an ANOVA comparing all treatment means (4 replicate tanks/mean) using an arcsin transformation. Individual means cannot be statistically distinguished at the 0.05 level if they are connected by a line (LSD multiple range test).

	P	Substrate Distribution			
		SAND GRASS	NO SAND	SAND BOTH	SAND NONVEG
Percent in the Grass					
Brown shrimp	< 0.001	94%	74%	68%	33%
(Night)	0.61	62%	62%	65%	52%
White shrimp	0.96	65%	68%	65%	64%
Percent Active					
Brown shrimp	0.34	5%	7%	11%	8%
White shrimp	0.84	30%	41%	43%	45%
Percent Burrowed					
Brown shrimp	< 0.001	77%		70%	54%
White shrimp	0.29	8%		6%	4%

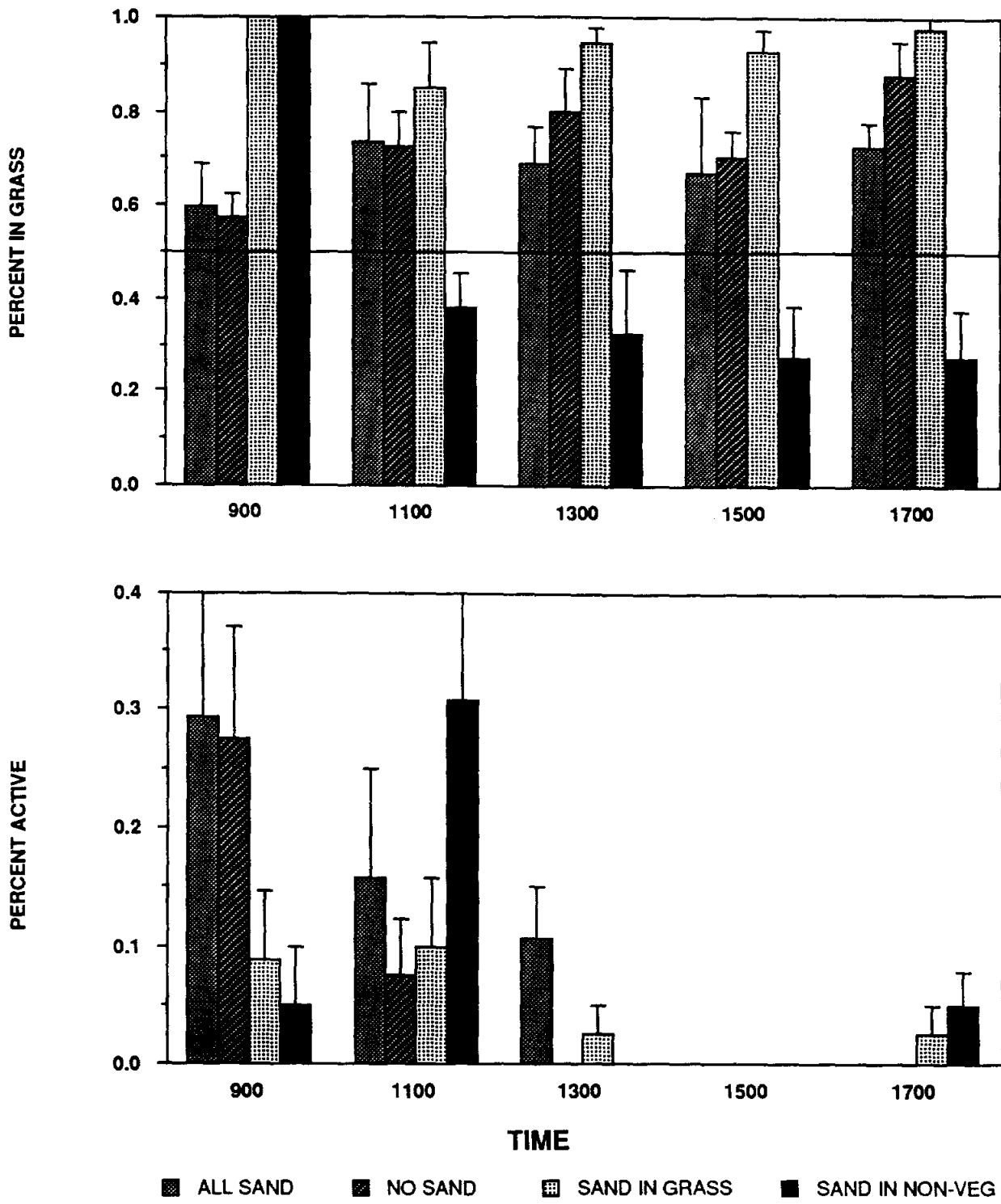


Figure 7. The effect of substrate on selection for structure and activity of brown shrimp. Each bar is a mean percentage from 4 replicate tanks; error bars represent 1 SE from untransformed data.

