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April 24, 1991

Dr. Gary Powell
Texas Water Development Board
Environmental Systems Section
P.O. Box 13231 Capitol Station
Austin, Texas 78711-3231

Dear Gary,

Enclosed are 10 copies of our final report on the Yarborough Pass study. As you will quickly see it is substantially changed from the original report we gave you last fall. These changes were made partially in response to the comments made by you and your staff and partially from my interest in analyzing the spotted seatrout and black drum data in more detail.

I think that in the new report we addressed all of the comments made in your letter of 20 November except for the question about the apparent preference shown by fish and shrimp for vegetated verses non-vegetated areas. I will address that here. You correctly point out that the NMFS observations deal with older life stages, we have shown the same thing ourselves for postlarval and early-juvenile red drum and spotted seatrout. The answer to your question of whether larvae also select for or concentrate in seagrass beds is a qualified probably not. We know from our studies and those of many others that all of the species we are dealing with in this report spawn in or near open water and release buoyant eggs which hatch into pelagic larvae. Larvae of species which spawn offshore must be open water over unvegetated bottom at least during the period when they are traversing the estuary between the tidal inlet and the vegetated nursery areas known to be used by older life stages.

We also know that spotted seatrout and black drum larvae are found in relatively high densities in open water but we in fact do not know what their densities are over seagrass meadows. Taking (and processing) ichthyoplankton samples in seagrass meadows is technically difficult because the shallow water excludes most boats and the seagrass debris collected by plankton nets creates havoc with finding 2-4 mm larval fish in the collections. I know of only one published study of seagrass ichthyoplankton (John Olney, VIMS). He found that the ichthyoplankton species composition was quite different from that seen in open water and most open water ichthyoplankton were not found over seagrass beds. This past winter I built a new sampler for our jet motor powered skiff. It worked well in initial trials. These samples showed that we could catch the postlarval red drum (7-15 mm) we knew inhabited the seagrass meadows but there were no small larvae in the samples. We will perfect the gear and our techniques this summer and will soon be able to examine pelagic ichthyoplankton populations in shallow (≈ 0.5 m) seagrass beds.

I appreciate the Texas Water Development Board's support for this project and look forward to working with you again.

Sincerely,

Scott Holt
Research Associate

Abundance and Distribution of Larval Fishes and Shrimps in the Laguna Madre, Texas: A Hypersaline Lagoon

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to

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P.O. Box 13087 Capitol Station
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ABSTRACT

Tidal inlets connecting the Gulf of Mexico with estuarine waters are widely spaced and relatively narrow along the Texas coast. These inlets provide the sole route for ingress of larvae to the estuary for estuarine-dependent marine species and the egress of juveniles and sub-adults of these species back to the ocean. This study was an investigation of the abundance and distribution of ichthyoplankton of selected fishes and shrimps in an area where the opening and maintenance of a new tidal pass has been proposed in the Laguna Madre, a sub-tropical, hypersaline lagoon along the southern Texas coast. Surface and bottom ichthyoplankton samples were taken bi-monthly in four zones in the Laguna Madre in areas which were directly influenced by tidal inlets from the Gulf of Mexico and areas isolated from such connections. Seasonal composition of the ichthyoplankton was similar to that reported from other Gulf of Mexico and southeastern United States estuaries with winter catches dominated by offshore spawners and summer catches dominated by inshore and estuarine spawners. The pelagic larvae of three species of estuarine spawners, bay anchovy (*Anchoa mitchilli*), spotted seatrout (*Cynoscion nebulosus*), and black drum (*Pogonias cromis*), were common throughout the Laguna Madre at salinities up to 50 ‰. Pelagic larvae of offshore spawners were abundant only in the area near the tidal inlet and only a few individuals were found dispersed throughout the lagoon. The majority of these species are distributed throughout the Laguna Madre as juveniles but the dispersion or advection of these species to areas not closely associated with tidal inlets occurs at development stages older than the pelagic larval stage. These data suggest that opening and maintaining a tidal inlet in the upper Laguna Madre would increase the opportunity for recruitment of larvae of offshore spawners into an area currently unoccupied by these life-history stages.

INTRODUCTION

The Texas coastline is dominated by a series of coastal lagoons running parallel to the mainland which are occasionally punctuated by relatively shallow, drowned-river-valley type estuaries. Tidal inlets connecting the estuaries with the Gulf of Mexico are both few and relatively small. These inlets serve as the sole conduit between bay and ocean for numerous estuarine-dependent marine species which are among the most important recreational and commercial marine organisms.

There is a north to south gradient in precipitation/evaporation along the coast such that the estuaries in the north have relatively low salinity while the estuaries in the south are often hypersaline. A plan was put forward in 1988 to dredge, jetty, and maintain a channel through Padre Island, on the south Texas coast, to connect the hypersaline upper Laguna Madre with the Gulf of Mexico. The purpose of this proposed project was to alleviate environmental stresses in this relatively isolated lagoon through increased circulation and, in addition, to provide regional boaters with access to the Gulf of Mexico. Although such a project would have a significant impact on migration of both larval and adult fishes, there is virtually no information on the distribution of larval fishes in the area. The project has great potential for impacting larval fishes by providing an immigration route for the larvae of estuarine-dependent marine species which spawn offshore and utilize the estuary as a nursery area. On the other hand, a tidal pass could also allow the introduction of larvae and juveniles of marine origin which might affect the resident spawning species through predation or competition for food or space within the nursery area (Bennett 1989).

Data on coastal and estuarine fish larvae in Texas are limited. There are no general surveys indicating seasonal and spatial distribution of ichthyoplankton throughout any major estuarine system in Texas. Holt and Strawn (1983) provide temporal data for Trinity Bay and Holt and Arnold (1986) report similar data for upper Lavaca Bay.

Occurrence of ichthyoplankton near tidal passes has received more attention. These studies have provided data on seasonal occurrence (Hoese 1965; King 1971) and vertical distribution (Allshouse 1983; Darnell and McEachron 1988; Holt et al. 1989) in the Cedar Bayou and Aransas Pass tidal inlets. There is virtually no data on the dispersion or distribution of these larvae into the estuaries.

The purpose of this paper is to examine both seasonal and spatial aspects of the ichthyoplankton in the hypersaline Laguna Madre and evaluate those data in light of the possible opening of a tidal inlet through the barrier island. The study was designed to determine: 1) the existing density and distribution of selected species in the immediate vicinity of the proposed inlet at Yarborough Pass; 2) the probable source for any larvae of estuarine-dependent marine species which might be found near Yarborough; and 3) the density and seasonality of selected species near an open tidal inlet in the lower Laguna Madre as a predictor of which species might be expected to immigrate into the upper Laguna Madre if Yarborough Pass was open.

STUDY AREA

The Laguna Madre, located along the southern portion of the Texas coast (Fig. 1), is a narrow, shallow lagoon about 225 km long and 5 to 8 km wide with an average depth of < 1.5 m. There are two direct connections through Padre Island with the Gulf of Mexico; one connection is in the extreme southern end of the Laguna Madre at Brazos Santiago Pass and the other is the Port Mansfield Channel near the middle of the lower Laguna Madre. On its northern boundary there is an indirect connection with the Gulf through Corpus Christi Bay via the Aransas Pass. Other passes open temporarily following hurricanes but close up again within a few months. On the northern end, the Laguna Madre joins Corpus Christi Bay.

Gunter (1945), Hedgpeth (1947), Breuer (1957), and Simmons (1957) have given detailed descriptions of the physical and chemical characteristics of the Laguna Madre and Baffin Bay and the substantial changes which occurred in the system during the period from 1900 to 1960. The most significant of these were: the filling of a 35 mile stretch of the lagoon just south of Baffin Bay by the hurricane of 1919 which essentially cut the Laguna Madre in half; the multiple failed attempts in 1941 and 1942 to dredge a pass through Padre Island at one of the aforementioned hurricane passes called Yarborough Pass; dredging of the Gulf Intercoastal Waterway (ICW) through the length of the Laguna in 1948; the construction of a landfill causeway across the northern end of the Laguna connecting Padre Island with the mainland near Corpus

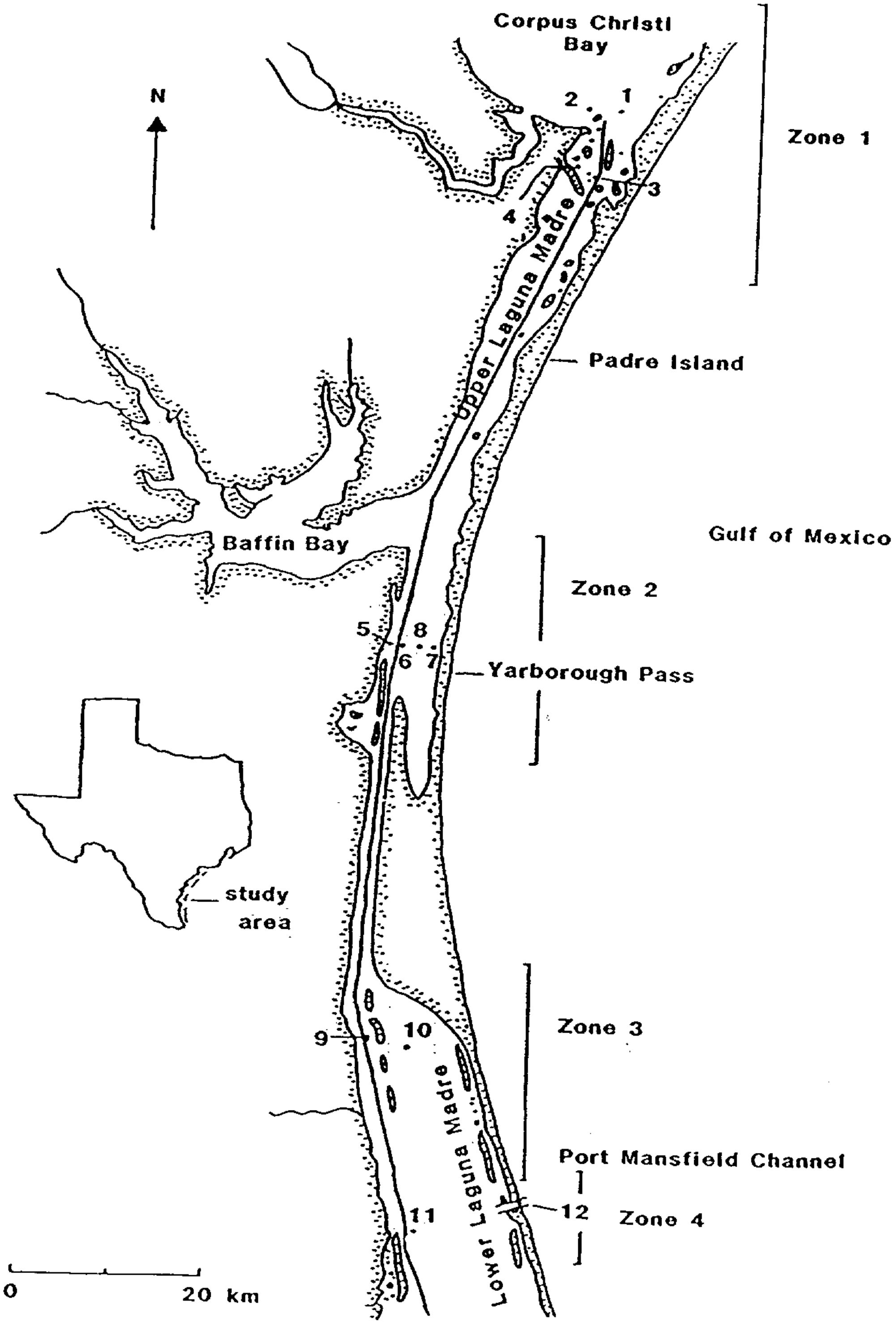

Figure 1. Location of study sites in the Laguna Madre.

Christi in 1950; and the cutting of a tidal inlet through Padre Island near Port Mansfield in 1962.

The upper half of the Laguna Madre was virtually isolated from both oceanic tidal flushing and freshwater inflow by the hurricane-induced shoaling to the south and the landfill causeway on the north. Between 1920 and 1948, salinities in the Upper Laguna Madre were generally 40 to 60 °/oo (Gunter 1945). Although salinities occasionally fell to near 0 °/oo following tropical storms, they regularly rose to near 100 °/oo during dry periods, resulting in substantial hypersalinity-induced fish kills (Simmons 1957). The ICW cut through the hurricane fill area (creating a channel called the "Land Cut") and reestablished a connection between the upper and lower Laguna Madre. This 5 m deep channel improved circulation throughout the Laguna Madre and salinities now seldom exceed 60 °/oo in open water, although they still go somewhat higher in isolated parts of Baffin Bay. Even though the landfill causeway still restricts water exchange with Corpus Christi Bay, substantial hypersalinity-induced fish kills are no longer reported in the Laguna Madre. Fish mortality due to cold weather was, and still is, a major fisheries problem along all of the Texas coast including the Laguna Madre. The construction of the ICW did not alleviate hypothermal mortalities in the Laguna Madre (Gunter and Hildebrand 1951).

Sample sites were established in four zones in the study area (Fig. 1). Zone designations were based primarily on distance from existing tidal inlets. Zone A was in the northern end of the Laguna Madre at its junction with Corpus Christi Bay near the landfill causeway. Sites 1 and 2 were in the southern edge of Corpus Christi Bay and Sites 3 and 4 were in the two major channels through the causeway connecting the Laguna Madre with Corpus Christi Bay (the ICW and Humble Channel respectively). Zone B was in the southern part of the upper Laguna Madre in the vicinity of Yarborough Pass. Sites 5-8 were on a transect across the lagoon from Padre Island to the mainland. Zone C (sites 9, 10, and 11) was south of the "Land Cut" in the lower Laguna Madre. Zone D (site 12) was in the Port Mansfield Channel about 2 km from its juncture with the Gulf of Mexico.

Sites 3, 6, and 9 were located in the ICW in depths of about 5 m. Site 12 was in the Port Mansfield Channel tidal inlet in 7 m of water. The remaining sites were in the "flats" portion of the Laguna Madre in 1.5-2.0 m depths. Although there are extensive seagrass meadows in the Laguna Madre, all sample sites were located over unvegetated bottom so that both surface and bottom plankton samples could be taken at all sites.

