III. FISHERIES

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MATERIALS AND METHODS

The TPWD Coastal Fisheries Branch (CF) conducts a standardized, fishery-independent Resource Monitoring Program (Mambretti et al. 1990), using several types of fishing gear. This study relied mostly on data from gill nets (used in the Galveston Estuary since 1975), bag seines (used since 1977), and otter trawls (used in a consistent sampling program since 1982).

Fourteen economically and ecologically important finfish and shellfish species were identified for trend analyses. For most species, multiple life stages, identified by size, were examined separately to take advantage of the selectivity of the three gear types. A standard protocol for data screening and analysis was drafted for use by the analysts to assure consistency and analytic quality. Statisticians were consulted throughout the study to assure that the most appropriate analytical methods were applied.

In addition, a search was conducted among state and Federal agencies for data sets gathered in years prior to those covered by the CF program. Several data sets were located and examined. Those not included in this study are listed in Appendix 1. Trawl data on white and brown shrimp abundances, gathered by TPWD from 1963 through 1980 and transcribed onto computer files by the National Marine Fisheries Service (TPWD/NMFS), were examined for possible population trends using the same methods as for CF data.

Sampling

Details for bag seine, trawl and gill net sampling procedures are described in the 1991 TPWD Marine Resource Monitoring Operations Manual which is updated annually. A brief description of gear and sampling history follows.

Bag seine

All bag seines were 18.3 m long, 1.8 m deep, had 19-mm stretched nylon #5 multifilament mesh wings (8.3 m long) and a 13-mm stretched nylon #5 multifilament mesh bag (1.8 m long). The bag seine was pulled parallel to the shoreline for a distance of 15.2 to 30.5 m. The Galveston Estuary system was divided into a series of one minute longitude by one minute latitude sampling grids. Only grids containing a minimum of 15.2 m of shoreline were used for bag seine sampling. Grids were divided into 144 "gridlets", 5 second longitude by 5 second latitude in size, and gridlets containing shoreline were chosen randomly. The shoreline within a gridlet was divided into 15.2 m sections and one of these was randomly selected as a starting point for the sample. Sites were sampled monthly with an equal number of samples taken in the first and second half of the month.

Sampling intensity varied. From October 1977 to September 1981, 6 sites were sampled each month, except for November 1977 when 10 samples were taken, and June 1978 when no samples were taken. From October 1981 to March 1988, 10 sites were sampled monthly. From April 1988 to December 1989, 12 samples were taken each month. From January 1990 to present, 16 sites were sampled each month. Data analyses were restricted to the period from October 1977 through 1990.

Trawl

Trawl nets were flat otter trawls, 6.1 m wide, with 38 mm stretched #9 nylon multifilament thread throughout. Samples were taken between dawn and dusk by pulling the net along the bay bottom at a speed of approximately 5-6 km per hour in a circular pattern for ten or fifteen minutes. Beginning in May 1982, 20 samples were taken per month, and all organisms recovered were identified and counted. Consequently most analyses covered an eight-year period from 1983 to 1990. Sample locations were selected at random using the grid system described previously for bag seines for the entire bay, except that grids were sampled only when at least 1/3 of the grid was at least one meter deep, and at least 1/3 was free from obstructions that could damage gear or compromise safety. No grid was sampled more than once in a month. Only data from within the Galveston Estuary proper were used; Gulf pass samples were not included in this study. Unlike bag seine or gill net, trawling was not restricted to the shoreline.

For the TPWD/NMFS historical data, the trawls used from 1963-1980 were flat otter trawls, 3.05 m wide, with 32 mm stretched #9 nylon twine throughout. The cod end of the net was fitted with a liner of 12 mm stretched mesh. The trawl was towed at approximately 5 km per hour. Standard towing times were 5 minutes for surveys during the period from June through December, and 15 minutes for surveys during April and May. Sample locations were fixed throughout the bay system, with 8 to 16 sites used per year during 1963-1968 and 23 to 39 sites used per year during 1972-1980. Data from the years 1969-1971 were not used because the surveys were conducted erratically and had too few samples to be comparable to other years.

Gill net

Gill nets were 183 m long and 1.2 m deep. Each net was divided into four panels, each 45.75 m long, with increasing mesh sizes (76 mm, 102 mm, 127 mm and 152 mm stretch). Gill nets were oriented perpendicular to the shore with the smallest mesh nearest the shoreline, suspended by hard plastic floats and weighted by a leadline.

Sampling intensity for gill nets varied over the study period. With the exception of the spring of 1976 when only two samples were taken, 8 to 12 samples were collected in each three-month season between the fall of 1975 and 1981. Beginning in fall 1982, sampling was restricted to two ten-week periods, in fall (beginning the second full week of September), and spring (beginning the second full week of April). Since then, a total of 45 samples have been collected per season (3 to 7 per week, with no more than 3 per

day). Data collected in fall from 1975 through 1989, and spring data from 1977 through 1990, were used for analysis.

A sample grid for each gill net site (using the same grid selection parameters as for bag seine) was selected at random subject to the following restrictions: (1) each grid contained no more than one set per night; (2) each grid contained no more than three gill net sets per season; and (3) sets occurring on the same night must be at least one kilometer apart. The sample site was selected by randomly choosing a gridlet from within a grid, as described for bag seine. Nets were set within one hour of sunset and retrieved within four hours after sunrise.

Data Processing and Screening

All organisms captured were identified to species or to the lowest taxon possible. For most samples, the total length (TL; the distance between the tips of the snout and the caudal fin for fish, or from the tip of the rostrum to the end of the telson for shrimp) or total width (TW; between the tips of the carapace for crabs) of all individuals caught were measured to the nearest millimeter. Whenever total length could not be measured directly, the standard length (SL; the distance between the tip of the snout and the caudal peduncle) was measured, and TL was estimated using conversion equations (Harrington et al. 1979). All measurements reported in this study are total lengths in millimeters.

Adjustment for unmeasured individuals

In cases where more than 20 individuals of a species were caught, generally only the first 19 were measured and the remainder were counted. In trawl samples up to 50 shrimp of each species and up to 35 blue crab were measured.

Unmeasured specimens were assumed to have a size frequency distribution identical to the measured individuals and were accordingly prorated into size groups and incorporated into the calculation of catch rates. The ratio of the number of measured individuals of a given size (N) to the total number of individuals measured (M), was multiplied by the total number of individuals not measured (X), to obtain the number of unmeasured individuals assigned to a length group (T):

$$T = X(N/M).$$

The total number of a given size is the sum T + N.

Before 1980, all individuals of each species caught in gill nets were counted and measured. Beginning in 1980, only the first 19 individuals of the same species caught in the same mesh size in the same week were measured, and all remaining individuals were counted. Consequently in some samples no fish were measured from an entire panel.

For example, 16.5 percent of the Atlantic croaker and 3 percent of the red drum were recovered from unmeasured panels. In these cases the data were tested by assigning size categories to fish from these panels in proportion to the size frequency distribution of the individuals captured within the same panel type over the entire fifteen year study

period. The analyses performed on data prorated this way produced results consistent with analyses performed on the same data sets in which data from unmeasured panels were discarded. Consequently it was considered justified to disregard unmeasured panels for most gill net data sets, with the exception of Gulf menhaden (where all fish were counted because separate size classes were not analyzed). Table III.1 summarizes the number of unmeasured fish for each species where gill net data were analyzed.

Data screening

Field data were recorded on standardized data sheets. After initial editing, field biologists submitted the data sheets to the TPWD Data Processing Section in Austin for transcription to computer files. Error-detection programs were routinely applied to identify unlikely or impossible values for each variable. Computer printouts of the original data, annotated with potential errors, and original field sheets were returned to field personnel for verification. These were corrected and resubmitted to Data Processing for file updates.

Samples having unusually high catches (>100 individuals for most species, >500 for shrimp, Gulf menhaden or striped mullet, >400 for bay anchovy or Atlantic croaker) were verified or corrected by the Coastal Fisheries Resource Program Leader. Suspicious sizes (e.g. a length of >200 mm for a blue crab) or sample locations were also verified or corrected.

Table III.1. Total number of fish caught by gill net during spring or fall season; number of fish measured; and number of fish in panels where none were measured. Percentages do not total to 100 because in some panels, only a fraction of the fish caught were measured (subsampled).

SPECIES	Season	Total Fish	Number Msrd	Fish in Unmsrd Panels	%Fish in Unmsrd Panels	%Fish Msrd
Atlantic croaker	F	2617	1601	432	16.5075	61.177
Black drum	F	4024	3209	404	10.0398	79.747
Blue crab	S	911	904	4	0.4391	99.232
Gulf menhaden	F	7449	2944	1737	23.3186	39.522
Red drum	S	4227	3833	124	2.9335	90.679
Sand seatrout	F	371	361	9	2.4259	97.305
Southern flounder	F	607	580	14	2.3064	95.552
Spotted seatrout	S	2693	2417	25	0.9283	89.751
Striped mullet	F	1345	1211	76	5.6506	90.037

Selection of Size Range and Season

The three gear types have different catch selectivities and were chosen to offer a broad representation of life stages: small individuals (especially juveniles) from nearshore habitats are preferentially recovered by bag seine, large individuals from nearshore habitats by gill net, and mixed populations from open bay bottom habitats by otter trawl (Hegen et al. 1983; Osburn 1988; Green et al. 1991). Recruitment to the gear serves as an estimate for the abundance of a species.

Size ranges and months of the year (or seasons) that best represented different life stages and optimized existing data were selected for every species in a series of meetings conducted by Coastal Fisheries and Resource Protection staff (Table III.2). For each species collected by bag seine or trawl, size frequency distributions and catch per sample were plotted by month for all years pooled. A restricted size range was then chosen, based on the growth rates of the species, in order to reduce the probability of repeatedly sampling the same cohort throughout the year, while keeping the range sufficiently broad to make efficient use of available data. For species collected by gill net, size frequency distributions were plotted by season (spring or fall) for all years pooled, and one of the two seasons was chosen. The choice of season was usually based on which data set was most likely to contain individuals of the age to spawn for the first time.

In this study "young of the year" refers to the smallest juveniles effectively sampled by bag seine (Table III.2), while "juvenile" refers to other subadult size classes. The term "first-time spawners" is used for the size class at or near the age to reproduce for the first time. Mature adults are referred to as "remaining adults" or, in cases where a class of first-time spawners was not specified, simply "adults".

Standardization of Catch Per Unit Effort

Bag seine

For fish caught by bag seine the Catch Per Unit Effort (CPUE) was defined as the number of individuals caught for a given area seined, calculated by multiplying the length of the bag seine (18.3 m) by the distance pulled. The area seined was 0.03 hectare for the majority of the samples (e.g. 84 percent of samples containing red drum), so bag seine CPUE was standardized as the number of individuals caught per 0.03 hectare.

Trawl

The CPUE for trawl samples was calculated as for bag seines, but using a time unit rather than area. For CF data, CPUE was standardized as the number of individuals caught per ten minutes of trawling (catch/0.16 hour). Ten minutes has been the specified trawl procedure in recent years and the majority of trawl times (70 percent) fell between 0.16 and 0.17 hours. For the TPWD/NMFS data set CPUE was standardized as the number of individuals caught per five minutes of trawl time because the majority of samples were taken in five-minute tows.

Gill net

The amount of time gill nets remained emplaced varied from 9 to 16 hours, with an average set duration of 12.5 hours in spring and 14 hours in fall. The relationship between duration of a gill net set and the number of individuals recovered was rarely simple for many reasons. For example, gill nets can become saturated, effectively stopping any increase in the number of fish caught. Fish trapped by gill net are subject to predation and scavenging, such as by blue crab, sharks, or fishermen. Other factors may include escape, crepuscular activity, or migratory patterns.

For many species it was common for catch to increase initially with set duration, then dramatically decline. This phenomenon was especially common in fall data sets, probably because set time increased as the day length decreased, and during the later portion of the sampling period many species migrate to the Gulf to overwinter or spawn.

Analysis of covariance (ANCOVA) models were applied using SAS (Version 5.18) to assess the effect of set duration (GTIME) on the catch rate:

$$CATCH = a + b_{Year}*Year + b_1*GTIME + b_{Year}*Year*GTIME$$

and

$$CATCH = a + b_{Year}*Year*GTIME$$

where CATCH was the total number of individuals of a particular size class per sample, Year was the year of the sample considered as a categorical variable, GTIME (in hours) was a continuous variable for the duration of each gill net sample, and b_{Year} represented the slope for each year that was significantly different from the mean. In this report all continuous variables are capitalized (YEAR) whereas categorical variables are represented in capital and lower case (Year).

Results of the ANCOVA analyses revealed colinearity between set duration and year; that is, the effects of these two factors overlapped to the extent that the order of elements in the model affected the significance of the results. Each data set was examined individually with the assistance of consulting statisticians to evaluate the importance of set duration to CPUE.

In some cases the results of the ANCOVA analysis indicated set duration was not significant. The CPUE was then calculated simply as catch per set.

When preliminary models indicated that set duration was significant, CPUE was standardized as catch per 12.5 hours for spring gill net data (the average set duration in spring), or catch per 14 hours for the fall season. Models were tested using GLIM (Version 3.77) to determine whether catch varied with GTIME, $GTIME^2$, or some other power (n) of set duration, in addition to YEAR, $YEAR^2$, and YEAR-GTIME interaction. If GTIME was significant, CPUE was then calculated using an appropriate coefficient (n) for set duration. Therefore CPUE for spring gill net data was calculated using the

Table III.2. Species, size ranges, months (or season), and gears from which data were selected for trend analysis. * = Insufficient data for trend analysis.

	SPECIES	SIZE (MM)	LIFE STAGES	GEAR		
				BAG SEINE	TRAWL	GILL NET
1.	Blue crab	25-45	Young of the year	Jan-Dec	Jan-Dec	*
	(*Callinectes sapidus*)	50-70	Juveniles	*	Jan-Dec	*
		120-140	1st-time spawners	*	Jan-Dec	Spring
		>140	Remaining adults	*	*	Spring
2.	Brown shrimp	All sizes	Total catch		Apr-Nov	
	(*Penaeus aztecus*)	30-55	Young of the year	Apr-Nov	*	*
		85-110	1st-time spawners	*	May-Aug	*
3.	Grass shrimp	25-35	Adults	Jan-Dec	*	*
	(*Palaemonetes* spp.)					
4.	White shrimp	All sizes	Total catch		Jun-Nov	
	(*Penaeus setiferus*)	35-55	Young of the year	Jun-Dec	*	*
		80-100	Juveniles	*	Jul-Apr	*
		110-130	1st time spawners	*	Apr-May &	*
				*	Aug-Nov	*
5.	Atlantic croaker	30-50	Young of the year	Dec-Mar	*	*
	(*Micropogonias*	115-135	1st-time spawners	*	Mar-Sept	*
	undulatus)	230-275	Remaining adults	*	*	Fall
6.	Bay anchovy	15-34	Juveniles	May-Oct	Dec-Mar	*
	(*Anchoa mitchilli*)	35-54	1st-time spawners	Apr-Oct	Jan-Dec	*
		≥55	Remaining adults	Apr-Nov	Jan-Dec	*
7.	Black drum	55-85	Young of the year	Jun-Aug	*	*
	(*Pogonias cromis*)	300-400	1st-time spawners	*	*	Fall
		>400	Remaining adults	*	*	Fall

Table III.2. (continued) Species, size ranges, months (or season), and gears from which data were selected for trend analysis. * = Insufficient data for trend analysis.

	SPECIES	SIZE (MM)	LIFE STAGES	GEAR		
				BAG SEINE	TRAWL	GILL NET
8.	Gulf Menhaden	20-30	Young of the year	Feb-Jul	*	*
	(*Brevoortia patronus*)	100-120	1st-time spawners	*	Jan-Dec	*
		All sizes	Remaining adults	*	*	Fall
9.	Pinfish	40-60	Young of the year	Mar-Jun	*	*
	(*Lagodon rhomboides*)	80-109	Juveniles	*	Jun-Aug	*
		110-140	1st-time spawners	*	Sept-Nov	*
10.	Red drum	25-65	Young of the year	Oct-Jan	*	*
	(*Sciaenops ocellatus*)	375-500	Juveniles	*	*	Spring
		501-700	1st-time spawners	*	*	Spring
11.	Sand seatrout	35-55	Young of the year	Apr-Oct	*	*
	(*Cynoscion arenarius*)	65-85	Juveniles	*	May-Dec	*
		140-160	1st-time spawners	*	Apr-Nov	*
		>160	Remaining adults	*	*	Fall
12.	Southern flounder	20-45	Young of the year	Feb-Mar	*	*
	(*Paralichthys lethostigma*)	>250	Adults	*	*	Fall
13.	Spotted seatrout	35-75	Young of the year	Jun-Nov	*	*
	(*Cynoscion nebulosus*)	350-450	1st-time spawners	*	*	Spring
		>450	Remaining adults	*	*	Spring
14.	Striped mullet	20-40	Young of the year	Feb-Mar	*	*
	(*Mugil cephalus*)	230-275	1st-time spawners	*	Dec-Mar	*
		275-314	Adults, Age IV	*	*	Fall
		>314	Adults, Age V+	*	*	Fall

formula

$$CPUE = CATCH / (GTIME/12.5)^n$$

and for fall gill net data

$$CPUE = CATCH / (GTIME/14)^n.$$

These definitions of CPUE were used in subsequent trend analyses (summarized in Table III.3).

Statistical Analysis

Many sources of variation influenced the raw data, including spatial and temporal variation attributable to environmental factors not specifically investigated in this study. Because sources of variation could not be neatly separated, statistical analyses were performed on the individual catches rather than on, for example, monthly or annual totals. This improved the resolution of the analysis and should improve the evaluation of long-term trends.

Table III.3. Summary of CPUE definitions used for analysis of species caught by gill net.

Species	Size (mm)	CPUE
Blue crab	120-140	Catch/set [a]
Blue crab	>140	Catch/set [a]
Atlantic croaker	230-275	$CATCH/(GTIME/14)^{-4}$
Black drum	300-400	$CATCH/(GTIME/14)^{1.5}$
Black drum	>400	Catch/set [a]
Gulf menhaden	>100	$CATCH/(GTIME/14)^{-3}$
Red drum	375-500	$CATCH/(GTIME/12.5)^{2}$
Red drum	501-700	Catch/set [a]
Sand seatrout	>160	Catch/set [a]
Southern flounder	>250	Catch/set [b]
Spotted seatrout	350-450	Catch/set [a]
Spotted seatrout	>450	Catch/set [a]
Striped mullet	275-314	Catch/set [a]
Striped mullet	>314	$CATCH/(GTIME/14)^{3}$

[a] Set duration not significant in test using GLIM.

[b] Set duration not significant in initial test using SAS ANCOVA; set duration and year colinear.

Data distribution and variance relationships

The CPUE for all species exhibited skewed distributions with a large proportion of samples having zero catches, many samples having intermediate catches, and a few samples with large catches. In no case was CPUE even approximately normally distributed.

Based on visual inspection of untransformed residuals, the distribution of most data sets appeared similar to a negative binomial distribution (NBD) with an inflated variance factor. Analyses based on Gamma distributions were also applied to some gill net data sets as appropriate. A generalized linear model (McCullagh and Nelder 1989), applicable to data with non-normal distributions, was used to analyze trends in CPUE, using the software GLIM (for Generalized Linear Interactive Modelling; Numerical Algorithms Group 1987).

The variance associated with the overdispersed NBD can be defined by two parameters, l and k. For these data, the relationship among l, k, monthly mean and variance of the dependent variable (CPUE) was

$$\text{variance} = l(\text{mean}) + k(\text{mean})^2.$$

PROC NLIN in SAS (Version 5.18; SAS Institute Inc., 1985) was used to obtain an iterative solution that best estimated l and k while minimizing an appropriately weighted residual sum of squares.

Some data sets initially yielded zero or negative values for l and/or k, which were incompatible with statistical software. In these cases it was usually a single exceptionally large mean monthly catch that excessively influenced the calculation, so that deleting one or two outlying data points resulted in positive values for l and k. All analyses were performed using positive values for l and k (summarized in Table III.4) on complete data sets; that is, possible outliers were removed to estimate l and k but retained in the final trend analysis.

Analysis of deviance

Analyses of deviance (ANODE) were conducted using GLIM 3.77. This software is appropriate for the statistical modeling of non-normal error distributions, such as the NBD.

The appropriate values for l and k (Table 4) were used to test the following models for bag seine and trawl data:

(i) Logarithm of mean CPUE = c + Month + Year + Month x Year
(ii) Logarithm of mean CPUE = c + Month + Year
(iii) Logarithm of mean CPUE = c + Month + b_1(YEAR)
(iv) Logarithm of mean CPUE = c + Month + b_1(YEAR) + b_2(YEAR)^2

where c was a constant. Month was treated as a categorical variable so that annual trend curves could be fitted and optimized. The categorical variable Year in models i and ii allowed calculation of a separate mean for each year, making it possible to recognize

Table III.4. Summary of estimated values of l and k used in the analysis for each species.

	Bag Seine		Trawl		Gill Net	
Species	l	k	l	k	l	k
Blue crab						
25-45 mm	0.7226	2.7491	0.5654	2.6004	-	-
50-70 mm	-	-	1.0702	1.4319	-	-
120-140 mm	-	-	0.8561	1.4792	1.000	5.000
>140	-	-	-	-	0.119	3.277
Brown shrimp						
All sizes 1963-68	-	-	0.2106	0.9751	-	-
All sizes 1972-80	-	-	0.5755	1.4812	-	-
30-55 mm	0.9454	2.3096	-	-	-	-
85-110 mm 1963-68	-	-	0.6611	0.9040	-	-
85-110 mm 1972-80	-	-	0.6859	1.5539	-	-
85-110 mm 1983-90	-	-	1.140	2.2422	-	-
Grass shrimp						
25-35 mm	0.5255	3.8976	-	-	-	-
White shrimp						
All sizes 1963-68	-	-	0.4371	1.228	-	-
All sizes 1972-80	-	-	8.7950	1.116	-	-
35-55 mm	0.827	2.9116	-	-	-	-
80-100 mm	-	-	1.1504	2.6653	-	-
110-130, 1963-68	-	-	0.5843	0.3262	-	-
110-130, 1972-80	-	-	0.7716	2.1908	-	-
110-130 mm, spring	-	-	1.4069	1.2963	-	-
110-130 mm, fall	-	-	1.4266	0.8958	-	-
Atlantic croaker						
30-50 mm	0.581	3.421	-	-	-	-
115-135 mm	-	-	0.8139	2.1338	-	-
230-275 mm	-	-	-	-	0.4980	3.264
Bay anchovy						
15-34 mm	0.4383	6.7809	0.4543	4.9008	-	-
35-54 mm	0.5951	3.8088	0.70529	3.1089	-	-
>= 55 mm	0.4416	3.5674	0.7146	2.935	-	-
Black drum						
55-85 mm	0.8017	2.9689	-	-	-	-
300-400 mm	-	-	-	-	0.776	1.951
>400 mm	-	-	-	-	0.325	3.384

Table III.4. (continued) Summary of estimated values of l and k used in the analysis for each species.

	Bag Seine		Trawl		Gill Net	
Species	l	k	l	k	l	k
Gulf menhaden						
20-30 mm	0.590	5.197	-	-	-	-
100-120 mm	-	-	0.5083	5.0355	-	-
All sizes	-	-	-	-	1.000	10.000*
Pinfish						
40-60 mm	0.452	3.980	-	-	-	-
80-109 mm	-	-	0.4859	7.5114	-	-
110-140 mm	-	-	0.2549	8.5648	-	-
Red drum						
25-65 mm	0.506	4.785	-	-	-	-
375-500 mm	-	-	-	-	0.710	1.369
501-700 mm	-	-	-	-	1.000	10.000*
Sand seatrout						
35-55 mm	0.662	3.243	-	-	-	-
65-85 mm	-	-	0.6898	3.4153	-	-
140-160 mm	-	-	0.8117	2.0569	-	-
>160 mm	-	-	-	-	0.850	1.581
Southern flounder						
20-45 mm	0.761	2.297	-	-	-	-
>250 mm	-	-	-	-	0.922	1.072
Spotted seatrout						
35-75 mm	0.558	3.641	-	-	-	-
350-450 mm	-	-	-	-	0.379	2.553
>450 mm	-	-	-	-	1.867	1.429
Striped mullet						
20-40 mm	0.3531	4.753	-	-	-	-
230-275 mm	-	-	0.4668	8.100	-	-
276-314 mm	-	-	-	-	1.151	1.899
>314 mm	-	-	-	-	0.232	2.246

* Note: l and k were chosen to make the coefficient of variation constant with respect to the mean, as suggested by the data distribution. It was not possible to use the gamma error option because of the large number of zeros in the data set.

significant differences among years which were not explained by trend curves (i.e. differences possibly related to events such as freezes, storms, floods, droughts or poor reproduction, that were not associated with a trend phenomenon). Month x Year refers to interaction between the categorical variables Month and Year. In models iii and iv, the variable YEAR was treated as a continuous variable.

The following models were tested for gill net data:

(i) Logarithm of mean CPUE = c + Year

(ii) Logarithm of mean CPUE = $c + b_1(YEAR)$

(iii) Logarithm of mean CPUE = $c + b_1(YEAR) + b_2(YEAR)^2$

where c was a constant. Year was treated as a categorical variable (Year) in the first model and as a continuous variable (YEAR) in models ii and iii. Because gill net samples were collected seasonally and not monthly, month was not considered as an explanatory variable.

Error deviance was determined for bag seine and trawl data by the model including Year, Month, and Year x Month interaction. Error deviance for gill net data was based on a model including Year, GTIME, and YEAR-GTIME interaction in those cases where set duration was possibly significant. When set duration was corrected or was not significant, error deviance was determined by a model based on the categorical variable Year.

For bag seine and trawl data, there were some months with zero mean monthly CPUE that did not contribute to the determination of error deviance. A corrected error mean deviance was calculated by subtracting the degrees of freedom (d.f.) represented by zero months from the error deviance d.f., then dividing the error deviance by the corrected d.f. The F ratios and P values were calculated using this corrected error mean deviance. Gill net data were collected seasonally and had no zero seasonal catches.

All models were tested and the results summarized in a series of tables. ANODE tables for bag seine and trawl data sets show results for categorical Month, linear YEAR, and quadratic YEAR ($YEAR^2$) effects, YEAR effects neither linear nor quadratic, categorical Year x Month interaction effects, and error. ANODE tables for gill net data do not have a Month term but may include results for the effects of set duration (the continuous variable GTIME).

Long-term trends were indicated by models in which YEAR or $YEAR^2$ were significant. The term YEAR corresponded to a linear annual trend on the logarithmic scale with a net increase or decrease in CPUE during the course of the study period, and $YEAR^2$ to a quadratic annual trend with a positive or negative curve. Annual models were fitted and the trends were presented graphically with observed annual means to allow visual evaluation of the predictive value of the models. In those cases where the analysis did not reveal significant linear or quadratic YEAR effects, the mean CPUE for the entire period was presented as a horizontal line.

Standard errors were calculated, using approximate methods, for the natural logarithms of estimated mean annual CPUE with estimates provided by the fitted trend curves.

Then approximate 95 percent confidence bands for the trend curves were found by calculating the unlogged (exponentiated) values of

$$\text{log estimate} \pm 2(\text{standard error}).$$

The calculations were based on an analogy with ordinary linear regression. If month-year response y_{ij} is described by the linear regression

$$y_{ij} = m_{ij} + \text{error} \ : \ m_{ij} = a_0 + a_1 t_i + b_j$$

where b_j, $j=1, 2,\ldots$ are the monthly effects relative to the grand mean such that the monthly effects sum to 0, then the estimated annual mean will be given by $a_0 + a_1 t_i$, as the sum of the monthly effects will drop out.

For balanced data, $a_0 + a_1 t_i$ can be obtained by regressing y_{ij}'s on t_i (ignoring months). This line would be the same as that obtained by regressing y_{ij} on $a_0 + a_1 t_i + b_j$ for each j (month) and then averaging the results for each year.

Unfortunately, this procedure gives an inflated value for the standard error. Estimating the variance of the fitted values involves multiplication by an estimate of the standard deviation of the observed values. This estimate is derived from the deviance obtained from the regression. The deviance obtained from regressing y_{ij} on $a_0 + a_1 t_i$ this way is too large because monthly effects were not included. To correct this, the standard errors have the incorrect deviance removed by division and the correct deviance inserted by multiplication.

Residual values from each analysis of deviance were plotted against time to further assess the appropriateness of the final model for each analysis by visually inspecting for a random distribution of the residuals between -2 and 2, the range expected to include 95 percent of residuals (D. V. Hinkley, pers. comm.). In all cases the residuals were randomly distributed, indicating a reasonably good fit for the models.

Spatial Distribution

Geographic distributions for each data set (species, size range and season) were plotted using the ATLAS GIS system, enabling a base map of the Galveston Estuary system to be superimposed upon plots of sample locations.

For bag seine and trawl data, mean CPUE for each latitude-longitude location (plotted to the nearest 0.001 degree) was calculated. For gill net data mean catch per set was plotted by location. Gill net data were not corrected for set duration because throughout this study CPUE calculated with a correction for set duration was comparable to uncorrected catch rates. This is not believed to invalidate the conclusions to be drawn from these plots about geographic distributions.

Relative abundance was shown by the relative size of the circles plotted at a given location. The largest circle size was set to represent values greater than or equal to overall mean CPUE for the study period plus two standard deviations, so that one or two very large catches would not dominate the plot; the smallest circles represent zero or very small catches. Because the data are averaged for all samples and all years pooled,

a circle of a given size may indicate that a single large catch and several small or zero catches occurred in the same location, or it may indicate a large number of intermediate catches. Consequently several large circles indicate high concentrations more reliably than one large circle among smaller ones. This should not invalidate the results but should be taken into consideration when examining distributions, especially when large catches are common.

RESULTS AND DISCUSSION

Blue Crab (Callinectes sapidus)

Young-of-the-year blue crab (25-45 mm TW) increased in abundance during the study period while juveniles (50-70 mm), first-time spawners (120-140 mm), and remaining adult blue crab (>140 mm) decreased in abundance. Young of the year increased in both bag seine and trawl catches (Figures III.1, III.2). Juveniles and first-time spawners showed a linear decrease through time in trawl data (Figures III.3, III.4); however, gill net data for first-time spawners did not show any significant trend (Figure III.5). Gill net data showed remaining adults increased in abundance from 1983 to 1986, then decreased through 1990 to levels lower than in 1983 (Figure III.6).

Season and Size Selection

Estimated growth rates for small (8-128 mm) blue crab in the Galveston Estuary were 15.3 to 18.5 mm per month (More 1969). A size range of 20 mm was used for all life stages except the remaining adults in order to avoid repeated sampling of the same cohort (Table III.4).

The smallest size completely recruited to both bag seine and trawl was 25 mm, so young of the year were defined to be 25-45 mm (Figures III.7 and III.8). The 25-45 mm size range was well represented in both bag seine and trawl, therefore both data sets were analyzed to determine trends in shoreline and open-water environments. The most abundant size range in trawl data was centered around 60 mm and juveniles were defined as the 50-70 mm size class (Figure III.8). The season for evaluating the abundance of these life stages was defined to be a calendar year because both young of the year and juveniles were present in all months in bag seine and trawl catches, confirming the findings of More (1969).

Most blue crab reach sexual maturity within one year after hatching, at about 127 mm (More 1969). The 120-140 mm size range was chosen to represent blue crab at the age of first spawning. Crab of this size were present throughout the year in trawl data (Figure III.8) and occurred in sufficient numbers in gill net data to allow analysis (Figure III.9). Remaining adults were defined as crabs greater than 140 mm. The spring gill net season was chosen as the best data set for the analysis of first-time spawners and remaining adults because it coincides with the period of peak spawning (More 1969).

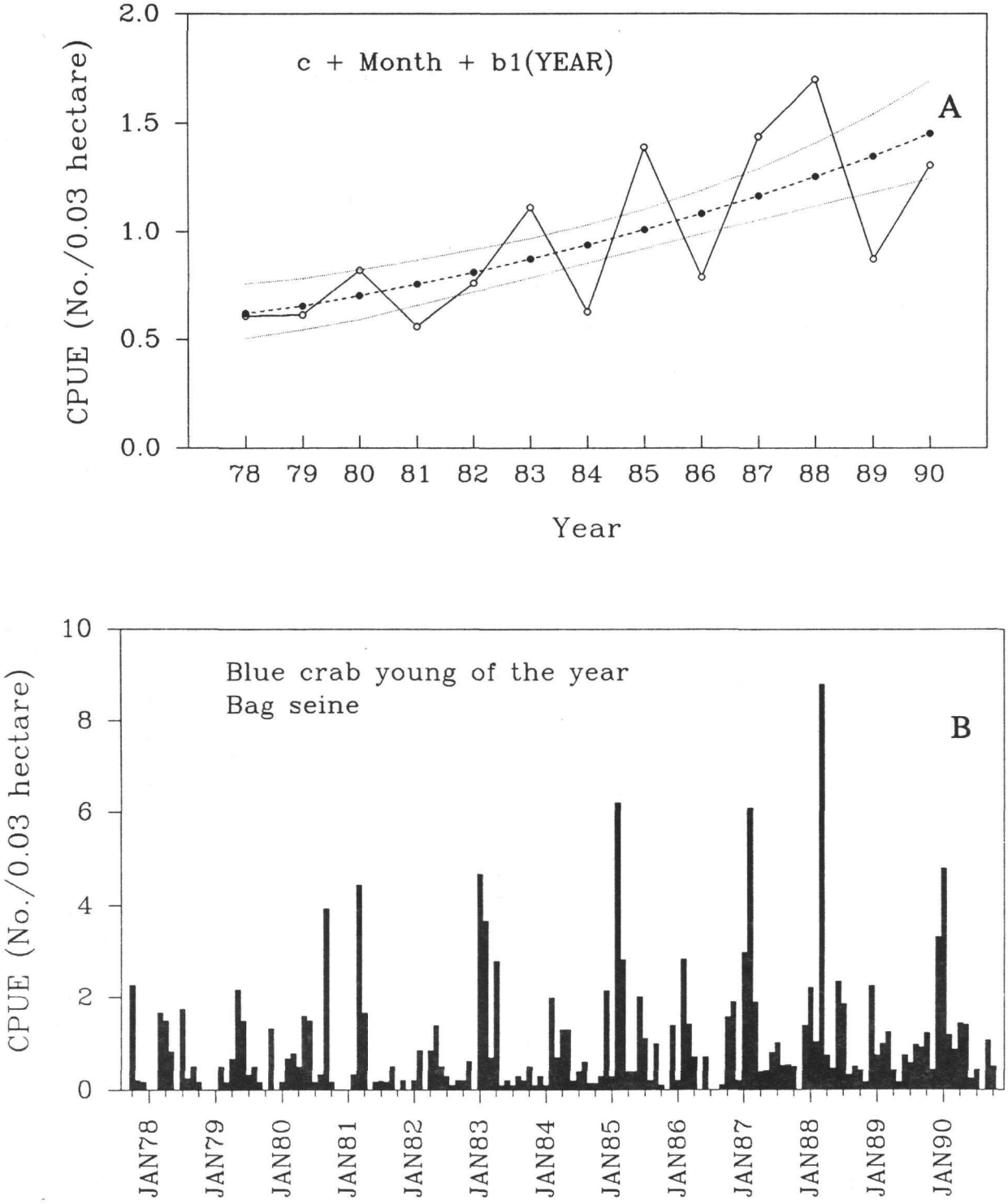


Figure III.1. A. Mean annual CPUE and predicted CPUE with confidence intervals for young-of-the-year blue crab (25-45 mm) caught by bag seine. B. Mean CPUE by month.

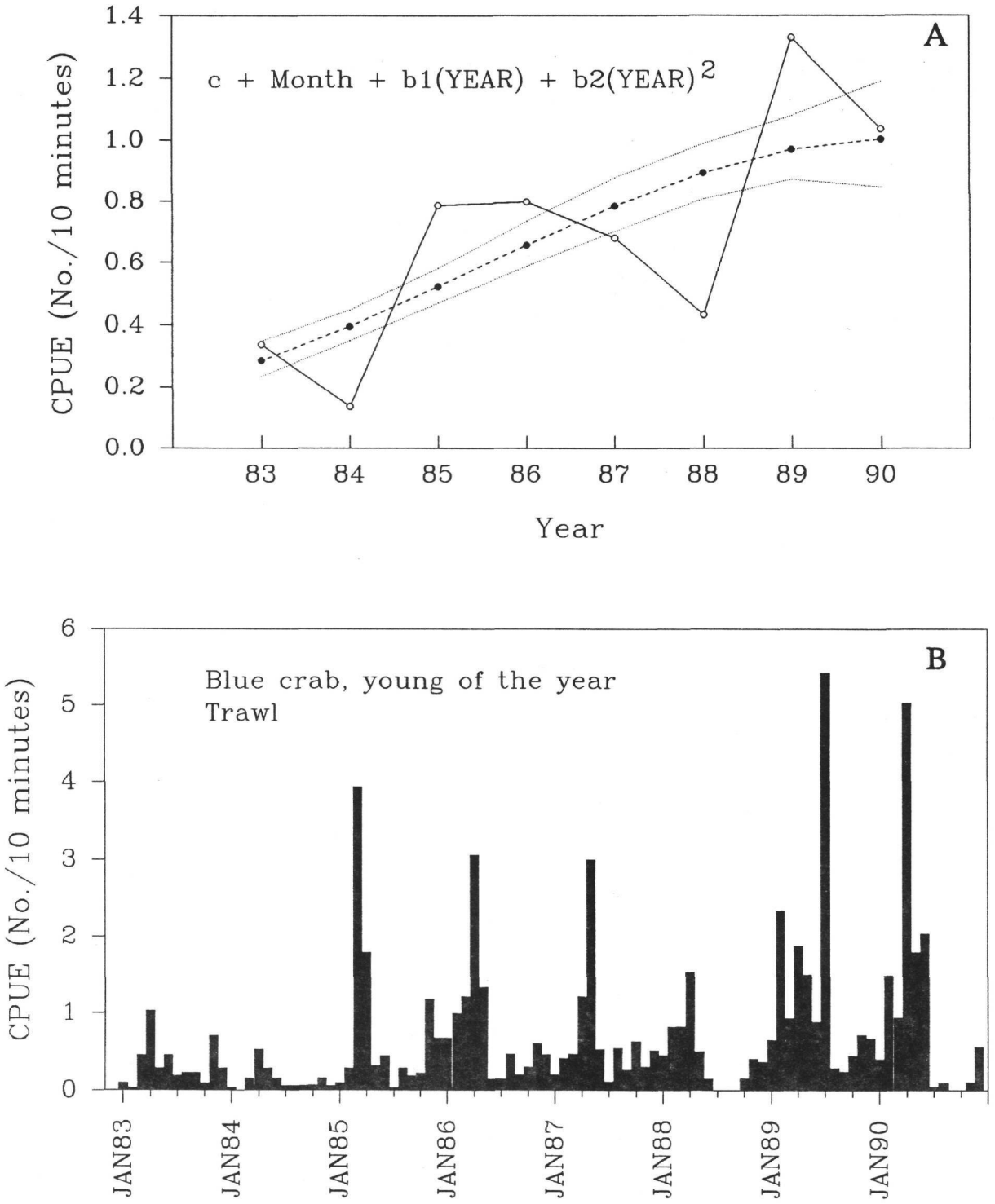


Figure III.2. A. Mean annual CPUE and predicted CPUE with confidence intervals for young-of-the-year (25-45 mm) blue crab caught by trawl. B. Mean CPUE by month.

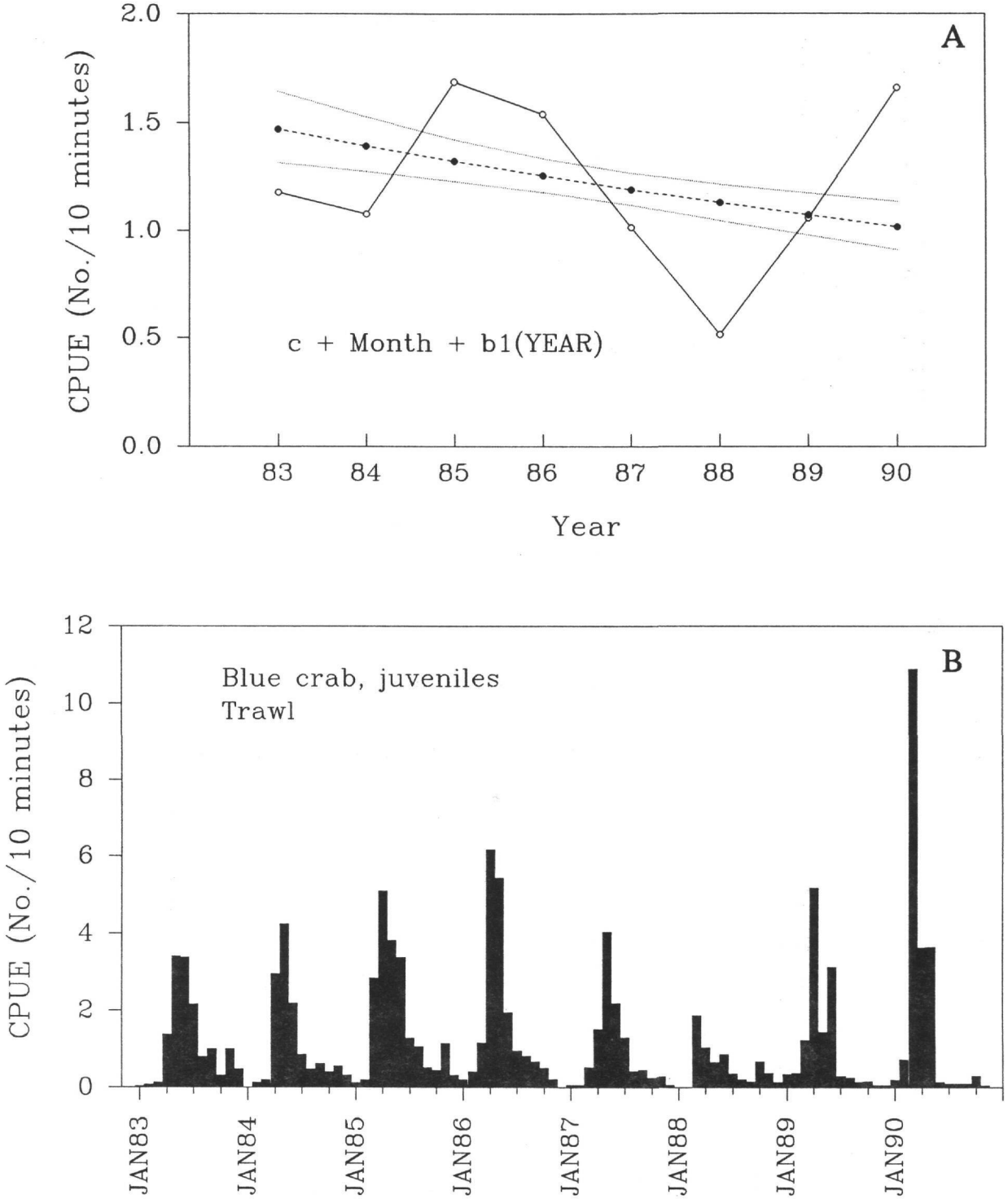


Figure III.3. A. Mean annual CPUE and predicted CPUE with confidence intervals for juvenile blue crab (50-70 mm) caught by trawl. B. Mean CPUE by month.

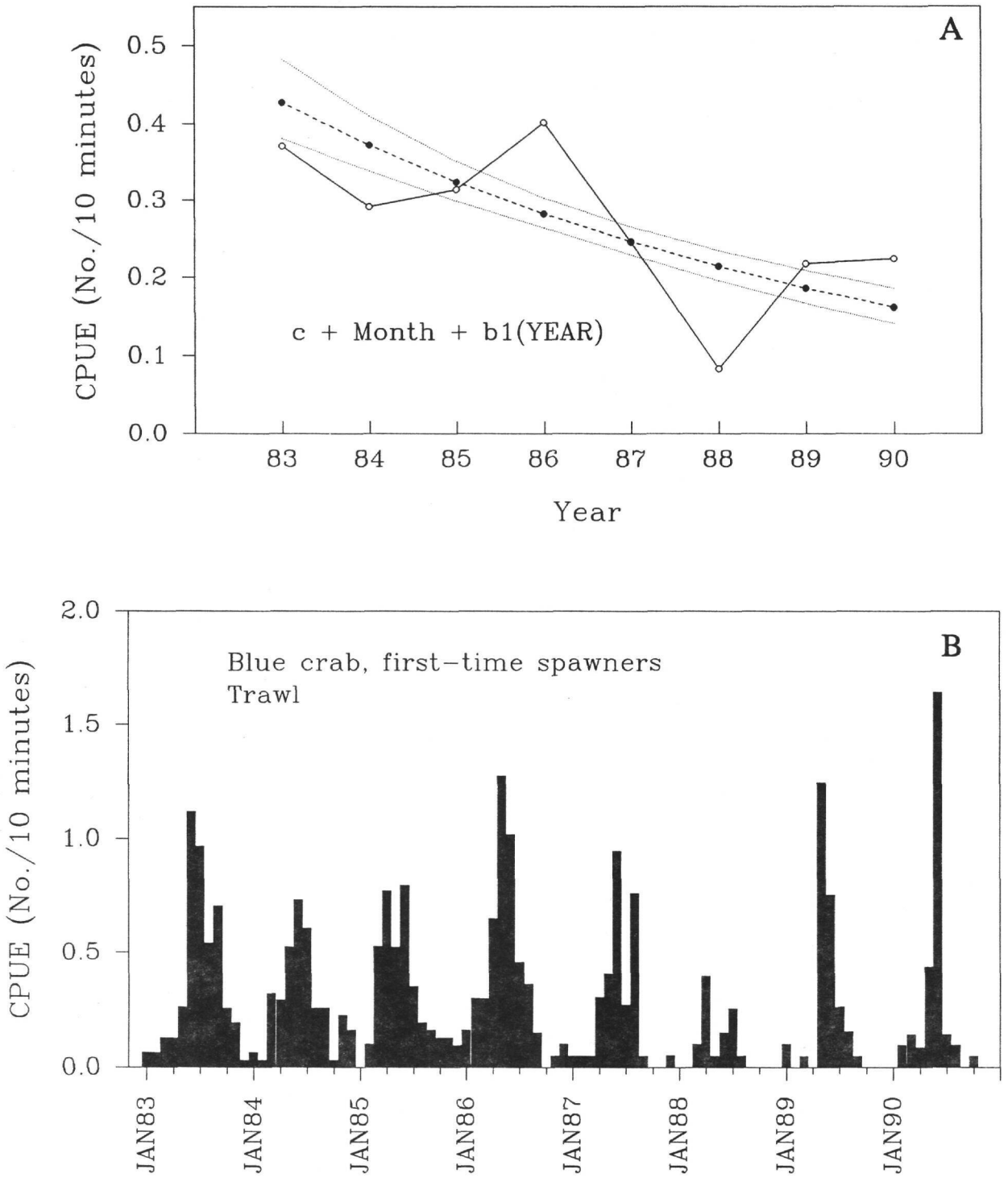


Figure III.4. A. Mean annual CPUE and predicted CPUE with confidence intervals for first-time spawning blue crab (120-140 mm) caught by trawl. B. Mean CPUE by month.

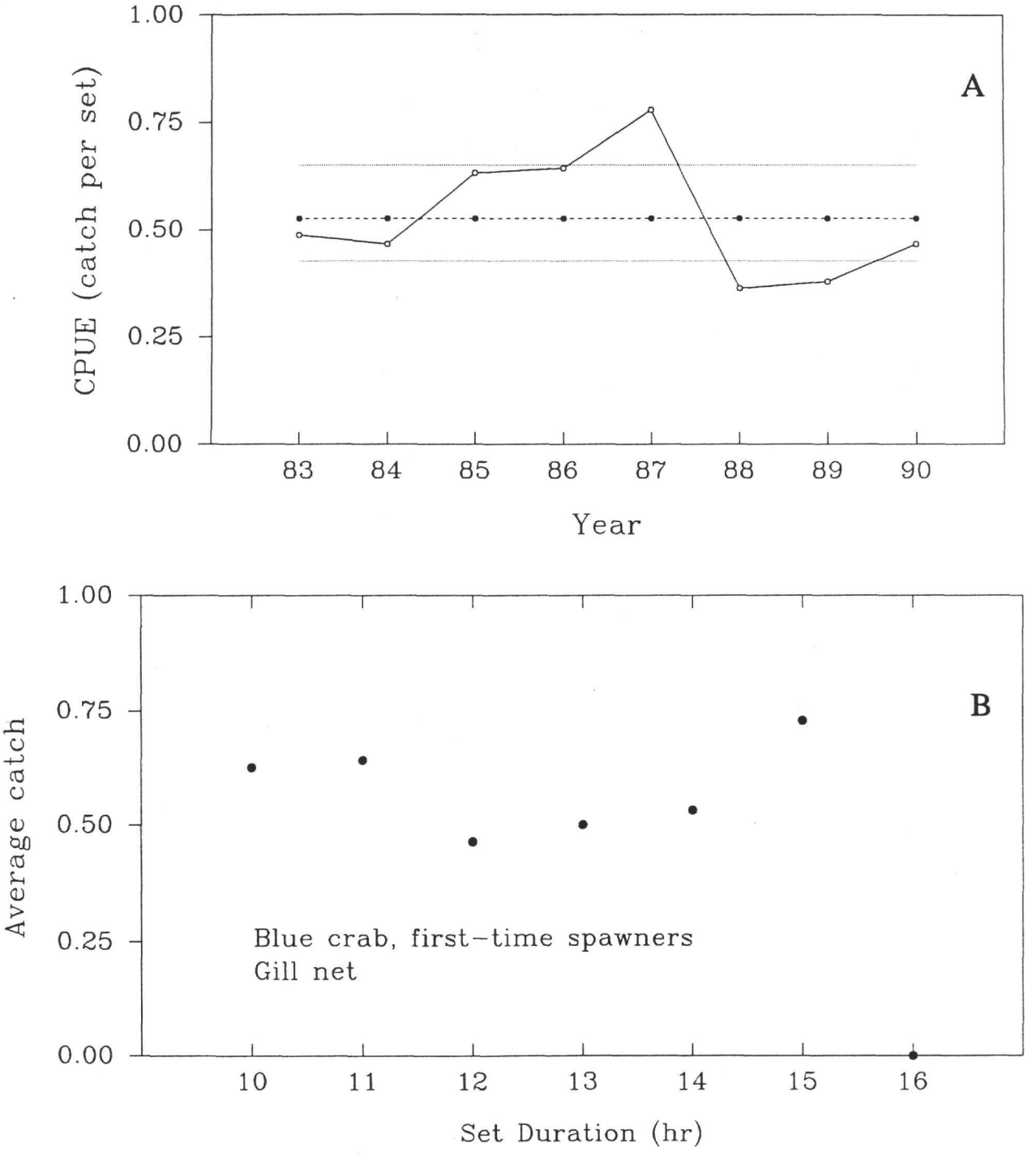


Figure III.5. A. Mean seasonal (spring) and predicted CPUE with confidence intervals for first-time spawning (120-140) blue crab caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1983-1990.

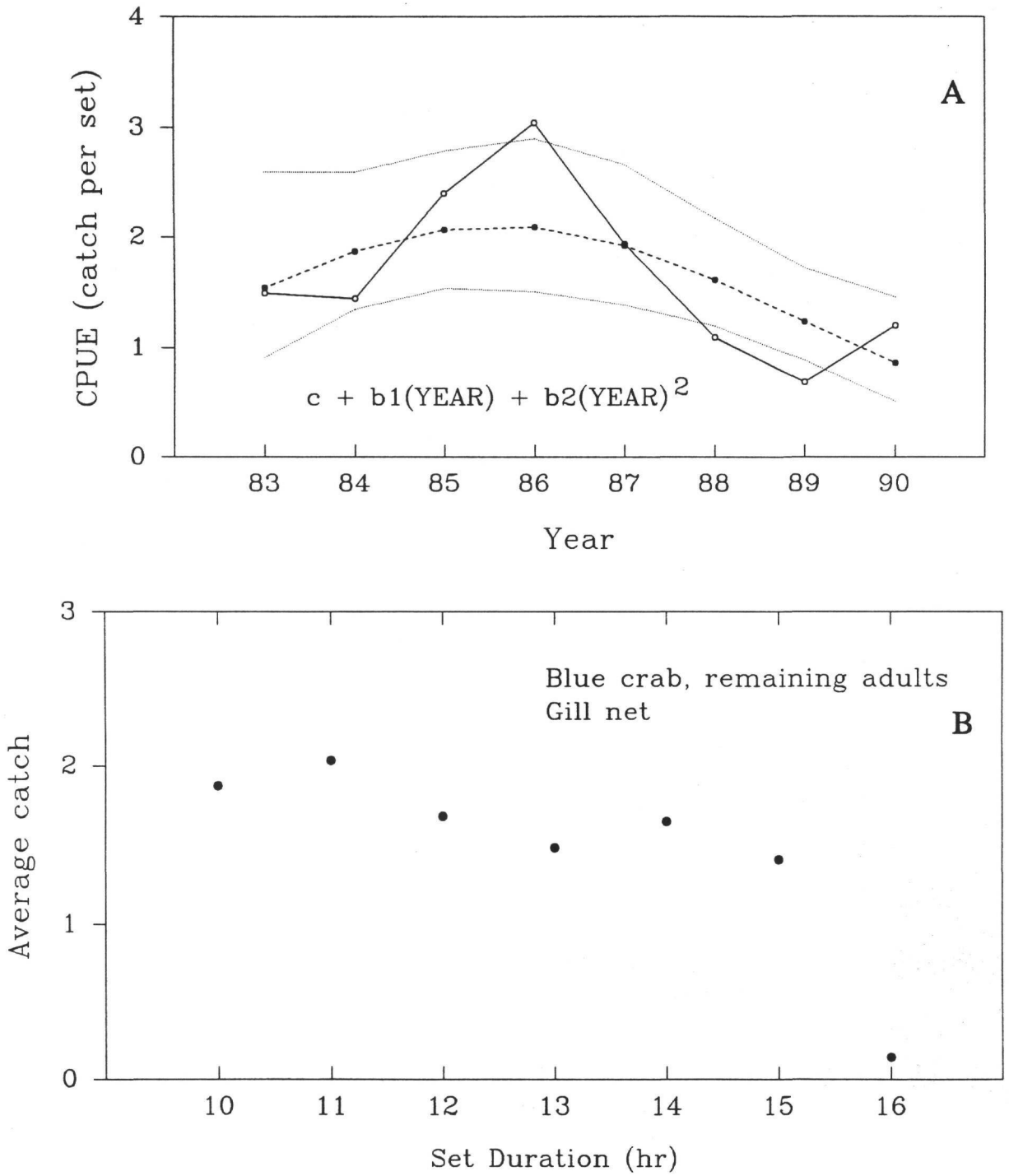


Figure III.6. A. Mean seasonal (spring) and predicted CPUE with confidence intervals for remaining adult blue crab (> 140 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1983-1990.

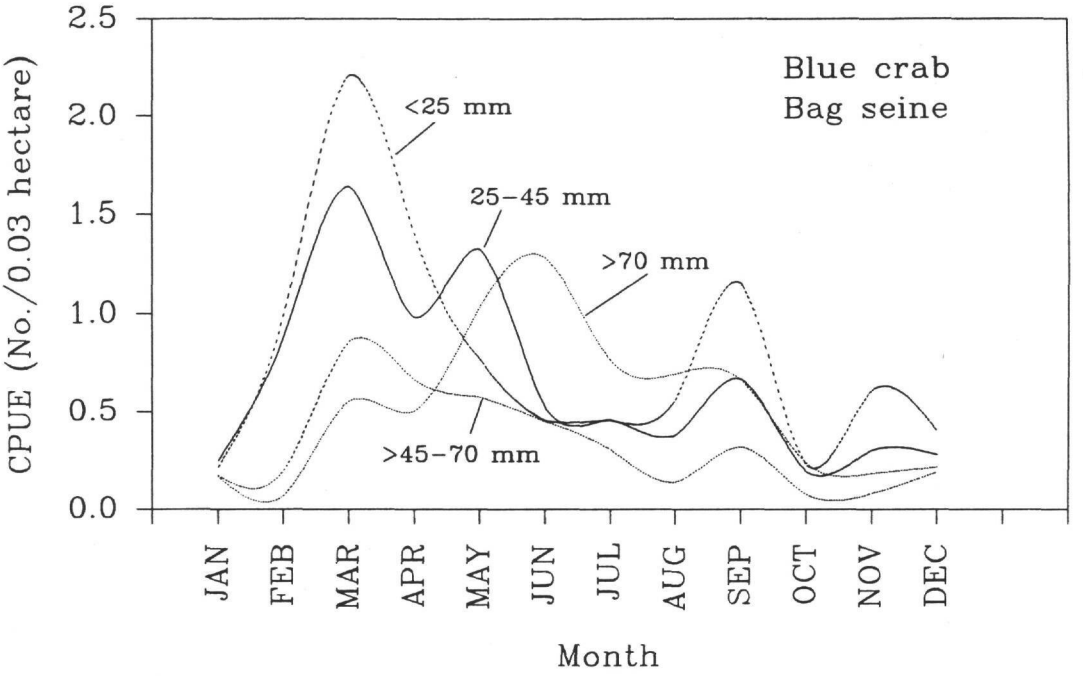


Figure III.7. Mean CPUE by month for four size classes of blue crab caught by bag seine (<25 mm, 25-45 mm, >45-70 mm, >70 mm). Data pooled from 1978-1989.

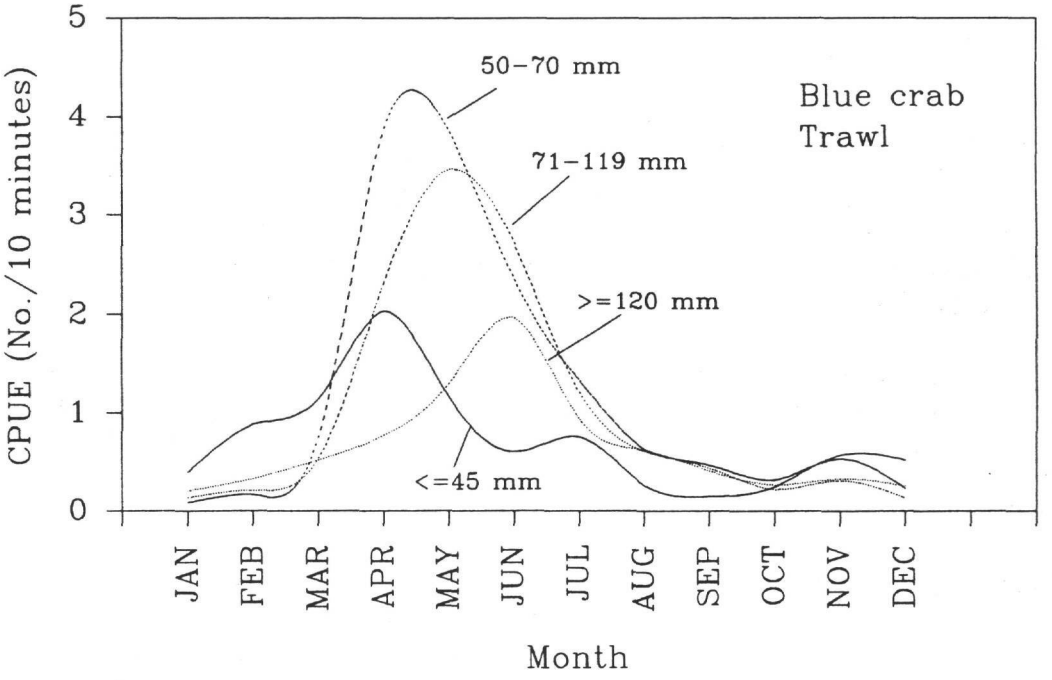


Figure III.8. Mean CPUE by month for four size classes of blue crab caught by trawl (< =45 mm, 50-70 mm, 71-119 mm, > =120 mm). Data pooled from 1983-1990.

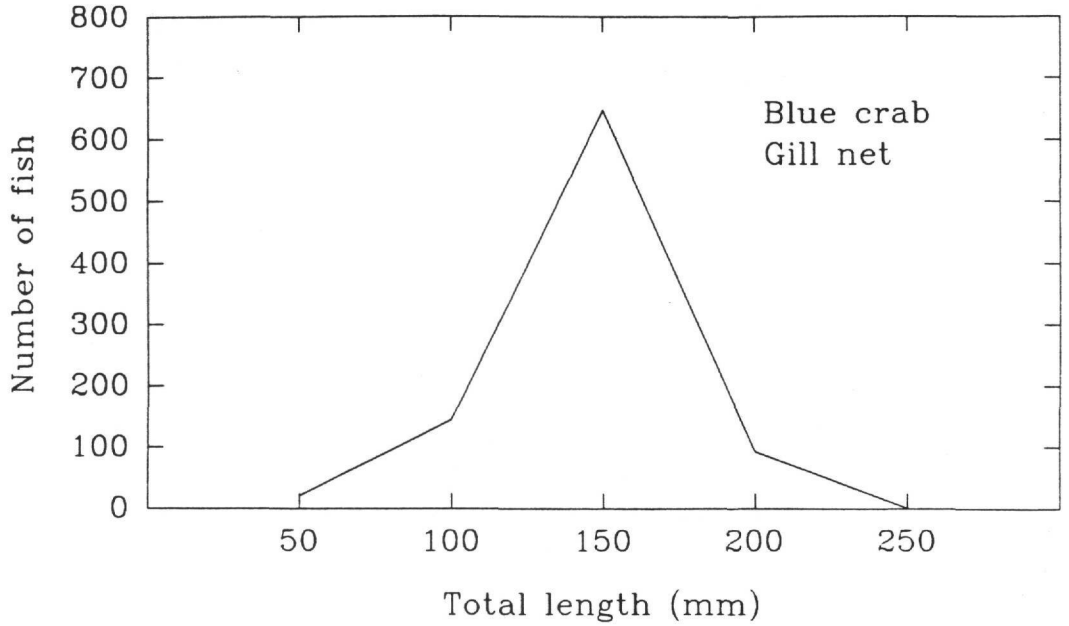


Figure III.9. Size frequency distribution for blue crab caught by gill net during spring sampling period. Data pooled from 1983-1990.

Young of the Year

Bag seine: The annual trend was linear with a positive slope (Table III.5, Figure III.1A); the quadratic component was not significant. The linear component only accounted for a small proportion (10.7 percent) of the total deviance, leaving a significant amount of the year-to-year variation unexplained (Table III.5). Deviance ascribed to Month was large, reflecting the large differences in CPUE among months (Figure III.1B).

Trawl: The annual trend showed an increase in abundance having significant linear and quadratic components (Table III.6, Figure III.2A). Again there was considerable month-to-month variation not explained by the quadratic model (Figure III.2B).

Juveniles

Trawl: Juveniles showed a significant decreasing linear trend (Table III.7, Figure III.3A). The quadratic component was not significant. The model including categorical Month and linear YEAR explained 34.5 percent of the total deviance. Most of the total deviance was ascribed to YEAR effects other than the linear or quadratic components. Mean monthly CPUE varied greatly (Figure III.3B).

Table III.5. Analysis of deviance for young-of-the-year blue crab (25-45 mm TW) caught by bag seine, January-December, 1978-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	176.7	16.06	16.48	<0.001
YEAR					
Linear	1	16.05	26.05	26.72	<0.001
Quadratic	1	0.44	0.44	0.45	0.50
Other	10	23.80	2.38	2.44	<0.01
Month x Year	131	342.20	2.61	2.68	<0.001
Corrected error	1200	1169.90	0.97		

Table III.6. Analysis of deviance for young-of-the-year blue crab (25-45 mm TW) caught by trawl, January-December, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	255.30	23.21	27.95	<0.001
YEAR					
Linear	1	5.70	5.70	6.86	<0.01
Quadratic	1	67.80	67.80	81.56	<0.001
Other	5	102.80	20.56	24.76	<0.001
Month x Year	77	289.30	3.76	4.52	<0.001
Corrected error	1711	1420.80	0.83		

Table III.7. Analysis of deviance for juvenile blue crab (50-70 mm) caught by trawl, January-December, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	850.70	77.34	96.06	<0.001
YEAR					
Linear	1	9.10	9.10	11.30	<0.001
Quadratic	1	0.00	0.00	0.00	>0.75
Other	5	49.80	9.96	12.37	<0.001
Month x Year	77	231.70	3.01	3.74	<0.001
Corrected error	1749	1408.10	0.81		

Table III.8. Analysis of deviance for first-time spawning blue crab (120-140 mm) caught by trawl, January-December, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	312.70	28.43	45.27	<0.001
YEAR					
Linear	1	32.90	32.90	52.39	<0.001
Quadratic	1	0.00	0.00	0.00	>0.75
Other	5	29.20	5.84	9.30	<0.001
Month x Year	77	171.30	2.22	3.54	<0.001
Corrected error	1463	918.70	0.63		

First-time Spawners

Trawl: The l parameter initially calculated by PROC NLIN (SAS) was negative. Deletion of one large outlier catch resulted in a positive estimate for l.

The annual trend was linear with a negative slope (Table III.8, Figure III.4A) and there was no significant quadratic component. The model including Month and linear YEAR explained 23.5 percent of the total deviance.

Gill net: The estimate of l was negative but close to 0. Because of the scatter of the data points there was no clear "outlier" to delete. A Gamma distribution was suggested by the data and was tested in addition to the negative binomial distribution. Set duration was not found to be significant ($P > 0.50$) and CPUE was defined as catch per set (Figure III.5B).

No significant linear or quadratic annual trend was found from 1983 to 1990, whether the data were analyzed as Gamma or negative binomial distributions (Table III.9). Mean CPUE by year was less than one crab per set (Figure III.5).

Remaining Adults

Gill net: Preliminary analysis showed that set duration (GTIME) was not significant (Figure III.6B). Therefore CPUE was defined as catch per set. The interaction between set duration and year was omitted because it did not contribute significantly to the deviance.

Mean annual CPUE (Figure III.6A) was highest for the remaining adults in 1986. There was a significant quadratic component to annual values of CPUE (Table III.10). The linear trend was marginally significant, but quadratic and linear effects in combination were significant ($p < 0.025$), suggesting there was a net decrease in abundance from 1983 to 1990.

Spatial Distribution

Young-of-the-year crab taken by bag seine were abundant along most shorelines sampled in the Galveston Estuary (Figure III.10). Young of the year taken by trawl (Figure III.11) were abundant in the low-salinity areas of Trinity Bay and moderately abundant in Upper and Lower Galveston Bay. Juvenile crab caught by trawl were abundant in Trinity, Upper, and Lower Galveston Bay (Figure III.12). First-time spawners were abundant in Trinity and Upper Galveston Bay (Figure III.13). The high abundance of first-time spawning crab (Figure III.14) and remaining adults (Figure III.15) in Christmas Bay and other parts of the coastline of East and West Bays may be related to areas of submerged aquatic vegetation and seagrasses (Thomas et al. 1990, Pulich and White 1989).

Densities for crab <40 mm were found by Thomas et al. (1990) to be highest in seagrass, intermediate in salt marsh, and lowest over bare sand. Seagrasses are

Table III.9. Analysis of deviance for first-time spawning blue crab (120-140 mm) caught by gill net, spring season, 1983-1990. CPUE=catch/set. Analysis based on Gamma distribution.

Source of Variation	D.F.	Deviance	M.D.	F	P
GTIME	1	1.34	1.34	0.82	>0.25
YEAR					
Linear	1	1.01	1.00	0.61	>0.25
Quadratic	1	3.64	3.64	2.22	>0.10
Other	5	7.45	1.49	0.91	>0.25
GTIME x YEAR	7	17.48	2.50	1.52	>0.10
Corrected error	344	562.92	1.64		

Table III.10. Analysis of deviance for remaining adult blue crab (>140 mm) caught by gill net, spring season, 1983-1990. CPUE=catch/set. Analysis based on negative binomial distribution.

Source of Variation	D.F.	Deviance	M.D.	F	P
GTIME	1	3.88	3.88	3.01	>0.05
YEAR					
Linear	1	4.41	4.41	3.42	>0.05
Quadratic	1	5.76	5.76	4.47	<0.025
Linear + Quadratic	2	10.17	5.09	3.94	<0.025
Other	5	10.54	2.11	1.64	>0.10
Error	351	451.51	1.29		

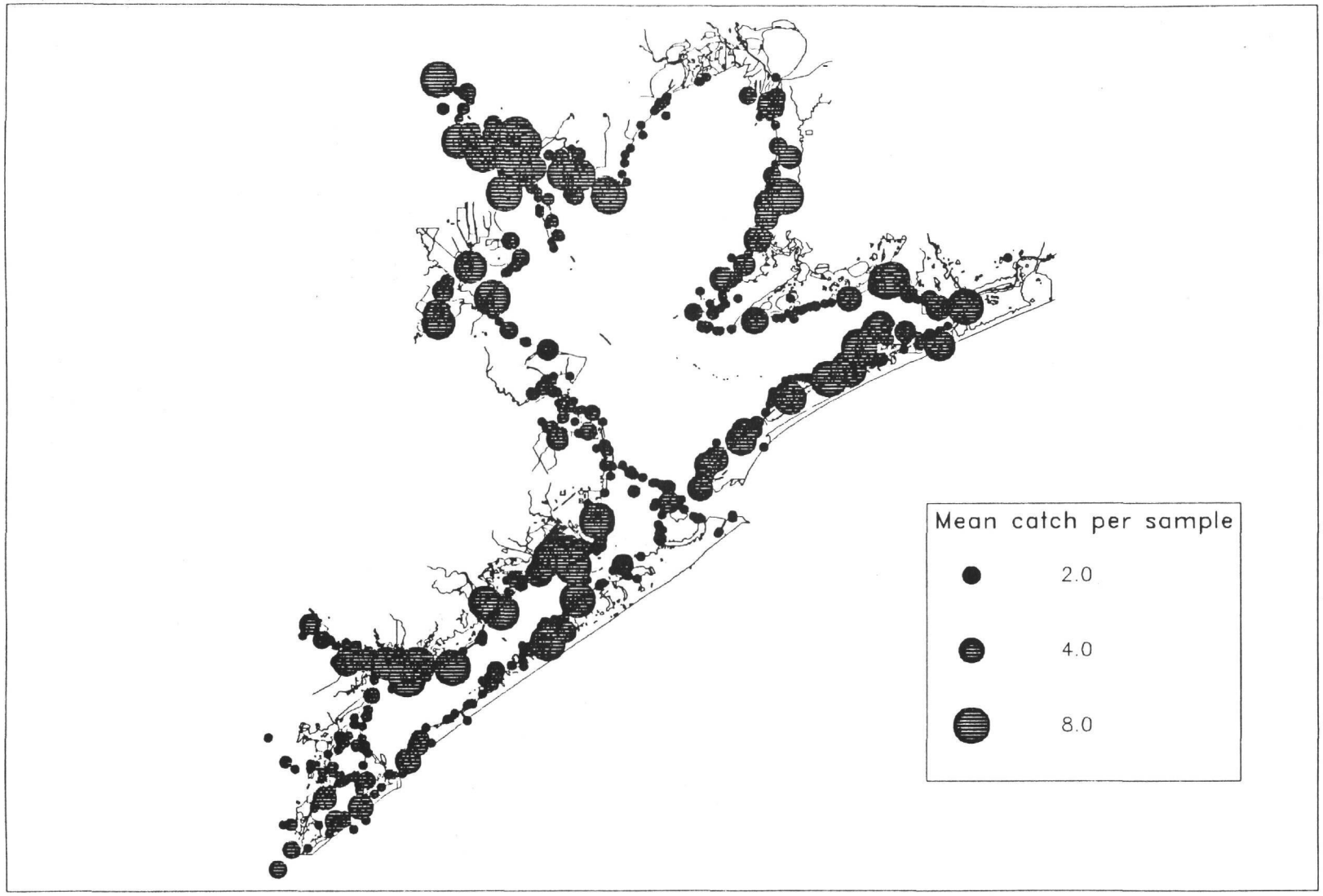


Figure III.10. Distribution of young-of-the-year blue crab (25-45 mm) caught by bag seine, January-December, 1978-1989. Circle size is proportional to mean CPUE.

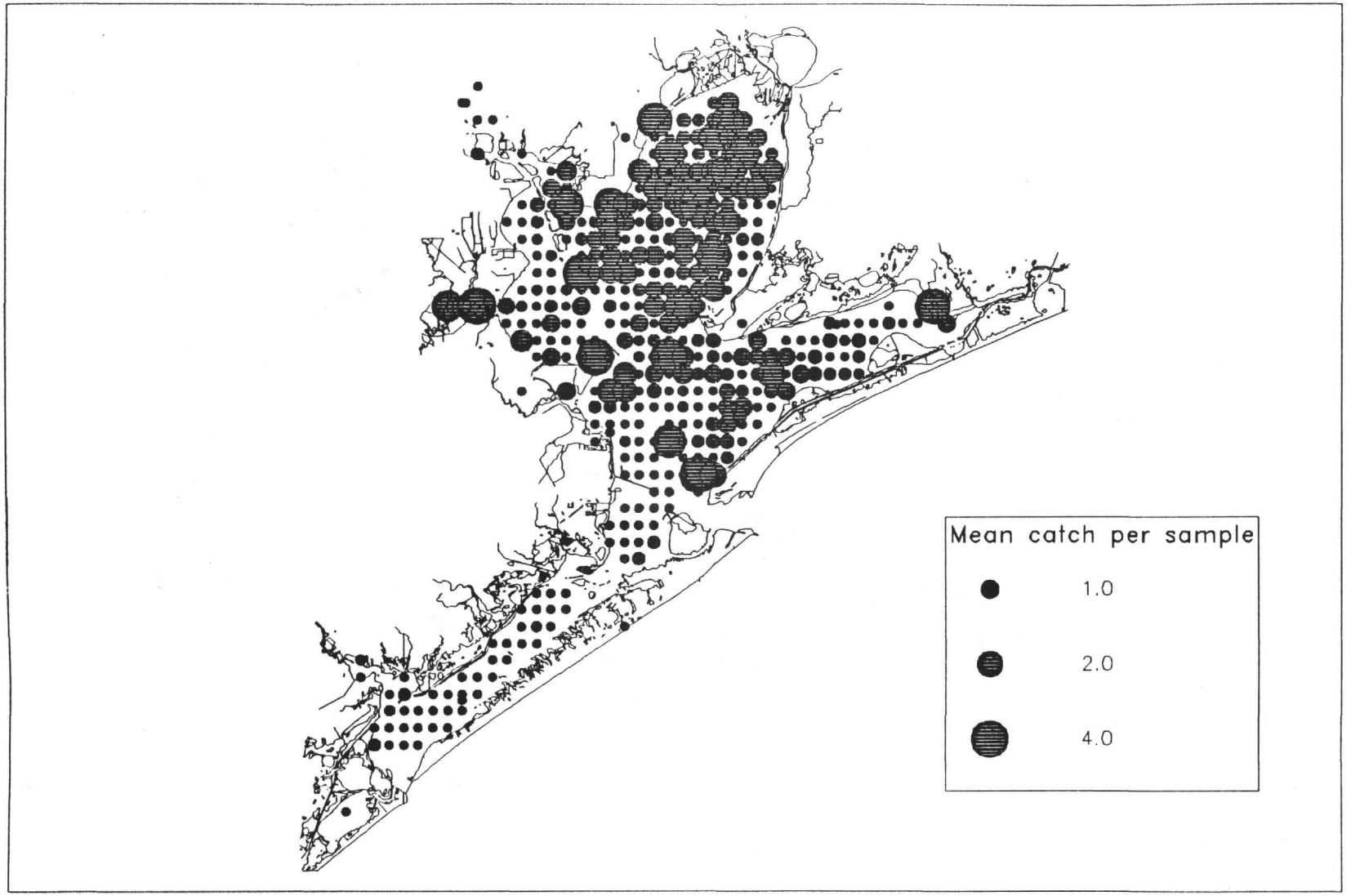


Figure III.11. Distribution of young-of-the-year blue crab (25-45 mm) caught by trawl, January-December, 1978-1989. Circle size is proportional to mean CPUE.

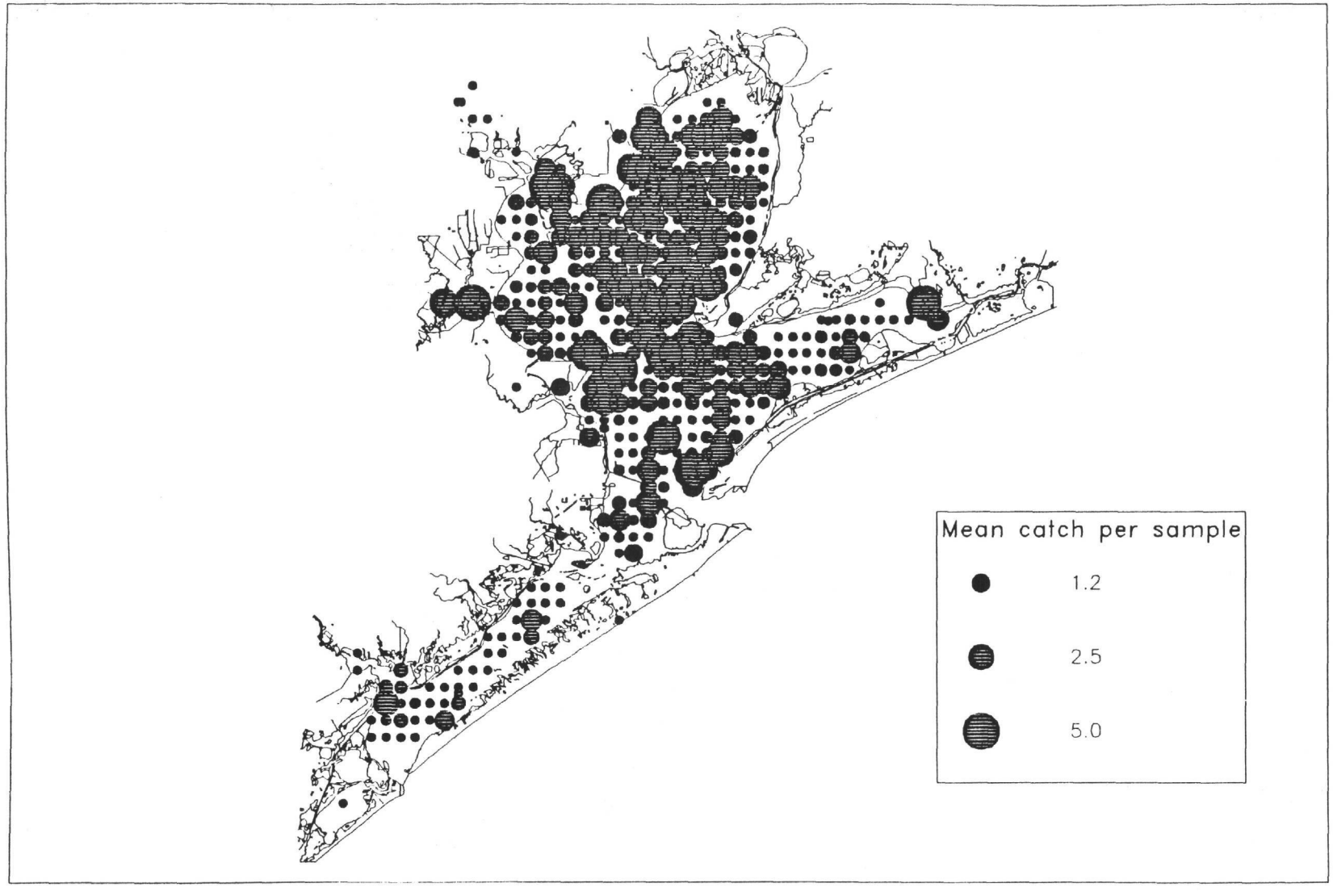


Figure III.12. Distribution of juvenile blue crab (50-70 mm) caught by trawl, January-December, 1983-1990. Circle size is proportional to mean CPUE.

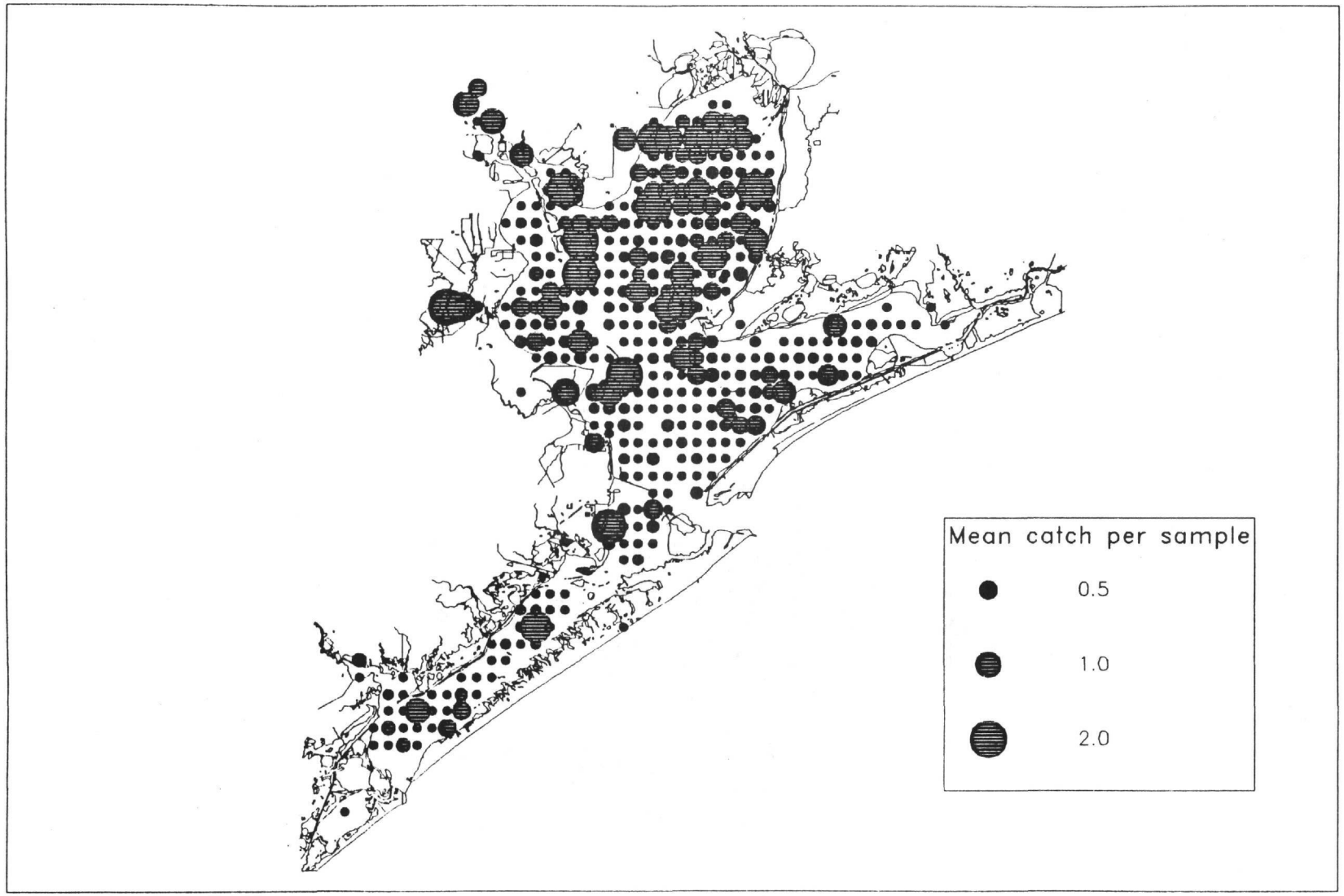


Figure III.13. Distribution of first-time spawning blue crab (120-140 mm) caught by trawl, January-December, 1983-1990. Circle size is proportional to mean CPUE.

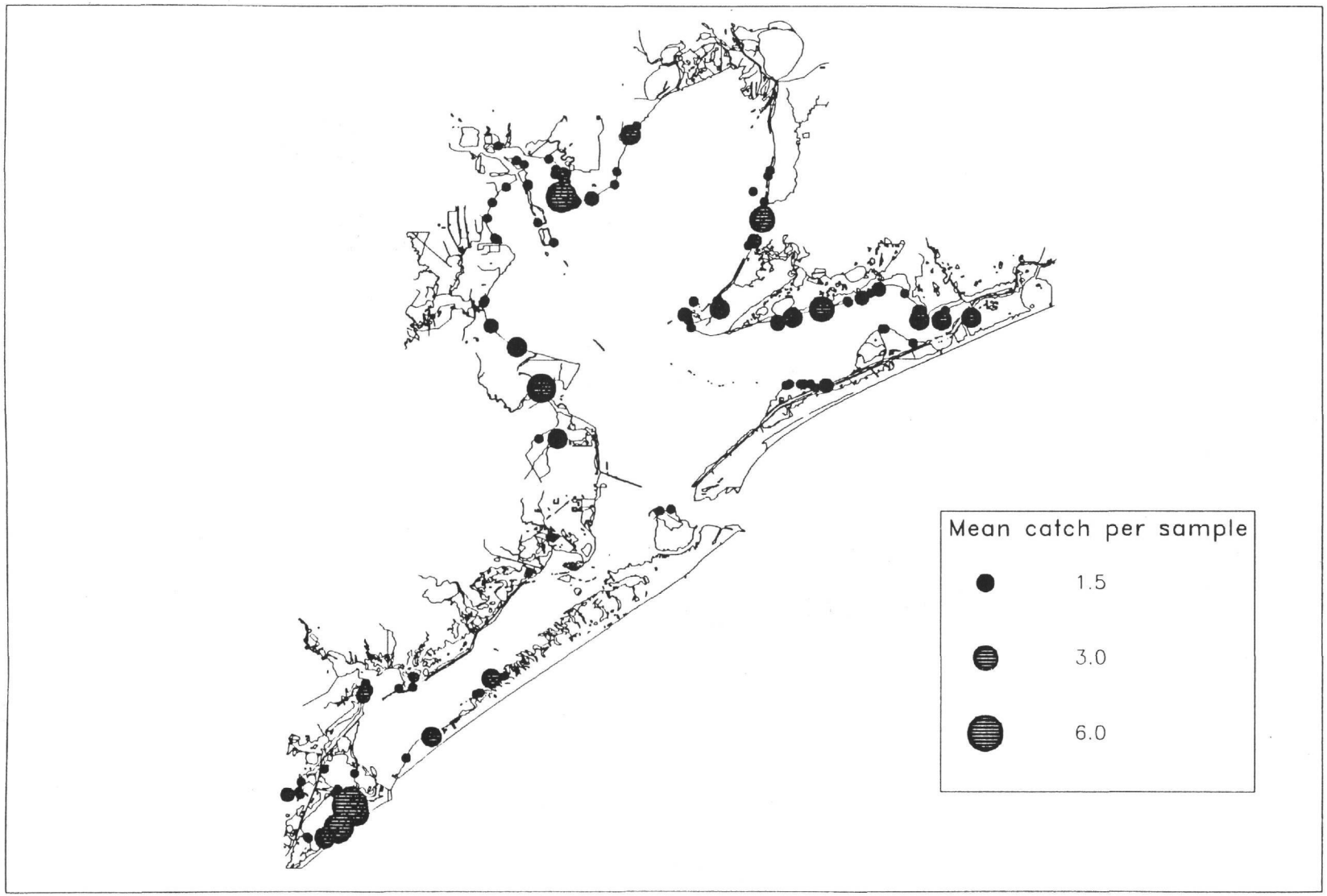


Figure III.14. Distribution of first-time spawning blue crab (120-140 mm) caught by gill net, spring, 1983-1990. Circle size is proportional to mean catch per sample.