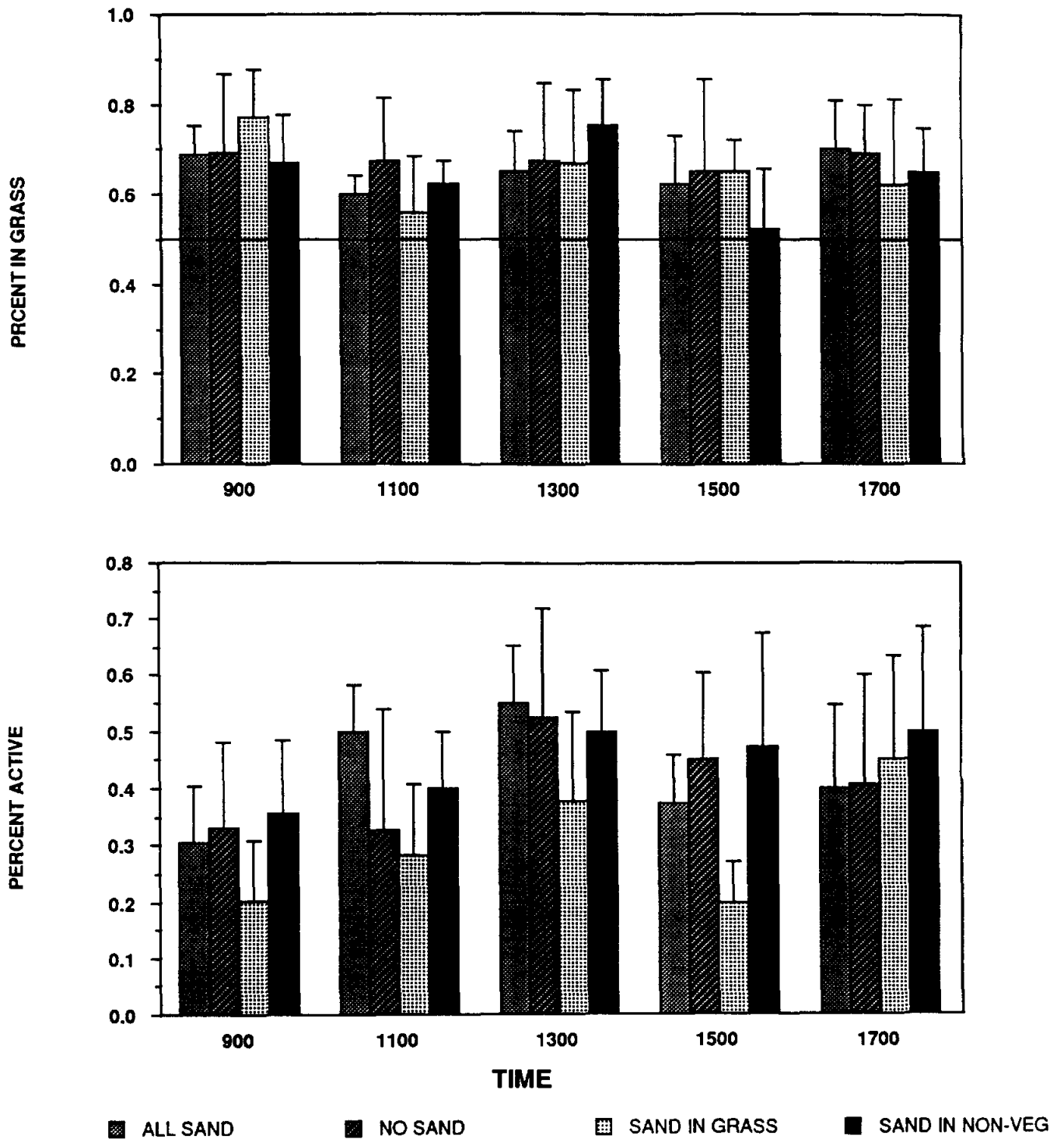


Figure 8. The effect of substrate on selection for structure and activity of white shrimp. Each bar is a mean percentage from 4 replicate tanks; error bars represent 1 SE from untransformed data.

Size

Within the size range of shrimp examined (35 to 84 mm, TL), size did not have a significant effect on selection for structure by either brown shrimp or white shrimp (Table 8, Figures 9 and 10). In addition, activity of the species did not appear to be affected by size.

Day Length and Light

Selection for structure by brown shrimp did not appear to be affected by day length (Figure 11). Shrimp had been held under the two day-length conditions (12-hr and 14-hr days) for approximately 2 weeks before the experiment, and ANOVA results indicated no significant differences in selection for structure ($P=0.24$, $df=1,12$) or in activity ($P=0.97$, $df=1,12$).

Light intensity during the day, however, did have an effect on selection for structure by brown shrimp (Figure 12). At 0900 hrs the lights were on in all 12 experimental tanks, and there was no significant difference in selection between the tanks randomly designated as "dark" and those designated as lighted. Lights in the dark tanks were turned off at 0930 hrs. At 1100 hrs the mean percentage of shrimp in the vegetated half of the tanks

was lower in the dark tanks (Figure 12), but the difference was not significant in an ANOVA ($P=0.11$, $df=1,10$). By 1300 hrs the percentage of shrimp in the grass in the dark tanks had dropped to 61%, significantly lower than the 89% in the lighted tanks (ANOVA, $P=0.008$, $df=1,10$). There was a large decline in activity following the 0900 hr observations in this experiment, but this decline occurred in both lighted and dark tanks. Light did not significantly affect the activity of shrimp at either 1100 hrs or 1300 hrs (ANOVA, $P>0.30$, $df=1,10$).

Shrimp Density

The white shrimp densities of 5, 10, and 20 shrimp per tank corresponded to densities of 5.4, 10.9, and 21.7 shrimp/m². The mean percentage of shrimp in the grass was highest in the low density treatment (82% in the grass) compared with percentages of 74 and 76% in the grass for densities of 10 and 20 shrimp per tank (Figure 13), but ANOVA results indicated no significant difference among the three density treatments ($P=0.35$, $df=2,12$). Activity levels were highly variable, and no difference in activity could be attributed to shrimp density (ANOVA, $P=0.92$, $df=2,12$).

Table 8. The effect of shrimp size on the percentage of shrimp in the grass and the percentage of active shrimp. The probability value (P) listed is from an ANOVA comparing all treatment means (5 replicate tanks/mean) using an arcsin transformation. Individual means cannot be statistically distinguished at the 0.05 level if they are connected by a line (LSD multiple range test).