MATERIALS AND METHODS

Collections were taken bi-monthly at all sites from March 1989 through January 1990. A minimum of three days was required to complete each set of samples but weather and mechanical problems occasionally stretched the sample period to as much as 8 to 10 days. This had the effect of pushing the "March" sampling into the first of April and sites 5,6,7 and 8 were occupied on 6 April but the entire suite of 12 sites will be referred to as "March" collections. All collections were taken during daylight.

Both surface and bottom samples were taken in triplicate at each site with 1 m diameter nets of 505 μm mesh pulled by an 8 m shallow-draft skiff. The bottom samples were taken with an epibenthic sled with the net mounted 18 cm off the bottom. Both nets were pulled in an arc to avoid disturbing the vertical structure of the plankton with the prop wash. Net-mounted flowmeters provided sampled water volumes. Samples were preserved in 5 % seawater formalin. Surface to bottom temperature, salinity, and turbidity profiles were taken at each site with a Seabird SBE19 CTD.

A selected group of species were targeted for examination in this study. Spotted seatrout (*Cynoscion nebulosus*) and black drum (*Pogonias cromis*) were chosen for extensive analysis because of their estuarine spawning habits and commercial and recreational importance. The other targeted species included: sand seatrout (*Cynoscion arenarius*), red drum (*Sciaenops ocellatus*), Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), southern flounder (*Paralichthys lethostigma*), pinfish (*Lagodon rhomboides*), bay anchovy (*Anchoa mitchilli*), striped anchovy (*Anchoa hepsetus*) and penaeid shrimp (*Penaeus* spp.). This list includes species with a variety of spawning times and strategies (Table 1).

Table 1. Spawning times and sites for targeted species.

Species	Primary Spawning Area	Season[a]	References
Spotted Seatrout	estuary, tidal inlets	Mar-Sep	5,6,7
Black Drum	estuary, tidal inlets	Nov-Apr	7,12,13
Bay Anchovy	estuary, coastal, offshore	year-round	7,8
Red Drum	tidal inlets, coastal	Aug-Nov	3,15
Striped Anchovy	coastal, offshore	Mar-Jul	6
Pinfish	offshore	Dec-Mar	10
Southern Flounder	offshore	Dec-Mar	11
Sand Seatrout	offshore	Mar-Sep	14
Atlantic Croaker	offshore	Oct-Jan	4
Spot	offshore	Nov-Feb	
Brown Shrimp	offshore	year-round	1,2
White Shrimp	offshore	Apr-Sep	9

a in the Gulf of Mexico where known

1 Christmas et al. 1966
2 Lassuy 1983a
3 Regan 1985a
4 Laussy 1983b
5 Laussy 1983c
6 Holt et al. 1985
7 this paper
8 Robinette 1983
9 Muncy 1984a
10 Muncy 1984b
11 Regan 1985b
12 Sutter 1986
13 Cornelius 1984
14 Shlossman and Chittenden 1981
15 Holt et al. 1989

All larvae were identified to species except anchovies and shrimp. It was not possible to identify small (≤ 10 mm) anchovies to species so they were lumped as anchovy spp. Anchovies > 10 mm were identified to species and anchovies > 15 mm were excluded from the analysis due to the likelihood of net avoidance by the larger individuals. While white shrimp (*Penaeus setiferus*) postlarvae could be positively identified, we were unable to separate brown (*P. aztecus*) and pink (*P. duorarum*) shrimp and these were lumped as grooved shrimp. Based on the positive identification of a few larger individuals in our collections, we feel that most grooved shrimp were brown shrimp. Target species were picked from the sample, enumerated, and up to 50 individuals of each species were measured to the nearest 0.1 mm. Lengths are notochord length for pre-flexion larvae and standard length for flexion and post-flexion larvae. No correction was applied to account for shrinkage. All abundances were adjusted for sample volume and are expressed as number per 100 m^3.

Statistical analysis of the data was done using SAS-PC (SAS 1987). Differences in density among zones were tested with ANOVA after densities were transformed by log+1. Differences in mean length among zones were tested with ANOVA on untransformed data. Differences among means were identified by Tukey's means test.

RESULTS

Hydrography

Both temperature and salinity were vertically homogeneous at most sites in all months. The only regular exceptions were sites 6 and 9 in the ICW (Fig. 2) where a 2-8 °/oo halocline and a 0.5-1.0 °C thermocline was typically seen at about 2 m, which was the average water depth of the "flats" on either side of the channel. Monthly surface salinities for each site are shown in Figure 3. Salinity generally ranged from 44 to 54 °/oo in the Yarborough area and 35 to 45 °/oo elsewhere. Salinity dropped substantially throughout the central and lower Laguna Madre following localized heavy rains in the spring but prolonged drought throughout the region led to progressively higher salinities through the rest of the study. The generally lower salinities at sites 11 and 12 were due to Gulf water entering the Laguna Madre through the Port Mansfield Channel.

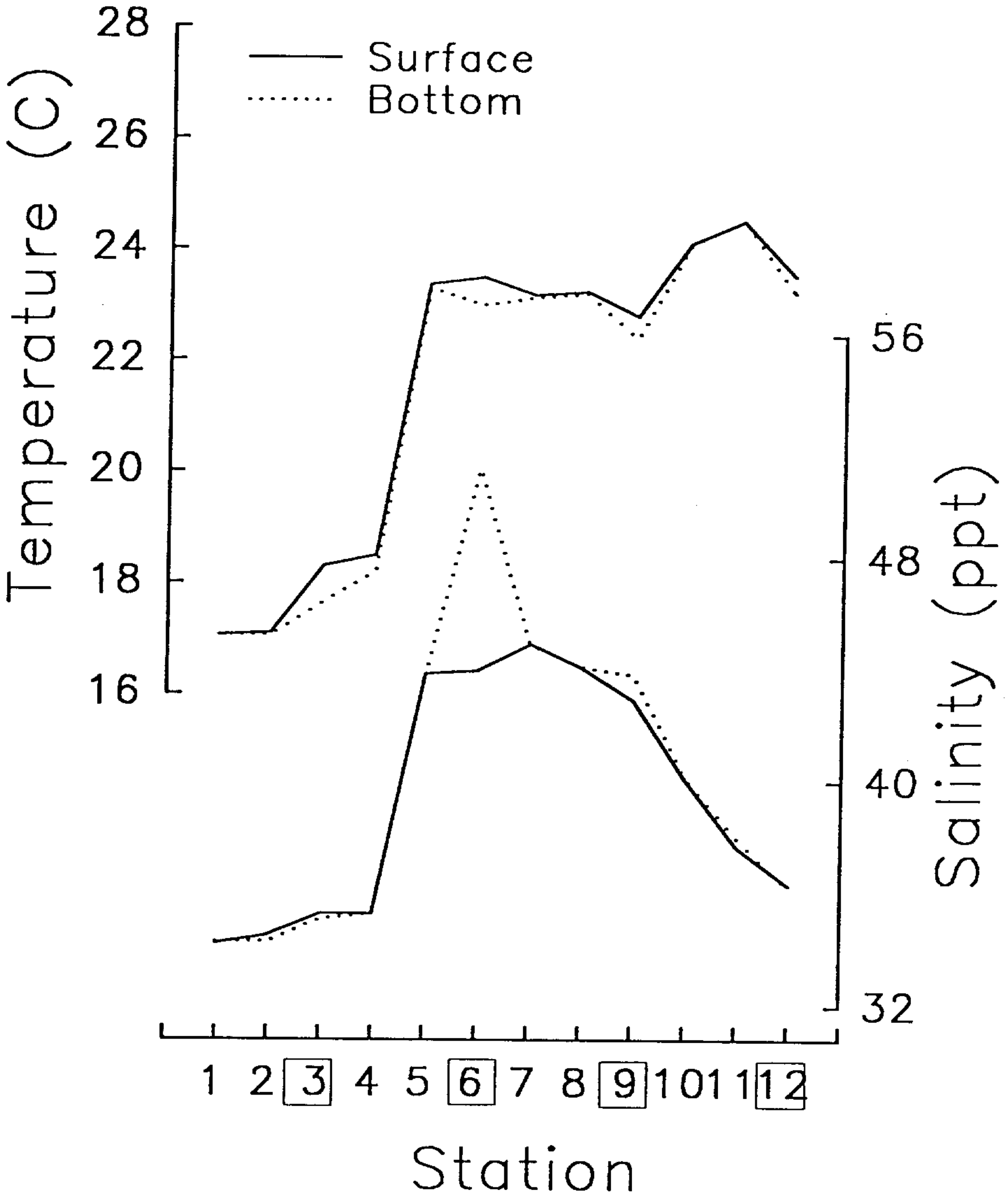

Figure 2. Mean surface and bottom temperature and salinity for each sample site. Station numbers in boxes are deep site in the Intercoastal Waterway or the Port Mansfield Channel.

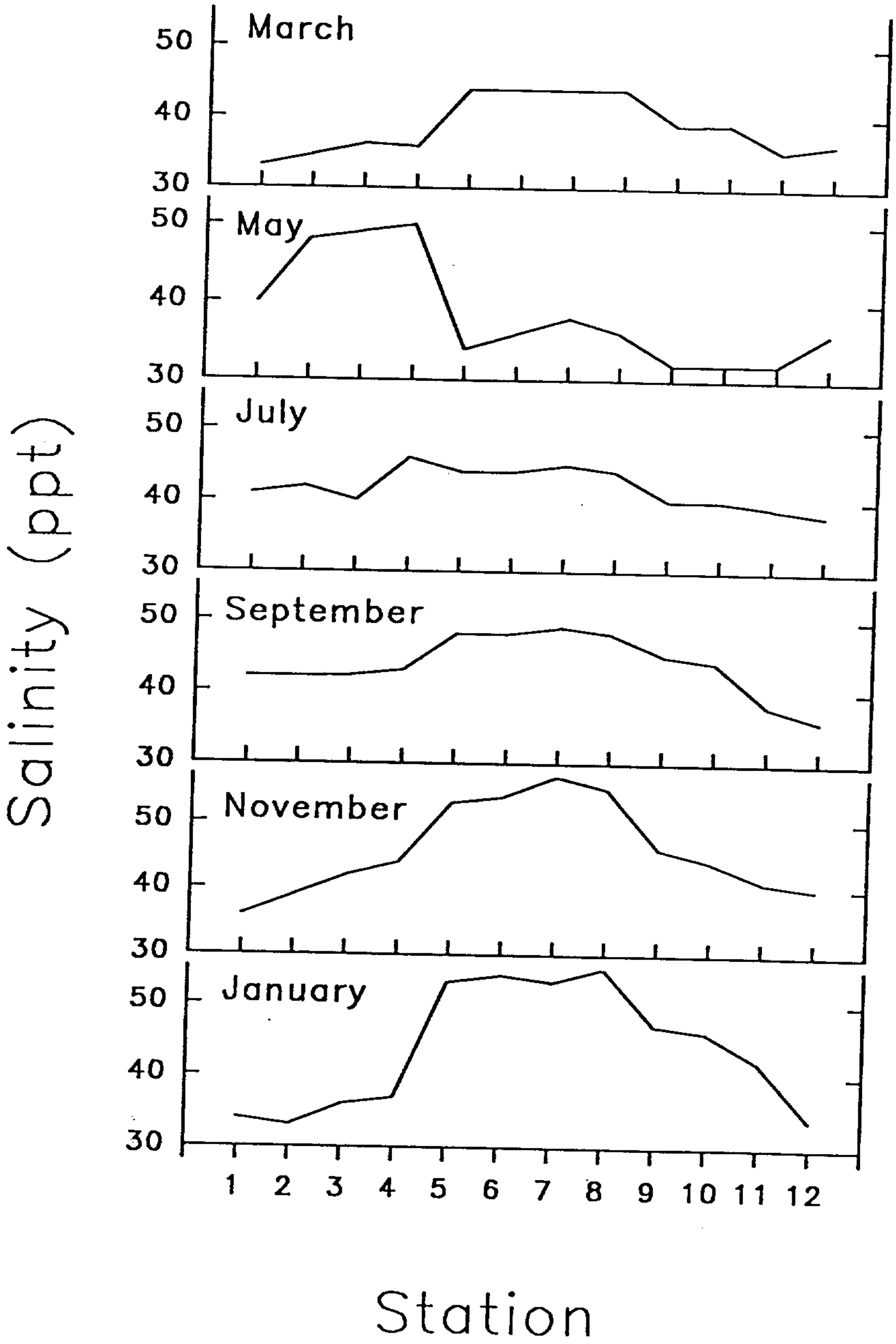

Figure 3. Surface salinity at each site for each sampling period.

Ichthyoplankton

Collections of targeted species totaled 139,878 individuals (Table 2). Anchovy spp. dominated the collections, accounting for > 71% of the catch. They were followed in dominance by white and grooved shrimp respectively, which together accounted for > 14% of the catch. The remaining species each accounted for < 5% of the catch. There was distinct vertical structure in the meroplankton despite the fact that most sites were < 2 m deep. Most fishes were substantially more abundant in bottom collections, with the exception of pinfish, while both shrimp "species" were taken at similar densities on both surface and bottom.

Temporal Distribution

The meroplankton could be roughly divided into three groups based on temporal occurrence in pooled surface and bottom data (Table 3). The cool season group included: spot, pinfish, Atlantic croaker, black drum, and red drum. Black drum were equally abundant in January and March while the other species were taken primarily in January. Red drum were rather arbitrarily assigned to this group. They occurred only in September and might have as easily been assigned to the warm-season group but they have life history characteristics similar to the members of the cool season group. The warm season group included: spotted seatrout, sand seatrout, silver perch, bay and striped anchovy, and the anchovy spp. group. While some of these species were abundant in March, they were all abundant in May and July and a few into September. The final group, comprised of grooved and white shrimp, were ubiquitous. They were not only taken in every month but were relatively abundant in all months except November (and March for white shrimp).

The greatest diversity of species was found in March when several of the cool season species were still found and most of the warm season species were also present, even though most members of both groups were in relatively low numbers or at least were not at their peak abundance. Maximum densities were found in May and July when most summer spawners reached their peak abundance while minimum densities occurred in November when neither cool nor warm season spawners were present in significant numbers.

Table 2. Total catch from surface and bottom tows pooled over all stations.