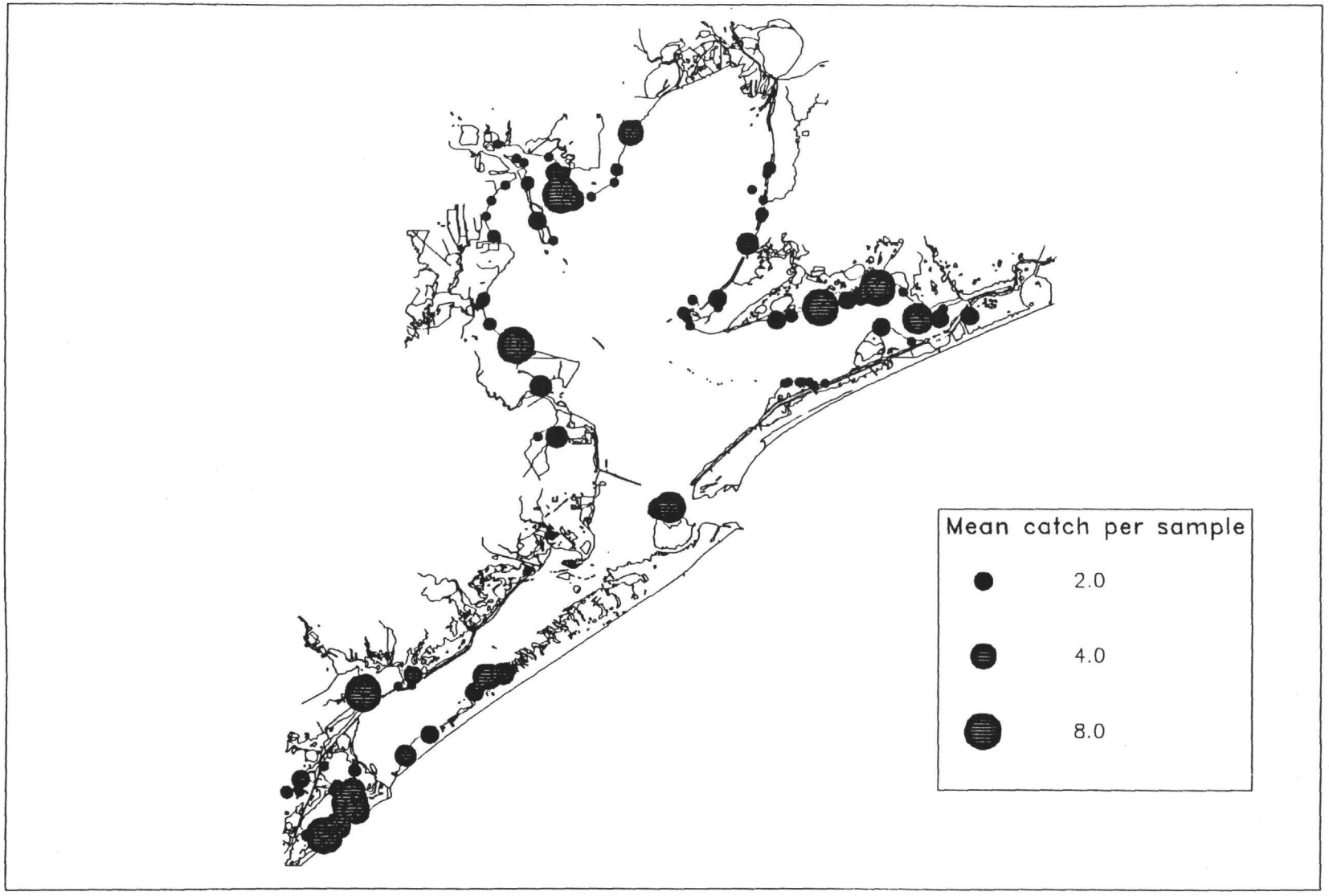


Figure III.15. Distribution of remaining adult blue crab (> 140 mm) caught by gill net, spring, 1983-1990. Circle size is proportional to mean catch per sample.

generally distributed as a narrow line along shorelines (Pulich and White 1989). High catches of young of the year by bag seine (Figure III.10) and adults in gill net (Figures III.14, III.15) may correspond to these areas. The high trawl catches of young of the year (Figure III.11), juveniles (Figure III.12) and first-time spawners (Figure III.13) in Trinity Bay may be related to low salinity. The abundances of adult crab in the middle and lower parts of the Galveston Bay system (Figure III.14, III.15) may also be related to the salt marsh and submerged seagrass beds in these areas (Zimmerman et al. 1990).

Discussion

This analysis did not specifically examine how differing habitat conditions such as temperature, salinity, or differing bottom type, factors that may affect blue crab abundance, may have influenced CPUE. The random sampling design should have dampened differences in CPUE due to spatial variability in habitat conditions. The trend toward increasing abundance in young-of-the-year crab indicated recruitment to the bays after spawning is not a problem. However, the declining abundance of juvenile and first-time spawners taken by trawl since 1983, and remaining adults caught by gillnet since 1986, are cause for concern. It is of interest to note that the mean size of crabs taken in research vessel trawls in Galveston Bay has declined from 91 mm in 1982 to 71 mm in 1988 (Mambretti et al. 1990).

The increase in abundance of young-of-the-year crab may be explicable on the basis of fragmentation of seagrass and marsh habitats, documented by Zimmerman et al. (1990, 1991). They found that adult blue crab were more abundant in the middle and lower parts of the Galveston Estuary along the coastline. The declining trends in abundance of the larger size classes of crab may be due to the decline in the export of organic detritus to the middle and lower portions of the estuary associated with the loss of wetland habitat (Turner and Boesch 1987, Pulich and White 1989, Teels 1990). The declining abundance of the larger size classes of blue crab could also be caused by overfishing. Further research is needed to determine which factors influenced trends in abundance of blue crab in the Galveston Estuary.

Brown Shrimp (*Penaeus aztecus*)

The historical data from the NMFS/TPWD data set were analyzed for total catch (all size classes for the months April through November) and for first-time spawners (85-110 mm TL for the months May through August). No clear trend appeared for the years 1963-1968 in either analysis (Figures III.16, III.17). However, the data showed a slight upward trend from 1972 through 1980 in both analyses, influenced by a high CPUE in 1980 (Figure III.18, III.19).

In the CF data set, both young of the year (30-55 mm) caught by bag seine and first-time spawners (85-110 mm) caught by trawl showed great year-to-year variation without any significant annual trend (Figures III.20 and III.21). The annual CPUE was highest during 1987 for both bag seine and trawl catches. Mean annual CPUE in bag seine and trawl catches appear to be correlated (1983 through 1990).

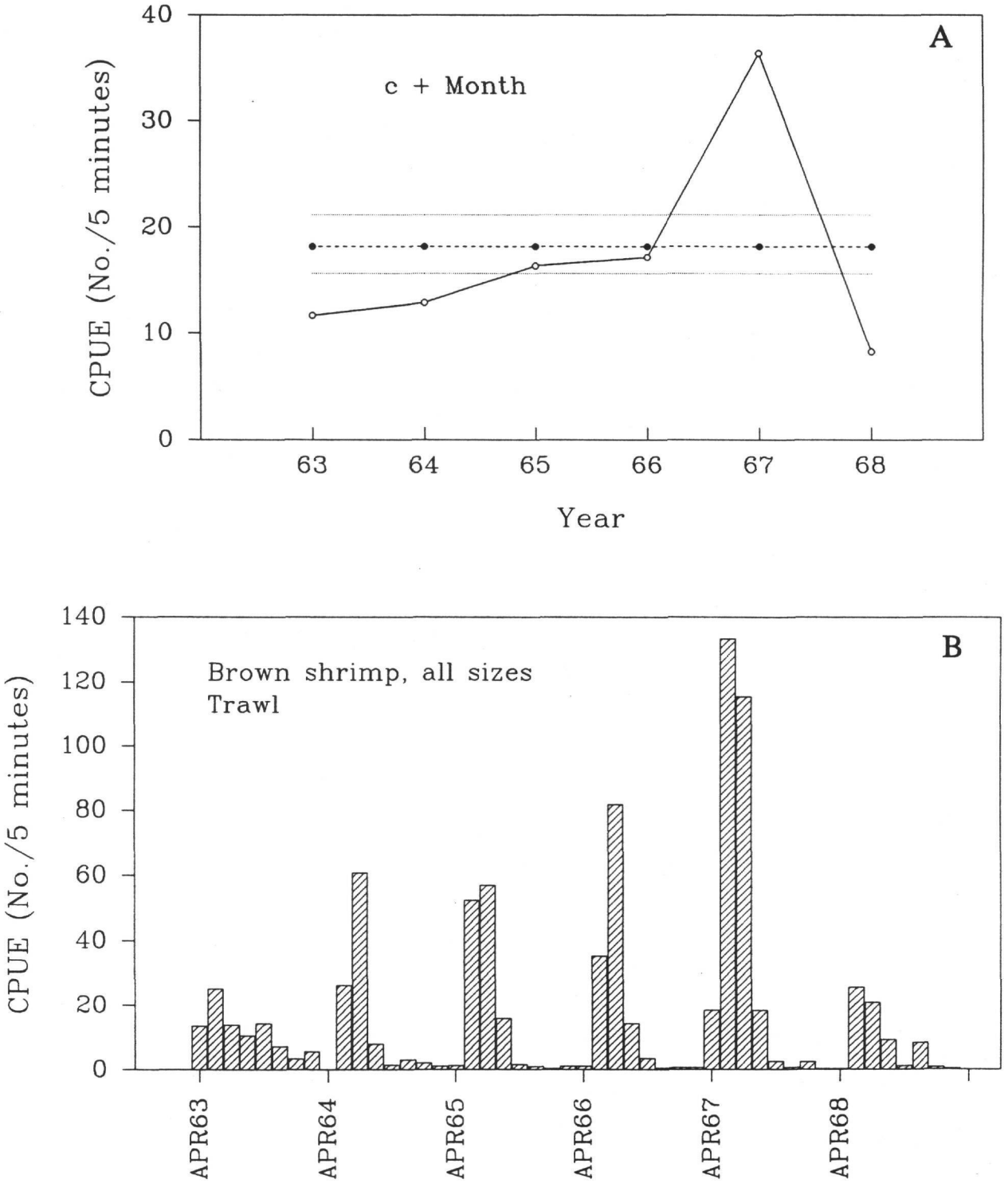


Figure III.16. A. Mean seasonal (April-November) CPUE and predicted CPUE with confidence intervals for all sizes of brown shrimp caught by trawl, 1963-1968 (TPWD/NMFS data). B. Mean CPUE by month, April-November only.

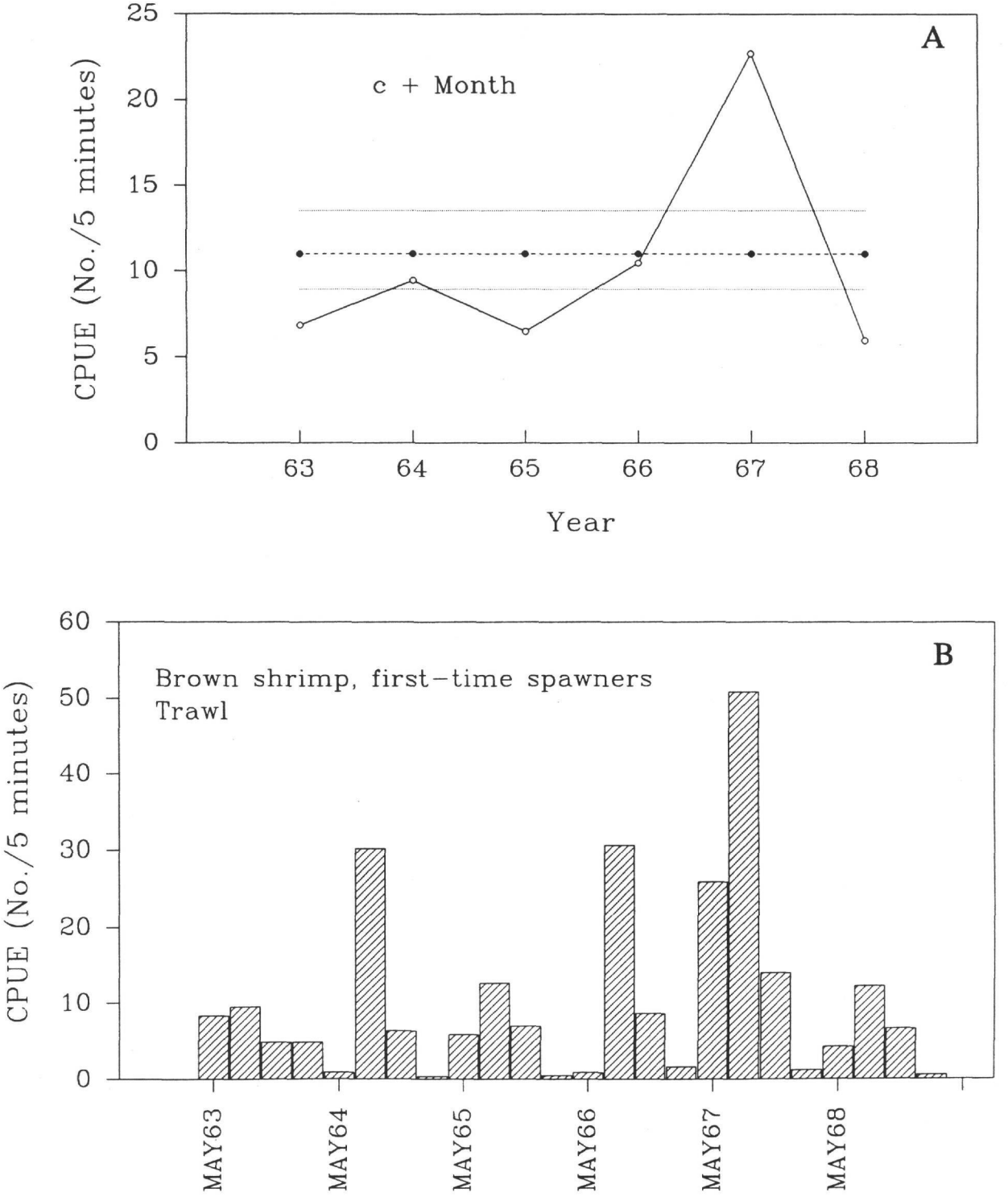


Figure III.17. A. Mean seasonal (May-August) CPUE and predicted CPUE with confidence intervals for first-time spawning brown shrimp (85-110 mm) caught by trawl, 1963-1968 (TPWD/NMFS data). B. Mean CPUE by month, May-August only.

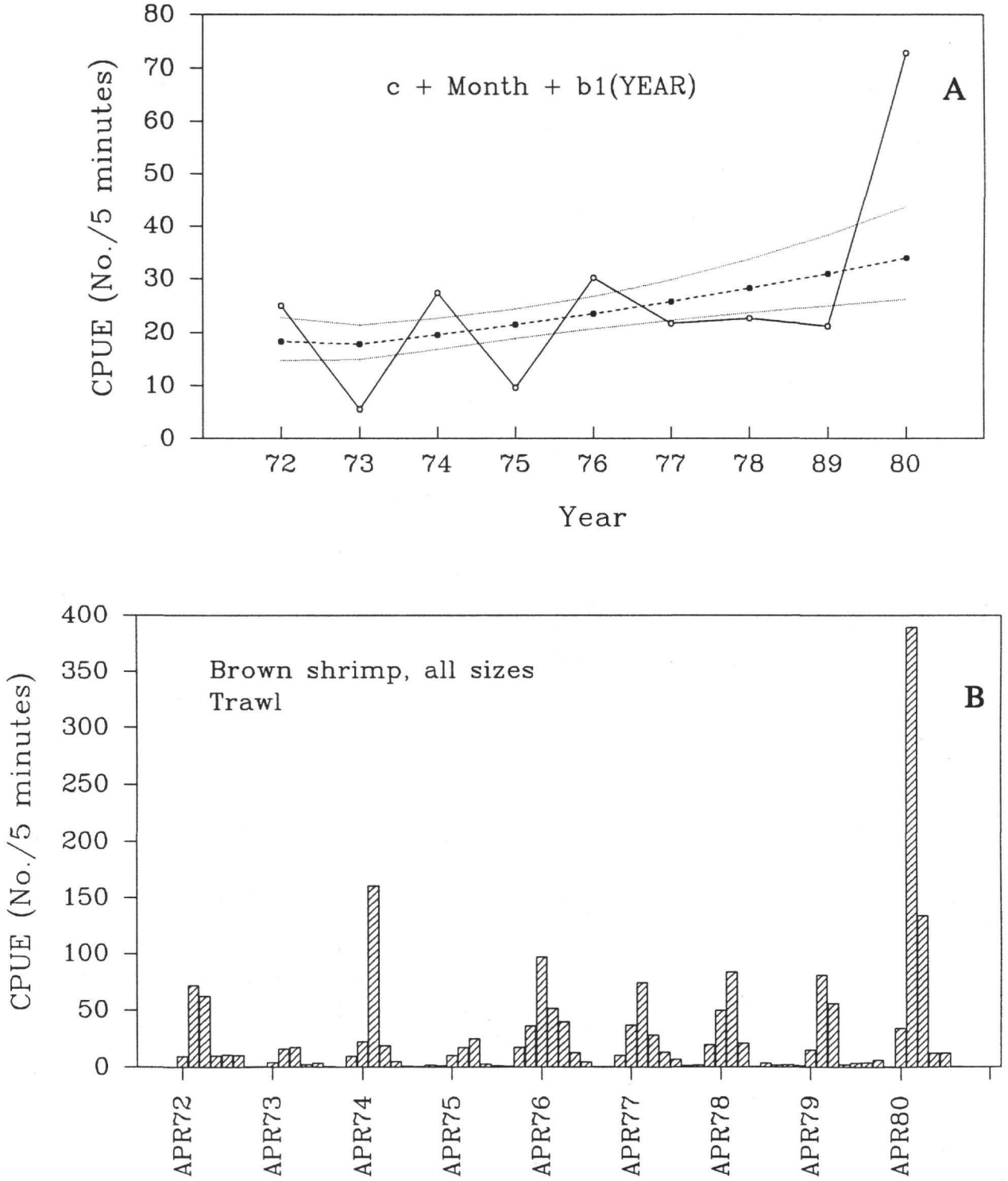


Figure III.18. A. Mean seasonal (April-November) CPUE and predicted CPUE with confidence intervals for all sizes of brown shrimp caught by trawl, 1972-1980 (TPWD/NMFS data). B. Mean CPUE by month, April-November only.

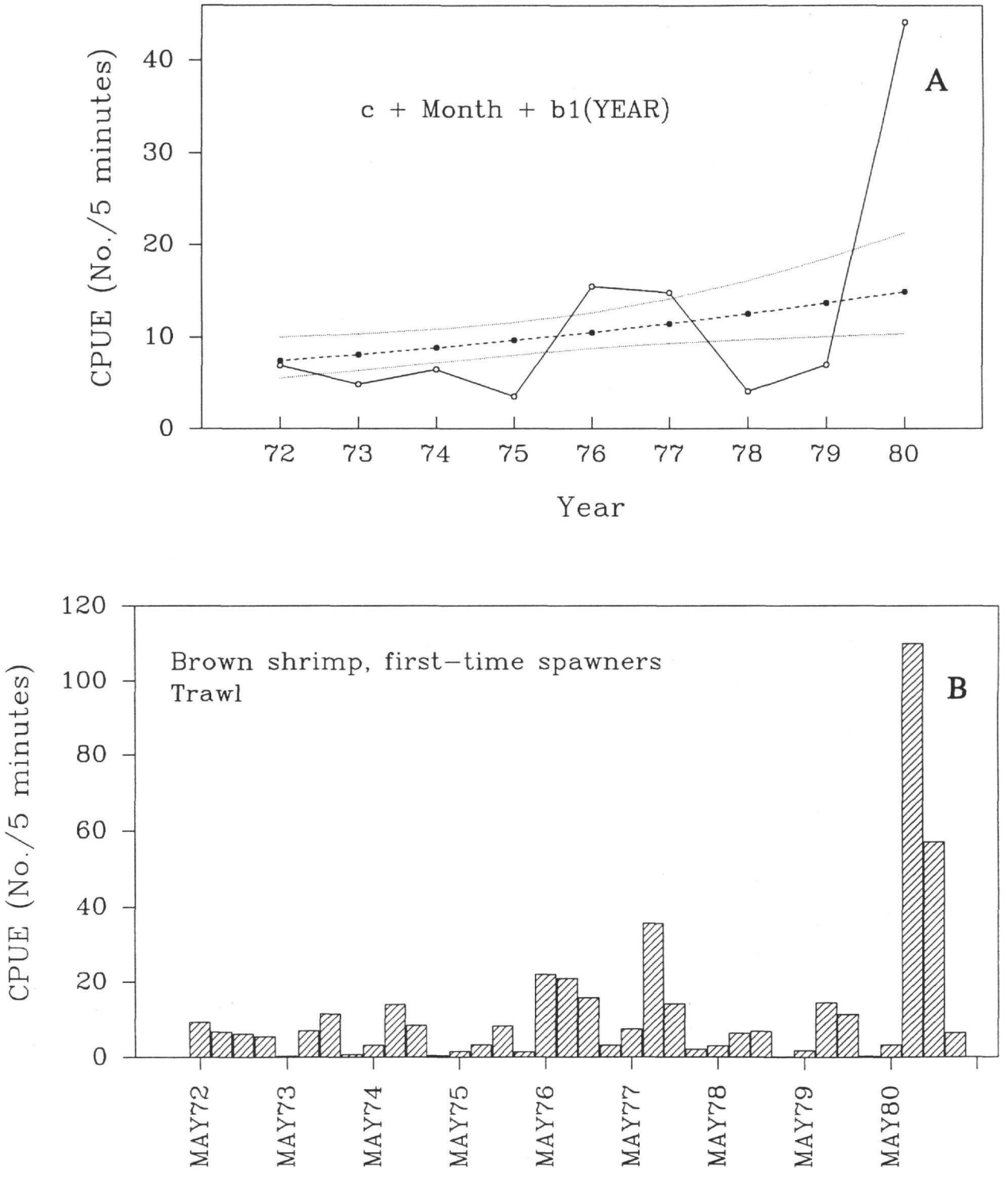


Figure III.19. A. Mean seasonal (May-August) CPUE and predicted CPUE with confidence intervals for first-time spawning brown shrimp (85-110 mm) caught by trawl, 1972-1980 (TPWD/NMFS data). B. Mean CPUE by month, May-August only.

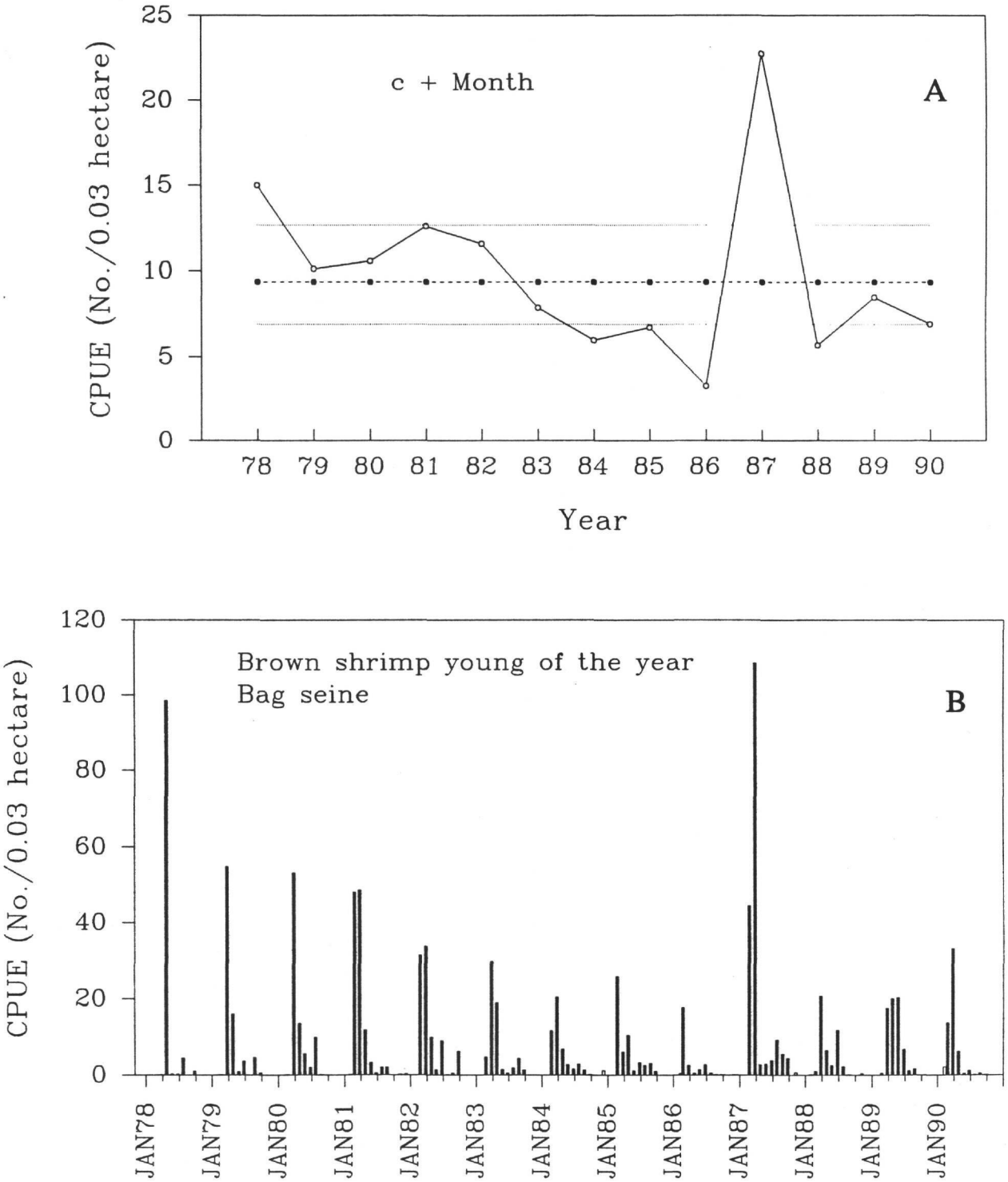
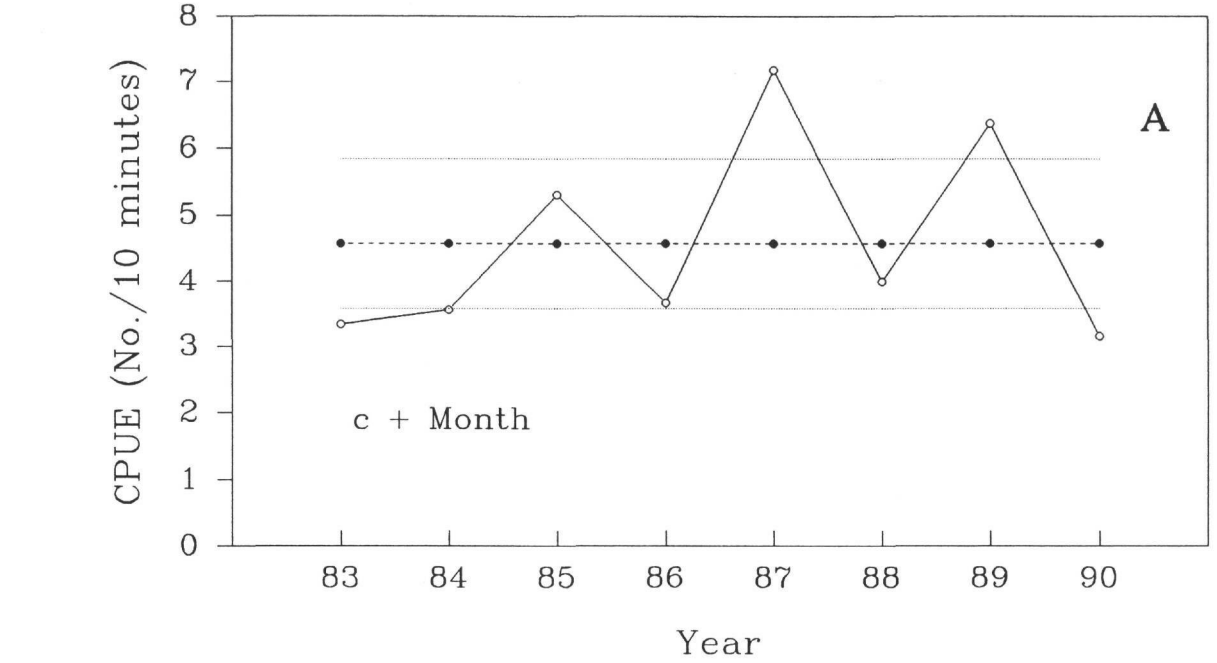


Figure III.20. A. Mean seasonal (April-November) CPUE and predicted CPUE with confidence intervals for young-of-the-year brown shrimp (30-55 mm) caught by bag seine (CF data). B. Mean CPUE by month. Filled bars: April-November. Hollow bars: months not used in analysis.



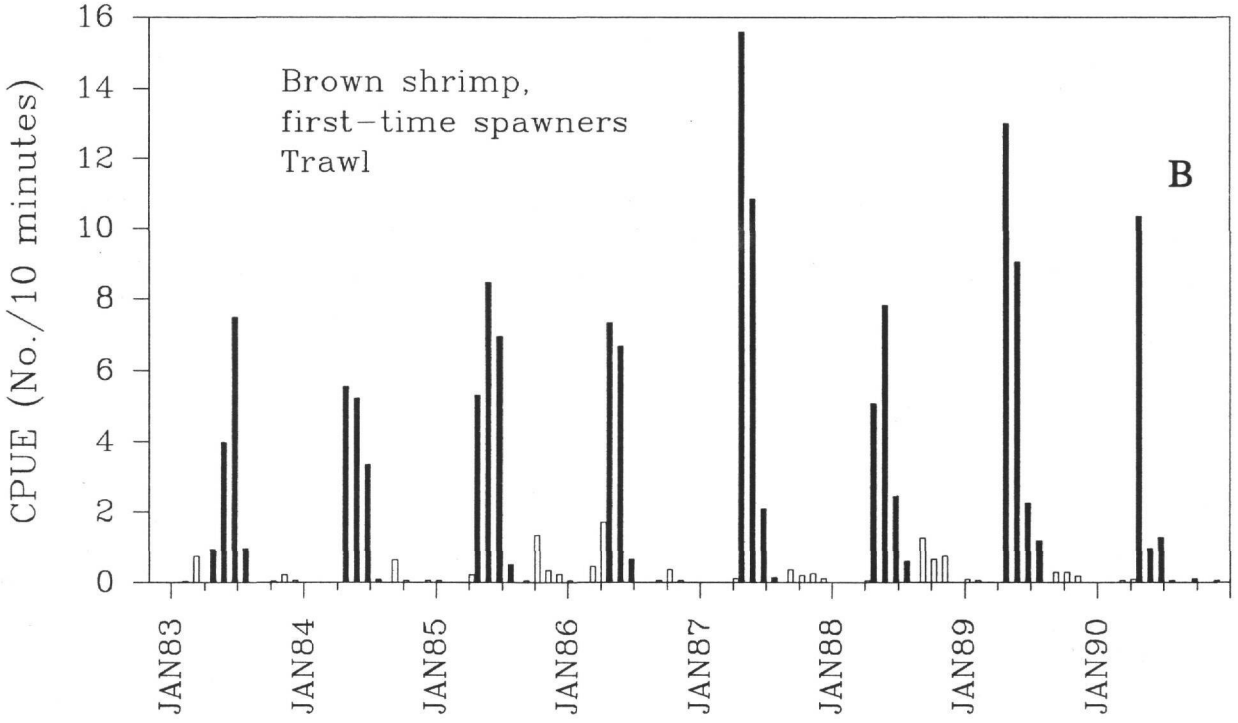


Figure III.21. A. Mean seasonal (May-August) CPUE and predicted CPUE with confidence intervals for first-time spawning brown shrimp (85-110 mm) caught by trawl, 1983-1990 (CF data). B. Mean CPUE by month. Filled bars: May-August. Hollow bars: months not used in analysis.

Season and Size Selection

Brown shrimp can grow more than 1 mm/day in spring and summer in the bays (Parrack 1979; Phares 1980; Garcia and Reste 1981; Nichols 1981). A size range of 25 mm was used to define life stages.

Small brown shrimp are abundant in bag seine catches. Young of the year were defined as the 30-55 mm size class (Figure III.22). Young of the year were present in all months but were most numerous from spring through fall, therefore the season for evaluating the abundance of this life stage was defined as April through November.

Most brown shrimp reach sexual maturity within one year after hatching, at about 140 mm. They attain a size of 85-110 mm in the bays before emigrating to the Gulf to spawn (Cody et al. 1989). The most abundant size in trawls was centered around 90 mm (Figure III.23), and the 85-110 mm size range was chosen to represent shrimp approaching the age to spawn for the first time. This size group was most numerous from May to August, the season chosen for analysis. In addition, all size groups in the TPWD/NMFS data set were analyzed collectively for the months of April to November.

Total catch, NMFS/TPWD data

Trawl: For the years 1963-1968, neither the linear annual trend nor the quadratic component were significant (Table III.11; Figure III.16A). Together they accounted for less than 12 percent of the deviance ascribed to annual variation. Deviance explained by Month was large, as shown by wide variation between months (Figure III.16B).

For 1972-1980, the linear trend was significant but not the quadratic component (Table III.12; Figure III.18A). The upward trend was probably influenced by high catches in May 1980 (Figure III.18B). Further analysis showed that when the 1980 data were removed, a less dramatic trend appeared. Again, the deviance attributed to Month was large.

Young of the year, CF data

Bag seine: The annual linear trend was not significant and the quadratic component was marginally significant (Table III.13). Together they accounted for less than 1 percent of the total deviance. Most of the deviance was accounted for by categorical year and Month effects, or was unexplained by the models tested, reflecting large differences in CPUE among months (Figure III.20B). With the exception of 1987, monthly mean CPUE decreased from 1978 to 1983 and remained at lower levels after 1983. When 1987 data were deleted, the analysis revealed a linear decrease ($0.005 > p > 0.001$) with no significant quadratic component.

First-time Spawners, TPWD/NMFS data

Trawl: For the years 1963-1968, neither the annual linear trend nor the quadratic component were significant (Table III.14). Together they accounted for less than 5

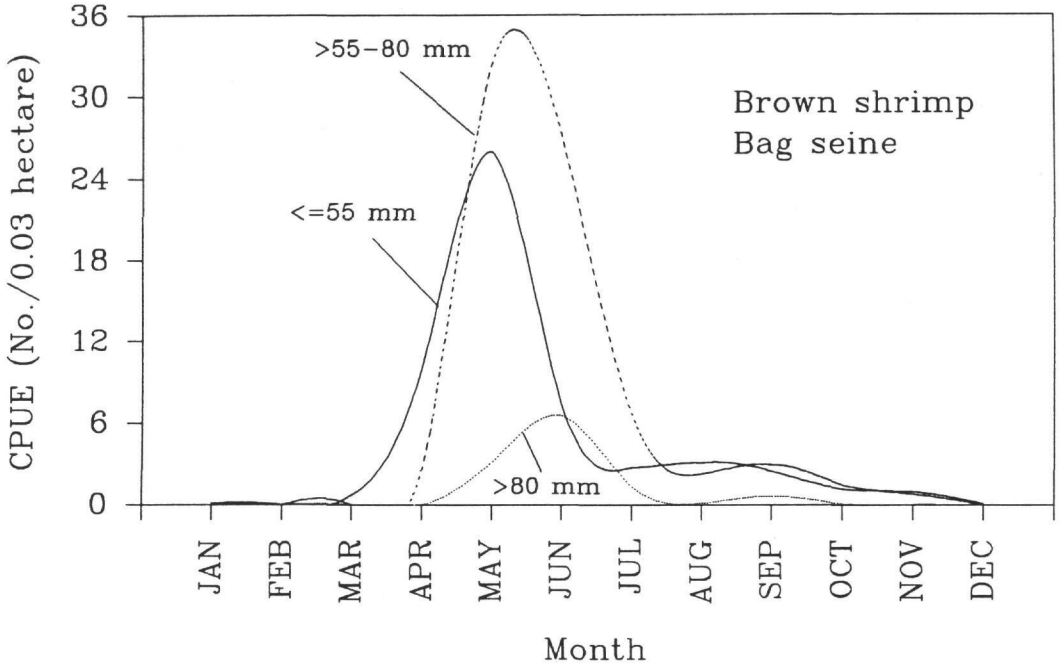


Figure III.22. Mean CPUE by month for three size classes of brown shrimp caught by bag seine (< =55 mm, >55-80 mm, >80 mm). CF data pooled from 1978-1989.

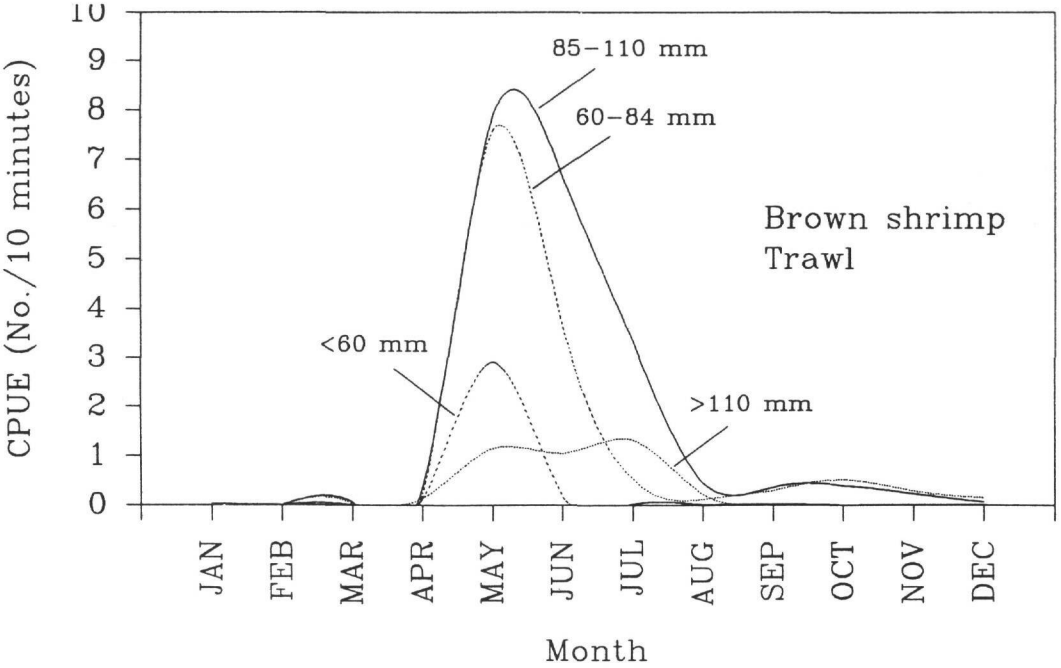


Figure III.23. Mean CPUE by month for four size classes of brown shrimp caught by trawl (<60 mm, 60-84 mm, 85-110 mm, >110mm). CF data pooled from 1983-1990.

Table III.11. Analysis of deviance for brown shrimp, all size classes, caught by trawl, April to November, 1963-1968. TPWD/NMFS data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	7	450.59	64.37	35.64	<0.001
YEAR					
Linear	1	4.42	4.42	2.45	>0.10
Quadratic	1	5.08	5.08	2.81	>0.05
Other	3	70.17	23.39	12.95	<0.001
Month x Year	35	198.91	2.83	1.57	<0.01
Corrected Error	248	448.00	1.81		

Table III.12. Analysis of deviance for brown shrimp, all size classes, caught by trawl, April to November, 1972-1980. TPWD/NMFS data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	7	399.50	57.07	35.98	<0.001
Year					
Linear	1	19.90	19.90	12.55	<0.001
Quadratic	1	1.40	1.40	0.88	>0.25
Other	6	64.50	10.75	6.78	<0.001
Month x Year	55	213.70	3.89	2.45	<0.001
Corrected Error	513	813.70	1.59		

Table III.13. Analysis of deviance for young-of-the-year brown shrimp (30-55 mm) caught by bag seine, April-November, 1978-1990. CF data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	7	499.30	7.13	5.84	<0.001
YEAR					
Linear	1	0.86	0.86	0.71	>0.25
Quadratic	1	4.70	4.70	3.85	<0.05
Other	10	88.90	8.89	7.28	<0.001
Month x Year	83	394.00	4.75	3.89	<0.001
Corrected error	845	1032.10	1.22		

Table III.14. Analysis of deviance for first-time spawning brown shrimp (85-100 mm) caught by trawl, May to August, 1963-1968. TPWD/NMFS data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	79.66	26.55	13.92	<0.001
YEAR					
Linear	1	1.42	1.42	0.77	>0.25
Quadratic	1	1.01	1.01	0.53	>0.25
Other	3	50.31	16.77	8.79	<0.001
Month x Year	15	61.40	4.09	2.15	0.01
Corrected Error	147	280.53	1.91		

Table III.15. Analysis of deviance for first-time spawning brown shrimp (85-100 mm) caught by trawl, May to August, 1972-1980. TPWD/NMFS data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	85.19	28.40	18.26	<0.001
YEAR					
Linear	1	9.79	9.79	6.30	<0.025
Quadratic	1	5.05	5.05	3.25	>0.05
Other	6	76.61	12.77	8.21	<0.001
Month x Year	24	74.90	3.12	2.01	<0.005
Corrected Error	287	446.24	1.56		

Table III.16. Analysis of deviance for first-time spawning brown shrimp (85-100 mm) caught by trawl, May-August, 1983-1990. CF data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	198.61	66.20	65.72	<0.001
YEAR					
Linear	1	0.22	0.22	0.22	>0.50
Quadratic	1	0.97	0.97	0.96	>0.25
Other	5	24.015	4.80	4.77	<0.001
Month x Year	21	96.01	4.57	4.54	<0.001
Corrected error	589	593.36	1.01		

percent of the deviance ascribed to annual variation. Most of the deviance was explained by monthly variation, as in the total catch data.

For the total catch, for 1972-1980 the linear trend was significant but not the quadratic component (Table III.15). A high CPUE in June 1980 influenced the upward trend (Figure III.19B); further analysis showed that when the 1980 data were removed, no trend was apparent. Most of the deviance was explained by Month.

First-time spawners, CF data

Trawl: For 1983-1990, neither the linear nor the quadratic annual trends were significant (Table III.16). Together they accounted for less than 5 percent of the deviance ascribed to annual variation. Deviance explained by Month was large. The removal of 1987 from the data set did not reveal an annual trend.

Variation appeared systematic in that years of greater-than-average CPUE alternated with lower-than-average years (Figure III.21). The annual fluctuations in bag seine and trawl catches appeared to be correlated (1983 through 1990).

Spatial Distribution, CF data

Young-of-the-year brown shrimp were abundant along most shorelines in the Galveston Estuary with the exception of Upper Galveston Bay and northern Trinity Bay, though intermediate catches occurred in Tabbs Bay and around the mouth of the San Jacinto River (Figure III.24). First-time spawners were also well distributed within the Estuary, including Trinity Bay and Upper Galveston Bay (Figure III.25).

Discussion

The CPUE for the TPWD/NMFS is not strictly comparable to that for the CF data, because of differing sampling methods (a smaller net with slightly different mesh size) and effort (shorter trawl times). A rough visual estimate suggests a four-fold difference between mean CPUE for the 1960s and 1970s compared to 1983-1990, implying spawning-age brown shrimp may have decreased in abundance over the long term.

All the brown shrimp data sets examined showed rare, short-term population peaks, raising the possibility that the trend analyses could be overly influenced by a small number of exceptional catches, specifically, that a decreasing trend may be obscured by rare high catch rates (such as those of 1987). A closer inspection of the data was warranted by these concerns.

Interesting trends were revealed when zero and non-zero catches were analyzed separately. For bag seine data, the proportion of samples containing no brown shrimp in the 30-55 mm size range remained moderate (37-67%; Figure III.26A). An analysis of non-zero catches alone revealed neither a linear nor a quadratic annual trend; most

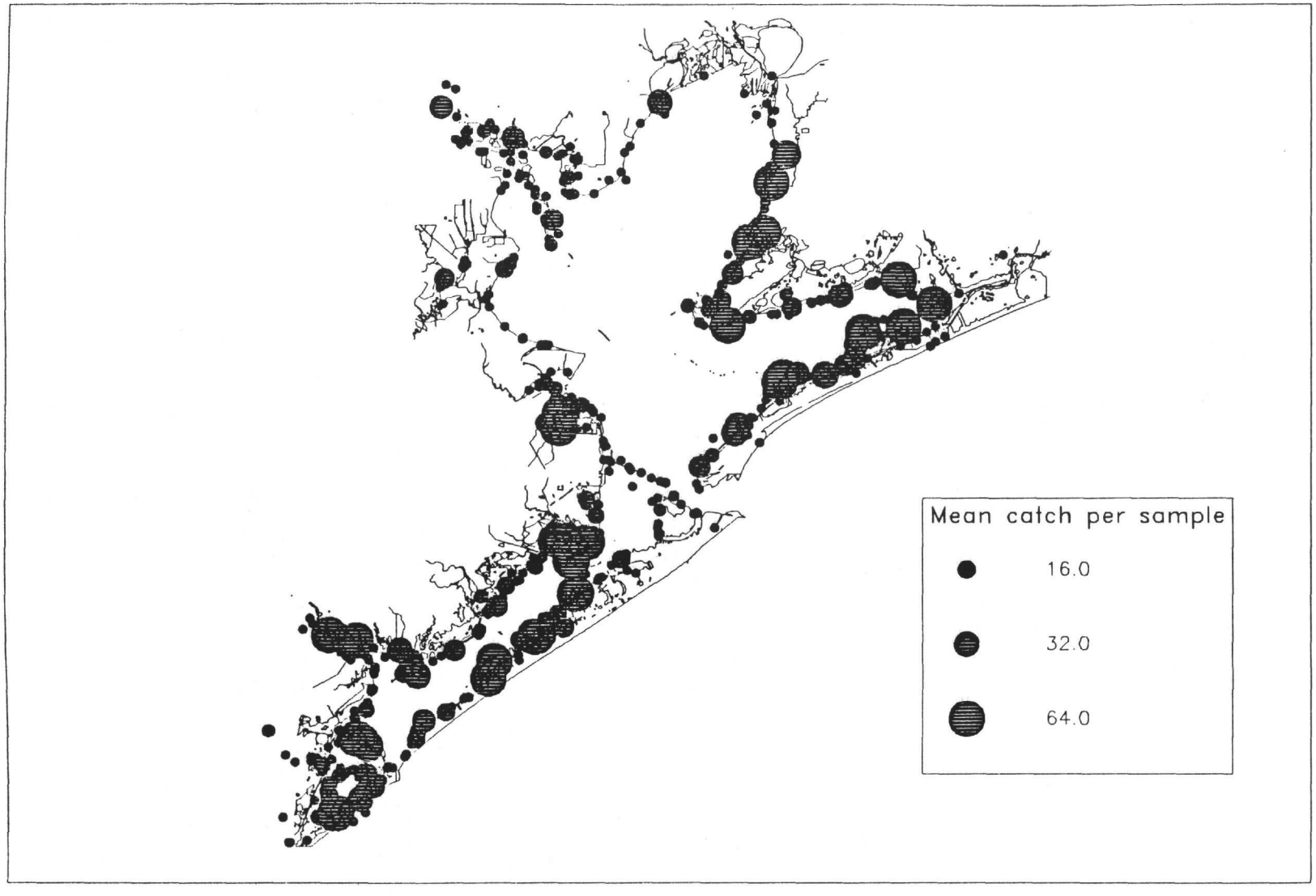


Figure III.24. Distribution of young-of-the-year brown shrimp (30-55 mm) caught by bag seine, April-November, 1978-1989. Circle size is proportional to mean CPUE.

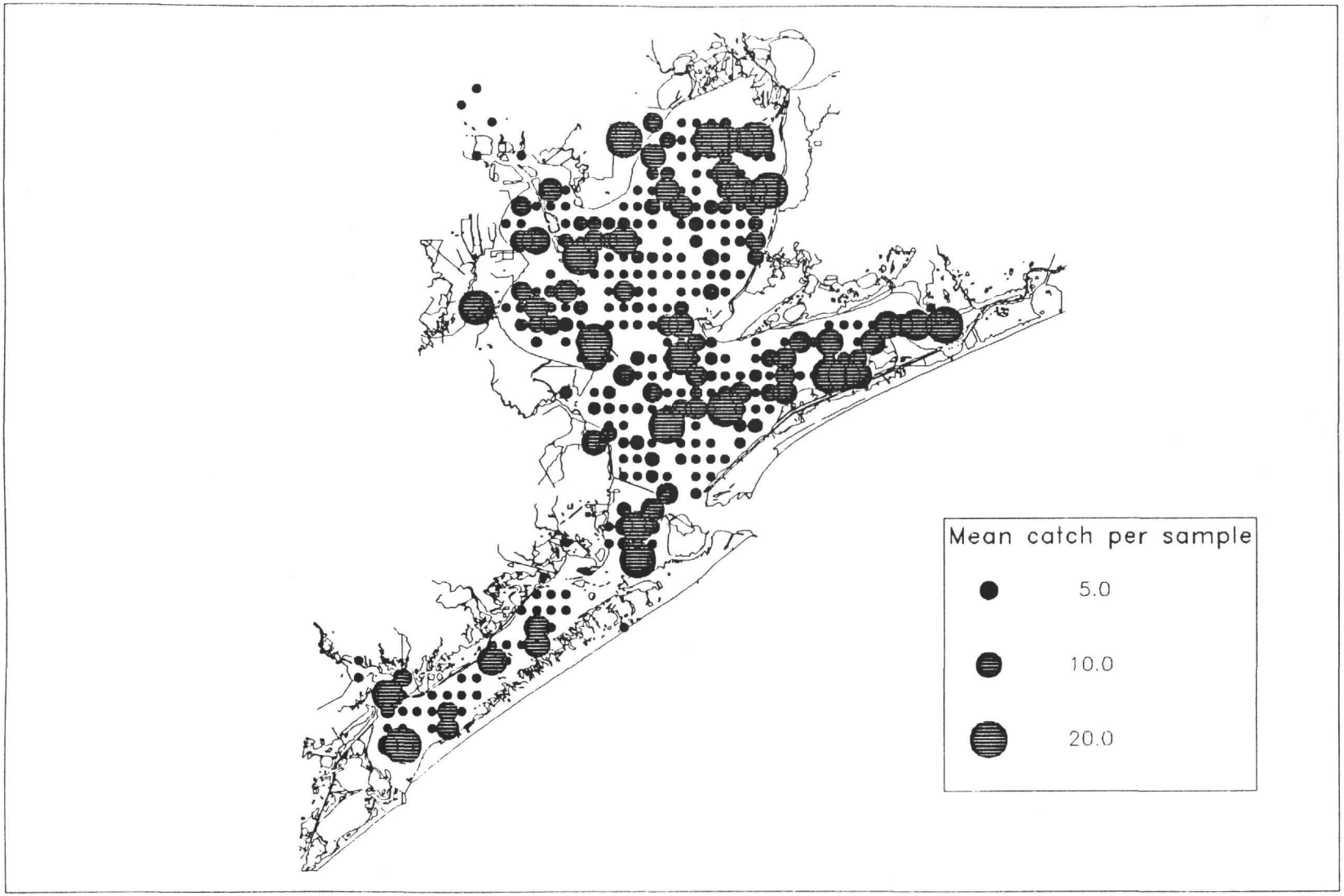


Figure III.25. Distribution of first-time spawning brown shrimp (85-110 mm) caught by trawl, May-August, 1983-1990. Circle size is proportional to mean CPUE.

of the deviance was explained by categorical Month effects, indicative of strong seasonality. An analysis modelling the probability of zero catches in proportion to the probability of non-zero catches, however, revealed significant linear and quadratic annual trends ($0.01 < p < 0.25$ and $0.001 < p < 0.005$, respectively), indicating an increase in the ratio of zero catches from 1982 to 1990 with the exception of 1987 (Figure III.26A).

The breakdown of zero and non-zero catches for trawl data (Figure III.26B) revealed a strong annual signature, even though the trawl data showed no annual trend when analyzed in their entirety. The proportion of zero catches in the CF data set increased from 36.25% in 1983 to 77.5% in 1990. Concurrently, CPUE exclusive of zero catches increased from 5.23 to 14.01. The analysis of non-zero CPUE showed a significant linear annual trend ($0.001 < p < 0.005$) with no additional quadratic component; similarly, modelling the probability of zero catches revealed a strong linear trend ($p < 0.001$), explaining 13.3% of the total deviance. In summary, though mean abundance did not change, the shape of the catch distribution curve changed from 1983 to 1990; shrimp were caught in greater numbers while the probability of catching no shrimp also increased.

Recent developments in the Galveston Estuary that may affect the abundance of brown shrimp are overfishing, which mainly affects the larger shrimp, and wetland loss, which is detrimental to juvenile shrimp. Juvenile brown shrimp are mostly safe from fishing and partially protected from other predators in their nursery habitat, the shallow areas in the estuaries. First-time spawning shrimp are exploited by the bay trawl fishery in deeper bay areas, and those that emigrate to the Gulf are further exploited by the Gulf trawl fishery. Commercial shrimping effort in Texas has increased considerably, especially in recent years (Cody et al. 1989; Klima et al. 1990). Substantial effort by bay shrimpers is directed at intercepting first-time spawning brown shrimp before they escape through the passes to the Gulf. The average size of brown shrimp in reported commercial landings from Texas has decreased (growth overfishing), probably because of greater fishing effort (Caillouet et al. 1980; Caillouet and Koi 1981; Klima et al. 1989; Nance et al. 1989).

Juvenile brown shrimp prefer vegetated habitat (salt marsh and seagrass beds) to non-vegetated habitat, and their densities are generally several times higher on the marsh surface than on the open-water bottom (Minello and Zimmerman 1984; Zimmerman and Minello 1984; Zimmerman et al. 1984). The loss of marsh and seagrass beds is clearly detrimental to shrimp (Turner 1977). A multitude of man-made and natural causes have contributed to the loss of saltwater marsh and seagrass beds in recent years (NOAA 1989; Pulich and White 1989).

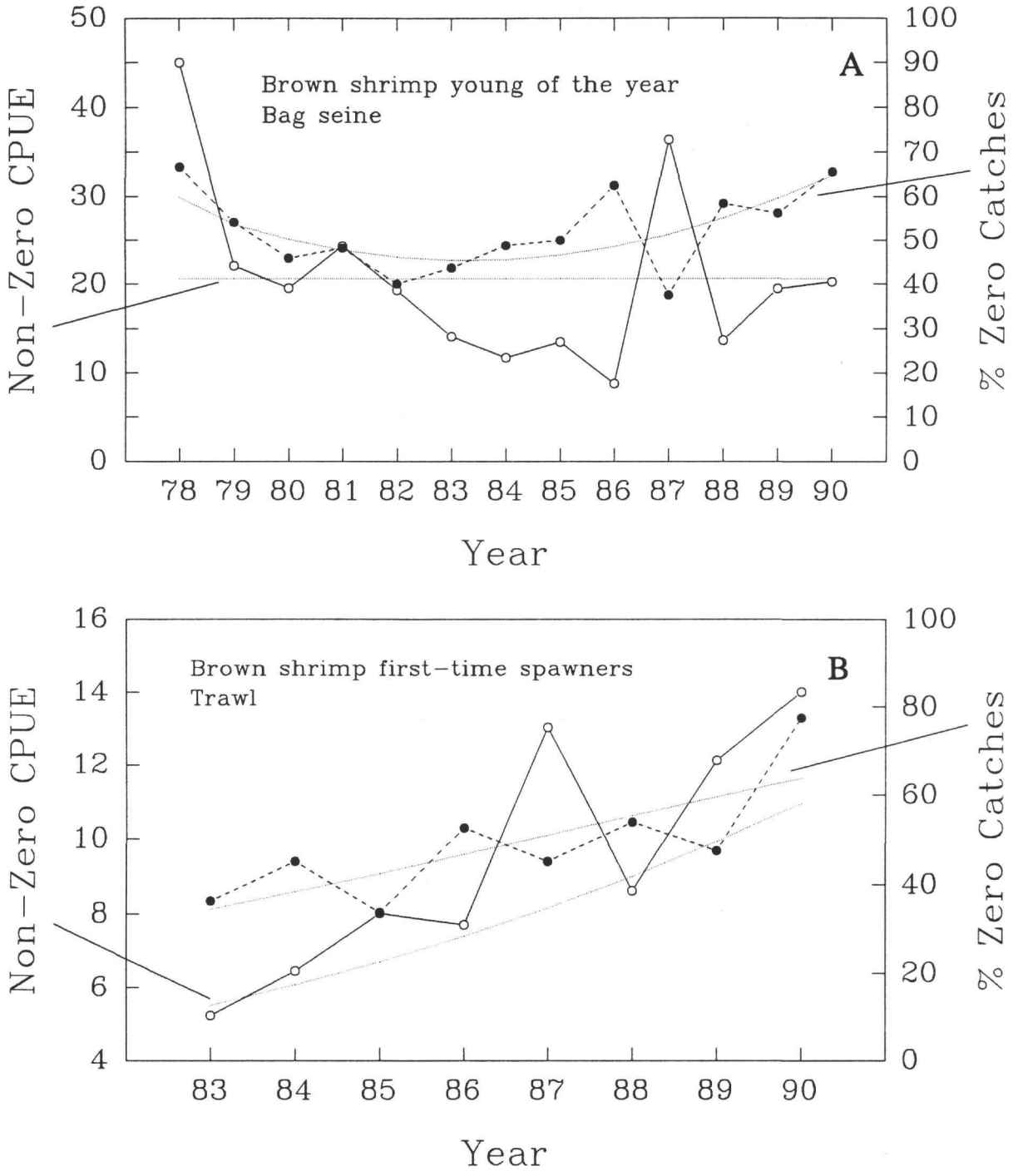


Figure III.26. A. Mean seasonal (April-November) CPUE exclusive of zero catches (solid line), percentage zero catches (dashed line), and predicted values for young-of-the-year brown shrimp (30-55 mm) caught by bag seine. B. Mean seasonal (May-August) CPUE exclusive of zero catches (solid line), percentage zero catches (dashed line), and predicted values for first-time spawning brown shrimp (85-110 mm) caught by trawl.

Grass Shrimp (Palaemonetes spp.)

Grass shrimp 25-35 mm in bag seine catches showed a quadratic trend, decreasing from 1983 to 1987 followed by an increase through 1990 (Figure III.27). Only one size group was analyzed because only adult grass shrimp were caught.

Selection of species, season and size

There are five species of grass shrimp with similar morphological characteristics in the Gulf of Mexico (P. pugio, P. intermedius, P. kadiakensis, P. paludosus, and P. vulgaris; Anderson 1985). All grass shrimp were lumped as Palaemonetes spp. for monitoring purposes and have been consistently recorded in bag seine samples only since 1982.

Though abundant and ecologically important, information on the growth and spawning of grass shrimp is limited. P. pugio in South Carolina mature when they are 1.5 to 2 months old and about 15 to 18 mm long (Alon and Stancyk 1982). Mainly large grass shrimp (>25 mm) are caught by bag seine (Figure III.28). A size range of 25-35 mm was selected to represent adult grass shrimp. Shrimp of this size range were present in sufficient numbers for analysis throughout the year.

Adults

Bag seine: A quadratic trend for annual effects explained the largest proportion of the total deviance (Table III.17). All factors were significant. The trend was strongly influenced by high catches in November 1983, January 1985, and December 1990 (Figure III.27B).

Spatial distribution

Grass shrimp were common in all parts of the Galveston Estuary shoreline with the exception of Upper and Lower Galveston Bay proper (Figure III.29), where seagrasses have been scarce since the 1960s (Pulich and White 1989). High densities along the eastern shore of Trinity Bay and in Christmas Bay probably corresponded to the extensive seagrass beds remaining in those areas (Pulich and White 1989).

Discussion

Grass shrimp are a favored food item for small fish. Any decrease in grass shrimp populations would be cause for concern because it could be detrimental to higher trophic groups. Grass shrimp populations would be expected to decrease with the well-documented loss of submerged vascular vegetation (Pulich and White 1989). The quadratic trend documented here may reflect normal population cycles with a period spanning several years, or may be the result of local environmental change.

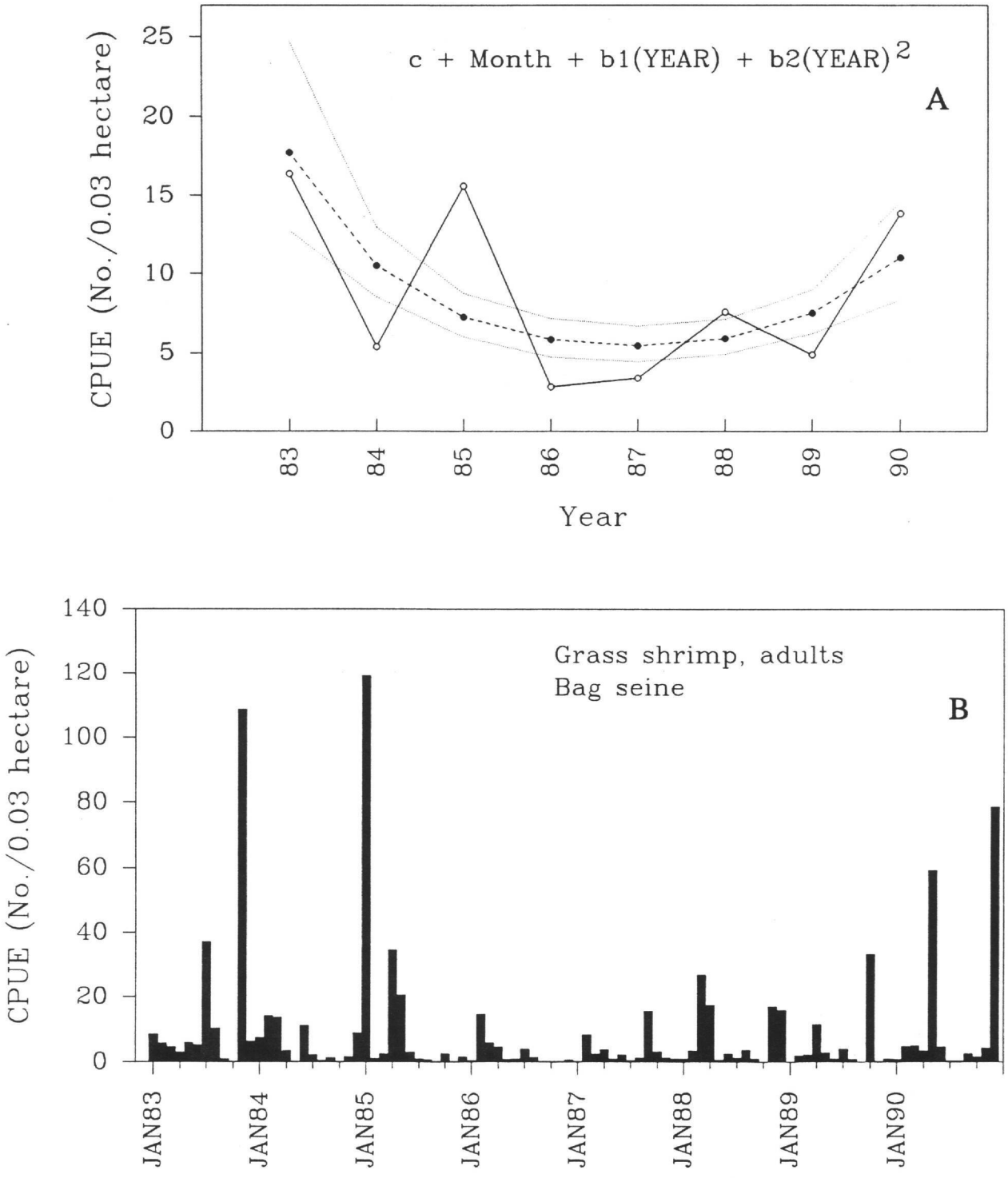


Figure III.27. A. Mean annual CPUE and predicted CPUE with confidence intervals for adult grass shrimp (25-35 mm) caught by bag seine. B. Mean CPUE by month.

Table III.17. Analysis of deviance for adult grass shrimp (25-35 mm) caught by bag seine, January-December, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	65.80	5.98	4.843	<0.001
YEAR					
Linear	1	7.41	7.41	6.00	<0.025
Quadratic	1	21.90	21.90	17.73	<0.001
Other	5	25.60	5.12	4.14	<0.001
Month x Year	77	544.70	7.07	5.73	<0.001
Corrected error	956	1180.80	1.235		

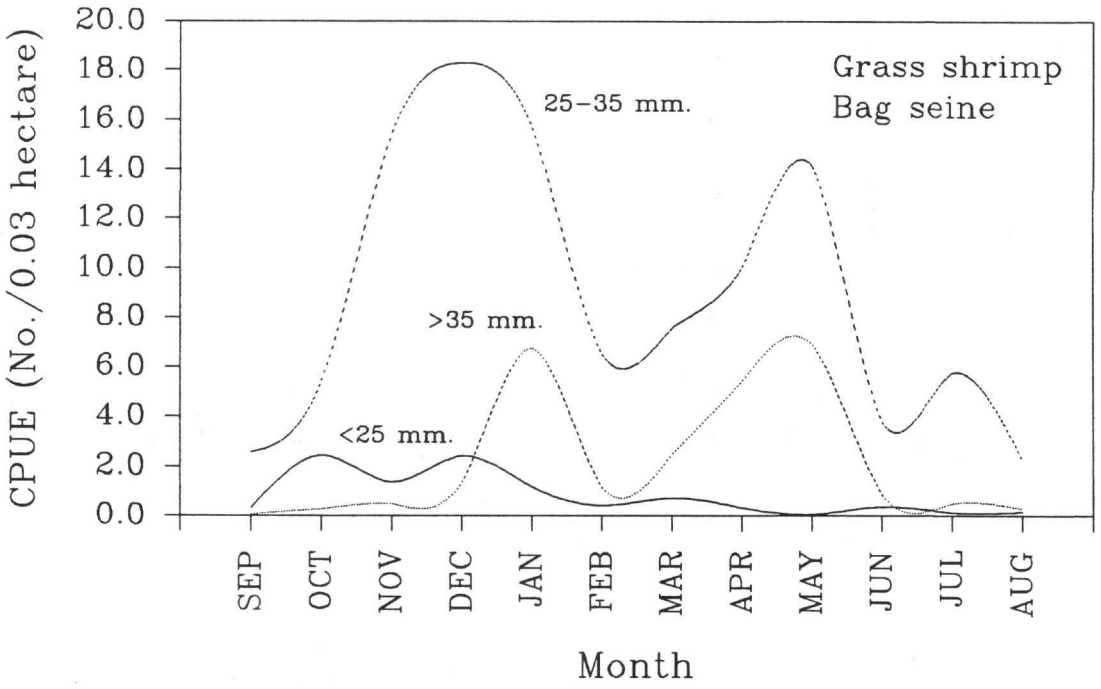


Figure III.28. Mean CPUE by month for three size classes of grass shrimp caught by bag seine (<25 mm, 25-35 mm, >35 mm). Data pooled from 1983-1989.

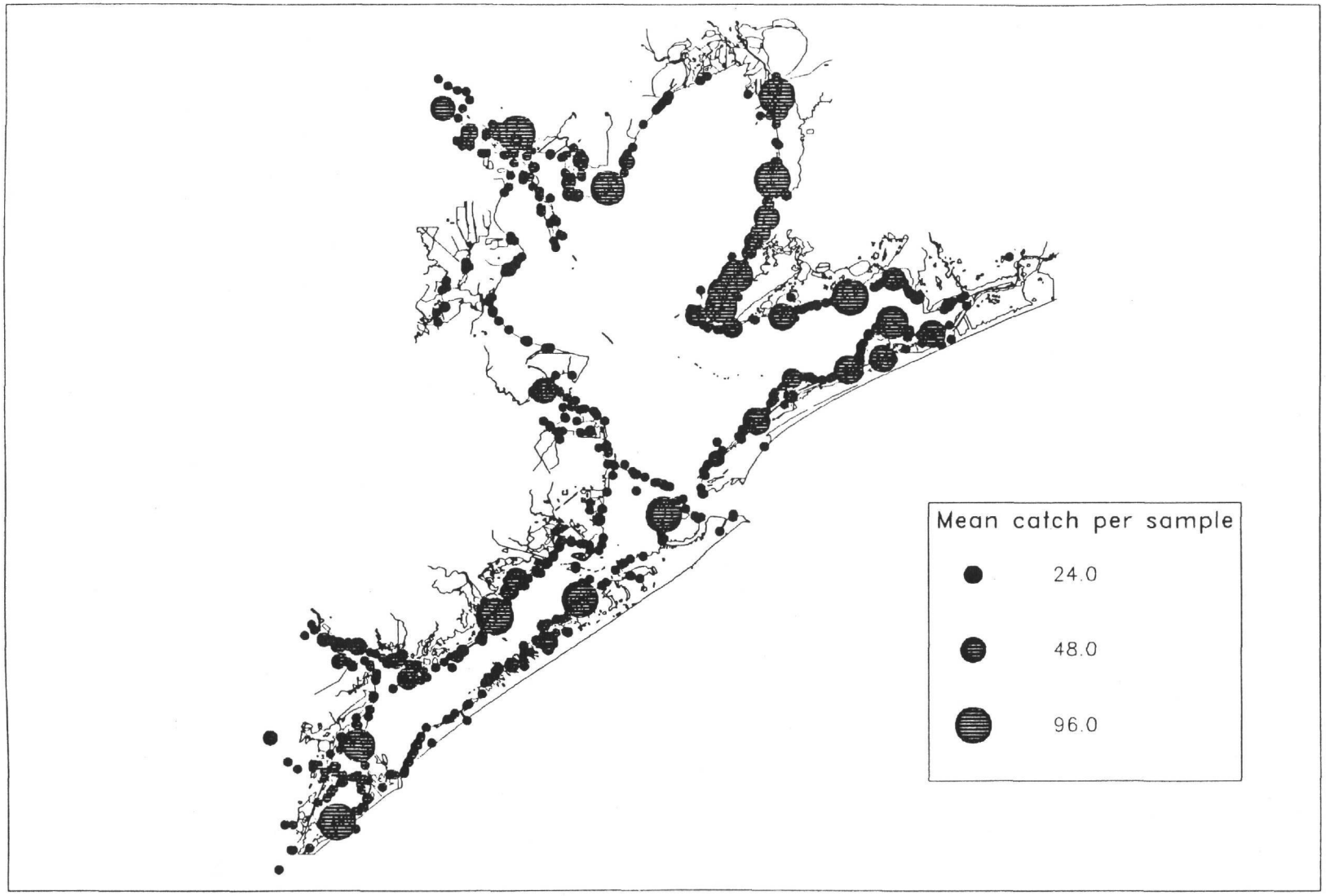


Figure III.29. Distribution of adult grass shrimp (25-35 mm) caught by bag seine, January-December, 1983-1989. Circle size is proportional to mean CPUE.

White Shrimp (Penaeus setiferus)

From 1963 to 1968 the TPWD/NMFS data set showed curvilinear trends for the analyses of both total catch and first-time spawners (Figures III.30, III.31). CPUE decreased from 1963 to 1965, then increased through 1968. From 1972 through 1980, CPUE increased for both groups (Figures III.32, III.33). First-time spawners increased linearly from 1972 through 1980 (Figure III.33) but all sizes combined showed a quadratic component with a decrease beginning after 1978 (Figure III.32).

In the CF data, all size categories studied showed a linear decrease from 1982 through 1990. However, the 1977-1990 time series for young of the year (35-55 mm) showed no significant annual trend when analyzed as a whole. Juveniles (80-100 mm) and shrimp approaching the size to reproduce for the first time (110-130 mm) caught by trawl showed a strong linear decrease in both the spring and fall seasons (Figures III.35, III.36, III.37). The fall season showed an additional quadratic component, with an increase from 1982 to 1985 followed by a decrease through 1990.

Season and Size Selection

Narrow size ranges (20 mm) were used for all size classes because white shrimp grow rapidly, especially juveniles (1.0 to 1.5 mm/day; Nichols 1982). Shrimp 35-55 mm TL were chosen to represent the young of the year because they were the smallest individuals effectively caught in bag seine samples and the most abundant 20-mm size class (Figure III.38). The analysis was confined to the months of June through December, when shrimp of this size range were numerous.

The monthly size frequency plot for CF trawl data (Figure III.39) shows a relatively complex, but regular, annual pattern. For all but the smallest shrimp there was a small spring peak from March to May. A long fall season of high catch rates occurred from August through December for all size groups. An analysis of all size ranges pooled was performed on the TPWD/NMFS data set, restricted to the months of June through November.

A size range of 80 to 100 mm was chosen to represent juveniles caught most effectively by bay trawling (Figure III.39). Shrimp in this size range appeared in high numbers in July and were abundant until the following spring. Consequently this size class was analyzed using data from July through April of the following year.

White shrimp become sexually mature at a size of 135-155 mm (Cody et al. 1989). A size range of 110 to 130 mm was well-represented in trawl data and selected to represent the population approaching the age of first spawning. This size group had peaks in the spring (April and May) and in the fall (August to November; Figures III.39, III.36B) that were analyzed separately for CF data. Only the fall season was analyzed in TPWD/NMFS data.

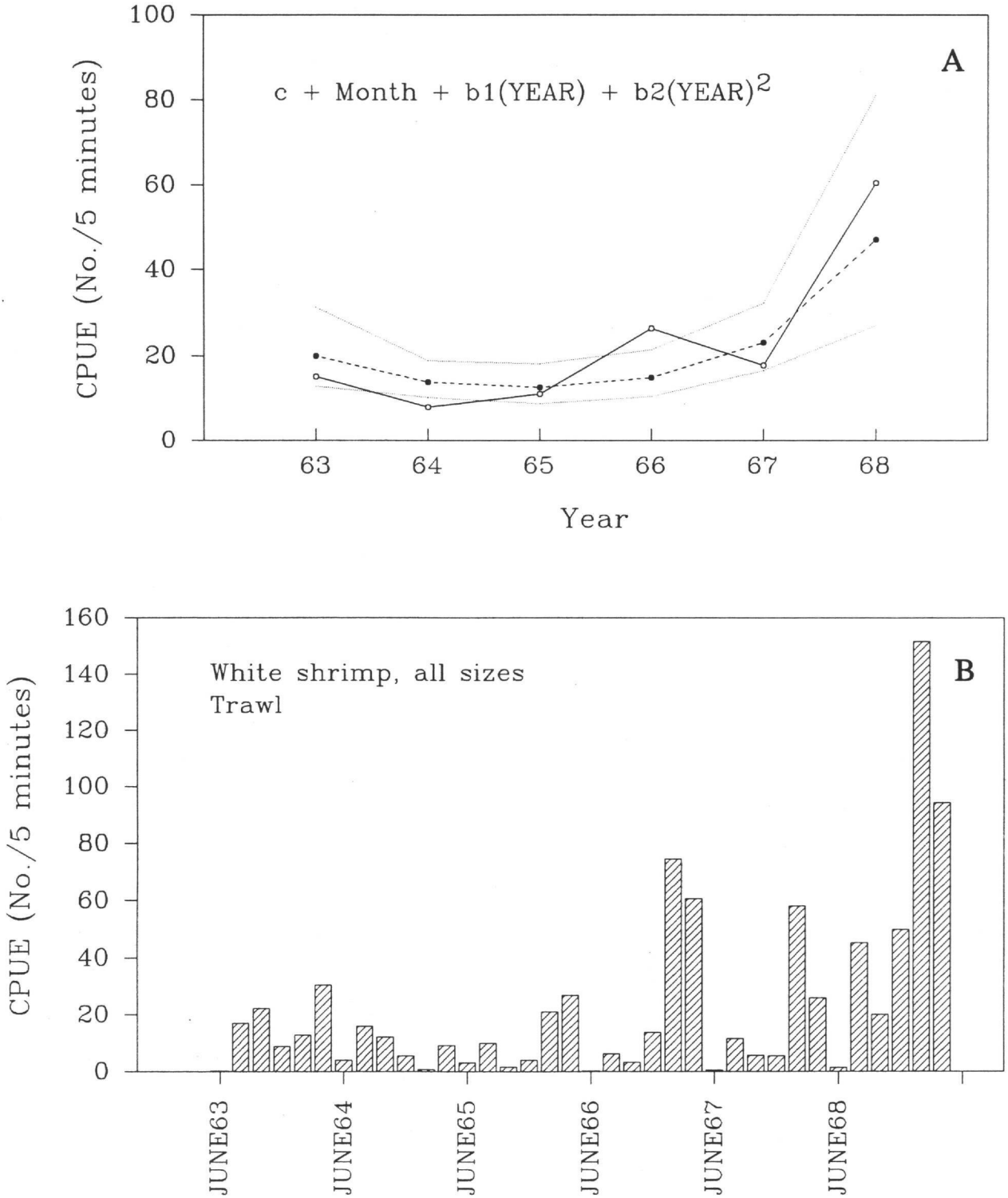


Figure III.30. A. Mean seasonal (June-November) CPUE and predicted CPUE with confidence intervals for all sizes of white shrimp caught by trawl, 1963-1968. TPWD/NMFS data. B. Mean CPUE by month, June-November only.

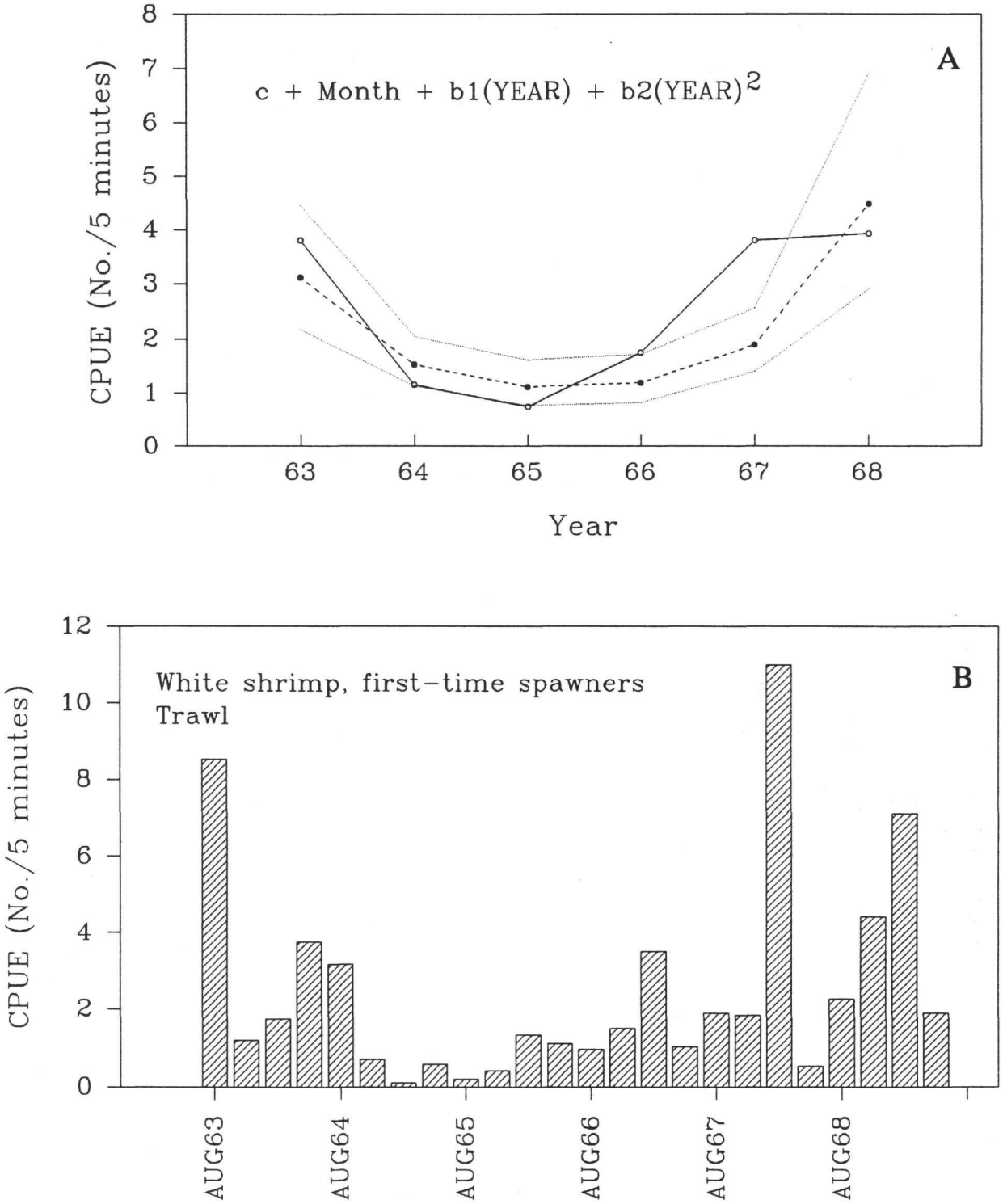
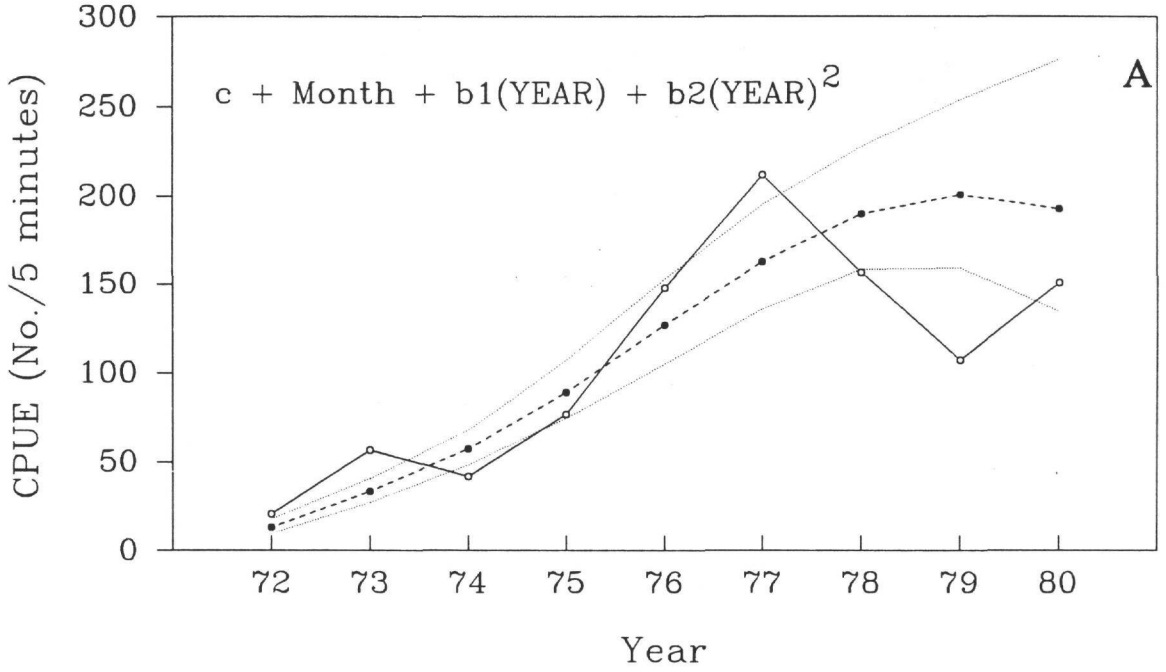


Figure III.31. A. Mean seasonal (August-November) CPUE and predicted CPUE with confidence intervals for first-time spawning white shrimp (85-110 mm) caught by trawl, 1963-1968. TPWD/NMFS data. B. Mean CPUE by month, August-November only.



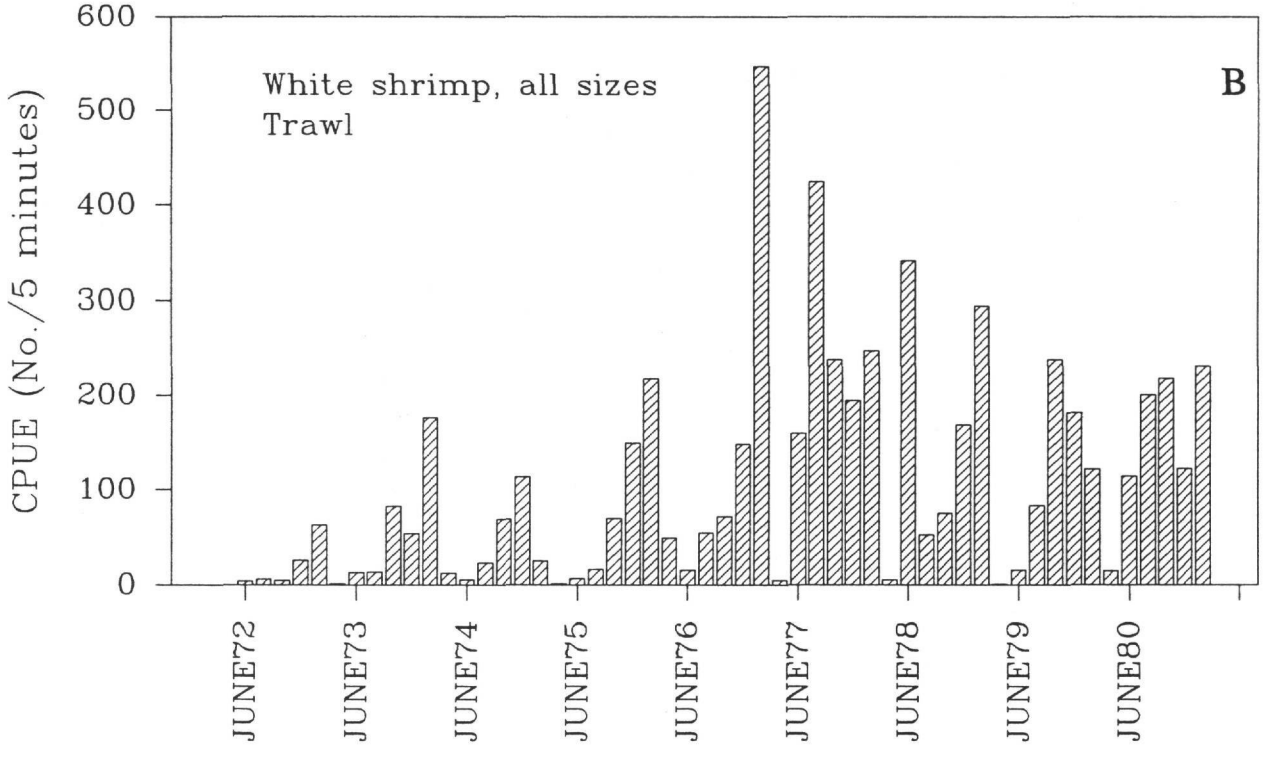
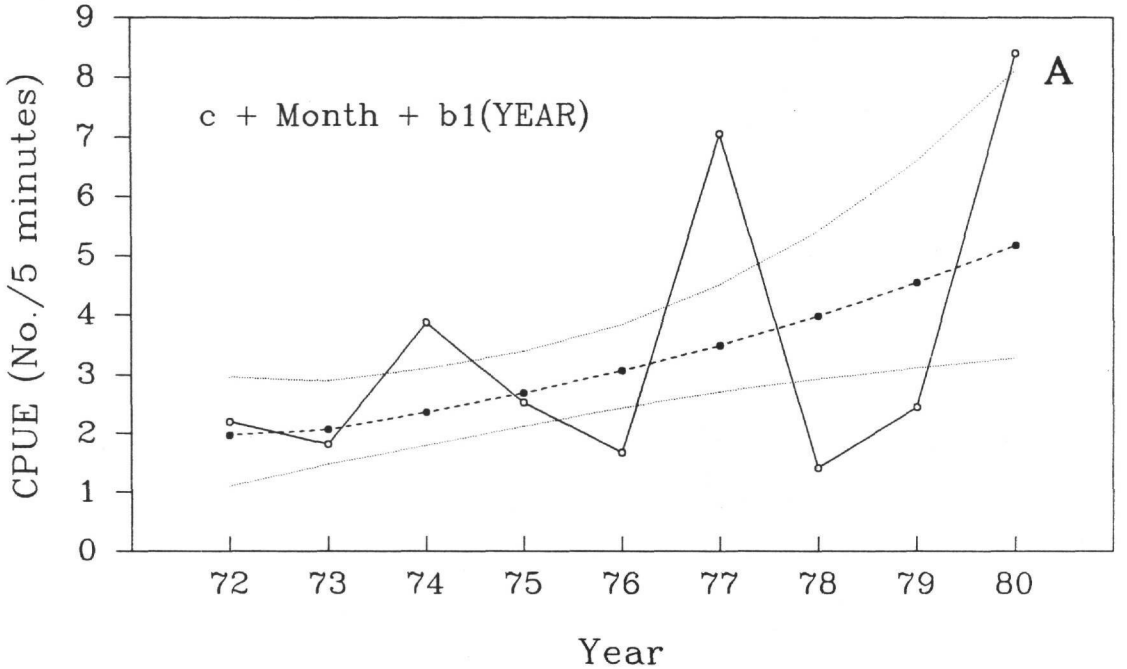


Figure III.32. A. Mean seasonal (June-November) and predicted CPUE with confidence intervals for all sizes of white shrimp caught by trawl, 1972-1980. TPWD/NMFS data. B. Mean CPUE by month, June-November only.