	P	Total Length		
		35-40 mm	50-60 mm	68-84 mm
Percent in the Grass				
Brown shrimp	0.18	72%	68%	81%
White shrimp	0.16	72%	84%	88%
Percent Active				
Brown shrimp	0.78	4%	4%	6%
White shrimp	0.84	10%	12%	14%

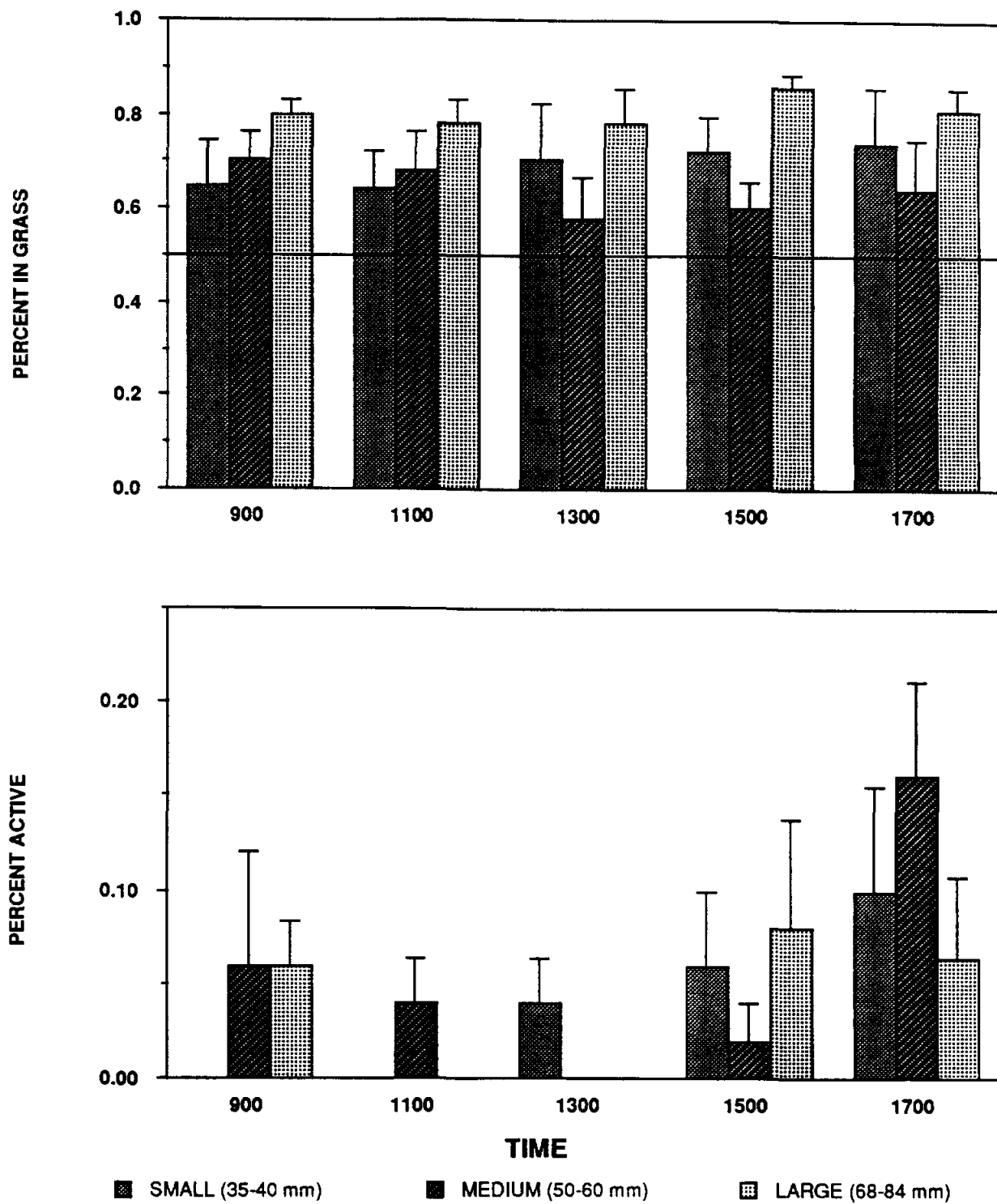


Figure 9. The effect of shrimp size on selection for structure and activity of brown shrimp. Each bar is a mean percentage from 5 replicate tanks; error bars represent 1 SE from untransformed data.