	Surface		Bottom		Combined	
	Catch	Percent	Catch	Percent	Catch	Percent
1 Anchovy spp.	21976	60.68	78613	75.84	100589	71.91
2 White Shrimp	5151	14.22	5310	5.12	10461	7.48
3 Grooved Shrimp	5626	15.53	4140	3.99	9766	6.98
4 Black Drum	1822	5.03	3882	3.74	5704	4.08
5 Bay Anchovy	280	0.77	4687	4.52	4967	3.55
6 Spotted Seatrout	451	1.25	2388	2.30	2839	2.03
7 Atlantic Croaker	43	0.12	1273	1.23	1316	0.94
8 Silver Perch	151	0.42	1143	1.10	1294	0.93
9 Striped Anchovy	355	0.98	877	0.85	1232	0.88
10 Spot	88	0.24	738	0.71	826	0.59
11 Sand Seatrout	5	0.01	328	0.32	333	0.24
12 Red Drum	57	0.16	192	0.19	249	0.18
13 Pinfish	186	0.51	12	0.04	198	0.14
14 Menticirrhus spp.	25	0.07	80	0.08	105	0.08
TOTALS	36216	100.00	103663	100.00	139879	100.00

Table 3. Monthly mean densities (No. per 100 m^3) from pooled surface and bottom tows.

Group	Species	March 1989	May 1989	July 1989	Sept 1989	Nov 1989	Jan 1990
1	Spot	0.01	0.00	0.00	0.00	0.00	3.60
	Pinfish	0.13	0.00	0.04	0.00	0.00	1.30
	Atlantic Croaker	0.06	0.00	0.00	0.00	0.04	1.30
	Red Drum	0.00	0.09	0.00	1.65	0.00	0.00
	Black Drum	18.26	0.01	0.00	0.00	0.28	17.59
2	Spotted Seatrout	3.53	3.52	2.72	7.49	0.03	0.00
	Bay Anchovy	0.02	28.16	9.06	3.55	0.99	0.00
	Anchovy sp.	166.93	142.18	268.78	82.90	0.58	0.18
	Striped Anchovy	0.51	5.56	0.55	1.37	0.17	0.00
	Silver Perch	3.67	4.83	0.59	0.01	0.00	0.00
	Sand Seatrout	0.02	1.48	0.52	0.08	0.00	0.00
3	Grooved Shrimp	2.23	8.34	1.31	24.54	0.61	25.93
	White Shrimp	0.61	14.78	5.40	21.01	0.33	26.04

Areal Distribution

Two aspects of larval fish distribution patterns were important. One is the general distribution pattern among zones which relates primarily to a species' distribution in relation to tidal passes. The other is the distribution within each zone, with the primary interest being the difference between shallow sites and deeper channel sites.

Both the diversity and density of fishes differed among zones. Table 4 shows that both number of species and density of all fishes were lowest in zones A and B. Both zones were dominated by larval anchovies although black drum contributed to the density of individuals at zone B. While both density and number of species were higher in zone C, the catches were still clearly dominated by larval anchovies which made up 90% of the catch in that zone. The highest number of species and the greatest mean density were found in zone D. The catches were not dominated by a single species since no species contributed more than 40 % to the total density in zone D.

The targeted species could be divided into three groups based on distribution patterns. The first group is composed of six species which had significantly higher densities in the Port Mansfield Channel (zone D) than at any other area (Table 4). It is important to note that some larvae of each of these species were found in other zones, including the relatively isolated zone B, but at substantially reduced densities. Sand seatrout and red drum were taken primarily at site 12 and at substantially reduced densities at site 11 (Figs. 4 and 5). Both species were taken occasionally in very low numbers at zone A but never at zone B. Pinfish were also found primarily at site 12 but substantial numbers were found in zone A at sites 1 and 2 (Fig. 6). Atlantic croaker and spot had significantly higher densities in zone D than the other zones but larvae of both species were more widely distributed, especially into zone B, than the previous species (Figs. 7 and 8). Larvae of both species taken in zone B were significantly larger than those in zones C or D (Table 5). The final species in this group, striped anchovy, was more abundant in zones A, B, and C than the other species but still had significantly higher densities in zone D (Fig. 9). The densities of

Table 4. Mean density in each zone in pooled surface and bottom tows. Means with same letter are not significantly different in Tukey's mean test.

Species Group		Zone			
		A	B	C	D
1	Pinfish	0.15 b	0.00 b	0.03 b	2.64 a
1	Red Drum	0.01 b	0.00 b	0.23 b	2.72 a
1	Sand Seatrout	0.01 b	0.00 b	0.05 b	4.30 a
1	Atlantic Croaker	0.00 b	0.05 b	0.04 b	16.11 a
1	Spot	0.00 b	1.22 b	0.01 b	2.47 a
1	Striped Anchovy	0.48 b	1.53 b	1.82 b	3.17 a
2	White Shrimp	0.29 c	0.01 c	4.07 b	135.02 a
2	Grooved Shrimp	0.61 c	0.05 c	6.68 b	114.10 a
2	Silver Perch	0.00 c	0.42 c	2.39 b	9.89 a
3	Black Drum	0.09 d	13.62 a	6.97 b	1.82 c
3	Spotted Seatrout	0.30 c	1.90 b	7.07 ab	4.97 a
3	Larval Anchovy	35.30 c	144.74 a	231.13 a	43.72 b
3	Bay Anchovy	0.31 b	13.93 a	9.02 ab	0.05 b
All Targeted Species		37.55	177.47	269.51	340.98
Number of Species		8	8	11	13

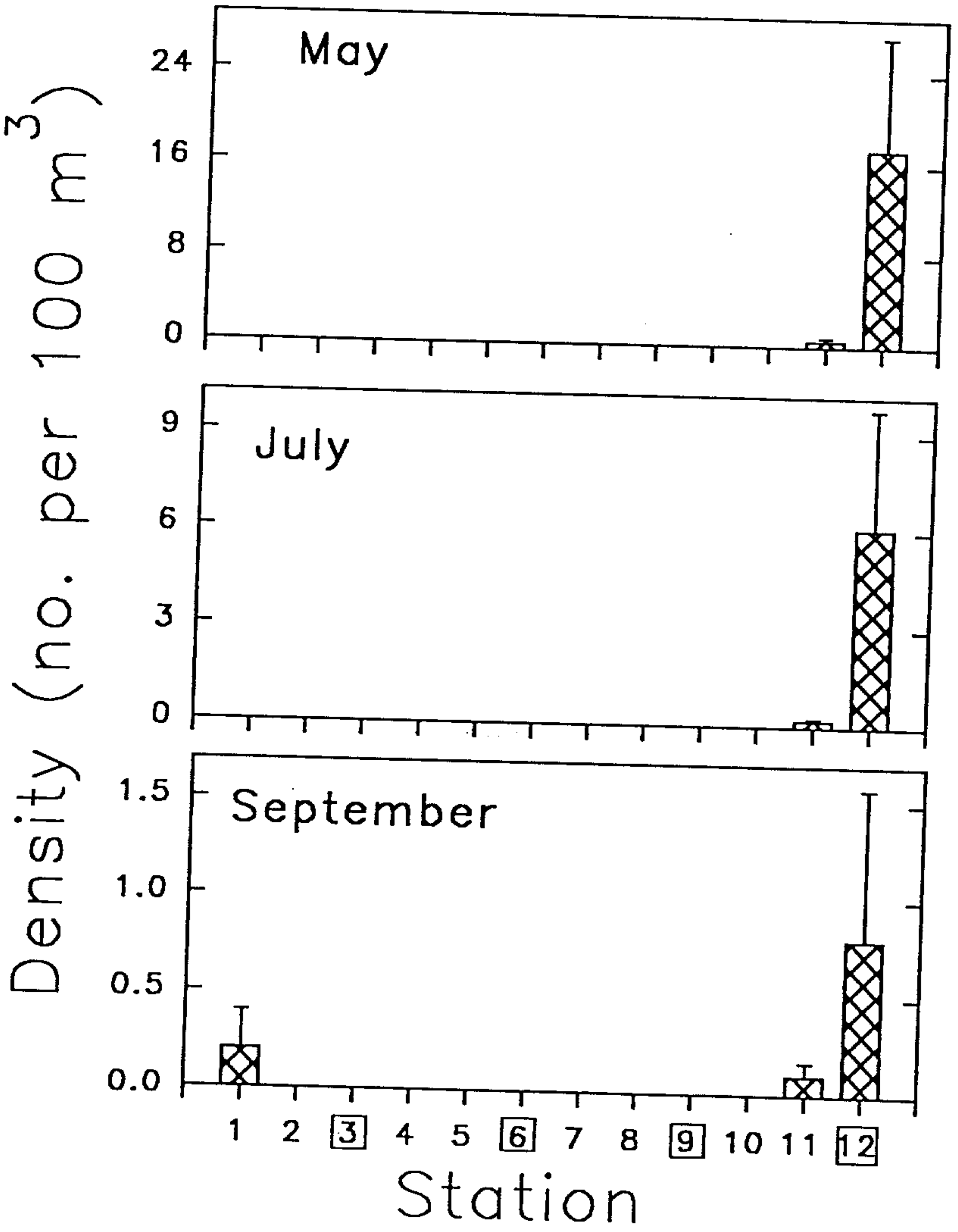

Figure 4. Mean density in pooled surface and bottom samples (± 1SE) of sand seatrout larvae at each sample site for all months during which they were relatively abundant.

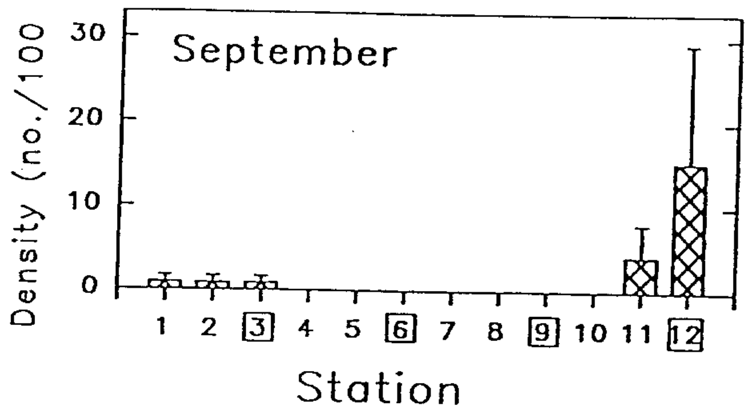

Figure 5. Mean density in pooled surface and bottom samples (± 1SE) of red drum larvae at each sample site for all months during which they were relatively abundant.

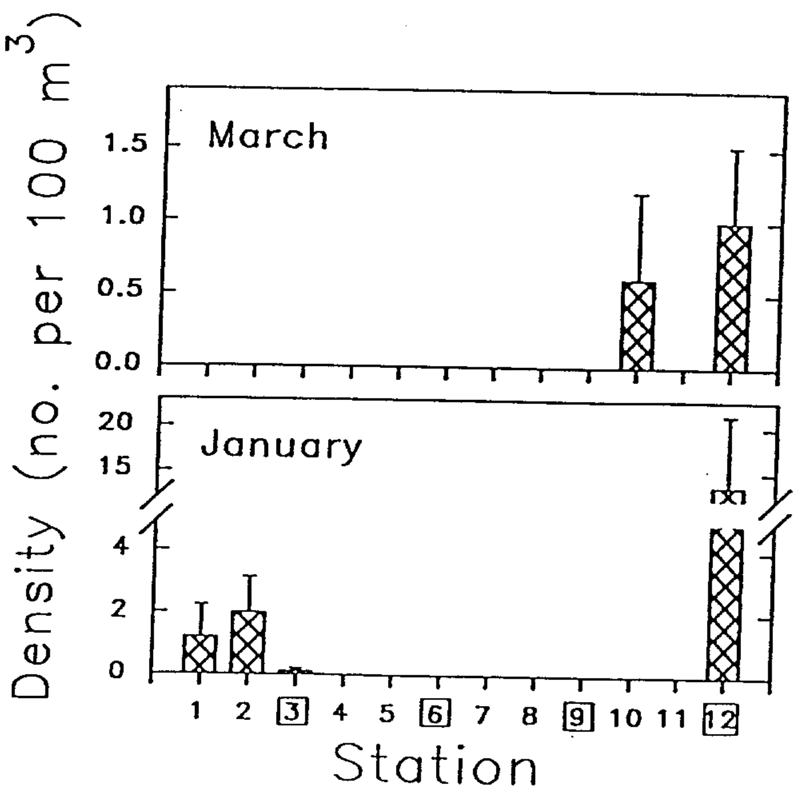

Figure 6. Mean density in pooled surface and bottom samples (± 1SE) of pinfish larvae at each sample site for all months during which they were relatively abundant.

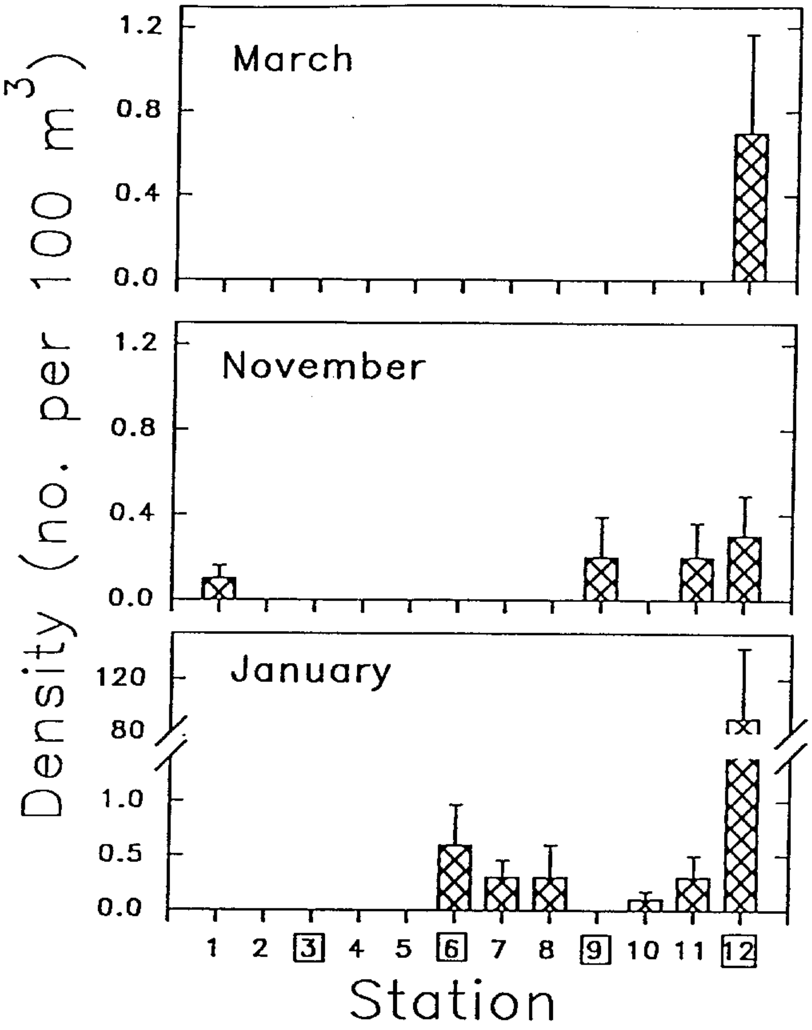

Figure 7. Mean density in pooled surface and bottom samples (± 1SE) of Atlantic croaker at all sample site for all months during which they were relatively abundant.