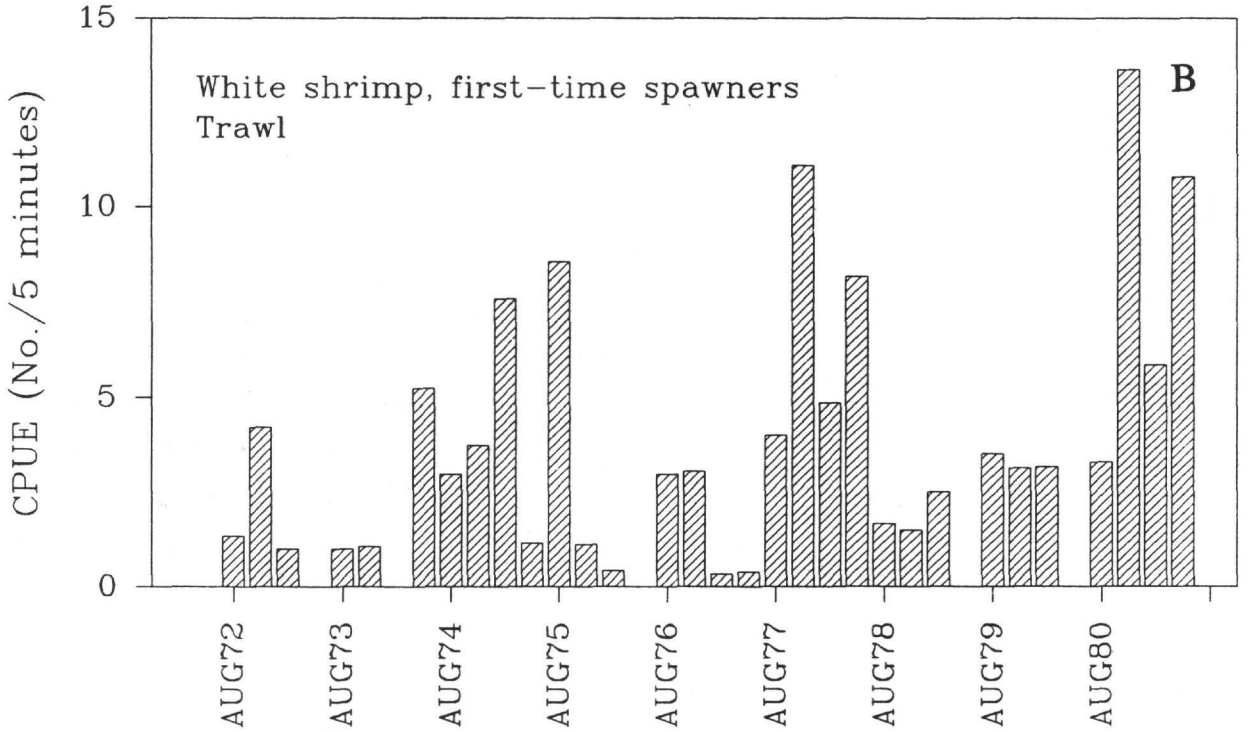


Figure III.33. A. Mean seasonal (August-November) CPUE and predicted CPUE with confidence intervals for first-time spawning white shrimp caught by trawl, 1972-1980. TPWD/NMFS data. B. Mean CPUE by month, August-November only.

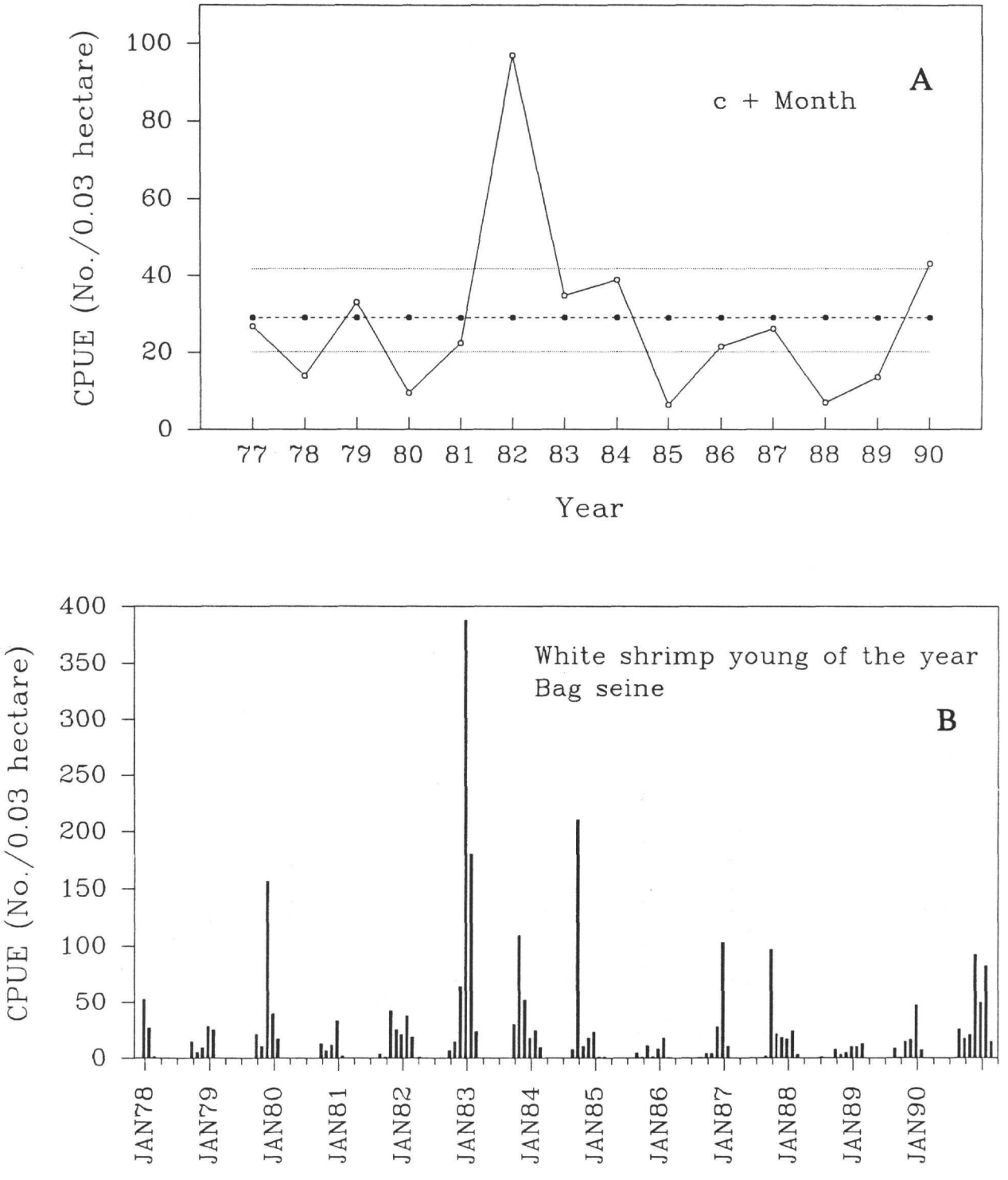


Figure III.34. A. Mean seasonal (June-December) CPUE and predicted CPUE with confidence intervals for young-of-the-year white shrimp (35-55 mm) caught by bag seine. CF data. B. Mean CPUE by month. Filled bars: June-December. Hollow bars: months not used in analysis.

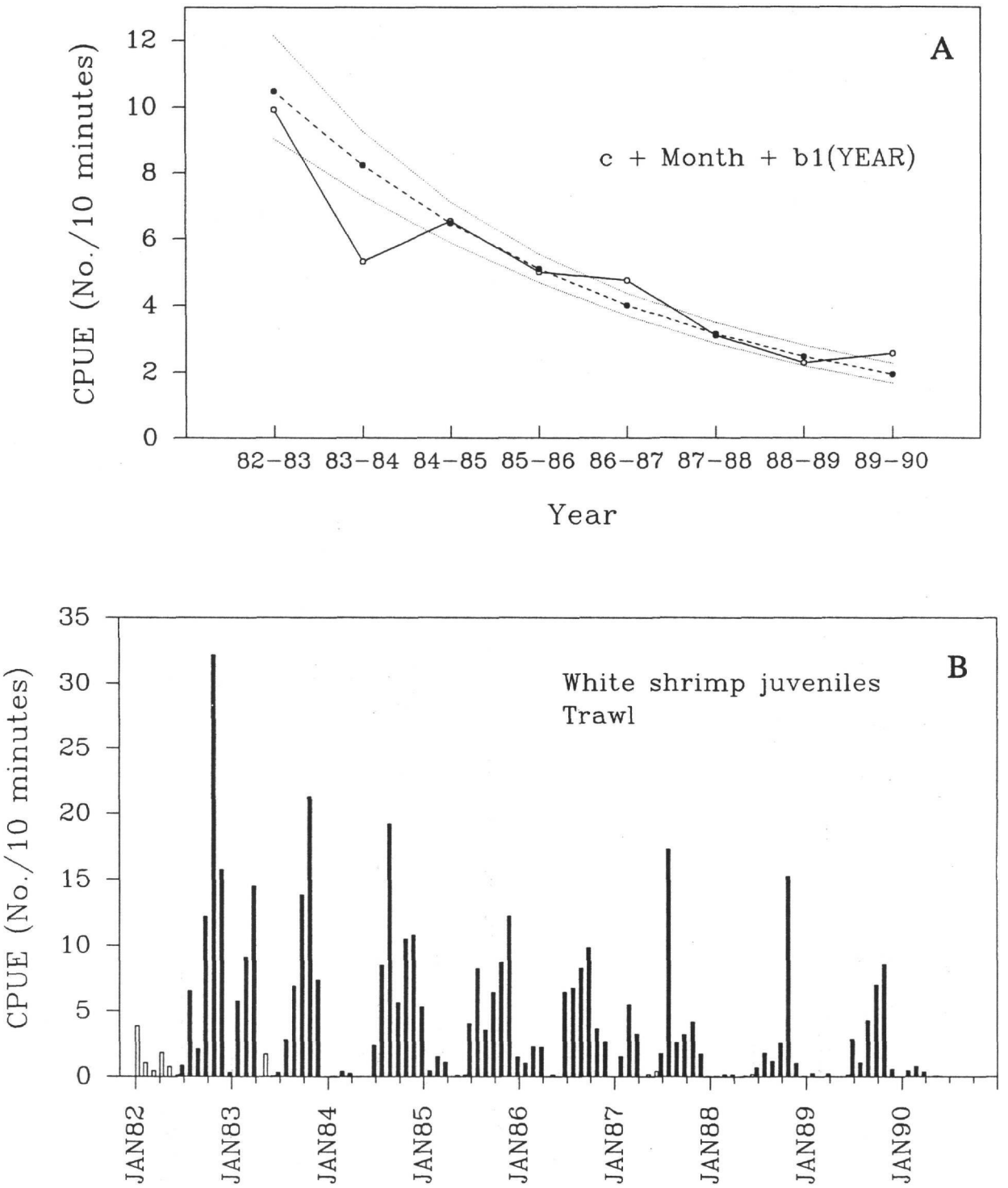
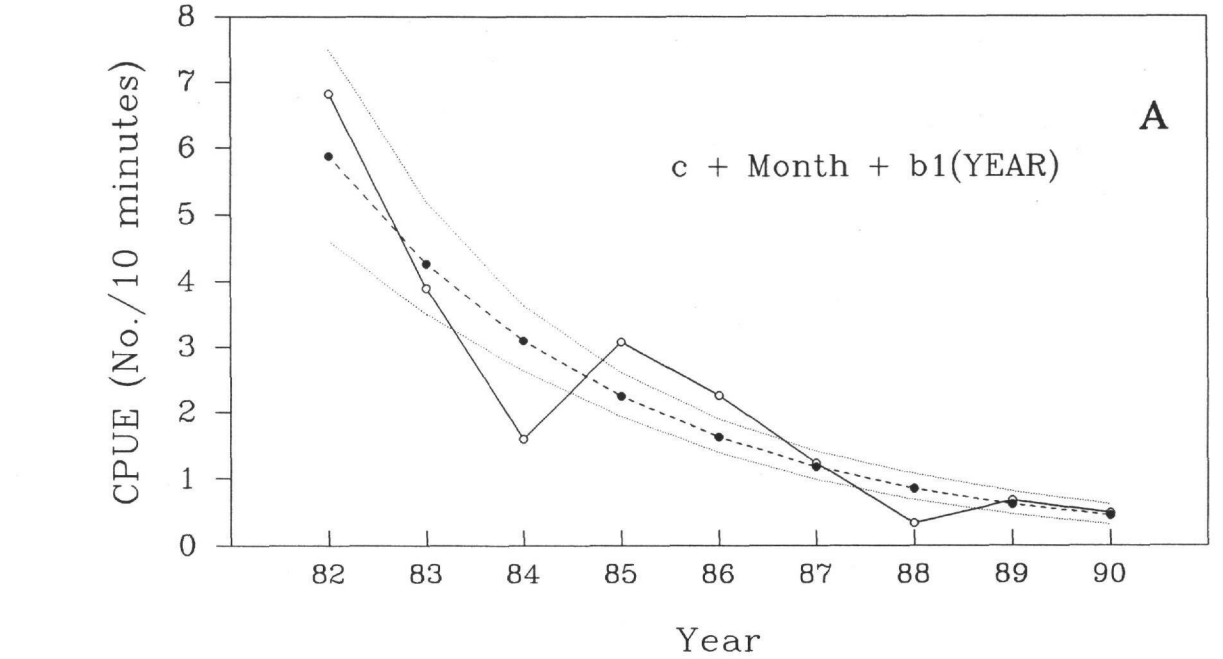


Figure III.35. A. Mean seasonal (July-April) CPUE and predicted CPUE with confidence intervals for juvenile white shrimp (80-100 mm) caught by trawl, 1982-1990. CF data. B. Mean CPUE by month. Filled bars: July-April. Hollow bars: months not used in analysis.



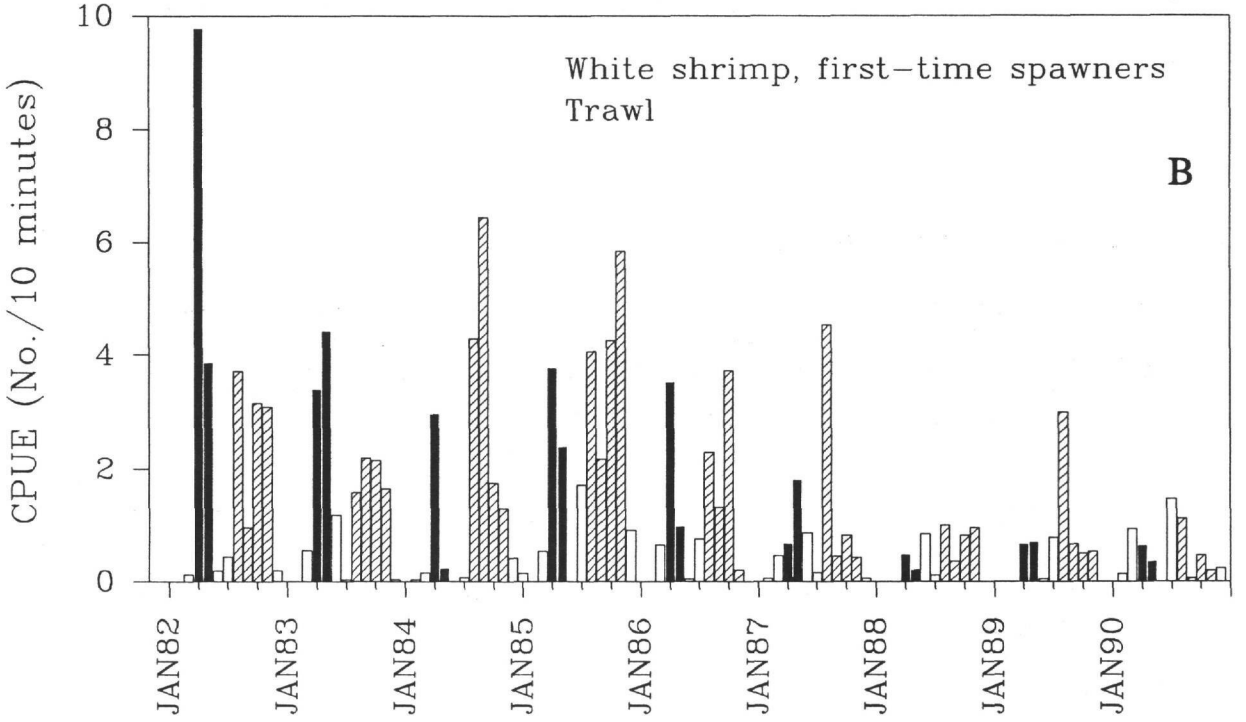


Figure III.36. A. Mean seasonal (April-May) CPUE and predicted CPUE with confidence intervals for first-time spawning white shrimp (110-130 mm) caught by trawl, 1982-1990. CF data. B. Mean CPUE by month. Filled bars: spring catch (April-May). Hatchured bars: fall catch (August-November). Hollow bars: months not used in analysis.

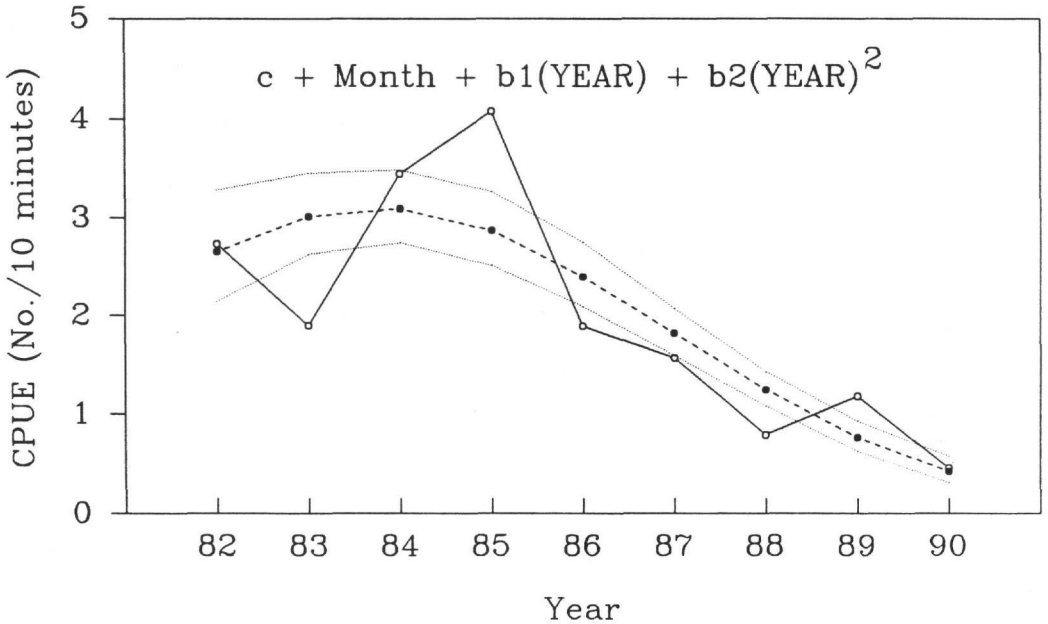


Figure III.37. Mean seasonal (August-November) and predicted CPUE with confidence intervals for first-time spawning white shrimp (110-130 mm) caught by trawl, 1982-1990. CF data.

Total catch, TPWD/NMFS data

Trawl: In the years 1963 through 1968, pooled size classes showed a quadratic trend (Figure III.30A). CPUE decreased slightly from 1963 to 1965, then increased from 1965 to 1968, with a maximum in October 1968 (Figure III.30B). The variables YEAR, YEAR^2, and Month were all significant (Table III.18).

All terms were significant in the analysis of deviance for the 1972-1980 period (Table III.19). The fitted trend showed an increase until 1979 followed by a decrease (Figure III.32A), though observed CPUE peaked in October 1976 (Figure III.32B). The linear and quadratic components accounted for over 82 percent of the deviance ascribed to annual effects.

Young of the year, CF data

Bag seine: The quadratic term explained most of the year-to-year variation (Table III.20). Figure III.34A shows a quadratic model centered on the modal year 1982, superimposed upon a small but significant linear decrease. Most of the temporal variation was attributed to Month effects, as expected in such a strongly seasonal species (Figure III.34B).

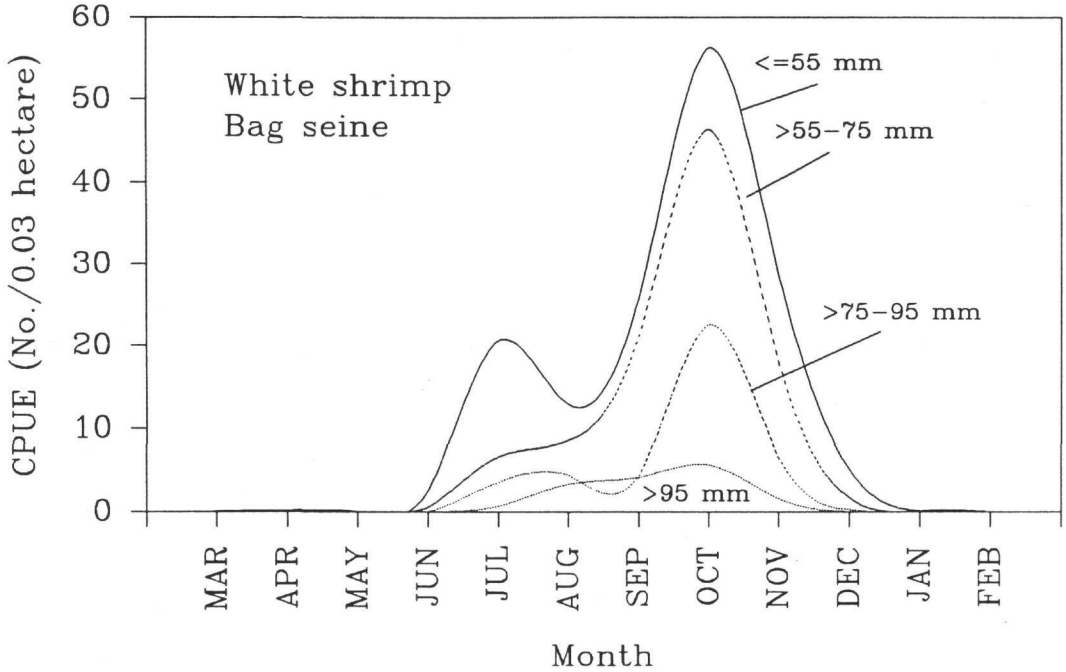


Figure III.38. Mean CPUE by month for four size classes of white shrimp caught by bag seine (< =55 mm, >55-75 mm, >75-95 mm, >95 mm). CF data pooled from 1977-1989.

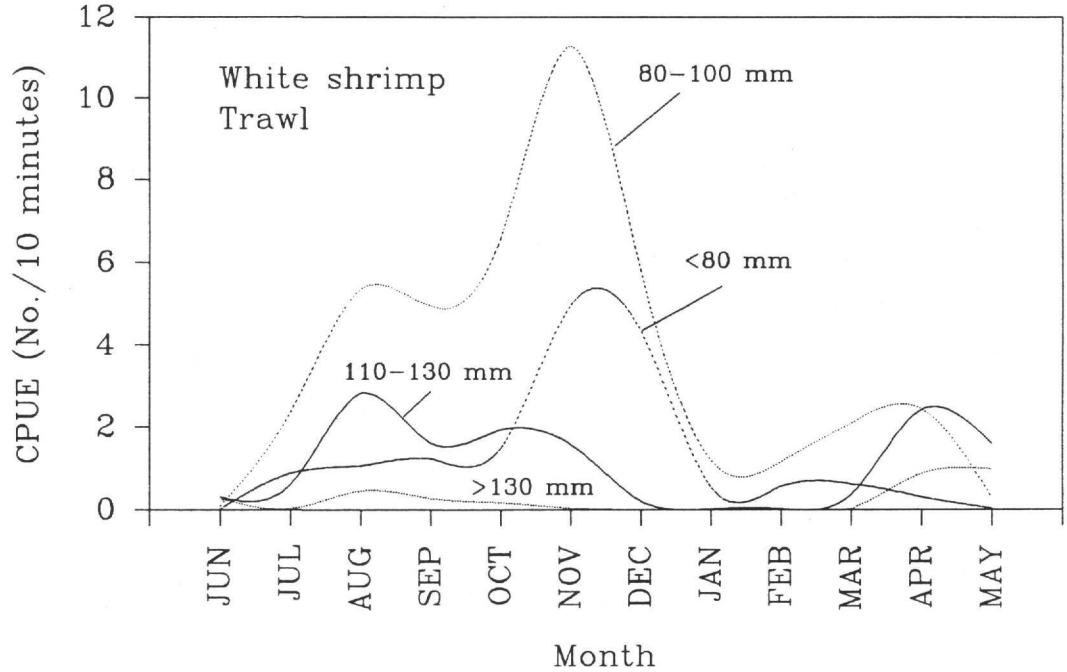


Figure III.39. Mean CPUE by month for four size classes of white shrimp caught by trawl (<80 mm, 80-100 mm, 110-130 mm, >130 mm). CF data pooled from 1982-1990.

Juveniles, CF data

Trawl: The CPUE for juvenile white shrimp decreased linearly from 1982 to 1990 (Figure III.35; Table III.21). Categorical Month effects explained a large proportion of the temporal variation (Figure III.35B). There was close correspondence between mean annual CPUE and the values predicted by a linear model.

First-time spawners, TPWD-NMFS data

Trawl: As for the total catch, CPUE for first-time spawners decreased from 1963 through 1965 and increased from 1965 through 1968 (Figure III.31). The quadratic component of the annual trend was the overwhelmingly influential factor in the analysis of deviance, accounting for over 80 percent of the deviance ascribed to annual effects (Table III.22). It is surprising that neither the linear annual trend nor the monthly component were significant; net increase in CPUE was superficial and seasonality was not clearly defined (Figure III.31B).

From 1972 to 1980, first-time spawners showed a fluctuating but generally linear increasing trend (Figure III.33). The quadratic component was not significant and the linear component explained most of the deviance ascribed to annual effects (Table III.23). Monthly effects were also significant.

First-time spawners, CF data

Trawl: A decrease in abundance since 1982 was visually apparent for both the spring and fall cohorts in the plot of CPUE (Figure III.36B). The analyses of deviance (Tables III.24, III.25) showed the linear annual trend was significant for both seasons but stronger for the spring catch (Figure III.36B, solid bars; Table III.24). There was close correspondence between the mean annual CPUE and the values predicted by the linear model (Figure III.36A). The fall season showed an additional quadratic component (Table III.25), the result of low fall catches in 1982-1983 followed by higher catches in 1984-1985 (Figure III.36B, hatchured bars).

Spatial distribution, CF data

High catch rates for young of the year occurred throughout the Galveston Estuary system with the exception of Upper Galveston Bay and the northern shore of Trinity Bay, where seagrass beds are scarce (Figure III.40; Pulich and White 1989). White shrimp caught by trawl occurred most densely in the low-salinity parts of the estuary, in Upper Galveston, Trinity, and East Bays, and were less dense in Lower Galveston and West Bays with the exceptions of Bastrop and Chocolate Bays (Figures III.41, III.42, III.43). The highest catches of first-time spawners during April-May were in East Bay (Figure III.42), while the longer fall season showed a broader distribution (Figure III.43).

Table III.18. Analysis of deviance for white shrimp, all size classes, caught by trawl, June to November, 1963-1968. TPWD/NMFS data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	5	74.23	14.85	7.11	<0.001
YEAR					
Linear	1	14.31	14.31	6.85	0.01
Quadratic	1	16.43	16.43	7.86	<0.01
Other	3	12.55	4.18	2.00	>0.10
Month x Year	25	76.96	3.08	1.47	0.10
Corrected Error	156	326.28	2.09		

Table III.19. Analysis of deviance for white shrimp, all size classes, caught by trawl, June to November, 1972-1980. TPWD/NMFS data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	5	188.72	37.74	29.26	<0.001
Year					
Linear	1	149.19	149.19	115.65	<0.001
Quadratic	1	20.69	20.69	16.04	<0.001
Other	6	35.19	5.87	4.55	<0.001
Month x Year	39	142.78	3.66	2.84	<0.001
Corrected Error	336	432.26	1.29		

Table III.20. Analysis of deviance for young-of-the-year white shrimp (35-55 mm) caught by bag seine, June-December, 1977-1990. CF data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	6	142.40	23.73	15.52	<0.001
YEAR					
Linear	1	0.65	0.65	0.43	>0.50
Quadratic	1	0.08	0.08	0.05	>0.75
Other	11	147.30	13.39	8.76	<0.001
Month x Year	73	390.20	5.34	3.50	<0.001
Corrected error	772	1180.30	1.53		

Table III.21. Analysis of deviance for juvenile white shrimp (80-100 mm) caught by trawl, July-April, 1982-1990. CF data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	9	415.30	46.14	47.92	<0.001
YEAR					
Linear	1	137.70	137.70	143.01	<0.001
Quadratic	1	0.66	0.66	0.71	>0.50
Other	5	76.00	15.20	15.79	<0.001
Month x Year	63	375.60	5.96	6.19	<0.001
Corrected error	1444	1390.40	0.96		

Table III.22. Analysis of deviance for first-time spawning white shrimp (110-130 mm) caught by trawl, August to November, 1963-1968. TPWD/NMFS data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	14.61	4.87	2.24	>0.05
YEAR					
Linear	1	0.33	0.33	0.15	>0.50
Quadratic	1	47.91	47.91	22.04	<0.001
Other	3	11.44	3.81	1.75	>0.10
Month x Year	15	79.99	5.33	2.45	<0.01
Corrected Error	96	208.74	2.17		

Table III.23. Analysis of deviance for first-time spawning white shrimp (110-130 mm) caught by trawl, August to November, 1972-1980. TPWD/NMFS data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	6.81	2.27	1.65	>0.10
YEAR					
Linear	1	10.13	10.13	7.36	<0.01
Quadratic	1	0.00	0.00	0.00	>0.75
Other	6	28.91	4.82	3.50	<0.005
Month x Year	23	69.61	3.03	2.20	<0.001
Corrected Error	197	271.01	1.38		

Table III.24. Analysis of deviance for first-time spawning white shrimp (110-130 mm) caught by trawl, April-May, 1982-1990. CF data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	1	10.37	10.37	11.82	<0.001
YEAR					
Linear	1	109.61	109.61	124.91	<0.001
Quadratic	1	0.003	0.003	0.003	>0.75
Other	6	21.79	3.63	4.14	<0.001
Month x Year	8	28.37	3.59	4.09	<0.001
Corrected error	342	300.08	0.88		

Table III.25. Analysis of deviance for first-time spawning white shrimp (110-130 mm) caught by trawl, August-November, 1982-1990. CF data.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	40.62	13.54	14.52	<0.001
YEAR					
Linear	1	100.00	100.00	107.23	<0.001
Quadratic	1	32.74	32.74	35.10	<0.001
Other	6	37.22	6.20	6.65	<0.001
Month x Year	24	210.58	5.02	5.39	<0.001
Corrected error	685	638.82	0.93		

Figure III.40. Distribution of young-of-the-year white shrimp (35-55 mm) caught by bag seine, June-December, 1977-1989. Circle size is proportional to mean CPUE.

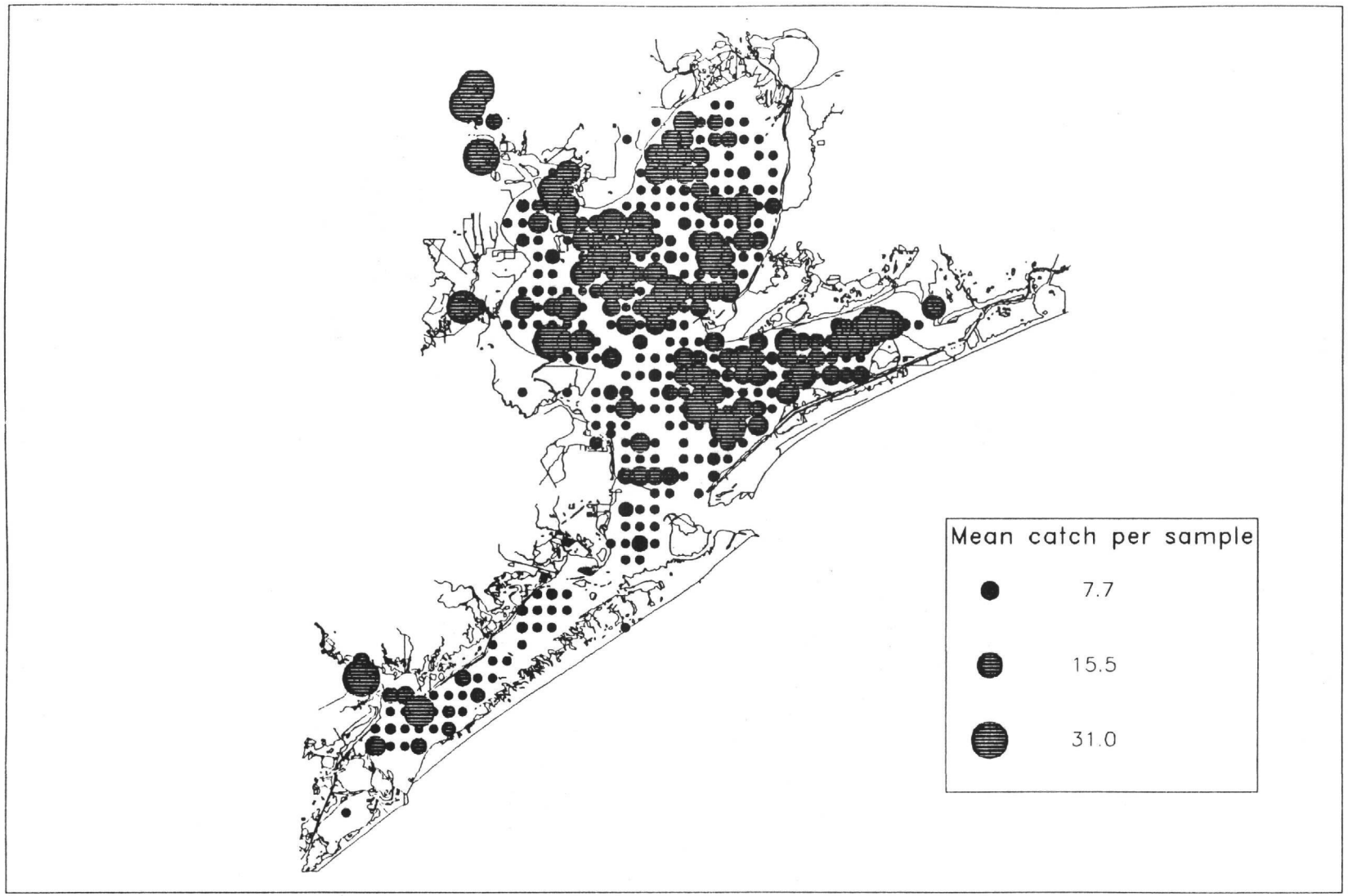


Figure III.41. Distribution of juvenile white shrimp (80-100 mm) caught by trawl, July-April, 1982-1990. Circle size is proportional to mean CPUE.

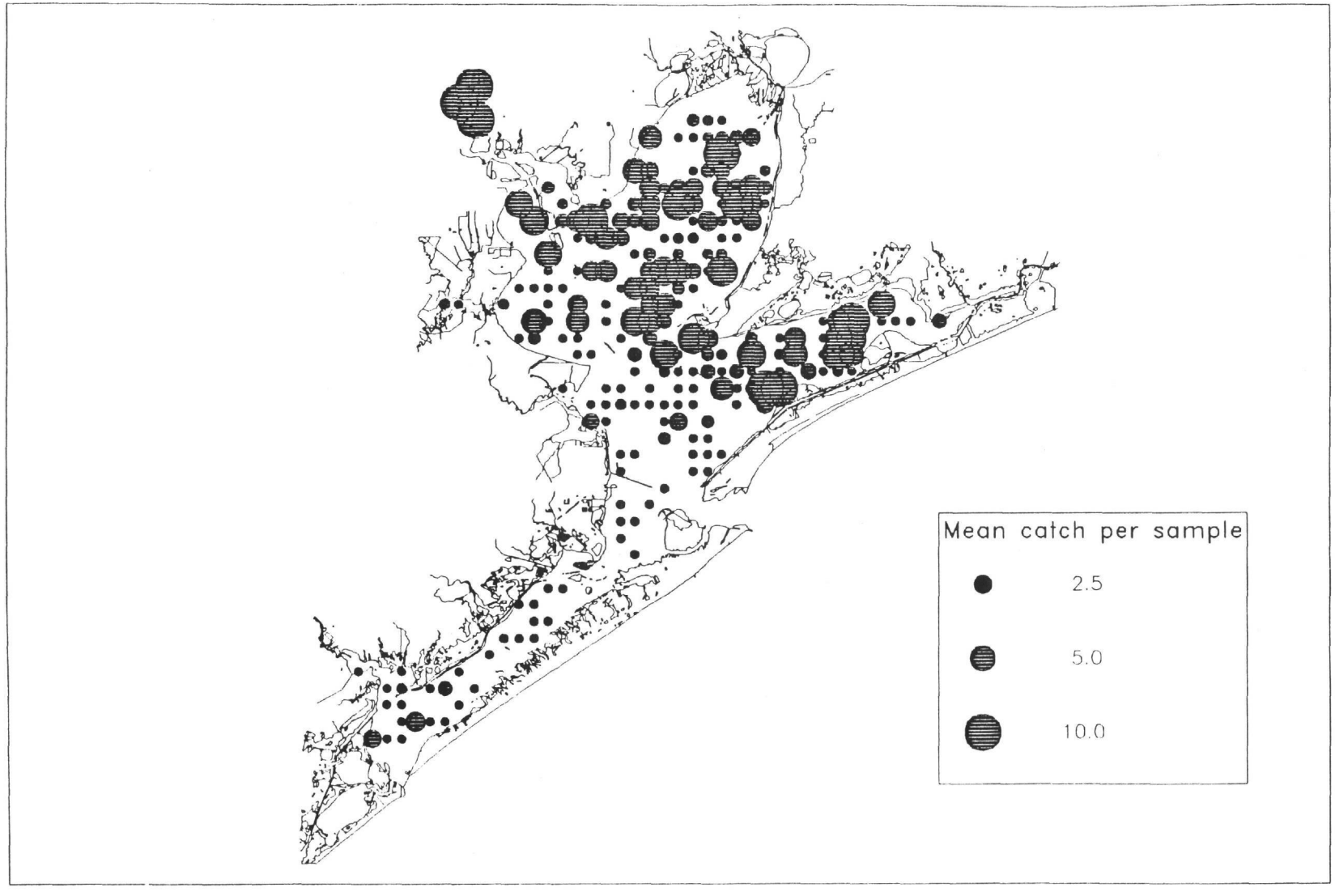


Figure III.42. Distribution of first-time spawning white shrimp (110-130 mm) caught by trawl, April-May, 1982-1990. Circle size is proportional to mean CPUE.

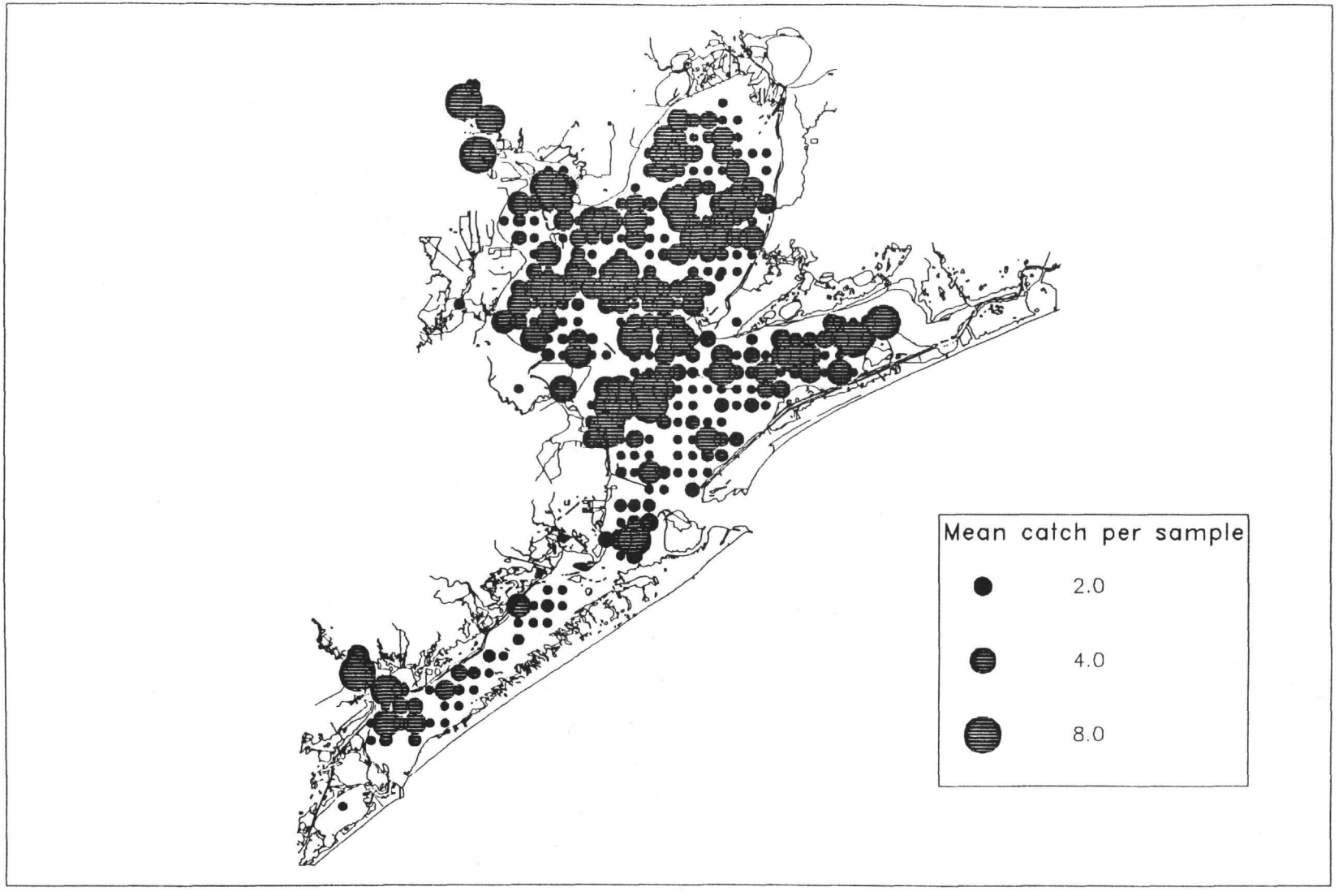


Figure III.43. Distribution of first-time spawning white shrimp (110-130 mm) caught by trawl, August-November, 1982-1990. Circle size is proportional to mean CPUE.

Discussion

Correlations calculated for CF trawl data alone (using PROC CORR in SAS) showed a strong correlation (Pearson's $r=0.93$, $p<0.001$) between the mean annual catch of juveniles in the fall months (July-December) and the spring catch of first-time spawners (April-May) the following year, the groups showing the most extremely negative linear trends. In contrast, the spring CPUE for juveniles or first-time spawners does not correlate robustly with fall catches, indicating turnover in the population between seasons, probably associated with spawning migration during the warm months (Cody et al. 1989). The decrease in CPUE was detectable from spring to fall within a single year. The relatively high fall catches of adult white shrimp in 1985-1986 possibly can be correlated with the large recruitment of juveniles reported for bag seine samples and for juveniles in trawl samples in 1983-1985.

First-time spawning white shrimp appeared to reach a peak approximately in 1980 and to have decreased dramatically in recent years (Figures III.31, III.33, III.37). In 1963, CPUE for first-time spawners was near four shrimp per catch (Figure III.31). CPUE decreased to a minimum of about one in 1965, followed by an increase from 1965 through 1968, back to over four shrimp per catch. There are no data for 1969 through 1971, but when the series resumed in 1972, CPUE had decreased to two shrimp per catch. In subsequent years CPUE fluctuated considerably but there was a general increase, achieving a maximum of over eight shrimp per 5-minute trawl in 1980, despite relatively low catches in the two previous years (Figure III.33). Another break in the series occurred and 1981 is not represented. In addition there was a change in methodology: from fixed stations to randomized selection of location, from 5-minute tows to 10- or 15-minute tows, and to a larger trawl net. CPUE for 1982-1990 is therefore not strictly analogous to that for earlier years, but four shrimp per 10-minute trawl is roughly comparable to one or two shrimp per 5-minute trawl. During the period represented by CF data (1982-1990) a marked decrease occurred in the fall catch of first-time spawners, reaching a minimum of less than one shrimp per 10-minute trawl in 1990 (Figure III.37).

The decrease in white shrimp CPUE in the CF trawl data was related to an increase in zero catches through time (Figures III.44B, III.45A and B), as well as smaller numbers per catch. The proportion of zero catches for juvenile white shrimp increased from 38.5 percent for the 1982-1983 study year to 66.3 percent for 1989-90 (Figure III.44B). An analysis modelling the probability of catching no juvenile white shrimp in proportion to the probability of non-zero catches revealed a strong linear annual trend ($p<0.001$) explaining most of the total deviance; CPUE data exclusive of zero catches similarly showed a linear annual trend ($p<0.001$) with no additional quadratic component.

First-time spawners decreased more rapidly. For 110-130 mm white shrimp in the fall months, zero catches increased from 25.3 percent in 1982 to 82.5 percent in 1990 (Figure III.45B). The trend of zero catches was strongly linear ($p<0.001$) with a small but significant quadratic component ($0.01<p<0.025$); in contrast, non-zero CPUE revealed a quadratic trend with marginally significant linear annual effects. During the spring season zero catches increased linearly ($p<0.001$) from 20 percent in 1982 to 80

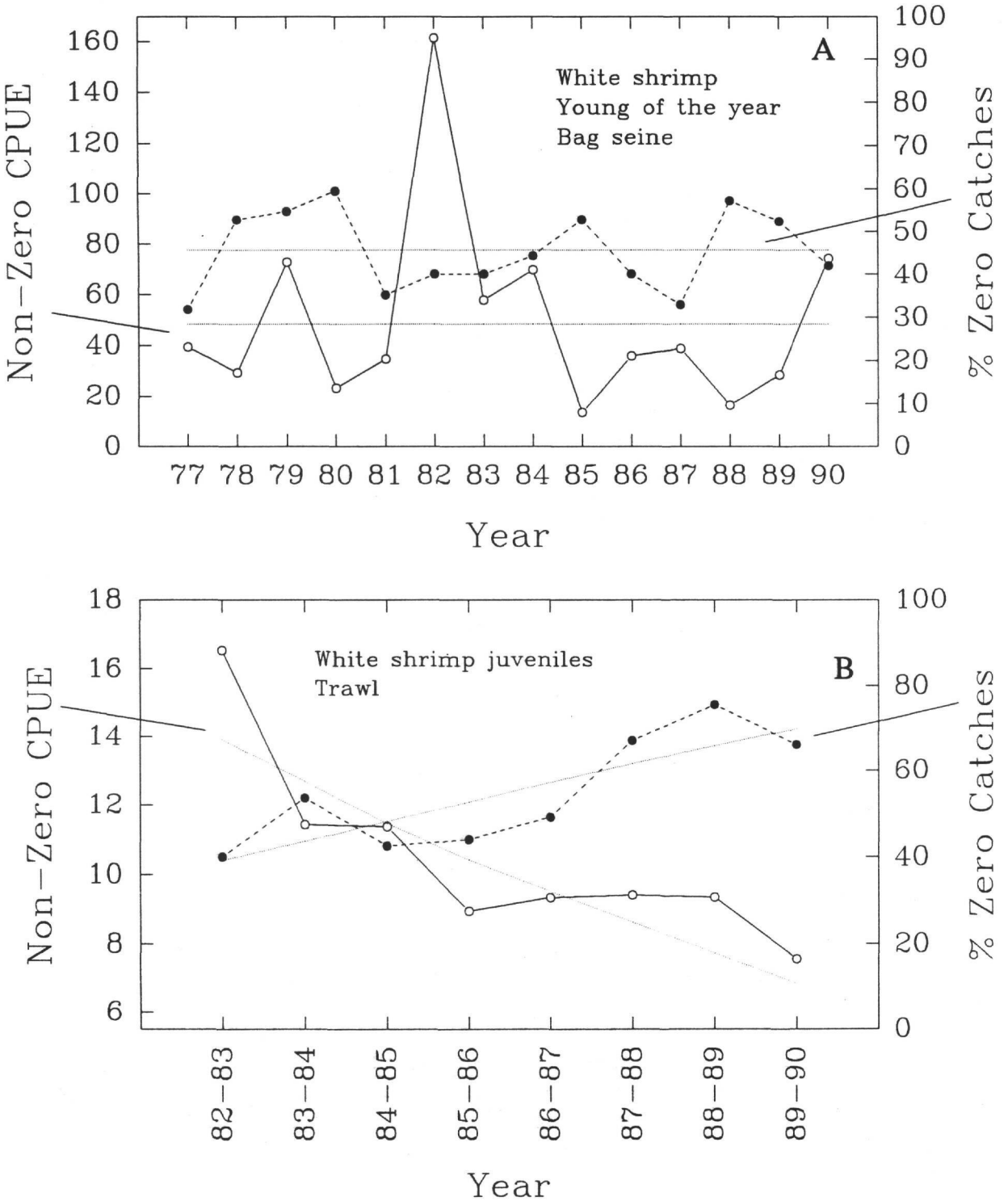


Figure III.44. A. Mean seasonal (June-December) CPUE exclusive of zero catches (solid line), percentage zero catches (dashed line), and predicted values for young-of-the-year white shrimp (35-55 mm) caught by bag seine. B. Mean seasonal (July-April) CPUE exclusive of zero catches (solid line), percentage zero catches (dashed line), and predicted values for juvenile white shrimp (80-100 mm) caught by trawl.

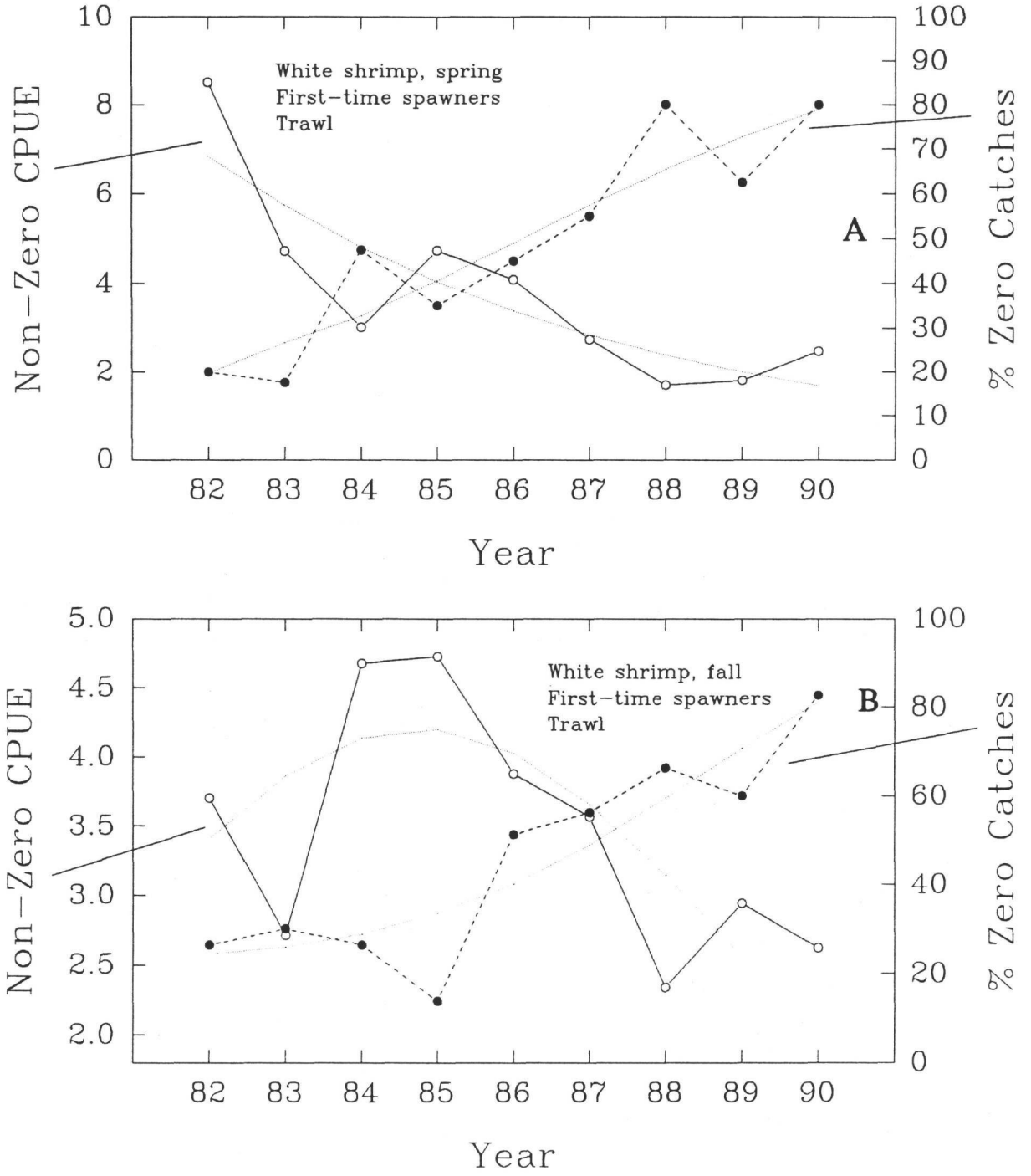


Figure III.45. A. Mean seasonal (April-May) CPUE exclusive of zero catches (solid line), percentage zero catches (dashed line), and predicted values for first-time spawning white shrimp (110-130 mm) caught by trawl. B. Mean seasonal (August-November) CPUE exclusive of zero catches (solid line), percentage zero catches (dashed line), and predicted values for first-time spawning white shrimp (110-130 mm) caught by trawl.

percent in 1990 (Figure III.45A). The trend in non-zero CPUE was similarly linear ($p<0.001$) with no significant additional quadratic component.

Bag seine data, in contrast, showed no significant annual trend for 1977-1990 (Figure III.30A), and no trend in the probability of zero catches or non-zero CPUE (Figure III.44A). When bag seine data were confined to the same years represented by trawl data, 1982 through 1990, all terms were significant in the analysis of deviance. The quadratic term, influenced by high catch rates in 1982 and 1990, explained most of the deviance ($p<0.001$); a linear trend was significant but less strong than other effects ($0.025<p<0.05$).

From the lack of a strong linear trend in the bag seine data it can be inferred that different factors act upon the immediate shoreline environments than the open bay, or upon different size groups. Overharvesting and/or the increase in shrimping effort in recent years (Nance et al. 1989; Klima et al. 1990) are the most obvious probable causes of the differential decline.

Atlantic Croaker (*Micropogonias undulatus*)

Juvenile Atlantic croaker caught by bag seine decreased slightly in abundance while mature croaker in both trawl and gill net catches increased. Young of the year (30-50 mm) increased in abundance from 1977 to 1983, then decreased through 1989 (Figure III.46). Croaker near the age to spawn for the first time (115-135 mm) caught by trawl showed a linear increase from 1983 through 1990 (Figure III.47). Mature croaker (230-275 mm) recovered by gill net also increased linearly from 1975 through 1989 (Figure III.48).

Season and size selection

Atlantic croaker showed a consistent seasonal pattern. Fish 20 mm or smaller appeared in bag seine samples as early as October and were continually recruited throughout the winter until spring (Figure III.49), corresponding to the prolonged fall-winter spawning season (Jackson 1976). Growth rates can be in excess of 12 mm/month (Parker 1971) and a 20-mm size range was chosen in order to minimize double sampling of a cohort. Thirty to 50 mm was selected as the smallest 20-mm size range that would effectively sample young of the year. The analysis covered the period from December to March, when fish of this size were continually recruited to bag seine (Figure III.49).

Atlantic croaker spawn for the first time at the end of their first year (Avault et al. 1969, Hansen 1970), at a size of 146-204 mm (Parker 1971, White and Chittenden 1976, Barger 1985). A size range of 115-135 mm, the most numerous 20-mm size class in trawl samples (Figure III.50), was chosen to represent croaker approaching the age of first spawning. The months of March through September were used for analysis.

The analysis of remaining adults in gill net data was restricted to the fall, when croaker emigrate from the estuary to the Gulf to spawn (Pearson 1929; Lassuy 1983; Parker

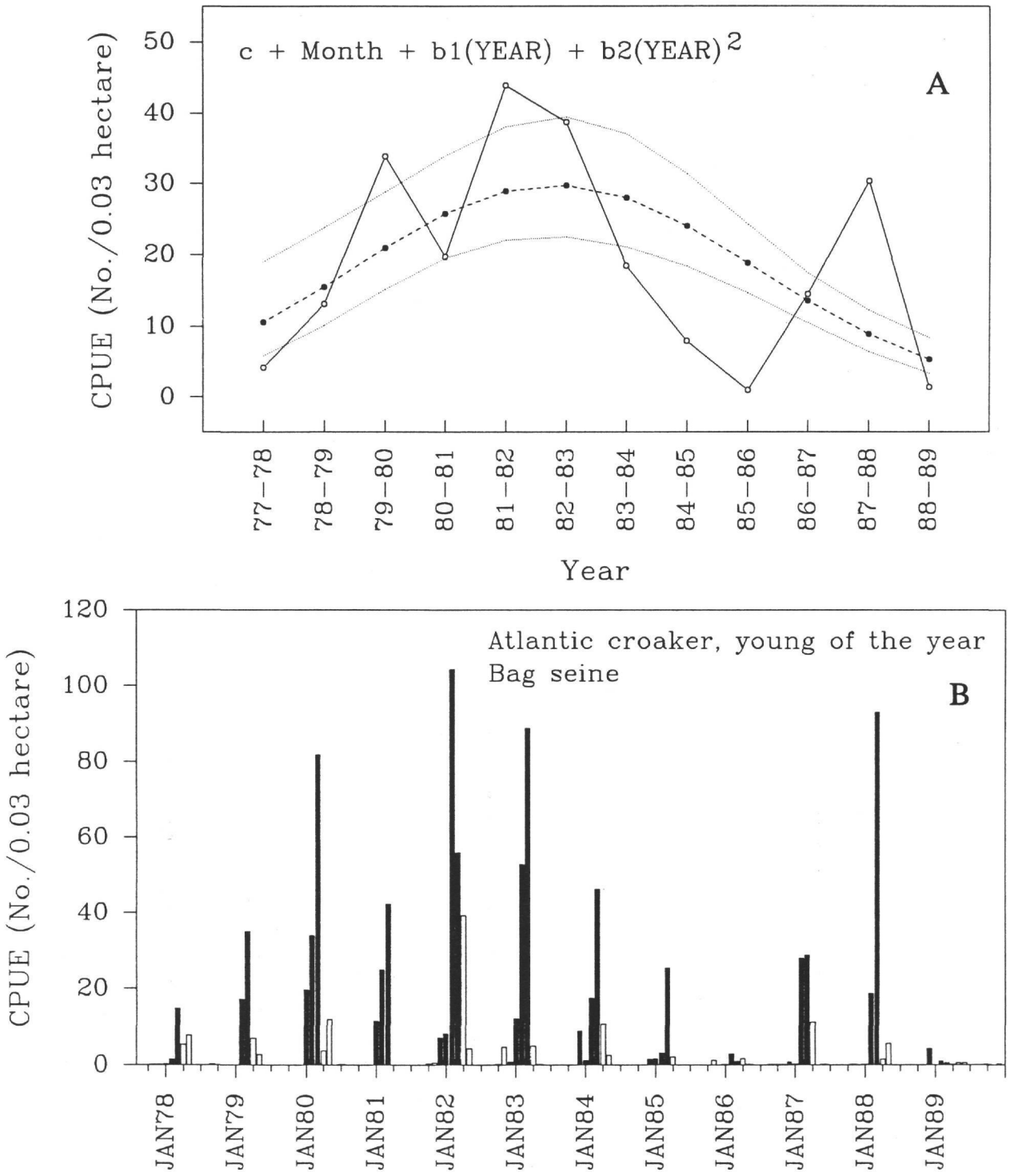


Figure III.46. A. Mean seasonal (December-March) CPUE and predicted CPUE with confidence intervals for young-of-the-year Atlantic croaker (30-50 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: December-March. Hollow bars: months not used in analysis.

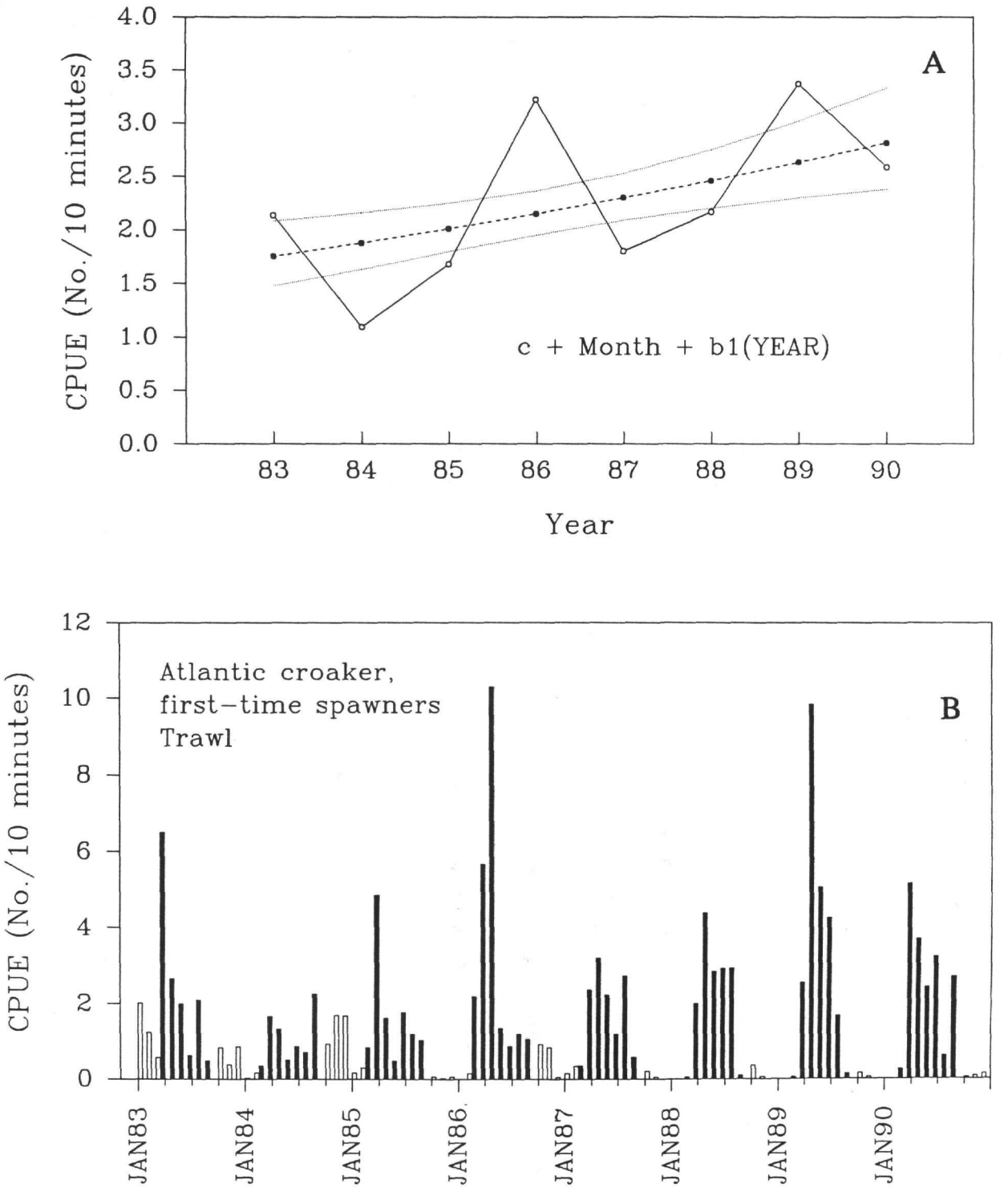


Figure III.47. A. Mean seasonal (March-September) CPUE and predicted CPUE with confidence intervals for first-time spawning Atlantic croaker (115-135 mm) caught by trawl. B. Mean CPUE by month. Filled bars: March-September. Hollow bars: months not used in analysis.

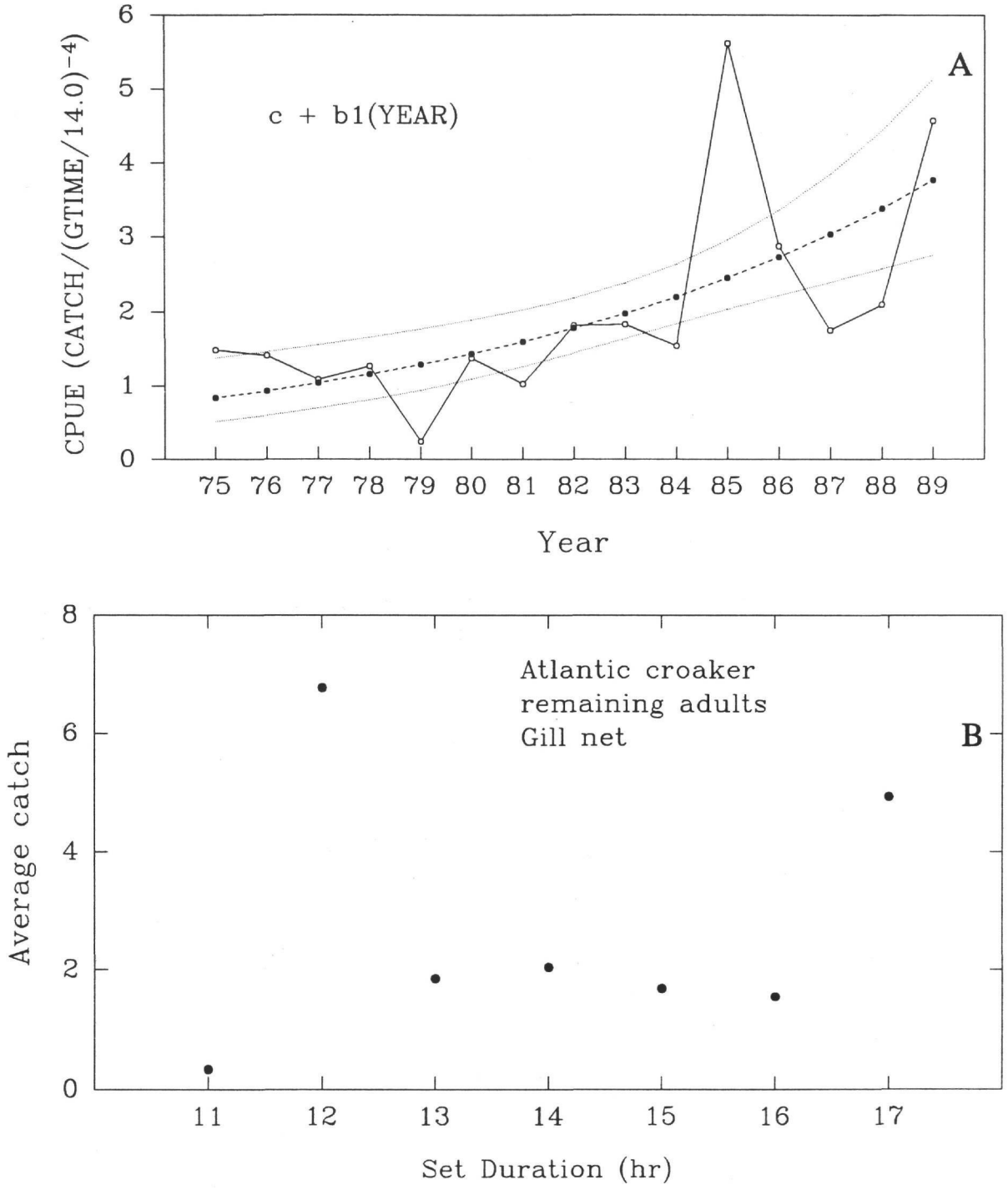


Figure III.48. A. Mean seasonal (fall) CPUE and predicted CPUE with confidence intervals for remaining adult Atlantic croaker (230-275 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1975-1989.

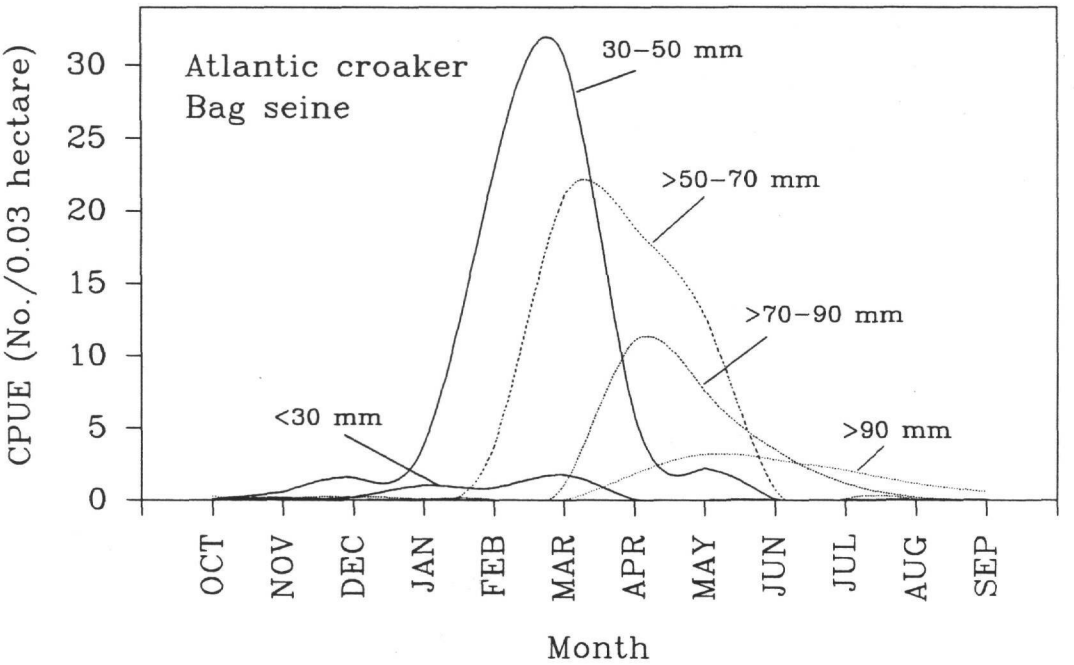


Figure III.49. Mean CPUE by month for five size classes of Atlantic croaker caught by bag seine (<30 mm, 30-50 mm, >50-70 mm, >70-90 mm, >90 mm). Data pooled from 1978-1989.

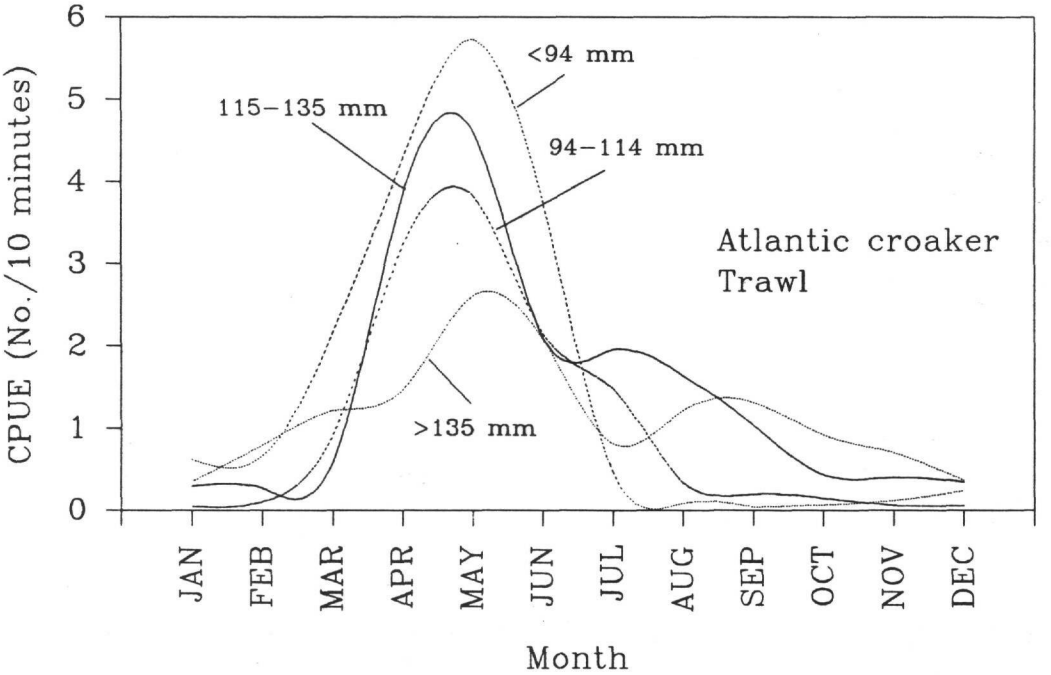


Figure III.50. Mean CPUE by month for four size classes of Atlantic croaker caught by trawl (<94 mm, 94-114 mm, 115-135 mm, >135 mm). Data pooled from 1983-1990.

1971). The 230-275 mm size range was well represented in gill net data (Figure III.51) and was used in the analysis of trends for remaining adults; the inclusion of fish greater than 275 mm would probably result in repeated sampling of the same cohort. Croaker of this size are about two years old (Pearson 1929; White and Chittenden 1976; Barger 1985).

Young of the year

Bag seine: All terms were significant in the analysis of deviance (Table III.26). Categorical Month effects explained most of the temporal variation, as expected in a strongly seasonal species; a linear trend and superimposed quadratic component explained 79.4 percent of the deviance attributed to YEAR effects (Figure III.46A). The plot of mean monthly CPUE (Figure III.46B) showed peak catches increased from 1978 to a modal year in 1982, then decreased to a low in 1986. High catches occurred in 1987 and 1988 but the lowest CPUE was in 1989. In all years but 1982, maximum catch rates occurred in March.

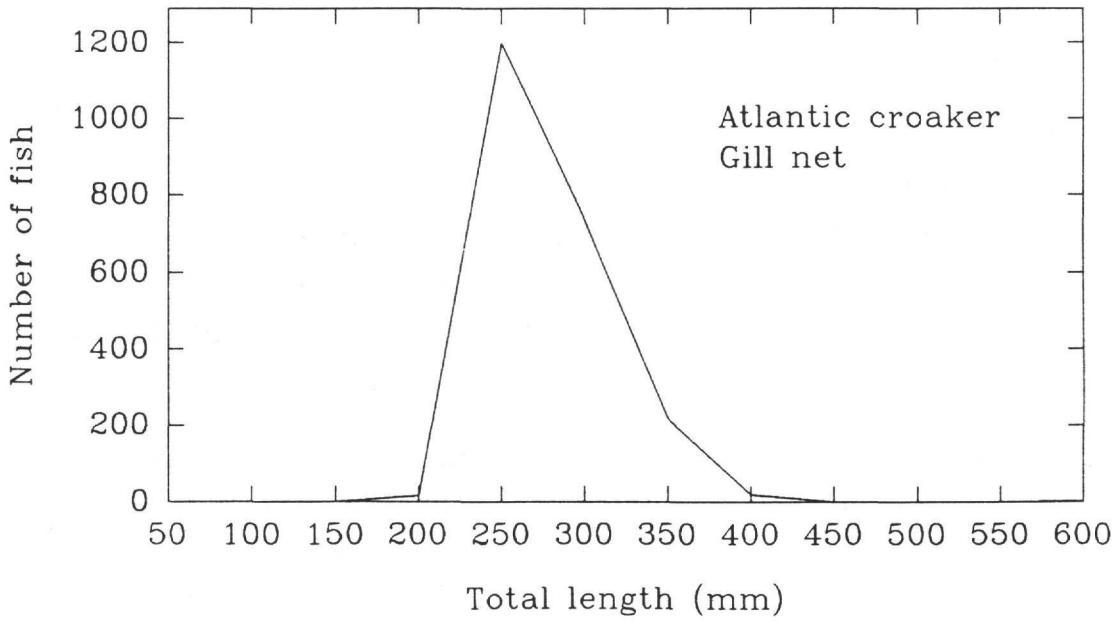


Figure III.51. Size frequency distribution for Atlantic croaker caught by gill net during fall sampling period. Data pooled from 1975-1989.

Table III.26. Analysis of deviance for young-of-the-year Atlantic croaker (30-50 mm) caught by bag seine, December-March, 1977-1989.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	129.80	43.27	32.53	<0.001
YEAR					
Linear	1	17.33	17.33	13.03	<0.001
Quadratic	1	15.44	15.44	11.61	<0.001
Other	9	79.69	8.85	6.66	<0.001
Month x Year	33	161.99	4.91	3.69	<0.001
Corrected error	327	435.40	1.33		

Table III.27. Analysis of deviance for first-time spawning Atlantic croaker (115-135 mm) caught by trawl, March-September, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	6	153.20	25.52	26.28	<0.001
YEAR					
Linear	1	9.54	9.54	9.82	>0.001
Quadratic	1	0	0	0	>0.75
Other	5	19.70	3.94	4.06	<0.001
Month x Year	42	184.60	4.39	4.52	<0.001
Corrected error	1064	1033.80	0.97		

First-time spawners

Trawl: The analysis of deviance showed the annual trend was linear with a positive slope, and no additional quadratic component (Table III.27, Figure III.47A). As in bag seine results, most of the deviance in the trawl data was explained by Month effects; peak catches usually occurred in April or May (Figure III.47B).

Remaining spawners

Gill net: The relationship between set duration and catch was not linear (Figure III.48B) and the initial analysis of deviance revealed that set duration effects were significant ($p<0.001$). A correction was applied using the formula

$$CPUE=CATCH/(GTIME/14)^{-4}$$

to yield a catch per 14 hours.

There was a significant linear increase from 1975 to 1989. The quadratic component was not significant and a large proportion of the total deviance was not explained by the model (Table III.28). The peak catch occurred in 1985; the lowest catch was recorded in 1979.

Spatial distribution

Young-of-the-year croaker are ubiquitous along the shorelines of the Galveston Estuary and are especially common in certain low-salinity areas: at the mouth of the San Jacinto River in Upper Galveston Bay, in Chocolate Bay, and in easternmost East Bay (Figure III.52). First-time spawners caught by trawl are also widespread, with the highest catch

Table III.28. Analysis of deviance for remaining adult Atlantic croaker (230-275 mm) caught by gill net, 230-275 mm, fall season, 1975-1989. CPUE = $CATCH/(GTIME/14)^{-4}$.

Source of Variation	D.F.	Deviance	M.D.	F	P
Year					
Linear	1	18.67	18.67	16.38	<0.001
Quadratic	1	0.18	0.18	0.16	>0.75
Other	12	32.38	2.70	2.37	0.005
Error	472	537.95	1.14		

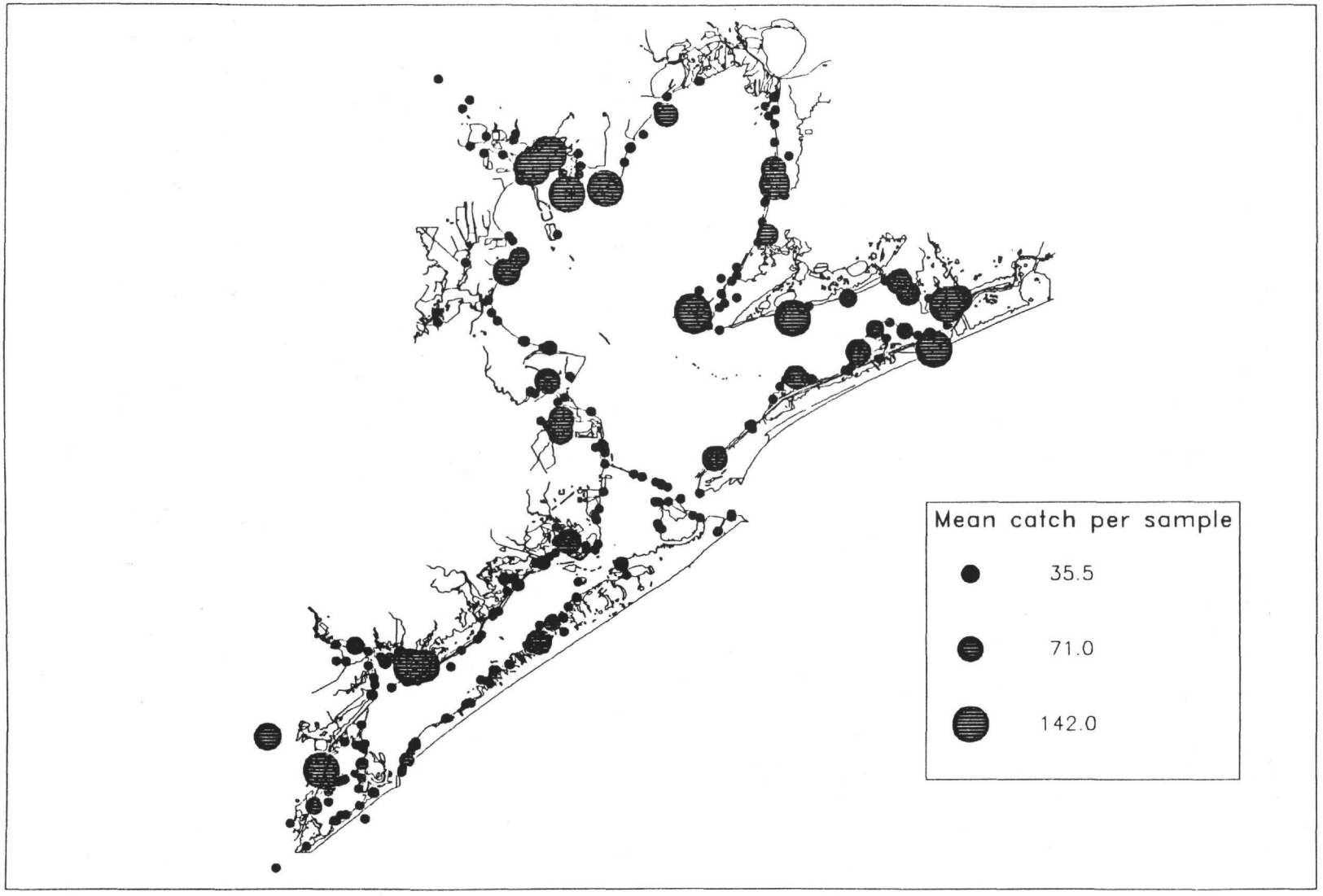


Figure III.52. Distribution of young-of-the-year Atlantic croaker (30-50 mm) caught by bag seine, December-March, 1977-1989. Circle size is proportional to mean CPUE.

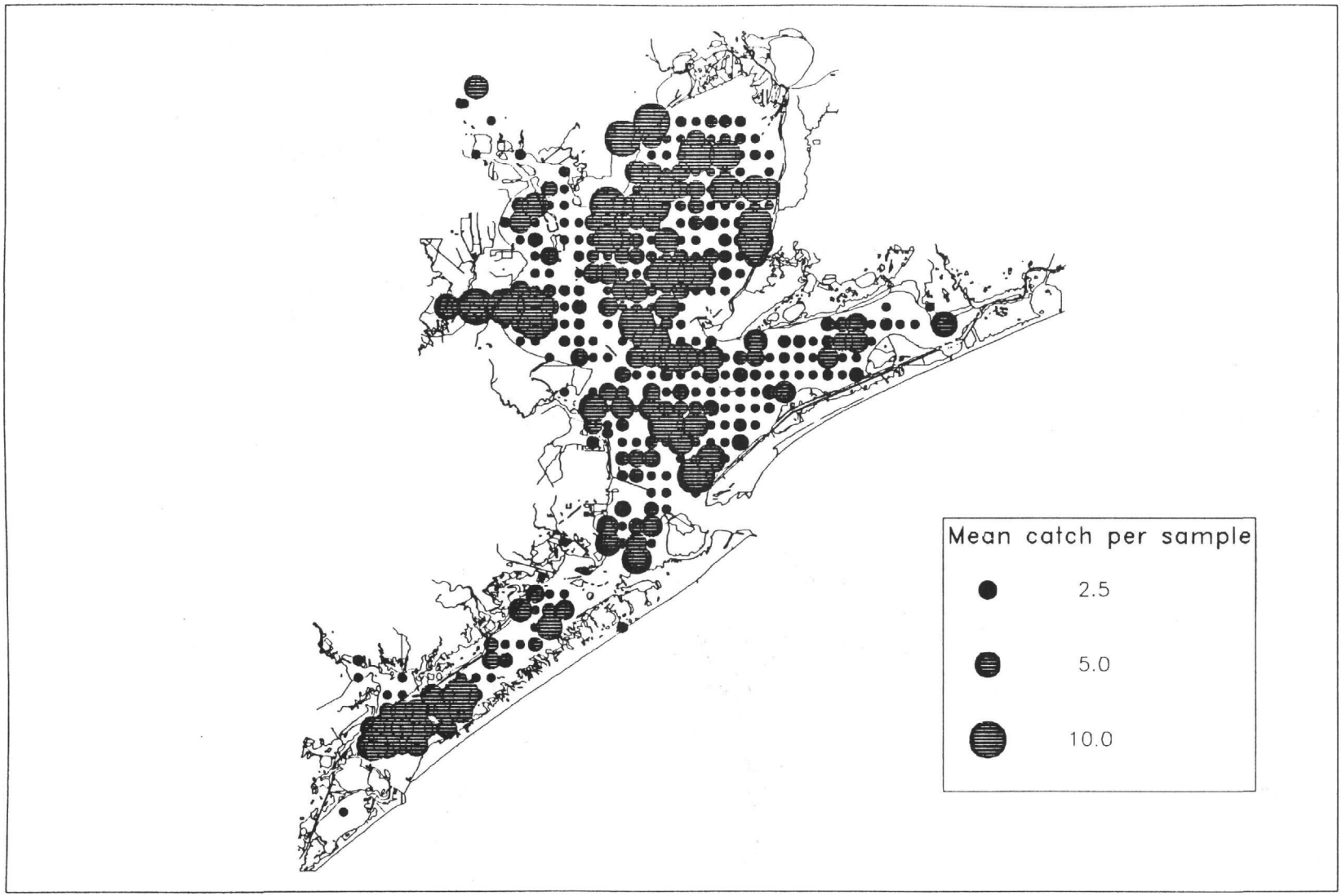


Figure III.53. Distribution of first-time spawning Atlantic croaker (115-135 mm) caught by trawl, March-September, 1983-1990. Circle size is proportional to mean CPUE.