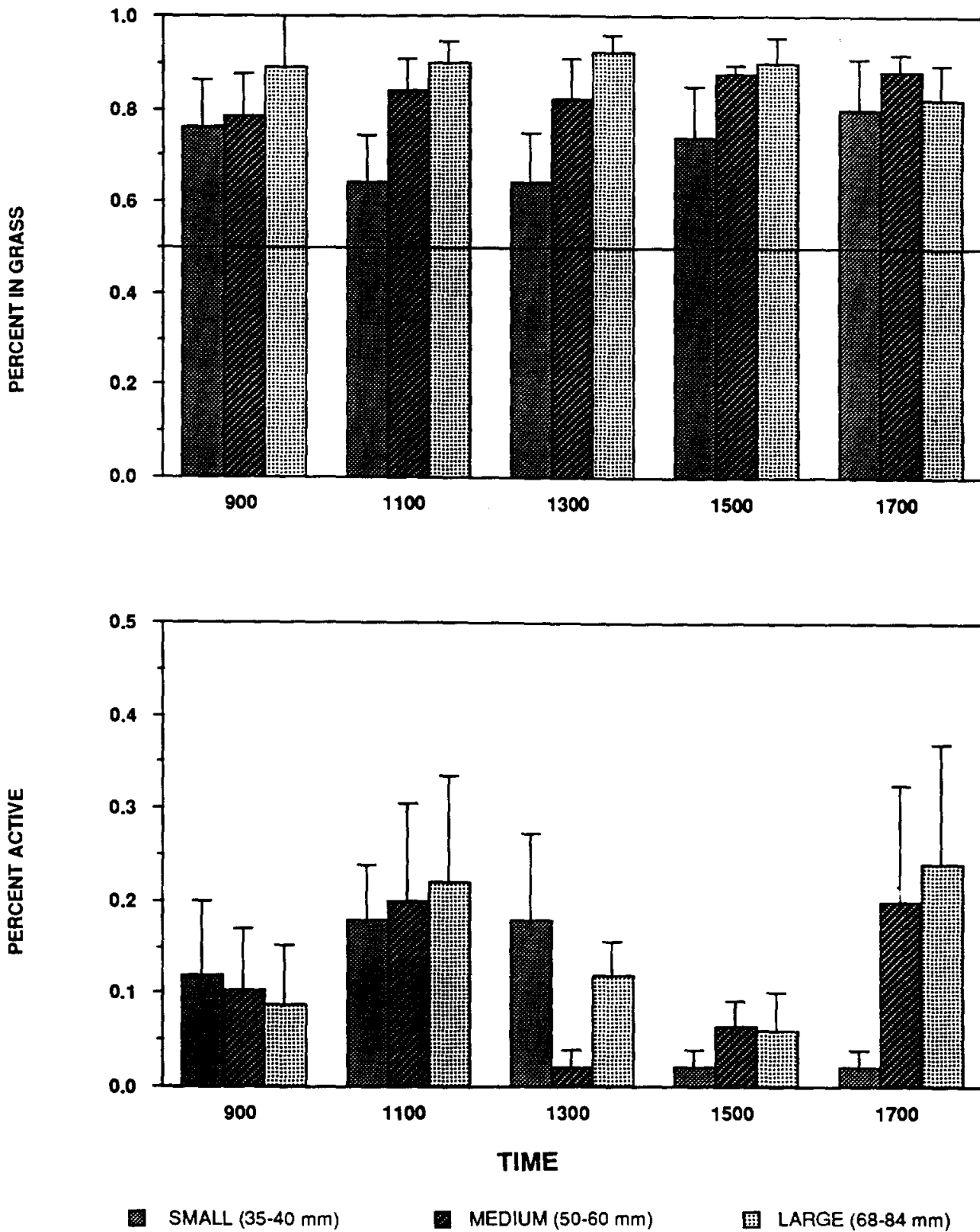


Figure 10. The effect of shrimp size on selection for structure and activity of white shrimp. Each bar is a mean percentage from 5 replicate tanks; error bars represent 1 SE from untransformed data.

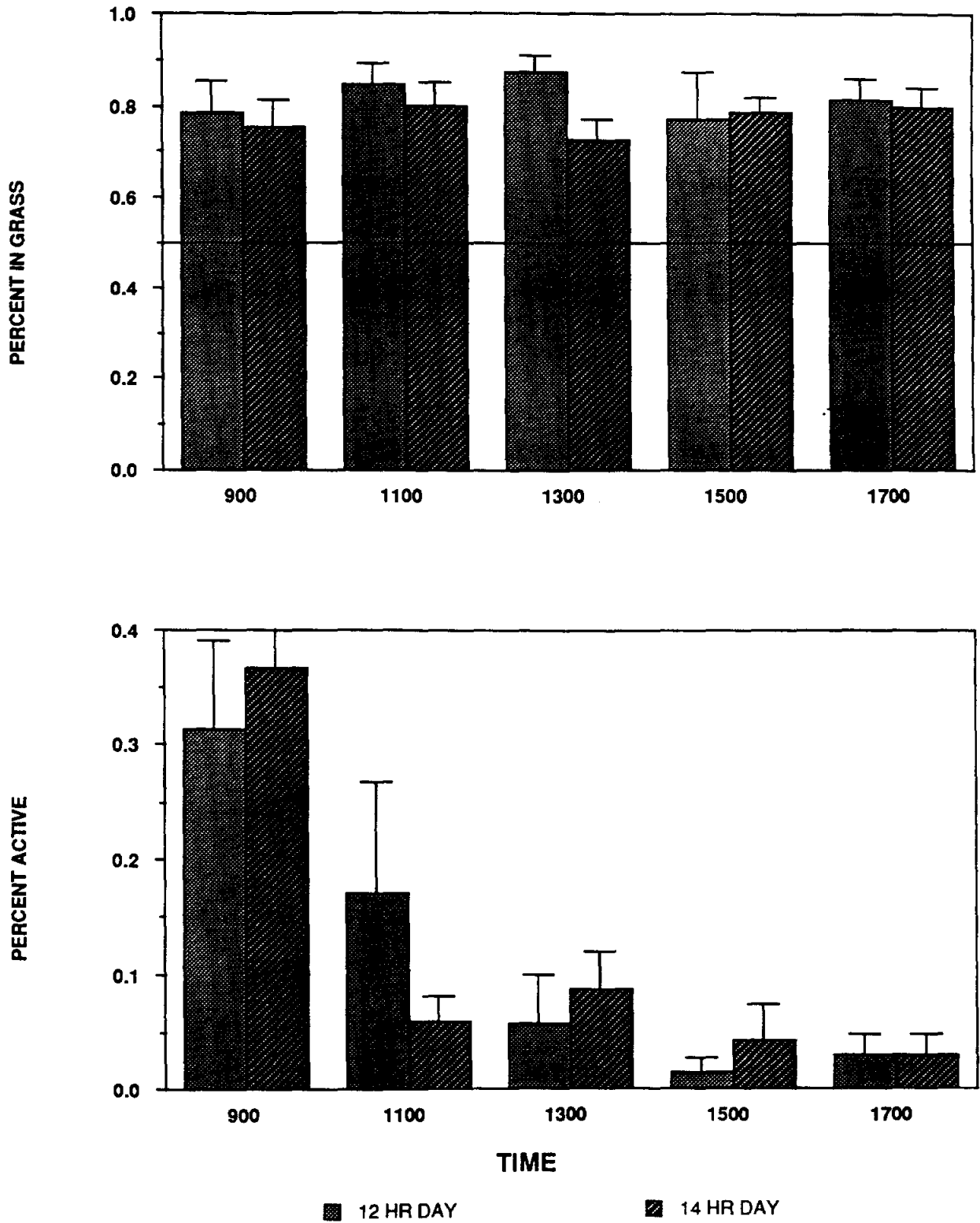


Figure 11. The effect of day length on selection for structure and activity of brown shrimp. Each bar is a mean percentage from 7 replicate tanks; error bars represent 1 SE from untransformed data.