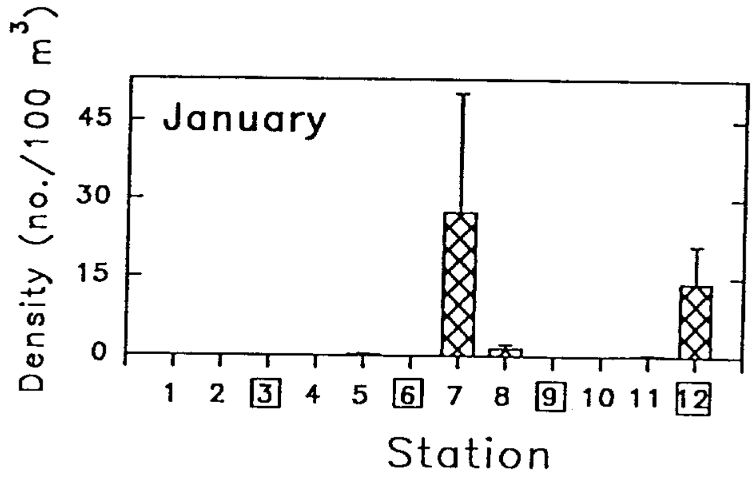

Figure 8. Mean density in pooled surface and bottom samples (± 1SE) of spot larvae at each sample site for all months during which they were relatively abundant.

Table 5. Mean length in each zone of pooled surface and bottom tows. Means with the same letter are not significantly different in Tukey's mean test. Numbers in parentheses are number of individuals measured.

Group	Species	Zone			
		A	B	C	D
	Sand Seatrout*	3.45 b (2)	--	7.47 a (18)	5.11 ab (211)
	Red Drum	3.78 a (3)	--	4.20 a (48)	4.78 a (67)
1	Pinfish*	12.13 a (44)	--	10.03 b (6)	11.91 a (114)
	Atlantic Croaker*	7.76 c (1)	16.09 a (19)	10.82 b (21)	10.72 b (205)
	Larval Striped Anchovy*	11.31 c (82)	11.78 b (109)	12.73 a (241)	12.08 b (182)
	Silver Perch	2.20 a (2)	2.82 a (122)	3.39 a (359)	3.07 a (321)
2	White Shrimp	8.52 a (64)	9.84 a (1)	9.29 a (439)	8.33 a (8.69)
	Grooved Shrimp	9.80 a (115)	10.66 a (17)	10.22 a (558)	9.91 a (612)
	Bay Anchovy*	11.85 ab (79)	12.20 ab (901)	12.53 a (416)	10.82 b (3)
	Spot*	--	18.40 a (178)	11.89 b (2)	10.94 b (171)
3	Anchovy spp.*	5.27 bc (1241)	5.39 b (4385)	5.23 c (3259)	6.12 a (812)
	Black Drum*	2.56 b (1961)	3.11 a (2083)	2.92 a (850)	3.17 a (123)
	Spotted Seatrout*	2.57 a (84)	2.49 a (538)	2.74 a (741)	3.41 a (233)

*P < 0.05

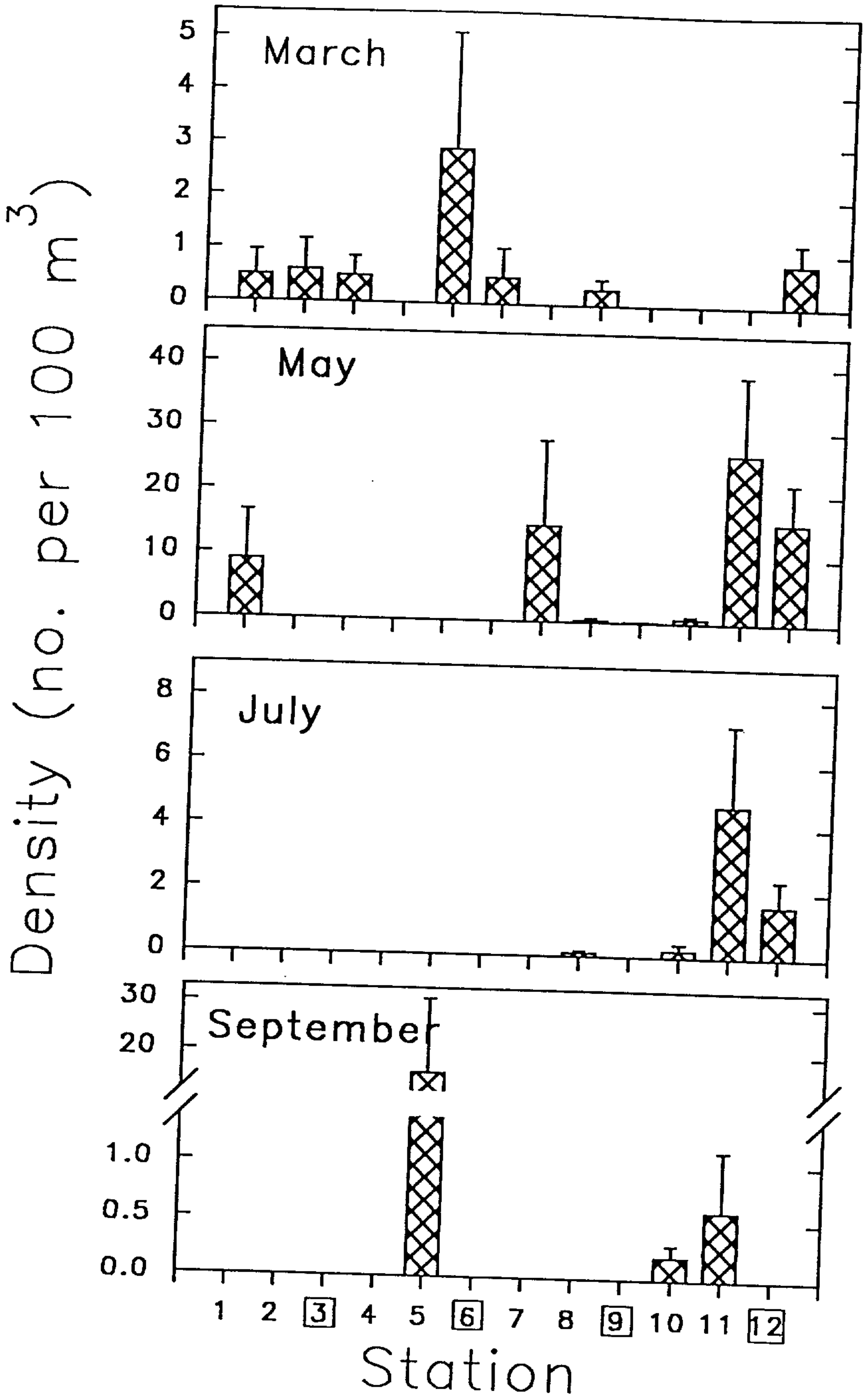

Figure 9. Mean density in pooled surface and bottom samples (± 1SE) of striped anchovy for all months during which they were relatively abundant.

the above species were not consistently different between the deeper ICW sites and the shallower "flats" site within any of the zones.

The second group is comprised of three species which had their highest density in zone D, a lower density in zone C, and their lowest densities in zones A and B. The distribution patterns for white shrimp and grooved shrimp were remarkably similar (Figs. 10 and 11) but a greater proportion of the grooved shrimp catches were from zone C sites farthest from the tidal inlet (sites 9 and 10), than for white shrimp. Silver perch distribution showed substantial variation among months (Fig. 12). Although the mean of all data pooled over months for silver perch was significantly higher at zone D, the March collections show a much higher density at zone C site 9 than at any other site. Although species in this group occasionally had highest densities at site 9, in the ICW, none of these species consistently had higher densities in all of the ICW sites than at the shallow sites. There was no difference in mean size among zones for any of these species.

The third group is composed of relatively abundant estuarine spawners which were widely distributed throughout the study area. The highest densities of bay anchovy and anchovy spp. were in zones B and C. They were generally found at all sites within these zones but their distribution was quite patchy (Figs. 13 and 14). Black drum and spotted seatrout are treated in detail below.

Spotted Seatrout

A total of 2839 spotted seatrout larvae were taken in the study. The average density of larval spotted seatrout over the entire study area was similar in March, May and July but was substantially higher in September (Table 3). While mean densities were similar among months, the distribution of the larvae among sites were not similar month to month (Fig. 15). Spotted seatrout larvae were taken primarily in zone B in March collections, in zones C and D in May, and widespread at all sites in July and September. In each month, with the exception of the March collections, spotted seatrout larvae were substantially more abundant at one site than at all the rest. In May nearly one-half of the 450 larvae were taken in the Port Mansfield Channel (site 12), primarily on the bottom. In July and September, substantially more larvae were

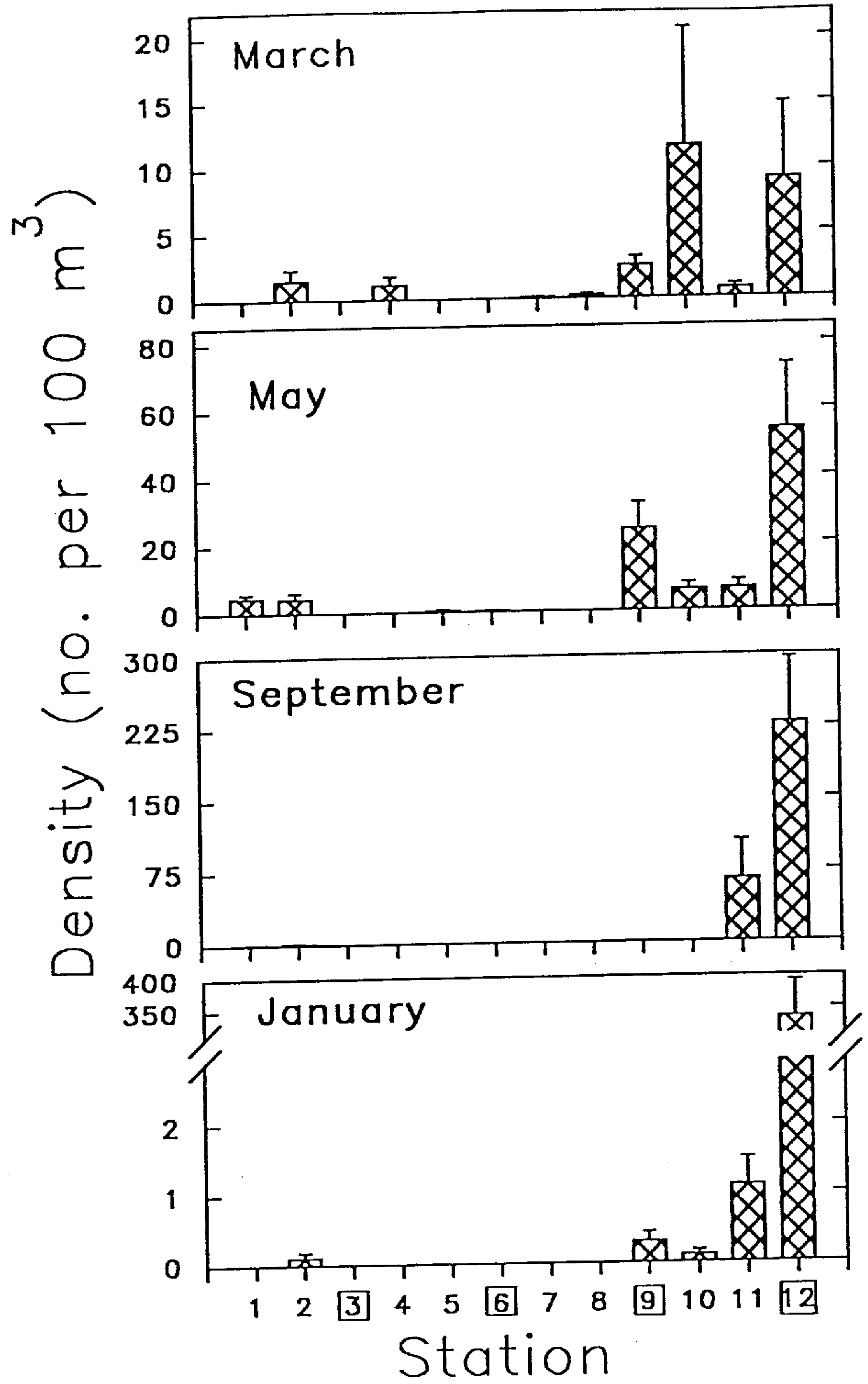

Figure 10. Mean density in pooled surface and bottom samples (± 1SE) of white shrimp larvae at each sample site for all months during which they were relatively abundant.