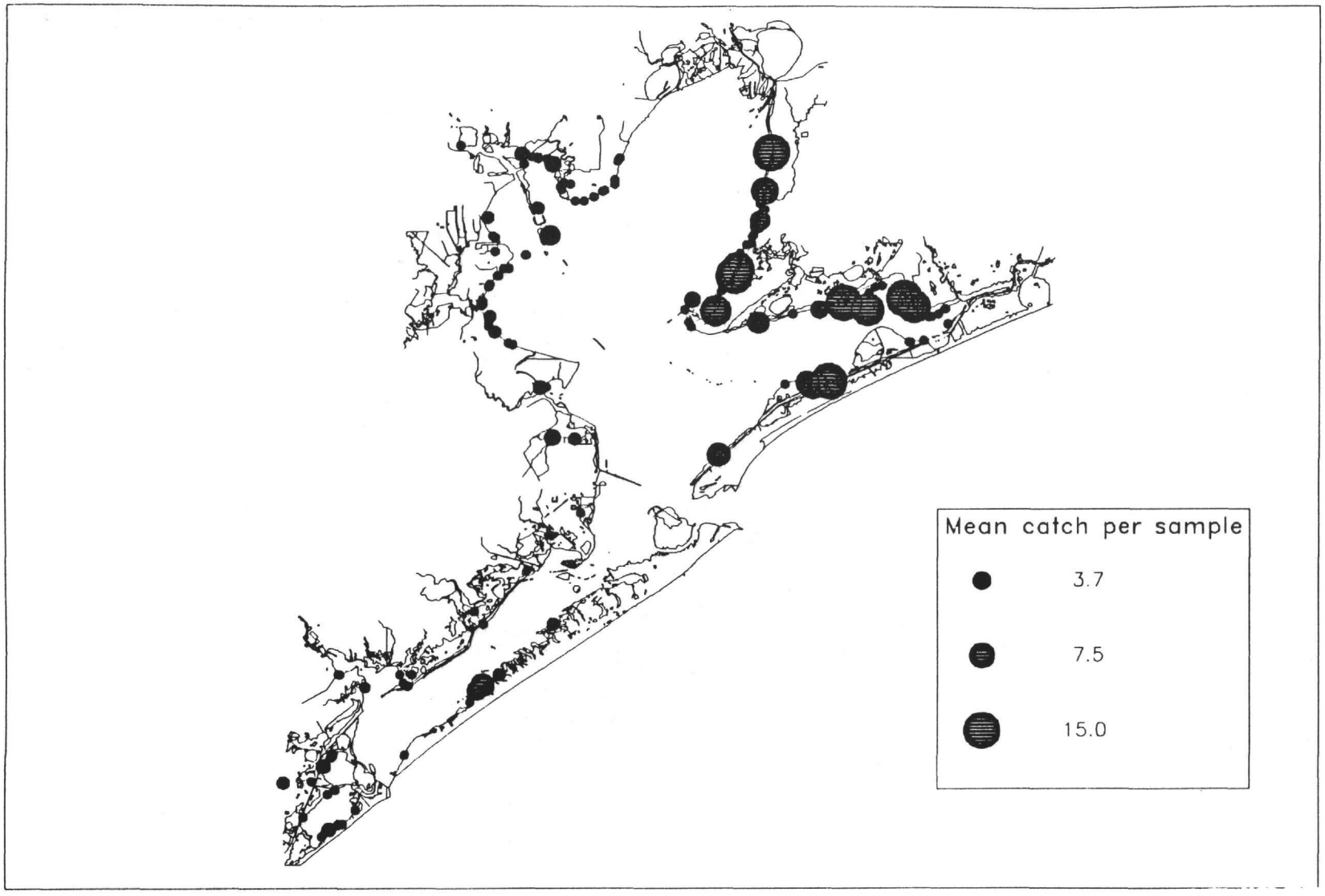


Figure III.54. Distribution of remaining adult Atlantic croaker (230-275 mm) caught by gill net, fall, 1975-1989. Circle size is proportional to mean catch per sample.

rates in Trinity and Upper Galveston Bays and in West Bay (Figure III.53). High catches by gill net of remaining adults, in contrast, are mainly confined to the eastern shore of Trinity Bay and to East Bay (Figure III.54).

Discussion

Detailed examination of trawl data for first-time spawning croaker revealed that the season became more narrowly defined, even though mean annual CPUE increased from 1983 to 1990 (Figure III.47B). During the years studied the first month with a mean CPUE of zero is January 1986; by 1987-1990 croaker were absent during three winter months (December-February), with low catch rates from September through March. Zero catches increased 10 percent from 1983 to 1990. The narrowing of the season apparent in trawl data is not conspicuous in bag seine data (Figure III.46B).

Large catches of young of the year in 1982 and 1988 were followed by large catches of first-time spawners in 1983 and 1989; however, the best year for croaker caught by trawl, 1986, was not preceded by exceptional catches of juveniles in 1985. The peak year for Age II croaker caught by gill net, 1985, possibly correlates with the high abundance of juveniles in 1982.

It can be inferred from the increasing trend in trawl and gill net data, contrasted with the quadratic trend and net decrease for bag seine data, that populations of mature croaker are influenced by different factors than those of juveniles. The differences could be related to differing food supplies, to the loss of nursery habitat, or to higher survival from juvenile to adult.

Bay Anchovy (Anchoa mitchilli)

Three size classes of bay anchovy (15-34 mm, 35-54 mm, and >55 mm) caught by bag seine all decreased in abundance from 1978 to 1990, with peak catches in 1981-1983 (Figures III.55, III.56, III.57). The same size classes caught by trawl showed an increasing trend with a superimposed quadratic component (Figures III.58, III.59, III.60) from 1983 to 1990. The differences between the gear types may be an artifact of sampling, because both show slight increases during the period 1984 through 1990.

Season and size selection

Bay anchovy are small fish that grow rapidly. Young of the year become sexually mature during their first summer, at an age of about 3 months and a size of 35-40 mm (Bingelow et al. 1963; Fives et al. 1986; Lou and Musick 1991). A size range of 35-54 mm was chosen to represent the population spawning for the first time. The adjacent smaller size class (15-34 mm) was chosen for the analysis of juveniles. Anchovy 55 mm long or longer represented remaining adults.

All size classes of anchovy were generally abundant in bag seine catches in all but the coldest months (Figure III.61), but in trawl catches anchovy were common during the

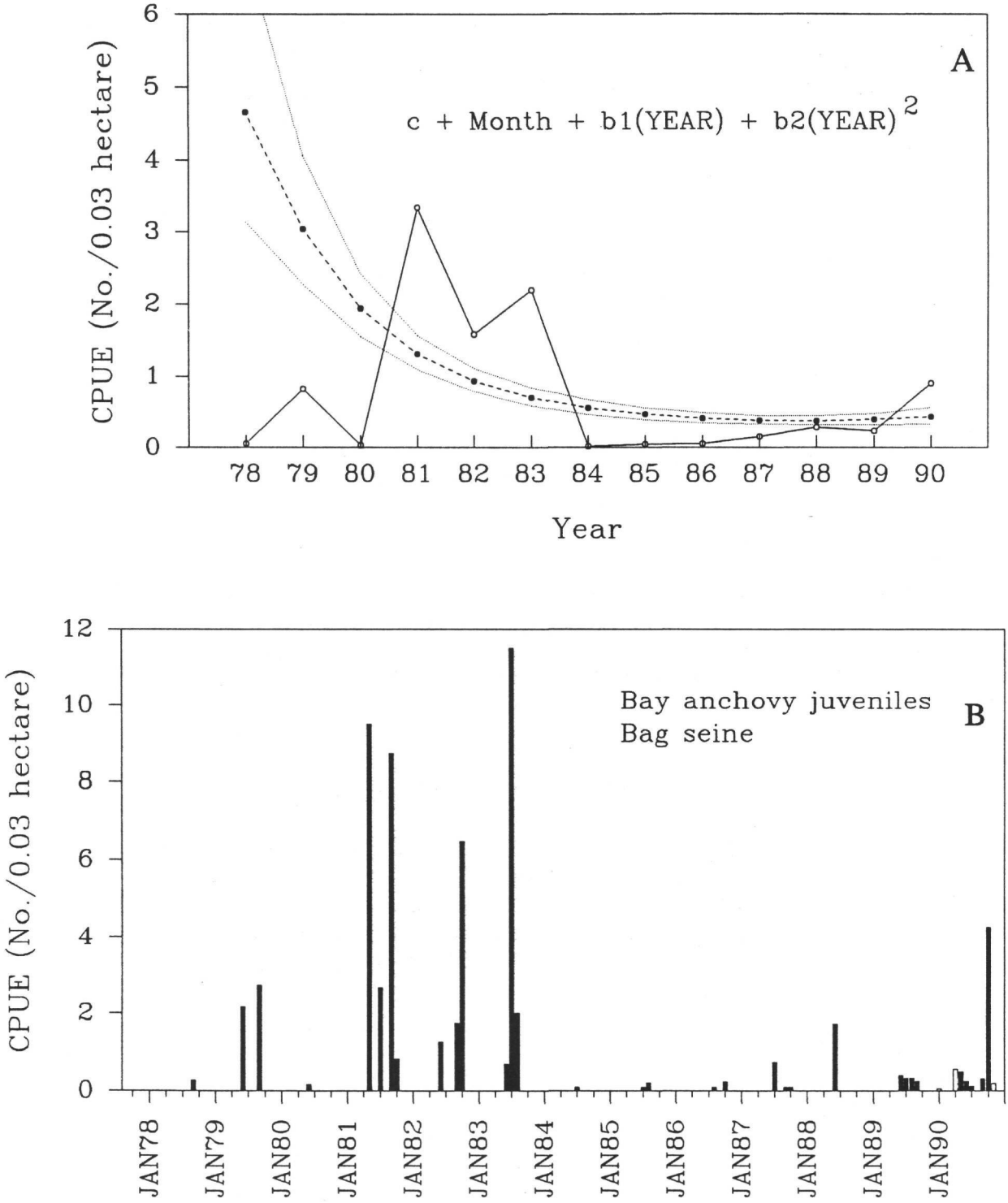


Figure III.55. A. Mean seasonal (May-October) CPUE and predicted CPUE with confidence intervals for juvenile bay anchovy (15-34 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: May-October. Hollow bars: months not used in analysis.

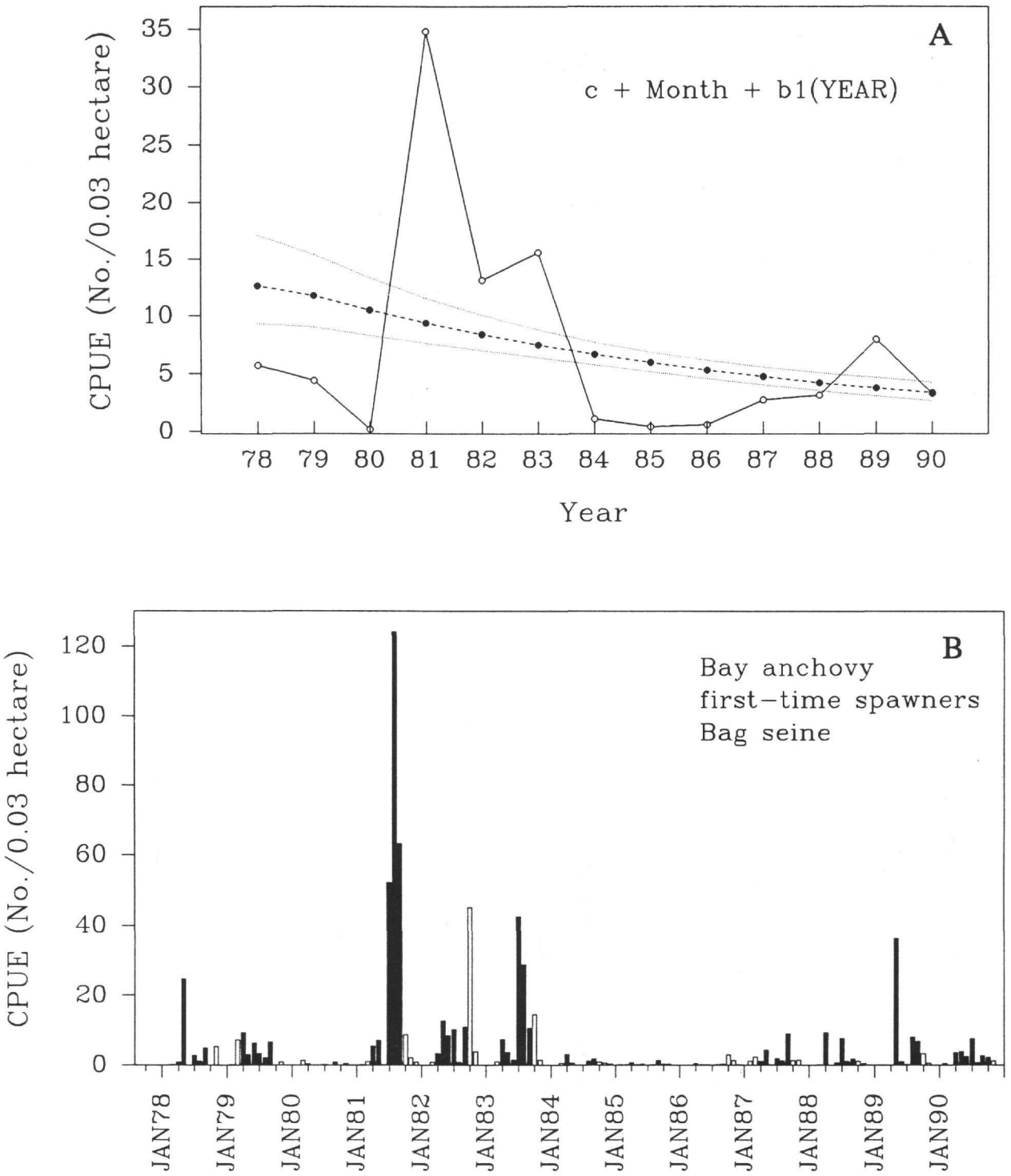


Figure III.56. A. Mean seasonal (April-October) CPUE and predicted CPUE with confidence intervals for first-time spawning bay anchovy (35-54 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: April-October. Hollow bars: months not used in analysis.

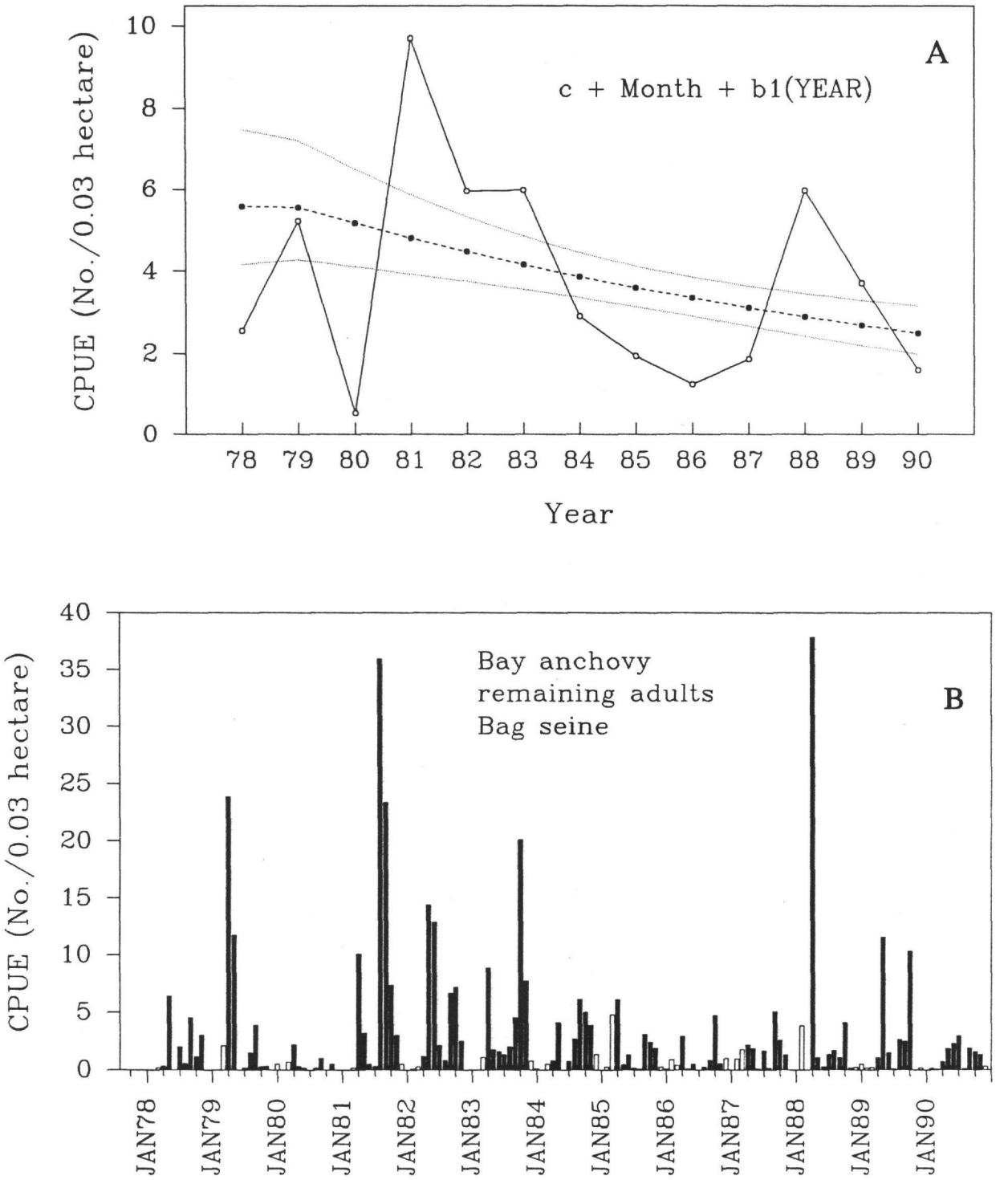


Figure III.57. A. Mean seasonal (April-November) CPUE and predicted CPUE with confidence intervals for remaining adult bay anchovy ($\geq$55 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: April-November. Hollow bars: months not used in analysis.

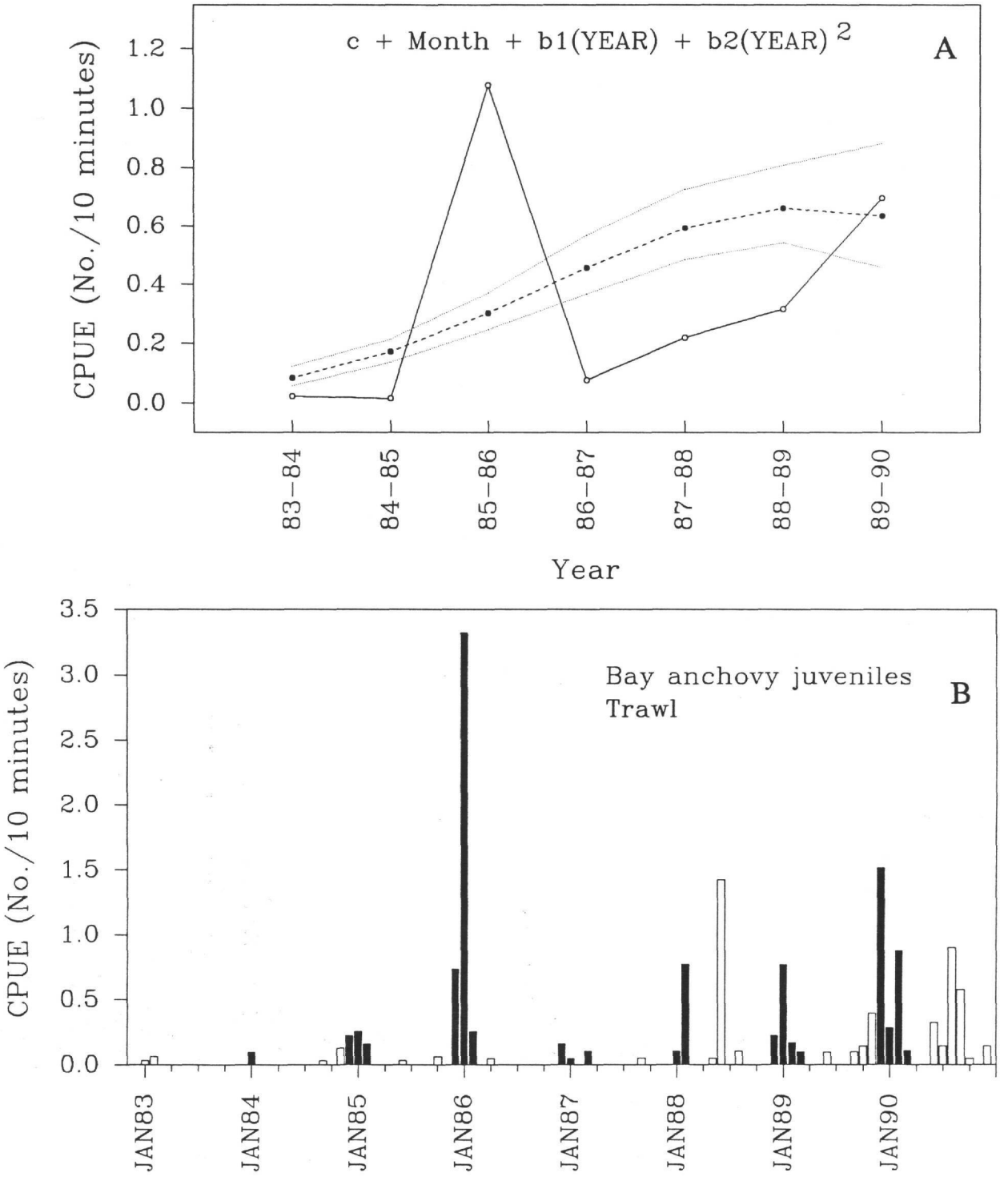


Figure III.58. A. Mean seasonal (December-March) and fitted CPUE with confidence intervals for juvenile bay anchovy (15-34 mm) caught by trawl. B. Mean CPUE by month. Filled bars: December-March. Hollow bars: months not used in analysis.

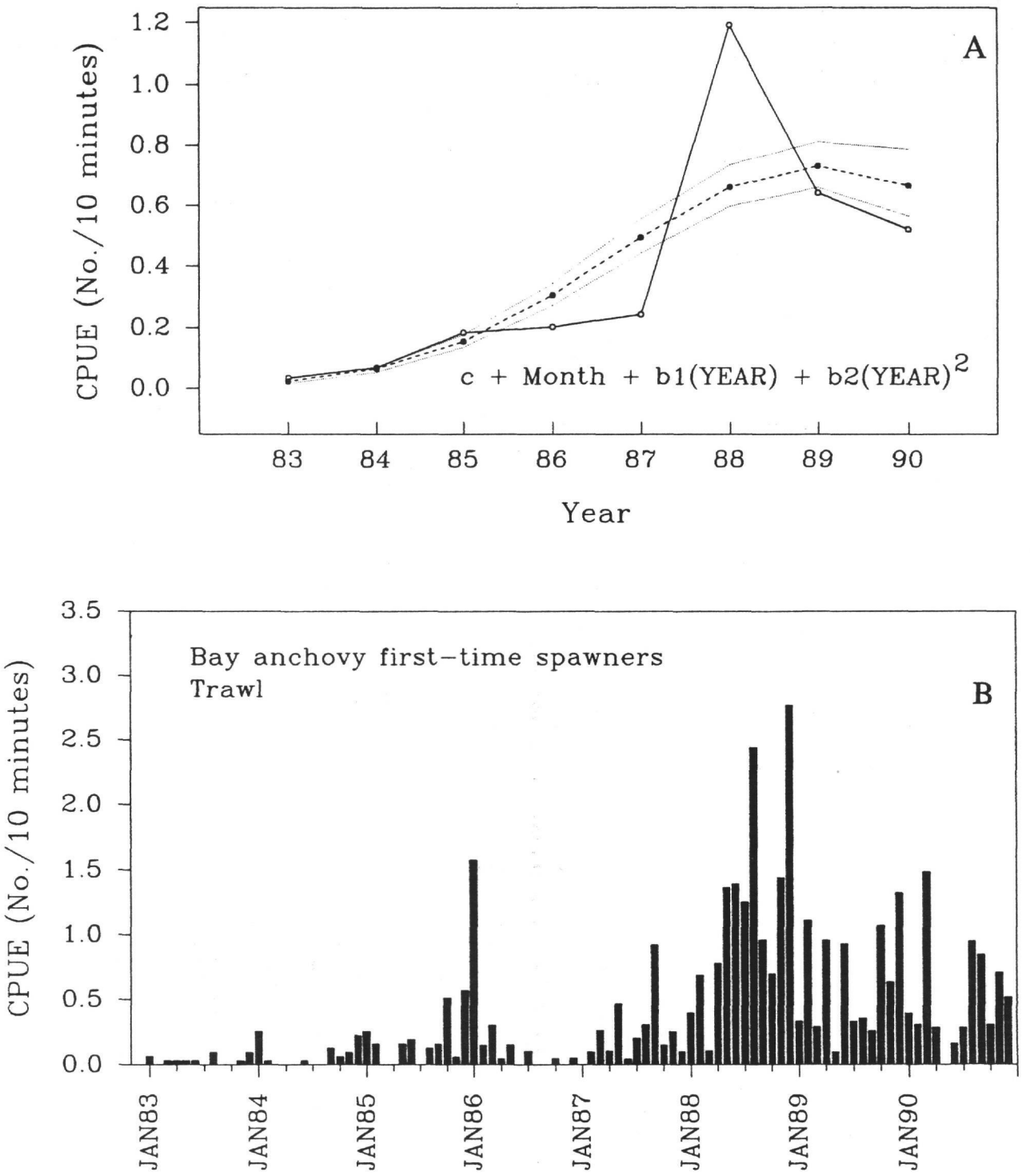


Figure III.59. A. Mean annual CPUE and predicted CPUE with confidence intervals for first-time spawning bay anchovy (35-54 mm) caught by trawl. B. Mean CPUE by month.

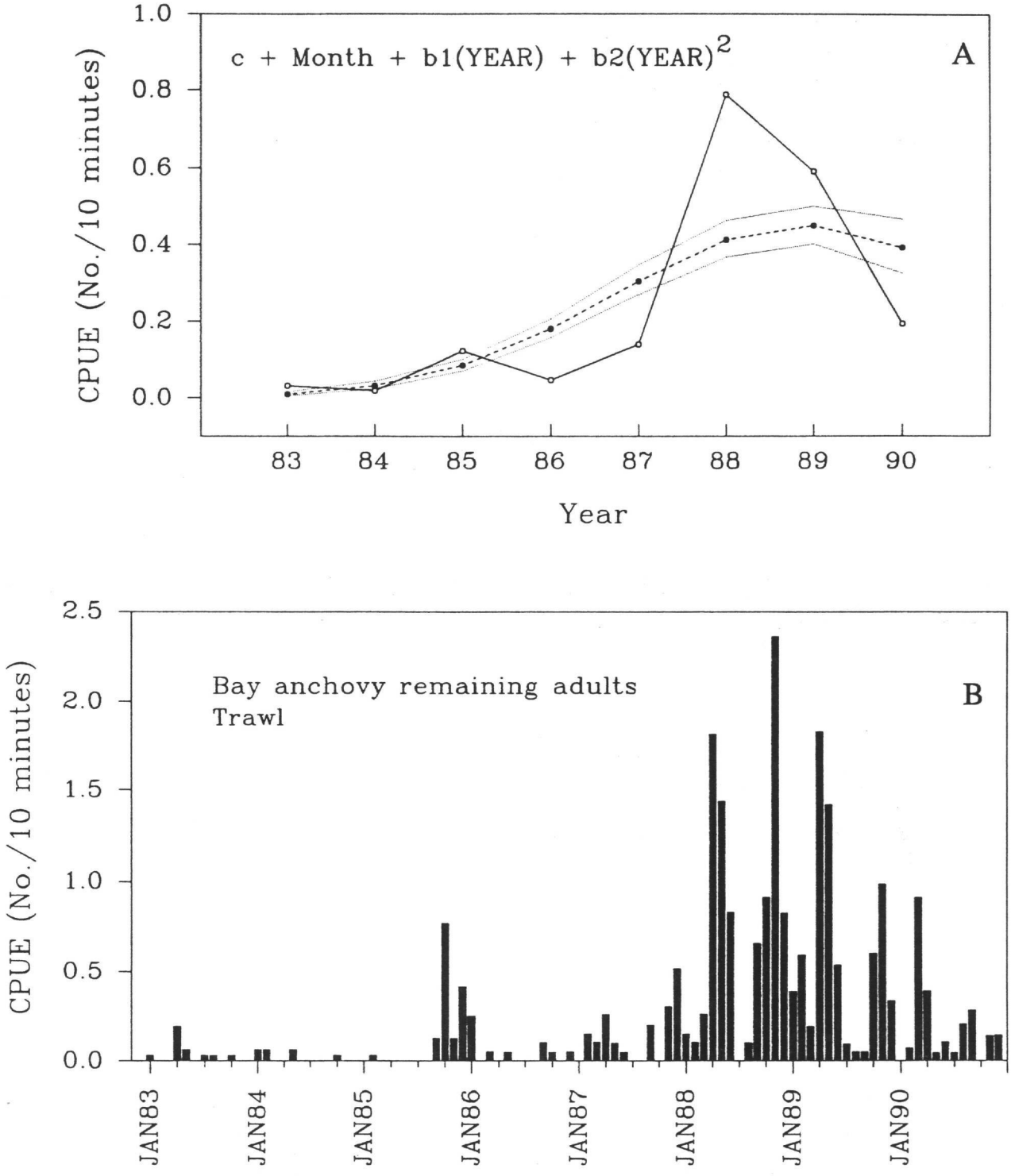


Figure III.60. A. Mean annual CPUE and predicted CPUE with confidence intervals for remaining adult bay anchovy ($\geq$55 mm) caught by trawl. B. Mean CPUE by month.

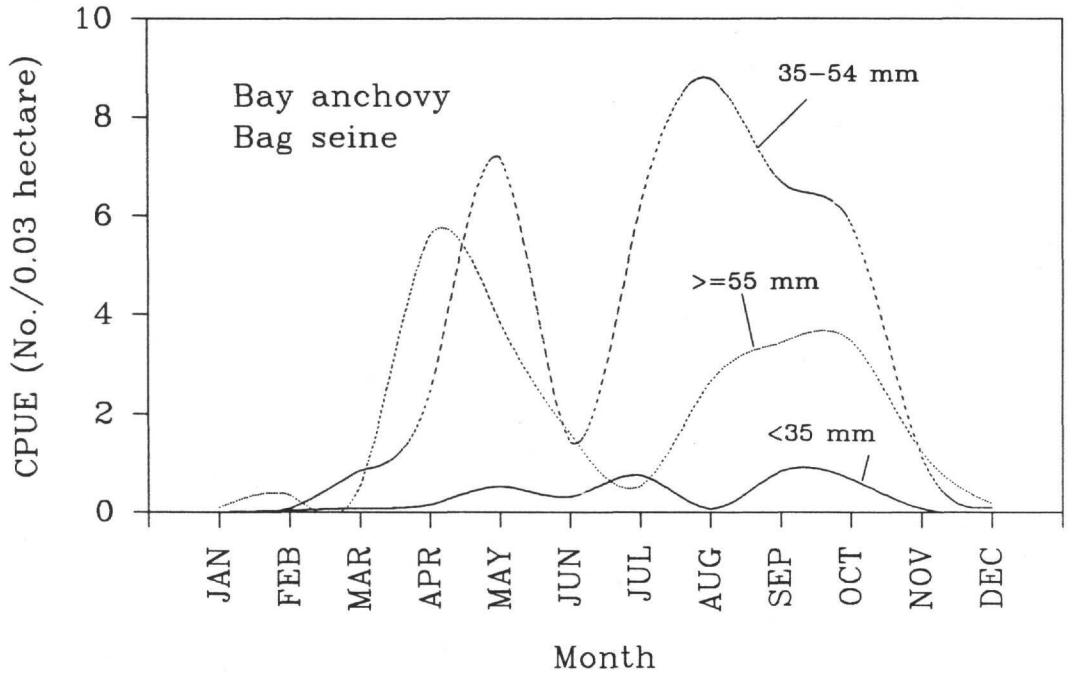


Figure III.61. Mean CPUE by month for three sizes of bay anchovy caught by bag seine (< =35 mm, 35-54 mm, ≥55 mm). Data pooled from 1978-1989.

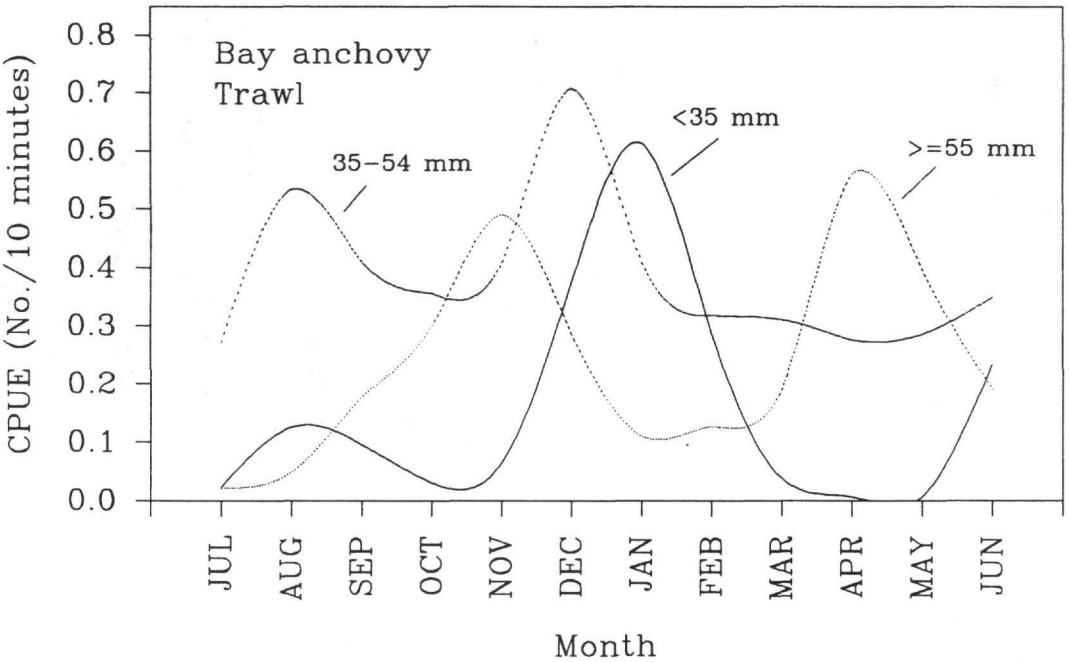


Figure III.62. Mean CPUE by month for three sizes of bay anchovy caught by trawl (< =35 mm, 35-54 mm, ≥55 mm). Data pooled from 1983-1990.

winter (Figure III.62), probably because fish migrate into the open bay to avoid low shoreline temperatures. The analysis of juveniles caught by bag seine was restricted to the months of May through October, when the 15-34 mm size class was abundant (Figure III.61; for trawl the same size class was analyzed using data from December through the following March (Figure III.62). First-time spawning anchovy were common from April through October in bag seine catches (Figure III.61) but were present throughout the year in trawl (Figure III.62). Similarly, the analysis of remaining adult anchovy was confined to April through November for bag seine data, but all months were used for trawl data.

Juveniles

Bag seine: The trend for young-of-the-year anchovy decreased from 1978 through 1990 (Table III.29, Figure III.55A). The linear trend of annual effects explained most of the deviance (10.06 percent). A quadratic component was also significant, reflecting the influence of high catch rates in 1981-1983 (Figure III.55B). A large proportion of the total deviance were explained by categorical Year effects or by neither the linear nor the quadratic components, so there was little correspondence between the observed mean yearly CPUE and the values fitted by the quadratic model.

Trawl: All terms were significant in the analysis of deviance (Table III.30). The annual trend showed an increase in abundance, with a significant quadratic component ascribed to an increase in high catches over a wider season in recent years (Figure III.58B). There was slight agreement between the observed mean yearly CPUE and values fitted by a quadratic model (Figure III.58A), because of unusually high catches during the winter of 1985-86 (Figures III.58B).

First-time spawners

Bag seine: Though the pattern of CPUE (Figure III.56) was similar to that observed for juveniles, the results of the analysis of deviance showed a linear decrease with no significant additional quadratic component (Table III.31). Most of the total deviance was explained by a linear annual trend but large proportions were ascribed to categorical Year or to YEAR effects that are neither linear nor quadratic.

Trawl: The annual trend was strongly linear with a superimposed quadratic component (Figure III.59A, Table III.32). CPUE increased from 1983 until a maximum in the winter of 1988-89, then decreased slightly through 1989 and 1990 (Figure III.59B).

Remaining adults

Bag seine: The pattern of CPUE (Figure III.57) and the results of the analysis of deviance (Table III.33) were much like bag seine results for first-time spawners, with the exception that the peak in 1981 was lower, the decrease after 1983 more gradual, and there was a relatively high abundance in 1988. The peak in 1988 was the result of a single large catch in April (406.74 fish). Deletion of this sample did not alter the

Table III.29. Analysis of deviance for juvenile bay anchovy (15-34 mm) caught by bag seine, May-October, 1978-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	5	42.69	8.54	13.88	<0.001
YEAR					
Linear	1	20.86	20.86	33.92	<0.001
Quadratic	1	6.19	6.19	10.06	<0.005
Other	10	149.34	14.93	24.28	<0.001
Month x Year	59	196.91	3.34	5.43	<0.001
Corrected error	419	257.71	0.615		

Table III.30. Analysis of deviance for juvenile bay anchovy (15-34 mm) caught by trawl, December-March, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	34.94	11.65	17.59	<0.001
YEAR					
Linear	1	18.54	18.54	28.01	<0.001
Quadratic	1	4.13	4.13	6.24	<0.025
Other	4	45.30	11.32	17.11	<0.001
Month x Year	18	71.71	3.98	6.02	<0.001
Corrected error	398	323.26	0.81		

Table III.31. Analysis of deviance for first-time spawning bay anchovy (35-54 mm) caught by bag seine, April-October, 1978-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	6	30.70	5.12	4.26	<0.001
YEAR					
Linear	1	33.35	33.35	27.80	<0.001
Quadratic	1	1.38	1.38	1.15	>0.25
Other	10	258.50	25.85	21.54	<0.001
Month x Year	71	251.50	3.54	2.95	<0.001
Corrected error	710	841.1	1.20		

Table III.32. Analysis of deviance for first-spawning bay anchovy (35-54 mm) caught by trawl, January-December, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	37.90	3.44	5.31	<0.001
YEAR					
Linear	1	233.80	233.80	360.52	<0.001
Quadratic	1	42.08	42.08	64.89	<0.001
Other	5	57.20	11.44	17.64	<0.001
Month x Year	77	242.40	3.15	4.85	<0.001
Corrected error	1483	961.80	0.65		

Table III.33. Analysis of deviance for remaining adult bay anchovy (>=55 mm) caught by bag seine, April-November, 1978-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	7	85.30	12.18	9.44	<0.001
YEAR					
Linear	1	15.74	15.74	12.19	<0.001
Quadratic	1	0.51	0.51	00.39	>0.50
Other	10	106.11	0.61	8.22	<0.001
Month x Year	83	299.70	3.61	2.80	<0.001
Corrected error	847	1093.60	1.29		

Table III.34. Analysis of deviance for remaining adult bay anchovy (>=55 mm) caught by trawl, January-December, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	100.29	9.12	15.69	<0.001
YEAR					
Linear	1	184.20	184.20	316.95	<0.001
Quadratic	1	29.56	29.56	50.86	<0.001
Other	5	87.69	17.54	30.18	<0.001
Month x Year	77	224.41	2.91	5.01	<0.001
Corrected error	1179	685.20	0.58		

conclusions of the analysis of deviance. Categorical Month effects explained almost as much of the total deviance as linear YEAR effects (Table III.33).

Trawl: The pattern of CPUE (Figure III.60) and the results of the analysis of deviance (Table III.34) were almost identical to trawl results for first-time spawners.

Spatial distribution

Both bag seine and trawl data showed interesting differences in geographic distribution among age classes. Juveniles caught by bag seine are most abundant throughout West Bay and the area of Bolivar Roads (Figure III.63), while first-time spawners and remaining adults are common on all parts of the shoreline except northern Trinity Bay and the north shore of Upper Galveston Bay (Figures III.64 and III.65). In contrast, the three size classes of bay anchovy caught by trawl (Figures III.66, III.67, and III.68) were all widespread in the main part of the Galveston Estuary, but were scarce in West Bay. Juveniles in particular did not occur in West Bay (Figure III.66), though adults were recovered from the area of the Causeway and from Christmas Bay (Figure III.68).

Discussion

Bag seine and trawl data showed consistently different results, an apparent paradox. However, bag seine and trawl data differ in several aspects of sampling: different localities, both on the local (shoreline vs open bay) and regional (West Bay vs Galveston-Trinity-East Bays) scales; different seasons and changes in seasonality; and different time periods. Any of these factors or a combination of them may be responsible for the apparent differences in trends.

Bag seine data showed a decreasing trend for all size groups (Figures III.55, III.56, III.57), associated with smaller catches and an increased number of zeros in years after 1981-83. The spacing of peak catches in bag seine results (conspicuous in Figures III.56B and III.57B) suggest a seven- or eight-year abundance cycle, though the time series is too short to verify the periodicity. In contrast, all size groups caught by trawl showed an increase in abundance. The increase was ascribed to larger individual catches along with a reduction in zero catches, specifically in the widening of the season; more months produced high catches in recent years.

From 1983 to 1986 high trawl catches were mainly confined to the winter months (November-February), and juveniles were caught almost exclusively in the winter months (Figures III.56B, III.59B, III.60B). However, low catches of mature anchovy in the winter of 1986-87 were followed by an increase in the late spring of 1987, and from 1988 to 1990 there were high catches in all seasons except midsummer (Figures III.59B, III.60B). Juvenile anchovy showed an unusual June peak in 1988 and an increased density of high catches through 1989 and 1990 (Figure III.58B). Changes in seasonality may be partially responsible for the differences between results for bag seine (warm months analyzed) and trawl data (cold months analyzed).

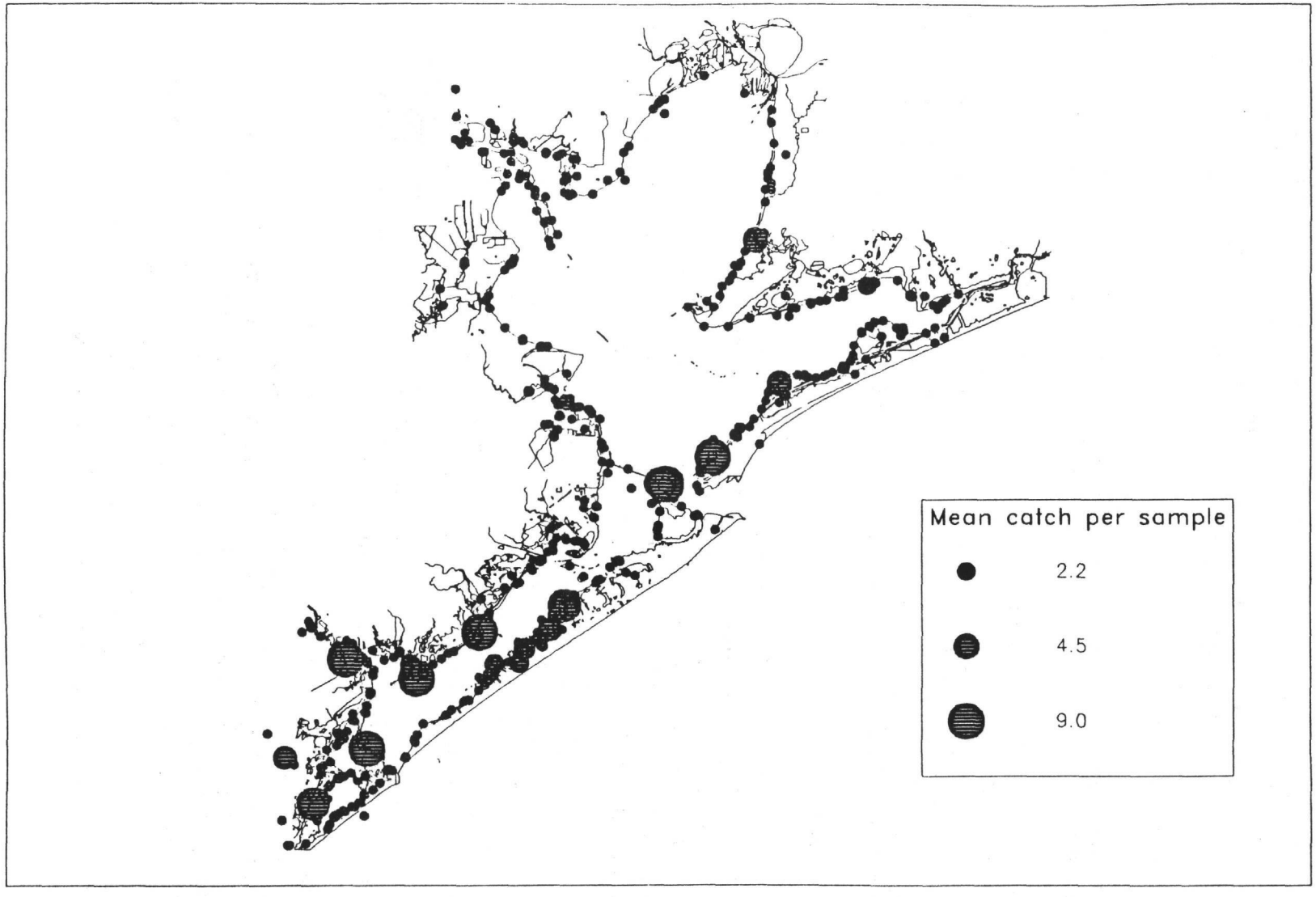


Figure III.63. Distribution of juvenile bay anchovy (15-34 mm) caught by bag seine, May-October, 1978-1989. Circle size is proportional to mean CPUE.

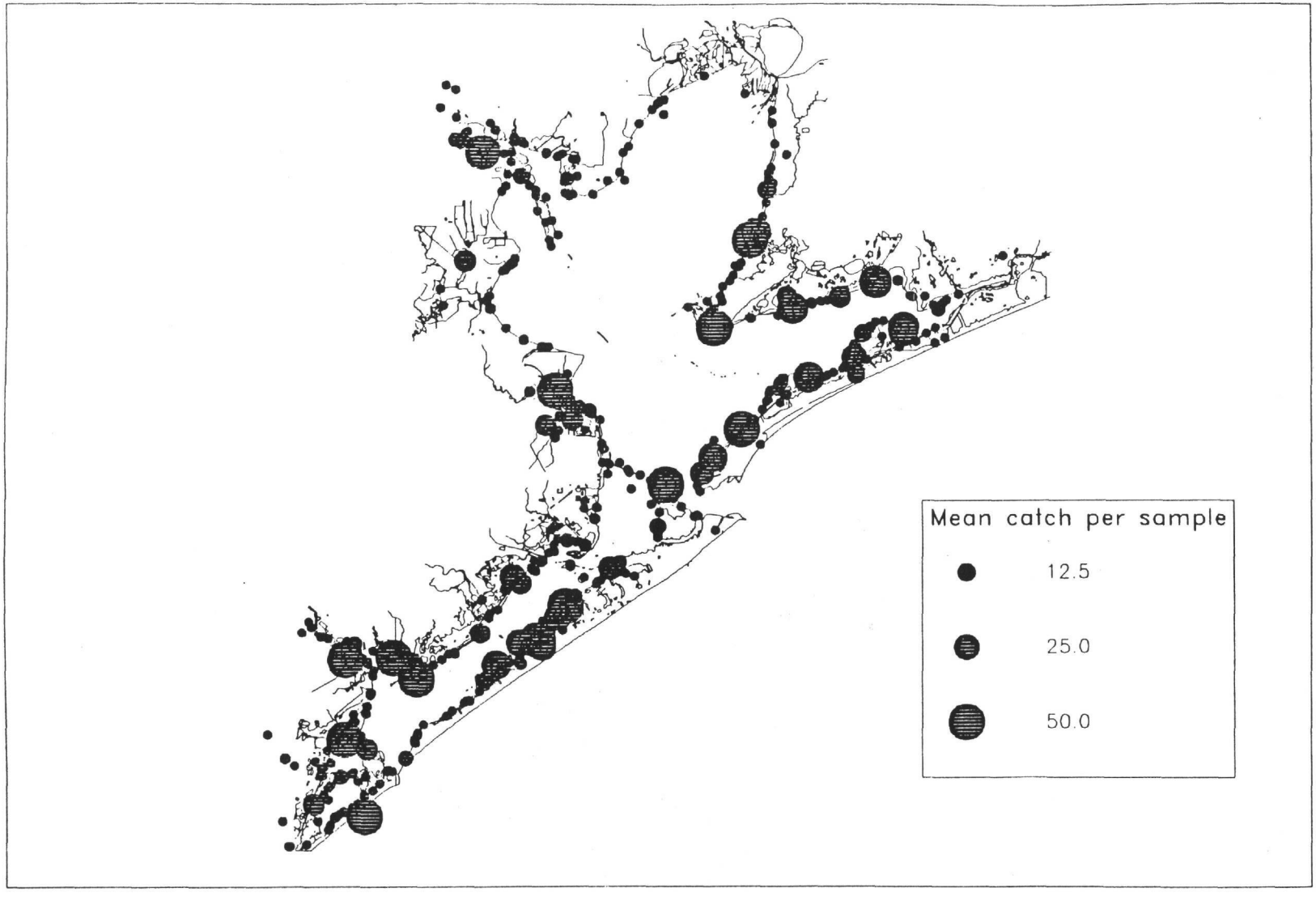


Figure III.64. Distribution of first-time spawning bay anchovy (35-54 mm) caught by bag seine, April-October, 1978-1989. Circle size is proportional to mean CPUE.

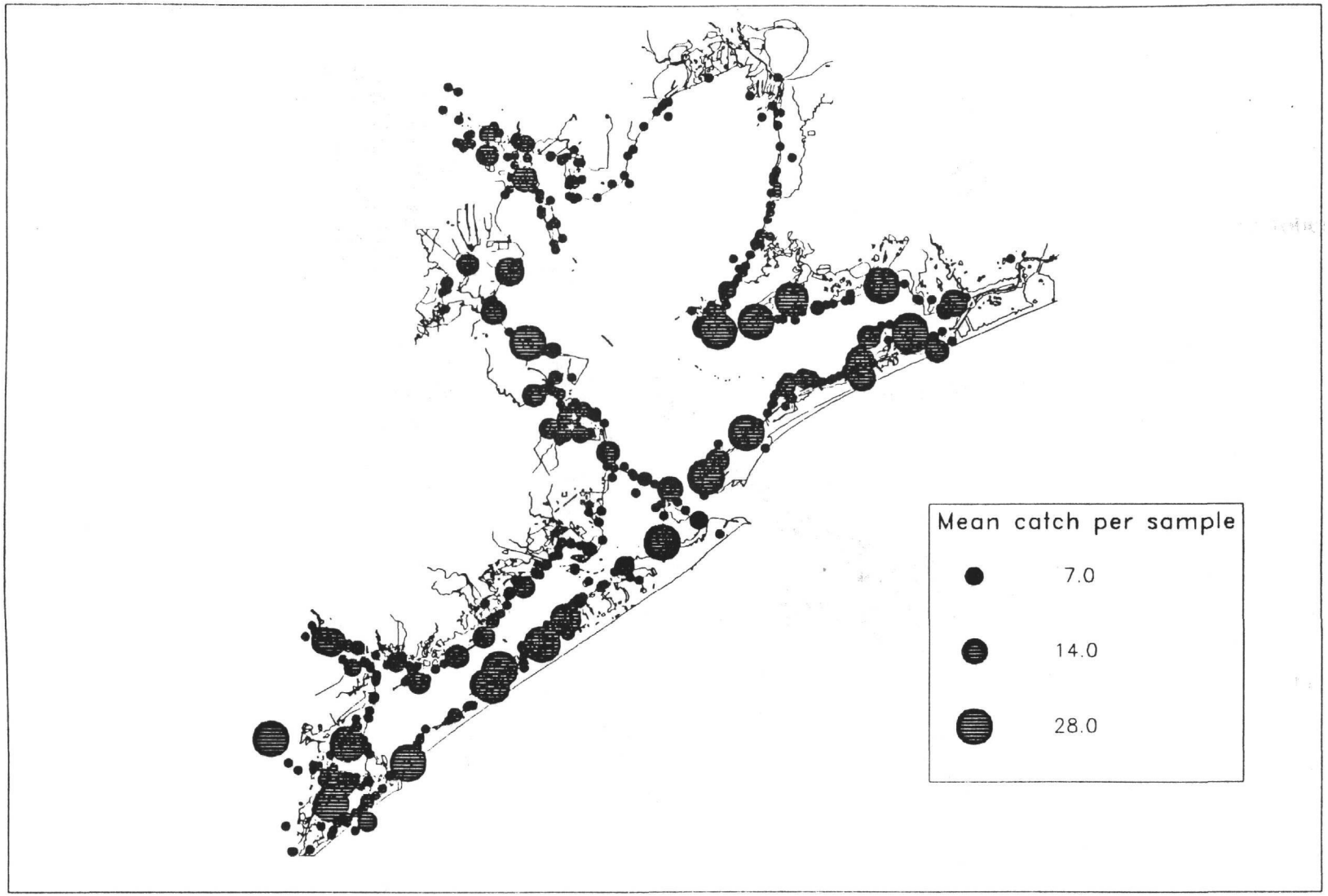


Figure III.65. Distribution of remaining adult bay anchovy (≥55 mm) caught by bag seine, April-November, 1978-1989. Circle size is proportional to mean CPUE.

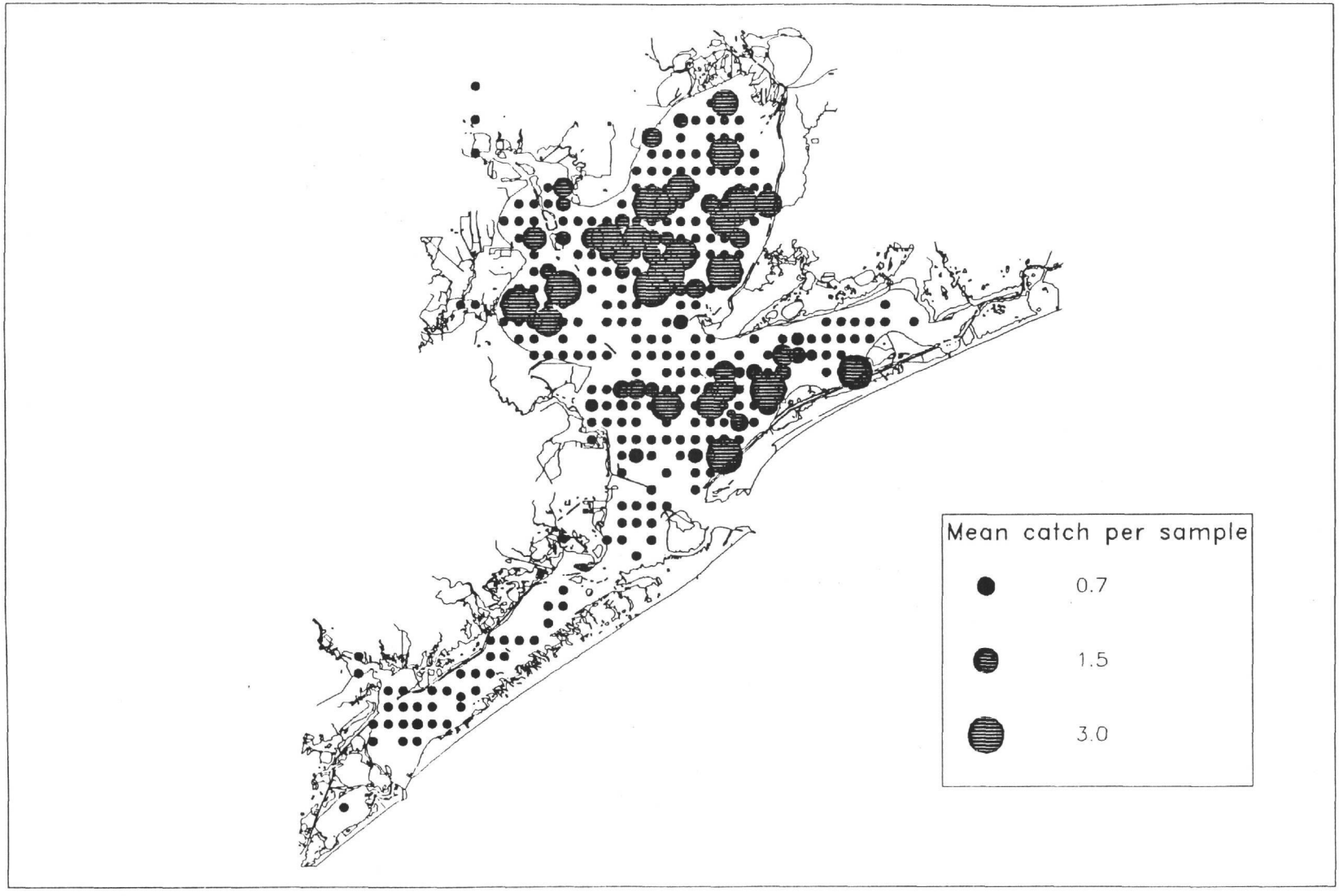


Figure III.66. Distribution of young-of-the-year bay anchovy (15-34 mm) caught by trawl, December-March, 1983-1990. Circle size is proportional to mean CPUE.

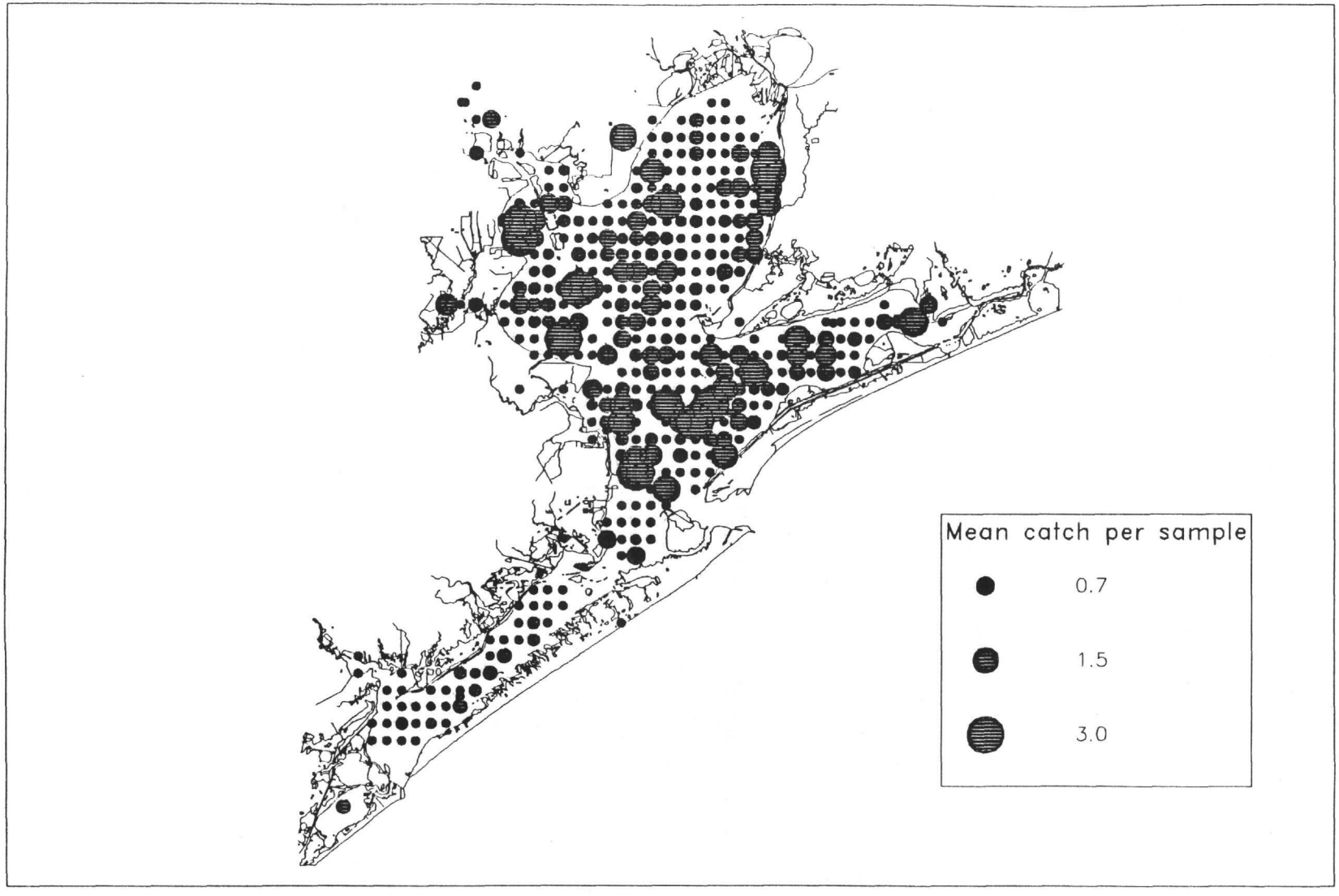


Figure III.67. Distribution of first-time spawning bay anchovy (35-54 mm) caught by trawl, January-December, 1983-1990. Circle size is proportional to mean CPUE.

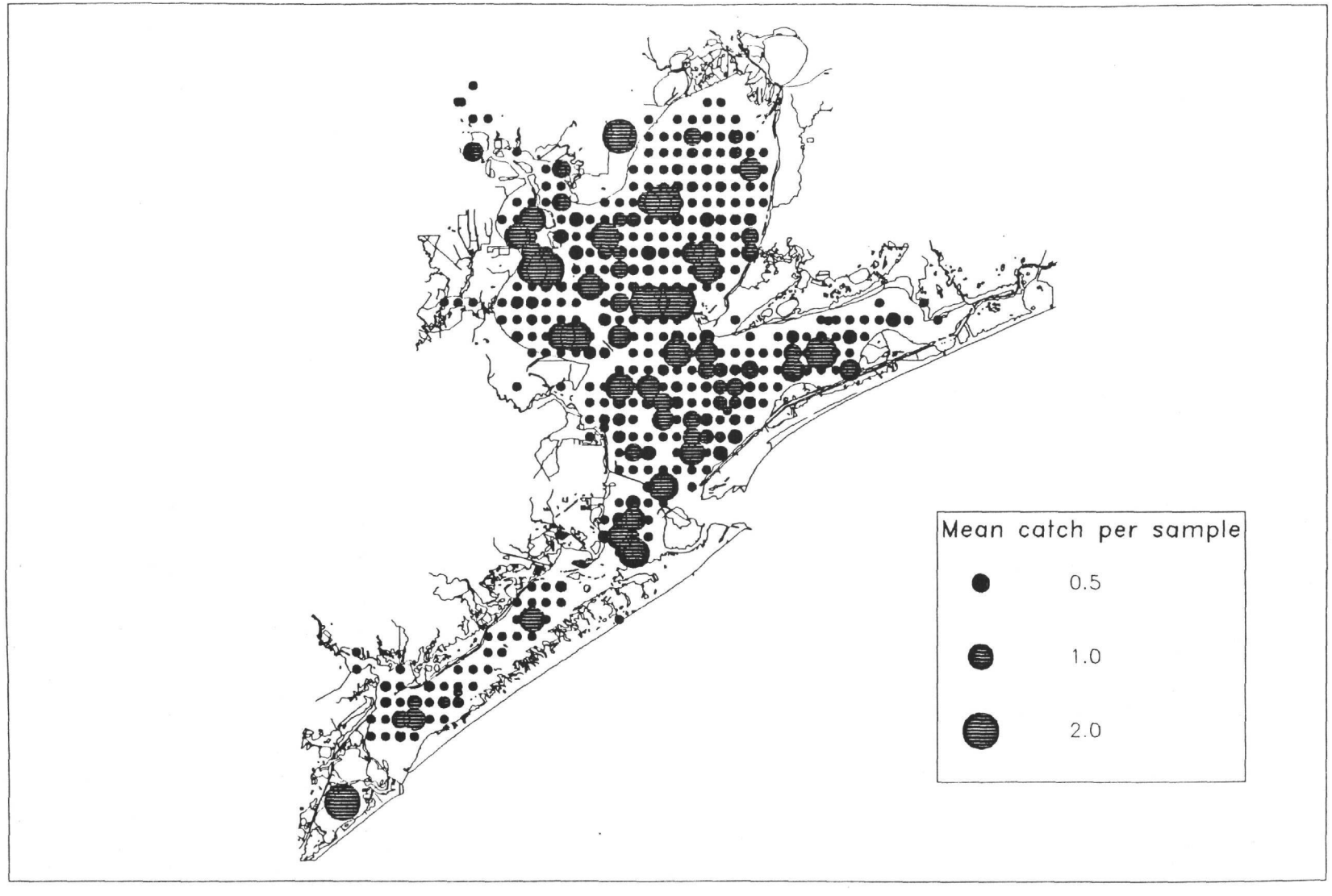


Figure III.68. Distribution of remaining adult bay anchovy (≥55 mm) caught by trawl, January-December, 1983-1990. Circle size is proportional to mean CPUE.

The apparent contrast between bag seine and trawl results also may be deceptive in that the differences between the trends were mainly caused by variation prior to 1984, when only bag seine data were available. When bag seine data from the same years as the trawl data sets (1983-1990) were analyzed, all three size classes showed a quadratic annual trend, influenced by the relatively high catch rates in 1983. Only young of the year had a significant linear component for 1983-90. When the analysis was confined to the years 1984-1990, both young of the year and first-time spawners showed a linear increase, similar to results for trawl data (but with no additional quadratic component). Remaining adults in 1984-90 showed no annual trend.

Though different results for the two gear types are probably not severe, the contrast in the data sets raises the possibility that a spatial shift in anchovy densities occurred during the late 1970s or early 1980s. A more detailed analysis of anchovy population trends in West Bay and in other parts of the estuary will be required in order to document such a shift or recognize its causes.

Black Drum (*Pogonias cromis*)

Young-of-the-year black drum (55-85 mm) decreased in abundance from 1978 through 1990, while first-time spawners (300-400 mm) and remaining adults (>400 mm) increased (Figures III.69, III.70, III.71).

Season and Size Selection

Tagging and length-frequency studies in Texas estuaries indicated that growth is rapid for small black drum (Pearson 1929, Simmons and Breuer 1962, Doerzbacher et al. 1988). A size range of 55 to 85 mm was chosen to represent young of the year. Fish of this size predominated in bag seine catches from June through August, the season chosen for analysis (Figure III.72).

Black drum reach sexual maturity by the end of their second year (Simmons and Breuer 1962). About 90 percent of the spawning activity occurs in February and March. Total length at Age II has been reported as 250 mm (Pearson 1929), 310 mm (Simmons and Breuer 1962), or 375 mm (Cornelius 1984). A size range of 300-400 mm included black drum of the age to spawn for the first time and was well represented in fall gill net data (Figure III.73). Remaining adults, defined as those greater than 400 mm TL, were also analyzed in the fall.

Young of the Year

Bag seine: The annual trend was linear with a negative slope (Figure III.69A, Table III.35). The quadratic component was not significant. The model including Month and linear YEAR effects explained 26.3 percent of the total deviance. About 53 percent of the deviance ascribed to annual effects was explained by the linear trend and 47 percent by YEAR effects other than the linear or quadratic components. Juvenile black drum are strongly seasonal (Figure III.69B).

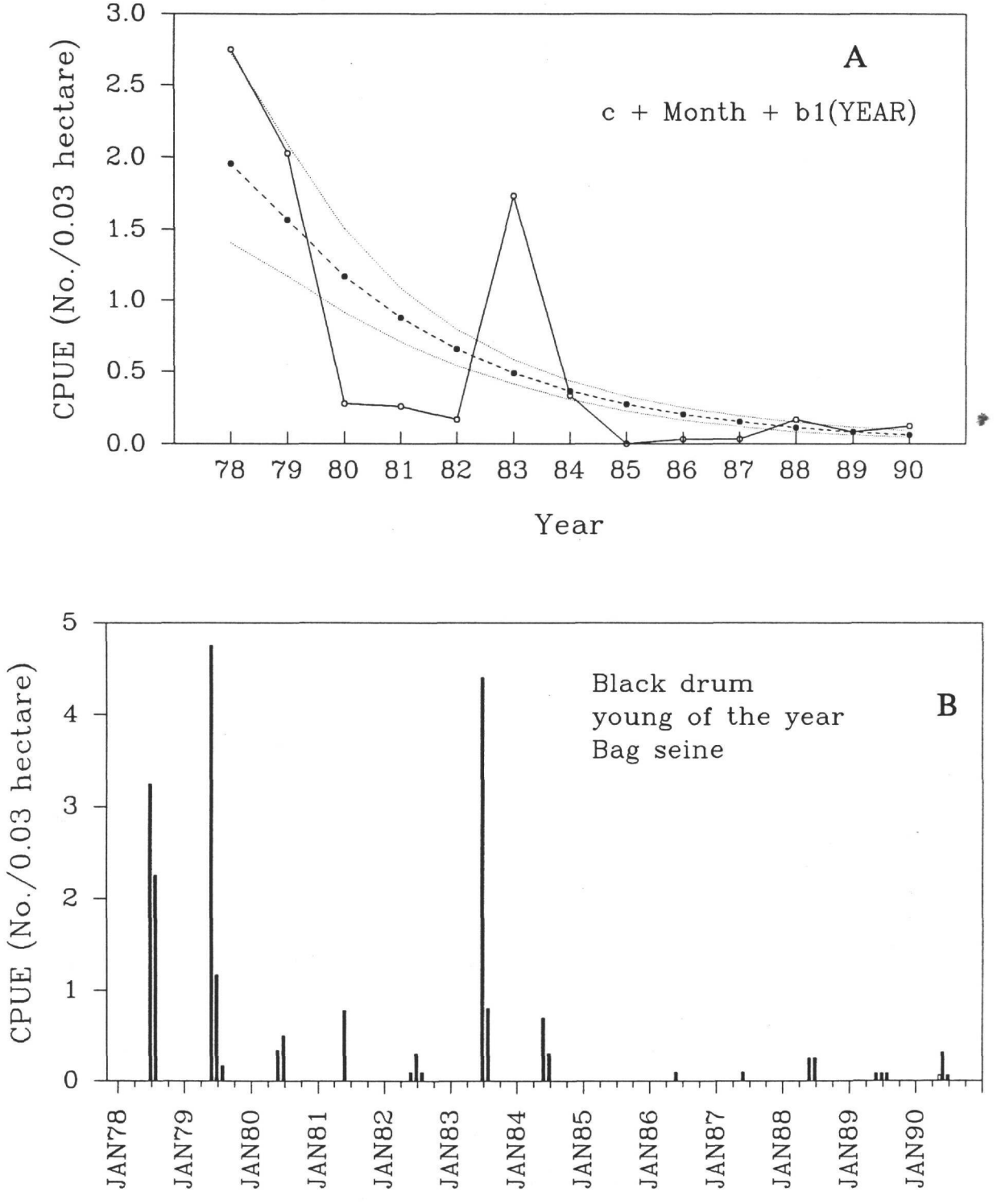


Figure III.69. A. Mean seasonal (June-August) CPUE and predicted annual CPUE with confidence intervals for young-of-the-year black drum (55-85 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: June-August. Hollow bars: months not used in analysis.

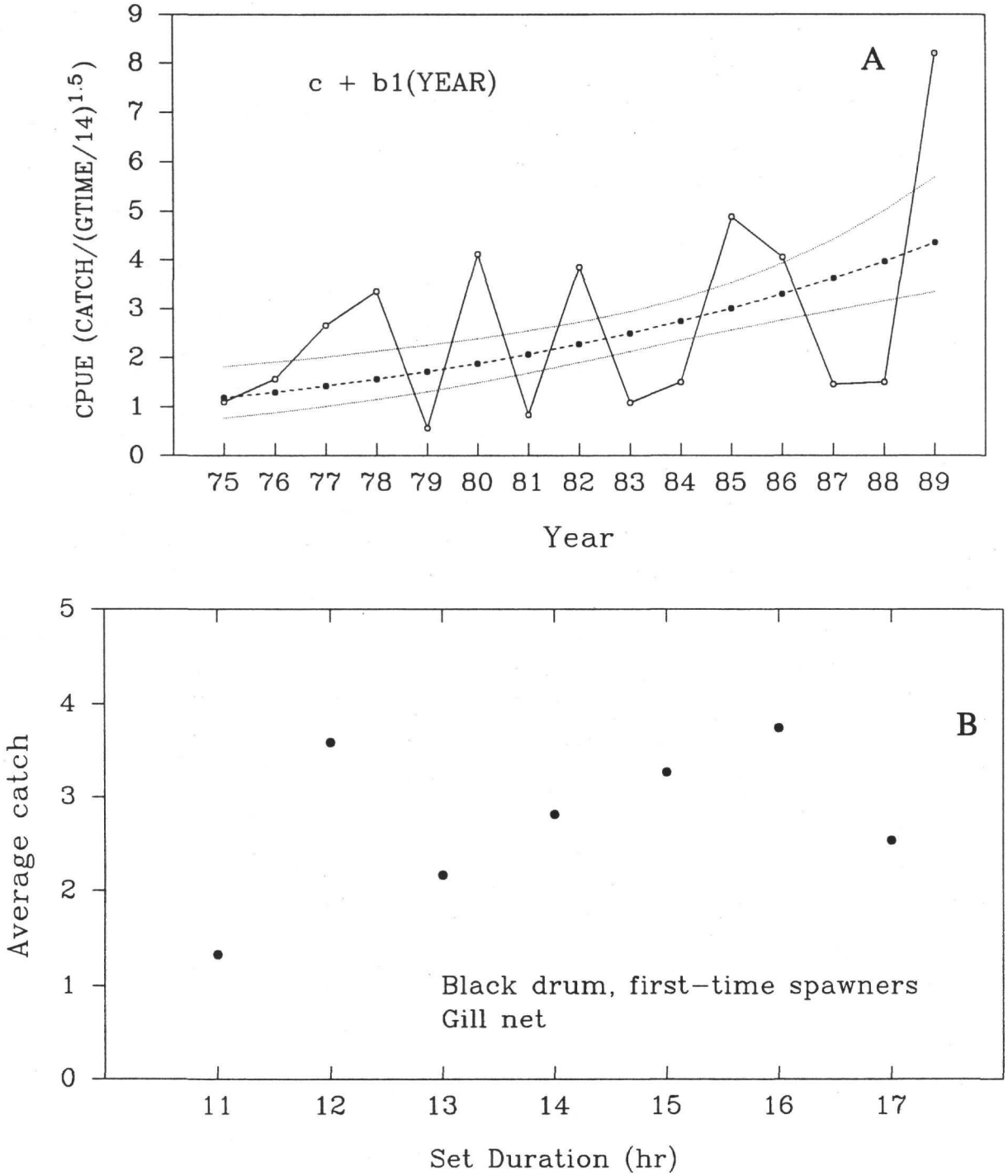


Figure III.70. A. Mean seasonal (fall) CPUE and predicted CPUE with confidence intervals for first-time spawning black drum (300-400 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1975-1989.

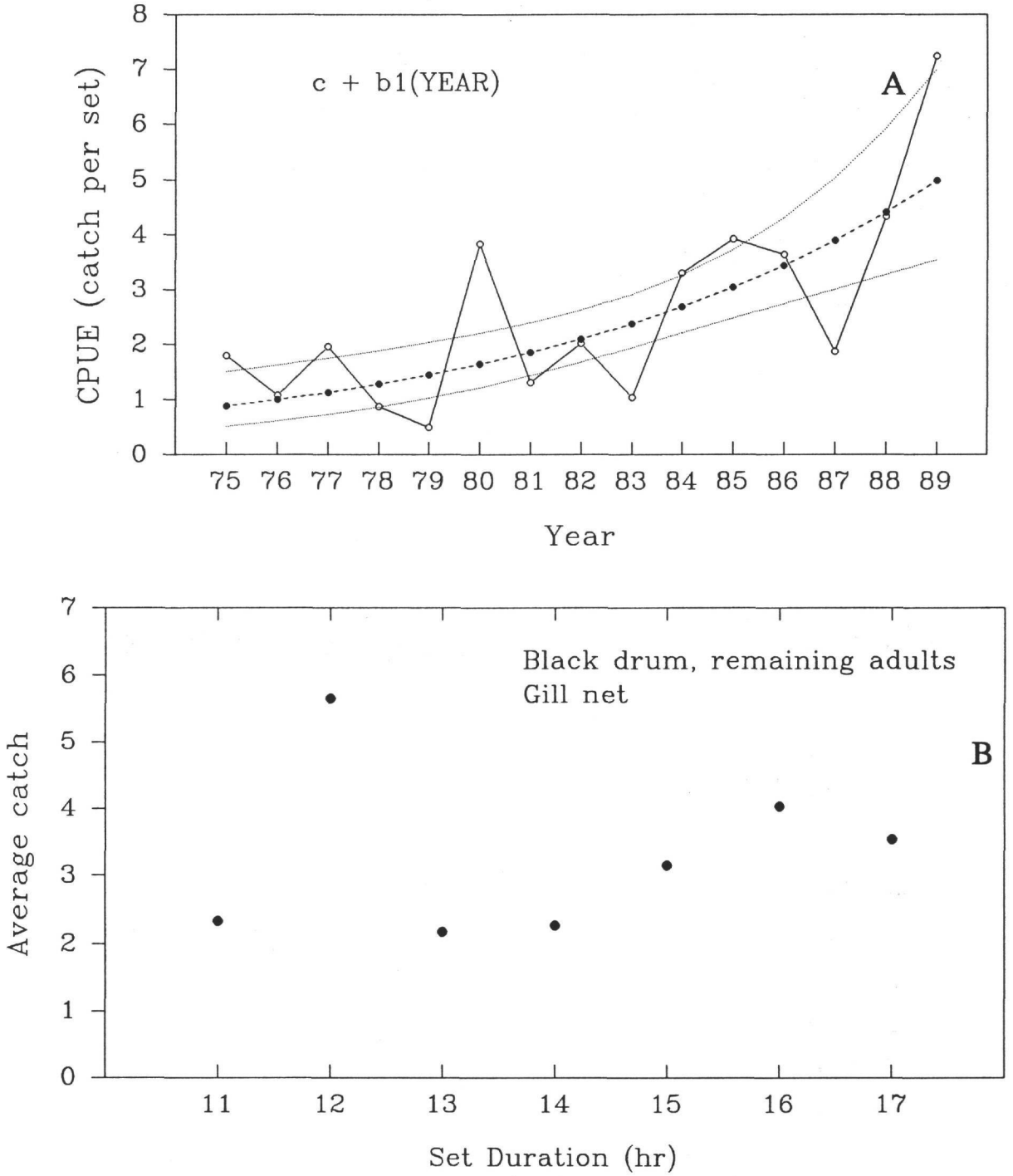


Figure III.71. A. Mean seasonal (fall) CPUE and predicted CPUE with confidence intervals for remaining adult black drum (>400 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1975-1989.

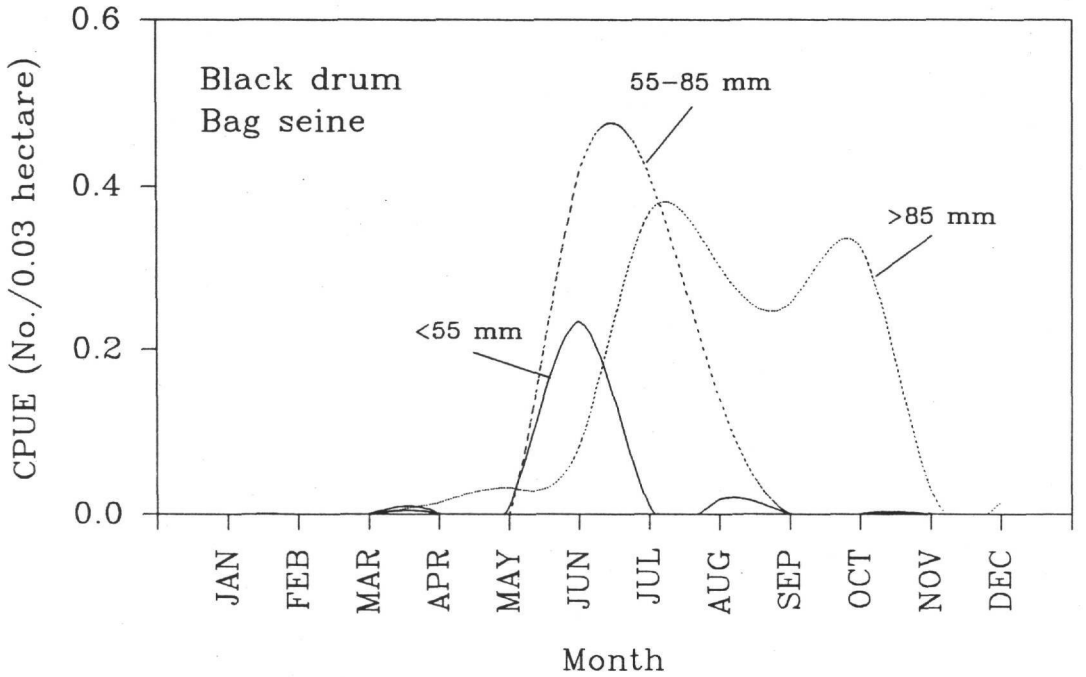


Figure III.72. Mean CPUE by month for three size classes of black drum caught by bag seine (<55 mm, 55-85 mm, >85 mm). Data pooled from 1978-1989.

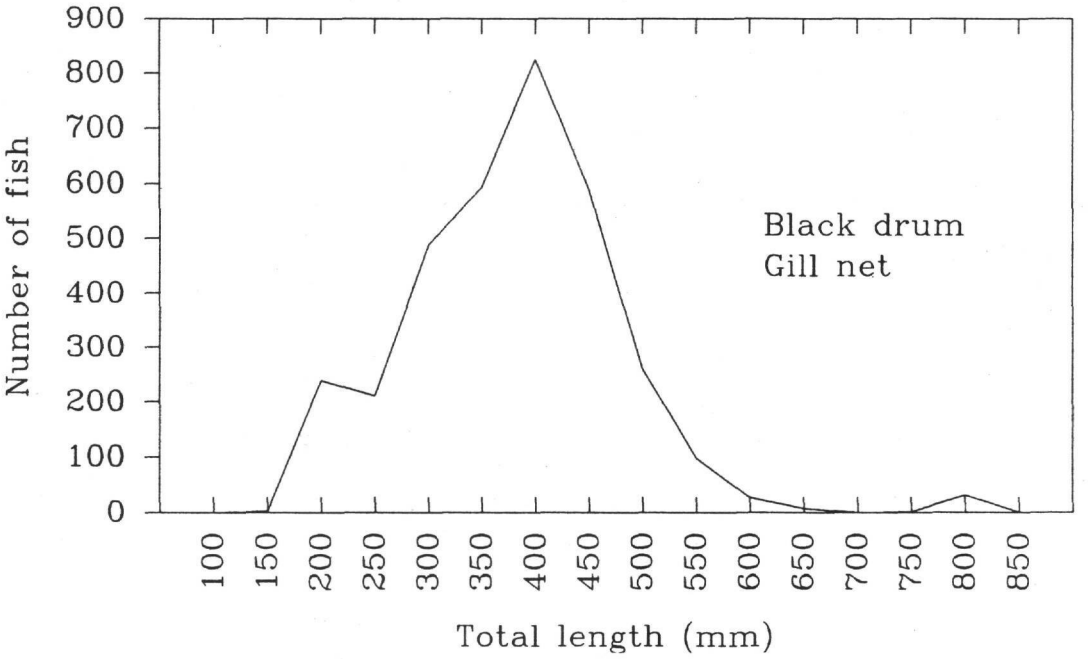


Figure III.73. Size frequency distribution for black drum caught by gill net during fall sampling period. Data pooled from 1975-1989.

First-time Spawners

Gill net: A preliminary analysis using GLIM indicated that set duration was significant (Figure III.70B), and CPUE was consequently standardized as $CATCH/(GTIME/14)^{1.5}$.

The analysis indicated that linear YEAR and the unexplained component of YEAR effects (Other) were significant, while the quadratic term was not significant (Table III.36). The fitted linear annual trend (Figure III.70A) was positive; first-time spawners increased in abundance. Most of the annual deviance (77 percent) was due to YEAR effects other than the linear or quadratic components.

Remaining Adults

Gill Net: A preliminary analysis using GLIM indicated that set duration (Figure III.71B) was not significant. Therefore CPUE was defined as catch per set.

Results of the analysis of deviance showed that the linear component of annual effects was significant, while the quadratic and other YEAR terms were not significant (Table III.37). The linear annual trend (Figure III.71A) was positive; remaining adults increased in abundance. The linear term explained 52 percent of the deviance associated with YEAR effects.

Spatial distribution

High catches of juvenile black drum were taken by bag seine in Christmas, Bastrop, and Chocolate Bays, some parts of the coastline of West Bay, and the north side of East Bay (Figure III.74). The abundance of benthic peracarid crustaceans has been shown to be higher in Christmas Bay than in West Bay or the Trinity Bay area (Zimmerman et al. 1990, 1991). It seems likely that high catches of young-of-the-year drum are tied to areas with submerged aquatic vegetation and seagrasses (Pulich and White 1989). This type of habitat generally has high densities of benthic crustaceans and annelid worms (Zimmerman et al. 1990) which serve as important food for young-of-the-year and juvenile drum (Pearson 1929, Simmons and Breuer 1962).

Adult drum gill net catches were highest along the shoreline of East Bay and the southern part of Trinity Bay (Figures III.75 and III.76); this may be related to the distributions of benthic clams (*Mulina transversa*), crabs, and small fish which are important in the diet of adult drum (Pearson 1929, Matlock and Garcia 1985). Adult black drum may aggregate in East Bay prior to moving through Rollover Pass to spawn. Pearson (1929) noted that commercial fishermen set gill nets to intercept the adult spawning migration through passes from Nueces Bay and the Laguna Madre. Osburn and Matlock (1984) found substantial intrabay movement of black drum, but no mass migration in the winter or during the spring spawning period was noted from Texas Bays.

Table III.35. Analysis of deviance for juvenile black drum (55-85 mm) caught by bag seine, June-August, 1978-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	2	20.69	10.35	14.15	<0.001
YEAR					
Linear	1	72.51	72.51	99.16	<0.001
Quadratic	1	1.74	1.74	2.38	>0.10
Other	10	63.09	6.31	8.63	<0.001
Month x Year	23	40.03	1.74	2.38	<0.001
Corrected error	206	150.63	0.73		

Table III.36. Analysis of deviance for first-time spawning black drum (300-400 mm) caught by gill net, fall season, 1975-1989. CPUE=CATCH/(GTIME/14)$^{1.5}$.

Source of Variation	D.F.	Deviance	M.D.	F	P
YEAR					
Linear	1	24.73	24.73	21.50	<0.001
Quadratic	1	2.85	2.85	2.48	>0.10
Other	12	90.13	7.51	6.53	>0.10
Error	445	511.74	1.15		

Table III.37. Analysis of deviance for remaining adult black drum (>400 mm), caught by gill net, fall season, 1975-1989. CPUE=catch/set.