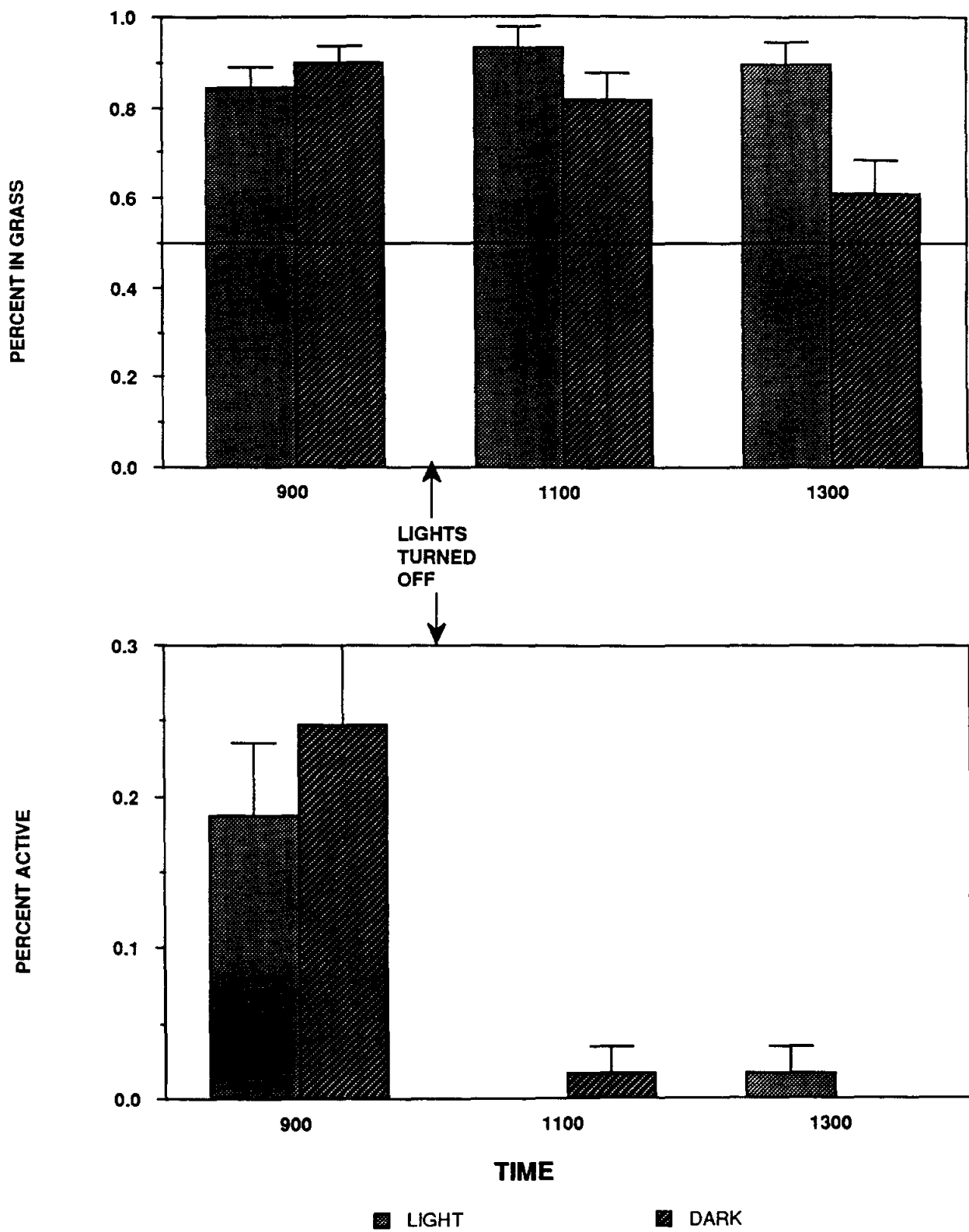


Figure 12. The effect of light on selection for structure and activity of brown shrimp. Each bar is a mean percentage from 6 replicate tanks; error bars represent 1 SE from untransformed data.