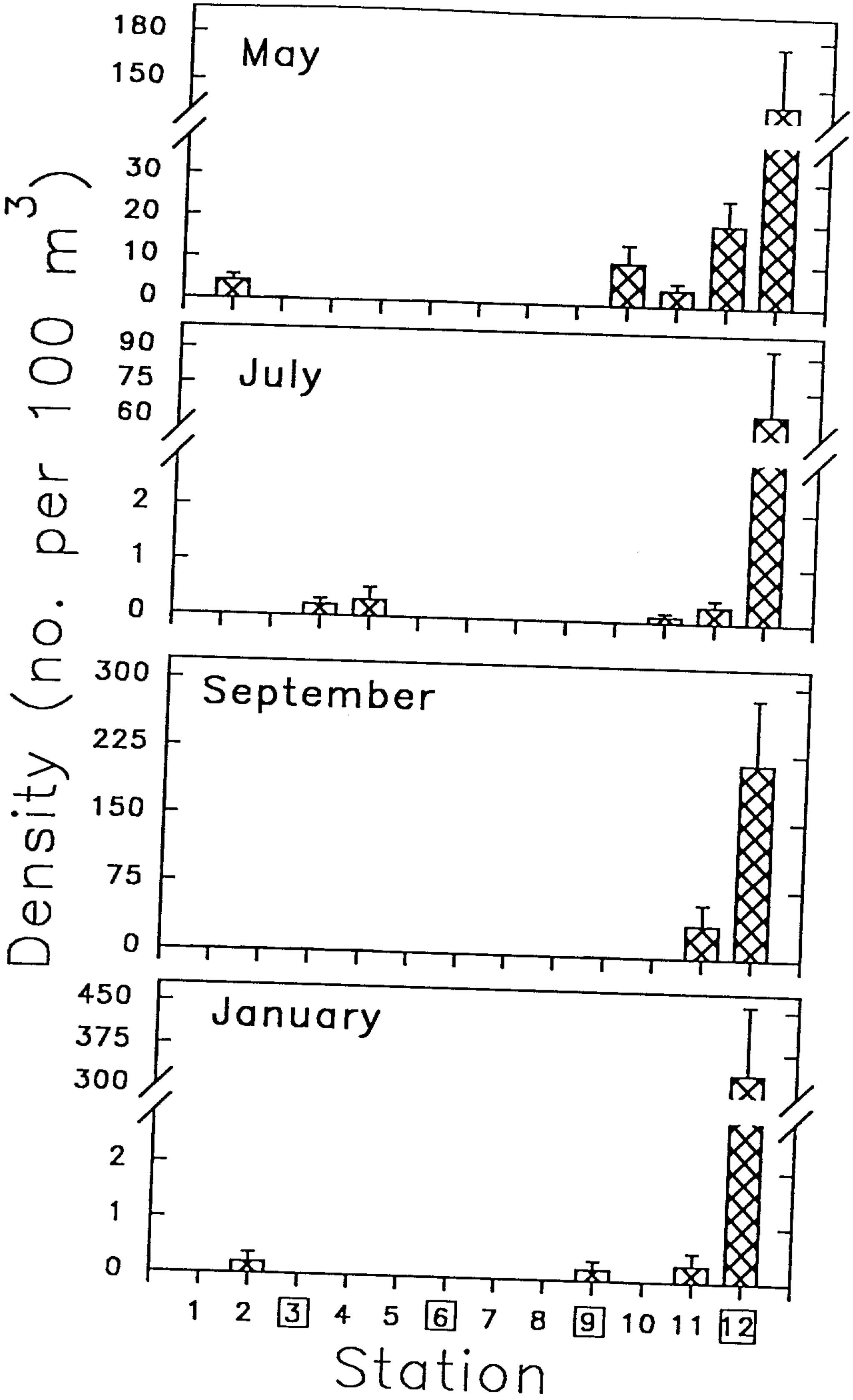

Figure 11. Mean density in pooled surface and bottom samples (± 1SE) of grooved shrimp larvae at each sample site for all months during which they were relatively abundant.

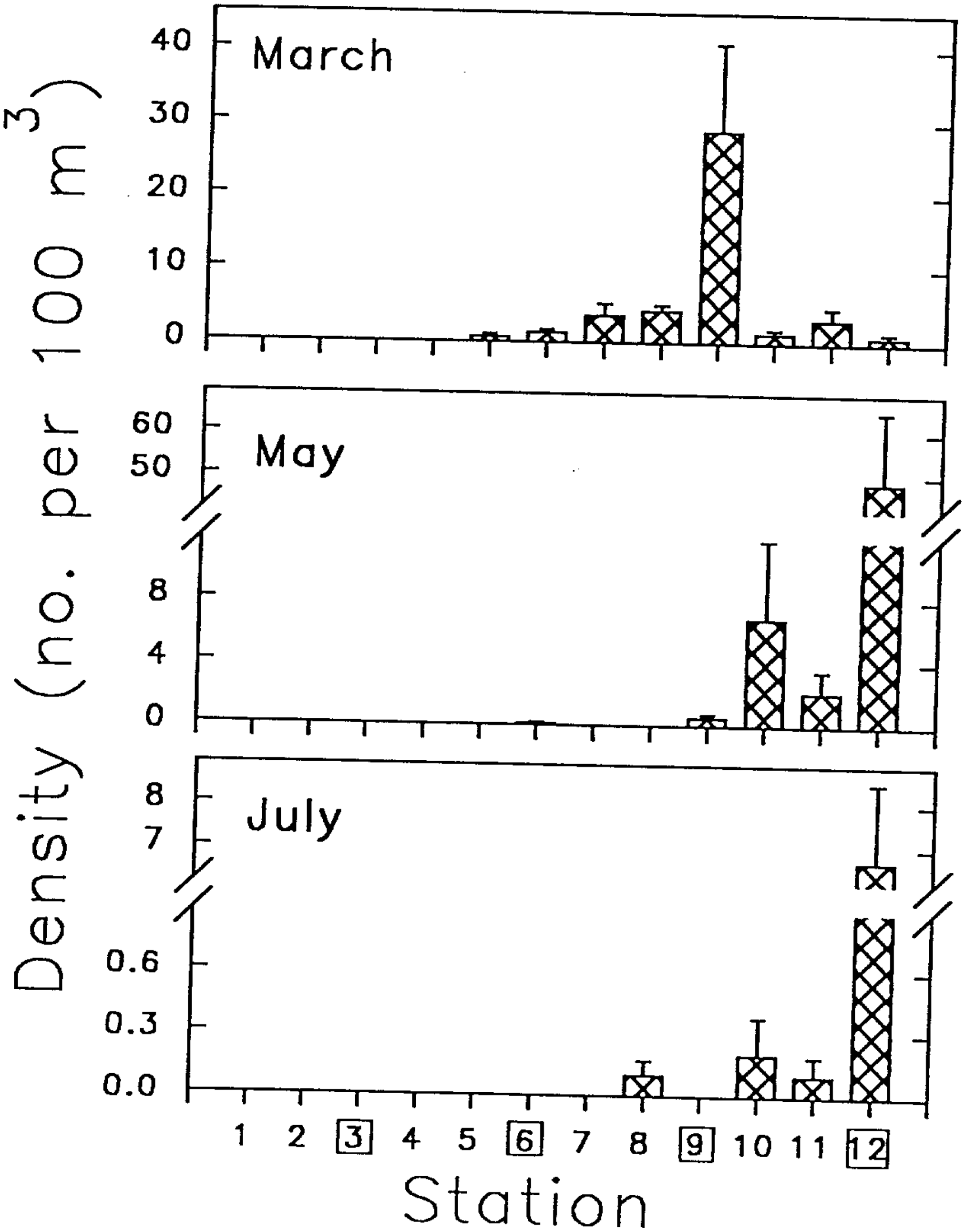

Figure 12. Mean density in pooled surface and bottom samples (± 1SE) of silver perch larvae at each sample site for all months during which they were relatively abundant.

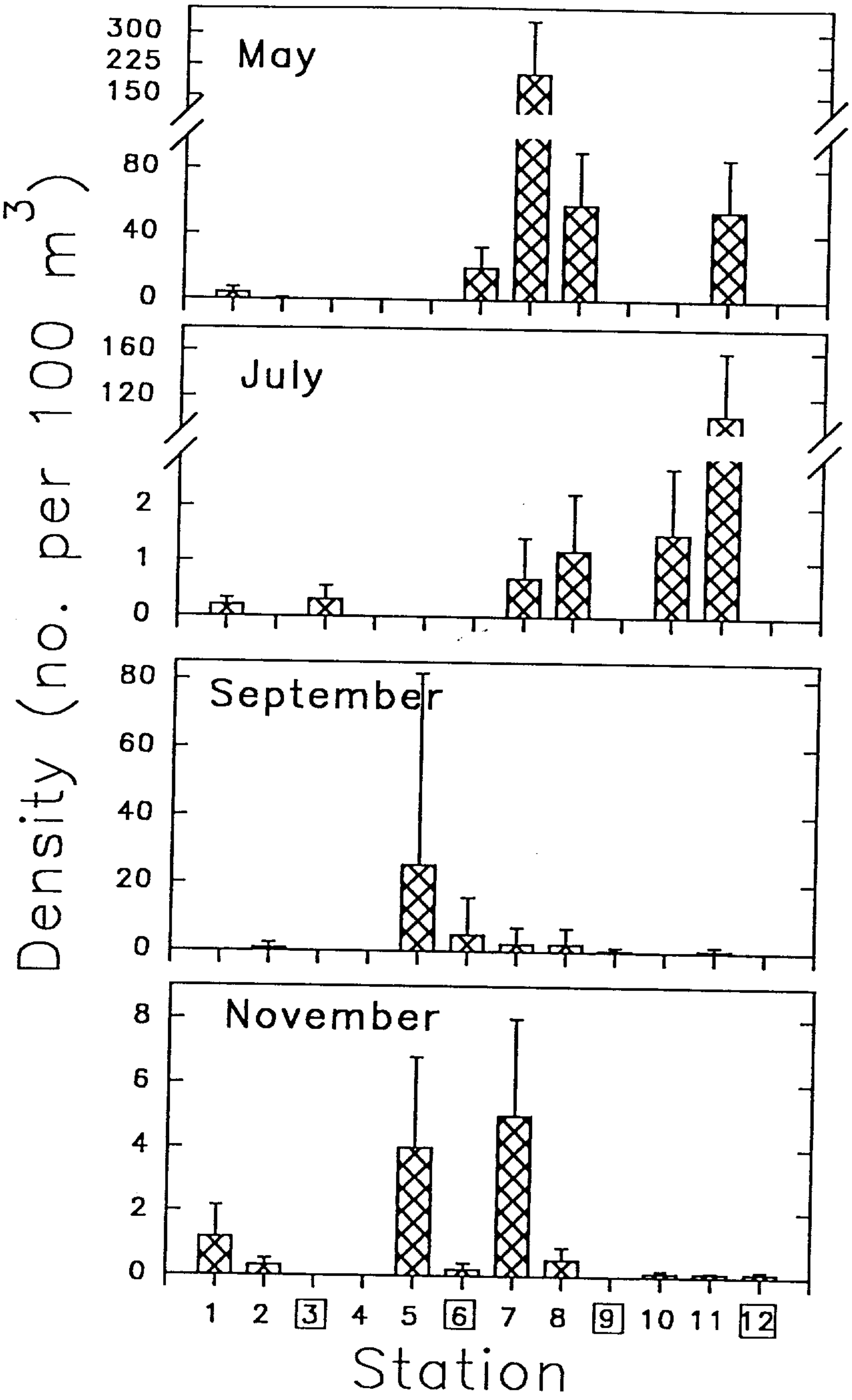

Figure 13. Mean density in pooled surface and bottom samples (± 1SE) of bay anchovy larvae at each sample site for all months during which they were relatively abundant.

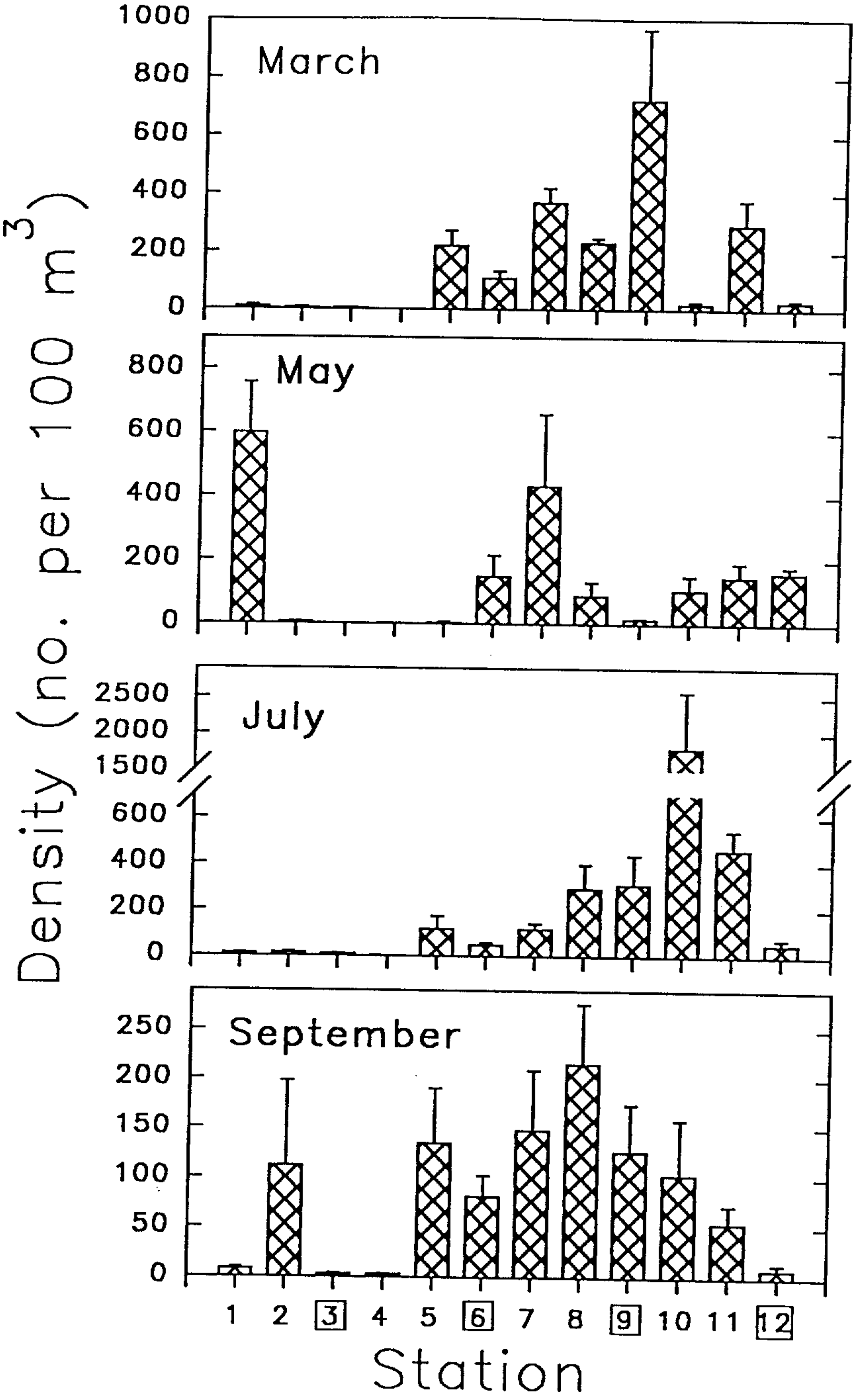

Figure 14. Mean density in pooled surface and bottom samples (± 1SE) of anchovy spp. larvae at each sample site for all months during which they were relatively abundant.