Source of Variation	D.F.	Deviance	M.D.	F	P
Set Duration	1	1.03	1.03	0.81	>0.25
YEAR					
Linear	1	27.72	27.72	21.74	<0.001
Quadratic	1	2.86	2.86	2.24	>0.10
Other	12	24.77	2.06	1.62	>0.05
Set Duration x Year	14	30.60	2.19	1.71	<0.05
Error	445	567.23	1.27		

Discussion

The fluctuations in observed CPUE for young-of-the-year black drum (Figure III.69) may reflect environmental influences and/or the size of the adult spawning population. A decrease in young-of-the-year in 1980 may have resulted from a drop in the abundance of first-time spawners in 1979 (Figure III.70). The marked drop in young-of-the-year in 1984 (Figure III.69) may be related to the freeze of 1983-84 (Anonymous 1985) and a red toxic dinoflagellate bloom off Galveston in June 1984 (Harper and Guillen 1989). Low CPUE for young-of-the-year from 1984 to 1990 is cause for concern.

Increases in the abundance of first-time spawners and remaining adult black drum since 1984 may have been a result of regulation of the commercial and sport fisheries. The use of commercial fishing gear was banned in several parts of the Galveston Estuary in 1984 (Anonymous 1985) and size, bag and possession limits for the recreational fishery were imposed by the Texas Parks and Wildlife Commission in 1988 (Anonymous 1988). In 1988, the TPWD Commission banned the use of gill nets, trammel nets and bag seines in Texas coastal waters, including the Galveston Estuary. The decline in the abundance of adults in 1987 may have been a result of the 1986 red tide (Hammerschmidt 1987).

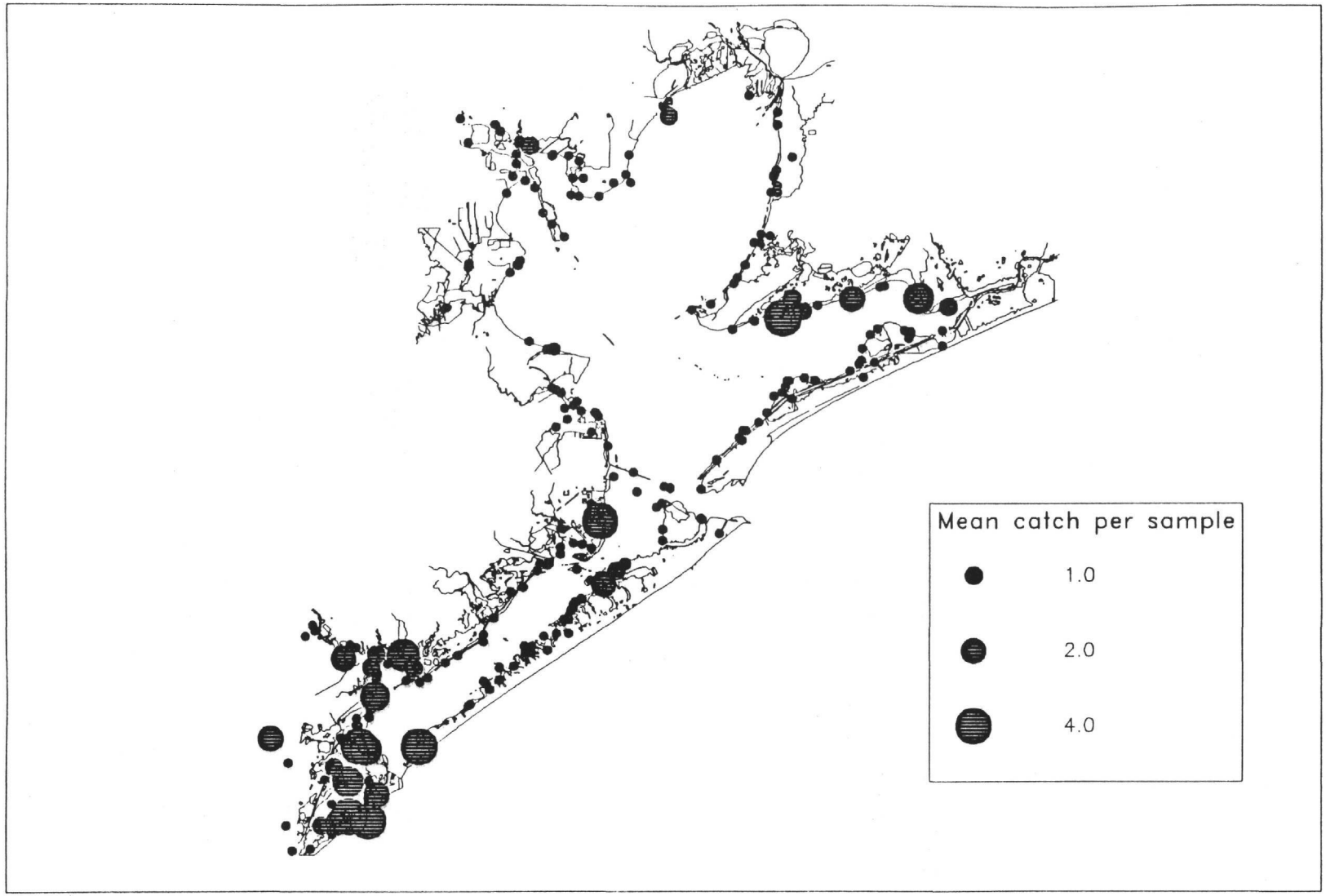


Figure III.74. Distribution of young-of-the-year black drum (55-85 mm) caught by bag seine, June-August, 1978-1989. Circle size is proportional to mean CPUE.

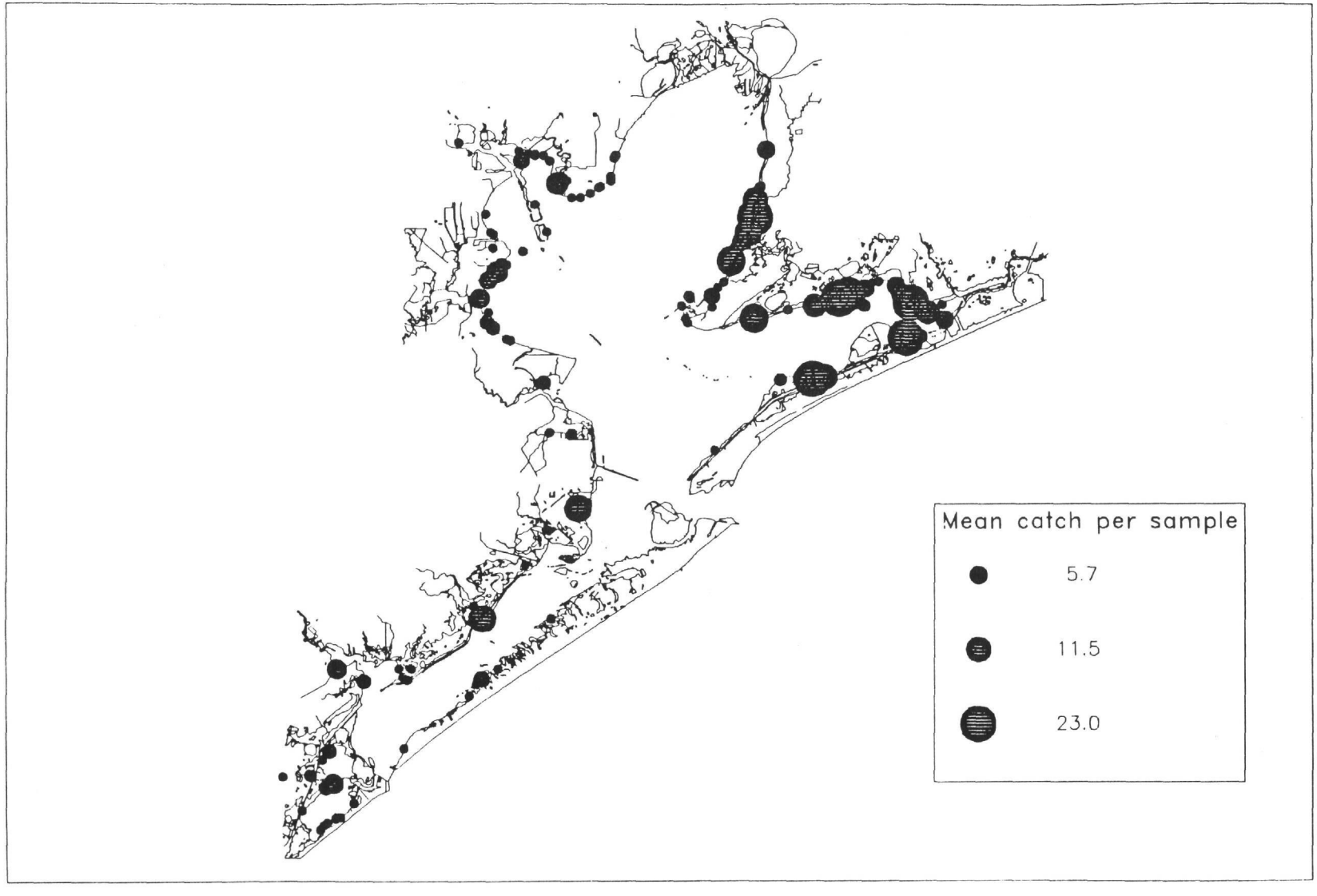


Figure III.75. Distribution of first-time spawning black drum (300-400 mm) caught by gill net, fall, 1975-1989. Circle size is proportional to mean catch per sample.

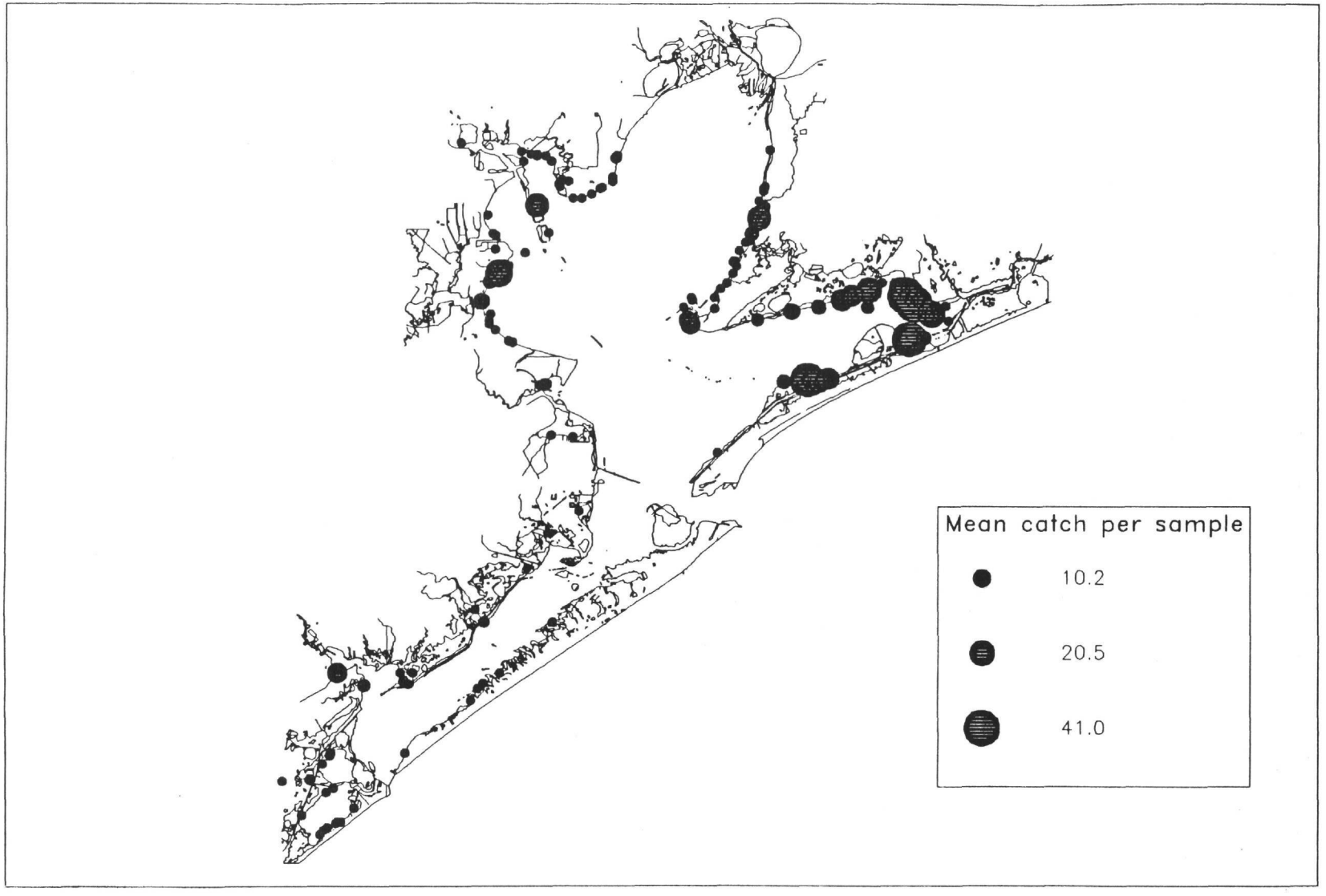


Figure III.76. Distribution of remaining adult black drum (>400 mm) caught by gill net, fall, 1975-1989. Circles size is proportional to mean catch per sample.

Gulf Menhaden (Brevoortia patronus)

The CPUE for young-of-the-year (20-30 mm) Gulf menhaden peaked in 1980, then declined through 1989 (Figure III.77). First-time spawners (100-120 mm) showed a quadratic trend, with maximum catch rates in the winter of 1985-86; 1990 levels are slightly higher than those for 1983 (Figure III.78). Remaining adults peaked in 1977 but showed no long-term trend (Figure III.79).

Season and Size Selection

Young menhaden grow rapidly and achieve a length of 130 mm by the end of their first year. Fish as small as 20 mm were effectively recruited to bag seine and it was possible to use an exceptionally narrow size range (20-30 mm). A few menhaden in this size range were caught in January, but heavy recruitment did not occur until February (Figure III.80). The months chosen for analysis of bag seine data were those when young of the year were continually recruiting, from February through July.

Menhaden spawn in Gulf waters at one year of age, at a size of approximately 130 mm (Etzold and Christmas 1979). A narrow size range (100-120 mm) was chosen to represent first-time spawners and to minimize repeated sampling of the cohort. A calendar year was used for analysis because menhaden in this size range were abundant in trawl data throughout the year (Figure III.81).

Gill nets captured an older size class than first-time spawners; menhaden smaller than 150 mm were not effectively recruited to gill net (Figure III.82). Fish of all sizes caught by gill net were used to represent the remaining adult population. The fall season was chosen for analysis because menhaden probably leave the estuaries to spawn in the Gulf during September or October (Turner 1969; Fore 1970; Etzold and Christmas 1979).

Young of the Year

Bag seine: Both linear and quadratic annual effects were significant (Table III.38). The linear component explained most of the total deviance. Categorical Month also explained much of the deviance, as expected in a strongly seasonal species (Figure III.77B).

High-catch years alternated with low catches from 1978 to 1985 (Figure III.77). The CPUE reached a maximum of over 350 fish per 0.03 hectare in March of 1980 and declined thereafter. From 1985 to 1989 annual CPUE was fairly constant at low levels.

First-time spawners

Trawl: The analysis of deviance showed the annual trend was strongly quadratic (Table III.39). The linear component, though significant, accounted for a relatively small proportion of the deviance. Categorical Month and Year-Month interaction, indicating variation in seasonality (Figure III.78B), accounted for much of the total deviance. The model including Month and linear and quadratic YEAR effects explained only 7 percent of the total deviance.

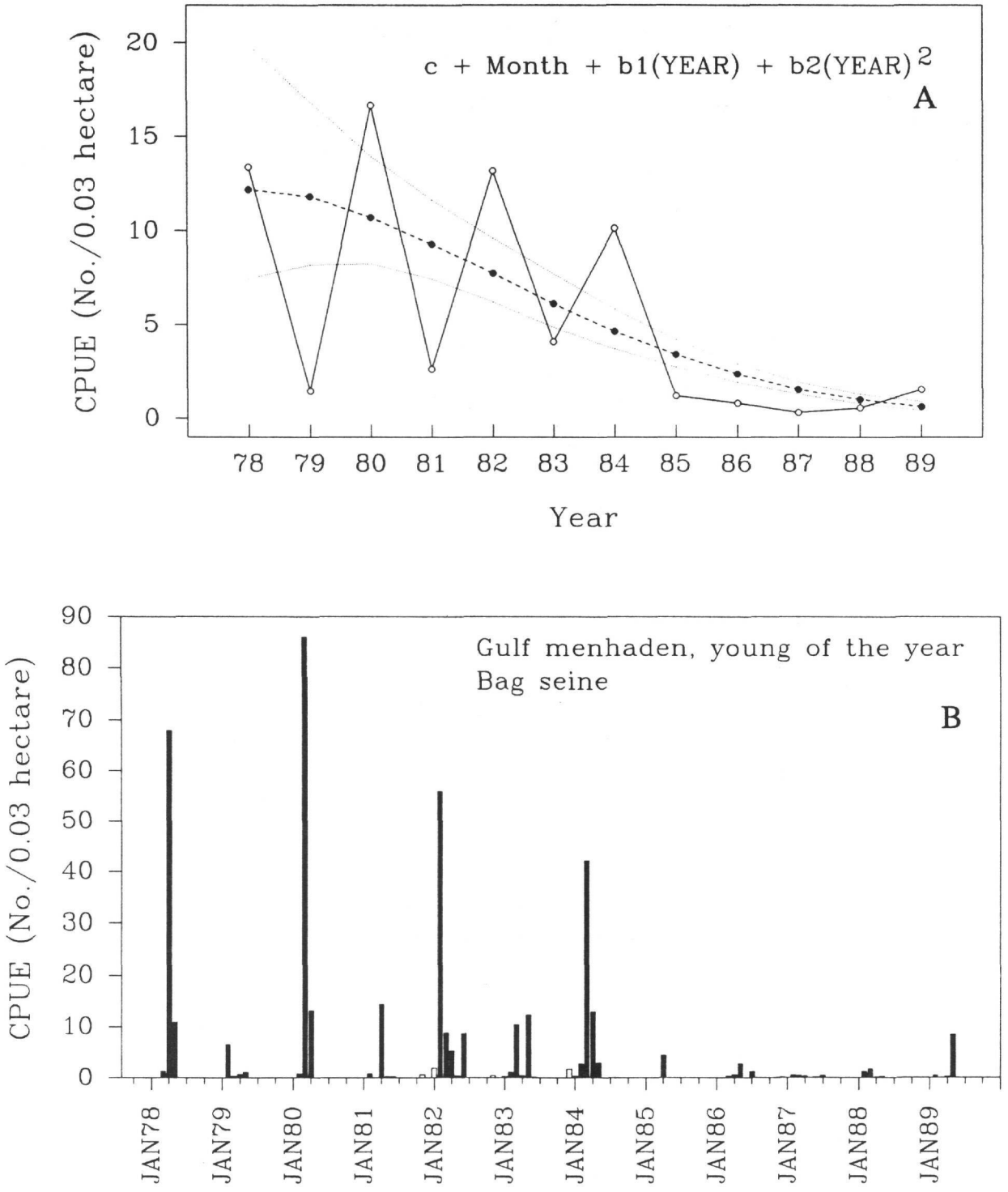


Figure III.77. A. Mean seasonal (February-July) CPUE and predicted CPUE with confidence intervals for young-of-the-year Gulf menhaden (20-30 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: February-July. Hollow bars: months not used in analysis.

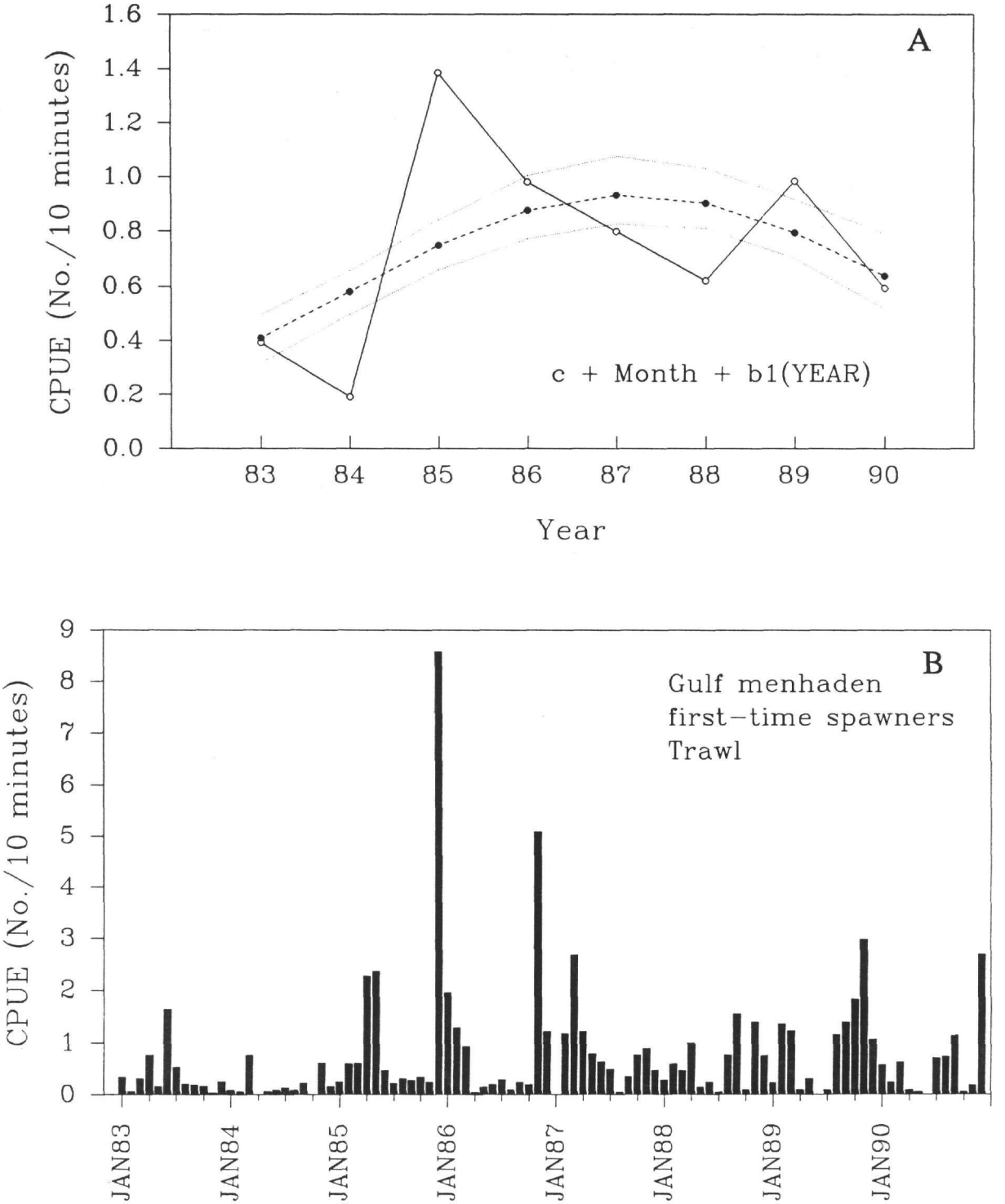


Figure III.78. A. Mean annual CPUE and predicted CPUE with confidence intervals for first-time spawning Gulf menhaden (100-120 mm) caught by trawl. B. Mean CPUE by month.

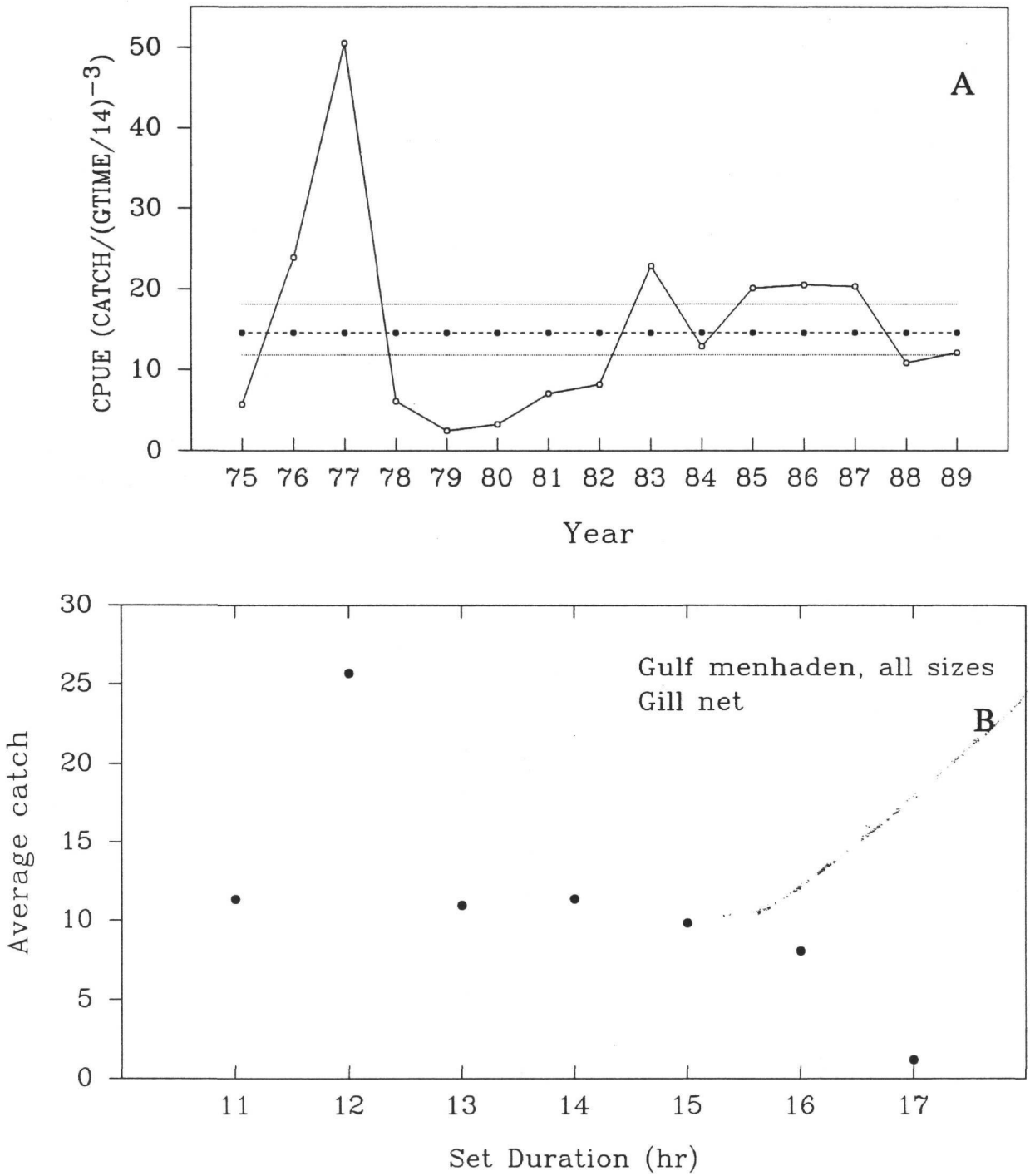


Figure III.79. A. Mean seasonal (fall) CPUE and predicted CPUE with confidence intervals for remaining adult Gulf menhaden (all sizes) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1975-1989.

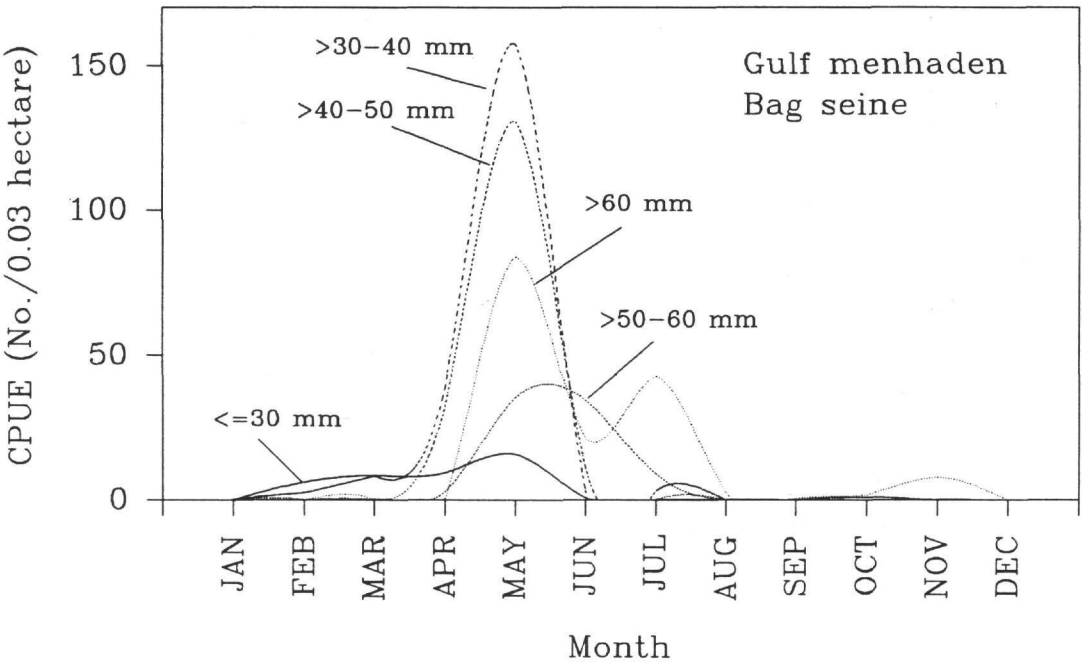


Figure III.80. Mean CPUE by month for five size classes of Gulf menhaden caught by bag seine (< =30 mm, >30-40 mm, >40-50 mm, >50-60 mm, >60 mm). Data pooled from 1978-1989.

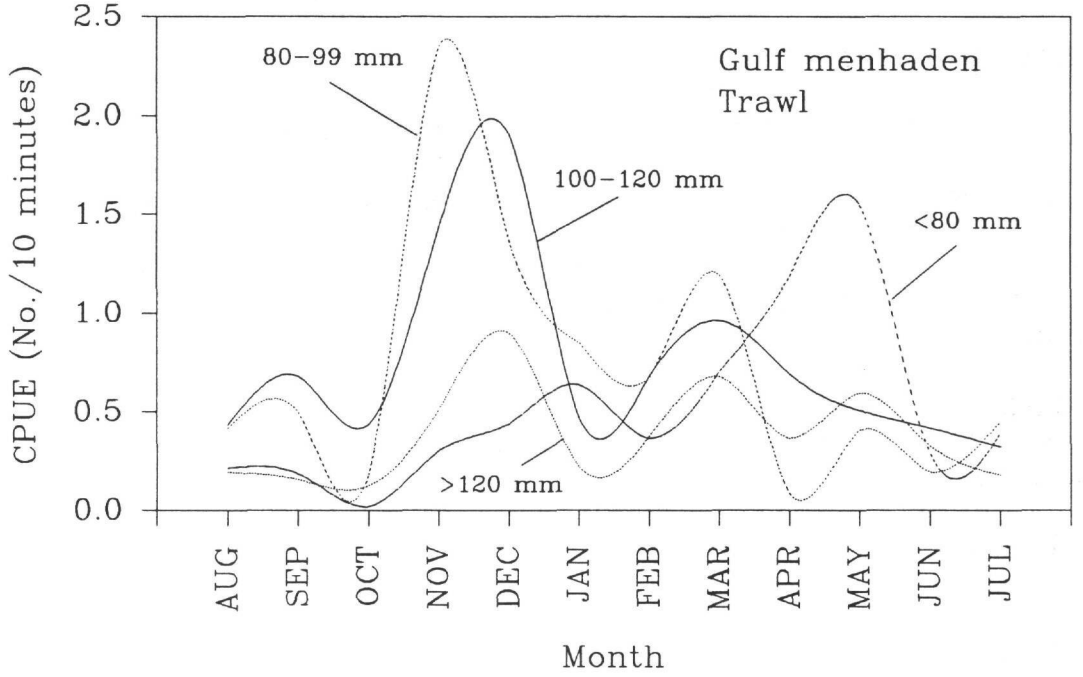


Figure III.81. Mean CPUE by month for four size classes of Gulf menhaden caught by trawl (<80 mm, 80-99 mm, 100-120 mm, >120 mm). Data pooled from 1983-1990.

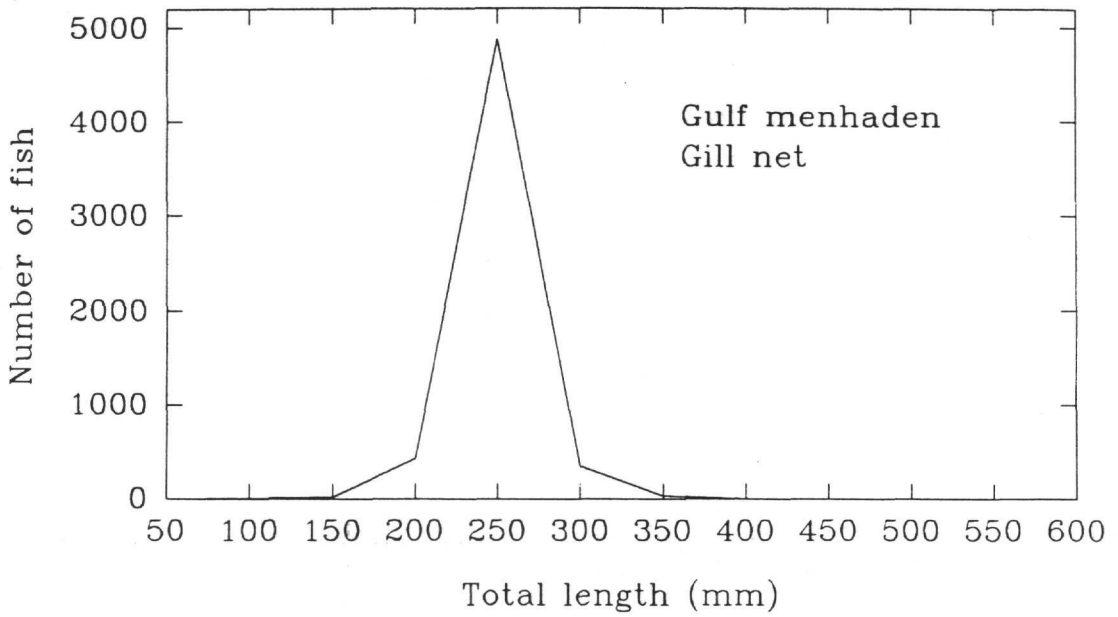


Figure III.82. Size frequency distribution of Gulf menhaden caught by gill net, fall sampling period. Data pooled from 1975 to 1989.

Remaining spawners

Gill net: The effect of set duration on catch was complex (Figure III.79B). Catch increased with set duration up to 12 hours, but as set time increased to 13 hours, catch declined dramatically. The number of individuals caught continued to decline more slowly until approximately 16 hours when a sudden drop in catch occurred as set time approached 17 hours. This decline in catch may be in part due to the tendency for long gill net sets to occur later in the season, after menhaden have migrated to the Gulf to spawn.

A model including GTIME, YEAR and $YEAR^2$ was tested using GLIM. Results indicated that set duration was significant, with a coefficient of -3. Therefore CPUE was calculated as

$$CPUE = CATCH/(GTIME/14)^{-3}$$

to give a catch per 14 hours.

Neither the linear nor quadratic trend was significant (Table III.40). The annual variation was not explained by the model. CPUE increased from 1975 to 1977, then decreased through 1979. CPUE then increased through 1983 and leveled off from 1985 through 1987, with a slight decrease in 1988 and 1989 (Figure III.79A).

Table III.38. Analysis of deviance for young-of-the-year Gulf menhaden (20-30 mm) caught by bag seine, February-July, 1978-1989.

Source of variation	D.F.	Deviance	M.D.	F	P
Month	5	102.55	20.51	17.68	<0.001
YEAR					
Linear	1	55.71	55.71	48.03	<0.001
Quadratic	1	4.58	4.58	3.95	<0.05
Other	9	84.36	9.37	8.06	<0.001
Month x Year	54	287.03	5.32	4.59	<0.001
Corrected error	362	418.72	1.16		

Table III.39. Analysis of deviance for first-time spawning Gulf menhaden (100-120 mm) caught by trawl, January-December, 1983-1990.

Source of variation	D.F.	Deviance	M.D.	F	P
Month	11	80.20	7.29	10.39	<0.001
YEAR					
Linear	1	4.73	4.73	6.74	<0.01
Quadratic	1	13.80	13.80	19.67	<0.001
Other	5	56.20	11.24	16.02	<0.001
Month x Year	77	311.20	4.04	5.76	<0.001
Corrected error	1730	1213.90	0.70		

Table III.40. Analysis of deviance for remaining adult Gulf menhaden (>100 mm) caught by gill net, fall season, 1975-1989. CPUE = CATCH/(GTIME/14)$^{-3}$.

Source of variation	D.F.	Deviance	M.D.	F	P
YEAR					
Linear	1	0.20	0.20	0.36	<0.50
Quadratic	1	0.02	0.02	0.04	>0.75
Other	12	14.96	1.25	2.27	<0.01
Error	472	261.27	0.55		

Spatial Distribution

Some similarities exist in the spatial distributions of the three size classes of Gulf menhaden. All size classes were relatively abundant in Upper Galveston Bay, while only a few large catches of adult menhaden and no large catches of young fish occurred in Trinity Bay (Figures III.83, III.84, III.85). The northern part of Lower Galveston Bay had a few high catches of adult menhaden (Figures III.84, III.85) but the first-time spawners did not extend to the south and west and were not found in West Bay (Figure III.84). There was one high catch of remaining adult fish in Chocolate Bay and a few intermediate catches in Bastrop Bay and the northern shore of West Bay, but fish of this size range were not abundant in West Bay (Figure III.85). Young of the year were relatively abundant along the shores of West Bay and in the Chocolate Bay area (Figure III.83). Distribution in East Bay was varied among the three age classes, with juveniles abundant on the southeastern shore (Figure III.83), first-time spawners most prevalent in the western section of the bay (Figure III.84), and remaining adults rare (Figure III.85).

Discussion

While young-of-the-year menhaden decreased in abundance, there was little change in first-time spawners and remaining adults. A slight increase was noted for the first-time spawners while remaining adults showed no apparent annual trend. The relative importance of factors influencing catch rates will vary for different size classes. It can

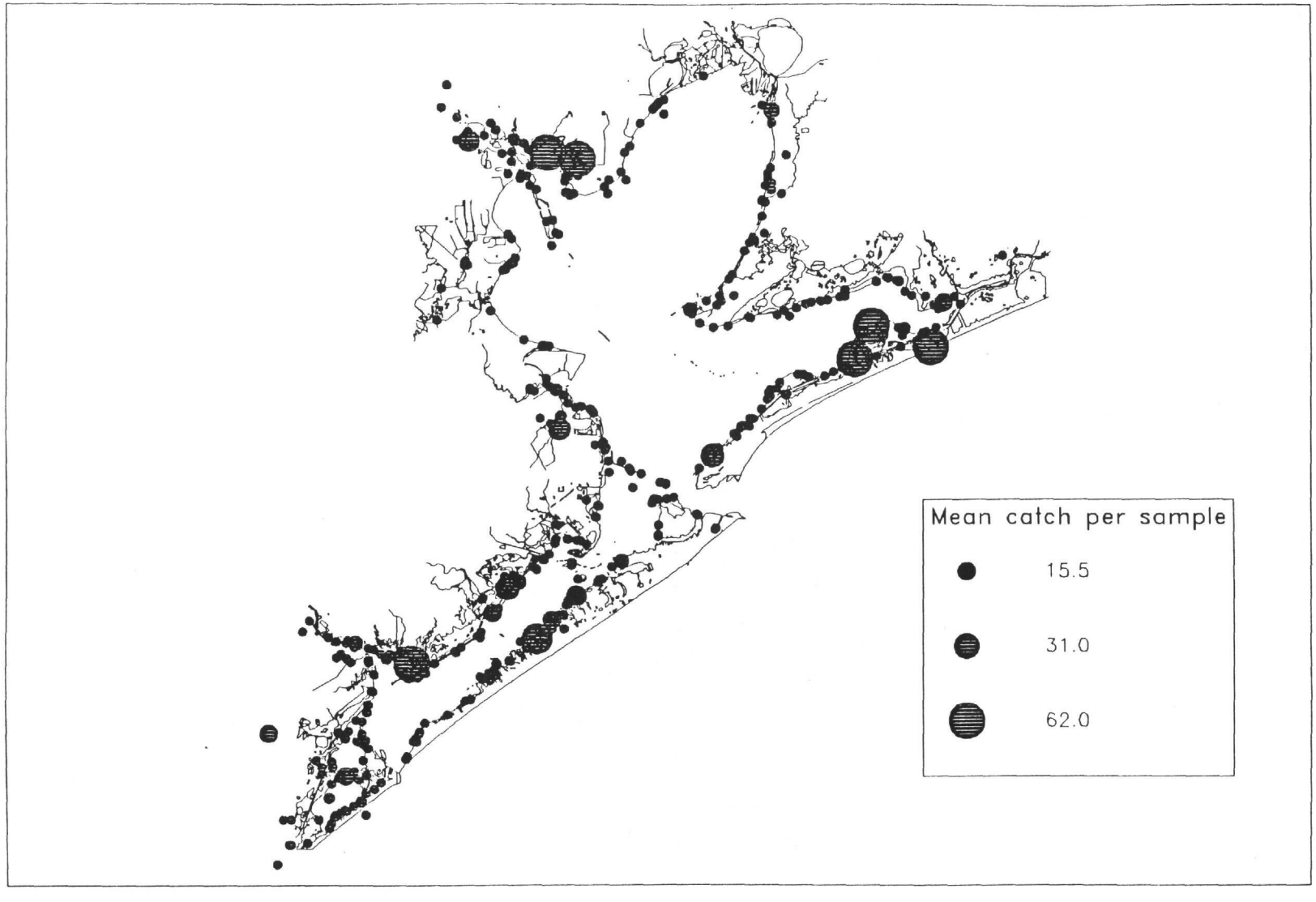


Figure III.83. Distribution of young-of-the-year Gulf menhaden (20-30 mm) caught by bag seine, February-July, 1978-1989. Circle size is proportional to mean CPUE.

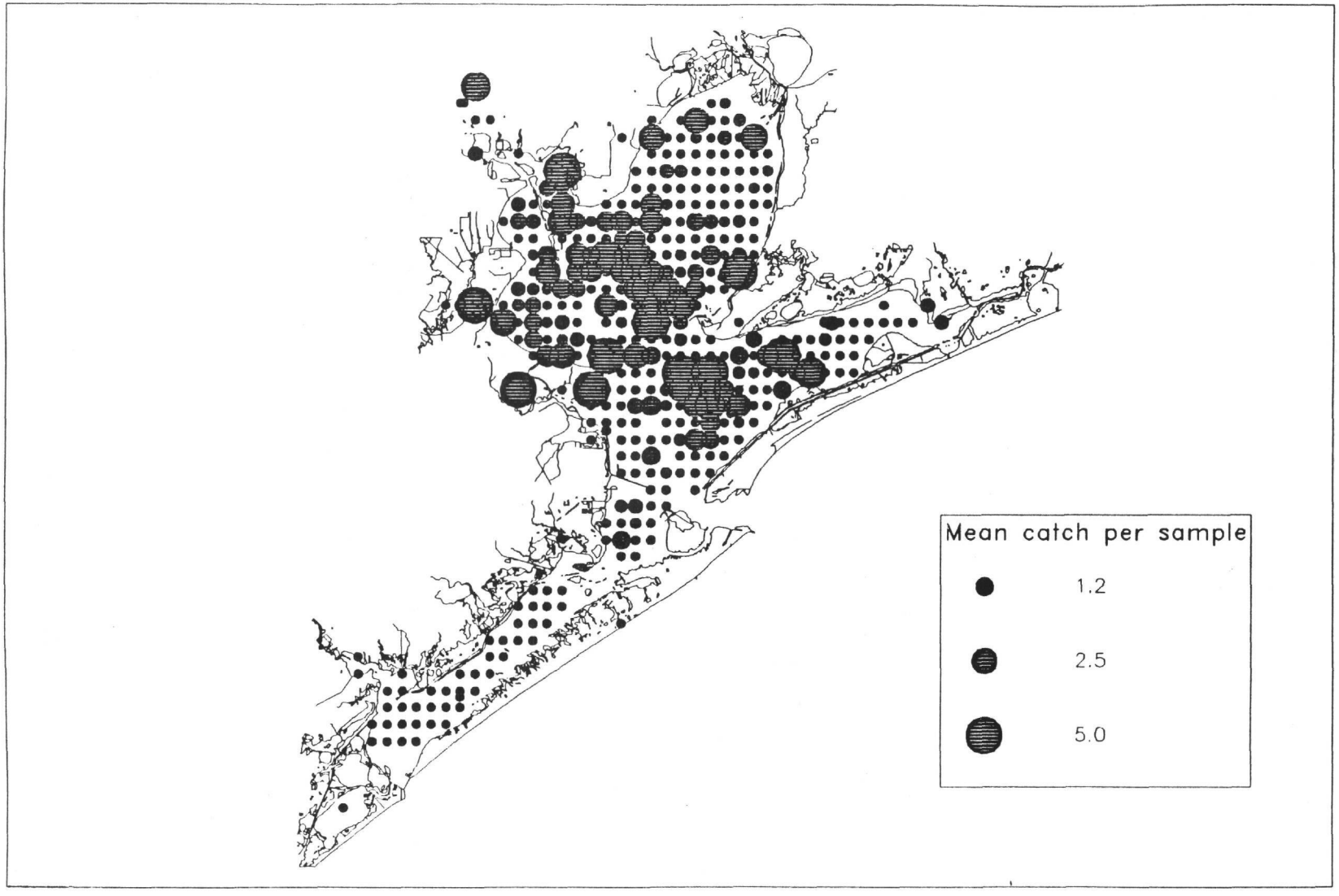


Figure III.84. Distribution of first-time spawning Gulf menhaden (100-120 mm) caught by trawl, January-December, 1983-1990. Circle size is proportional to mean CPUE.

Figure III.85. Distribution of remaining adult Gulf menhaden (>100 mm) caught by gill net, fall, 1975-1989. Circle size is proportional to mean catch per sample.

be inferred that factors influencing young fish have had a more pronounced effect on these populations than on the more mature fish. For example, the loss of estuarine marsh, important to the food supply of young menhaden (Copeland and Bechtel 1974), probably has a detrimental effect on juveniles that is not immediately apparent in the older population.

Pinfish (Lagodon rhomboides)

Young-of-the-year pinfish (40-60 mm) in bag seine catches peaked in 1984-85 and declined after 1985 (Figure III.86). Both juvenile (80-109 mm) and first-time spawning pinfish (110-140 mm) in trawl catches showed an upward trend in abundance (Figure III.87 and III.88).

Season and Size Selection

Estimated growth rates for pinfish at 30-70 mm in Texas were about 5.8 to 7.5 mm per month (Hellier 1962; Cameron 1969). A 20-mm size range for young of the year and a 30-mm size range for juveniles and first-time spawners were selected as a compromise between including enough individuals for analysis and minimizing the possibility of repeatedly sampling the same cohort.

The most numerous 20-mm size range in bag seine samples was between 40 and 60 mm (Figure III.89). Young of the year were recruited to bag seine as early as March and decreased by July, therefore the season used to estimate annual recruitment strength for pinfish was March to June.

The length frequency distribution for trawl data indicated that pinfish in the range of 80-140 mm were fully recruited to the gear (Figure III.90). Two size classes in two seasons were analyzed separately. Pinfish in the 80-109 mm size range were mostly caught in the summer (June-August), coinciding with the recruitment and growth pattern found in bag seine samples, and were used to examine the trend of juveniles. Pinfish in the 110-140 mm size range were mostly caught in the fall (September-November). The smallest sexually mature pinfish collected by Caldwell (1957) was a 189-mm female taken in October, though Hansen (1970) concluded that most pinfish mature during the fall offshore spawning migration or at offshore spawning sites and that maturation size was about 103 mm. Therefore the 110-140 mm size range was chosen to represent pinfish at or near the age to reproduce for the first time. The season used for analysis was a three-month period from September to November (Figure III.90).

Young of the year

Bag seine: The annual linear trend was not significant, but the quadratic component was significant (Table III.41). The quadratic component only accounted for 17 percent of the deviance ascribed to YEAR effects, leaving a significant fraction unexplained. The deviance associated with Month was large, reflecting the large differences in CPUE among months (Figure III.86B). High catch rates occurred in 1981, 1984 and 1985 but there was generally low recruitment in the first (1978-80) and last three years (1987-

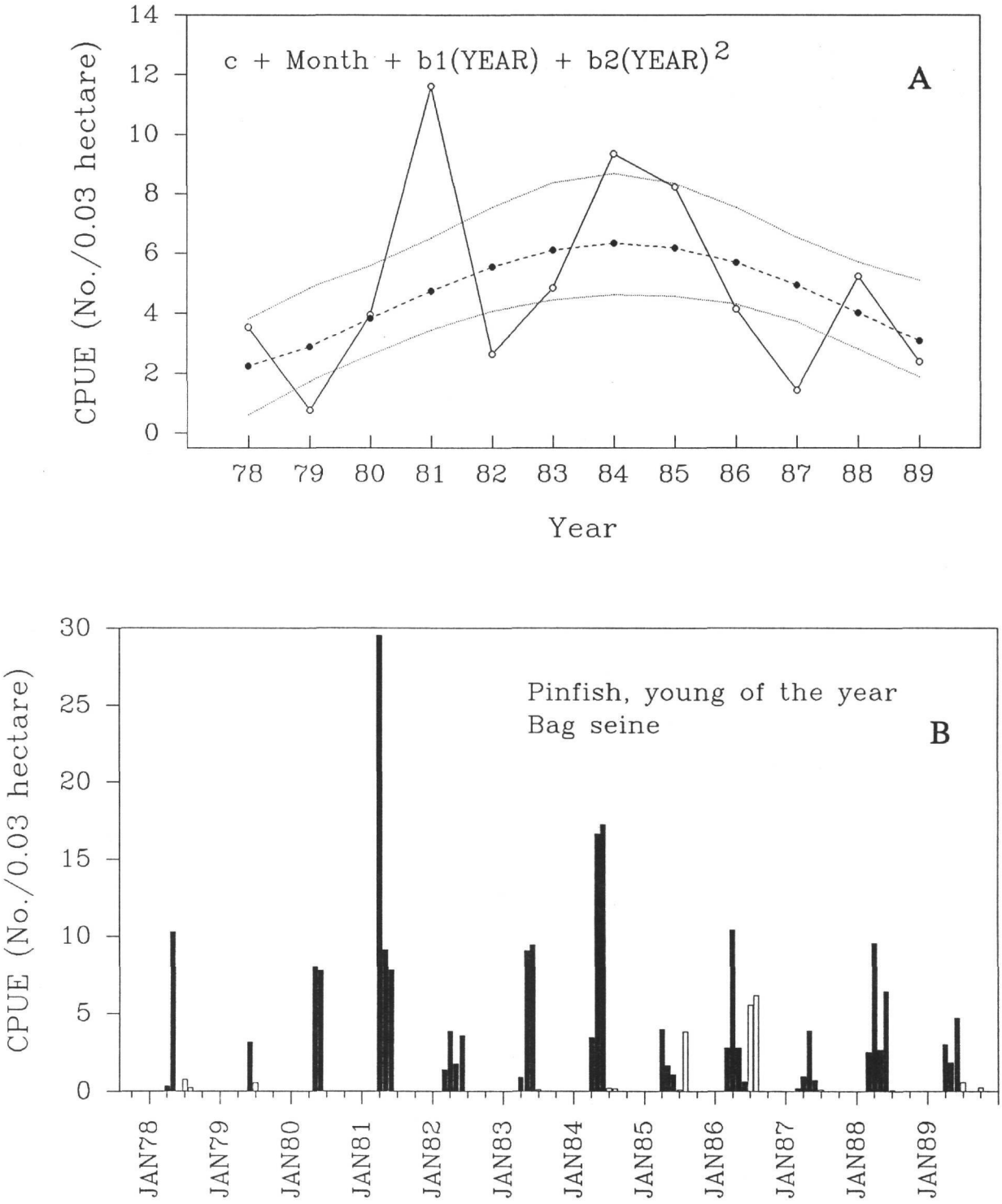


Figure III.86. A. Mean seasonal (March-June) CPUE and predicted CPUE with confidence intervals for young-of-the-year pinfish (40-60 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: March-June. Hollow bars: months not used for analysis.

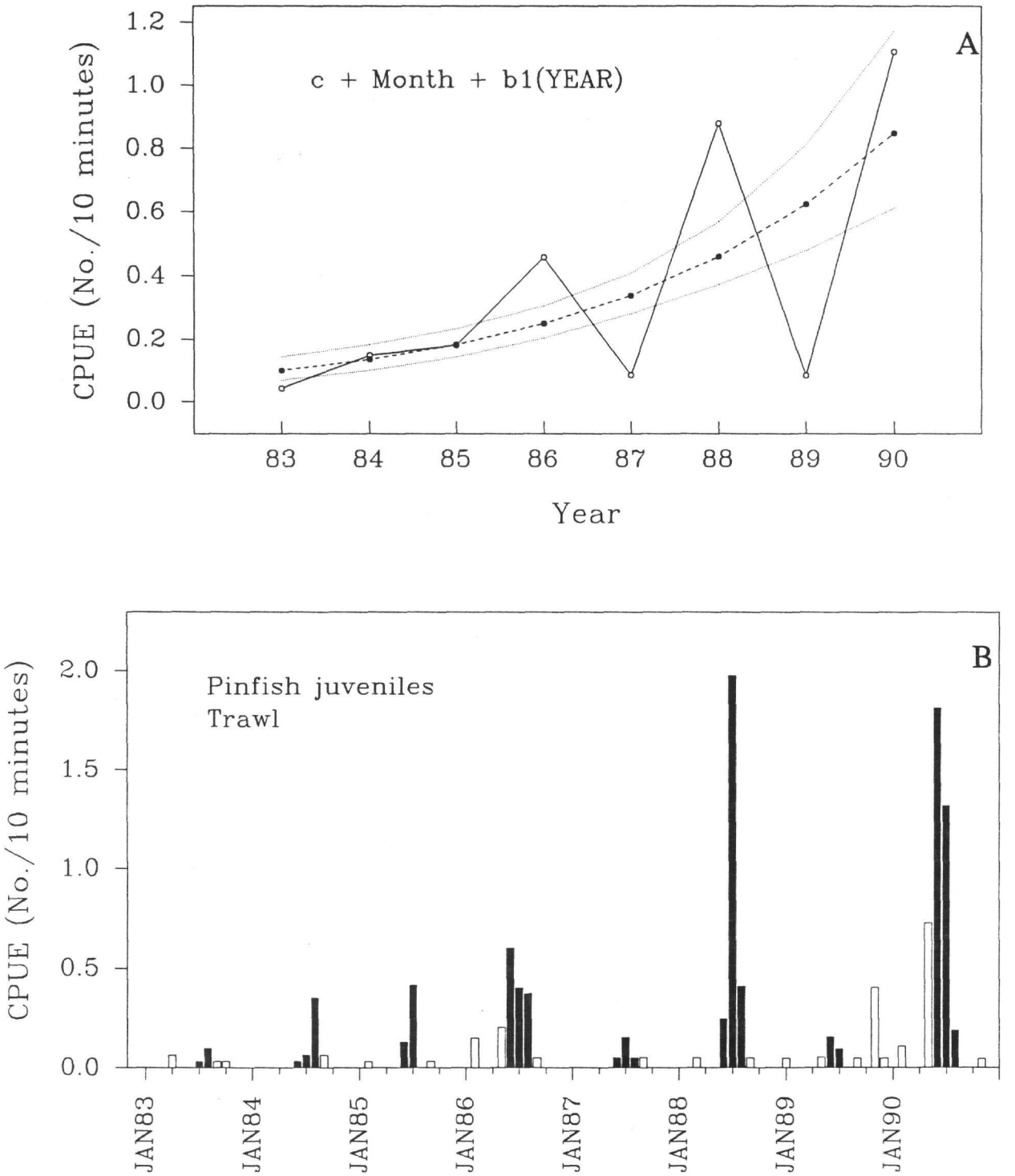


Figure III.87. A. Mean seasonal (June-August) CPUE and predicted CPUE with confidence intervals for juvenile pinfish (80-109 mm) caught by trawl. B. Mean CPUE by month. Filled bars: June-August. Hollow bars: months not used for analysis.

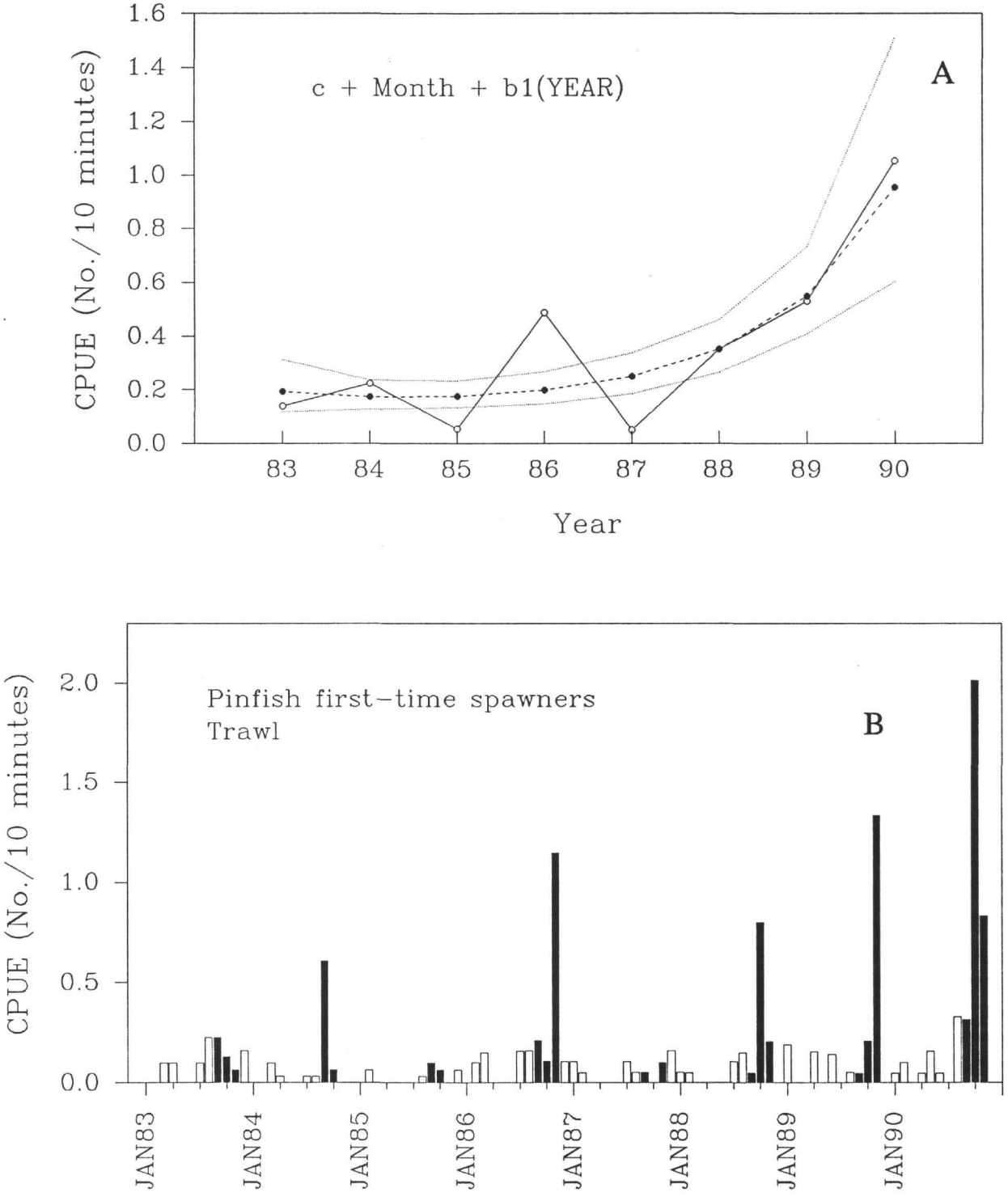


Figure III.88. A. Mean seasonal (September-November) CPUE and predicted CPUE with confidence intervals for first-time spawning pinfish (110-140 mm) caught by trawl. B. Mean CPUE by month. Filled bars: September-November. Hollow bars: months not used for analysis.

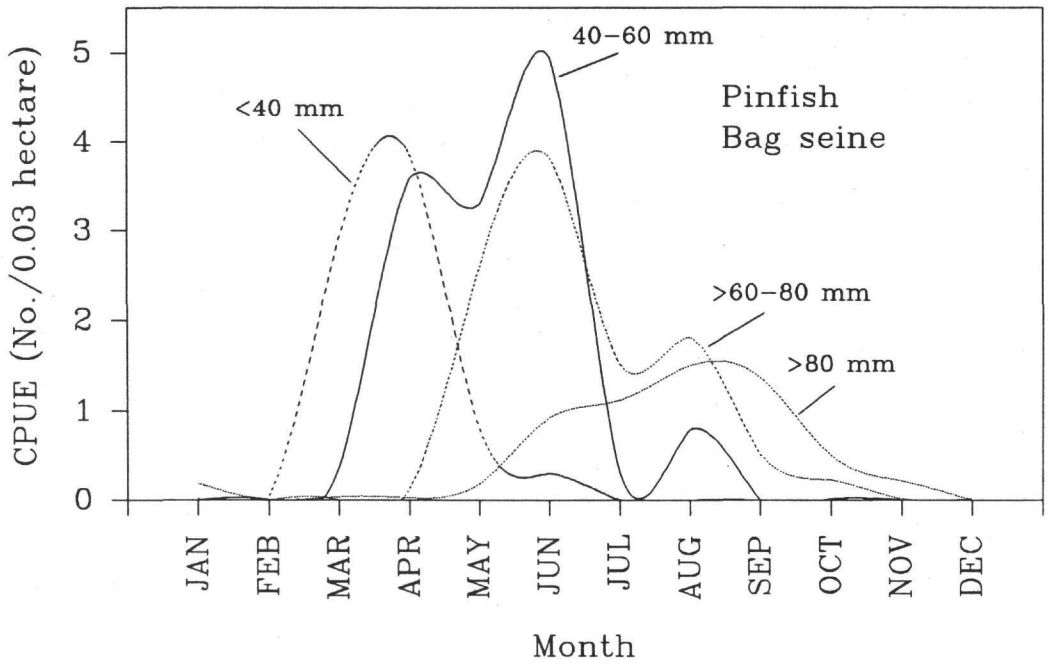


Figure III.89. Mean CPUE by month for four size classes of pinfish caught by bag seine (<40 mm, 40-60 mm, >60-80 mm, >80 mm). Data pooled from 1978-1989.

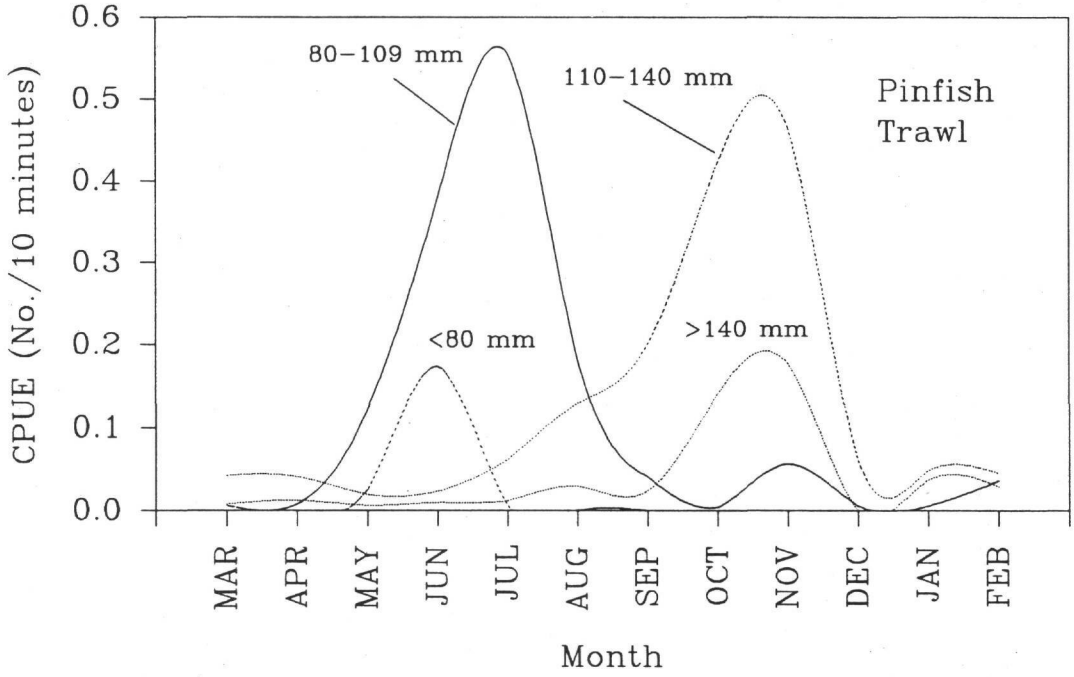


Figure III.90. Mean CPUE by month for four size classes of pinfish caught by trawl (<80 mm, 80-109 mm, 110-140 mm, >140 mm). Data pooled from 1983-1990.

89). This resulted in a negative estimate for the quadratic term and a convex-shaped trend curve (Figure III.86A).

Juveniles

Trawl: Juvenile pinfish showed a significant increasing linear trend (Table III.42, Figure III.87). The quadratic component was not significant. The linear component accounted for 39 percent of the deviance associated with YEAR effects.

First-time spawners

Trawl: The analysis of deviance showed that both the linear trend and the quadratic component were positive and significant (Table III.43, Figure III.88). The linear component explained 37 percent of the annual variation, and the quadratic component accounted for 8 percent; almost as much was explained by Year-Month interaction.

The pattern of relative abundance for juveniles and first-time spawners may be correlated, with the exception of 1989. For juveniles, high catch years were 1986, 1988, and 1990, and low catches occurred in 1983, 1987, and 1989 (Figure III.87B); for first-time spawners, high catches occurred in 1986, 1989, and 1990, and low catches in 1983, 1985, and 1987 (Figure III.88B).

Spatial Distribution

Young-of-the-year pinfish were recovered almost exclusively from West Bay and the southern shore of East Bay (Figure III.91). Juveniles and first-time spawners occurred almost entirely in West Bay and the adjacent part of Lower Galveston Bay southwest of the GSC (Figures III.92 and III.93). Pinfish were one of the most geographically restricted species studied.

Discussion

Pinfish were the fifth most numerous fish caught by bag seine. In contrast, they were not common in trawl samples, probably because pinfish generally prefer the shallow vegetated flats of estuaries (Muncy 1984), and bay trawls do not sample in water less than 1 m deep. Only 196 juvenile fish and 192 first-time spawners were caught. Though pinfish were scarce in trawl samples, the data should parallel the abundance trend for the population as a whole, if pinfish abundances in preferred habitats correlated with relative abundances in non-preferred habitat.

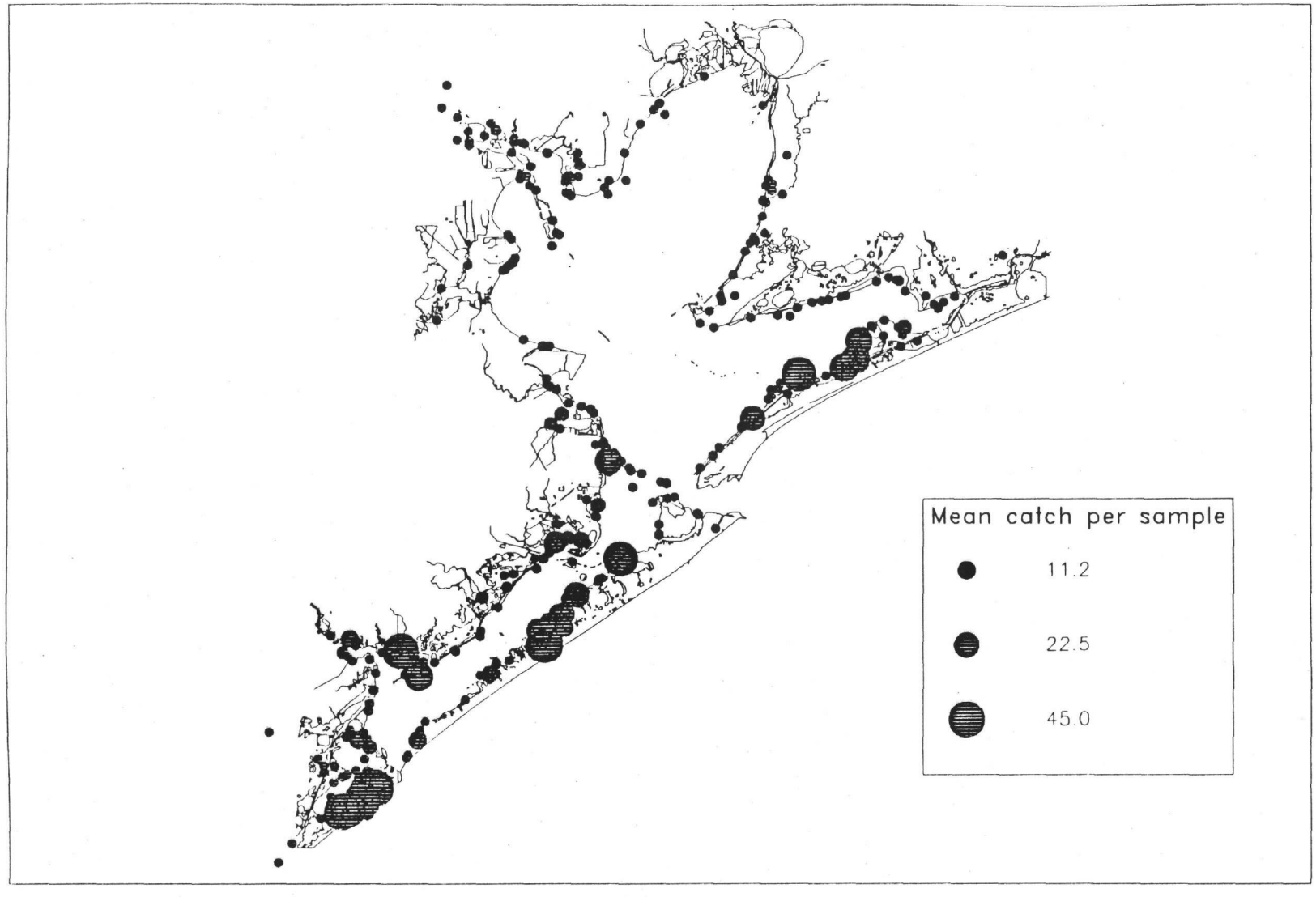


Figure III.91. Distribution of young-of-the-year pinfish (40-60 mm) caught by bag seine, March-June, 1978-1989. Circle size is proportional to mean CPUE.

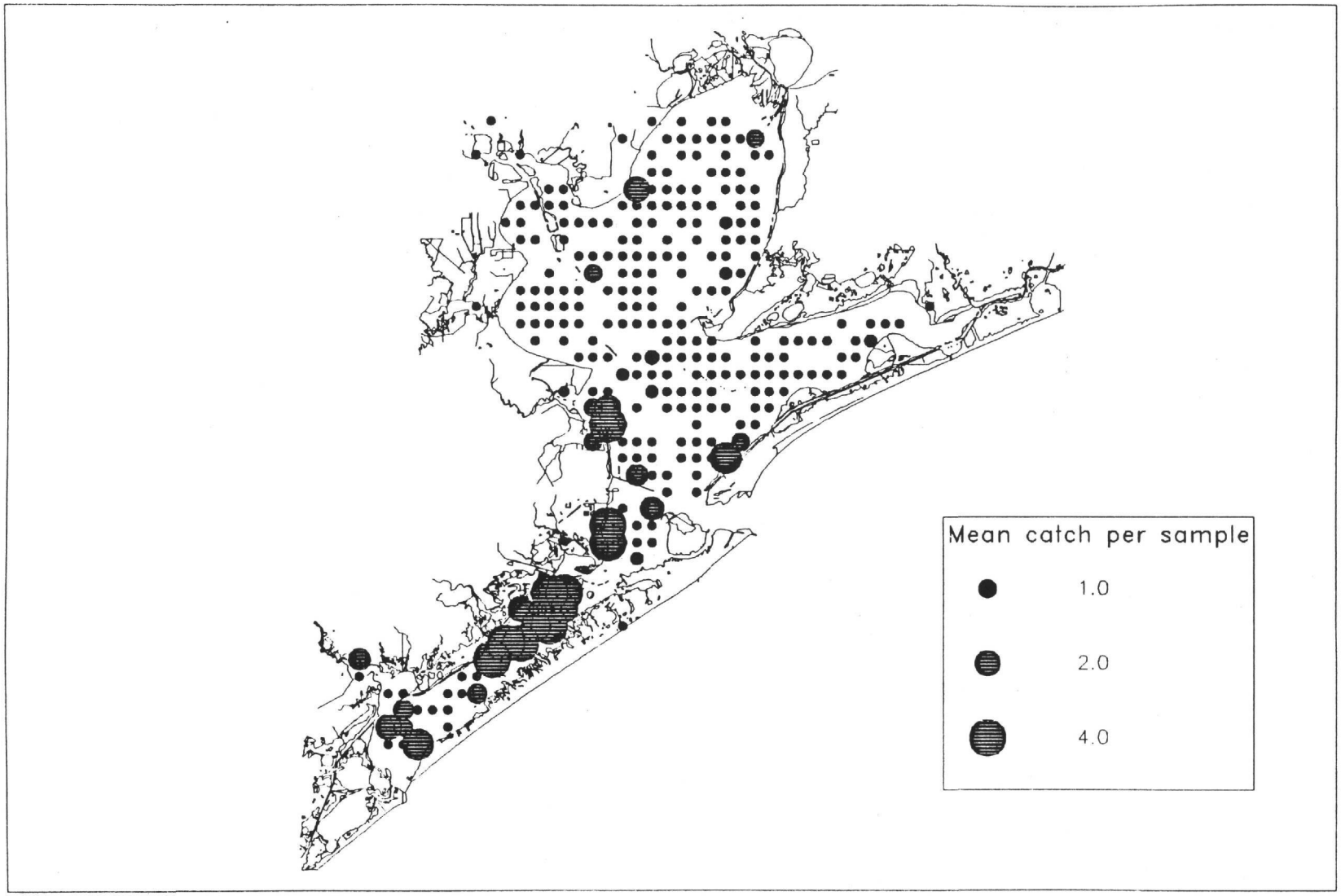


Figure III.92. Distribution of juvenile pinfish (80-109 mm) caught by trawl, June-August, 1983-1990. Circle size is proportional to mean catch per sample.

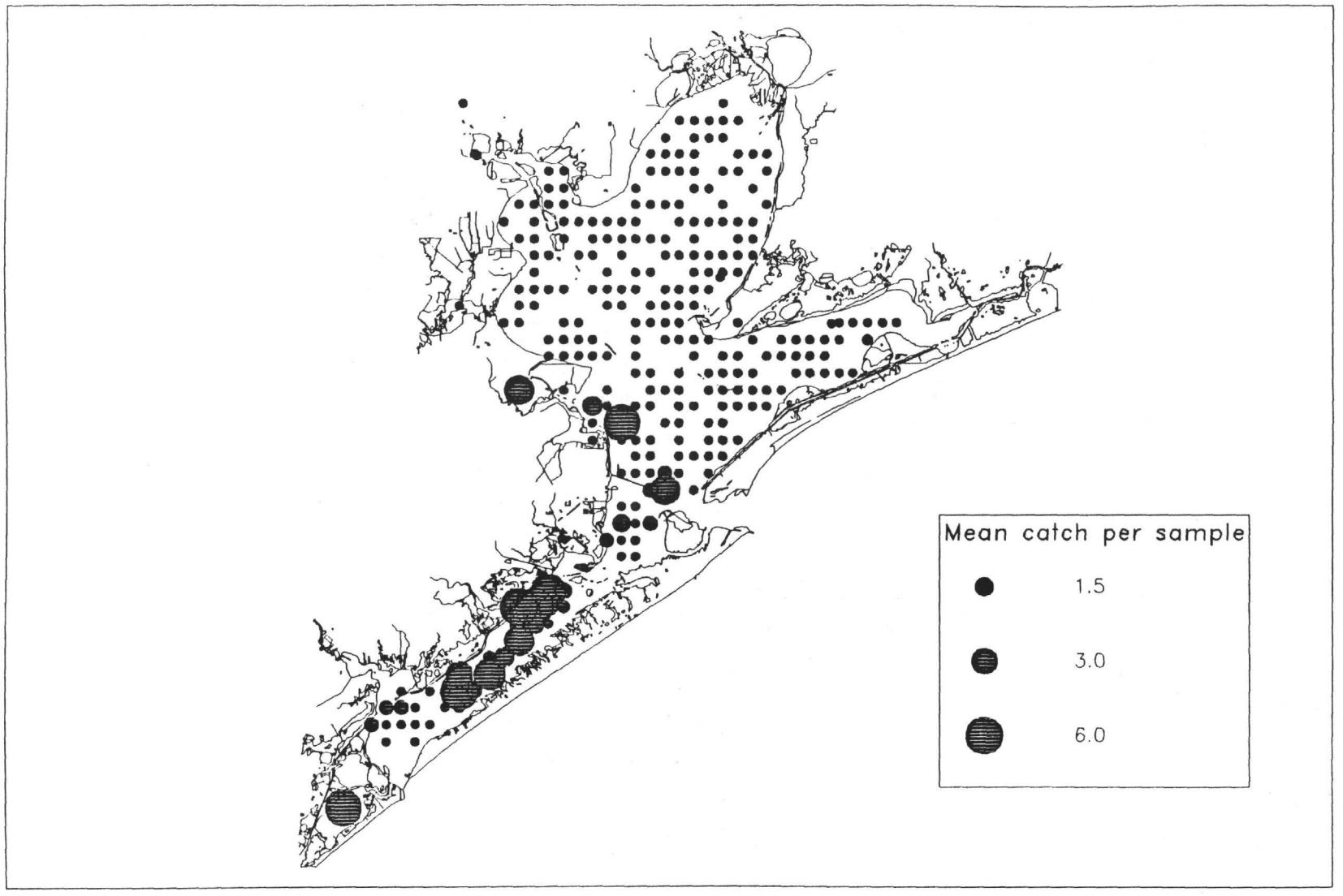


Figure III.93. Distribution of first-time spawning pinfish (110-140 mm) caught by trawl, September-November, 1983-1990. Circle size is proportional to mean CPUE.

Table III.41. Analysis of deviance for juvenile pinfish (40-60 mm) caught by bag seine, March-June, 1978-1989.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	69.61	23.20	15.71	<0.001
YEAR					
Linear	1	0.18	0.18	0.12	>0.75
Quadratic	1	8.31	8.31	5.43	<0.025
Other	9	39.55	4.39	2.87	<0.005
Month x Year	32	137.35	4.29	2.81	<0.001
Corrected error	304	463.87	1.53		

Table III.42. Analysis of deviance for juvenile pinfish (80-109 mm) caught by trawl, June-August, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	2	4.06	2.03	3.97	<0.025
YEAR					
Linear	1	20.36	20.36	39.83	<0.001
Quadratic	1	0.48	0.48	0.93	>0.25
Other	5	31.25	6.25	12.23	<0.001
Month x Year	14	32.01	2.29	4.47	<0.001
Corrected error	399	203.94	0.51		

Table III.43. Analysis of deviance for first-time spawning pinfish (110-140 mm) caught by trawl, September-November, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	2	0.32	0.16	0.28	>0.75
YEAR					
Linear	1	13.88	13.88	24.01	<0.001
Quadratic	1	3.08	3.08	5.33	<0.025
Other	5	20.84	4.17	7.21	<0.001
Month x Year	14	53.93	3.85	6.66	<0.001
Corrected error	400	231.23	0.58		

Red Drum (Sciaenops ocellata)

Young-of-the-year red drum (25-65 mm) showed a quadratic trend with a gradual increase in CPUE until a peak in 1982, a decrease from 1983 to 1986, followed by a sudden increase in 1987. The CPUE was low in the two following years (1988 and 1989; Figure III.94). Both juveniles and first-time spawners showed a general increase in CPUE through 1986, followed by a decline in 1987 (Figures III.95, III.96). Year-to-year variation in CPUE was large for young of the year and juveniles compared with that observed for first-time spawners.

Size and Season Selection

Young red drum grow rapidly; a growth rate of 0.7 to 1.7 mm per day is common (Swingle et al. 1983). A size range of 25 to 65 mm was selected to represent young of the year. Fish of this size range appeared in bag seine samples in October through February of the following year (Figure III.97), though virtually all of the fish caught in February were recruits from earlier months and fell close to the upper end of the size range. Data from October through January of the following year were used to estimate the annual recruitment strength.

Red drum spawn in the fall between mid-August and December in the Gulf of Mexico (Reagan 1973); consequently the spring season was chosen to represent the group most likely to migrate to the Gulf to spawn for the first time. While the size of red drum at sexual maturity is not well known, Matlock (1984) indicated it may be at least 500 to

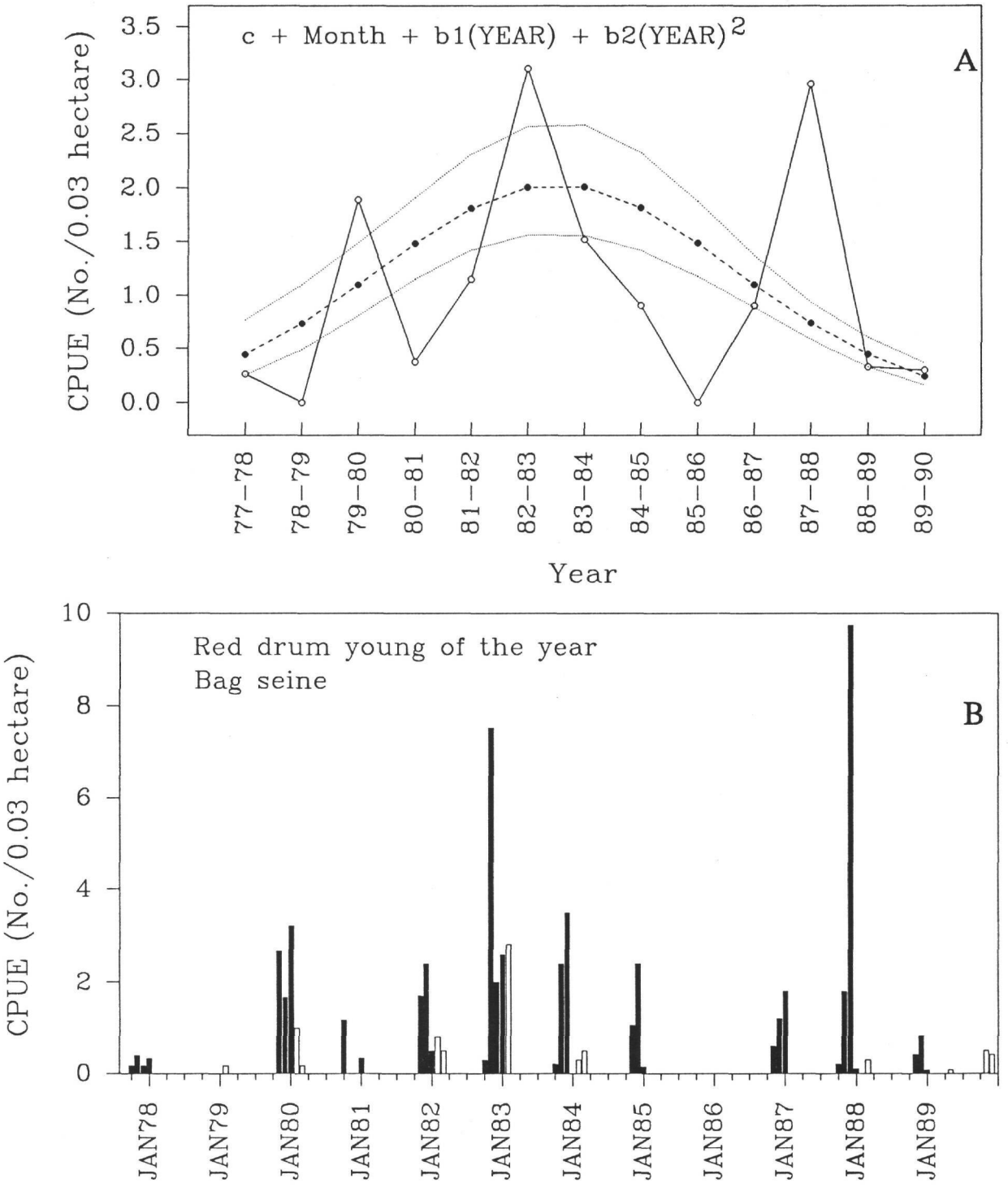


Figure III.94. A. Mean seasonal (October-January) CPUE and predicted CPUE with confidence intervals for young-of-the-year red drum (25-65 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: October-January. Hollow bars: months not used for analysis.

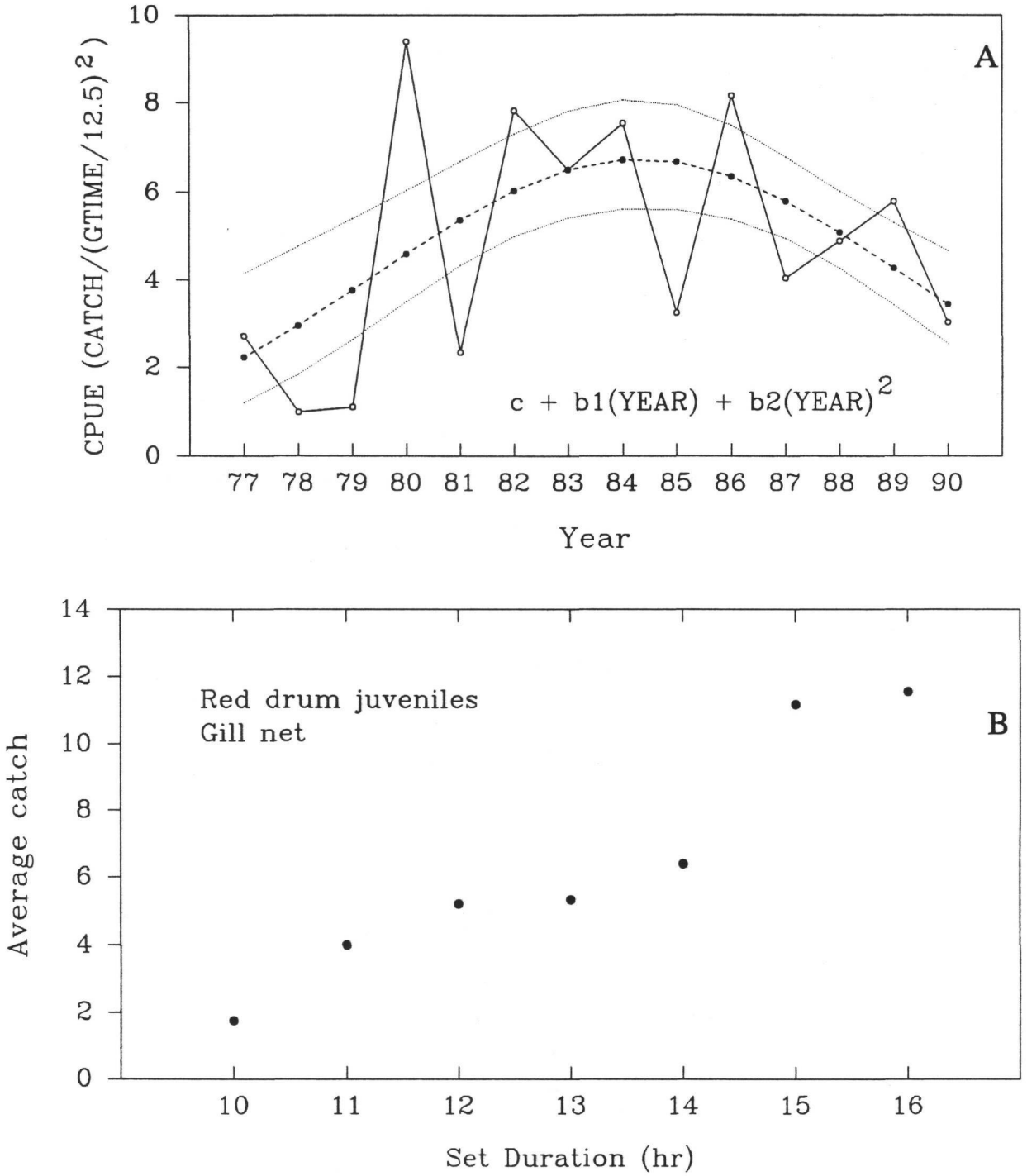


Figure III.95. A. Mean seasonal (spring) CPUE and predicted CPUE with confidence intervals for juvenile red drum (375-500 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1977-1989.