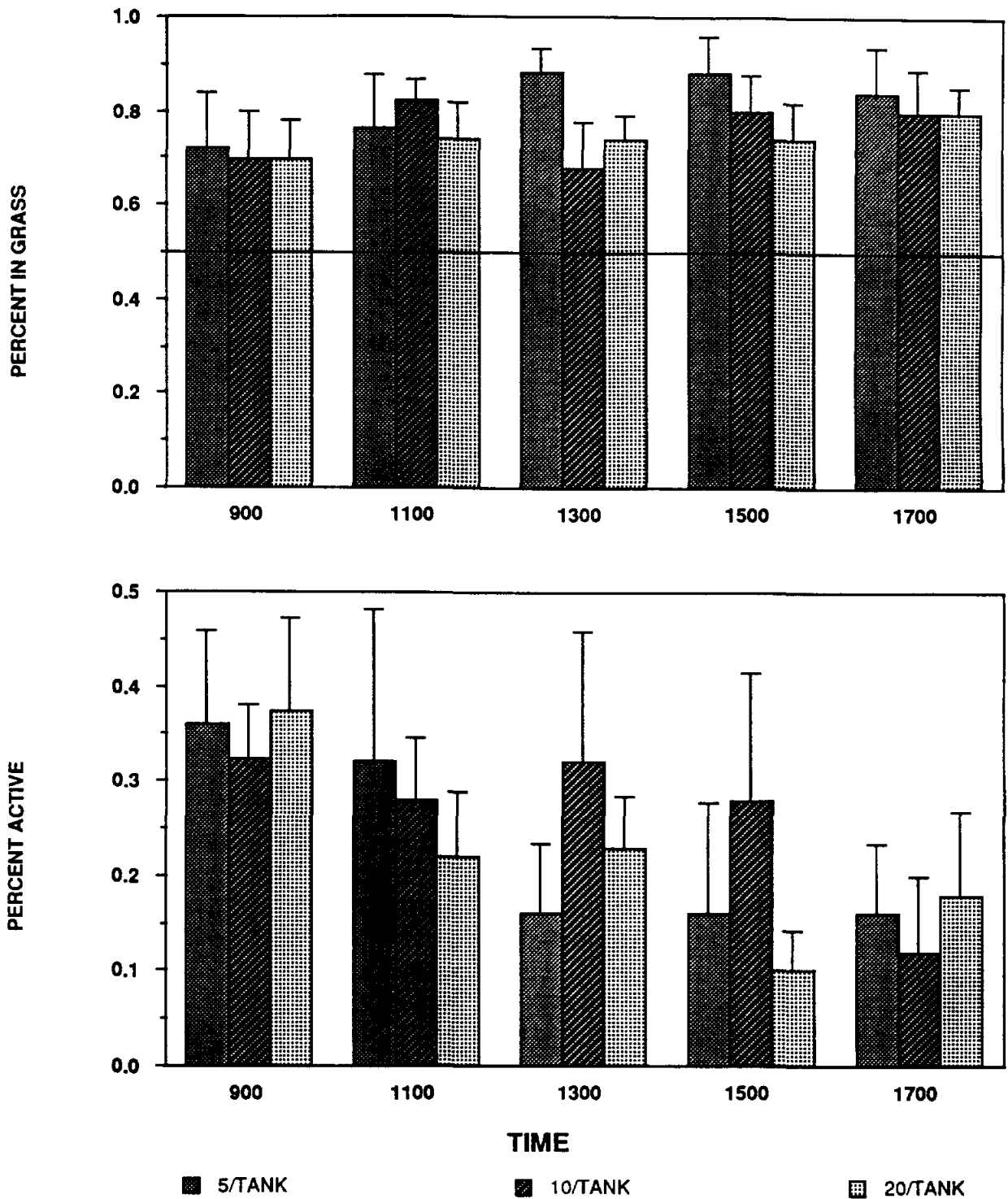


Figure 13. The effect of shrimp density on selection for structure and activity of white shrimp. Each bar is a mean percentage from 5 replicate tanks; error bars represent 1 SE from untransformed data.

Predators

The presence of a southern flounder in the experimental tanks did not significantly affect selection for structure by white shrimp (Figure 14; ANOVA, $P=0.36$, $df=1,17$). The southern flounder generally remained stationary on the bottom in the nonvegetated half of the tank, but the location of the fish did not appear to affect selection for structure by shrimp. Southern flounder were on nonvegetated bottom during 79% of the observations, but the percentage of shrimp in the grass was 87.6% both when fish were on nonvegetated bottom and when fish were in the grass. Activity of shrimp was affected by the presence of this predator (Figure 14), and the mean percentage of active shrimp over the day was significantly reduced from 31.7% in tanks without a predator to 10.5% when a predator was present (ANOVA, $P=0.005$, $df=1,17$). Only five shrimp were eaten by the predators during the experimental period.

Control Variability and Within Tank Error

In every experiment, one of the treatment levels was basically a control treatment with similar conditions of salinity (20 ‰), turbidity (0 FTUs), food (no food), substrate (no sand), temperature, and light. Differences in selection for structure and in shrimp activity among these control treatments from the experiments were relatively high. For brown shrimp, control data were collected from 39 tanks over the 9 days of experiments. The daily mean percentages of shrimp in the grass ranged from 64% to 94% ($\bar{x}=81\%$, $SE=3.2$, $n=9$), and the mean activities ranged from 1% to 39% ($\bar{x}=12\%$, $SE=4.5$, $n=9$). Control data for white shrimp were collected from 42 tanks over 10 experimental days, and daily mean percentages of shrimp in the grass ranged from 65% to 88% ($\bar{x}=75\%$, $SE=2.2$, $n=10$) with mean activities ranging from 2% to 44% ($\bar{x}=28\%$, $SE=4.9$, $n=10$). Selection for structure by both species was associated with inactivity, and there was a significant negative correlation between the transformed percentage in the

grass and activity in the control tanks for both brown shrimp ($r= -0.44$, $P= 0.005$, $n=39$) and white shrimp ($r= -0.57$, $P< 0.001$, $n=42$). For white shrimp this correlation was even more pronounced when daily means were compared ($r= -0.87$, $P< 0.001$, $n= 10$), indicating that daily differences in activity could explain over 75% of the variability in selection. In addition, paired comparisons of shrimp activity within control tanks indicated that activity was lower within the vegetation. Only 10% of the brown shrimp were active in the vegetated half of the tanks while 20% were active on nonvegetated bottom (paired $t=3.08$, $P=0.004$, $df= 34$). The white shrimp activity pattern was similar with 23% of the shrimp active in vegetation and 42% active on nonvegetated bottom (paired $t= 5.58$, $P< 0.001$, $df= 40$).

Main effects in the ANOVAs for each experiment were tested using an among tank error term, but a comparison of the within tank error (variability throughout the day) and the among tank error was also made. For both species, most analyses (11 of 13) of the percent shrimp in the grass showed that the among tank error was significantly (0.05 level) greater than the within tank error. These data suggest that our observations within a tank throughout the day were probably not independent, and the separation of within tank error from among tank error was necessary in order to meet assumptions of ANOVA. In the analyses of activity, results for white shrimp were similar with 6 of 7 significant differences. However, in the brown shrimp analyses of activity, within tank error was relatively high, and only 2 of 6 of these variance comparisons were significant. This large within tank variability generally reflected a decrease in brown shrimp activity from relatively high levels in the morning to lower levels throughout the day.