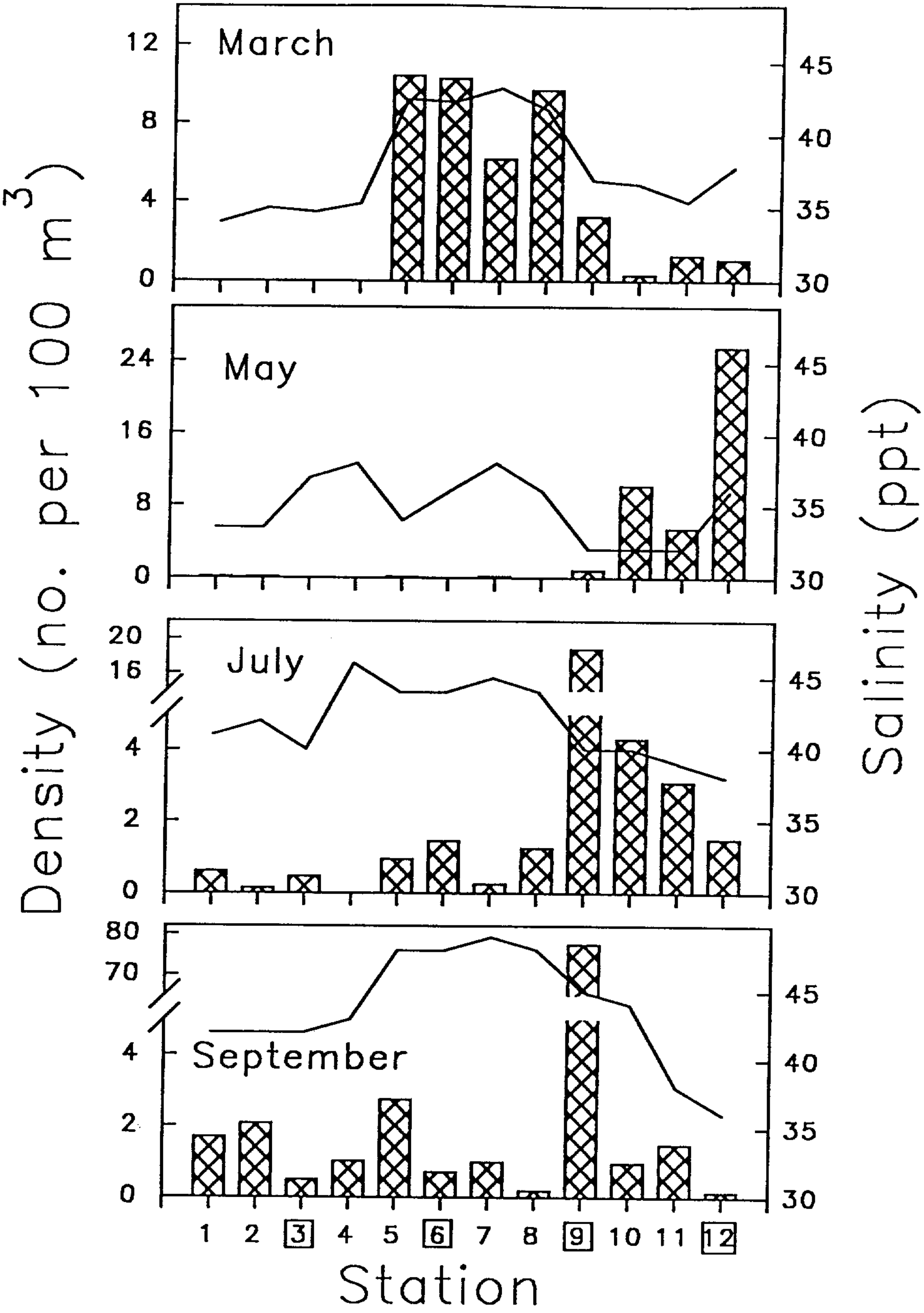

Figure 15. Mean density in pooled surface and bottom samples of all spotted seatrout larvae at each sample site for all months during which they were relatively abundant and surface salinities at each site.

taken at site 9 than at any other station. The September collections were quite remarkable. The mean density of pooled surface and bottom tows at site 9 was 77.5 larvae per 100 m3. The major contributor to this relatively high density was a bottom tow with a density of 307.9 larvae per 100 m^3. Densities in the other two bottom replicates at this site were 35.4 and 59.4 larvae per 100 m^3.

Spotted seatrout larvae ranged from 1.1 to 18.2 mm but less than 1% were > 9.0 mm. Most larvae were between 1.0 and 5.0 mm and excluding the May collections, over 70% were < 2.5 mm. Ages of larvae taken in the Laguna Madre were estimated using a growth equation given by McMichael and Peters (1989) for spotted seatrout 10-50 mm in Tampa Bay, Florida at a mean seawater temperature of 28.1 °C, approximately 1.5 °C greater than in this study. The estimated age of a 2.5 mm larva is ≈ 6 days. Figure 16 shows the distribution of these young larvae. Since the large majority of larvae in most collections were < 2.5 mm, the distribution pattern of small larvae closely resembles the distribution pattern of all larvae but densities were reduced by 80-90 % in the May collections and 10-20% in other months.

The distribution of spotted seatrout larvae appears to be unrelated to salinity (Figs. 15 and 16). High larval densities were seen at both relatively low salinities (>24 larvae per 100 m^3 at site 12 in May at 35.4 °/oo) and relatively high salinities (>75 larvae per 100m^3 at site 9 in September at 45.0 °/oo).

Spotted seatrout larvae were consistently taken at higher densities on the bottom than on the surface. Figure 17 shows that at most sites, more than 70% of the larvae were taken on the bottom. The variation between mean surface and bottom densities was not related to water depth. The dominance of bottom over surface densities at deep sites in the ICW ranged from 58% at station 6 to > 85% at stations 3 and 9. Likewise, the dominance of bottom over surface densities at shallow sites ranged from 62% at site 8 to 82% at site 10, both in approximately 2 m of water.

The difference in mean size between surface and bottom catches varied among months (Fig 18). Results of the Wilcoxon two-sample test (SAS 1987) show that larval size was significantly different between surface and bottom in March and May samples ($P > Z = 0.009$ and 0.001 respectively) but not significantly different in July or September ($P > Z = 0.301$ and 0.903 respectively). Mean size was smaller in bottom

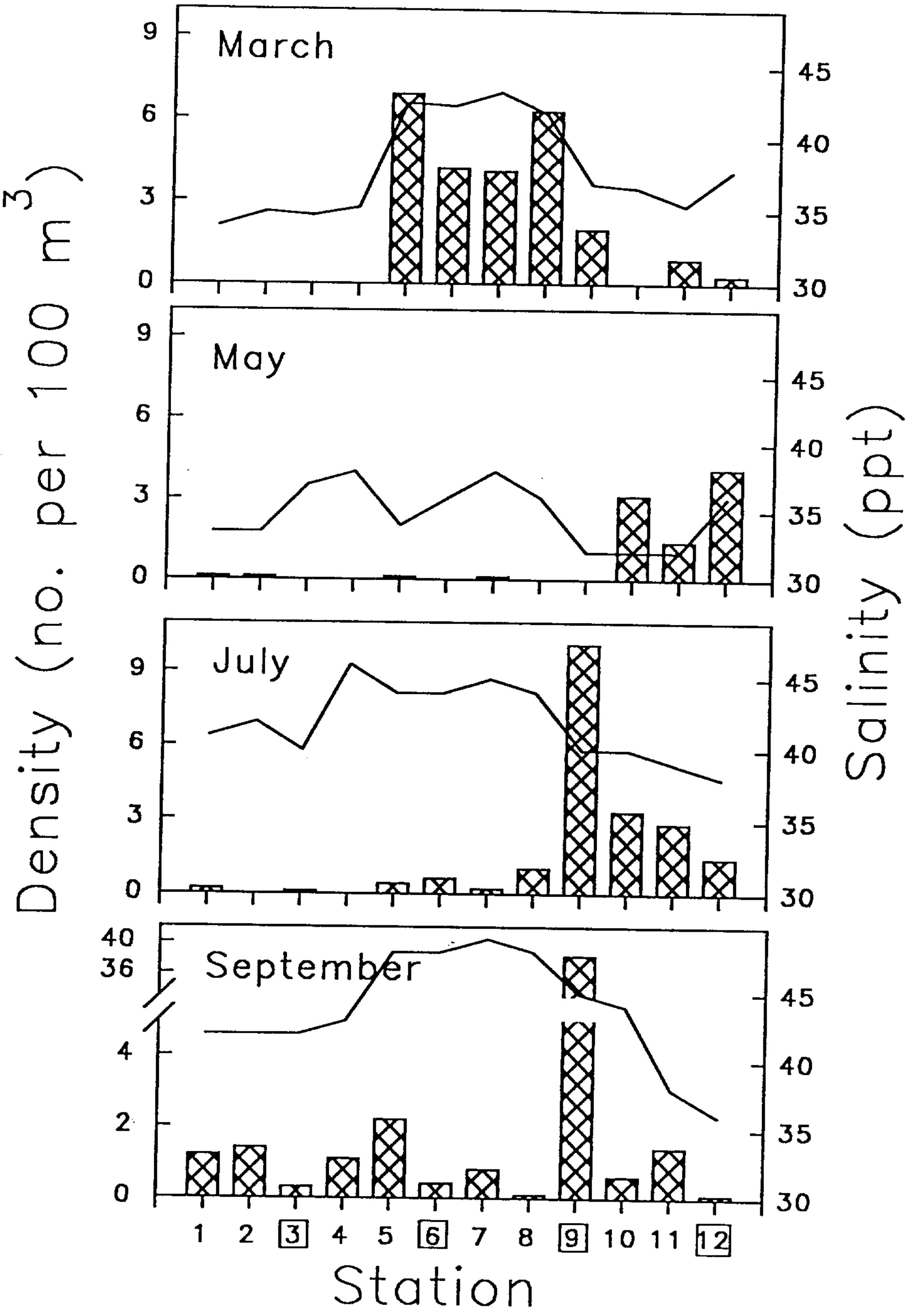

Figure 16. Mean density in pooled surface and bottom samples of small (<2.5 mm) spotted seatrout larvae at each sample site for all months during which they were relatively abundant and surface salinity at each site.

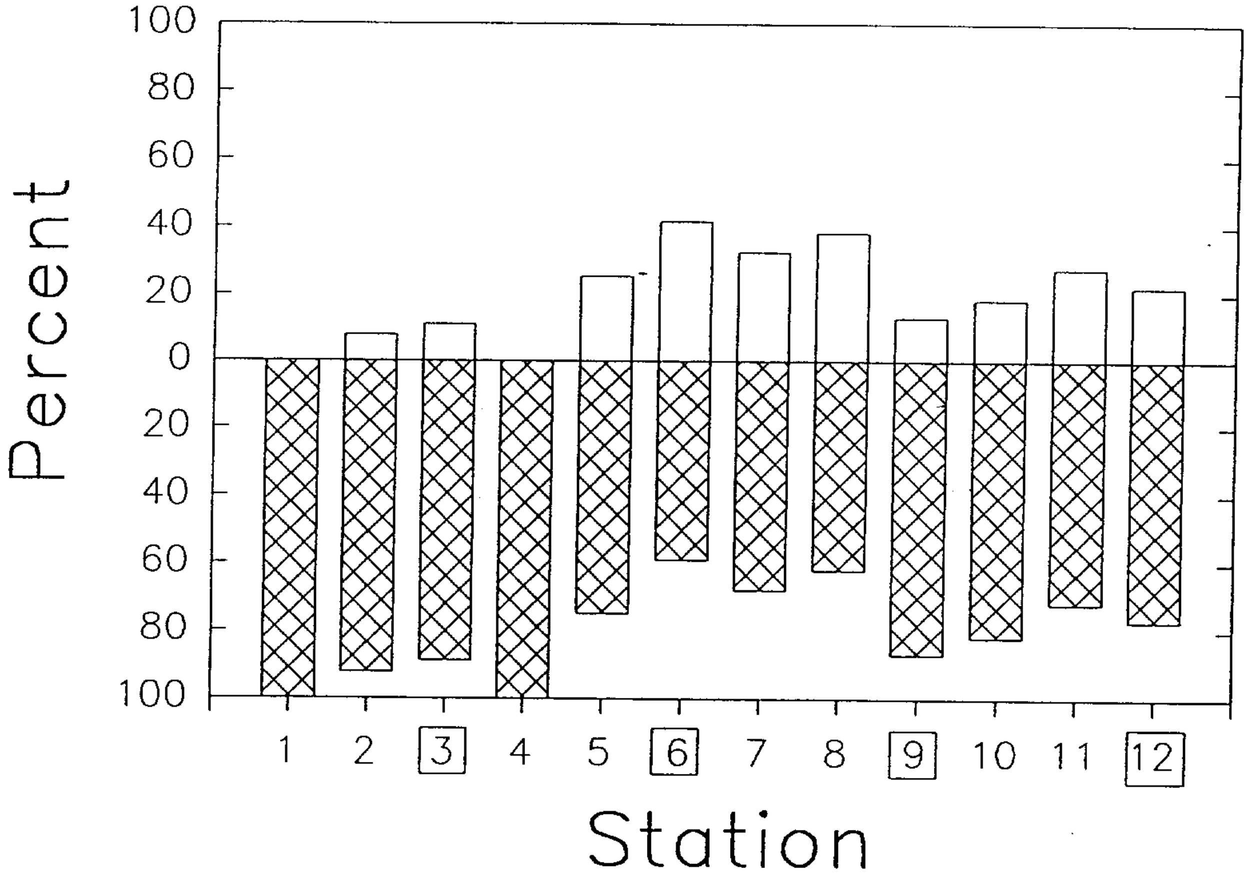

Figure 17. Percent of spotted seatrout larvae collected from surface samples (open bars above the zero axis) and bottom samples (hatched bars below the zero axis) at each site.