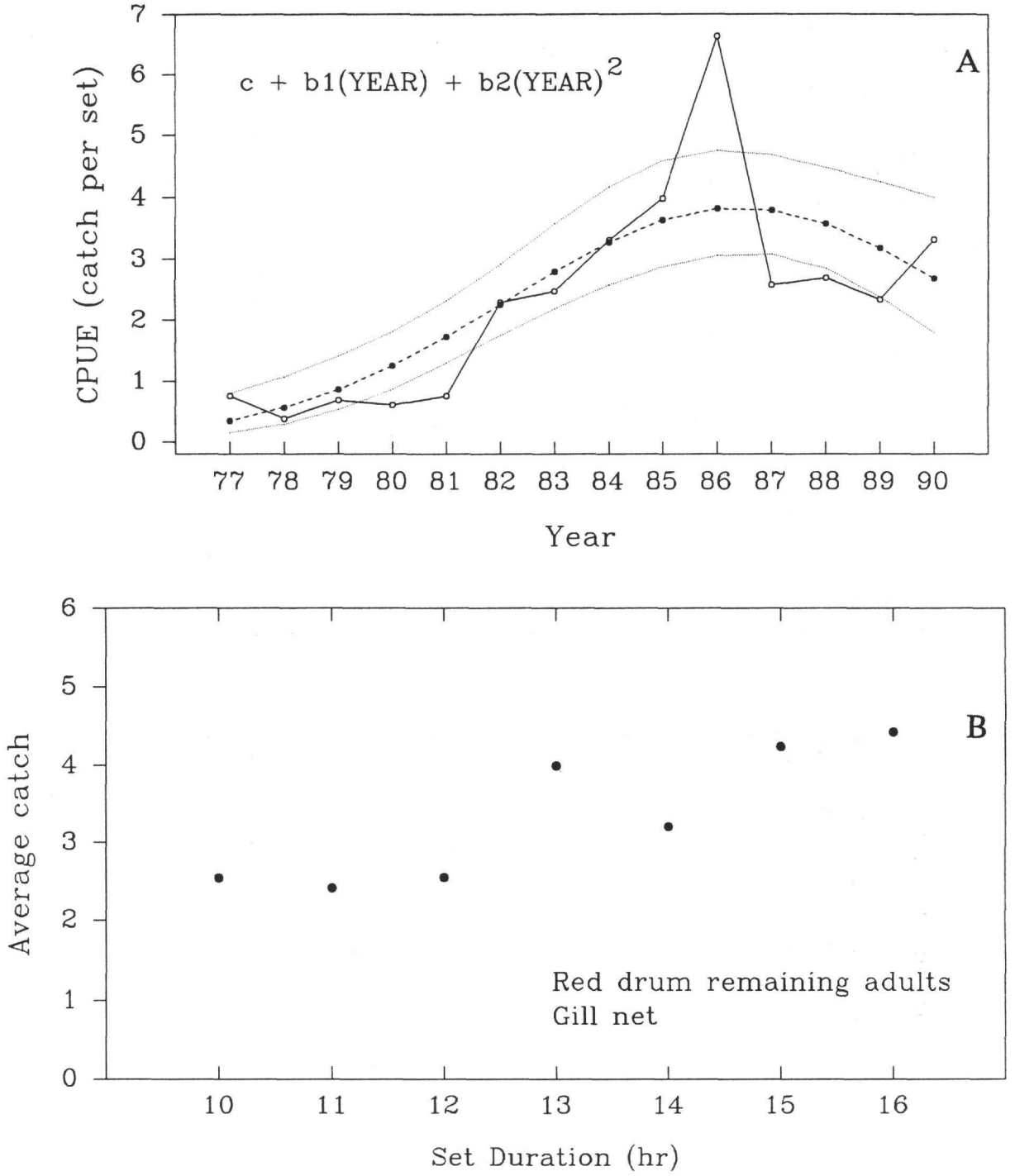


Figure III.96. A. Mean seasonal (spring) CPUE and predicted CPUE with confidence intervals for first-time spawning red drum (501-700 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1977-1989.

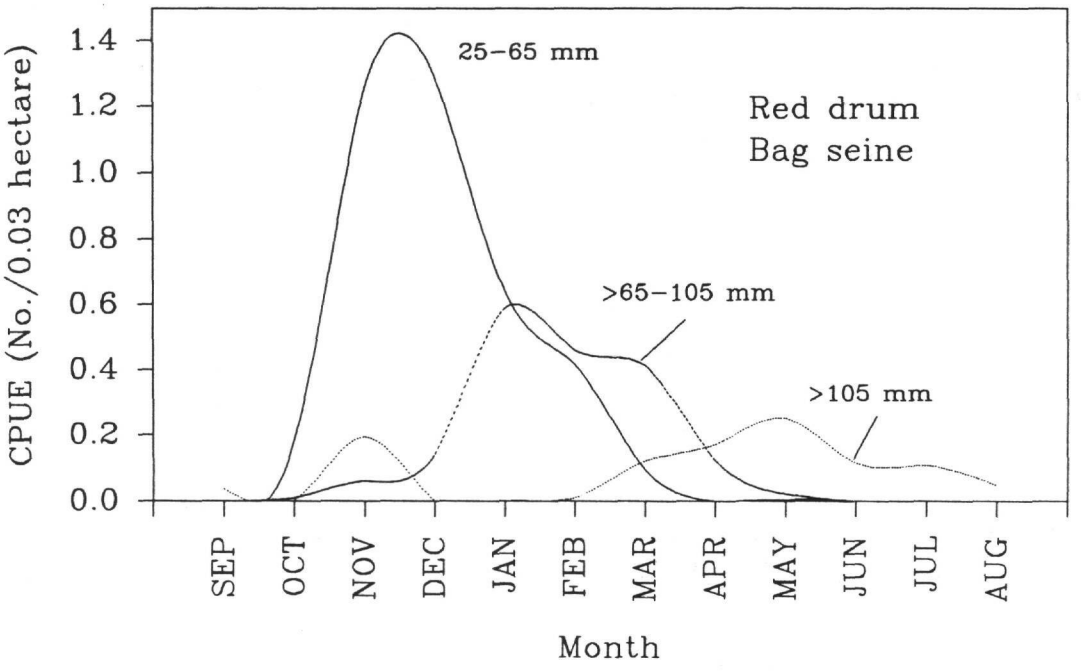


Figure III.97. Mean CPUE by month for three sizes of red drum caught by bag seine (25-65 mm, >65-105 mm, >105 mm). Data pooled from 1977-1989.

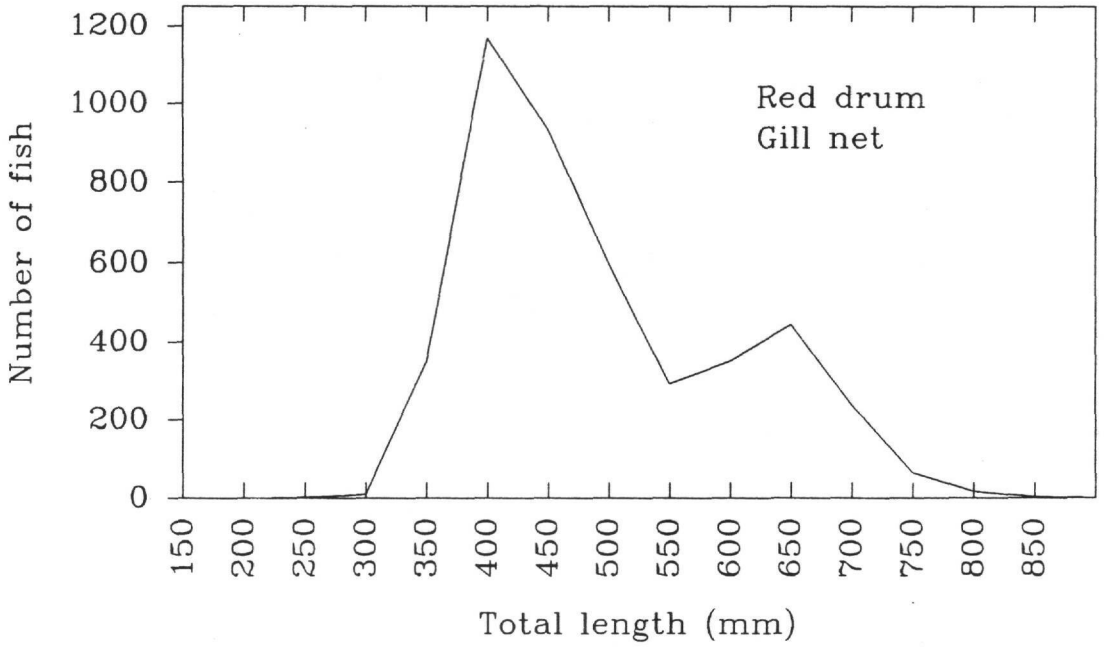


Figure III.98. Size frequency distribution of red drum caught by gill net during spring sampling period. Data pooled from 1977-1989.

700 mm on the Texas coast, and a size range of 501-700 mm was chosen to represent the first-time spawners. Smaller fish were also abundant in spring gill net data (Figure III.98) and the adjacent smaller size class, 375-500 mm, was selected to represent juveniles. Growth rates of 150 mm per year are documented for red drum of this age (Doerzbacher et al. 1988); the 125-mm size range for juveniles was used in order to confine sampling to a single year class.

Young of the year

Bag seine: Both the linear and quadratic components of YEAR were significant in the analysis of deviance (Table III.44). The quadratic component explained the greatest proportion of the annual variation; the trend centered on the peak year 1984-85. Categorical Month also explained much of the variation (Figure III.94B).

Juveniles

Gill net: Visual inspection of the plot of catch versus set duration suggested that catch varies with $GTIME^2$ (Figure III.95B). A significant relationship was indicated by both the SAS ANCOVA models and GLIM ($P<0.001$). The coefficient for GTIME obtained by GLIM was approximately 2. Therefore, CPUE was defined as

$$CPUE = CATCH/(GTIME/12.5)^2$$

to give a catch per 12.5 hours (the average set time for the spring data).

The quadratic annual trend was significant though the linear component was not (Table III.45). The model only explained a small amount of the total deviance.

Table III.44. Analysis of deviance for young-of-the-year red drum (25-65 mm) caught by bag seine, October-January, 1977-1989.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	43.43	14.48	14.77	<0.001
YEAR					
Linear	1	8.43	8.43	8.60	<0.005
Quadratic	1	20.94	20.94	21.37	<0.001
Other	10	84.15	8.42	8.59	<0.001
Month x Year	36	76.92	2.14	2.18	<0.001
Corrected error	293	286.74	0.98		

Table III.45. Analysis of deviance for juvenile red drum (375-500 mm) caught by gill net, spring season, 1983-1990. CPUE=CATCH/(GTIME/12.5)^2.

Source of Variation	D.F.	Deviance	M.D.	F	P
YEAR					
Linear	1	1.27	1.27	0.94	>0.25
Quadratic	1	15.94	15.94	11.81	<0.001
Other	11	43.72	3.97	2.94	<0.001
Error	450	607.57	1.35		

Table III.46. Analysis of deviance for first-time spawning red drum (501-700 mm) caught by gill net, spring season, 1983-1990. CPUE=catch/set.

Source of Variation	D.F.	Deviance	M.D.	F	P
GTIME	1	2.88	2.88	2.62	>0.10
YEAR					
Linear	1	11.29	11.29	10.26	<0.005
Quadratic	1	19.95	19.95	18.14	<0.001
Other	11	22.30	2.03	1.84	<0.05
GTIME x YEAR	13	10.10	0.78	0.71	>0.75
Error	425	469.26	1.10		

First-time spawners

Gill net: Figure III.96B suggested a linear relationship between catch and set duration. However, when a GLIM model including GTIME, YEAR, and $YEAR^2$ was tested, results showed set duration was not significant (P=0.25). CPUE was therefore defined as catch per set.

Both the linear and quadratic annual trends were found to be significant (Table III.46). There was relatively close correspondence between mean annual CPUE and values fitted by a model including linear and quadratic YEAR effects (Figure III.96A).

Spatial distribution

Young of the year were found throughout the estuary with the highest concentrations in Christmas Bay, Bastrop Bay, Chocolate Bay, West Bay, East Bay, around Smith Point and near the Clear Lake area (Figure III.99). The geographic distributions of juvenile and first-time spawning red drum were similar; the highest catches for both size classes were concentrated in East Bay, around Christmas Bay, Bastrop Bay, and the northern part of Upper Galveston Bay (Figures III.100, III.101).

Discussion

For all three size classes of red drum analyzed the quadratic component of YEAR was significant. In all cases, there was a general increase in CPUE during the first years of the study followed by a decline. The timing of the decline varied. The causes of these trends are not fully understood but a number of factors may contribute to them. Young red drum are usually found in protected waters with grass and mud bottoms (Simmons and Breuer 1962), and recent losses of this habitat could be detrimental to them. Food studies show that shrimp are a favorite food of juvenile red drum (Pearson 1928, Miles 1950), and fluctuations in shrimp populations could affect red drum. Population trends are further complicated by regulation and stocking efforts to rehabilitate the species. Commercial fishing was banned in 1979 and, at least initially, adult populations increased. Close to five million red drum fry were stocked in the Galveston Estuary in 1979 and over one million in 1983 (Matlock 1986); stocking may be reflected by the peak catches of young fish in those years and, to some degree, in subsequent peaks in the two larger size classes. However, no such peak appeared in 1985 when over one and a half million fingerlings were stocked, possibly because most of them were released later in the year and were not of sufficient size to be included in the 25-65 mm size range.

Sand Seatrout (Cynoscion arenarius)

Young-of-the-year sand seatrout (35-55 mm) caught by bag seine increased in abundance from 1978 through 1984, then decreased from 1984 until 1988 (Figure III.102), with peak catches in 1982-84 and 1989. Juveniles (65-85 mm) caught by trawl increased in abundance from 1983 to 1990 (Figure III.103) though first-time spawners (140-160 mm)

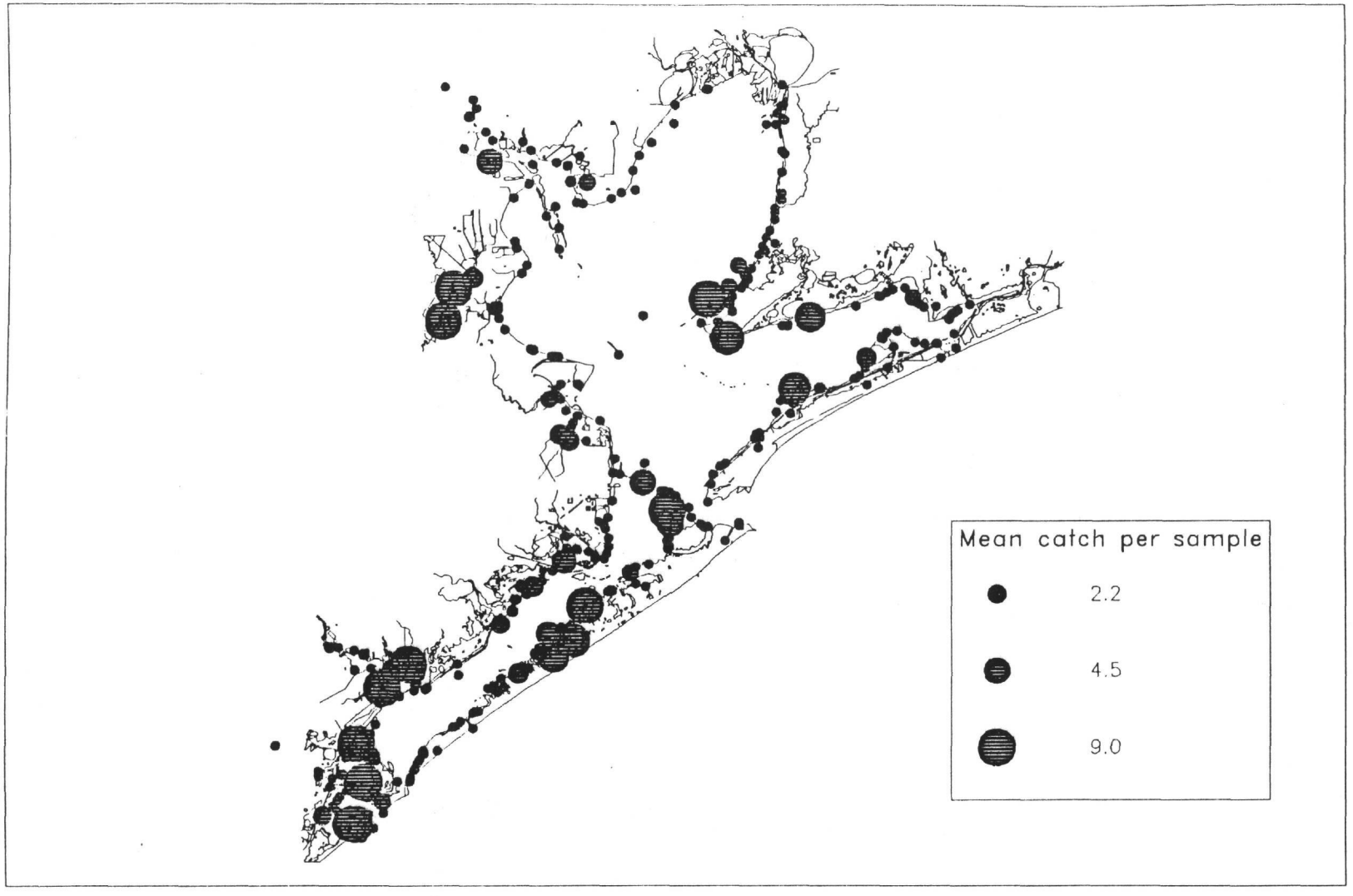


Figure III.99. Distribution of young-of-the-year red drum (25-65 mm) caught by bag seine, October-January, 1978-1989. Circle size is proportional to mean CPUE.

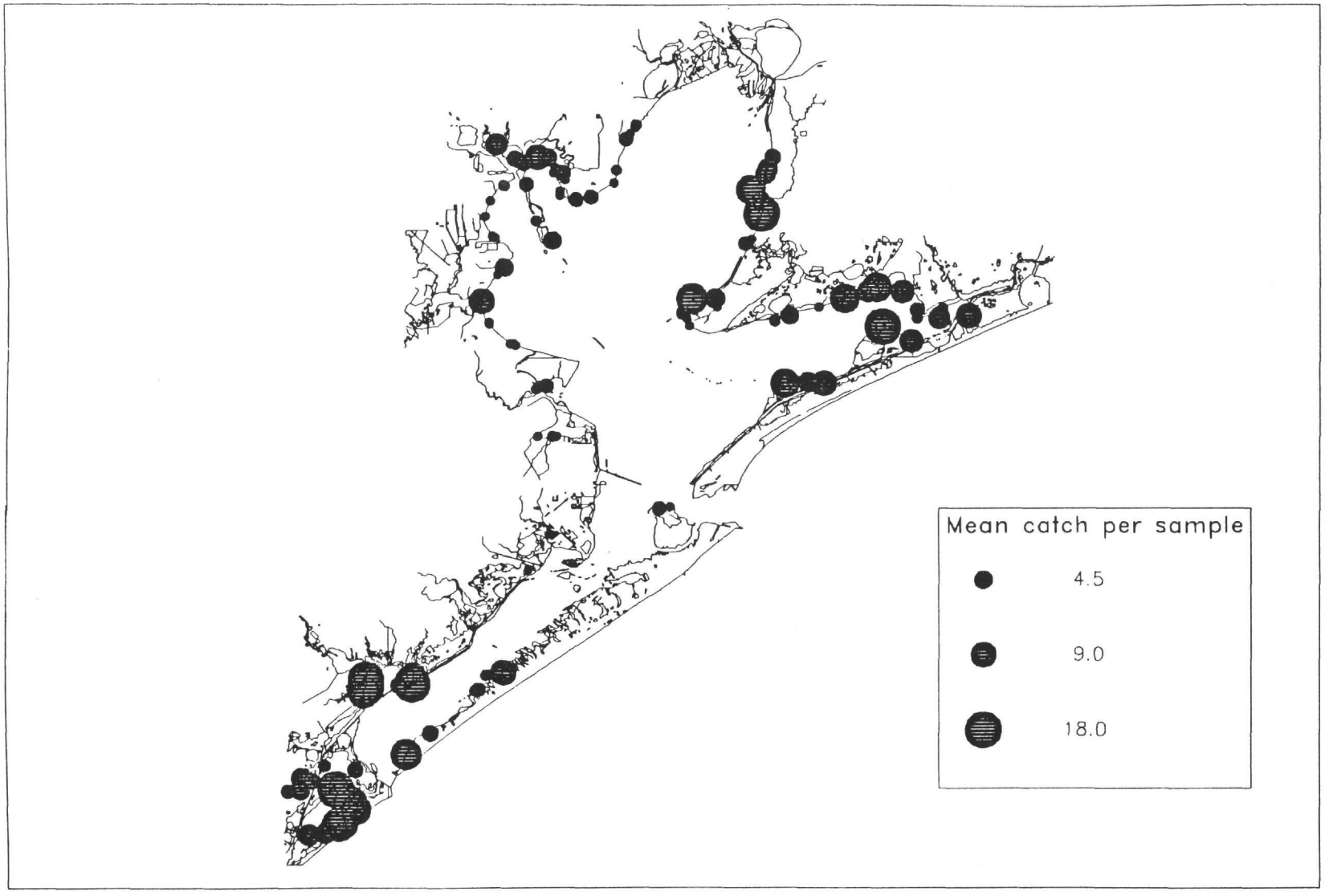


Figure III.100. Distribution of juvenile red drum (375-500 mm) caught by gill net, spring, 1977-1990. Circle size is proportional to mean catch per sample.

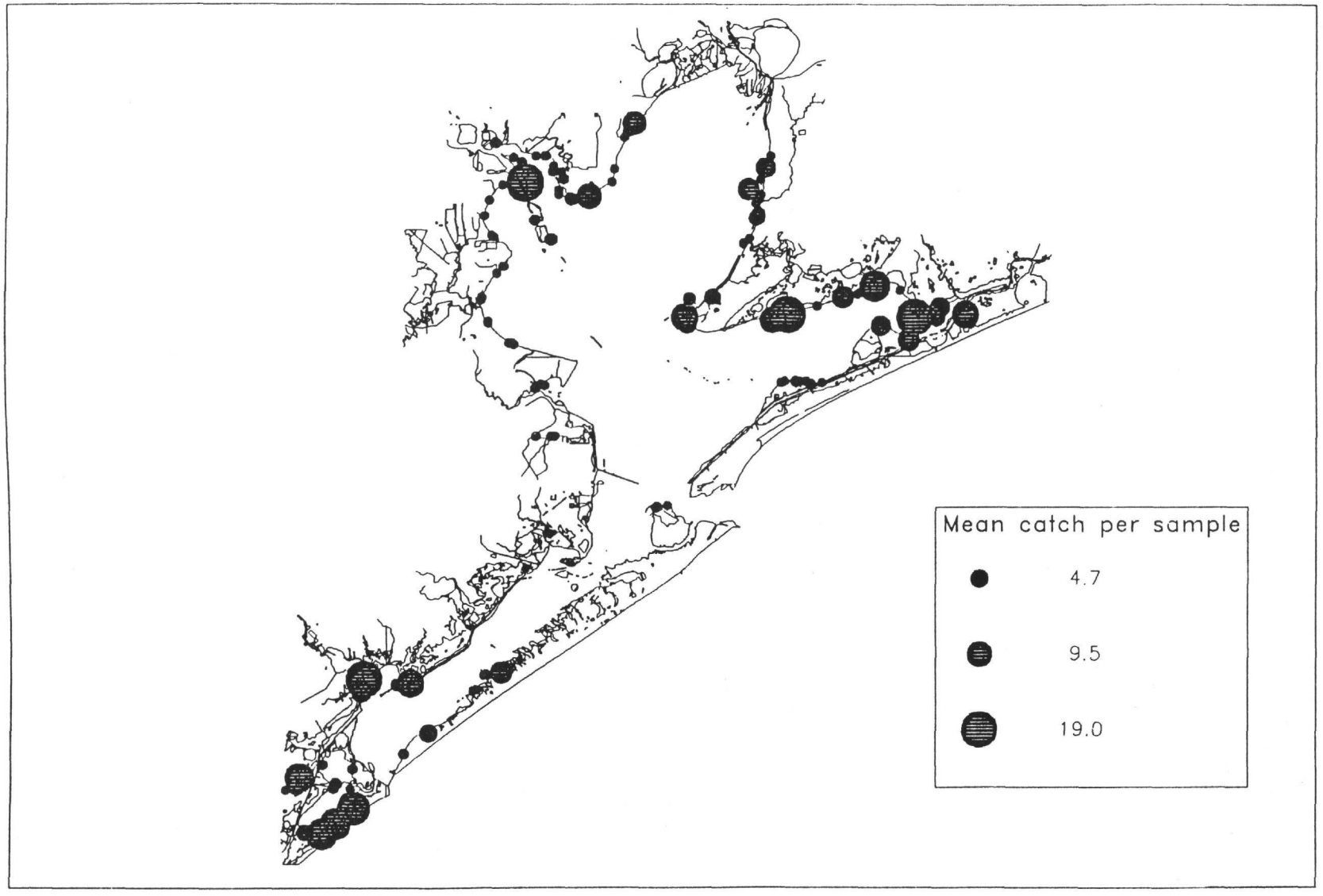


Figure III.101. Distribution of first-time spawning red drum (501-700 mm) caught by gill net, spring, 1977-1990. Circle size is proportional to mean catch per sample.

showed no annual trend during the same period (Figure III.104). Remaining adults (>=160 mm) caught by gill net decreased in abundance from 1975 to 1989 (Figure III.105).

Season and size selection

Young of the year showed a bimodal pattern of recruitment to bag seine samples during April through October, corresponding to the March-May and August-September spawning periods (Schlossman and Chittenden 1981). The 35-55 mm size range was the most numerous 20-mm group in the bag seine samples (Figure III.106). The entire recruitment period (April through October) was used for analysis.

Sand seatrout were common in trawl samples in all but the coldest months. New recruits, as small as 17 mm, appeared from May to July; large catches of juveniles less than 85 mm occurred in the summer and fall (Figure III.107). To minimize the repeated sampling of the same cohort the analysis was restricted to a size range of 65-85 mm during the months of May through December.

Females mature at 140-180 mm as they approach one year of age (Schlossman and Chittenden 1981). The 140-160 mm size range was selected to represent fish at or near the age to spawn for the first time. The months of April through November, when fish of this size were common in trawl samples, were used for analysis (Figure III.107). Remaining adults, defined as those over 160 mm, were analyzed using gill net samples taken during the fall, when they were caught in sufficient numbers for analysis (Figure III.108).

Young of the year

Bag seine: The analysis of deviance revealed no significant linear trend and a marginally significant ($0.10 > P > 0.05$) quadratic component (Table III.47). A model including Month and linear and quadratic YEAR, shown in Figure III.102A, explained 9.95 percent of the total deviance, a relatively small proportion. Most of the deviance was explained by Month and the component of YEAR that is neither linear nor quadratic. The plot of mean monthly CPUE from 1978 to 1989 showed considerable variation but little indication of a trend (Figure III.102B). High catches occurred in October 1984, while 1980, 1987, and 1988 had low catch rates. In most years the greatest mean monthly CPUE occurred in late spring (April through June), but in four of the twelve years studied (1981, 1983, 1984, and 1989) the peak month was in early fall (August through October).

Juveniles

Trawl: A linear annual trend accounted for most of the temporal variation (Table III.48). Values fitted by the linear model (Figure III.103A) corresponded closely to observed mean seasonal CPUE, with the exception of high catches in the summer of 1989. Variation in seasonality is reflected in the significance of Month effects and Year-Month interactions (Figure III.103B).

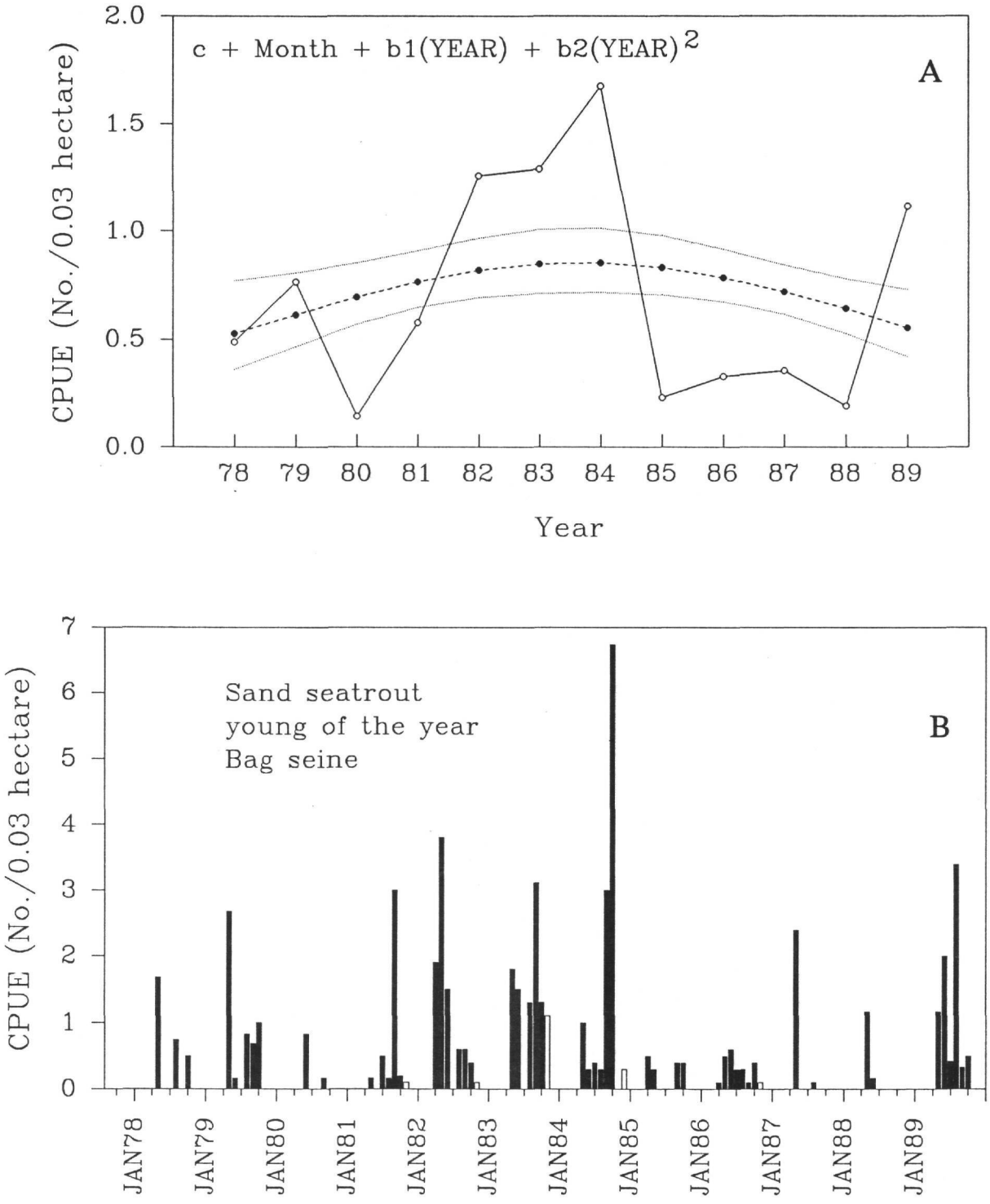


Figure III.102. A. Mean seasonal (April-October) CPUE and predicted CPUE with confidence intervals for young-of-the-year sand seatrout (35-55 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: April to October. Hollow bars: months not used for analysis.

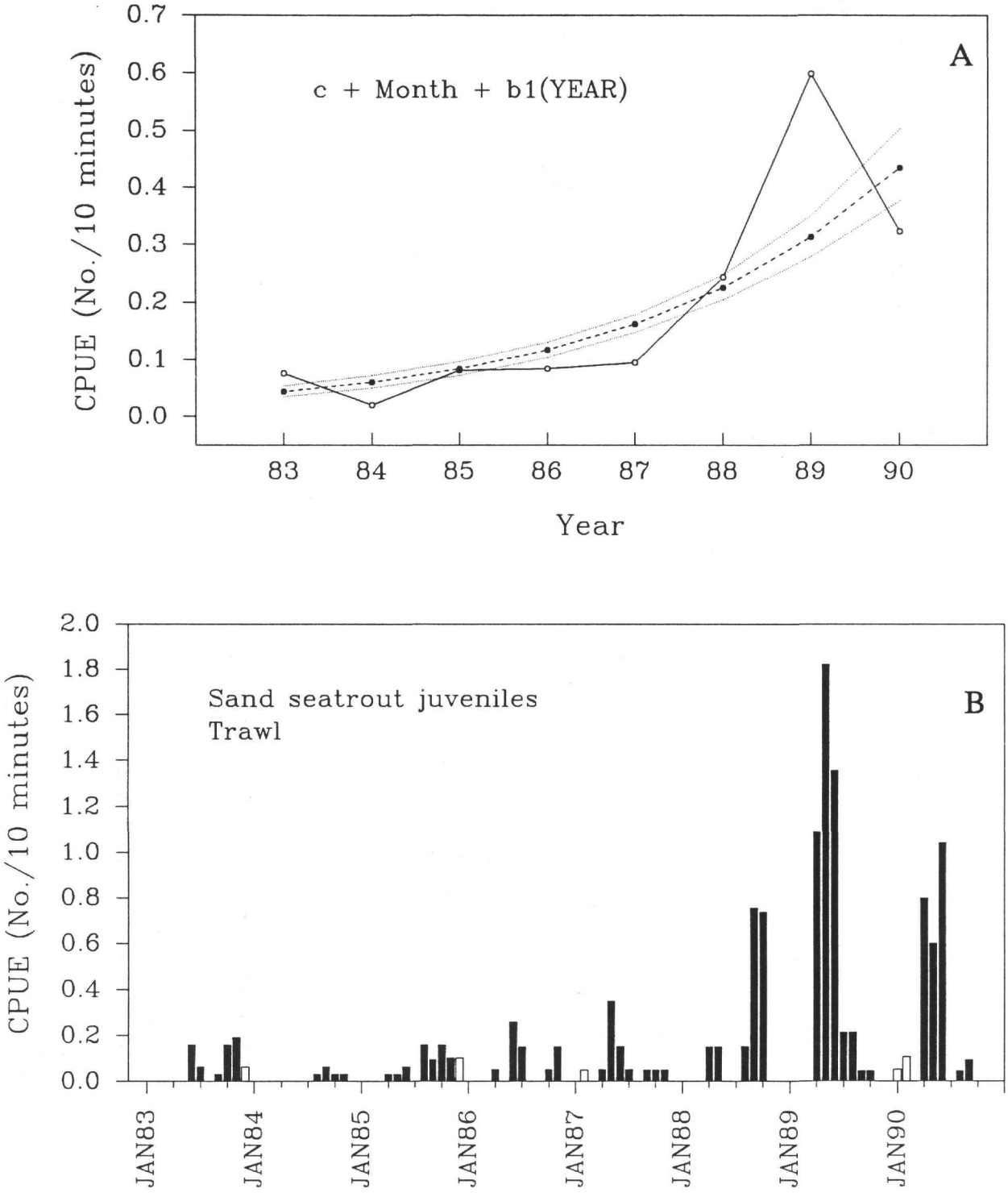


Figure III.103. A. Mean seasonal (May-December) CPUE and predicted CPUE with confidence intervals for juvenile sand seatrout (65-85 mm) caught by trawl. B. Mean CPUE by month. Filled bars: May-December. Hollow bars: months not used for analysis.

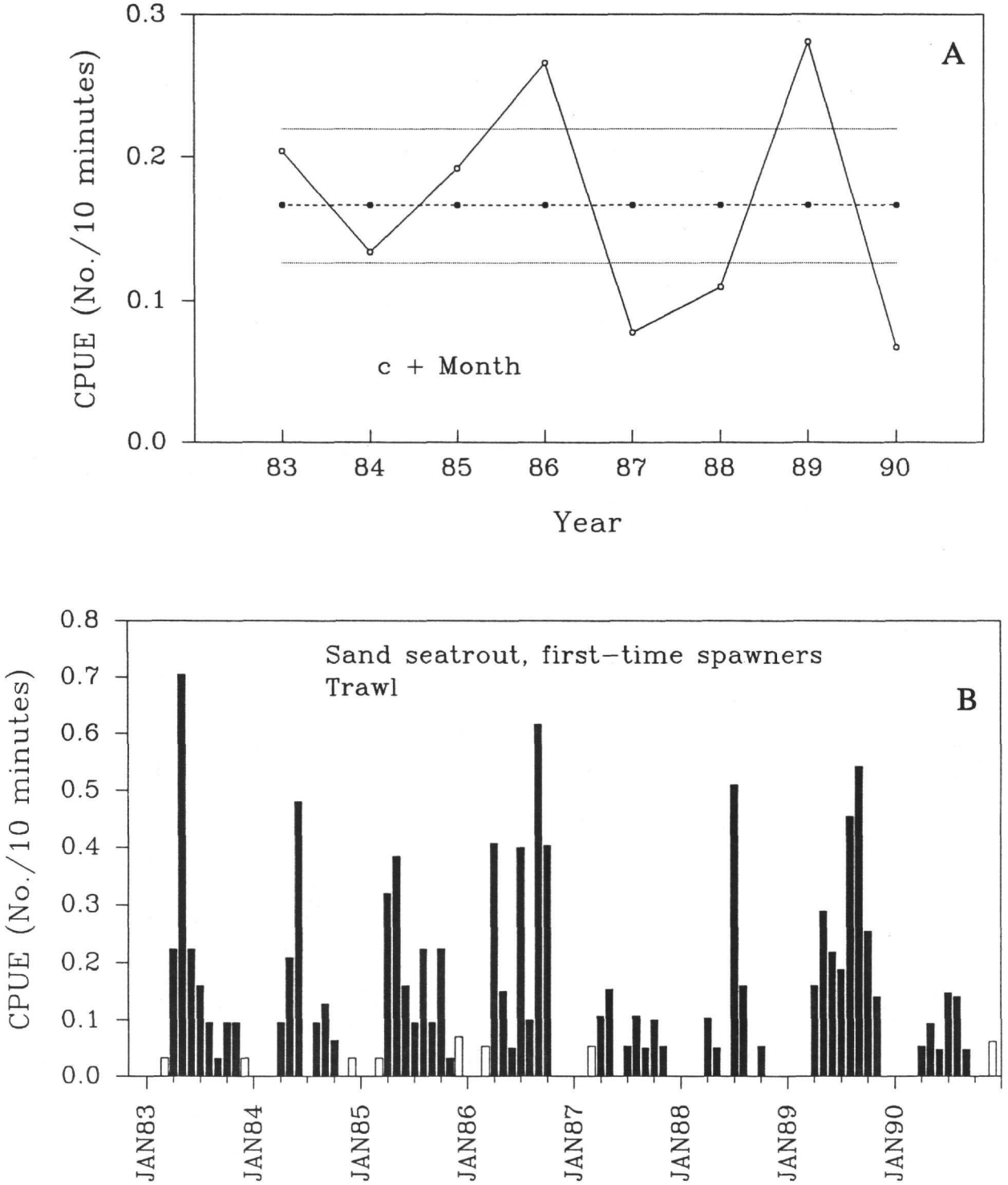


Figure III.104. A. Mean seasonal (April-November) CPUE and predicted CPUE with confidence intervals for first-time spawning sand seatrout (140-160 mm) caught by trawl. B. Mean CPUE by month. Filled bars: April-November. Hollow bars: months not used for analysis.

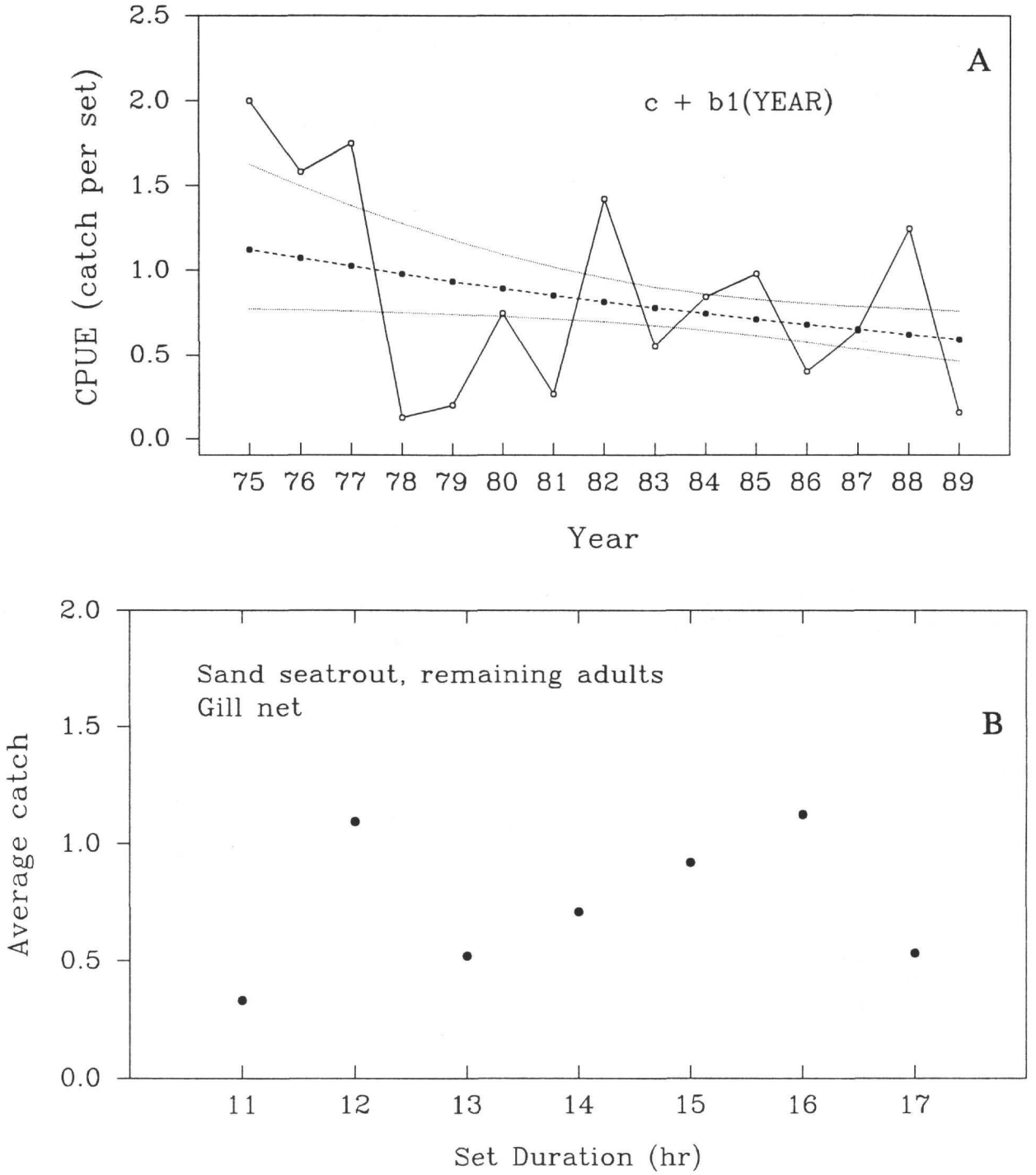


Figure III.105. A. Mean seasonal (fall) CPUE and predicted CPUE with confidence intervals for remaining adult sand seatrout (>160 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1975-1990.

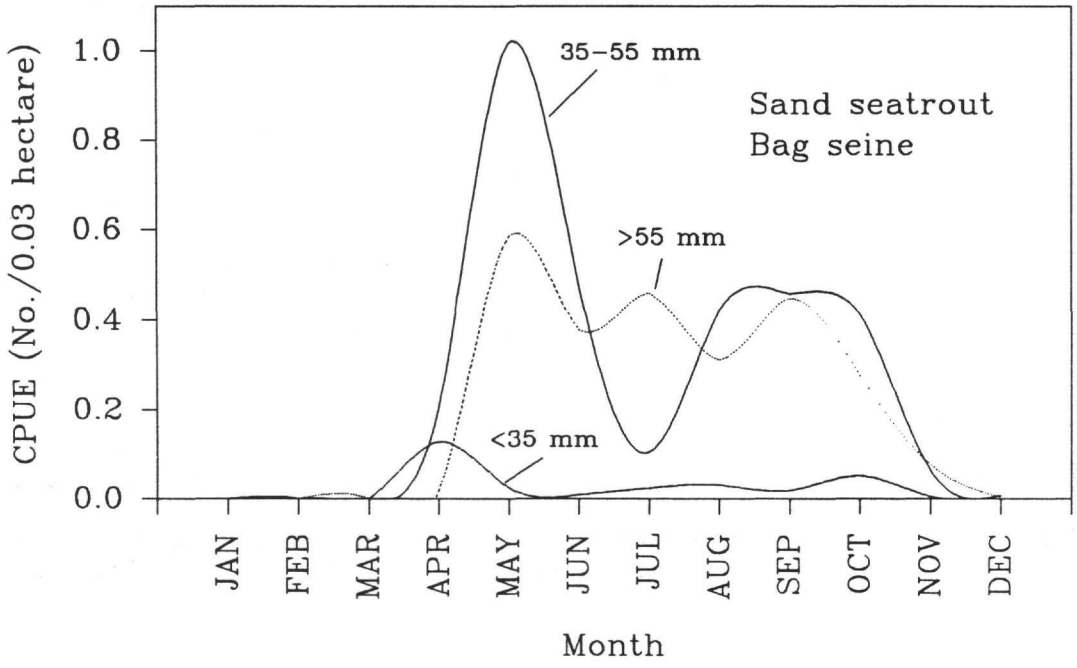


Figure III.106. Mean CPUE by month for three size classes of sand seatrout caught by bag seine (<35 mm, 35-55 mm, >55 mm). Data pooled from 1978-1989.

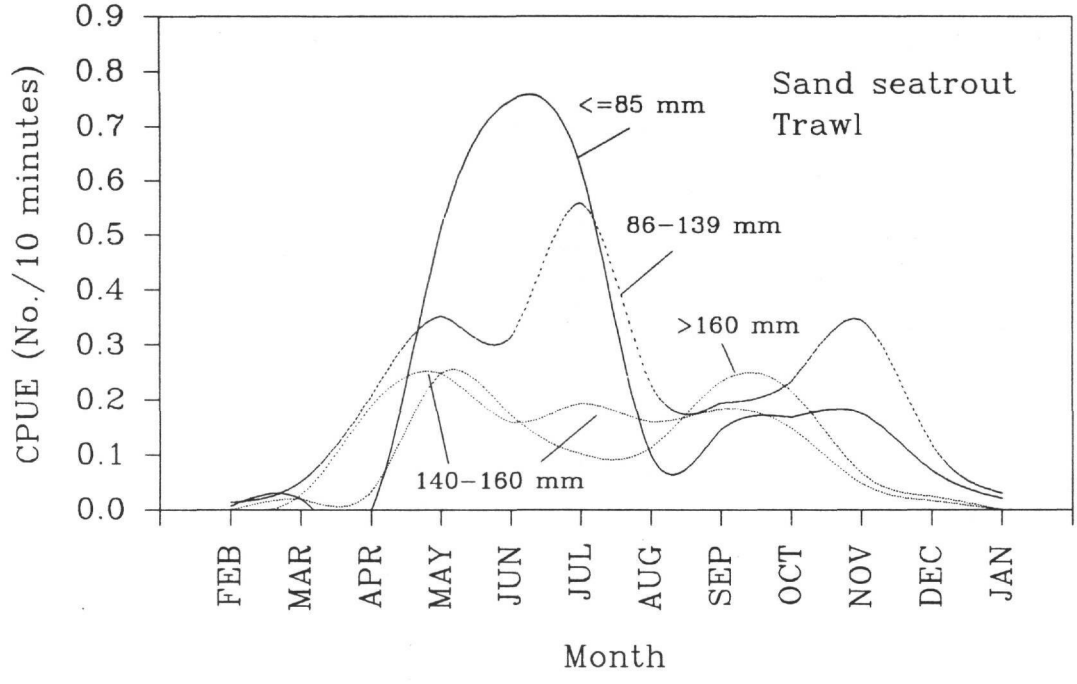


Figure III.107. Mean CPUE by month for four size classes of sand seatrout caught by trawl (≤85 mm, >85-<140 mm, 140-160 mm, >160 mm). Data pooled from 1983-1990.

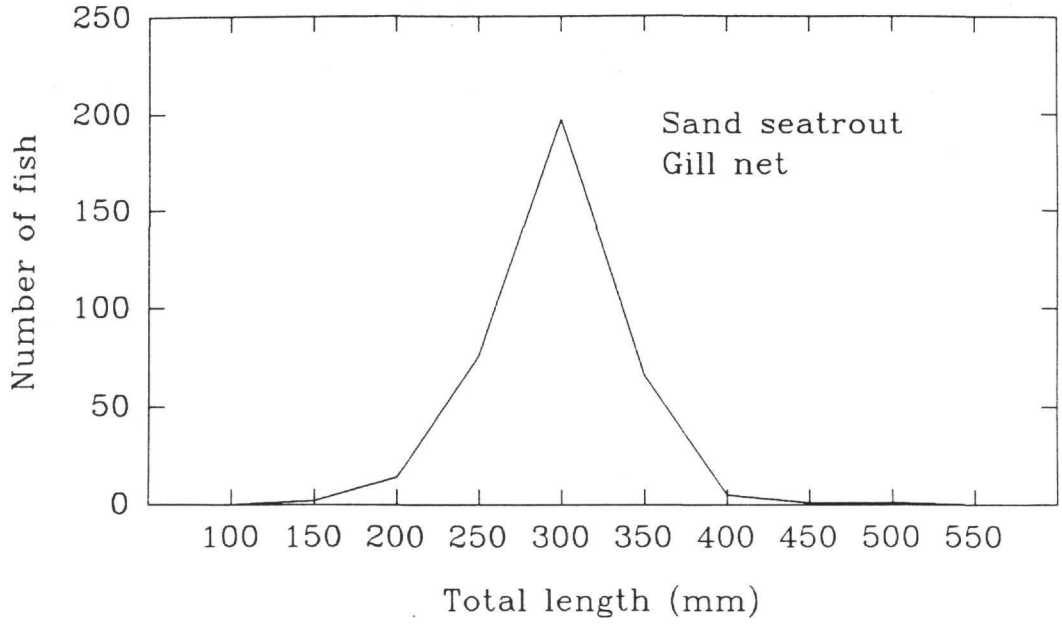


Figure III.108. Size frequency distribution for sand seatrout caught by gill net during fall sampling period. Data pooled from 1975-1990.

First-time spawners

Trawl: Most of the temporal variation was accounted for by Month effects (Table III.49, Figure III.104B) or was unexplained by the model. There was no significant quadratic component and linear YEAR was marginally significant ($0.05 < P < 0.10$).

Remaining adults

Gill net: The relationship between catch and set duration was not linear (Figure III.105B). The significance of set duration was tested using a GLIM model including GTIME, linear and quadratic YEAR, and YEAR-GTIME interaction. The initial analysis of deviance (Table III.50) showed that set duration was not significant. No correction for set duration was made and CPUE was defined as catch per set.

There was a linear decrease in CPUE from 1975 to 1989 (Figure III.105A), though there was considerable temporal variation and much of the total deviance was unexplained by the model (Table III.50).

Table III.47. Analysis of deviance for young-of-the-year sand seatrout (35-55 mm) caught by bag seine, April-October, 1978-1989.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	6	82.56	13.76	12.98	<0.001
YEAR					
Linear	1	0.43	0.43	0.41	>0.50
Quadratic	1	3.81	3.81	3.59	>0.05
Other	9	100.17	11.13	10.50	<0.001
Month x Year	65	217.49	3.30	3.11	<0.001
Corrected error	407	429.62	1.06		

Table III.48. Analysis of deviance for juvenile sand seatrout (65-85 mm) caught by trawl, May-December, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	7	41.91	5.99	12.38	<0.001
YEAR					
Linear	1	72.14	72.14	149.17	<0.001
Quadratic	1	0.11	0.11	0.23	>0.50
Other	5	31.69	6.34	13.11	<0.001
Month x Year	49	101.12	2.06	3.92	<0.001
Corrected error	1046	550.50	0.53		

Table III.49. Analysis of deviance for first-time spawning sand seatrout (140-160 mm) caught by trawl, April-November, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	7	23.28	10.47	19.89	<0.001
YEAR					
Linear	1	1.70	1.70	3.23	>0.05
Quadratic	1	0.62	0.62	1.18	>0.25
Other	5	37.88	7.58	14.40	<0.001
Month x Year	49	101.12	2.06	3.92	<0.001
Corrected error	1046	550.50	0.53		

Table III.50. Analysis of deviance for remaining adult sand seatrout (>160 mm) caught by gill net, fall season, 1975-1990. CPUE=catch/set.

Source of Variation	D.F.	Deviance	M.D.	F	P
GTIME	1	0.85	0.85	0.96	>0.50
YEAR					
Linear	1	5.19	5.19	5.83	<0.025
Quadratic	1	0.56	0.56	0.63	>0.25
GTIME x YEAR	14	18.82	1.34	1.51	>0.05
Other	12	70.85	5.90	6.63	<0.001
Corrected error	445	396.26	0.89		

Spatial distribution

Catch rates for young-of-the-year sand seatrout are highest in the distal parts of East and West Bays (Figure III.109), though they are recovered from all parts of the Galveston Estuary shoreline except northern Trinity Bay. Juveniles caught by trawl are also most common in East Bay, West Bay, and southern Trinity Bay (Figure III.110). High catches for first-time spawners were most dense in West Bay and southern Trinity Bay, but also occurred in patches of Lower Galveston Bay, northern Upper Galveston Bay, and East Bay (Figure III.111). Remaining adults caught by gill net (in contrast with young of the year caught by bag seine) are densest along the shores of East Bay, southern Trinity Bay, and upper Galveston Bay, but are relatively scarce in West Bay (Figure III.112).

Discussion

Though bag seine data were inconclusive, trawl and gill net results showed an increase in juveniles while first-time spawners showed no trend and remaining adults decreased in abundance. This phenomenon appeared as a decrease in mean size when trawl data were examined as a whole (Figure III.113). A 12 percent decrease in mean length was also reported for sand seatrout caught by sportboat fishermen between 1974 and 1988 coastwide in Texas (Maddux et al. 1989, fig. 19). One obvious reason for differing trends among size groups might be fishing pressure, because large sand seatrout are a popular food fish while small sand seatrout are not retained by fishermen. However, other factors that may differentially affect larger sand seatrout, such as a loss of the preferred food supply of adults or shrimping bycatch (Bryan et al. 1982), should be investigated.

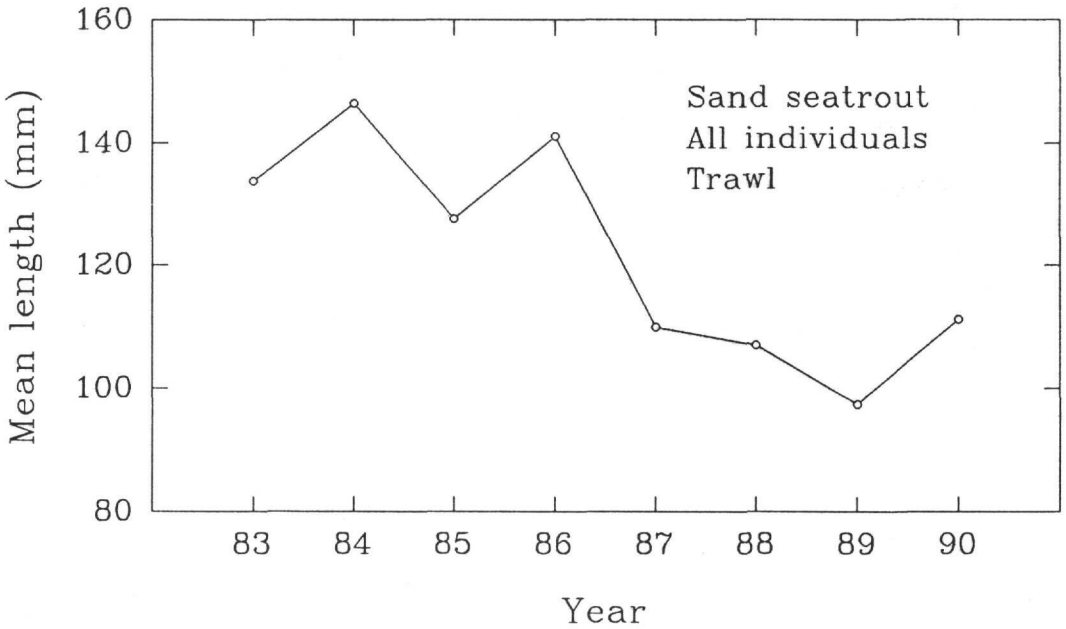


Figure III.113. Mean length for sand seatrout caught by trawl, 1983-1990.

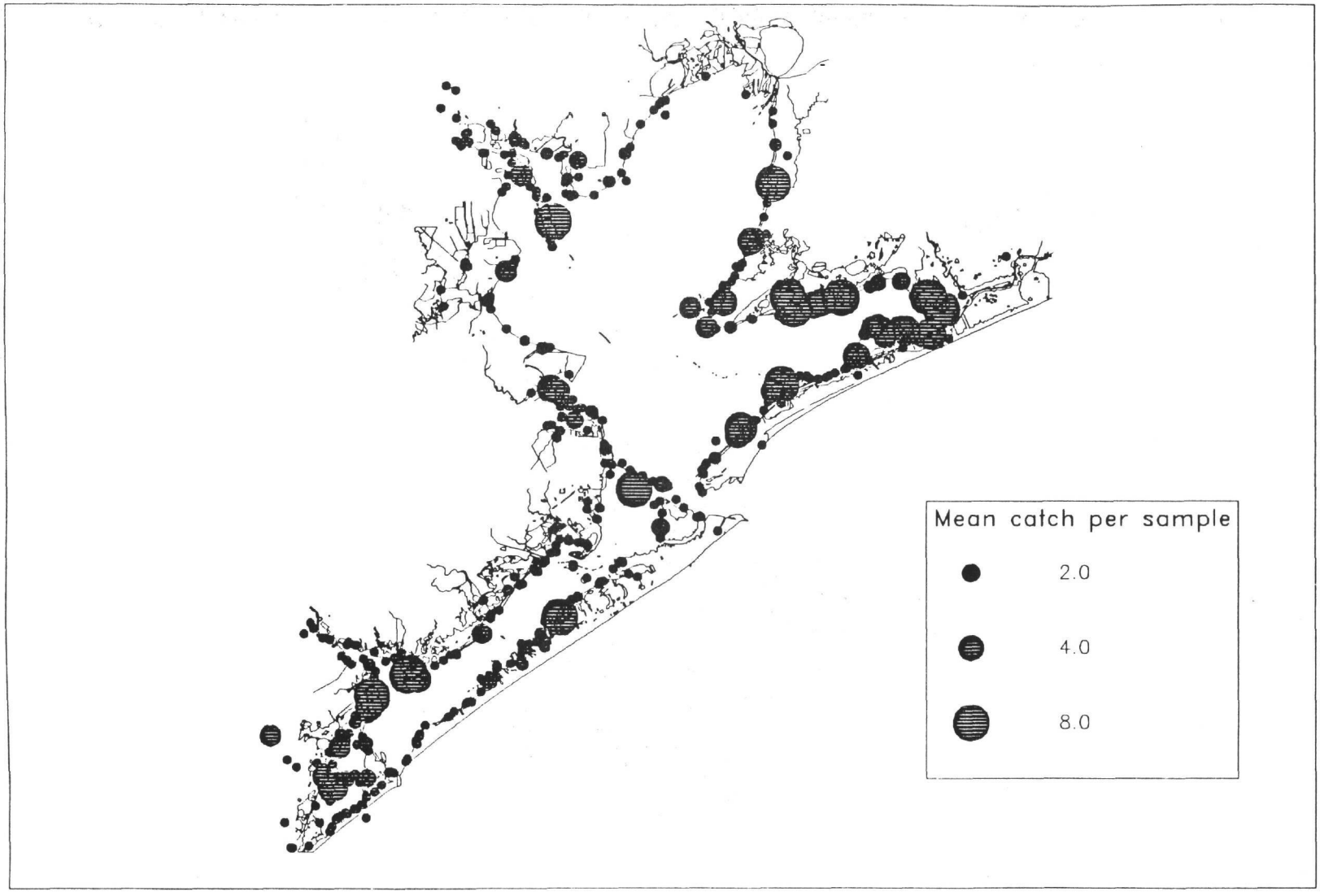


Figure III.109. Distribution of young-of-the-year sand seatrout (35-55 mm) caught by bag seine, April-October, 1978-1989. Circle size is proportional to mean CPUE.

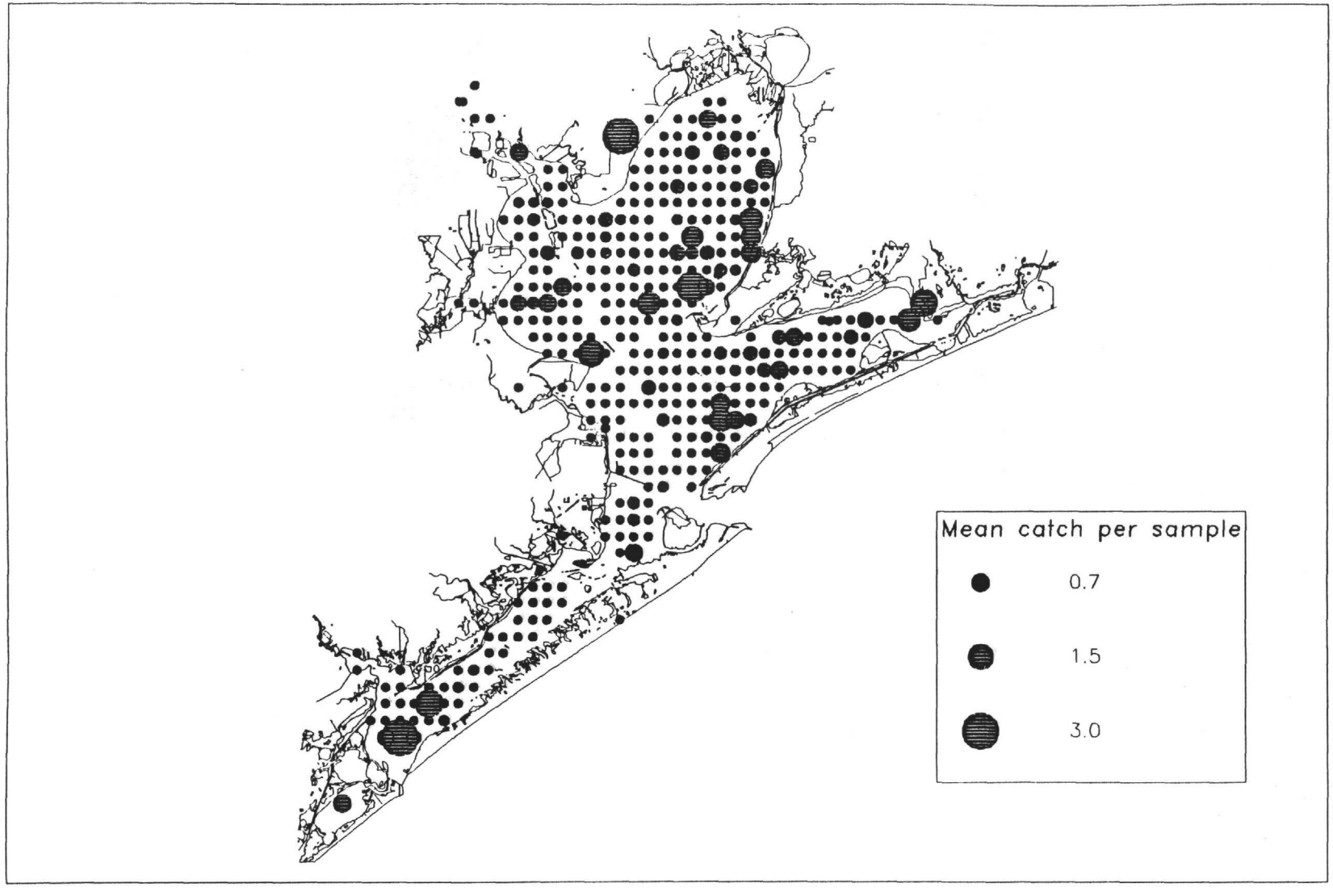


Figure III.110. Distribution of juvenile sand seatrout (65-85 mm) caught by trawl, May-December, 1983-1990. Circle size is proportional to mean CPUE.

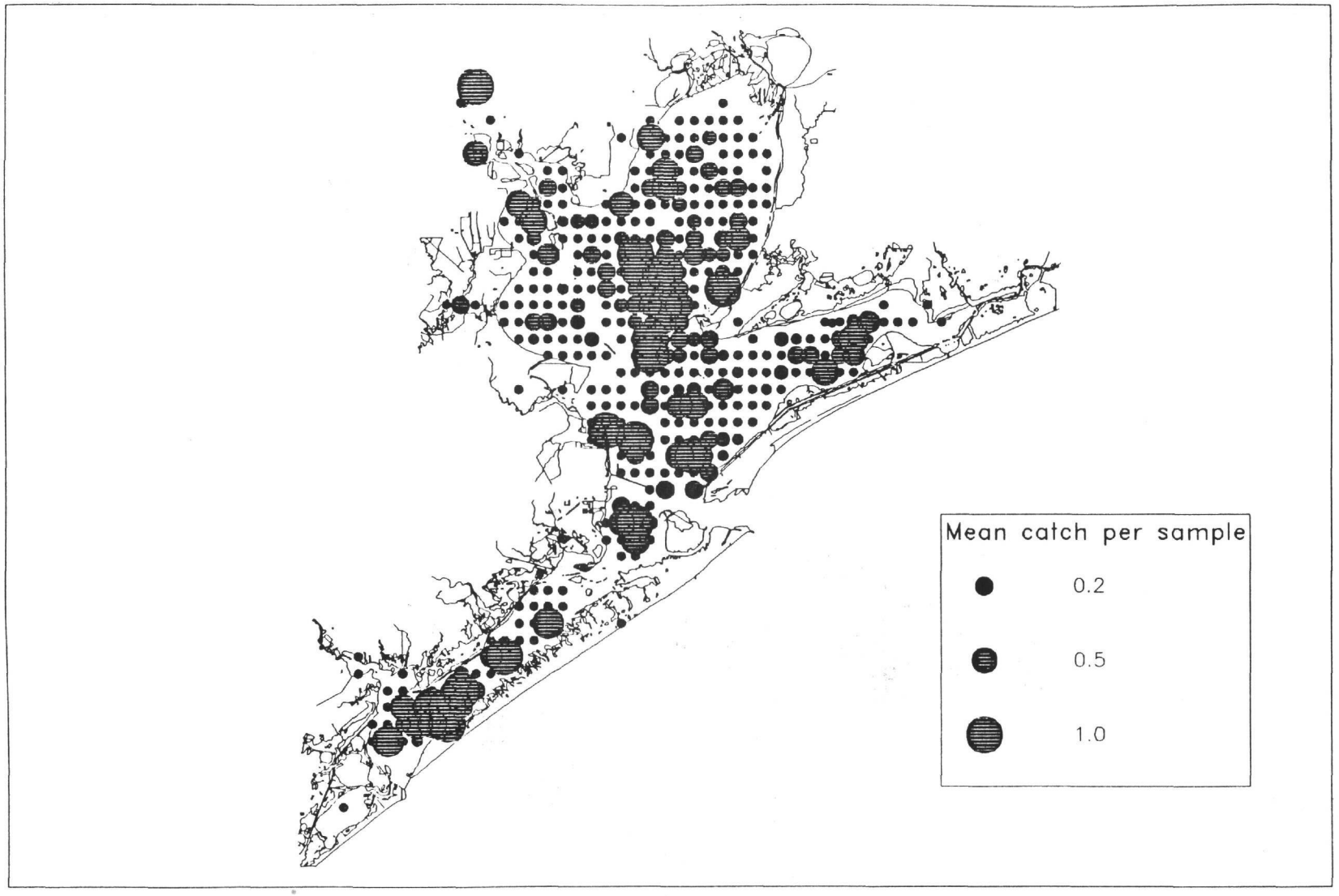


Figure III.111. Distribution of first-time spawning sand seatrout (140-160 mm) caught by trawl, April-November, 1983-1990. Circle size is proportional to mean CPUE.

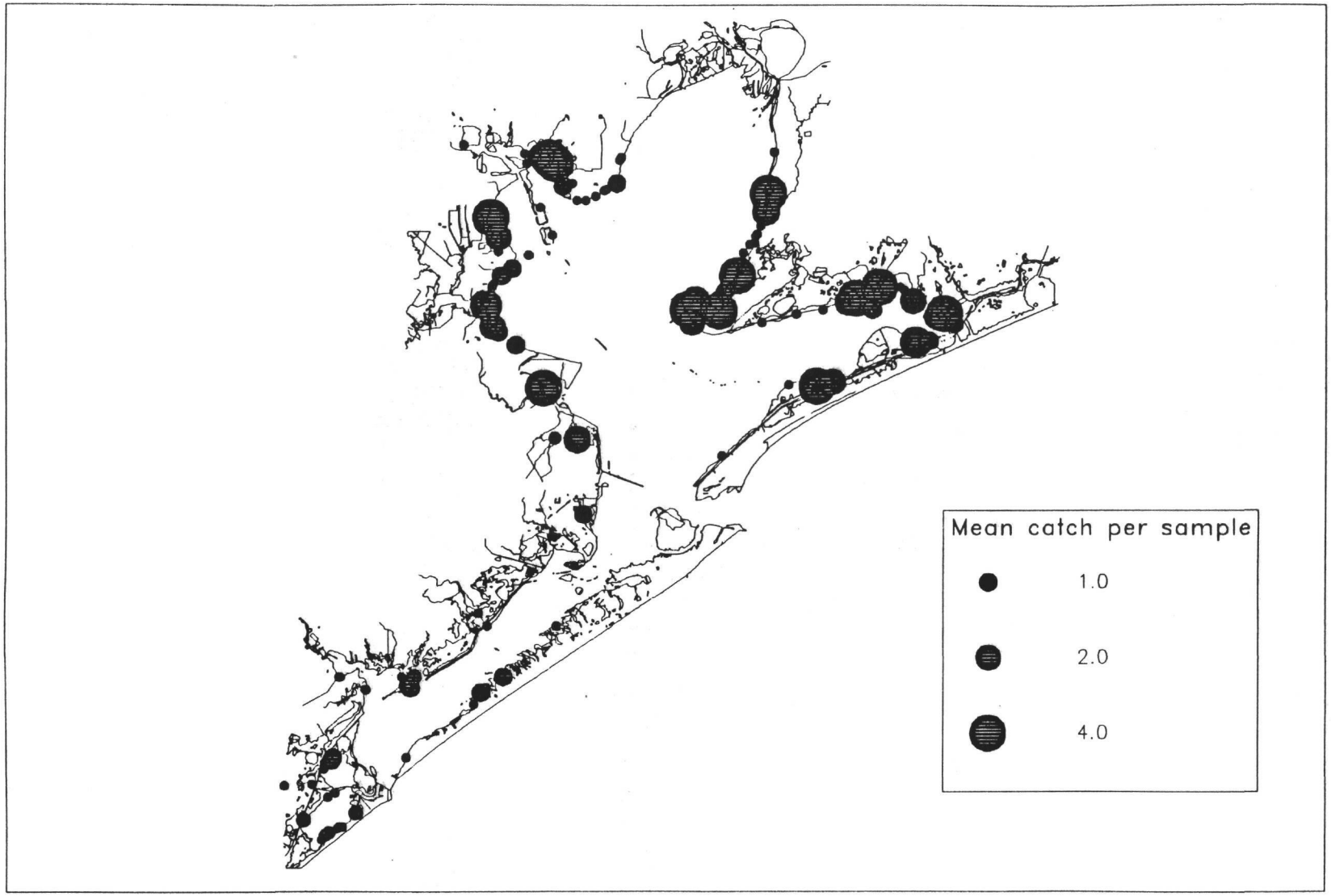


Figure III.112. Distribution of remaining adult sand seatrout (>160 mm) caught by gill net, fall, 1975-1989. Circle size is proportional to mean catch per sample.

Southern Flounder (Paralichthys lethostigma)

There was no significant trend in CPUE for either young-of-the-year (20-45 mm) or adult (>250 mm) southern flounder in this study (Figures III.114, III.115).

Size and Season Selection

McEachron et al. (1977) reported that juvenile flounder grew an average of 20 mm per month between February and June 1973 in Christmas Bay. At approximately 20 mm flounder are effectively recruited to bag seine. Large numbers of young of the year are caught by bag seine in February and March (Figure III.116). Data analysis was confined to these two months, using a size range of 20-45 mm to minimize repeated sampling of the cohort.

Southern flounder leave the Estuary in October through December to spawn in the Gulf when they are approximately two years old (Stokes 1977). Males grow more slowly than females and are approximately 231-280 mm at this age while females are approximately 301-450 mm (Stokes 1977). Recruitment to gill net was effective when fish were larger than 200 mm (Figure III.117). Flounder greater than 250 mm caught by gill net in the fall season were chosen to represent the adult population.

Young of the Year

Bag seine: Neither the linear nor the quadratic components were significant in the analysis of deviance (Table 12A). Most of the deviance was explained by Month, that is, by strongly seasonal behavior (Figure III.51). Month-Year interaction was also significant.

Adults

Gill net: For short gill net set times (9-10 hours) catch increased with set duration (Figure III.115B). As the set time continued to increase, however, the number of fish caught decreased. One possible explanation for this effect is that flounder migrate to the Gulf to spawn from October to December (Stokes 1977), while set duration increases during the fall. Despite the appearance of a quadratic relationship for set duration and catch, initial SAS ANCOVA models suggested that neither GTIME nor $GTIME^2$ contributed significantly to the deviance. In addition the models indicated that set duration and linear effects were colinear. A model was tested that included only linear and quadratic YEAR terms, without a set duration or interaction term. The calculation of CPUE did not include a correction for set duration and CPUE was defined to be catch per set.

Results of the analysis of deviance showed that neither linear nor quadratic YEAR were significant (Table III.52).

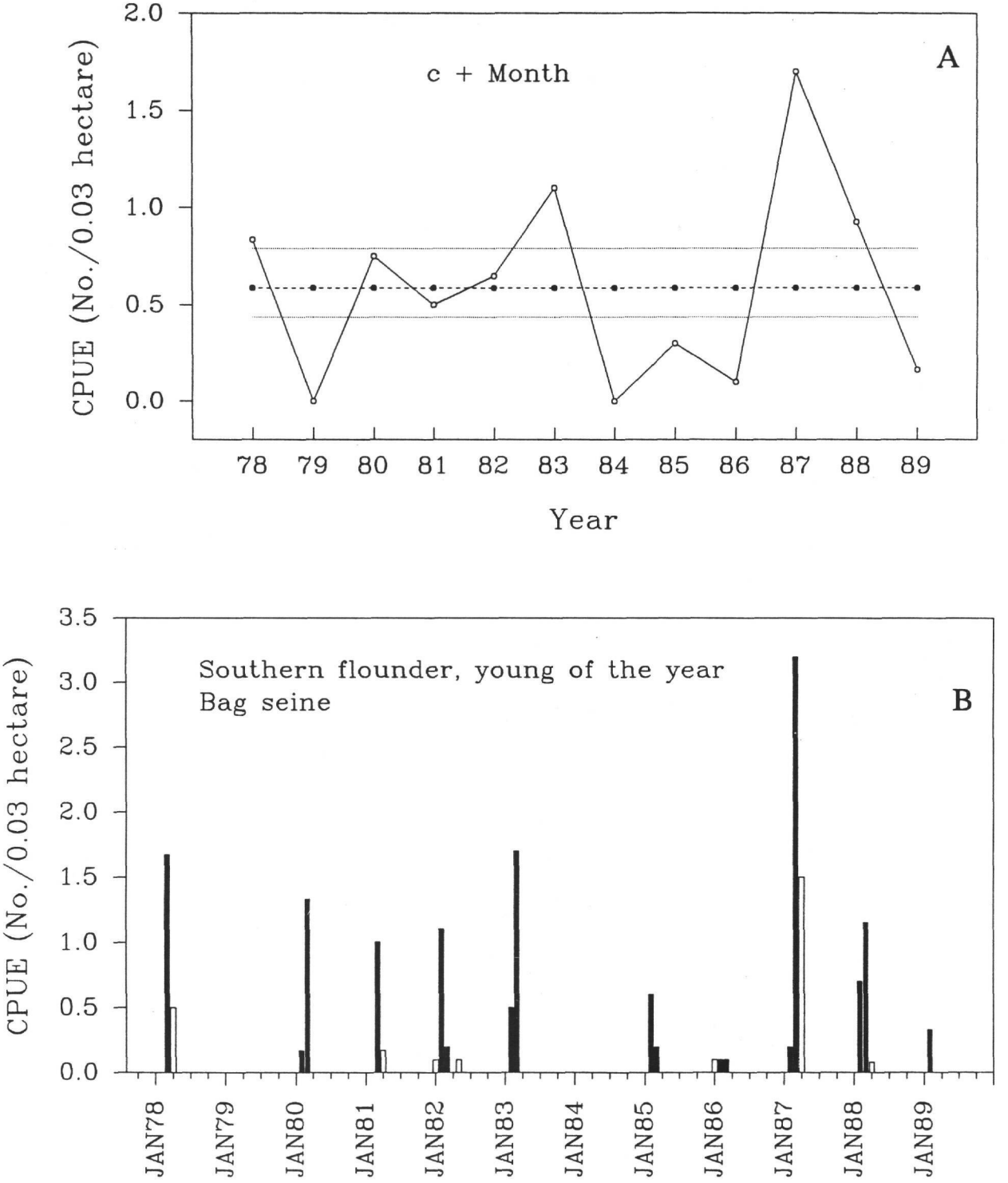


Figure III.114. A. Mean seasonal (February-March) CPUE and predicted CPUE with confidence intervals for young-of-the-year southern flounder (20-45 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: February-March. Hollow bars: months not used for analysis.

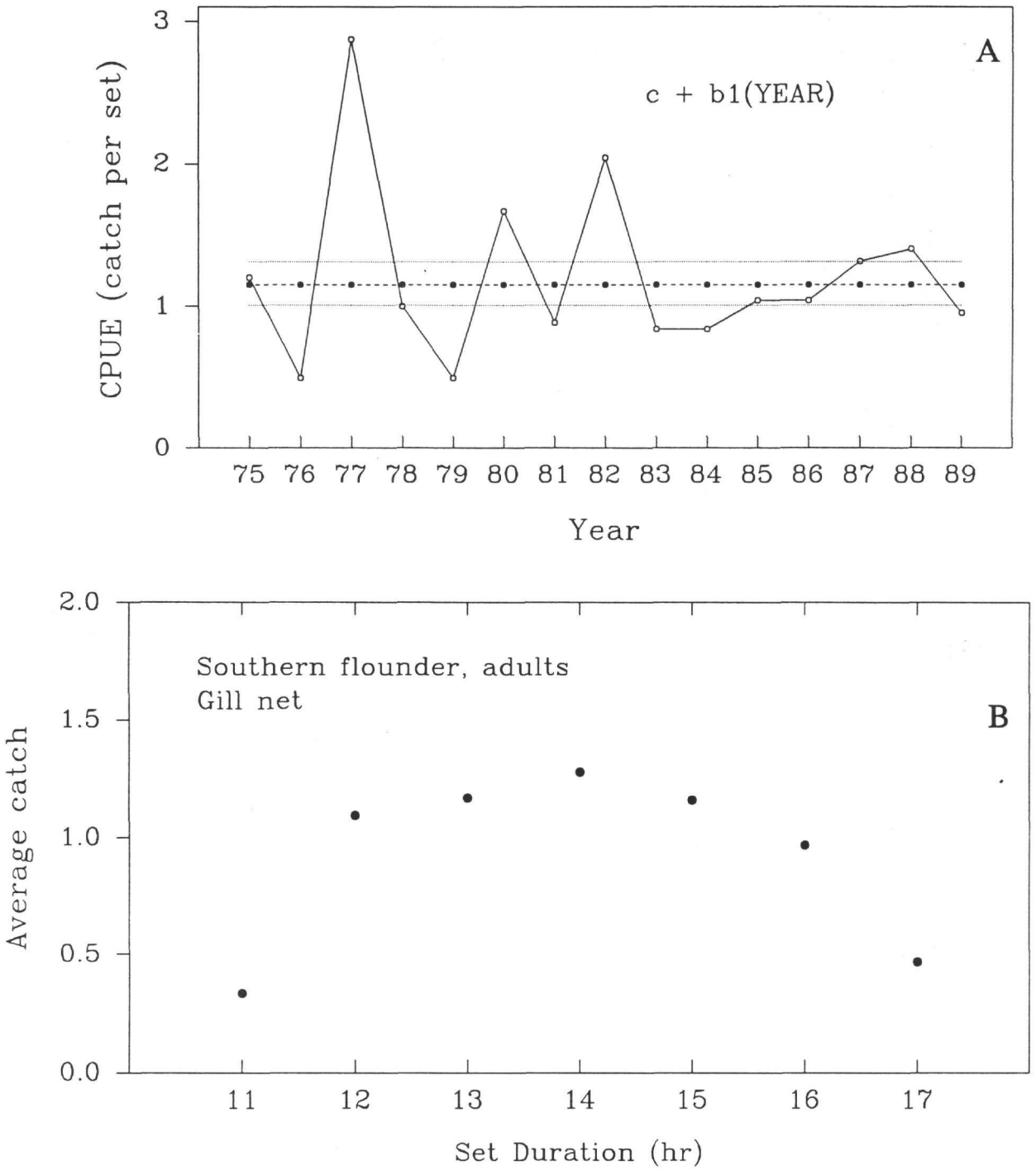


Figure III.115. A. Mean seasonal (fall) CPUE and predicted CPUE with confidence intervals for adult southern flounder (>250 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled for 1975-1989.

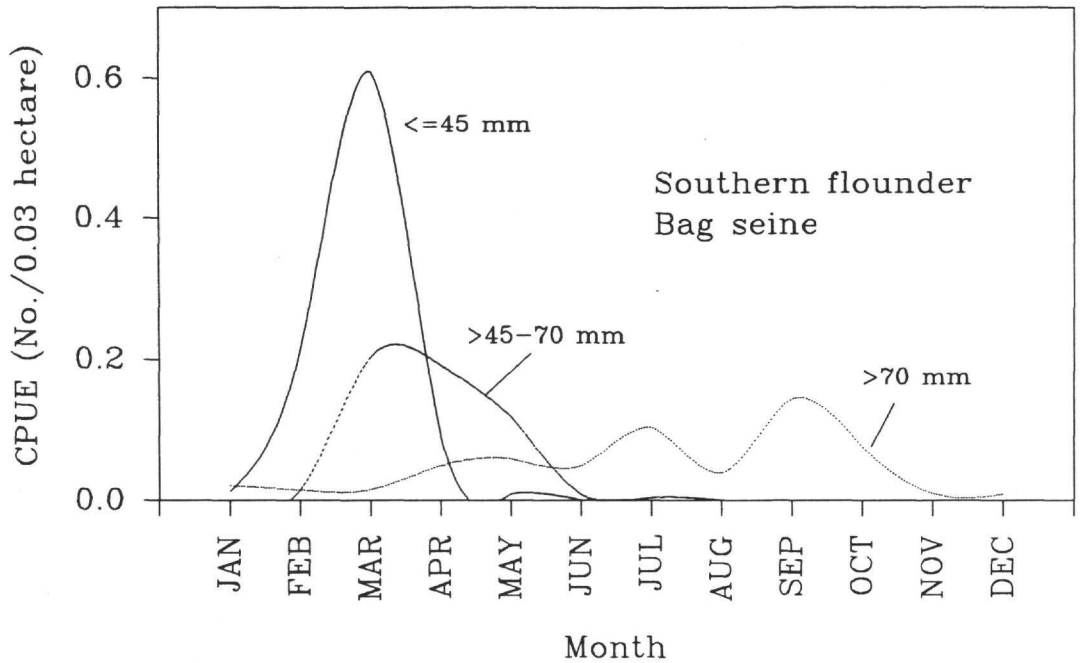


Figure III.116. Mean CPUE by month for three size classes of southern flounder caught by bag seine (< =45 mm, >45-70 mm, >70 mm). Data pooled over 1978-1989.

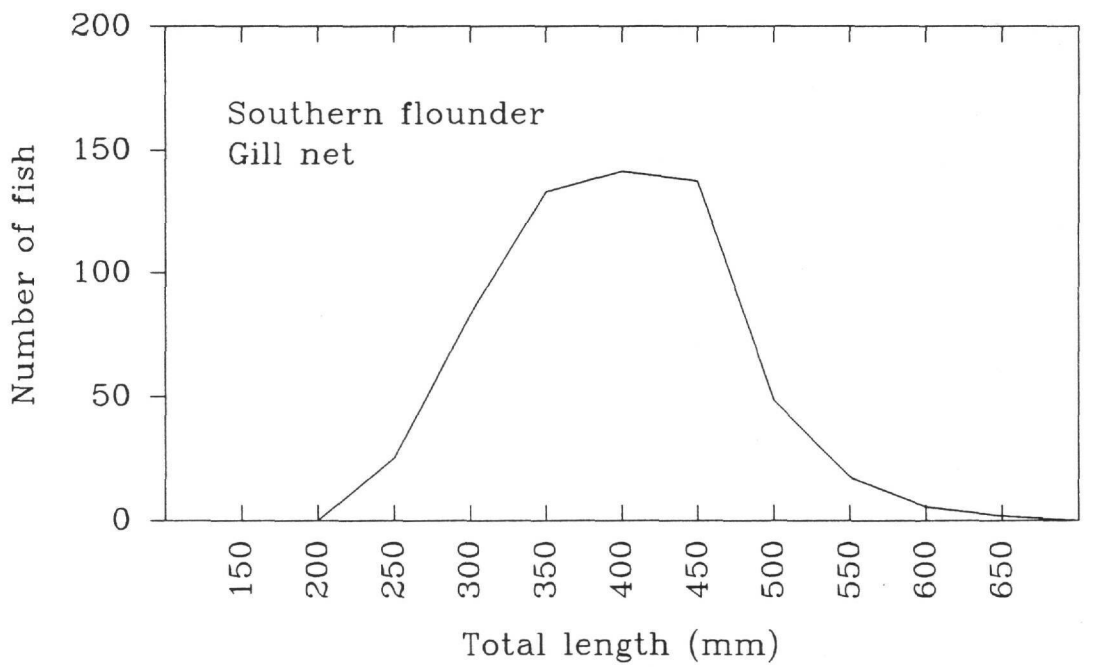


Figure III.117. Size frequency distribution for southern flounder caught by gill net during fall sampling period. Data pooled for 1975-1989.