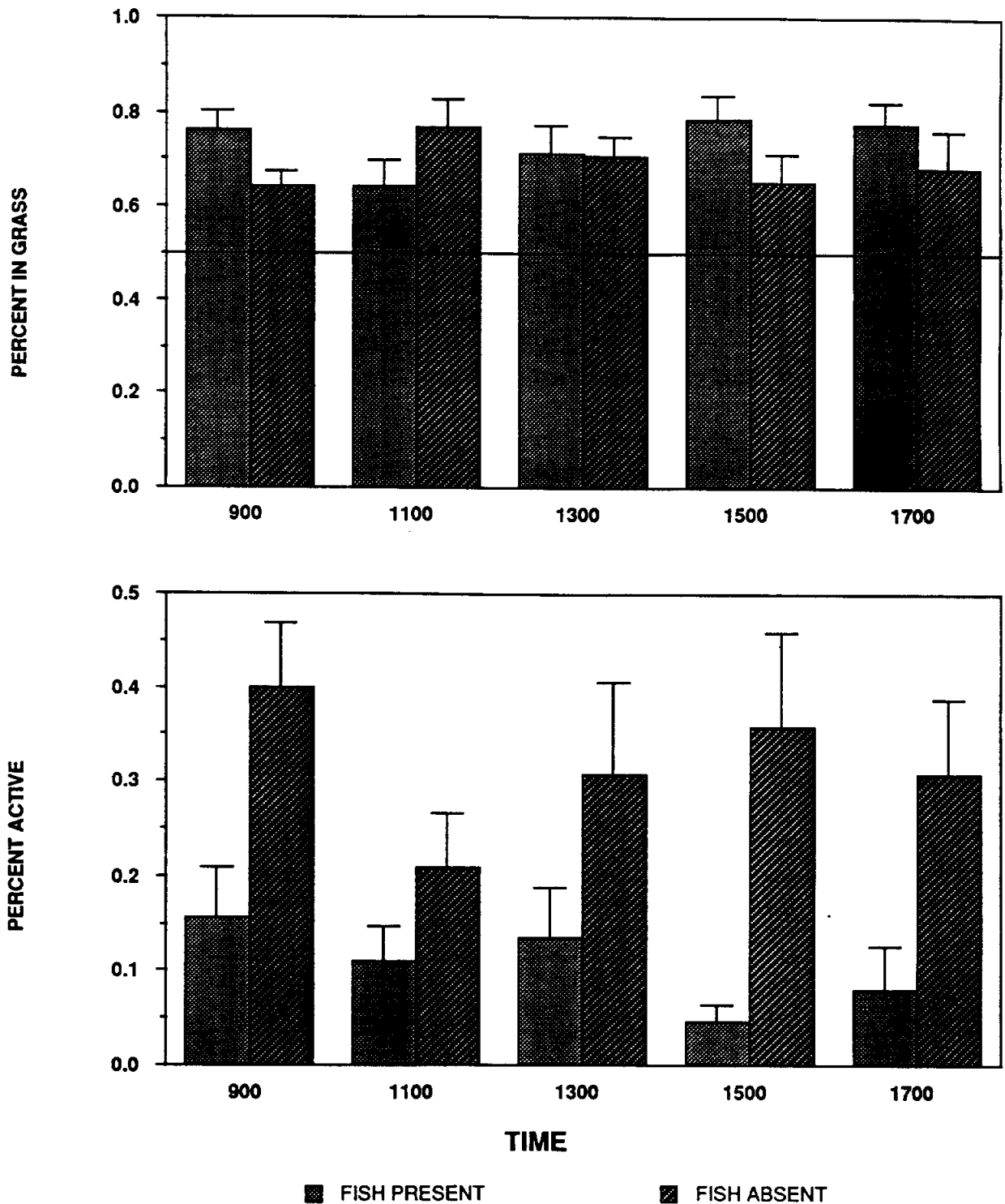


Figure 14. The effect of fish predator on selection for structure and activity of white shrimp. Each bar is a mean percentage from 10 replicate tanks; error bars represent 1 SE from untransformed data.

DISCUSSION

Selection for Structure by Brown Shrimp

Brown shrimp exhibited an inherent selection for structure in these experiments as in previous laboratory studies (Minello and Zimmerman, 1985). This selective behavior, however, was readily influenced by environmental conditions (Table 9). Salinity, turbidity, and light interacted with selection for structure by brown shrimp, and the distribution of food and a substrate for burrowing also affected the distribution of this species.

The reduction of salinity to oligohaline levels in our experiments reduced selection for structure. These results suggest that under some conditions, flood events in mesohaline areas of estuaries may result in reduced selection for vegetated habitats. Zimmerman et al. (1990) examined animal distributions in vegetated and nonvegetated habitats of upper Lavaca Bay, Tx, and the percentage of brown shrimp in marsh habitats appeared to decline

following flood events. Increased mortality associated with lowering the salinity in our experiments also suggests that effects on selection for structure may be related to increased physiological stress.

Turbidity also affected selection for structure by brown shrimp, and this effect may have been related to the reduction of underwater light levels caused by turbid water. In another experiment, decreased light during the day significantly reduced the percentage of brown shrimp in the vegetation from 89% to 61%. This percentage in the dark was similar to the percentage in the grass during night observations. The light levels used in our experiments ($22-27 \mu\text{E s}^{-1} \text{m}^{-2}$) correspond to early morning or late afternoon light in shallow water habitats, and effects of turbidity and perhaps other experimental variables may interact with overall light levels.