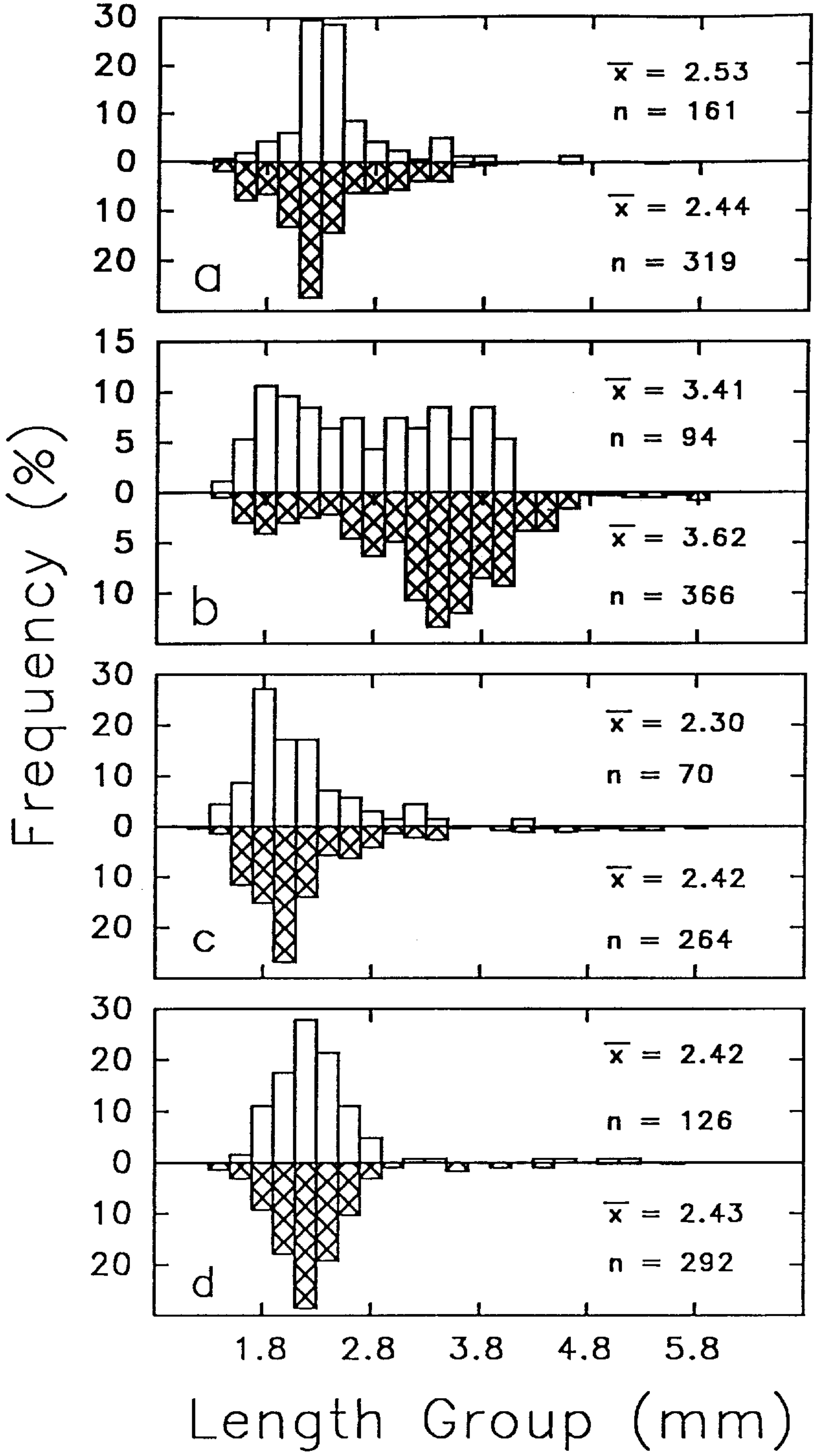

Figure 18. Length-frequency distribution of spotted seatrout larvae in surface (open bars above the zero axis) and bottom (hatches bars below the zero axis) collections for March (a), May (b), July (c), and September (d) sampling periods.

samples in March collections and larger in bottom samples in May collections (Panels a and b, Fig. 18). There was no significant difference in mean size of spotted seatrout larvae among zones (ANOVA; df = 3; F = 2.83; p = 0.067; Table 5).

Black Drum

Black drum was the most abundant sciaenid taken in the study with 5704 larvae collected. Average density of black drum larvae over the whole study area was similar and relatively high in March 1989 and January 1990, and much lower in November (Table 4). Black drum larvae were not found in other months. In contrast to the variable distribution of spotted seatrout larvae among months, the distribution of black drum larvae among sites did not change substantially from month to month (Fig. 19). They were virtually absent from all sites in zone A in every collection period and were usually found in relatively low densities in zone D in the Port Mansfield Channel. Densities were relatively high in zone C only in January.

No age/size relationship is available for black drum larvae. Mean water temperature for all positive larval black drum collections was ≈ 20 °C and growth rate of black drum larvae should be substantially slower than for spotted seatrout larvae growing in 28 °C. Another member of the sciaenid family, Atlantic croaker, grows at a rate of 0.18-0.20 mm^{-d} during early to mid-winter in oceanic waters off North Carolina (Warlen 1981) and Louisiana (Cowan 1988). If black drum grow at a similar rate, then the median size larvae in this study (3.01 mm) would be 8-12 d old. Figure 20 shows that the distribution of small (less than the median) black drum larvae was substantially different than for all larvae (Fig. 19) in November and January, a period of very high salinity in zone B. A comparison of Figures 19 and 20 shows that in these months small larvae were restricted to zones C and D, south of the "Land Cut". All black drum larvae in zone B were larger and hence older larvae.

Salinity had no obvious effect on abundance or distribution of larger black drum larvae (Fig. 19). They were found at relatively high densities at the highest observed salinities of 53 °/oo. Small larvae, however, were never abundant at salinities above 45 °/oo (Fig. 20).

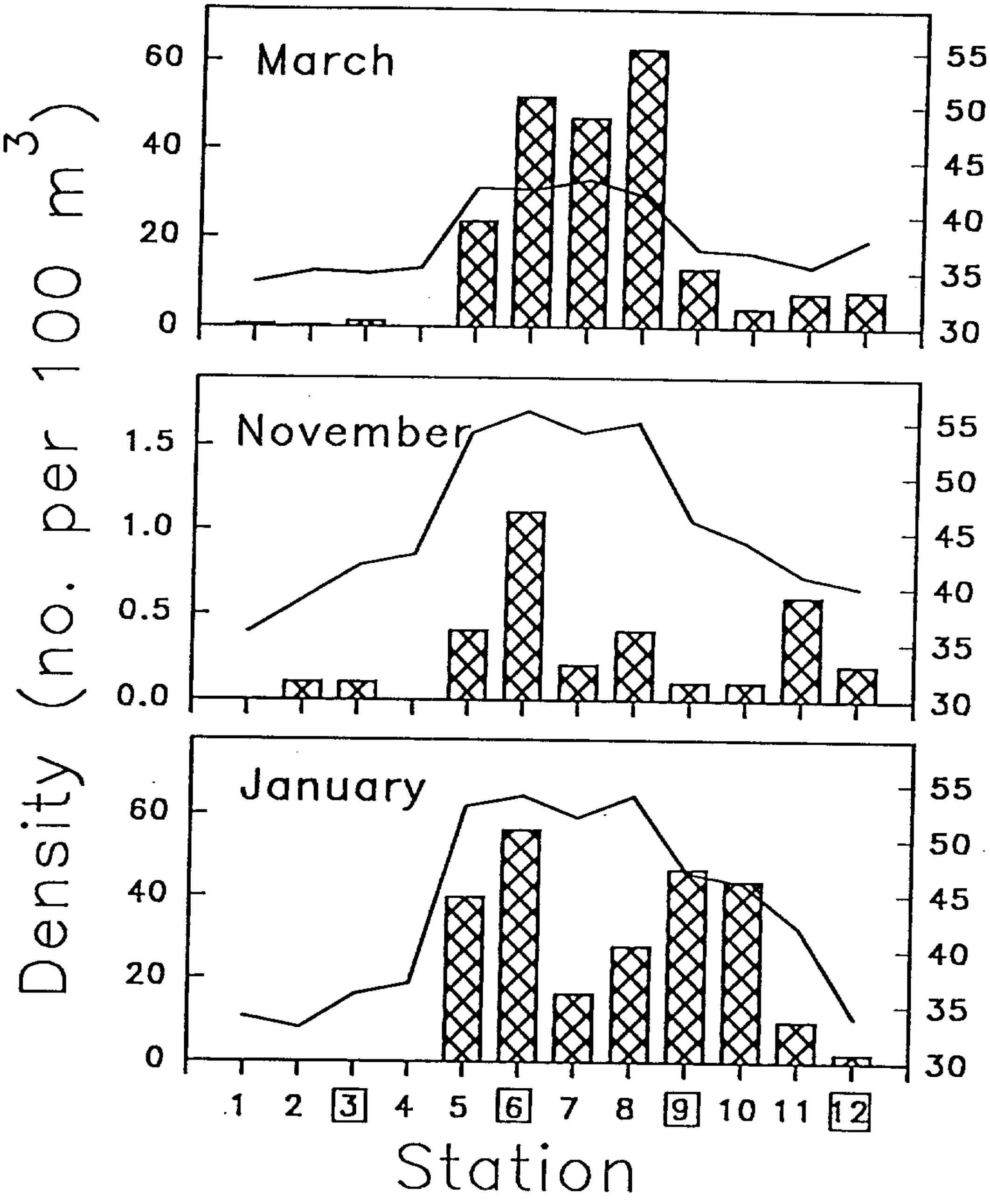

Figure 19. Mean density in pooled surface and bottom samples of all black drum larvae at each sample site for all months during which they were relatively abundant and surface salinity at each site.

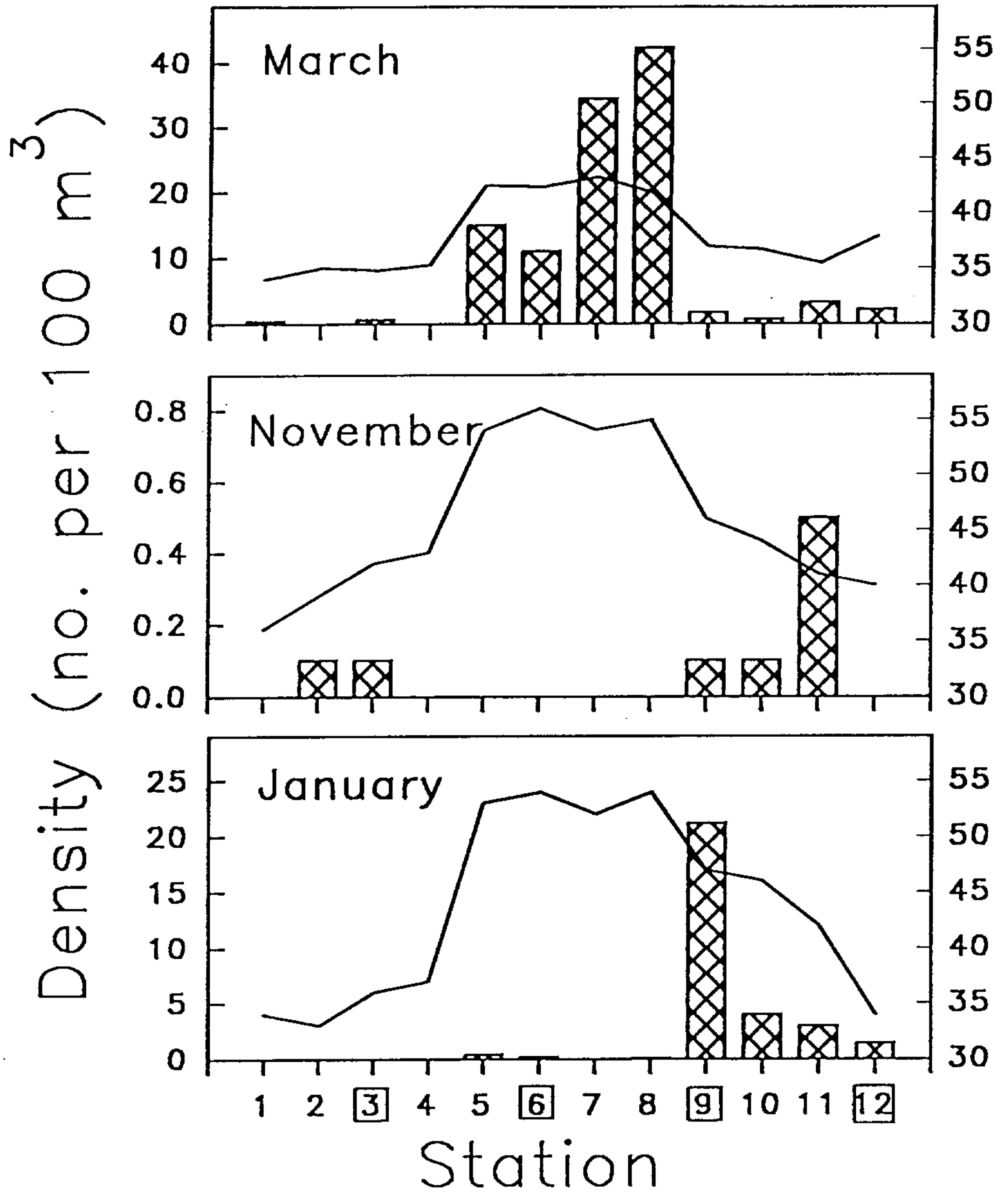

Figure 20. Mean density in pooled surface and bottom samples of small (<2.5 mm) black drum larvae at each sample site for all months during which they were relatively abundant and surface salinity at each site.

Mean bottom densities of black drum larvae generally exceeded mean surface densities (Fig. 21) but not to the extent seen for spotted seatrout larvae. Mean bottom density exceeded mean surface density by as much as 84% at station 3 in data pooled over all trips but were generally <70% of the total at other sites and were exceeded by mean surface densities at sites 10 and 11 (mean bottom densities were 44.6 and 43.9% of total catch respectively). Mean bottom densities constituted a greater proportion of the catch at the channel sites than at shallow sites with the exception of the Port Mansfield Channel. Mean bottom densities at sites 3, 6, and 9 were >74% of the site mean.

Differences in mean surface and bottom densities of black drum larvae were clearly size related. Plots of length frequency distributions for March and November 1989 and January 1990 collections (Fig. 22) show that larger larvae were more predominant in bottom samples. Results of the Wilcoxon two-sample test show that larval size at each depth was significantly different in both March and January samples ($P > Z = 0.0007$ and 0.0001 respectively) but not in the November samples ($P > Z = 0.288$) where sample size was small (only 49 larvae).

Mean size of black drum larvae was significantly different among zones. Results of Tukey's means test (Table 5) show that the larvae taken in zone A were significantly smaller than those larvae taken in the other three zones. It should be noted that only 19 larvae were taken in zone A compared to more than one hundred taken in each of the other zones.