Table III.51. Analysis of deviance for young-of-the-year southern flounder (20-45 mm) caught by bag seine, February-March, 1978-1989.

Source of variation	D.F.	Deviance	M.D.	F	P
Month	1	9.21	9.21	9.69	<0.005
YEAR					
Linear	1	0.28	0.28	0.29	>0.50
Quadratic	1	0.04	0.04	0.04	>0.75
Other	9	51.97	5.77	6.07	<0.001
Month x Year	11	35.18	3.20	3.37	<0.001
Corrected error	130	122.94	0.95		

Table III.52. Analysis of deviance table for adult southern flounder (>250 mm) caught by gill net, fall season, 1975-1989. CPUE = catch/set.

Source of variation	D.F.	Deviance	M.D.	F	P
YEAR					
Linear	1	0.01	0.01	0.01	>0.75
Quadratic	1	0.00	0.00	0.00	>0.75
Other	12	33.11	2.76	2.49	<0.005
Error	472	524.46	1.11		

Spatial Distribution

Young-of-the-year southern flounder were most abundant on the northern shore of West Bay, in Chocolate Bay, Bastrop Bay, Christmas Bay, and the northern and eastern shores of East Bay (Figure III.118). Adults, in contrast, were well dispersed throughout the estuary system with highest concentrations in Christmas Bay, Bastrop Bay, the northern and southern shores of West Bay, the northern and southern shores of East Bay, Smith Point, and Trinity Bay (Figure III.119).

Discussion

No significant trend was shown for either size class of flounder. There appeared to be a balance between factors which would tend to increase the abundance of the fish and those tending to cause a decrease.

Spotted Seatrout (Cynoscion nebulosus)

Young-of-the-year spotted seatrout (35-75 mm) showed a linear decrease in abundance from 1978 to 1990 (Figure III.120). In contrast, first-time spawners (350-450 mm) showed a stepwise increase in CPUE from 1977 until a peak in 1987, followed by a decrease through 1990 (Figure III.121). Remaining spawners (>450 mm) also increased nonlinearly in abundance (Figure III.122).

Size and season selection

Small spotted seatrout grow an average of 25 mm in forty days in Tampa Bay, Florida (McMichael and Peters 1989). A size range of 35-75 mm was chosen to represent juvenile spotted seatrout. Fish in this size range began to appear in bag seine catches in June and new recruitment ceased by end of November (Figure III.123). Therefore the analyses were confined to data collected from June through November.

The spring season was chosen for the analysis of spotted seatrout in gill net data because spawning peaks in late April to July (Perret et al. 1980). Studies in South Texas showed that 90 percent of female spotted seatrout were sexually mature at 320 mm and males at 240 mm (Brown-Peterson et al. 1988). Fish began to be recruited to gill net at approximately 300 mm (Figure III.124). The 350 to 450 mm size class most closely represented the age of first reproduction and was used for analysis of first-time spawners. Fish greater than 450 mm represented the remaining adults.

Young of the year

Bag seine: All factors were significant in the analysis of deviance except for the quadratic component. Most of the deviance was explained by a negative linear trend (Table III.53). Categorical Month was also important, because high catches occur exclusively in the fall (Figure III.120B).

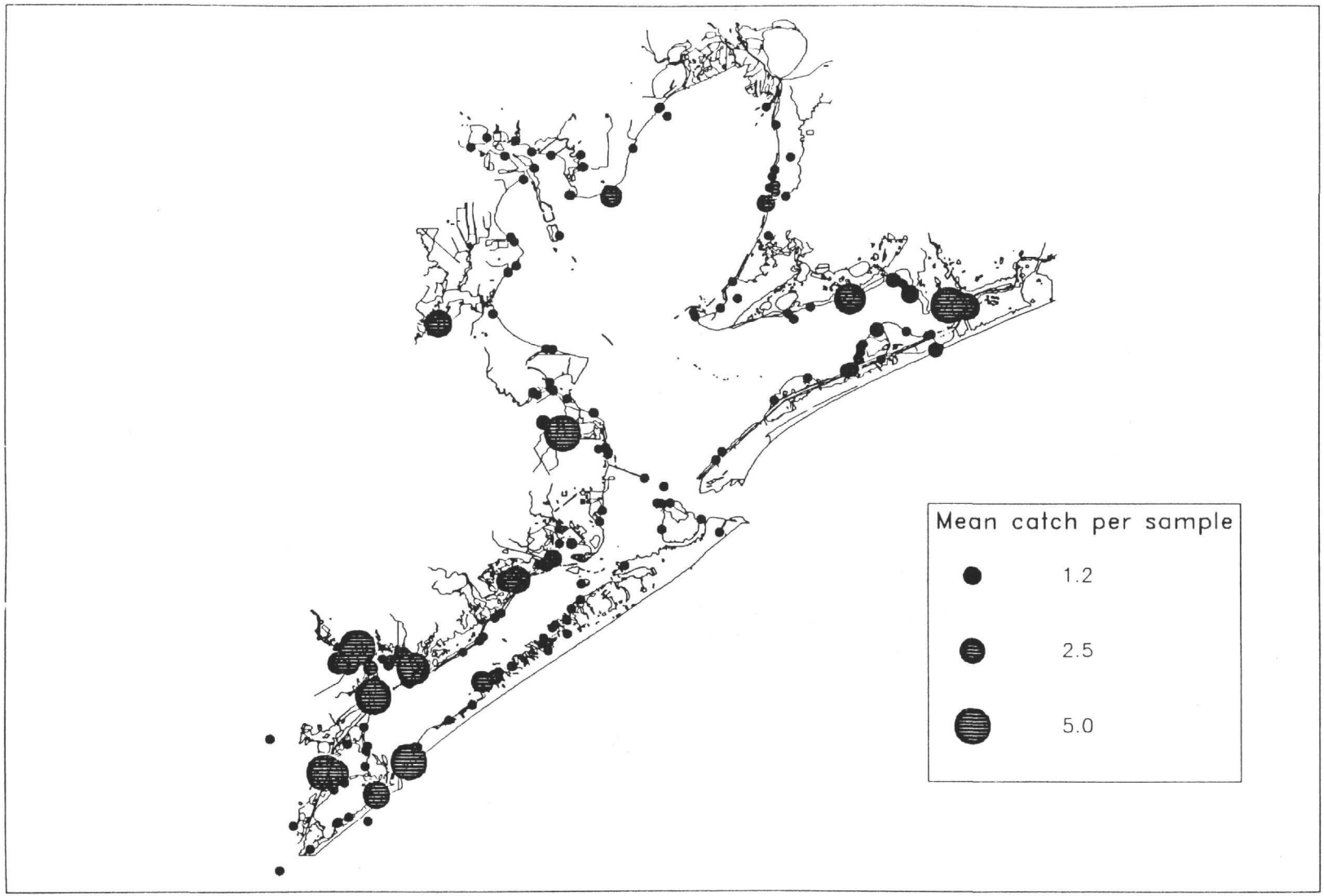


Figure III.118. Distribution of young-of-the-year southern flounder (20-45 mm) caught by bag seine, February-March, 1978-1989. Circle size is proportional to mean CPUE.

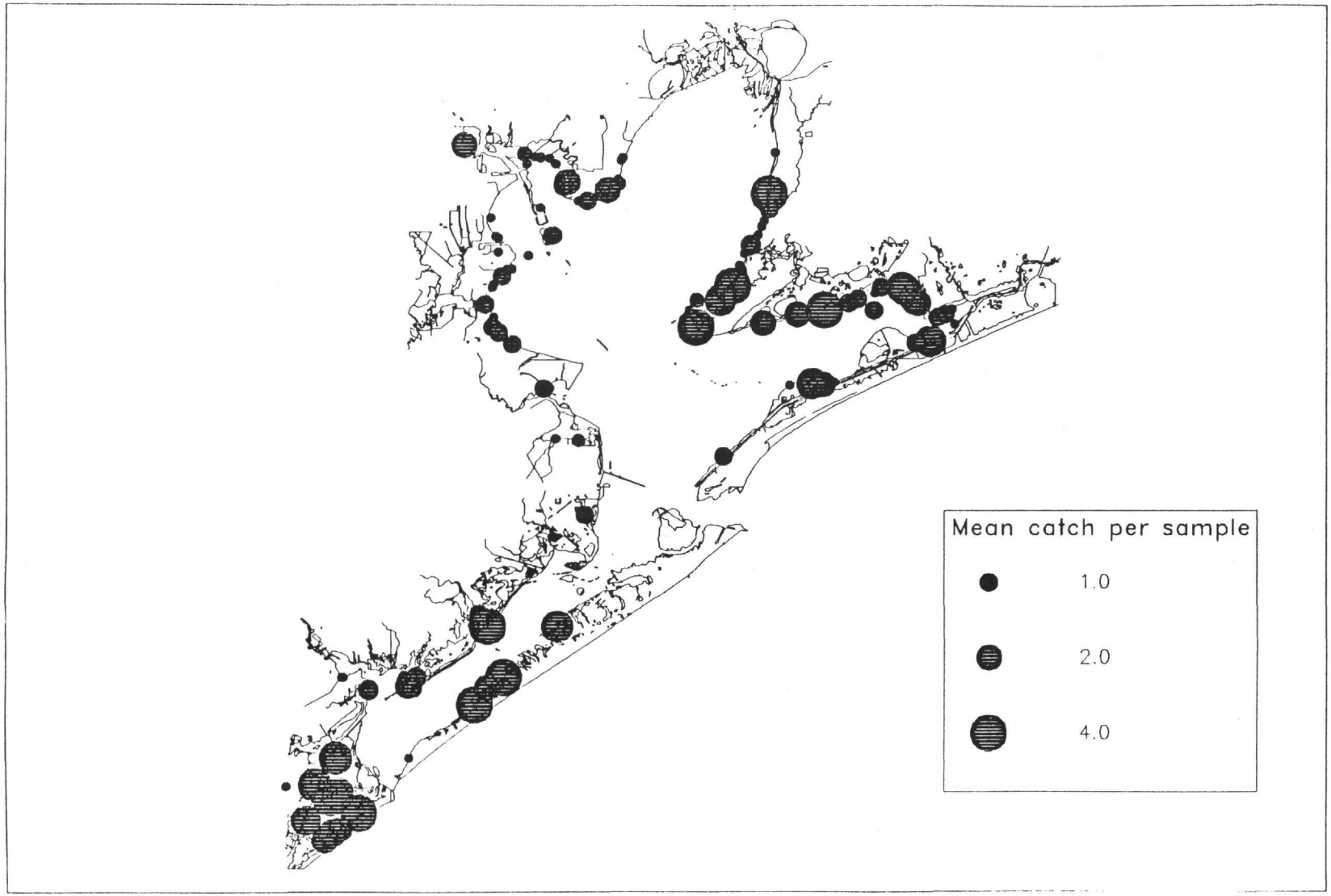


Figure III.119. Distribution of adult southern flounder (>250 mm) caught by gill net, fall, 1975-1989. Circle size is proportional to mean catch per sample.

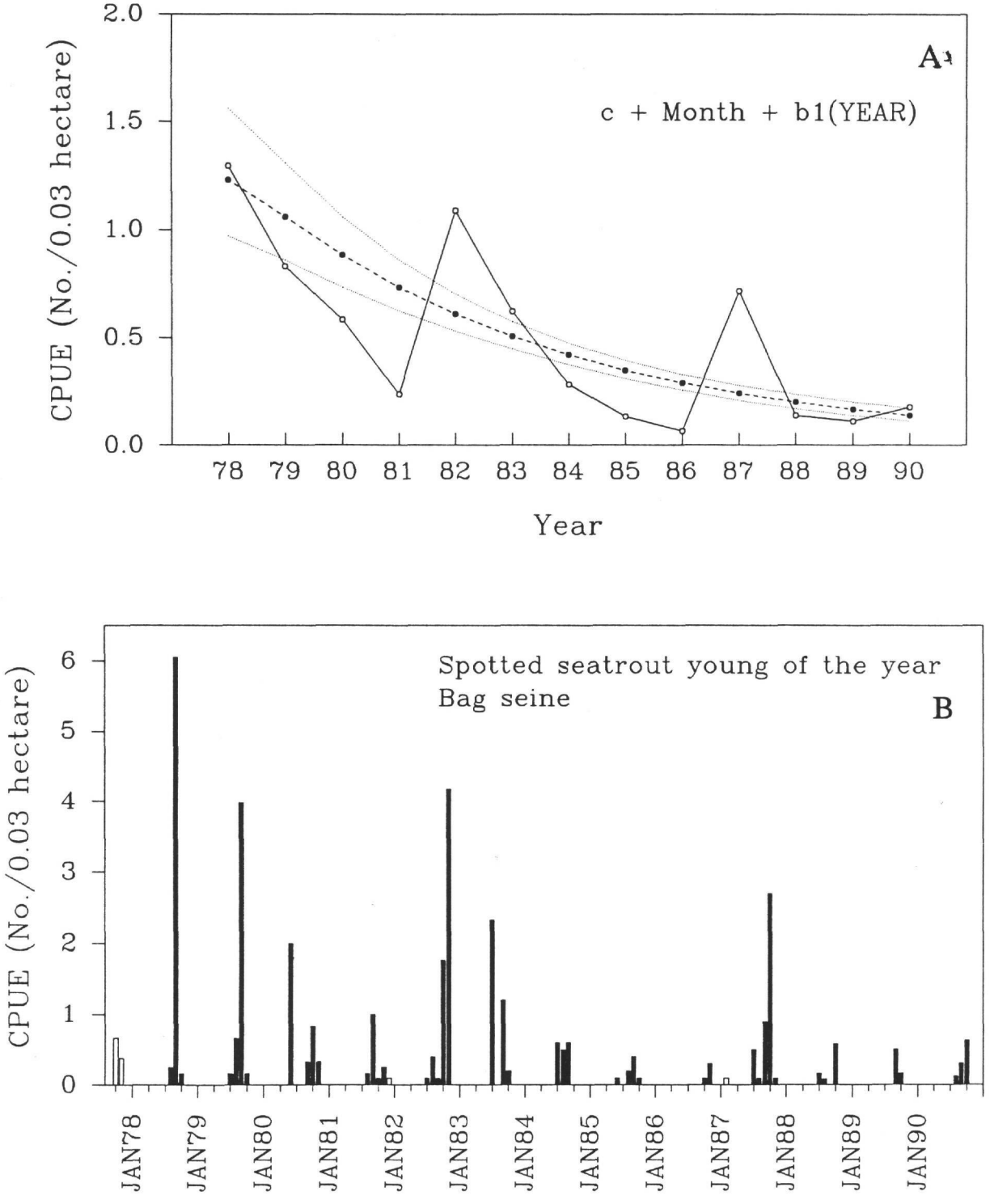
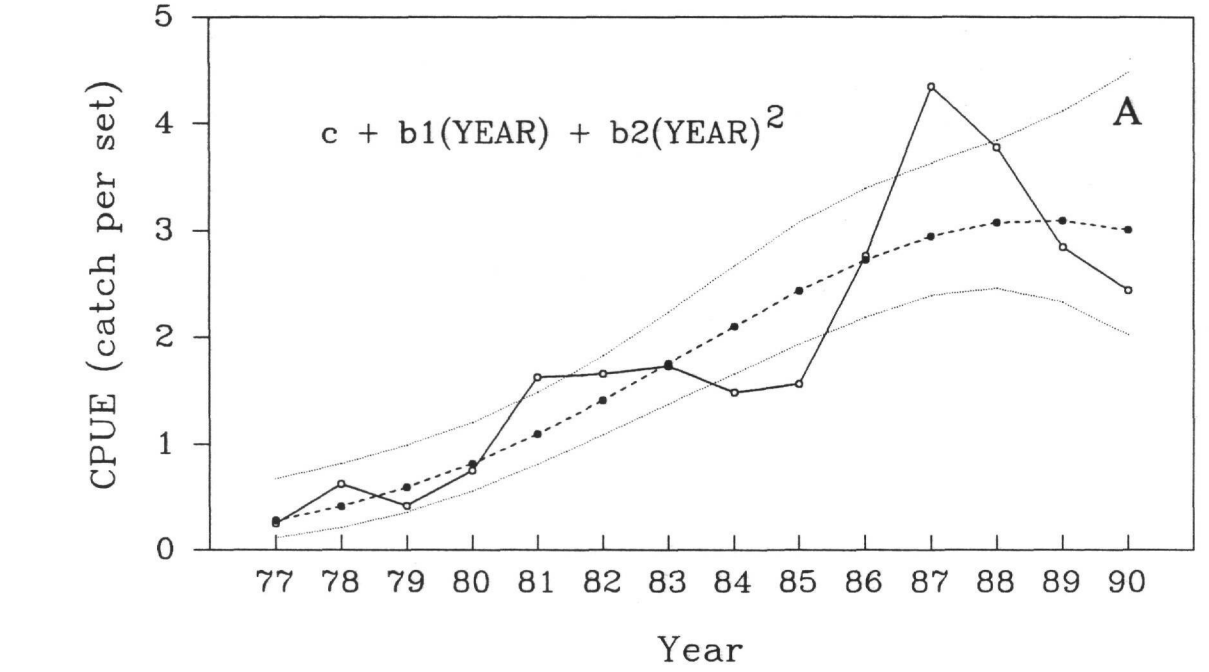


Figure III.120. A. Mean seasonal (June-November) CPUE and predicted CPUE with confidence intervals for young-of-the-year spotted seatrout (35-75 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: June-November. Hollow bars: months not used for analysis.



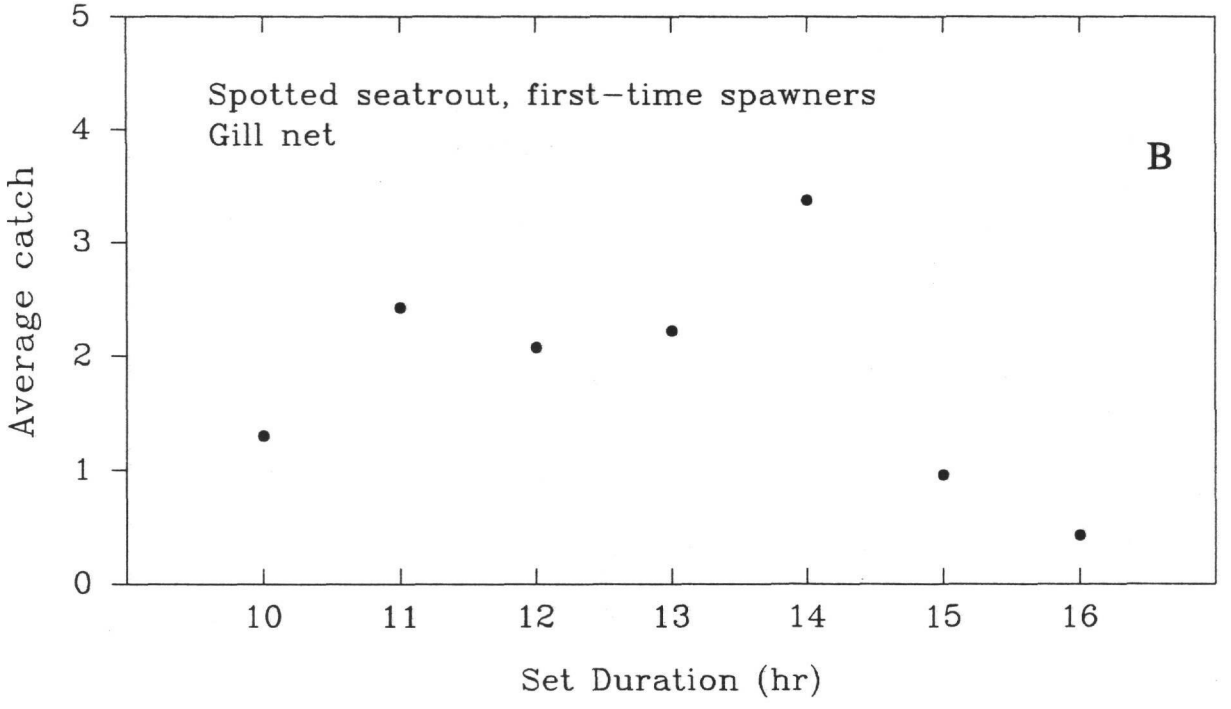


Figure III.121. A. Mean seasonal (spring) CPUE and predicted CPUE with confidence intervals for first-time spawning spotted seatrout (350-450 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1977-1990.

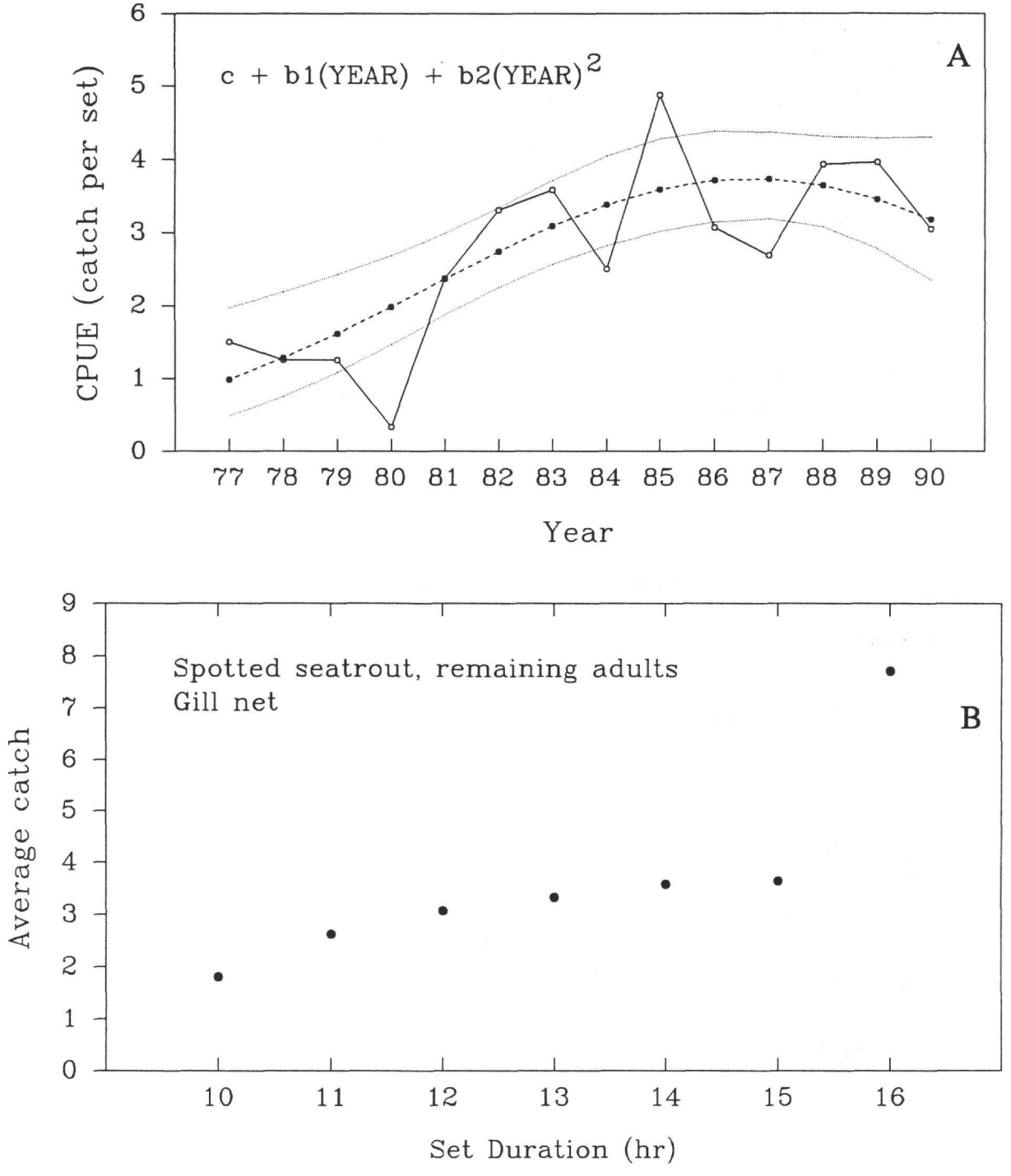


Figure III.122. A. Mean seasonal (spring) CPUE and predicted CPUE with confidence intervals for remaining adult spotted seatrout (>450 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1977-1990.

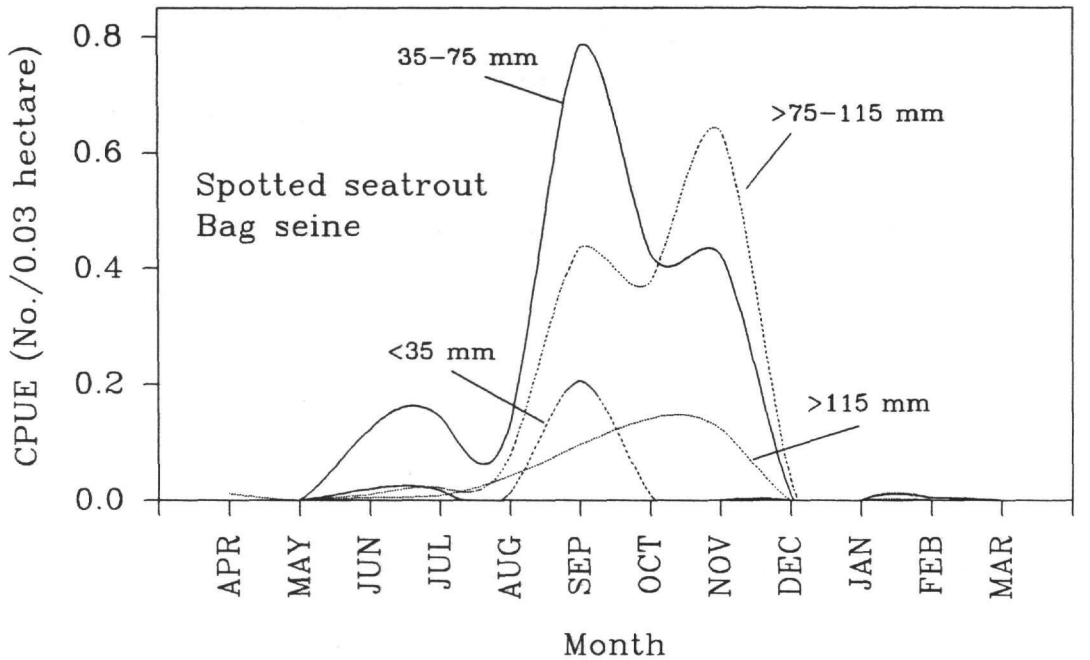


Figure III.123. Mean CPUE by month for four size classes of spotted seatrout caught by bag seine (<35 mm, 35-75 mm, >75-115 mm, >115 mm). Data pooled from 1978-1989.

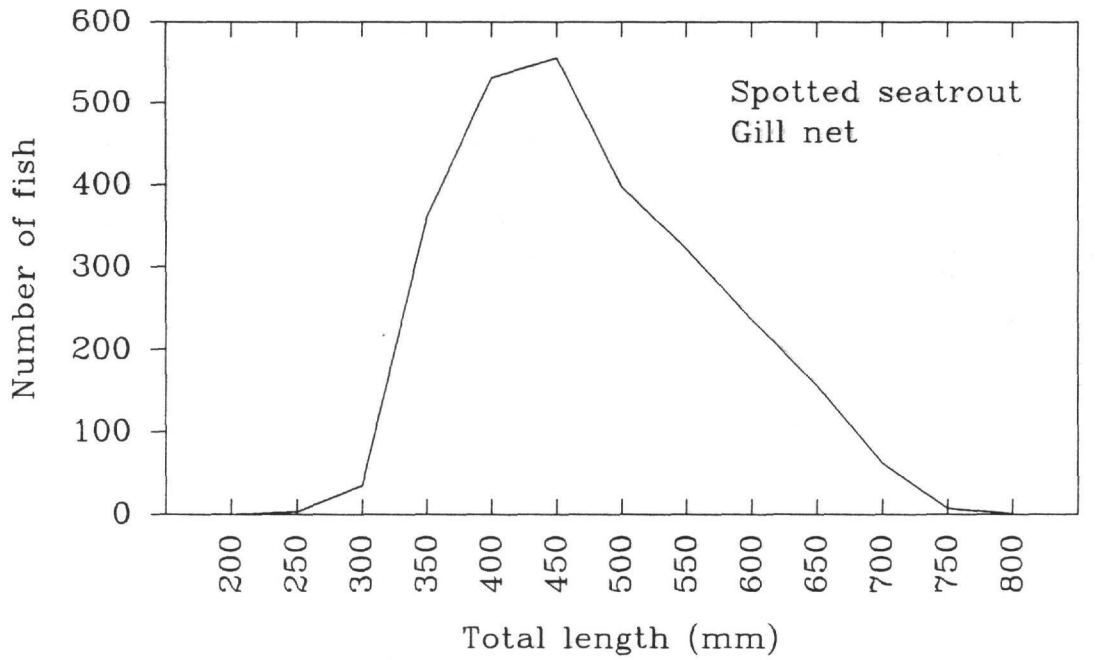


Figure III.124. Size frequency distribution of spotted seatrout caught by gill net during spring sampling period. Data pooled from 1977-1990.

Table III.53. Analysis of deviance for young-of-the-year spotted seatrout (35-75 mm) caught by bag seine, June-November, 1978-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	5	60.85	12.17	14.38	<0.001
YEAR					
Linear	1	52.85	52.85	62.47	<0.001
Quadratic	1	1.28	1.28	1.51	>0.10
Other	10	52.74	5.27	6.23	<0.001
Month x Year	59	217.55	3.69	4.36	<0.001
Corrected error	381	322.32	0.85		

First-time spawners

Gill net: Catch did not appear to be related to set duration (Figure III.121B). A model including GTIME was tested using GLIM, but the term was not significant ($P > 0.75$). CPUE was consequently defined as catch per set.

Both the linear and quadratic components of YEAR were significant (Table III.54). The annual pattern suggests some periodicity, with strong increases over a two-year period (1979-1981, 1985-1987) followed by four-year periods of stable or decreasing CPUE (1981-1985, 1986-1990; Figure III.121).

Remaining spawners

Gill net: It was unclear whether the relationship between set duration and catch was significant (Figure III.121B). A model including GTIME, YEAR, $YEAR^2$, and GTIME-YEAR interaction was tested using GLIM. Results of the preliminary analysis showed that GTIME was not significant in determining catch rates ($P < 0.25$), and CPUE was defined as catch per set.

Both the linear and quadratic terms were significant (Table III.55). The pattern of mean annual CPUE (Figure III.122A) showed a gentle increase from 1977 to a peak in 1985, and fairly stable levels through 1990, though there was considerable year-to-year variation.

Table III.54. Analysis of deviance for first-time spawning spotted seatrout (350-450 mm) caught by gill net, spring season, 1977-1990. CPUE = catch/set.

Source of variation	D.F.	Deviance	M.D.	F	P
GTIME	1	0.00	0.00	0.00	>0.75
Year					
Linear	1	27.20	27.20	22.11	<0.001
Quadratic	1	6.08	6.08	4.94	<0.05
Other	11	10.97	1.00	0.81	>0.50
GTIME x YEAR	13	18.14	1.40	1.13	>0.25
Error	425	523.40	1.23		

Table III.55. Analysis of deviance for remaining adult spotted seatrout (>450 mm) caught by gill net, spring season, 1977-1990. CPUE = catch/set.

Source of Variation	D.F.	Deviance	M.D.	F	P
GTIME	1	2.28	2.28	2.38	>0.10
Year					
Linear	1	5.21	5.21	5.43	<0.025
Quadratic	1	5.06	5.06	5.27	<0.025
Other	11	16.47	1.50	1.56	0.10
GTIME x YEAR	13	11.77	0.91	0.94	>0.50
Error	425	406.27	0.96		

Spatial distribution

Young-of-the-year spotted seatrout are found in highest concentrations in Bastrop Bay, Christmas Bay, and the southern shores of West and East Bays (Figure III.125). Relatively large numbers were also caught in some sites in Upper and Lower Galveston Bay. Trinity Bay catches were low. First-time spawners were widely distributed but not as common in Trinity Bay, and were mainly found on the southern shores of West and East Bay and the Bastrop and Chocolate Bay areas (Figure III.126). In contrast, large catches of remaining adults occurred throughout the bay system, including the Trinity Bay area (Figure III.127).

Discussion

Young-of-the-year spotted seatrout decreased in abundance during the study period, while first-time spawners and remaining adults apparently increased, at least in the early years of the study. Loss of nursery habitat may have played a critical role in the decrease of young fish. The slight decrease in recent years of the adult population may reflect random year to year variation or a cyclic pattern; alternatively it may indicate a true decrease related to the decrease in juveniles, increased fishing pressure, or other factors not taken into account in this study.

Striped Mullet (*Mugil cephalus*)

Young-of-the-year striped mullet (20-40 mm) showed peak CPUE in 1981 and 1987, with five years of poor recruitment between peaks (Figure III.128). First-time spawners (230-275 mm) increased from 1983 to 1990, with peaks in the winters of 1985-86 and 1989-90 (Figure III.129). Age IV adults (275-314 mm) decreased from 1975 to 1979, then maintained fairly constant levels through 1990 (Figure III.130), while Age V+ adults (>314 mm) exhibited no quantifiable trend during the same period (Figure III.131); minimum CPUE occurred in 1979 and a maximum in 1984.

Season and Size Selection

New recruits $\leq$40 mm were most abundant in bag seine catches in February and March (Figure III.132). A size range of 20-40 mm was selected to represent young-of-the-year mullet.

Moore (1973, 1974) found that striped mullet near Port Aransas became sexually mature at Age III, at a size of 230-275 mm. CPUE for all size groups in trawl data was highest from December to March, the months selected for analysis (Figure III.133).

Mullet ranging in size from 200 to over 650 mm were taken in gill nets during the fall sampling period (Figure III.134). The fall gill net season was considered the best time to monitor the abundance of remaining adults because spawning takes place in the winter (October to March with peak spawning from December through February; Gunter 1945, Anderson 1958, Arnold and Thompson 1958, Arnold et al. 1960, Hellier 1962, Moore

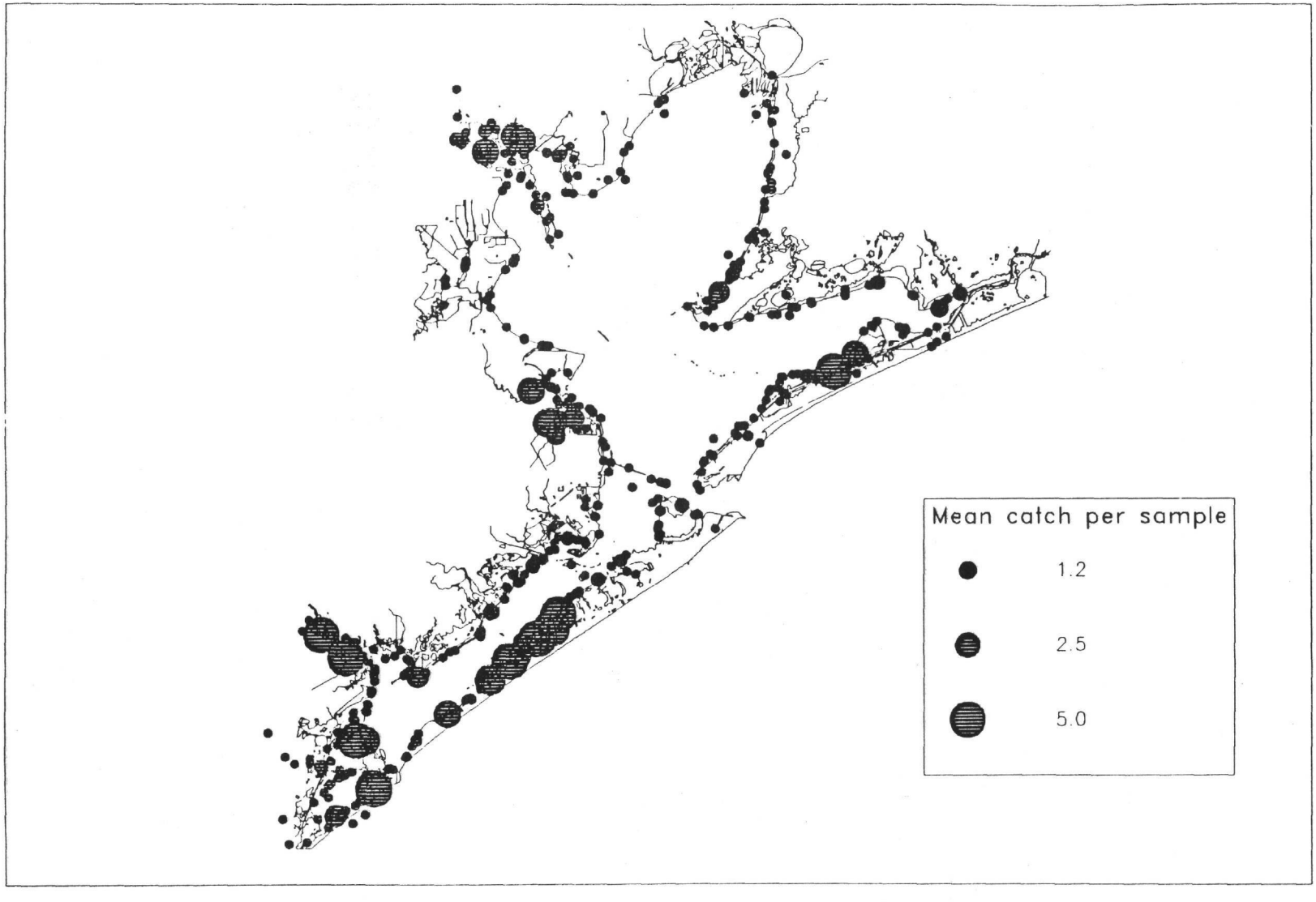


Figure III.125. Distribution of young-of-the-year spotted seatrout (35-75 mm) caught by bag seine, June-December, 1978-1989. Circle size is proportional to mean CPUE.

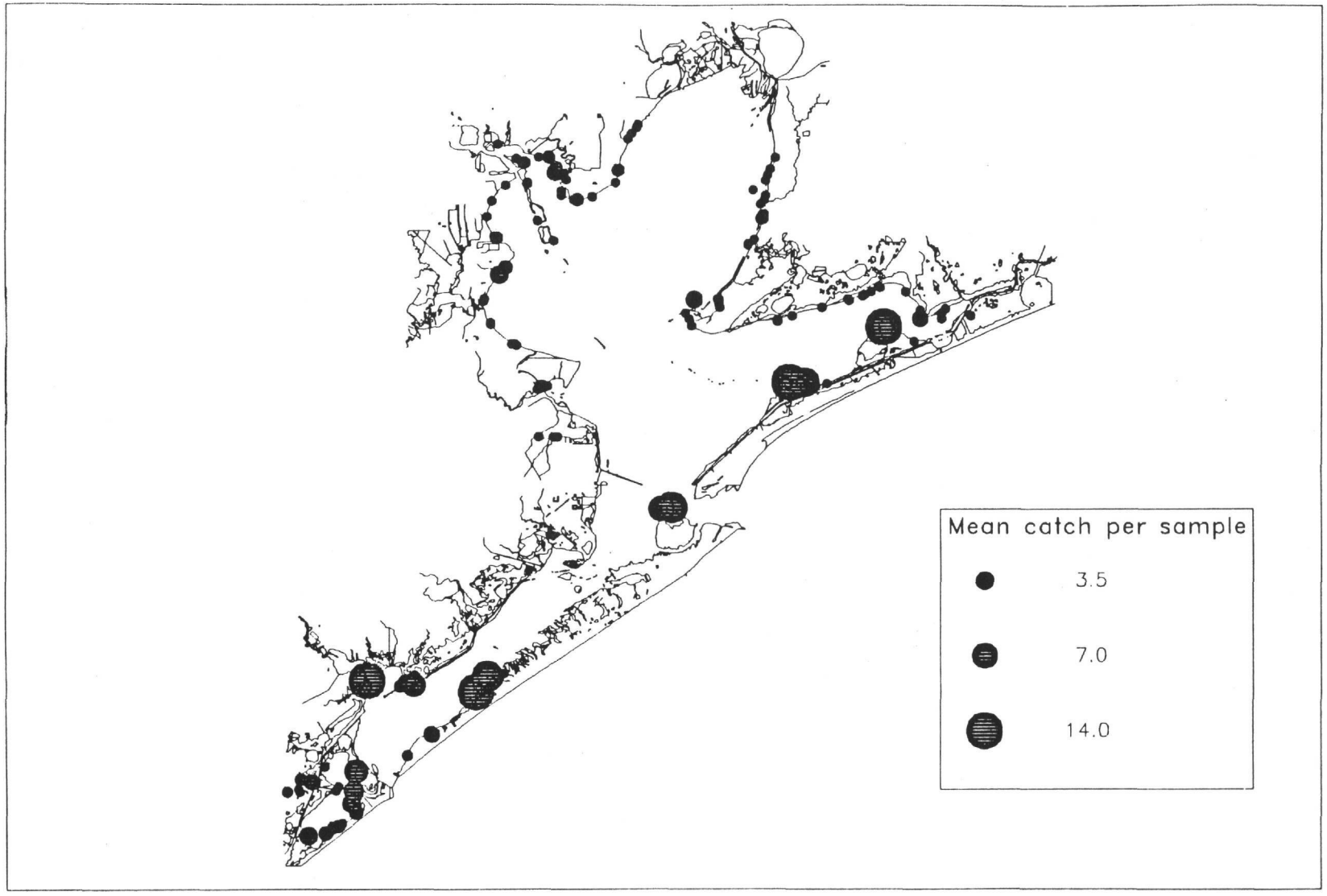


Figure III.126. Distribution of first-time spawning spotted seatrout (350-450 mm) caught by gill net, spring, 1977-1990. Circle size is proportional to mean catch per sample.

Figure III.127. Distribution of remaining adult spotted seatrout (>450 mm) caught by gill net, spring, 1977-1990. Circle size is proportional to mean catch per sample.

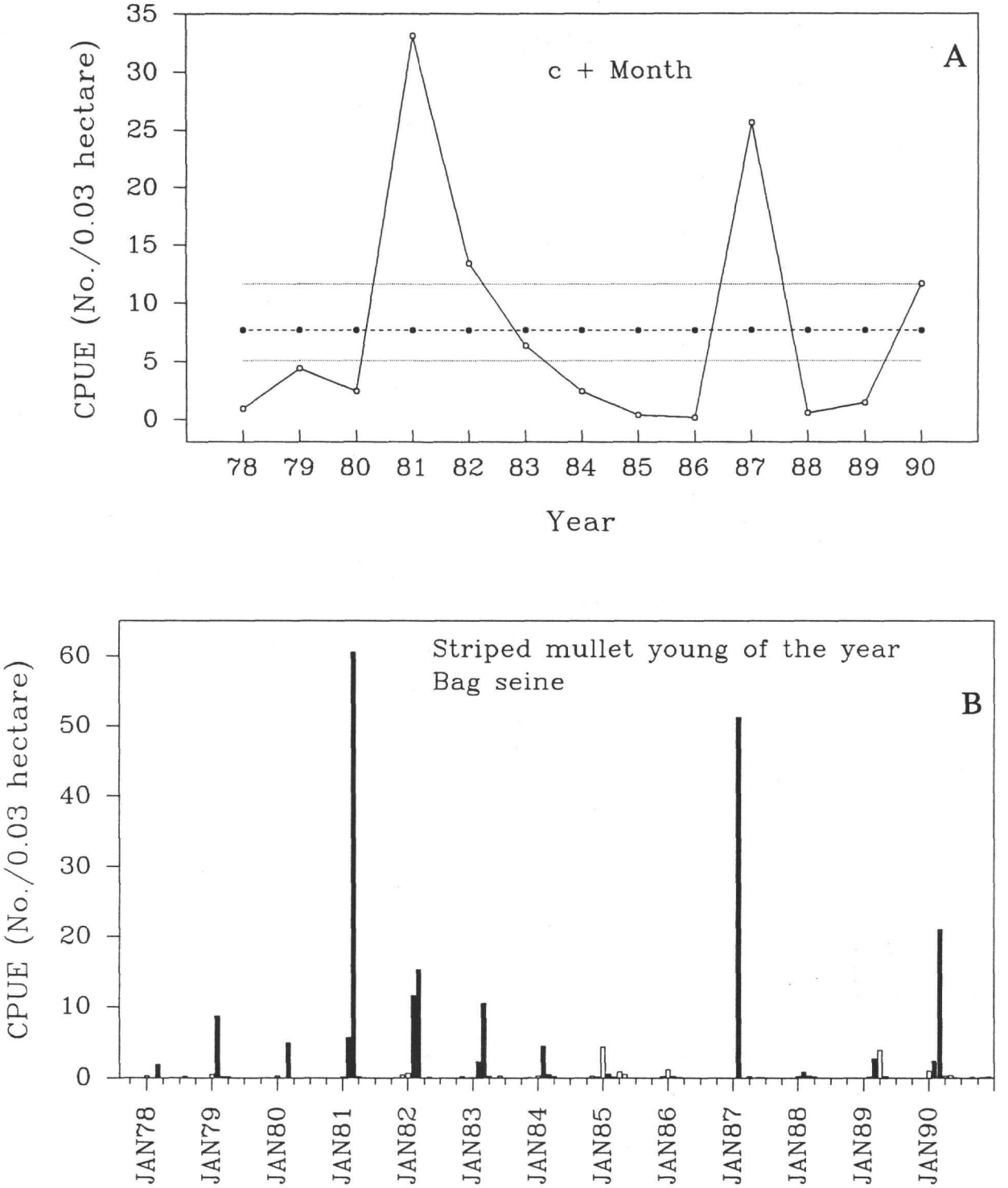


Figure III.128. A. Mean seasonal (February-March) CPUE and predicted CPUE with confidence intervals for young-of-the-year striped mullet (20-40 mm) caught by bag seine. B. Mean CPUE by month. Filled bars: February-March. Hollow bars: months not used in analysis.

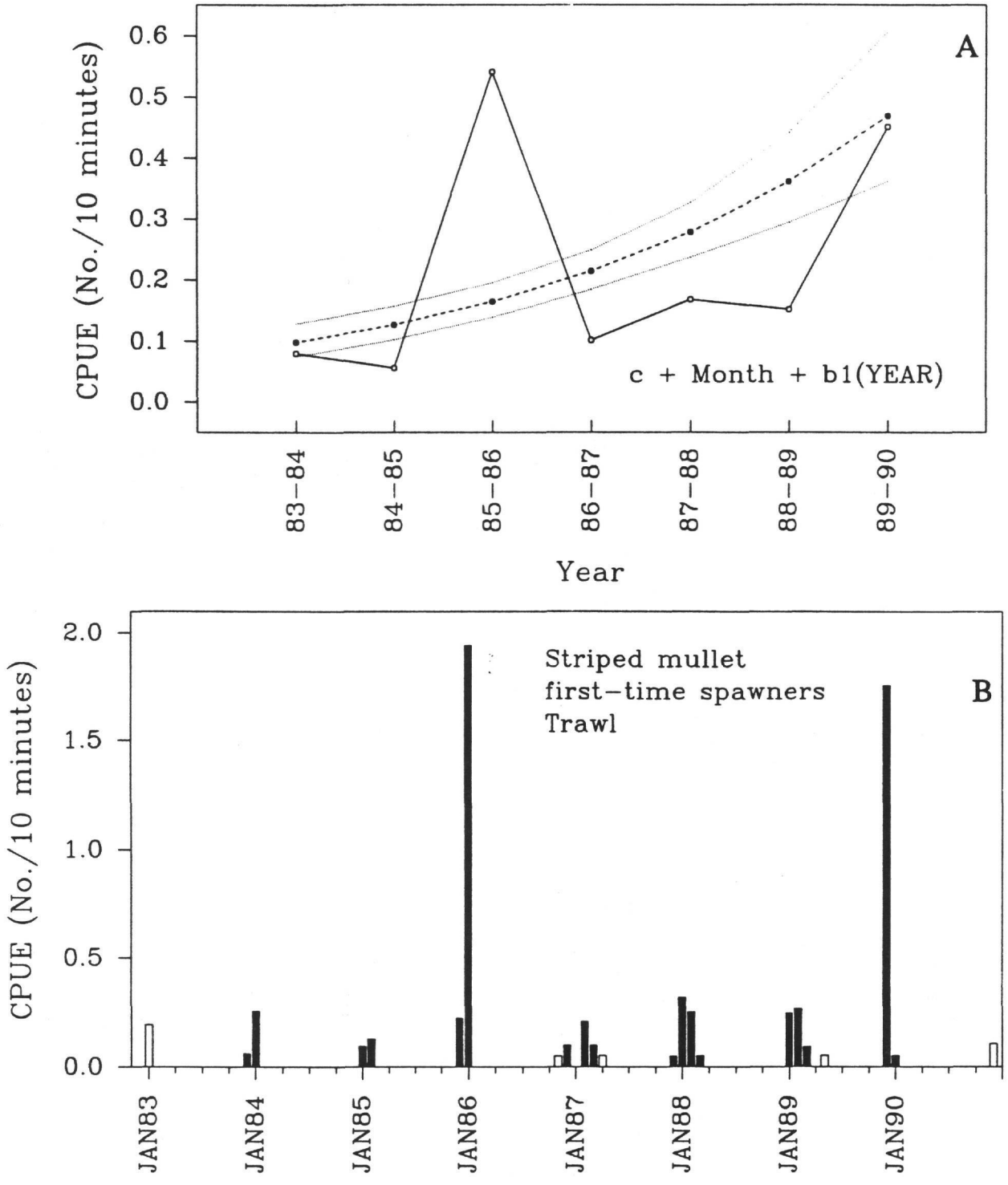


Figure III.129. A. Mean seasonal (December-March) CPUE and predicted CPUE with confidence intervals for first-time spawning striped mullet (230-275 mm) caught by trawl. B. Mean CPUE by month. Filled bars: December to March. Hollow bars: months not used in analysis.

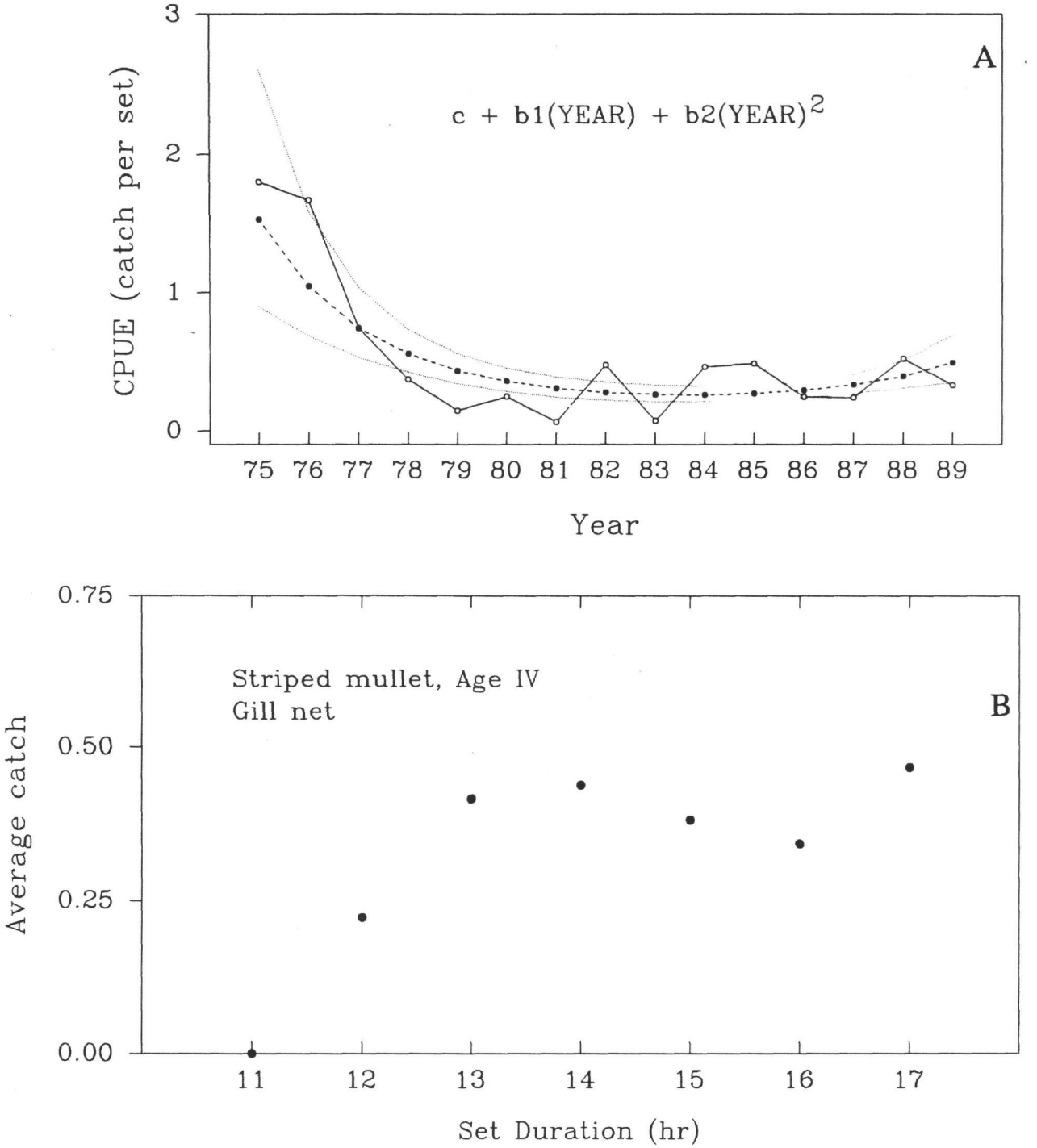


Figure III.130. A. Mean seasonal (fall) CPUE and predicted CPUE with confidence intervals for Age IV adult striped mullet (275-314 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1975-1989.

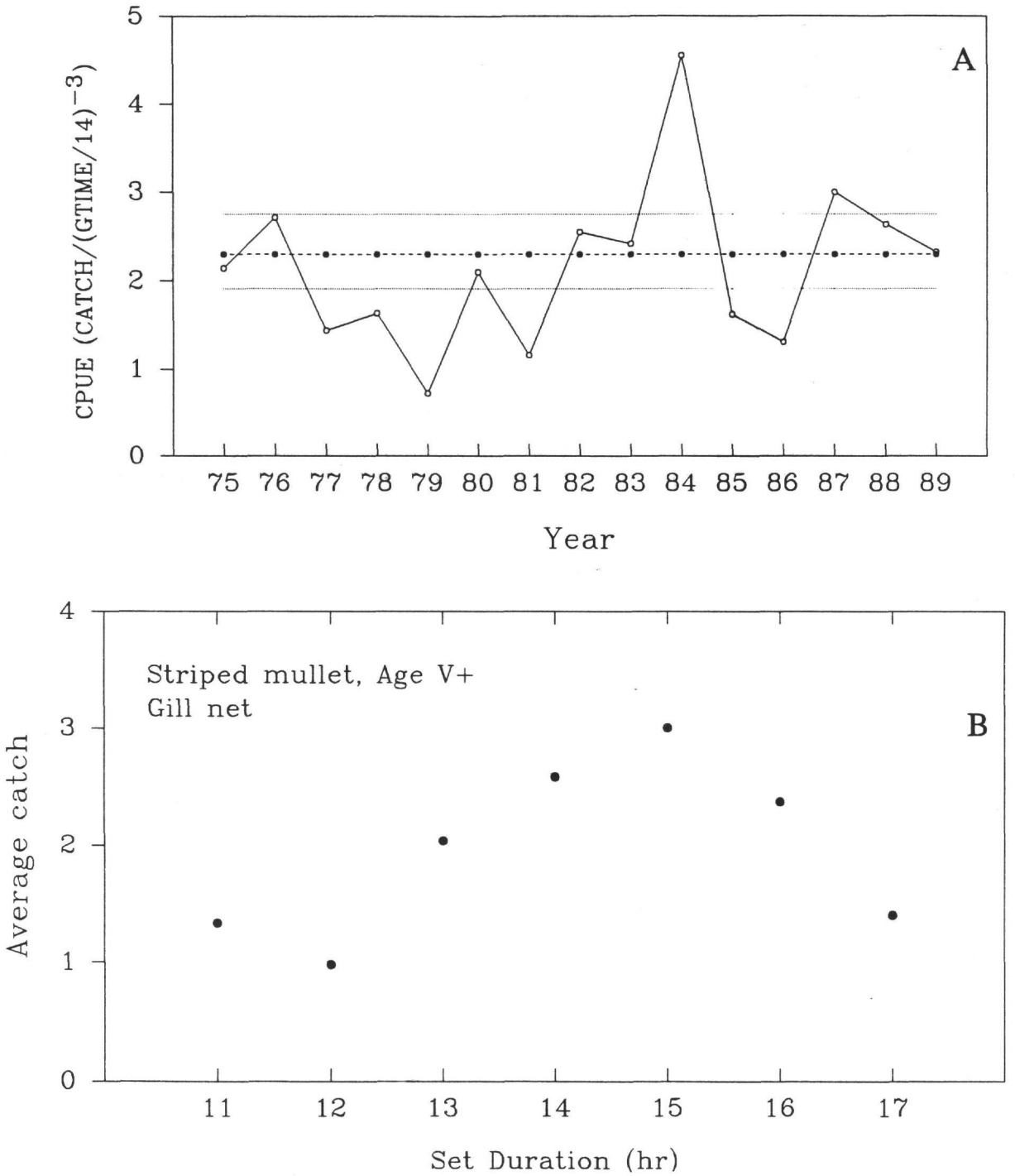


Figure III.131. A. Mean seasonal (fall) CPUE and predicted CPUE with confidence intervals for Age V+ adult striped mullet (>314 mm) caught by gill net. B. Mean catch per hour gill net set duration. Data pooled from 1975-1989.

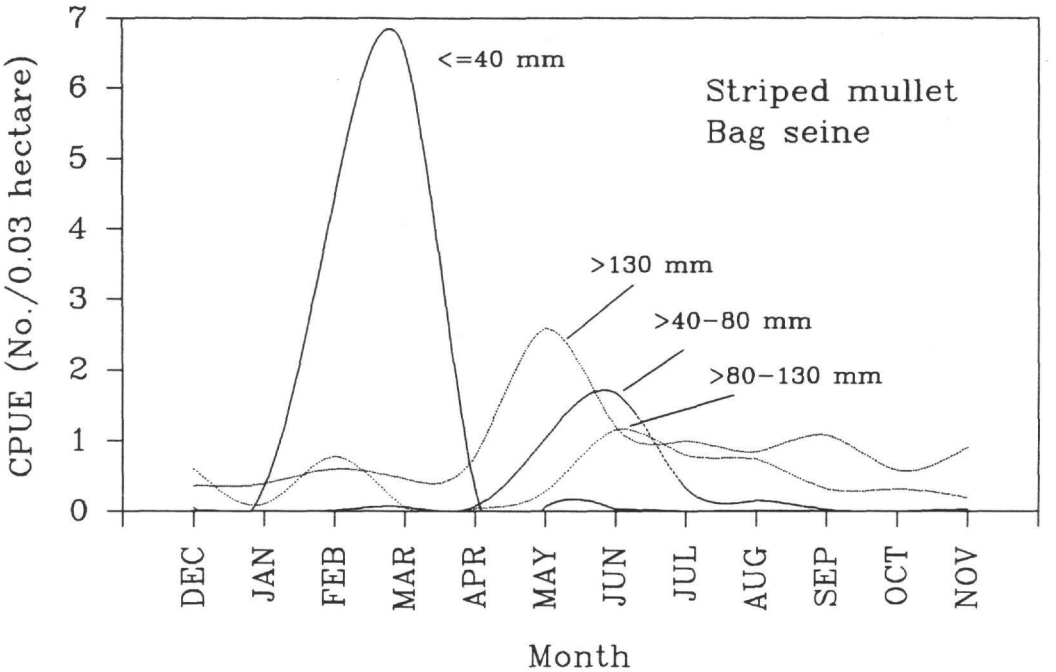


Figure III.132. Mean CPUE by month for four size classes of striped mullet caught by bag seine ($\leq$40 mm, >40-80 mm, >80-130 mm, >130 mm). Data pooled from 1978-1989.

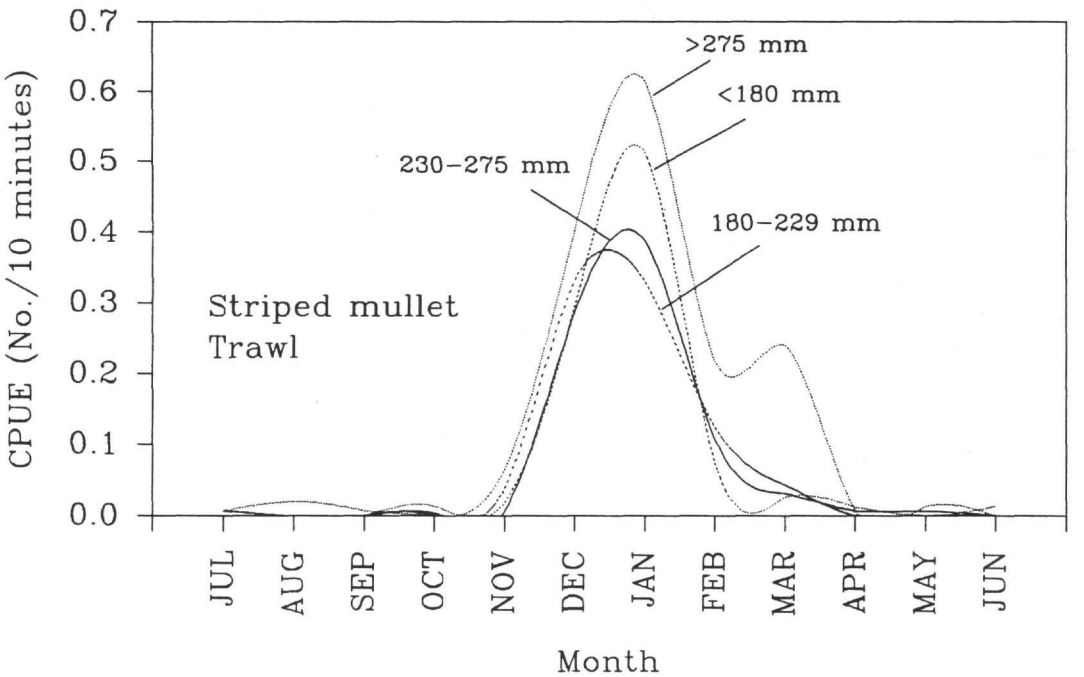


Figure III.133. Mean CPUE by month for four size classes of striped mullet caught by trawl (<180 mm, 180-229 mm, 230-275 mm, >275 mm). Data pooled from 1982-1990.

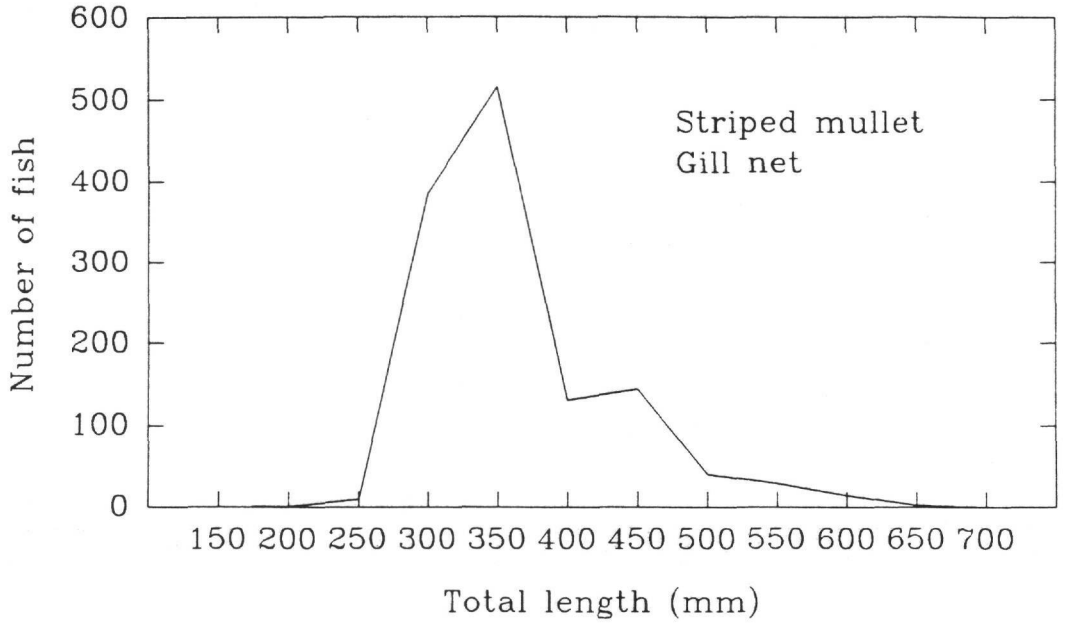


Figure III.134. Size frequency distribution for striped mullet caught by gill net during fall sampling period. Data pooled from 1975-1989.

1974, Finucaine et al. 1978, DeSilva 1980). Two size classes of remaining adult mullet were chosen for analysis: 275-314 mm, representing Age IV fish, and >314 mm, representing mullet Age V and over (Hellier 1962, Moore 1973).

Young of the Year

Bag seine: Neither monthly nor annual trends were significant in the analysis of deviance (Table III.56), reflecting the narrow season for striped mullet (Figure III.128B) and no net change in CPUE from 1978 to 1990. Most of the deviance was the result of categorical Year effects or was unexplained. Abundances of young-of-the-year mullet were evidently strongly affected by year, but in a manner not adequately explained by the simple models tested.

First-time Spawners

Trawl: Monthly and linear annual effects were significant, while the quadratic term was not significant (Table III.57). The fitted annual trend had a positive slope (Figure III.129A). The model including Month and linear YEAR explained 19.0 percent of the total deviance. The linear component explained 61.3 percent of the deviance ascribed to YEAR, and 33.2 percent was not accounted for by either linear or quadratic effects (Other). Peak catches occurred in January 1986 and December 1989 (Figure III.129B).

Table III.56. Analysis of deviance for young-of-the-year striped mullet (20-40 mm) caught by bag seine, February-March, 1978-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	1	1.15	1.15	0.99	>0.25
YEAR					
Linear	1	0.002	0.002	0.001	>0.75
Quadratic	1	0.39	0.39	0.34	>0.50
Other	10	97.01	9.70	8.37	<0.001
Month x Year	12	73.17	6.10	5.26	<0.001
Corrected error	207	240.03	1.16		

Table III.57. Analysis of deviance for first-time spawning striped mullet (230-275 mm) caught by trawl, December-March, 1983-1990.

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	29.75	9.92	21.52	<0.001
YEAR					
Linear trend	1	14.36	14.36	31.16	<0.001
Additional quadratic	1	1.29	1.29	2.80	>0.75
Other	5	7.77	1.55	3.37	<0.005
Month x Year	20	83.48	4.17	9.06	<0.001
Corrected error	361	166.39	0.46		

Remaining Adults Age IV

Gill net: Preliminary analysis using GLIM indicated that set duration was not significant (Figure III.130B). Therefore CPUE was defined as catch per set.

The analysis (Table III.58) showed that all types of annual effects were significant; the quadratic term explained 27.3 percent and the unexplained (Other) term 58.9 percent of the deviance related to annual effects. The model including linear and quadratic YEAR terms explained 8.7 percent of the total deviance. The fitted trend (Figure III.130A) was negative, indicating that Age IV adults decreased in abundance. High catches (>1.5/set) occurred in 1975 and 1976. Since then, catch rates have been low (≤ 0.5/set) and relatively constant. When the first high-catch years (1975 and 1976) were deleted from the data set the analysis revealed no annual trend.

Remaining Adults Age V+

Gill net: Preliminary analysis using GLIM indicated that set duration was significant (Figure III.131B). Consequently CPUE was standardized as $CATCH/(GTIME/14)^3$.

The analysis of deviance (Table III.59) showed that neither the linear nor quadratic annual terms were significant. Annual effects that were neither linear nor quadratic were significant and accounted for 93.9 percent of the deviance due to annual variation. No annual model was fitted to the data (Figure III.131A).

Spatial Distribution

Young-of-the-year striped mullet taken by bag seine were common in small bays off of Trinity and West Bay (Figure III.135). First-time (Age III) spawners taken in trawls from December to March were most abundant in Trinity and East Bay (Figure III.136). Age IV adults taken in gill nets in the fall were abundant along the coastline of East Bay, the southern side of Trinity Bay, along the coastline of Upper Galveston Bay, and at some localities in West Bay, Chocolate Bay and Christmas Bay (Figure III.137). Age V+ adult mullet were abundant at various localities in East Bay, southern Trinity Bay and Upper Galveston Bay (Figure III.138). These sporadic distributions may be related partly to schooling behavior, and to the availability of the benthic algae and detritus consumed by striped mullet (Odum 1968, Alexander 1983, Matlock and Garcia 1985).

Discussion

The peak in CPUE for Age III first-time spawners in 1989-90 (Figure III.129) may be the consequence of high recruitment of young of the year in 1987, but other peaks did not correlate. The distinctive pattern of juvenile recruitment (Figure III.128) did not seem to be echoed by larger size groups, with the possible exception of first-time spawners (Figure III.129).

Table III.58. Analysis of deviance for Age IV striped mullet (275-314 mm) caught by gill net, fall season, 1975-1989.

Source of Variation	D.F.	Deviance	M.D.	F	P
GTIME	1	1.73	1.73	2.98	>0.05
YEAR					
Linear	1	7.37	7.37	12.71	<0.001
Quadratic	1	14.48	14.48	24.96	<0.001
Other	12	31.25	2.60	4.49	<0.001
GTIME x YEAR	14	21.56	1.54	2.66	<0.001
Error	445	258.95	0.58		

Table III.59. Analysis of deviance for Age V+ striped mullet (>314 mm) caught by gill net, fall season, 1975-1989. CPUE=CATCH/(GTIME/14)^3.

Source of Variation	D.F.	Deviance	M.D.	F	P
YEAR					
Linear	1	2.15	2.15	1.55	>0.10
Quadratic	1	0.09	0.09	0.06	>0.75
Other	12	34.64	2.89	2.08	<0.025
Error	472	656.67	1.39		

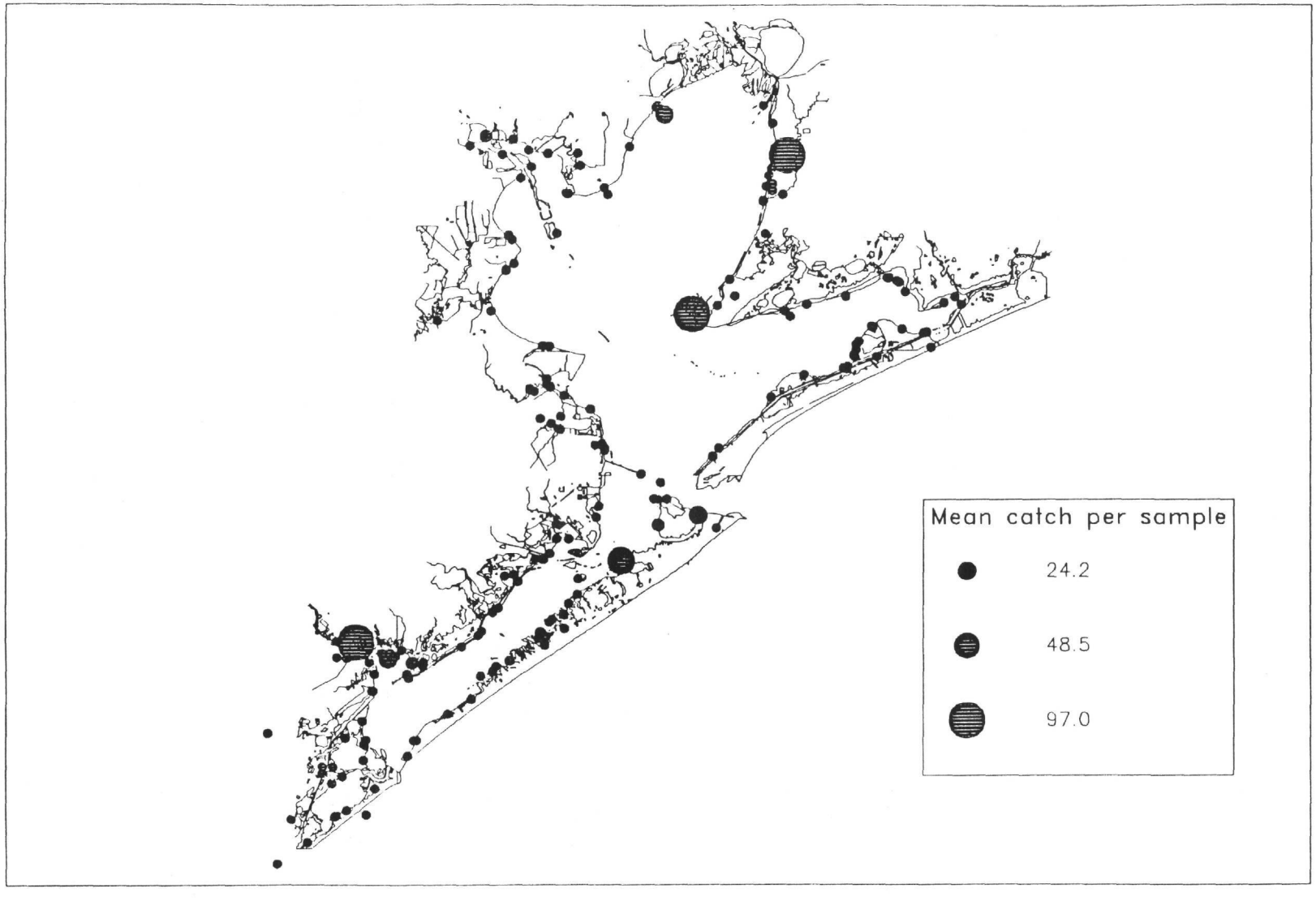


Figure III.135. Distribution of young-of-the-year striped mullet (20-40 mm) caught by bag seine, February-March, 1978-1989. Circle size is proportional to mean CPUE.

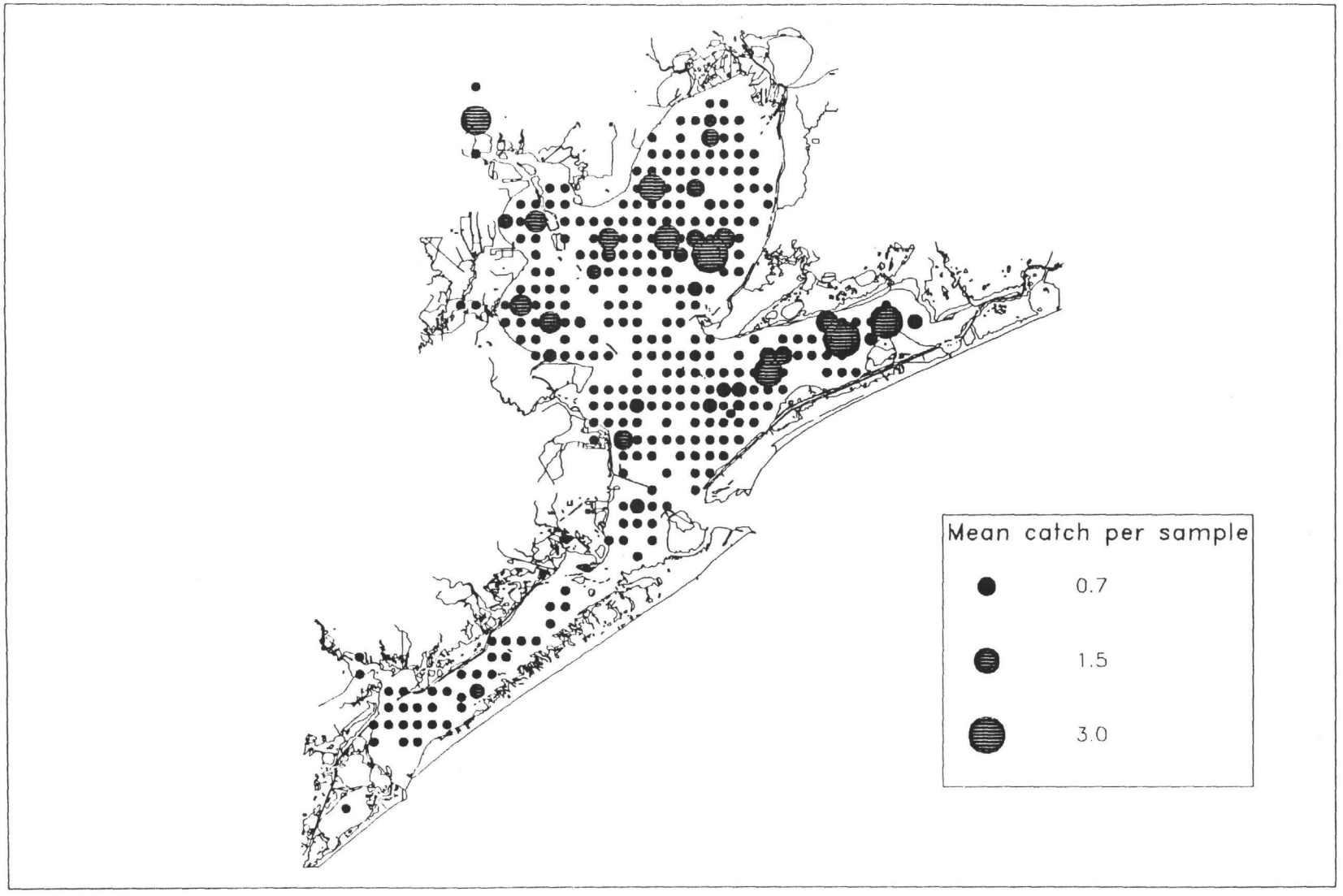


Figure III.136. Distribution of first-time spawning striped mullet (230-275 mm) caught by trawl, December-March, 1983-1990. Circle size is proportional to mean CPUE.

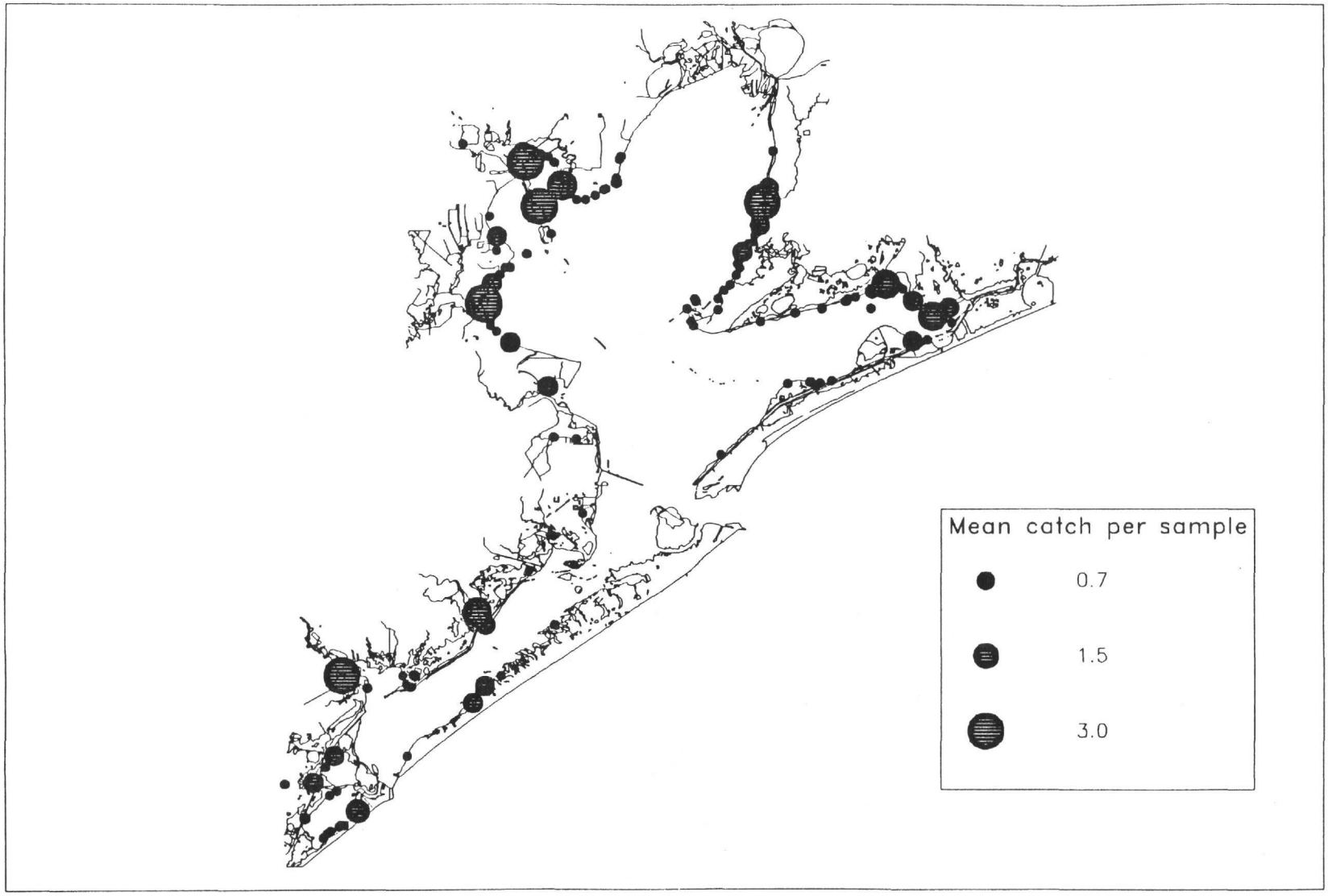


Figure III.137. Distribution of Age IV adult striped mullet (275-314 mm) caught by gill net, fall, 1975-1989. Circle size is proportional to mean catch per sample.

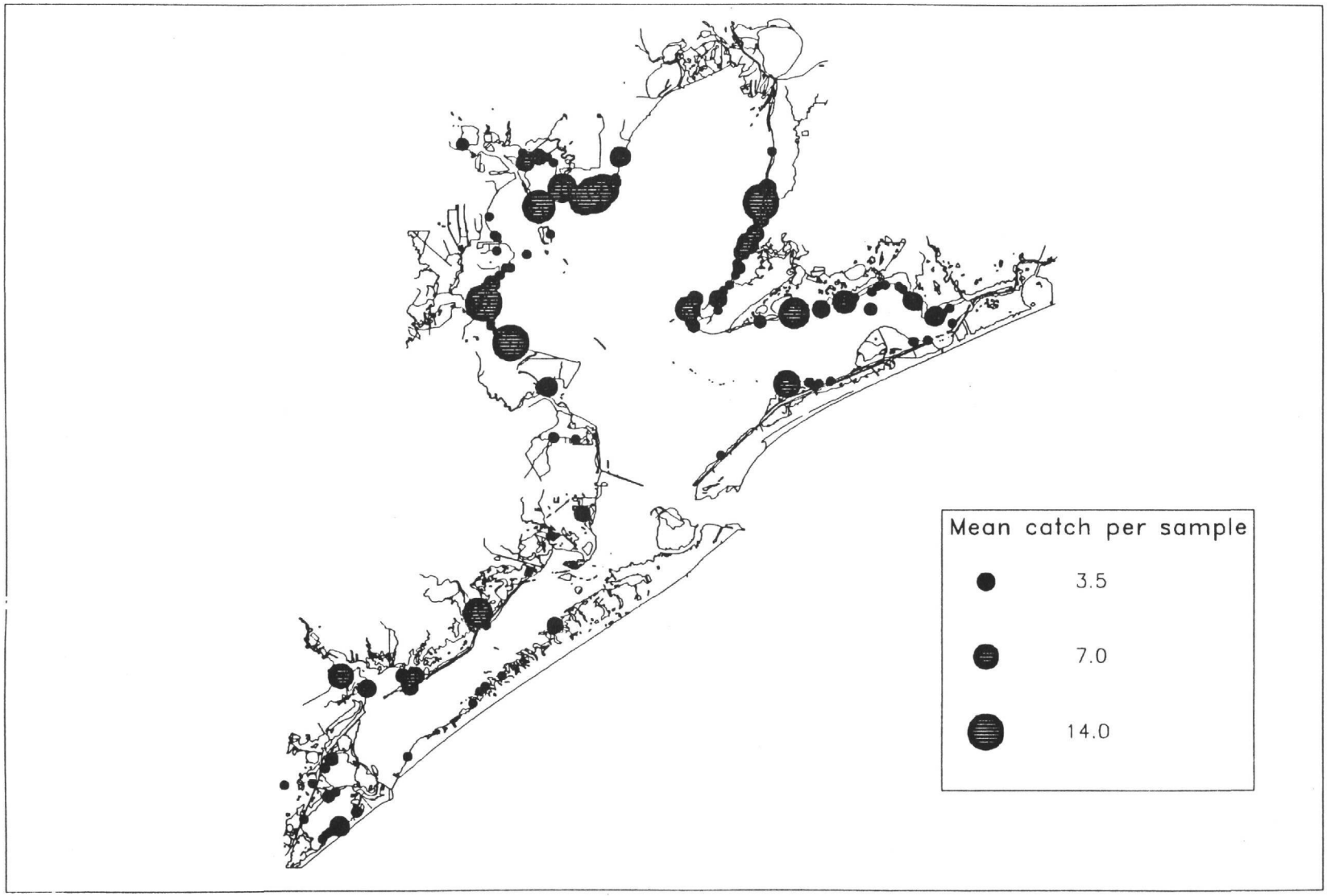


Figure III.138. Distribution of Age V+ adult striped mullet (>314 mm) caught by gill net, fall, 1975-1989. Circle size is proportional to mean catch per sample.

Age IV mullet taken in gill net exhibited a drop in abundance after 1975 and 1976 (Figure III.130) that could be partly due to increasing fishing pressure. Mullet are exploited for bait for the blue crab fishery, though these removals are difficult to monitor (C.E. Bryan, personal communication 1991). They have also been harvested for their roe in recent years. The reported commercial landings in Galveston Bay increased from 1,946 pounds in 1978 to 108,024 pounds in 1989 (Johns 1990). However, an analogous decreasing trend was not evident for Age V+ mullet (Figure III.131).

It is also possible that the CPUE values for Age IV mullet taken in the fall gill net surveys in 1975 and 1976 are biased. Less sampling effort was expended during the fall sampling period in these earlier years (< 10 sets) than in later years (45). When 1975 and 1976 were omitted from the analysis, the YEAR terms were not significant, analogous to the lack of annual trend found for Age V+ mullet from 1975 to 1989. Further research on striped mullet is needed to determine the factors influencing changes in abundance.

GENERAL DISCUSSION

Status of the Fishery

A comparison of the commercial landings of 1893 (Collins and Smith 1893), the CF monitoring data (Appendix III.2), the trend analyses presented in this study, other monitoring data sets (Appendix III.1), and current commercial finfish and shellfish landings (Johns 1990), showed that the Galveston estuarine community is still a very viable ecosystem. All species named in Collins' and Smith's 1893 report were still present (although recent catches of striped bass were probably the result of stocking programs rather than an original population). Data from the independent monitoring program showed that there was a wide assortment of prey animals present and that the estuary still supported top-level consumers (sharks, dolphins, and humans).