Although the overall presence or absence of food or an appropriate substrate for burrowing did not interact with selection for structure,

Table 9. Summary of ANOVA probability values for the main effect of experimental variables on selection for structure and activity.

Experimental Variable	Brown Shrimp		White Shrimp	
	Selection	Activity	Selection	Activity
Salinity	0.052	0.78	0.35	0.90
Freshwater Event	< 0.001	0.29	0.055	0.21
Turbidity	< 0.001		0.39	
Food	< 0.001	0.28	0.62	0.90
Substrate	< 0.001	0.34	0.96	0.84
Size	0.18	0.78	0.16	0.84
Day Length	0.24	0.97		
Light	0.11, 0.008	> 0.3		
Shrimp Density			0.35	0.92
Predator			0.36	0.005

the distribution of these habitat characteristics dramatically affected brown shrimp distributions. Attraction to food or a substrate for burrowing could either enhance or override selection for structure. In salt marshes, abundances of peracarid crustaceans and polychaetes, which serve as food for juvenile brown shrimp, are frequently higher on the marsh surface in relation to nonvegetated bottom, although distributions of these food organisms in the marsh vary considerably in space and time (Kneib 1984; Rader 1984, Zimmerman et al., in press). The distribution of food, therefore, may partly regulate the distribution of brown shrimp in relation to vegetation. Substrate type, however, may also modify selection for vegetation in the field, and the effect of substrate appeared to be closely related to burrowing behavior. The presence of root mats or the compaction of clay substrates in the intertidal zone due to intermittent drying may prevent shrimp from burrowing in vegetated habitats. Under these conditions, selection for vegetation may be reduced as young brown shrimp remain on nonvegetated bottom more appropriate for burrowing. All of the above habitat characteristics can be expected to interact in their influence on selection for vegetated habitats, but our laboratory data would suggest that the distribution of food and substrate are dominant factors.

Selection for Structure by White Shrimp

In direct contrast to brown shrimp results, laboratory experiments on white shrimp showed little effect of environmental variables on selection for structure (Table 9). There was a marginally significant ($P=0.055$) reduction in selection due to salinity reduction, but evidence for any major salinity effect was not persuasive. The lack of a response to the distribution of a substrate for burrowing parallels the relatively low burrowing frequency for this species. Lack of any significant response to the distribution of food, however, is puzzling. The low feeding frequency by white shrimp on the animal food used in the experi-

ment (squid pieces) suggests that either the food was unpalatable or that the group of shrimp used during this experiment was anomalous (supported by unusually low activity levels). There is some evidence indicating that white shrimp are less carnivorous than brown shrimp (Zimmerman et al. in press) and therefore may be less attracted to squid as food, but squid has frequently been used in maintenance diets for white shrimp at the Galveston Laboratory. Additional experiments using different foods and experimental shrimp may be required before we can make any conclusions as to the effect of food on the distribution of white shrimp.

These experiments have provided little insight into the regulation of white shrimp distributions in relation to vegetative structure. Results from our control tanks on each of the nine experimental days revealed an overall selection for structure by white shrimp, unlike previous laboratory experiments with artificial vegetation (Minello and Zimmerman, 1985). This kind of unexplained variability parallels the enigma of white shrimp distributions in the field. The experimental design of this study differed from the design of our previous experiments in overall light levels, substrate type, and the size, shape and material of the experimental containers. In our previous work circular cages of black mesh were used, and the structure of the cage walls themselves or their coloration may have attracted shrimp to nonvegetated areas.

Relationships Between Activity and Selection for Structure

Results from control tanks for both species of shrimp indicated that activity was negatively related to selection for structure. Activity levels for white shrimp were relatively high in relation to brown shrimp, coincident with relatively lower selection for structure by white shrimp. The importance of this relationship is unclear, however, and it may be difficult to determine whether activity affects selection, selection affects activity, or both are respond-

ing to some other factor. There is some evidence for independence between activity and selection, especially for brown shrimp, because effects of experimental factors on selection for structure seldom appeared related to any effect on activity (Table 9). Many experimental factors affected selection for structure by brown shrimp, but activity was only marginally affected in the salinity reduction experiment. Reduced selection in salinity treatments with 3 ‰ did coincide with increased activity, but analysis of covariance designed to remove the effect of activity on selection did not have any great effect on the ANOVA results. White shrimp activity was significantly affected in only one experiment, in which activity was reduced by the presence of southern flounder. However, selection for structure was not significantly increased in this experiment.

The highly significant correlation for white shrimp between overall daily activity and selection for structure in controls ($r = -0.87$, $P < 0.001$, $n = 10$), suggests that variability in activity among days may affect selection for structure by this species. If this relationship between activity and selection is not simply an artifact of our experimental design, environmental factors regulating activity may also regulate selection for structure by white shrimp in shallow estuarine habitats. Many environ-

mental factors not examined fully in this study have been shown to affect activity of penaeid shrimp, including light (Moller and Jones 1975, Wickham and Minkler 1975, Bishop and Herrnkind 1976, Moctezuma and Blake 1981), food (Hughes 1968), lunar and tidal phase (Aaron and Wisby 1964, Fuss and Ogren 1966), current speed (Fuss and Ogren 1966, Wickham 1967) water levels (Hughes 1966), temperature (Fuss and Ogren 1966, Aldrich et al. 1968), and shrimp size (Hughes 1968, Moctezuma and Blake 1981).

Evidence from our experiments, however, could also be interpreted to indicate that selection for structure can regulate activity. Activity of shrimp in the nonvegetated half of control tanks was approximately double that in the vegetated half. Environmental conditions affecting activity, unrelated to the presence of structure, should have been similar on both sides of the tanks. Structure may inhibit crawling and swimming or the lack of structure may stimulate these activities. The overall relationship between reduced activity and selection for structure by shrimp should be examined in greater detail. The large ranges in daily means from our experimental controls indicate that factors, not controlled in these experiments, were affecting both selection and activity.

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