DISCUSSION

The Laguna Madre was generally hypersaline at all sites throughout the study and the salinity range of about 35 to 55 °/oo was similar to that observed by Simmons (1957) from 1951 to 1956. The region near the proposed Yarborough Pass averaged 5 °/oo higher than the remainder of the study area. Despite the hypersalinity, the species composition of the meroplankton was typical of that of other estuarine regions along the Gulf of Mexico and the Atlantic coastal regions of the southern United States (Holt and Strawn 1983, Houde and Lovdal 1984, Allen and Barker 1990). The seasonal assemblages outlined here, which represent spawning period and larval

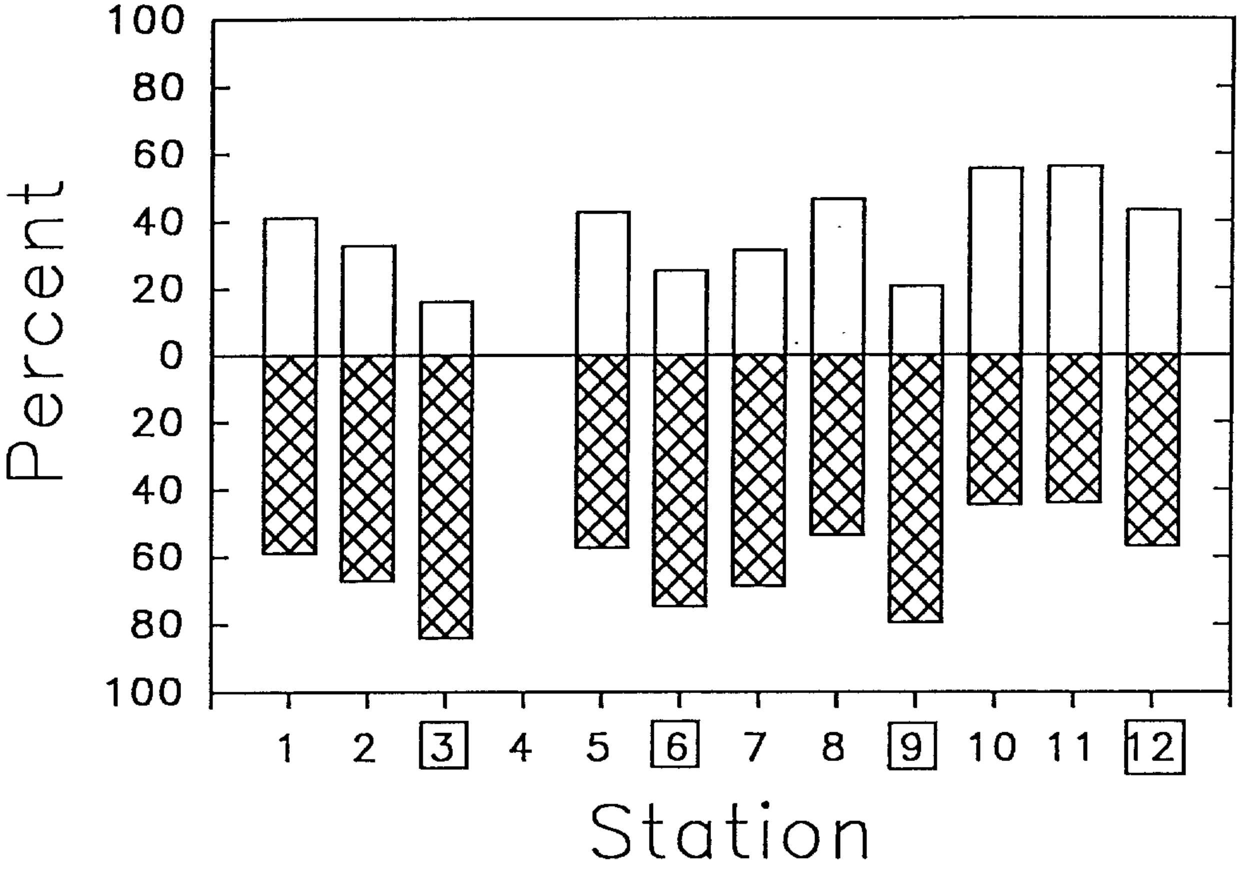

Figure 21. Percent of black drum larvae collected from surface samples (open bars above the zero axis) and bottom samples (hatched bars below the zero axis) at each site.

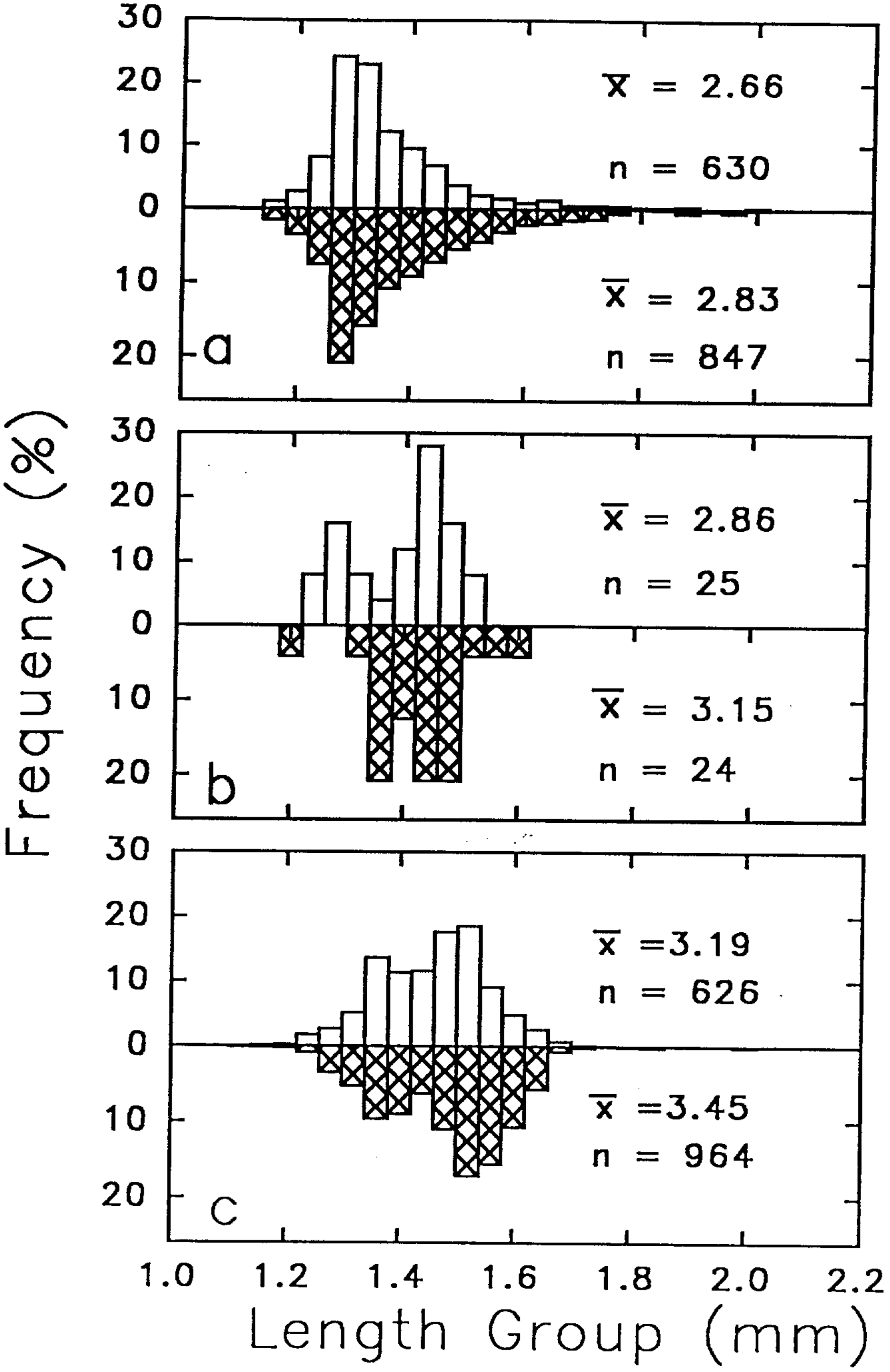

Figure 22. Length-frequency distribution of black drum larvae in surface (open bars above the zero axis) and bottom (hatches bars below the zero axis) collections for March (a), May (b), July (c), and September (d) sampling periods.

recruitment to estuarine nursery areas, correspond closely to those identified by Hoese (1965) and Sabins and Truesdale (1974) in other Gulf of Mexico estuaries. Allen and Barker (1990) have pointed out the year to year consistency in seasonality of spawning and larval recruitment in these species throughout their geographical range.

Although we enumerated only selected or "important" species, it was clear that larval Engraulids (predominately bay anchovy) were the dominant ichthyoplankton in the Laguna Madre, accounting for over 70% of the total number of individuals identified. Similar dominance of anchovy larvae has been reported in estuaries as diverse as the Chesapeake (Olney 1983), Biscayne Bay (Houde and Lovdal 1984), and Mississippi Sound (Lyczkowski-Shultz *et al.* 1990). Among the engraulids large enough to be identified, bay anchovy substantially outnumbered striped anchovy but both species were sufficiently abundant such that the identity of the <10 mm larvae could not be determined by an association with older, identifiable larvae. They were probably a mixture of both species dominated by bay anchovy.

The dominance of anchovy larvae in the ichthyoplankton was seen throughout the study area and throughout the year with the exception of November and January. Although their mean density in zone A was significantly less than in zones B-D, anchovies were still clearly the dominant ichthyoplankton at that site. Anchovy densities averaged 100-200 larvae per 100 m^3 in zones B-D but never reached the densities of 1000-3000 per 100 m^3 observed by Olney (1983) in the Chesapeake. Based on the distribution and abundance of ≤ 10 mm individuals, it appears that both bay and striped anchovies spawn throughout the Laguna Madre at least from March through September and some spawning occurs throughout the year since these larvae were never completely absent from our collections.

Larvae of two other estuarine spawners, spotted seatrout and black drum, were also widely distributed but their reduced densities in zone A was even more pronounced than for bay anchovy. It is assumed that this means the area is not a good spawning habitat for either species. Specific characteristics of their spawning sites within estuaries have not been determined. Tabb (1961) suggests spotted seatrout spawn in deep open water of estuaries while Brown-Peterson *et al.* (1988) found them spawning along edges of seagrass meadows. Both of these environments are available throughout the study area, including zone A. Spawning by spotted seatrout could be limited by salinity extremes (Tabb 1961) but average salinities at zone A (40.2 °/oo) were the second lowest in the study area. McMichael and Peters (1989) suggest that spawning sites vary between years and additional investigations might show that spawning does occur in zone A in some years.

Spawning by spotted seatrout was not affected by salinities up to 48 °/oo since the highest densities of small larvae were consistently found at high salinities (>40 °/oo). Salinities >48 °/oo were not encountered during the spotted seatrout spawning season. Spawning by black drum may have been limited by salinity since small larvae were generally not found at salinities >45 °/oo. The relatively high densities of larger black drum larvae at the highest salinities observed (54 °/oo) suggest that high salinity did not limit the dispersion or advection of larger larvae throughout the Laguna Madre. The high densities of spotted seatrout and black drum larvae in zones B and C indicate that the proximity of tidal inlets is not an essential feature regulating spawning activity of either species. These data confirm that the upper Laguna Madre, particularly the area near the proposed tidal inlet, is an currently an important spawning area for black drum and spotted seatrout despite persistent hypersaline conditions and the lack of proximity to a tidal pass.

Bottom densities of both spotted seatrout and black drum were consistently higher than surface densities in both shallow and deep sites. Both small (<3 mm) and large larvae contribute to this difference but depth stratification was more pronounced for larger larvae, especially for black drum. These results contrast with those of Peebles and Tolley (1988) who found no differences in spotted seatrout density with depth in nighttime samples from two shallow west Florida estuaries although they did find a correlation between larval length and depth in one of the two estuaries. Jannke (1971) also found no difference in vertical distribution of spotted seatrout in a tidal inlet in the Florida Everglades from samples taken on nighttime flood tides. Collections in this study were only taken in daylight. While daytime net avoidance in surface collections is often reported (Ruple 1984; Olney and Boehlert 1988) and can truly be a problem, the vertical structure observed here is probably realistic for two reasons. First, the shallow water in the Laguna Madre (generally < 2m) is relatively clear so that the net would be as visible to the larvae in the bottom meter as it is in the surface meter. Second, the poor locomotor ability of small larvae (most sciaenids were < 4 mm) would probably preclude their avoiding a 1 m net towed at 1-1.5 knots (Hilden and Urho 1988). In addition, vertical density differences were similar between sites in 2 m of water and the 5 m deep sites in the ICW.

Larval densities of most species which spawn exclusively offshore were relatively high only in the immediate vicinity of the Port Mansfield Channel. Larvae of these species are not rapidly advected through the lagoon as pelagic larvae but are dispersed relatively slowly as postlarvae or small juveniles. Many species adopt a decidedly more benthic orientation during this stage (Boehlert and Mundy 1988) and may select for habitats other than open bay bottom, such as seagrasses, oyster reefs, etc. This relatively slow dispersal of offshore spawned larvae into a variety of estuarine habitats will result in a reduction in densities due to both dilution and mortality. Results of this slow dispersal process are reflected in both finfish monitoring data and commercial and recreational catches reported by Texas Parks and Wildlife Department (TPWD) (Mambretti *et al.* 1989; Maddux *et al.* 1989). Both bag seine catches of small juveniles and commercial and recreational catches of larger individuals of offshore spawning species are generally higher in the lower Laguna Madre than in the upper Laguna Madre. TPWD data for juveniles of estuarine spawners is similar to the larval data presented here. Both black drum and spotted seatrout juveniles were more abundant in the upper Laguna Madre than in the lower Laguna Madre in bag seine catches (Mambretti 1989).

The species composition and density of larval fish and shrimp in zones C and D in the lower Laguna Madre are representative of what could reasonably be expected in the upper Laguna Madre if a tidal inlet at Yarborough Pass were opened, since habitats both inside and outside the lagoon are similar in both areas. The diversity (ie. number of species) and density of larval fish and shrimp was highest in the tidal inlet itself but relatively high diversity extended into zone C, 10-20 km from the inlet. The direct connection with the Gulf of Mexico through the Port Mansfield Channel provides for ingress of larvae of offshore spawning species into the lower Laguna Madre which may contribute to the higher finfish production there compared to the more isolated upper Laguna Madre. Densities of estuarine spawning species were not substantially increased by proximity of a tidal inlet and were generally more abundant at sites away from the inlet.

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