Of the fourteen different species that were analyzed, only trends for blue crab and white shrimp showed distinct chronic problems. Blue crab young of the year increased but there was a strong decreasing trend for juveniles and first-time spawners, the life stage most valuable for reproduction (Elseth and Baumgardner 1981; Figures III.1-III.5). Adult crabs (> 140 mm TW) also decreased in the later years of the analysis period (Figure III.6). The decrease in large crabs in recent years may be a response to the dramatic increase in landings apparent since 1981 (Appendix III.3, Figure III.3.5). For white shrimp, a strong linear decrease was evident throughout the last ten-year period for juveniles and first-time spawners (Figure III.35-III.37). These decreases may be the result of overharvesting, loss of habitat, sublethal contamination by a chemical, or a combination of these. These three species are declining, and if there is no change in current population parameters, they may continue to decline.

Only one life stage for grass shrimp (adults) was available for analysis and it showed a strong non-linear decrease with a recent increase (Figure III.27). This species is food for many juvenile fish, and should it decline, it could cause a major break in the food chain. Unfortunately, increasing the sample size with sampling gear now in use will not catch smaller grass shrimp. A more comprehensive investigation in the future would require the use of different sampling gear with a finer mesh.

Bay anchovy trends were a paradox. All the analyses using bag seine data showed decreasing trends for juveniles, first-time spawners, and adults (Figure III.55-III.57), whereas all analyses for these same life stages in trawl data showed an increase (Figures III.58-III.50). These differences could be caused by the differing time periods, seasons, or habitats examined, or may be a real response to change in the environment. Bag seine CPUE in hectares and trawl CPUE in time units prohibited a direct comparison; however, bag seines were used in shallow areas along the shore and trawls were used in deeper waters offshore, and the contrast in trends gives the impression that the decreases along the shore were the effect of the fish moving to offshore areas. Because the deeper offshore area is larger than the shallow shoreline area (Matlock and Osborn, 1982), one conclusion is that there may actually have been a net increase in abundance.

All other species investigated showed different life stages to be a mixture of trends, including no trend at all (e.g. brown shrimp, southern flounder). For species which have high fecundity and live in an unstable environment, it is natural for the abundances of different age classes to be highly variable and for different trends to be exhibited simultaneously (Elseth and Baumgardner 1981). Fish populations can be dominated by one or two age classes coming from highly successful spawns and subsequent excellent survival (Beverton and Holt 1957), so that a downward trend in later life stages as members of this group die off, should not be alarming when different trends are found in the other life stages. Obviously, sustained declines in young of the year and first-time spawners should attract attention, especially if they occur simultaneously.

A hypothesis exists among local resource managers (TPWD, NMFS, and USFWS) that many fish and shellfish populations already were in a state of reduced abundance and that analyses of recent data (after 1960) would not reveal meaningful trends. Unfortunately, the only data sets available to compare for a longer time period were commercial landings, and this could only be done using non-rigorous assumptions because the validity of self reporting, amount of effort, location of catch, and current market conditions were not always available (Higgins and Lord 1926; Lahr et al. 1987). The most robust comparison (requiring the fewest or least stringent assumptions) that could be made with these data was that if there has always been a demand for a species and it was legal to harvest, then at least presence or absence could be determined. Any higher-level comparisons would require more complex models and a greater number of assumptions, increasing the probability of arriving at the wrong conclusion.

As an example, commercial landings reported from the Galveston Estuary during 1989 (7,148,411 lb) were double the amount reported during 1890 (3,435,800 lb; Table III.60). Based on this comparison it would appear there has been a significant decline in finfish landings (1,485,810 lb during 1890 and 221,104 lb during 1989) and in oyster

Table III.60. Commercial landings (X1000 lb) reported from the Galveston Estuary during 1890 and 1989.

Species	Total 1890	Total 1989
Red drum	404.2	0
Black drum	4.0	21.8
Flounder	46.0	14.6
Mullet	39.3	108.0
Sheepshead	17.0	16.2
Striped bass	5.0	0
Trout	427.4	0
Other fish	542.9	60.5
Total fish	1,485.8	221.1
Oysters	1,647.1	705.5
Crabs	162.5	2,149.5
Shrimp	138.0	4,056.1
Terrapins	2.4	0
Other shellfish	0	13.4
Total	3,435.8	7,145.6

landings (1,647,100 in 1890 and 705,490 lb in 1989), and an increase in shrimp landings (138,000 and 4,056,132 lb, respectively).

Do these differences represent changes in abundance? Probably not. During 1988-89, recreational finfish landings from the Galveston estuary were approximately 1,100,000 lb (Appendix 3, Figure III.3.21), and in 1981 the retention and sale of red drum and spotted seatrout was made illegal. Red drum and spotted seatrout accounted for about half of the commercial landings in 1890 and in 1979. Recreational landings for 1890 were not available but they were probably insignificant (based on total human population, its distribution, and the availability of transportation). Therefore it would seem that for finfish, a large part of the apparent differences in landings between the 1890s and the 1990s can be explained as a shift from one user group to another.

The apparent decline in oyster landings is not substantiated given that reported landings have been below 1,600,000 lb only eight times during the period 1972 through 1989, and have been as high as 6,900,000 lb (1983). Stevenson (1893) states that oyster fishermen did not use all the reef that was available to support their harvest. Apparently they did not need to travel to distant out-of-the-way reefs to support the demand. Today all reef

areas are used to support the oyster harvest, including reefs in closed areas (oysters in closed areas are moved to leased areas to depurate and are then harvested and sold).

The comparison of shrimp landings would infer that shrimp have become 10 to 30 times more abundant than they were in 1889 or 1890, when in fact, changes in harvest technique, effort, and methodology has caused the major increase in landings (Cody et al. 1989).

One piece of evidence supporting the hypothesis that some fish stocks were in a state of reduced abundance is provided by trends in red drum and spotted seatrout. These species showed increasing trends for first-time spawners and remaining adults (Figures III.95, III.96, III.121, III.122) after regulations restricting their harvest were passed. The increases occurred in spite of three major freezes and a red tide outbreak in the area during the analysis period. Regulations that were recently passed to reduce the mortality of juvenile red drum and spotted seatrout included: the prohibition of commercial sale since 1981, the banning of all nets in 1988, and the implementation of minimum and maximum sizes and daily bag and possession limits for recreational fishermen in 1982.

During the last 100 years the total landings from the Galveston Estuary have doubled, consisting mostly of shrimp and crabs, while it appears total landings for other species have remained essentially unchanged (with the exception of decreased landings for striped bass and grouper). However, since 1890, the commercial landings coming from bays and Gulf waters off the Texas Coast have increased over 2000 percent. Total state-wide inshore and offshore landings were 7,959,400 lb in 1890, and 185,274,000 lb in 1989. Over 90 percent of the weight in these landings are from species that depend on estuaries for part of their lives and are commonly found in the Galveston Estuary. This includes brown and white shrimp (63,000,000 lb), Gulf menhaden (95,000,000 lb taken off Galveston but landed in other Gulf states), blue crab (9,200,000 lb), oysters (2,000,000 lb), and finfish (black drum, southern flounder, sand seatrout, sheepshead and mullet, totalling approximately 1,000,000 lb).

Although analyses of recent data sets indicate that the Galveston Estuary has a basically healthy estuarine community, there is evidence that there has been some degradation during the past 100 years. Striped bass are listed in commercial landings during 1880, 1889, 1890, and 1926 but disappear thereafter and current independent sampling does not show them to be sufficiently abundant to support a commercial or recreational fishery. The disappearance of the green turtle and diamondback terrapin fishery (Collins and Smith 1891; Stevenson 1893) and current independent sampling indicates that turtles and terrapins have declined in abundance. Seagrasses and emergent marsh, important feeding and habitat areas for many juvenile finfish and shellfish (Subrahmanyam and Drake 1975), have been declining during the past 40 years because of subsidence or sea-level rise (Zimmerman et al. 1990) and the frequent occurrence of prolonged high turbidity (Pulich and White 1989). Comparisons of old maps of the Texas coast archived in the General Land Office with recent maps and recent reports indicate an extensive loss of intertidal oyster reef within the Galveston Estuary (Quast et al. 1988). Although oyster landings have not significantly declined during the last 100 years, the amount of reef and the habitat that it provided to other animals has probably declined.

It is interesting to note that four of the analyses done for young of the year caught by bag seine revealed a quadratic trend indicating an initial increase in abundance and then a decrease (Figures III.46, III.86, III.94, III.102). Most of these indicate a maximum during 1983, making 1983 and possibly years immediately before and immediately after worthy of further investigation.

Another phenomenon revealed by the analyses is that 8 of the 17 bag seine analyses showed decreasing trends and 8 of the 17 trawl analyses showed increasing trends, giving some credence to a hypothesis that some species may be using less of the shoreline habitat. These differences were usually not paired for the same species because many times the same life stage was not represented by data from both gear types. Bay anchovy was an obvious exception and accounted for three of the eight analyses in each gear type (Figures III.55-III.60).

It is also interesting that young of the year, in general, were fairly abundant in Christmas Bay, Bastrop and Chocolate Bays, and East and West Bay. These areas have extensive emergent marsh habitat (White et al. 1985) and probably correlate with high catches for some species. While the geographic distributions presented in this study were not specifically correlated with trends, they will be valuable in studies to examine probable causes for trends.

Finfish landings over the last hundred years have not substantially changed. This is not difficult to understand given that humans are in direct competition for many of the same species that other estuarine animals use as food (i.e. shrimp, oysters, menhaden, and crabs), and the general reduction in emergent marsh, seagrass meadows, and oyster reef in the Galveston Estuary during the past 50-60 years. It is surprising to find most of the populations have done so well. The data testify to the resilience of most species, that evolved to withstand drastic natural changes in estuarine environments.

Analytical Problems

The main analytical problem encountered during the analysis of the status and trends of estuarine organisms was that there were no truly long-term data that had been collected in a comparable manner. The best data sets for determining present abundance and examining changes over a period of at least five years were those used in this report (the Texas Parks and Wildlife Coastal Fisheries monitoring program, which sampled randomly selected sites with gill nets, otter trawls, bag seines, and oyster dredges, and the TPWD/NMFS data set collected during the 1960s and early 1970s with otter trawls at fixed stations).

Commercial harvest data certainly had the longest history, from 1880 to the present (Collins and Smith 1891, Stevenson 1893, Higgins and Lord 1926, Johns 1990). Unfortunately, the self-reporting techniques, the absence of effort data, the inability to quantify the effects that different regulations had on landings, and the inability to isolate where fish were actually caught (i.e. were they caught in the estuary in which they were landed?) rendered commercial data nearly useless in interpreting the results in a

statistically rigorous way and relating the results to abundance (Higgins and Lord 1926, Lahr et al. 1987). However, these old commercial landings reports were valuable for evaluating estuarine community composition. Collins and Smith's (1893) report on commercial landings was very complete and it was invaluable in that it listed many commercially landed species by scientific names. At least a valid comparison of presence or absence for many species could be attempted.

There were biological and technical problems which complicated or impeded the analyses. Most of the animals in an estuary had a seasonal presence and although the season was fairly consistent, the months of highest and lowest mean catch rates did not correspond exactly from year to year. This was routinely observed in the analyses in that a large amount of the variation was associated with month to month differences and month by year interactions. Catch rate distributions were not normal and required special computer programs that would allow for Poisson, negative binomial or Gamma distributions in the analysis.

Maps of catch rates showed few species are distributed regularly throughout the estuary and some species have a strong geographic bias (e.g. blue crab, white shrimp, pinfish). Some of the year-to-year variation may be the result of randomly selected sample sites in a given month falling in or out of favored habitat areas. Also, the favored habitat area may change from year to year depending on freshwater inflows, drought, or freezes. Note that for bay anchovy, different gear types showed different trends (Figures III.55-III.60), associated with a change of position within the estuary. It was not possible to rigorously stratify the data spatially for this study, but the distribution patterns from maps presented here may make it possible to stratify data for future studies.

Monthly sample sizes were small during the earlier years of data collection. Small sample sizes resulted in less precise estimates of statistical parameters such as CPUE and could only detect very large differences in abundance. Small sample sizes also made it possible that in a given month all the samples may have been taken from an area having high or low abundance for a particular species, giving the false impression that a change in abundance occurred. Fortunately, sample sizes have been increased in recent years and more precise estimates are now possible.

The period of record available from the CF monitoring program was too short to evaluate natural cycles with a period greater than two or three years. Data from some species such as white shrimp and striped mullet (Figures III.35, III.128, 111.129) indicate there may be cycles in abundance and these data should be reexamined when more years are available.

Some panels of a given mesh size in gill net samples did not have length measurements for any fish for some species. Analysis of the data required assumptions that the fish caught adhered to the same pattern as other fish of the same species caught in the same panel at other times. This unfortunate omission was caused by instructions in the TPWD field manual requiring only the first 19 specimens of a given species captured within a week to be measured. This practice results in a larger proportion of large fish caught

in the largest meshes to be measured than the more numerous small fish. Consequently, when data from each of the mesh sizes were merged, the data were biased towards larger fish unless they were reapportioned or removed. There is nothing inherently wrong with subsampling provided it is done randomly and within a sample.

Recommendations

The TPWD should continue to improve the Coastal Fisheries Monitoring Program. If it were not for this program, it would not have been possible to do any definitive evaluation of the current status and recent trends of finfish and shellfish in the Galveston Estuary. This program provides excellent data on the abundance and distribution of estuarine aquatic animals. It could be improved by increasing the sample sizes for all gear types, stratifying gill net and bag seine samples within a month in the same manner as trawl samples (i.e. require one half of the samples to come from an area north of an imaginary line between Smith Point and a point northwest of Point Bolivar), add a panel to the gill nets to catch fish that are not currently caught by bag seine or 3-inch stretch gill nets, ensure that some minimum number of fish caught in each gill net panel are measured from each sample, develop a way to sample the open water pelagic area of the estuary (i.e. fish trawl or small purse seine), and (finally but not least) increase the ability to analyze data from programs like this and provide timely updated reports.

Perform more analyses to determine causes for the changes in abundance. Update trend analyses on these species and others (sheepshead, gizzard shad, spot, hardhead catfish, etc.) to detect chronic declines should they occur. Develop ways to relate events causing year to year variation to monitoring data so that causes can be more accurately determined. Develop ways to improve the statistical reliability, area covered, and increase the numbers and size ranges of species caught in future monitoring programs without losing continuity with the existing monitoring program.

Appropriate agencies (i.e., TPWD, NMFS, etc.) should continue to develop management plans and enact harvesting regulations designed to protect and rehabilitate species living in and adjacent to the Galveston Estuary. These agencies should protect existing emergent marsh and remnant seagrass beds from any further loss to development, because many species use these types of habitat. Studies should be initiated to substantiate reasons for the causes of seagrass loss within the Galveston Estuary and develop ways to restore this valuable habitat type where favorable conditions exist. Some upland areas that have the correct slope and other favorable characteristics that might evolve into emergent marsh should subsidence and sea-level rise continue should be protected in order to replace drowned marsh. Oyster fishermen should be required to return shell to reefs from which they harvest to provide substrate for spat and habitat for other animals (Zimmerman et al. 1989).

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APPENDIX III.1. FISHERY DATA SETS NOT USED FOR ANALYSIS

Sean Spanyers

In addition to using the current TPWD-Coastal Fisheries monitoring data and the historical data from TPWD/NMFS to evaluate the status and trends of selected species in the Galveston Estuary area, several other datasets were evaluated for possible inclusion in this report. Sources for the datasets were NOAA/NMFS, annual project reports from TPWD-Coastal Fisheries, and summaries provided by the Galveston Bay National Estuary Program Data Inventory Project.

The criteria used to evaluate each dataset included: (1) wide geographical coverage of the Galveston Estuary, (2) a data collection period of five years or longer, (3) periodic collection of data, i.e. monthly or seasonally, and (4) data were relevant to the analysis of trends in the species studied in this report.

For the most part, the datasets that were found unacceptable were restricted either geographically, in the time period covered, or both. Most data were collected over a period of days or a few months. Others collected data from small areas of the bay system. Also, some datasets either did not examine the species studied in this report or did not include population abundance figures, which excluded them from being considered for the analysis of population trends. The list below describes the datasets considered and the reasons they were not appropriate for analysis.

Abbreviations

A & M	: Texas A & M University
A & M / Galv.	: Texas A & M University at Galveston
HSC	: Houston Ship Channel
NMFS	: National Marine Fisheries Service
NOAA	: National Oceanic and Atmospheric Administration
NOS	: National Ocean Service
TPWD	: Texas Parks and Wildlife Department
USFWS	: United States Fish and Wildlife Service
UT	: University of Texas
UTMSI	: University of Texas Marine Science Institute

(1) A & M; organism collection; Upper Galveston Bay, Dickinson Bay; 1974-75. Time and geographically restrictive.

(2) A & M (Stickney and Williamson 1979); photos of small animal activity; Bolivar Peninsula; 1976-78. Time and geographically restrictive, without abundance data.

(3) A & M (Tanner 1979); culm density and biomass samples; Bolivar Peninsula 1976-78. Time and geographically restrictive.

(4) A & M (Webb et al. 1981); Spartina data on Bolivar Peninsula and Bolivar Roads; 1977-78. Time and geographically restrictive, not likely to contain data on species of direct interest.

(5) A & M; water quality, Fundulus grandis data; Trinity Bay; 1980. Time and geographically restrictive, does not contain natural abundance data.

(6) A & M (Craig and Bright 1986); clam populations and measurements, water quality; Christmas Bay; 1982-85. Time and geographically restrictive.

(7) A & M (Dixon 1974); silverside stomach contents; Trinity and Tabbs Bays; 1969-71. Time and geographically restrictive, does not include data on species of direct interest.

(8) A & M (Gallaway and Strawn 1974, 1975); water quality, fish and crustacean samples; Upper Galveston Bay; 1969. Time and geographically restrictive.

(9) A & M (McAden 1977); water quality; fish, invertebrate, plankton samples; Upper Galveston Bay, Dickinson Bay; 1974-75. Time and geographically restrictive.

(10) A & M (Matlock 1972); species collection, water quality; Cedar Bayou, Trinity and Tabbs Bays; 1970-71. Time and geographically restrictive.

(11) A & M (Williams 1972); water quality, bottom sampling; Trinity Bay, Cedar Bayou; 1969-70. Time and geographically restrictive.

(12) A & M / Dept. of Biology; clam tissue study, water quality; Trinity Bay; 1970-71. Time and geographically restrictive.

(13) A & M / Dept. of Biology; presence of benthic algae; Galveston Island; 1972-73. Time and geographically restrictive, not likely to include natural abundance data.

(14) A & M / Dept. of Marine Biology; soil quality and Spartina data; Bolivar Peninsula and West Bay; 1978. Time and geographically restrictive, not likely to contain data on species of direct interest.

(15) A & M / Dept. of Wildlife Management; water quality, grass shrimp data; Galveston Bay periphery; 1963-64. Time restrictive.

(16) A & M / Galv. (Minello and Matthews 1981); zooplankton samples and hydrography; West Bay; 13-15 April 1976. Time and geographically restrictive.

(17) A & M / Galv. (Alexander 1983); fish stomach contents; West Bay; 1981. Time and geographically restrictive, does not contain data on natural abundance.

(18) A & M / Galv.; clam parasite extraction; Lower Galveston Bay; (time n/a). Geographically restrictive, not likely to contain data on natural abundance.

(19) A & M / Texas Agricultural Extension Service (Parker, 1970); shrimp counts and measurements, salinity; Galveston Bay; 1963-64. Time restrictive.

(20) Bureau of Commercial Fisheries (Chin 1961); water quality, fish and invertebrate samples; Clear Lake; 1958-59. Time and geographically restrictive.

(21) Copeland-Bechtel Galveston Bay Project; water quality, fish collection and measurement; Galveston Bay; 1969. Time restrictive.

(22) Copeland-Fruh Galveston Bay Project; nekton, plankton, and benthos samples; Galveston Bay; 1969. Time restrictive.

(23) Houston Lighting & Power, A & M, Southwest Research Institute; hydrography and ecology; Trinity Bay and Cedar Bayou (time n/a). Geographically restrictive.

(24) Humble Oil & Refining (Exxon); water and sediment quality, fish and invertebrate counts; HSC; 1958. Time and geographically restrictive.

(25) Philadelphia Academy of Natural Sciences (Hohn 1959); diatom counts and benthos samples; HSC, Upper Galveston Bay, Chocolate and Mustang Bayous; 1954. Time and geographically restrictive.

(26) NMFS; water quality and shrimp data; Dollar Bay; 1973. Time and geographically restrictive.

(27) NMFS (Zimmerman et al. 1990); water quality, fauna count and speciation; West and Christmas Bays, Moses Lake, Trinity Bay; 1987. Time restrictive.

(28) NMFS (Zimmerman 1981); fauna counts and samples; West Bay; 1988, 1989. Time and geographically restrictive.

(29) NOAA / NMFS; total catch and mean length for brown shrimp; Galveston Bay System; 1963-1967. Inconsistency in frequency and location of sampling, marginal length of data collection.

(30) NOAA / NOS; sediment quality and fish tissue analysis; Galveston Bay; 1984-present. Not likely to contain data on natural abundance.

(31) Texas Game and Fish Commission; water quality, benthos and plankton surveys; East Bay and Gulf; 1954-55. Time and geographically restrictive.

(32) TPWD; sand seatrout data; Trinity, Galveston, East, West, Chocolate, and Christmas Bays; 1966-68. Time restrictive, does not include natural abundance data.

(33) TPWD; water quality, chlorophyll a; Dickinson Bayou; 1972. Time and geographically restrictive.

(34) TPWD; fish tag and return; Texas coast with release from Galveston Bay; 1975-78. Time and geographically restrictive, does not contain data on natural abundance.

(35) TPWD (Baker et al. 1986); fish tag and recapture; Bastrop Bayou, West and Christmas Bays, and San Luis Pass; 1976-81. Geographically restrictive, not likely to contain data on natural abundance.

(36) TPWD Coastal Fisheries; annual population and catch data for brown shrimp, white shrimp, and blue crab; Galveston Bay System; 1961-74 (Blue crab 1962-66). Inconsistency in sampling procedures, sampling periods, and locations. Marginal length of study for crab.

(37) Texas Water Commission (previously Texas Water Quality Board); water and sediment quality, benthos and plankton species and numbers; Chocolate Bayou, 1983. Time and geographically restrictive.

(38) U.S. Commission of Fish and Fisheries (Stevenson 1893); methods and economics of fisheries; Galveston Bay; c.1890. Time restrictive.

(39) U.S. Corps of Engineers; water quality, samples of various species; Trinity delta marsh; 1975-76. Time and geographically restrictive.

(40) U. S. National Museum (Jordan and Gilbert 1882); fish descriptions; Galveston Bay; late 1800s. No quantitative data present.

(41) USFWS and Rice U.; vegetation and dominant species surveys; Chambers county, c.1975. Time and geographically restrictive.

(42) UT (Dykstra et al. 1972); algal speciation; Galveston shorefront; 1972. Time and geographically restrictive.

(43) UT Medical Branch, Galveston (Connell and Cross 1950); plankton, red tide; Offatts Bayou, West Bay; 1949. Time and geographically restrictive.

(44) UTMSI (Whitten et al. 1950); faunal observations; North and South jetties; 1938-40,46-47. Time and geographically restrictive, not likely to contain data on species of direct interest.

(45) UTMSI (Odum et al. 1963); water quality, zooplankton counts; Upper and Lower Galveston Bay, West Bay, HSC; 1961-62. Time restrictive.

(46) UTMSI (Wilson 1963); total organic carbon; Upper Galveston Bay; 1962. Time and geographically restrictive, does not contain population data.

(47) UTMSI; benthos speciation and counting; Galveston Bay; 1971-72. Time restrictive.

Cindy Loeffler

Appendix III.2. Organisms caught in the Galveston Estuary by Gill Net (1), Trawl (2), Bag Seine (3) and Oyster dredge (4).

Scientific Name	Common Name	Mean, standard error and sample size												Percent of samples			
		Gillnet			Trawl			Bagseine			Oyster dredge			Gill net	Trawl	Bag seine	Oyster dredge
Acetes americanus	Sergestid shrimp	.	.	.	.	.	.	0.1	1.9	1085	.	.	.	.	.	0.09	.
Achirus lineatus	Lined sole	0.0	0.0	945	0.0	0.0	2008	0.0	0.0	1085	.	.	.	0.11	1.89	2.21	.
Adinia xenica	Diamond killifish	.	.	.	.	.	.	0.1	0.0	1085	.	.	.	.	.	2.40	.
Alosa chrysochloris	Skipjack herring	0.1	0.0	945	0.0	0.0	2008	0.0	0.0	1085	.	.	.	3.39	0.10	0.09	.
Alpheus heterochaelis	Pistol shrimp	.	.	.	0.4	0.4	2008	0.0	0.0	1085	0.0	0.0	2797	.	0.20	0.18	0.04
Anadara ovalis	Blood Ark	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.10	.	.
Anadara transversa	Transverse ark	.	.	.	.	.	.	.	.	.	0.0	0.0	2797	.	.	.	0.04
Anchoa hepsetus	Striped anchovy	.	.	.	0.0	0.0	2008	0.0	0.0	1085	.	.	.	.	0.10	0.46	.
Anchoa mitchilli	Bay anchovy	.	.	.	0.3	0.0	2008	7.1	1.2	1085	.	.	.	.	14.4	38.4	.
Anchoa nasuta	Longnose anchovy	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.15	.	.
Ancylopsetta quadrocellata	Ocellated flound	0.0	0.0	945	0.0	0.0	2008	.	.	.	.	.	.	0.21	1.69	.	.
Anisotremus virginicus	Porkfish	.	.	.	.	.	.	0.0	0.1	1085	.	.	.	.	.	0.09	.
Archosargus probatocephalus	Sheepshead	0.7	0.0	945	0.0	0.0	2008	0.1	0.0	1085	0.0	0.0	2797	33.4	3.59	3.69	0.04
Arenaeus cribrarius	Speckled crab	0.0	0.0	945	0.0	0.0	2008	0.0	0.0	1085	.	.	.	0.11	0.35	0.09	.
Arius felis	Hardhd catfish	22.0	1.1	945	1.0	0.1	2008	1.3	0.2	1085	.	.	.	79.2	23.1	19.5	.
Astroscopus y- graecum	So. stargazer	.	.	.	0.1	0.0	2008	0.0	0.0	1085	.	.	.	.	2.64	0.18	.
Aurelia aurita	Moon jellyfish	0.2	0.1	945	0.1	0.0	2008	0.0	0.2	1085	.	.	.	0.53	0.75	0.09	.
Bagre marinus	Gafftopsail catf	2.2	0.3	945	0.1	0.0	2008	0.0	0.0	1085	.	.	.	26.5	3.24	0.46	.
Bairdiella chrysoura	Silver perch	0.0	0.0	945	0.4	0.1	2008	0.2	0.1	1085	.	.	.	4.02	9.26	4.88	.
Beroe ovata	Large comb jelly	.	.	.	32.4	2.9	2008	4.8	1.7	1085	0.0	0.1	2797	.	20.5	1.29	0.04
Bothus robinsi	Twospot flounder	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Brevoortia gunteri	Finescale menhad	0.0	0.0	945	0.0	0.0	2008	0.0	0.0	1085	.	.	.	0.42	0.65	0.46	.
Brevoortia patronus	Gulf menhaden	19.0	5.2	945	2.5	0.2	2008	83.5	31.8	1085	.	.	.	50.8	37.8	28.8	.
Busycon perversum	Lightning whelk	0.0	0.0	945	0.0	0.0	2008	.	.	.	0.0	0.0	2797	0.32	1.15	.	0.07
Busycon spiratum	Pear whelk	0.0	0.1	945	0.0	0.0	2008	.	.	.	.	.	.	0.11	0.05	.	.
Callinectes sapidus	Blue crab	1.0	0.1	945	5.1	0.2	2008	3.3	0.2	1085	0.0	0.0	2797	27.1	60.5	53.5	1.86
Callinectes similis	Lesser blue crab	0.0	0.0	945	0.1	0.0	2008	0.2	0.1	1085	.	.	.	0.11	6.03	3.41	.
Cantharus cancellarius	Cancellate canth	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Caranx crysos	Blue runner	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Caranx hippos	Crevalle jack	0.0	0.0	945	0.0	0.0	2008	0.1	0.0	1085	.	.	.	1.38	1.74	4.42	.
Carcharhinus brevipinna	Spinner shark	0.0	0.3	945	.	.	.	.	.	.	.	.	.	0.11	.	.	.
Carcharhinus isodon	Finetooth shark	0.0	0.0	945	.	.	.	.	.	.	.	.	.	0.63	.	.	.
Carcharhinus leucas	Bull shark	0.1	0.0	945	.	.	.	0.0	0.0	1085	.	.	.	4.97	.	0.09	.
Carcharhinus limbatus	Blacktip shark	0.2	0.1	945	.	.	.	.	.	.	.	.	.	5.50	.	.	.
Carcharhinus obscurus	Dusky shark	0.0	0.1	945	.	.	.	.	.	.	.	.	.	0.11	.	.	.
Centropristis philadelphica	Rock sea bass	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Chaetodipterus faber	Atlantic spdfish	0.1	0.0	945	0.0	0.0	2008	0.1	0.0	1085	.	.	.	4.87	2.59	2.30	.

Appendix III.2. (continued) Organisms caught in the Galveston Estuary by Gill Net (1), Trawl (2), Bag Seine (3) and Oyster dredge (4).

Scientific Name	Common Name	Mean, standard error and sample size												Percent of samples			
		Gillnet			Trawl			Bagseine			Oyster dredge			Gill net	Trawl	Bag seine	Oyster dredge
Chasmodes bosquianus	Striped blenny	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Chilomycterus schoepfi	Striped burrfish	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.35	.	.
Chloroscombrus chrysurus	Atlantic bumper	0.0	0.0	945	0.3	0.1	2008	0.0	0.0	1085	.	.	.	0.21	5.93	0.65	.
Citharichthys spilopterus	Bay whiff	.	.	.	0.6	0.1	2008	0.6	0.1	1085	.	.	.	.	17.2	13.1	.
Class Ascidiacea	Class/sess tunc	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.15	.	.
Class Holothuroidae	Class sea cucumber	.	.	.	0.0	0.1	2008	.	.	.	.	.	.	.	0.05	.	.
Class Ophiuroidae	Class brittle star	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.10	.	.
Class Polychaeta	Polychaete worms	.	.	.	.	.	.	.	.	.	0.0	0.0	2797	.	.	.	0.07
Clibanarius vittatus	Striped hermit cb	0.0	0.0	945	1.5	0.2	2008	0.2	0.0	1085	0.0	0.0	2797	1.27	16.7	6.27	0.61
Crassostrea virginica	Eastern oyster	0.1	0.0	945	1.3	0.3	2008	0.3	0.1	1085	55.1	1.2	2797	1.48	7.02	5.90	97.2
Ctenopharyngodon idella	Grass carp	0.0	0.1	945	.	.	.	.	.	.	.	.	.	0.11	.	.	.
Cyclinella tenuis	Atlantic cyc	.	.	.	.	.	.	.	.	.	0.0	0.0	2797	.	.	.	0.04
Cynoscion arenarius	Sand seatrout	0.5	0.1	945	1.0	0.1	2008	1.0	0.1	1085	.	.	.	21.9	30.3	20.1	.
Cynoscion nebulosus	Spotted seatrout	4.6	0.2	945	0.0	0.0	2008	0.6	0.1	1085	.	.	.	74.9	2.39	12.7	.
Cynoscion nothus	Silver seatrout	0.0	0.0	945	0.0	0.0	2008	0.0	0.1	1085	.	.	.	0.32	1.69	0.09	.
Cyprinodon variegatus	Sheepshead minnow	.	.	.	0.0	0.0	2008	9.6	2.8	1085	.	.	.	.	0.05	22.1	.
Cyprinus carpio	Common carp	0.0	0.0	945	0.0	0.0	2008	.	.	.	.	.	.	1.48	0.05	.	.
Cyrtopleura costata	Angle wing	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Dactylometra quinquecirrha	Stinging nettle	0.5	0.3	945	14.0	2.0	2008	0.1	0.0	1085	0.0	0.1	2797	0.85	13.6	0.83	0.04
Dasyatis americana	Southern stingray	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.20	.	.
Dasyatis sabina	Atlantic stingray	0.0	0.0	945	0.1	0.0	2008	0.1	0.0	1085	.	.	.	3.17	4.83	5.81	.
Diplectrum formosum	Sand perch	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.10	.	.
Dorosoma cepedianum	Gizzard shad	10.6	0.5	945	0.0	0.0	2008	0.0	0.0	1085	.	.	.	74.9	2.29	1.47	.
Dorosoma petenense	Threadfin shad	0.0	0.0	945	0.1	0.0	2008	0.0	0.0	1085	.	.	.	0.21	7.17	1.20	.
Dosinia discus	Disk dosinia	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Elops saurus	Ladyfish	0.1	0.0	945	0.0	0.0	2008	0.0	0.0	1085	.	.	.	5.82	0.10	2.40	.
Etropus crossotus	Fringed flounder	.	.	.	0.7	0.1	2008	0.0	0.0	1085	.	.	.	.	16.1	0.65	.
Eucinostomus argenteus	Spotfin mojarra	.	.	.	0.0	0.0	2008	0.1	0.0	1085	.	.	.	.	0.05	2.67	.
Eucinostomus gula	Silver jenny	.	.	.	0.0	0.0	2008	0.1	0.0	1085	.	.	.	.	0.25	3.87	.
Eucinostomus lefroyi	Mottled mojarra	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Eurypanopeus depressus	Flat mud crab	.	.	.	0.0	0.0	2008	0.0	0.0	1085	0.2	0.0	2797	.	0.15	0.09	11
Family Atherinidae	Family silversides	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Family Carangidae	Family jacks	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.18	.
Family Centrarchidae	Family sunfishes	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Family Clupeidae	Family herrings	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Family Cyprinidae	Family min/carps	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Family Gobiidae	Family gobies	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.18	.
Family Lobotidae	Family tripletails	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.

Appendix III.2. (continued) Organisms caught in the Galveston Estuary by Gill Net (1), Trawl (2), Bag Seine (3) and Oyster dredge (4).

Scientific Name	Common Name	Mean, standard error and sample size												Percent of samples			
		Gillnet			Trawl			Bagseine			Oyster dredge			Gill net	Trawl	Bay seine	Oyster dredge
Family Penaeidae	Family penaeid shr	.	.	.	.	.	.	0.0	0.1	1085	.	.	.	.	.	0.09	.
Family Pomacentridae	Family damselfish	0.0	0.0	945	.	.	.	.	.	.	0.0	0.0	2797	0.21	.	.	0.04
Family Portunidae	Family portunid cr	.	.	.	0.0	0.1	2008	.	.	.	.	.	.	.	0.05	.	.
Family Scombridae	Family mackerels	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Family Syngnathidae	Family pipefishes	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Family Xanthidae	Family mud crabs	0.0	0.1	945	0.0	0.0	2008	0.0	0.0	1085	0.3	0.0	2797	0.11	0.85	0.09	11.9
Fundulus grandis	Gulf killifish	.	.	.	0.0	0.0	2008	2.8	0.6	1085	.	.	.	.	0.05	22.1	.
Fundulus pulvereus	Bayou killifish	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.28	.
Fundulus similis	Longnose killifish	.	.	.	.	.	.	2.6	0.5	1085	.	.	.	.	.	23.2	.
Gerres cinereus	Yellowfin mojarra	.	.	.	.	.	.	0.0	0.1	1085	.	.	.	.	.	0.09	.
Gobiesox strumosus	Skilletfish	.	.	.	0.0	0.0	2008	0.0	0.0	1085	0.0	0.0	2797	.	1.00	1.94	0.64
Gobioides broussoneti	Violet goby	.	.	.	0.0	0.0	2008	0.0	0.0	1085	.	.	.	.	0.05	0.09	.
Gobionellus boleosoma	Darter goby	.	.	.	0.0	0.0	2008	0.0	0.0	1085	.	.	.	.	0.05	1.47	.
Gobionellus hastatus	Sharptail goby	.	.	.	0.0	0.0	2008	0.0	0.0	1085	.	.	.	.	0.10	0.46	.
Gobiosoma bosci	Naked goby	.	.	.	0.0	0.0	2008	0.1	0.0	1085	0.0	0.0	2797	.	0.15	3.50	1.32
Gobiosoma robustum	Code goby	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Gonioplectrus hispanus	Spanish flag	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Gunterichthys longipenis	Gold brotula	.	.	.	0.0	0.3	2008	.	.	.	.	.	.	.	0.05	.	.
Gymnachirus texae	Fringed sole	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Harengula jaguana	Scaled sardine	0.0	0.0	945	0.0	0.0	2008	0.4	0.4	1085	.	.	.	0.32	0.15	0.83	.
Hemicaranx amblyrhynchus	Bluntnose jack	.	.	.	0.0	0.0	2008	0.0	0.0	1085	.	.	.	.	1.49	0.55	.
Hepatus epheliticus	Calico crab	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.10	.	.
Hexapanopeus angustrifrons	Narrow mud crab	.	.	.	0.0	0.1	2008	0.0	0.0	1085	.	.	.	.	0.05	0.09	.
Hypleurochilus geminatus	Crested blenny	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.15	.	.
Hypsoblennius ionthas	Freckled blenny	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Ictalurus furcatus	Blue catfish	0.1	0.0	945	0.1	0.0	2008	.	.	.	.	.	.	3.17	2.19	.	.
Ictalurus natalis	Yellow bullhead	0.0	0.0	945	.	.	.	.	.	.	.	.	.	0.42	.	.	.
Ictalurus punctatus	Channel catfish	0.0	0.0	945	.	.	.	.	.	.	.	.	.	0.21	.	.	.
Ischadium recurvum	Hooked mussel	0.1	2.6	945	0.0	0.0	2008	0.0	0.1	1085	.	.	.	0.11	0.10	0.09	.
Laevicardium mortoni	Morton's egg cock	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Lagodon rhomboides	Pinfish	0.1	0.0	945	0.2	0.0	2008	4.9	0.7	1085	.	.	.	3.28	9.46	27	.
Larimus fasciatus	Banded drum	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.60	.	.
Leiostomus xanthurus	Spot	1.3	0.1	945	3.8	0.6	2008	8.6	0.9	1085	.	.	.	31.5	40.4	40.8	.
Lepisosteus oculatus	Spotted gar	0.2	0.0	945	.	.	.	0.0	0.0	1085	.	.	.	6.24	.	0.18	.
Lepisosteus osseus	Longnose gar	0.0	0.0	945	.	.	.	0.0	0.0	1085	.	.	.	0.42	.	0.09	.
Lepisosteus platostomus	Shortnose gar	0.0	0.0	945	.	.	.	.	.	.	.	.	.	0.32	.	.	.
Lepisosteus spatula	Alligator gar	0.7	0.1	945	.	.	.	0.0	0.0	1085	.	.	.	28.4	.	0.28	.
Lepomis gulosus	Warmouth	0.0	0.0	945	.	.	.	.	.	.	.	.	.	0.11	.	.	.

Appendix III.2. (continued) Organisms caught in the Galveston Estuary by Gill Net (1), Trawl (2), Bag Seine (3) and Oyster dredge (4).

Scientific Name	Common Name	Mean, standard error and sample size				Percent of samples			
		Gillnet	Trawl	Bagseine	Oyster dredge	Gill net	Trawl	Bag seine	Oyster dredge
Libinia dubia	Spider crab	. . .	0.0 0.0 2008	. . .	0.0 0.0 2797	.	0.15	.	0.04
Libinia emarginata	Spider crab	. . .	0.0 0.0 2008	. . .	. . .	.	0.60	.	.
Littorina irrorata	Marsh periwinkle	. . .	. . .	0.0 0.0 1085	. . .	.	.	0.37	.
Lobotes surinamensis	Tripletail	0.1 0.0 945	. . .	0.0 0.0 1085	. . .	3.07	.	0.28	.
Loligo brevis	Squid	. . .	0.0 0.0 2008	0.0 0.3 1085	. . .	.	1.15	0.09	.
Lolliguncula brevis	Brief squid	. . .	1.0 0.1 2008	0.0 0.0 1085	. . .	.	22.2	1.94	.
Lucania parva	Rainwater killifsh	. . .	. . .	0.0 0.0 1085	. . .	.	.	0.18	.
Lutjanus apodus	Schoolmaster	. . .	. . .	0.0 0.0 1085	. . .	.	.	0.09	.
Lutjanus griseus	Gray snapper	. . .	0.0 0.0 2008	. . .	. . .	.	0.05	.	.
Lutjanus synagris	Lane snapper	. . .	0.0 0.0 2008	. . .	. . .	.	0.15	.	.
Macrobrachium ohione	River shrimp	0.0 0.0 945	0.0 0.0 2008	0.0 0.0 1085	. . .	0.11	1.25	0.74	.
Malaclemys terrapin	Diamondback terr	0.0 0.0 945	. . .	. . .	. . .	0.32	.	.	.
Megalops atlanticus	Tarpon	0.0 0.0 945	. . .	. . .	. . .	1.16	.	.	.
Membras martinica	Rough silverside	. . .	. . .	0.1 0.0 1085	. . .	.	.	1.66	.
Menidia beryllina	Inland silverside	. . .	0.0 0.0 2008	6.8 0.8 1085	. . .	.	0.05	46	.
Menippe mercenaria	Stone crab	0.1 0.0 945	0.0 0.0 2008	0.0 0.0 1085	0.1 0.0 2797	7.72	1.54	1.11	9.33
Menticirrhus americanus	Southern kingfish	0.0 0.0 945	0.1 0.0 2008	0.3 0.0 1085	. . .	1.90	4.38	7.28	.
Menticirrhus littoralis	Gulf kingfish	0.0 0.0 945	0.0 0.0 2008	0.2 0.1 1085	. . .	0.42	0.25	2.49	.
Mercenaria campechiensis	Southern quahog	. . .	0.0 0.0 2008	. . .	0.0 0.0 2797	.	0.15	.	0.36
Micropogonias undulatus	Atlantic croaker	3.4 0.2 945	6.8 0.4 2008	20.1 2.1 1085	. . .	56.2	65.4	53.2	.
Mnemiopsis mccradyi	Phosphorus jelly	. . .	. . .	0.0 1.5 1085	. . .	.	.	0.09	.
Monacanthus hispidus	Planehead filefish	. . .	0.0 0.0 2008	0.0 0.0 1085	. . .	.	0.10	0.28	.
Monacanthus setifer	Pygmy filefish	. . .	0.0 0.0 2008	. . .	. . .	.	0.05	.	.
Morone chrysops	White bass	0.0 0.0 945	. . .	. . .	. . .	0.32	.	.	.
Morone mississippiensis	Yellow bass	0.0 0.0 945	. . .	0.0 0.0 1085	. . .	1.27	.	0.09	.
Morone saxatilis	Striped bass	0.0 0.0 945	. . .	. . .	. . .	0.42	.	.	.
Mugil cephalus	Striped mullet	2.6 0.2 945	0.3 0.1 2008	3.6 0.8 1085	. . .	66	6.18	48.1	.
Mugil curema	White mullet	0.0 0.0 945	0.0 0.0 2008	2.2 0.5 1085	. . .	0.21	0.10	18.8	.
Mulinia lateralis	Dwarf surf clam	. . .	. . .	. . .	0.0 0.1 2797	.	.	.	0.04
Murex fluvescens	Giant eastern murex	. . .	0.0 0.0 2008	. . .	. . .	.	0.05	.	.
Mustelus canis	Smooth dogfish	. . .	0.0 0.0 2008	. . .	. . .	.	0.05	.	.
Myrophis punctatus	Speckled worm eel	0.0 0.0 945	0.0 0.0 2008	0.0 0.0 1085	. . .	0.11	0.10	0.28	.
Negaprion brevirostris	Lemon shark	0.0 0.0 945	. . .	. . .	. . .	0.53	.	.	.
Nemopsis bachei	Hydromedusa	. . .	0.0 0.1 2008	. . .	. . .	.	0.05	.	.
Neopanope texana	Xanthid crab	. . .	0.0 0.0 2008	0.0 0.0 1085	0.0 0.0 2797	.	0.35	0.18	0.39
Ogcocephalus radiatus	Polka-dot batfish	. . .	0.0 0.0 2008	. . .	. . .	.	0.05	.	.
Oligoplites saurus	Leatherjacket	. . .	. . .	0.2 0.0 1085	. . .	.	.	6.45	.
Ophichthus gomesi	Shrimp eel	. . .	0.0 0.0 2008	0.0 0.0 1085	. . .	.	0.20	0.37	.

Appendix III.2. (continued) Organisms caught in the Galveston Estuary by Gill Net (1), Trawl (2), Bag Seine (3) and Oyster dredge (4).

Scientific Name	Common Name	Mean, standard error and sample size												Percent of samples			
		Gillnet			Trawl			Bagseine			Oyster dredge			Gill net	Trawl	Bag seine	Oyster dredge
Ophidion holbrooki	Bank cusk-eel	.	.	.	.	.	.	0.0	0.3	1085	.	.	.	.	.	0.09	.
Opisthonema oglinum	Atlantic thread her	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	1.89	.	.
Opsanus beta	Gulf toadfish	.	.	.	0.0	0.0	2008	0.0	0.0	1085	0.0	0.0	2797	.	1.00	0.46	0.14
Order Actiniaria	Order anemones	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.20	.	.
Order Hydroidea	Order Hydroids	4.9	6.4	945	3.8	1.1	2008	1.0	0.7	1085	0.4	0.3	2797	0.85	0.65	0.28	0.07
Orthopristis chrysoptera	Pigfish	0.1	0.0	945	0.1	0.0	2008	0.1	0.0	1085	.	.	.	3.70	3.24	3.23	.
Ovalipes guadulpensis	Lady crab	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	1.29	.	.
Pagurus annulipes	Brown-banded hrmt cb.	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.10	.	.
Pagurus longicarpus	Long claw hrmt crab	.	.	.	0.2	0.0	2008	0.0	0.0	1085	.	.	.	.	7.17	0.37	.
Pagurus pollicaris	Big claw hrmt crab	.	.	.	0.7	0.1	2008	0.0	0.0	1085	0.0	0.0	2797	.	12.2	0.37	0.04
Palaemonetes pugio	Grass shrimp	.	.	.	.	.	.	0.5	0.2	1085	.	.	.	.	.	4.24	.
Palaemonetes sp.	Grass shrimp-unidt	.	.	.	0.0	0.0	2008	7.1	1.4	1085	.	.	.	.	0.15	29.5	.
Panopeus herbstii	Xanthid crab	.	.	.	0.0	0.0	2008	0.0	0.0	1085	0.1	0.0	2797	.	0.10	0.09	5.61
Paralichthys albigutta	Gulf flounder	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.55	.	.
Paralichthys lethostigma	Southern flounder	0.9	0.0	945	0.1	0.0	2008	0.2	0.0	1085	0.0	0.0	2797	43.7	7.02	11.3	0.04
Paralichthys squamilentus	Broad flounder	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Penaeus aztecus	Brown shrimp	.	.	.	4.8	0.6	2008	24.0	2.2	1085	.	.	.	.	29.9	49.1	.
Penaeus duorarum	Pink shrimp	.	.	.	0.1	0.0	2008	.	.	.	.	.	.	.	2.59	.	.
Penaeus setiferus	White shrimp	0.0	0.0	945	14.9	0.9	2008	44.6	5.9	1085	.	.	.	0.21	59.2	43.1	.
Peprilus alepidotus	Harvestfish	0.1	0.0	945	0.1	0.0	2008	.	.	.	.	.	.	2.65	6.42	.	.
Peprilus burti	Gulf butterfish	.	.	.	0.4	0.1	2008	0.0	0.0	1085	.	.	.	.	8.62	0.09	.
Persephona aquilonaris	Purse crab	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.15	.	.
Persephona crinita	Raninid crab	.	.	.	0.0	0.1	2008	.	.	.	.	.	.	.	0.05	.	.
Petrolisthes armatus	Porcellanid crab	.	.	.	0.0	0.0	2008	0.0	0.0	1085	0.2	0.0	2797	.	0.35	0.18	9.40
Phylum Ctenophora	Phylum ctenophores	.	.	.	26.7	2.7	2008	4.5	1.5	1085	.	.	.	.	12.4	2.86	.
Phylum Rhynchocoela	Phylum ribbon worm	.	.	.	.	.	.	.	.	.	0.0	0.0	2797	.	.	.	0.04
Poecilia latipinna	Sailfin molly	.	.	.	.	.	.	0.1	0.0	1085	.	.	.	.	.	1.57	.
Pogonias cromis	Black drum	6.9	0.3	945	0.0	0.0	2008	0.3	0.1	1085	.	.	.	81	2.99	10.3	.
Polinices duplicatus	Shark's eye	.	.	.	0.1	0.0	2008	0.0	0.0	1085	0.0	0.0	2797	.	3.34	0.18	0.07
Polydactylus octonemus	Atlantic threadfin	0.0	0.0	945	0.1	0.0	2008	2.1	0.9	1085	.	.	.	0.21	3.83	8.66	.
Pomatomus saltatrix	Bluefish	0.0	0.0	945	.	.	.	.	.	.	.	.	.	1.38	.	.	.
Pomoxis nigromaculatus	Black crappie	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Porcellana sayana	Porcellanid crab	0.0	0.1	945	0.0	0.2	2008	.	.	.	.	.	.	0.11	0.05	.	.
Porichthys plectrodon	Atlantic midshipman	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	1.69	.	.
Portunus gibbesii	Purple crab	.	.	.	0.1	0.0	2008	0.0	0.0	1085	.	.	.	.	2.84	0.09	.
Portunus sayi	Sargassum crab	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.15	.	.
Portunus spinicarpus	Portunid crab	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Prionotus salmonicolor	Blackwing searobin	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.15	.	.

Appendix III.2. (continued) Organisms caught in the Galveston Estuary by Gill Net (1), Trawl (2), Bag Seine (3) and Oyster dredge (4).

Scientific Name	Common Name	Mean, standard error and sample size												Percent of samples			
		Gillnet			Trawl			Bagseine			Oyster dredge			Gill net	Trawl	Bag seine	Oyster dredge
Prionotus tribulus	Bighead searobin	0.0	0.0	945	0.4	0.0	2008	0.1	0.0	1085	.	.	.	0.42	15.6	4.79	.
Pylodictis olivaris	Flathead catfish	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Rachycentron canadum	Cobia	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.05	.	.
Rangia cuneata	Common rangia	0.0	0.0	945	2.6	1.0	2008	0.0	0.0	1085	0.1	0.0	2797	0.42	3.54	0.92	2.93
Rangia flexuosa	Brown rangia	0.0	0.0	945	0.8	0.4	2008	0.0	0.0	1085	0.0	0.0	2797	0.32	1.20	0.37	0.25
Rhinoptera bonasus	Cownose ray	0.0	0.0	945	.	.	.	.	.	.	.	.	.	0.42	.	.	.
Rhithropanopeus harrisii	Xanthid crab	.	.	.	0.0	0.0	2008	0.0	0.0	1085	0.0	0.0	2797	.	0.05	0.37	1.04
Rhizoprionodon terraenovae	Atl sharpnose shk	0.0	0.0	945	0.0	0.0	2008	.	.	.	.	.	.	1.48	0.05	.	.
Sardinella aurita	Spanish sardine	.	.	.	0.0	0.0	2008	0.1	0.0	1085	.	.	.	.	0.05	0.55	.
Sciaenops ocellatus	Red drum	9.3	0.4	945	0.0	0.0	2008	0.8	0.1	1085	.	.	.	84.1	0.15	18.1	.
Scomberomorus cavalla	King mackerel	0.0	0.0	945	.	.	.	0.0	0.0	1085	.	.	.	0.11	.	0.09	.
Scomberomorus maculatus	Spanish mackerel	0.1	0.0	945	0.0	0.0	2008	0.0	0.0	1085	.	.	.	3.81	0.05	0.28	.
Selene setapinnis	Atlantic moonfish	0.0	0.0	945	0.2	0.1	2008	.	.	.	.	.	.	0.11	3.04	.	.
Selene vomer	Lookdown	.	.	.	0.0	0.0	2008	0.0	0.0	1085	.	.	.	.	2.59	0.28	.
Sicyonia brevirostris	Rock shrimp	.	.	.	.	.	.	.	.	.	0.0	0.0	2797	.	.	.	0.04
Sicyonia dorsalis	Lesser rock shrimp	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.10	.	.
Sphoeroides parvus	Least puffer	0.0	0.0	945	0.4	0.0	2008	0.9	0.4	1085	.	.	.	0.11	13.6	11.5	.
Sphyrna lewini	Scalloped hammerhd	0.0	0.0	945	.	.	.	.	.	.	.	.	.	0.74	.	.	.
Sphyrna tiburo	Bonnethead	0.0	0.0	945	.	.	.	.	.	.	.	.	.	1.69	.	.	.
Spissula solidissima	Atlantic surf clam	.	.	.	.	.	.	0.0	0.1	1085	.	.	.	.	.	0.09	.
Squilla empusa	Mantis shrimp	.	.	.	0.2	0.0	2008	.	.	.	.	.	.	.	5.43	.	.
Stellifer lanceolatus	Star drum	.	.	.	0.2	0.0	2008	0.1	0.0	1085	.	.	.	.	4.53	1.75	.
Stomolophus meleagris	Cabbagehead	0.0	0.0	945	0.3	0.1	2008	0.0	0.0	1085	.	.	.	0.63	5.38	0.18	.
Strongylura marina	Atlantic needlefish	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	1.38	.
Suborder Reptantia	Suborder reptantia	.	.	.	0.0	0.1	2008	.	.	.	.	.	.	.	0.05	.	.
Syacium gunteri	Shoal flounder	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.25	.	.
Symphurus plagiusa	Blackcheek tongfh	.	.	.	0.1	0.0	2008	0.2	0.0	1085	.	.	.	.	4.18	9.31	.
Syngnathus floridae	Dusky pipefish	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.09	.
Syngnathus louisianae	Chain pipefish	.	.	.	.	.	.	0.0	0.0	1085	0.0	0.0	2797	.	.	0.28	0.04
Syngnathus scovelli	Gulf pipefish	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	0.18	.
Synodus foetens	Inshore lizardfish	.	.	.	0.0	0.0	2008	0.0	0.0	1085	.	.	.	.	2.09	2.12	.
Tagelus plebeius	Stout tagelus	.	.	.	0.0	0.0	2008	.	.	.	0.0	0.0	2797	.	0.05	.	0.04
Thais haemastoma	Florida rock shell	0.0	0.0	945	0.2	0.0	2008	0.0	0.0	1085	0.1	0.0	2797	0.53	6.87	0.55	3.22
Trachemys scripta (elegans)	Red-eared slider	0.0	0.1	945	.	.	.	.	.	.	.	.	.	0.11	.	.	.
Trachinotus carolinus	Florida pompano	0.0	0.0	945	0.0	0.0	2008	0.1	0.0	1085	.	.	.	1.59	0.10	1.38	.
Trachinotus falcatus	Permit	0.0	0.0	945	.	.	.	.	.	.	.	.	.	0.21	.	.	.
Trachycardium muricatum	Yellow cockle	.	.	.	.	.	.	.	.	.	0.0	0.0	2797	.	.	.	0.04
Trachypenaeus constrictus	Broken nk shrp-cons	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	0.10	.	.

Appendix III.2. (continued) Organisms caught in the Galveston Estuary by Gill Net (1), Trawl (2), Bag Seine (3) and Oyster dredge (4).

Scientific Name	Common Name	Mean, standard error and sample size									Percent of samples			
		Gillnet			Trawl			Bagseine			Oyster dredge				Gill net	Trawl	Bag seine	Oyster dredge
Trachypenaeus similis	Broken-nk shrp-sim	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	.	1.64	.	.
Trachypenaius sp.	Trachypeneid-unid	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	.	0.15	.	.
Trichiurus lepturus	Atlantic cutlassfh	.	.	.	0.1	0.0	2008	.	.	.	.	.	.	.	.	5.93	.	.
Trinectes maculatus	Hogchoker	.	.	.	0.1	0.0	2008	0.0	0.0	1085	.	.	.	.	.	4.58	0.74	.
Uca panacea (pugilator)	Sand fiddler crab	.	.	.	.	.	.	0.0	0.0	1085	.	.	.	.	.	.	0.09	.
Urophycis floridana	Southern hake	.	.	.	0.0	0.0	2008	.	.	.	.	.	.	.	.	1.89	.	.
Xiphopeneus kroyeri	Seabob	.	.	.	0.0	0.0	2008	0.0	0.0	1085	.	.	.	.	.	1.79	1.11	.

APPENDIX 3. COMMERCIAL AND RECREATIONAL FISHERIES LANDINGS

Maury Osborn

INTRODUCTION

Gulland (1977) emphasized the importance to the fishery manager of knowing the landings of a marine resource. Landings data from both recreational and commercial fishermen are required to assess the need for and the effect of saltwater fishing regulations on fish populations. Economic and sociological data can also be inferred from landings data to allow management for optimum sustainable yield (Radovich 1975).

Commercial landings of marine species from Texas bays and the Gulf of Mexico off Texas have been collected from seafood dealers since 1880 (Stevenson 1893; Perret et al. 1980). These early data were collected sporadically until 1936 when annual surveys were initiated by the Texas Legislature (Texas Game, Fish and Oyster Commission 1937). Since then, the Texas Parks and Wildlife Department (TPWD) has monitored the landings and value of marine fishes, oysters, crabs and shrimp through a mandatory self-reporting system known as the Monthly Marine Products Report (MMPR) which is completed by seafood dealers (Johns 1990). Since 1956, the National Marine Fisheries Service (NMFS) has collected shrimp landings data through dealer reports and shrimp vessel crew interviews (Prytherch 1980) while TPWD continued to collect data on fishes, crabs and oysters. An informal data exchange between agencies permitted compilation of total self-reported landings of marine species. Beginning in April 1985, TPWD and NMFS instituted a formal cooperative agreement to collect and exchange commercial fisheries statistics.

Recreational finfish landings in Texas have been estimated since 1974 based on on-site interviews at fishing access sites (Heffernan et al. 1976; Breuer et al. 1977; Green et al. 1978; McEachron 1980a, 1980b, 1983, 1984; McEachron and Green 1981, 1982, 1983, 1984a; McEachron et al. 1981, 1984a; Osburn and Ferguson 1985a, 1985b, 1986, 1987; Osburn et al. 1988; Maddux et al. 1989). Survey procedures and estimation calculations are described in Osburn and Osborn (in press). Recreational shrimp, crabs, and oyster landings, beginning with May 1983, can also be estimated using these procedures; however, these estimates have not been generated or published.

TPWD publishes annual trend reports of commercial and recreational landings; however, the commercial trend report does not contain data collected prior to 1972 (Johns 1990). Although the recreational trend report does present detailed data for the Galveston Estuary, these data are not presented graphically. The objectives of this study were to 1) compile and graph available commercial landings data collected prior to 1972, and 2) graph Galveston Estuary recreational landings by species and year.

MATERIALS AND METHODS

Commercial Landings

Annual Reports (fiscal years) of the Texas Game, Fish and Oyster Commission (1912, 1919, 1922 to 1930, and 1932 to 1951), the Texas Game and Fish Commission (1952 to 1963), and the Texas Parks and Wildlife Department (1964 to 1965, 1967 to 1972) on file in the TPWD Austin and Rockport Marine Laboratory libraries and the Texas State Library were examined. Landings data for fiscal years 1931, 1933, 1935, and 1971 were not found. Reports from 1913 to 1918, 1931, and 1966 were not on file at any of the libraries; however, data for 1966 were available in the 1967 report. The reports for 1933, 1935 and 1971 were examined but no commercial landings data for those years were included. When tables of commercial landings were found, data were entered onto a LOTUS spreadsheet. Data for all species and estuarine systems were entered on the LOTUS file although only Galveston Estuary data are presented and discussed in this report. Data from 1972 onward (Johns 1990) were also entered on the spreadsheet. Commercial landings prior to 1972 were reported on a fiscal year basis (i.e. September 1926 to August 1927 is referred to here as 1927). Beginning with 1972, data were reported on a calendar year basis. No individual graphs were generated for freshwater or primarily Gulf-dependent species, although they were included in total finfish.

Formats for reporting commercial landings varied considerably before 1972. Data from 1909 to 1926 were included in a table in the 1926 report; however it was for coastwide totals and was reported for total finfish, shrimp, crabs, and oysters, rather than by individual species. These data could not be used for graphing Galveston Estuary landings. From 1927 to 1936, landings were presented by the same four species groups, by port, with bay and Gulf landings at a port combined. Ports considered to represent Galveston Estuary landings were Galveston, Freeport, Anahuac, Kemah, La Porte, San Leon, Seabrook, Smith Point, and Wallisville. Data for some individual species were available from 1937 to the present. From 1937 to 1941, landings were presented by bay areas and for the entire Gulf off Texas. In 1939, 1940, and 1941, only landings from all other minor bays were listed; landings for the Galveston Estuary were obtained by subtraction from totals off a monthly landings table which appeared to be coastwide. This resulted in negative numbers in some cases, which were set to zero; these data should be considered less reliable. In 1940, landings of all other finfish species were reported on a coastwide basis, not by estuary (except for trout, redfish, drum, and flounder). From 1942 to 1949, landings were presented by individual species by major estuary or combinations of estuaries, and by those areas of the Gulf off each estuary. From 1950 to 1972, landings were presented for estuaries (sometimes combined areas such as Aransas-Corpus Christi) and associated Gulf areas combined. Shrimp landings for Gulf and inshore areas combined (statistical area 18 and the Galveston Estuary) were obtained from the National Marine Fisheries Service and graphed by species. Only bay landings for shrimp after 1972 were graphed. Four major groups (finfish, crabs, shrimp, and oysters) were graphed from 1927 onward. With some exceptions, individual species were graphed from 1937 or 1942 onward.

Shrimp were reported as "green" from 1926 to 1937, and this was assumed to mean heads-off. From 1938 to 1959, there was no indication as to whether they were weighed heads-off or heads-on. From 1960 onward, shrimp have been specifically designated as heads-on. Data from 1926 to 1937 were converted to heads-on using the conversion factor for brown shrimp of 1.61 (Johns 1990). Data for 1938 to 1959 were not converted. Oyster landings were recorded as barrels until 1937, then as pounds until 1947, then as gallons until 1950, and as pounds since 1950. Conversion to pounds were made according to Johns (1990).

Species names varied and were colloquial; some assumptions were made based on historical knowledge and experience with colloquial names. "Drum" were considered to be black drum (Pogonias cromis) because "redfish" (red drum, Sciaenops ocellatus) were reported separately. "Trout" were considered to be spotted seatrout (Cynoscion nebulosus), and sand seatrout (C. arenarius), because in some years both "trout" and "sand seatrout" were reported but in other years only "trout" were reported. Although the following species were not graphed, they were assigned species codes on the LOTUS file for future automation. "Mackerel" was assumed to be Spanish mackerel (Scomberomorus cavalla) because "kingfish" was assumed to be king mackerel (S. maculatus), and true kingfish (Menticirrhus sp.) were referred to as "whiting". "Rockfish" was assumed to be striped bass (Morone saxatilis).

Recreational Landings

Survey procedures and estimation calculations are described in Osburn and Osborn (in press). Data through 1989 were obtained from tables published in Green et al. (1991). The survey year runs from May 15 of one year to May 14 of the next year (high use season is May to November and low use season is November to May). The year 1976 refers to combined estimates for 1974-75 and 1975-76 because only half of the coast was surveyed in each survey year. The Galveston area was surveyed in 1974-75. Data are for private sport-boat fishermen fishing the Galveston Estuary and its passes to the Gulf of Mexico. Offshore Gulf landings were not included. Private sport-boat fishermen comprise a large portion of the pressure and landings and provide the longest continuous, comparable data set for recreational fishing. Other types of fishing estimates (wade/bank, lighted pier and jetty, party-boat and headboat fishermen) are available (Heffernan et al. 1976; Green et al. 1978; McEachron and Green 1981, 1982, 1983, 1984; McEachron et al. 1981, 1984; McEachron 1984; Osburn and Ferguson 1985a, 1985b, 1986, 1987; Osburn et al. 1988; Maddux et al. 1989), but those surveys have been conducted on a periodic basis or do not have as many years of data. Numbers of fish and weight in pounds were graphed, except for other species which were only plotted by numbers of fish. Mean weights are not routinely calculated for other finfish combined, therefore calculation of total weight landed (mean weight times number landed) was not possible.

RESULTS

Commercial Landings

Shrimp (Penaeus spp.) comprised almost 52 percent of all species landed in Galveston Bay from 1972 to 1989 (Figure III.3.1). Those years were chosen in order to exclude Gulf data. Blue crab (Callinectes sapidus) comprised over 20 percent, American oysters (Crassostrea virginica) comprised 23 percent, and finfish comprised only 5 percent of the landings by weight. Generally, landings of shellfish and finfish remained low until the early 1950s and then increased dramatically.

Shellfish

Total shrimp landings began increasing in the early to middle 1950s (Figures III.3.2, III.3.3). Bay landings have fluctuated without any strong trend since 1972 (Figure III.3.2). Slightly more white shrimp (Penaeus setiferus) than brown and pink shrimp (P. aztecus, P. duorarum) are caught in Galveston bay, excluding Gulf landings, while the opposite appears true offshore (Figure III.3.3). Oyster landings remained below one million pounds until a rapid increase in the early 1960s (Figure III.3.4). They decreased dramatically in the late 1970s and then increased to a record high in 1983, followed by another decline. Except for a few hundred pounds in one or two years, all landings were reported from the bays. Blue crab landings also began increasing in the 1960s, remained fairly stable through the 1970s at around two million pounds, and then reached new heights in the middle 1980s (Figure III.3.5). Nearly all landings were from bay

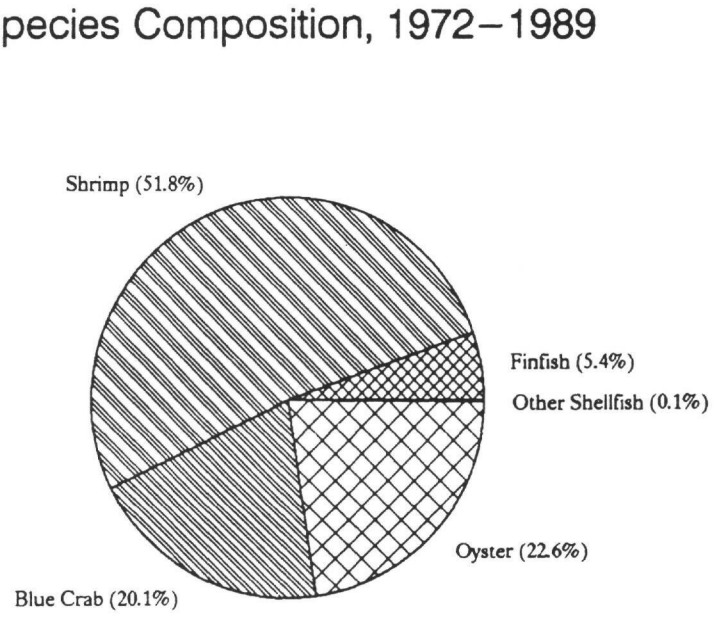

Figure III.3.1. Species composition, by weight, of commercial landings in Galveston Bay from 1972 to 1989.

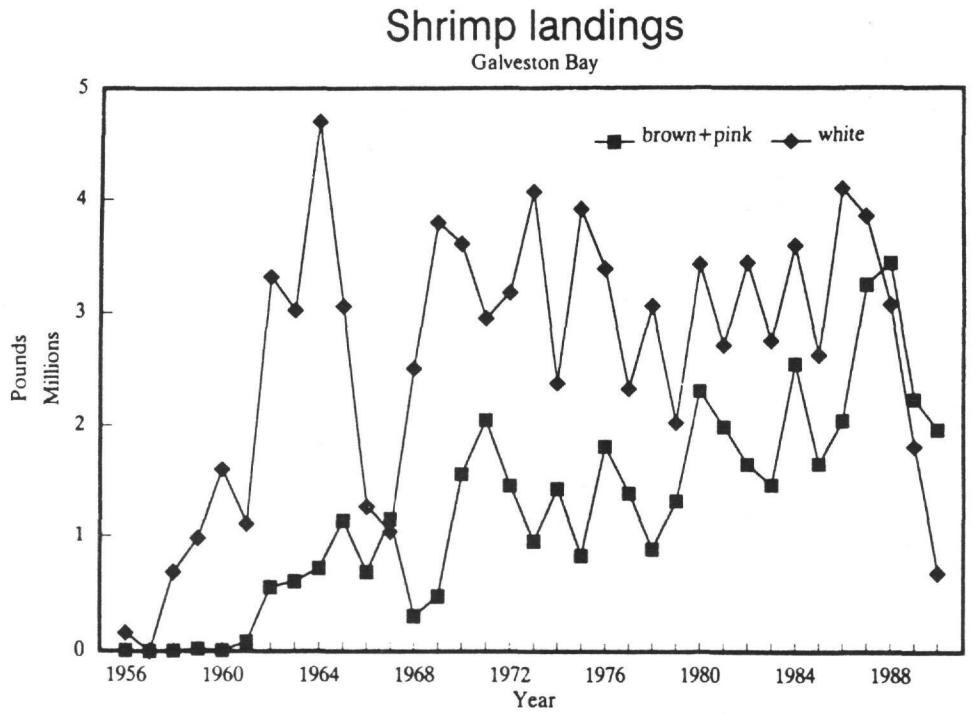

Figure III.3.2. Commercial landings of white shrimp and brown and pink shrimp (Penaeus spp.) in Galveston Bay, 1957-1989.

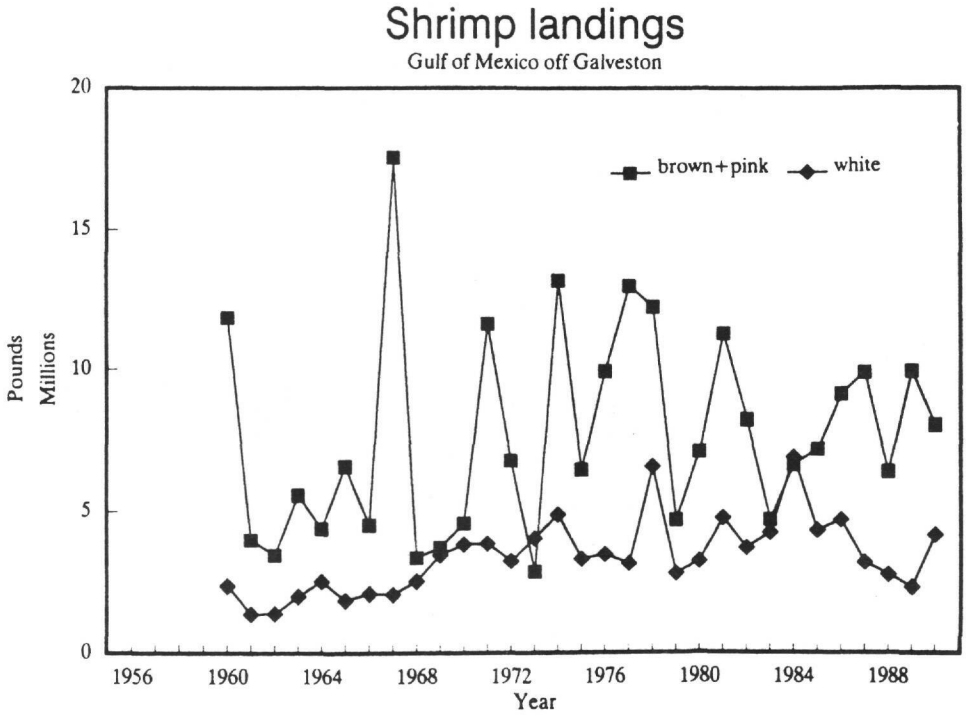

Figure III.3.3. Commercial landings of white shrimp and brown and pink shrimp (Penaeus spp.) in the Gulf of Mexico offshore of Galveston Bay, 1957-1989.

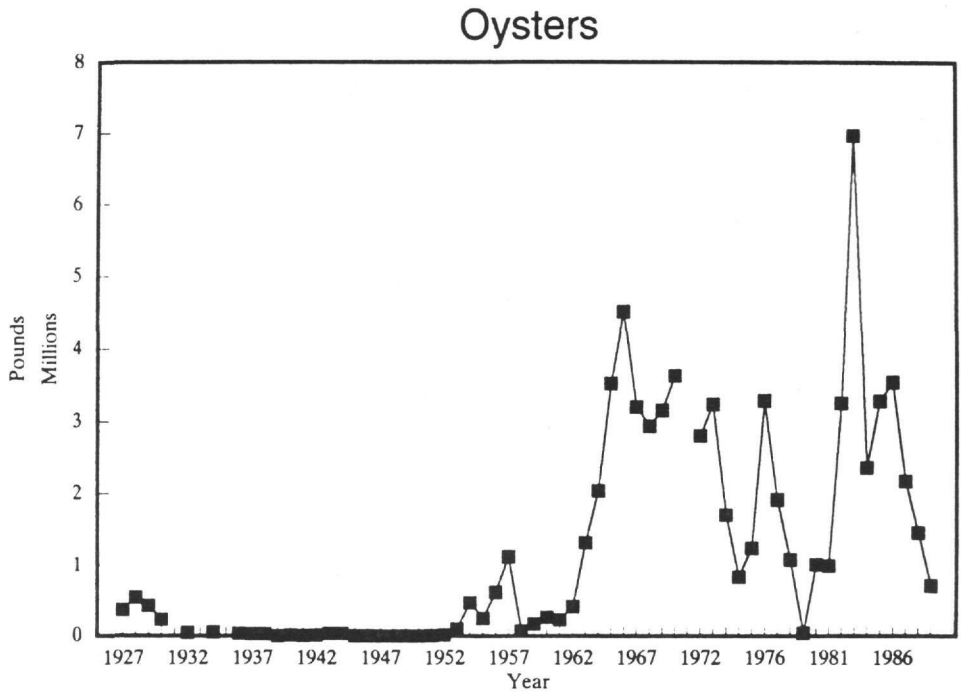

Figure III.3.4. Commercial landings (meat weight in pounds) of American oysters (Crassostrea virginica) in Galveston Bay, 1927-1989.

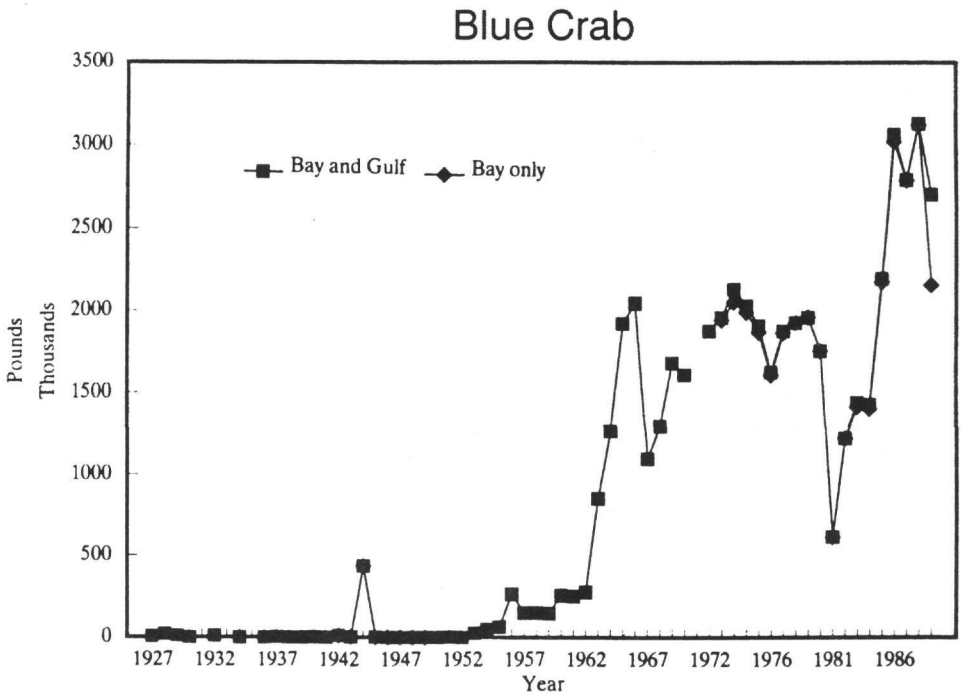

Figure III.3.5. Commercial landings (whole weight in pounds) of blue crab (Callinectes sapidus) in Galveston Bay, 1927-1989.

landings were from estuarine waters. Squid landings also began increasing in the 1960's and have fluctuated greatly since then (Figure III.3.6). Surprisingly, stone crab (Menippe adinae) landings began appearing in the Galveston Estuary in 1984 and reached a high of 30,000 pounds in 1988 (Figure III.3.7).

Finfish

Total finfish increased from below 250,000 pounds prior to the 1940s to around one million pounds through the 1950s, with a large increase in the middle 1960s, and a decrease since then (Figure III.3.8). Species composition since 1982, when commercial sale of red drum and spotted seatrout was banned (Anonymous 1982), shows that flounder (Paralichthys spp.) make up 26 percent of the landings, followed by black drum (17 percent), mullet (Mugil spp.; 16 percent), and sheepshead (Archosargus probatocephalus; 12 percent; Figure III.3.9). Much of the increase during the 1950s was due to Gulf species such as red snapper (Lutjanus campechanus), which had landings approaching one million pounds during that period. The large landings in the middle 1960s were due to both Gulf and estuarine species, including seatrout (Figure III.3.10), red drum (Figure III.3.11), black drum (Figure III.3.12), flounder (Figure III.3.13), sheepshead (Figure III.3.14), Atlantic croaker (Micropogonias undulatus; Figure III.3.15), kingfish (whiting; Figure III.3.16), red snapper, and unclassified food and scrap (Figure III.3.17).

Red drum and spotted seatrout reached record landings of over 100,000 and 600,000 pounds, respectively, in the middle 1970s and then steadily declined until the ban on their sale in September 1981. Most of the landings of "seatrout" were spotted seatrout, not sand seatrout (Figure III.3.18). Mullet landings increased in the late 1960s and early 1970s, remained low in the 1970s, and increased to over 100,000 pounds in the early 1980s (Figure III.3.19). Black drum and flounder also increased during the 1980s. Gafftopsail catfish landings (Bagre marinus) declined during the 1980s (Figure III.3.20).

Recreational Landings

Recreational boat landings for all finfish combined in the Galveston Estuary have declined since 1974-76 (Figure III.3.21), although effort has not shown a decline (Figure III.3.22). Galveston Estuary recreational landings are dominated by Atlantic croaker, sand seatrout and spotted seatrout (Figure III.3.23), while Southern flounder and other finfish have increased as a percent of the total since 1982. Landings of Atlantic croaker (Figure III.3.24), sand seatrout (Figure III.3.25), spotted seatrout (Figure III.3.26), black drum (Figure III.3.27), sheepshead (Figure III.3.28), and gafftopsail catfish (Figure III.3.298) all declined in the mid to late 1980s. Southern flounder (Paralichthys lethostigma) remained relatively stable except for an extremely high landings estimate in 1980 (Figure III.3.30). Red drum landings are slightly lower than those during the 1970s, although the weight landed has been the same and in some years shown large increases (Figure III.3.31).

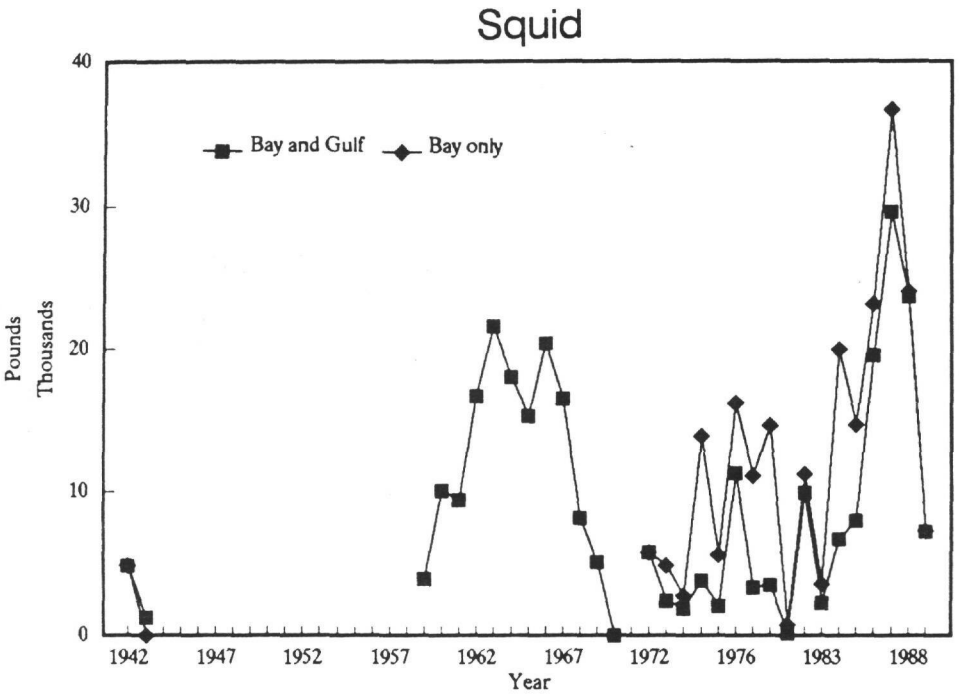

Figure III.3.6. Commercial landings (whole weight in pounds) of squid (Lolliguncula brevis and Loligo pealei) in Galveston Bay, 1942-1989.

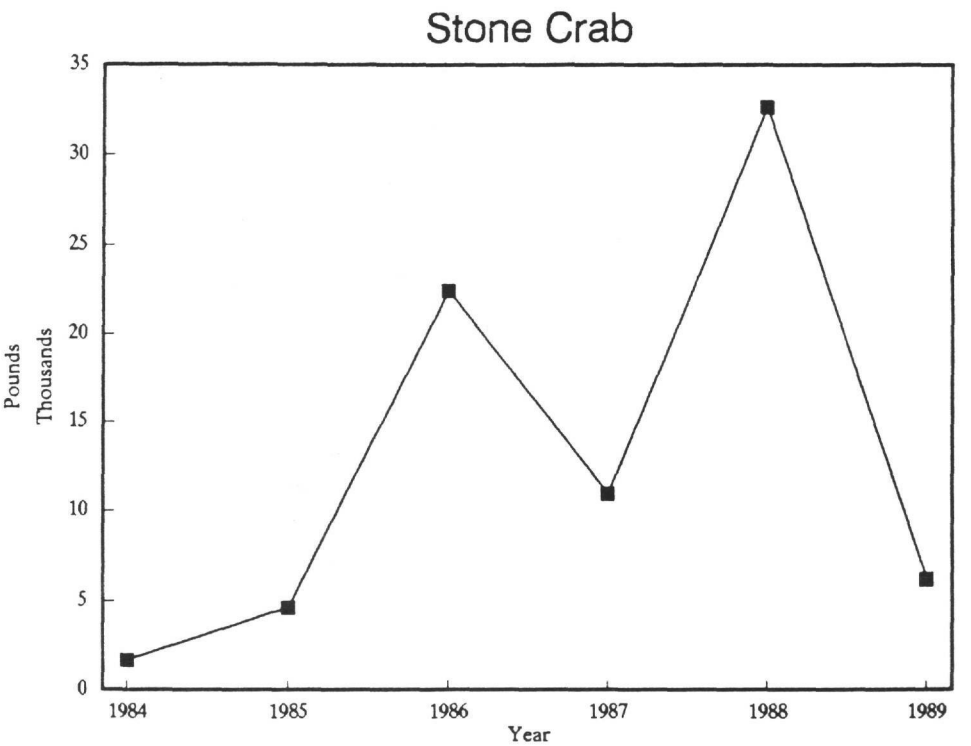

Figure III.3.7. Commercial landings (whole weight in pounds) of stone crab (Menippe adinae) in Galveston Bay, 1984-1989.

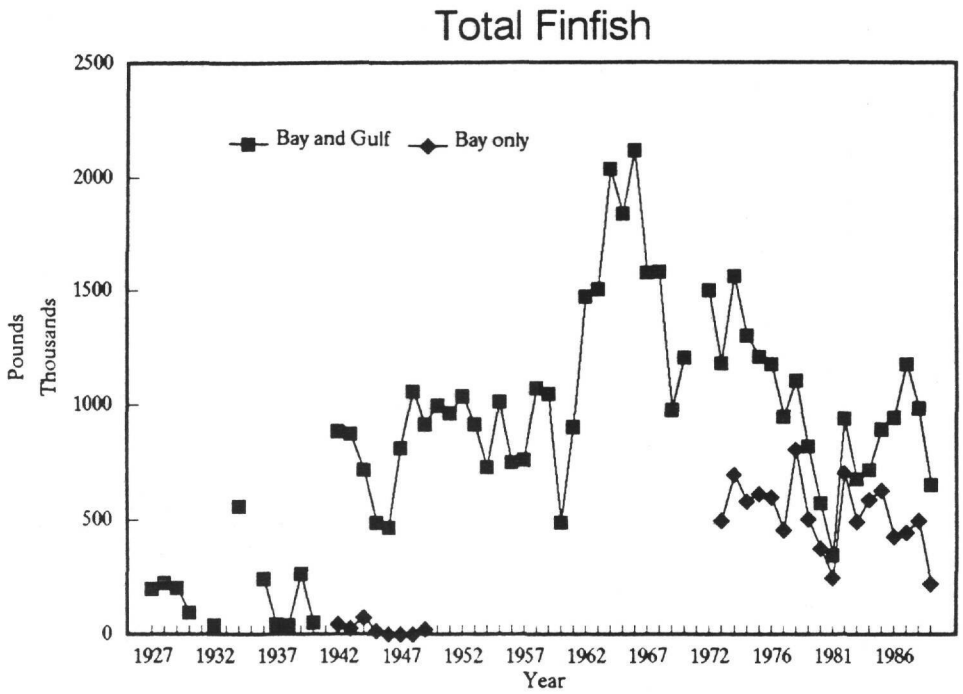

Figure III.3.8. Commercial landings (whole weight in pounds) of all finfish in Galveston Bay, 1927-1989.

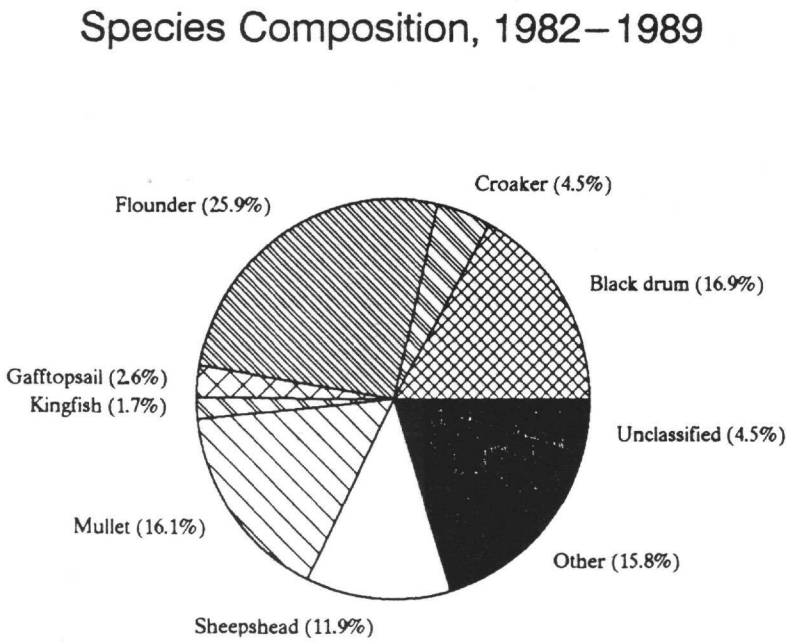

Figure III.3.9. Species composition, by weight, of commercial finfish landings in Galveston Bay from 1982 to 1989.

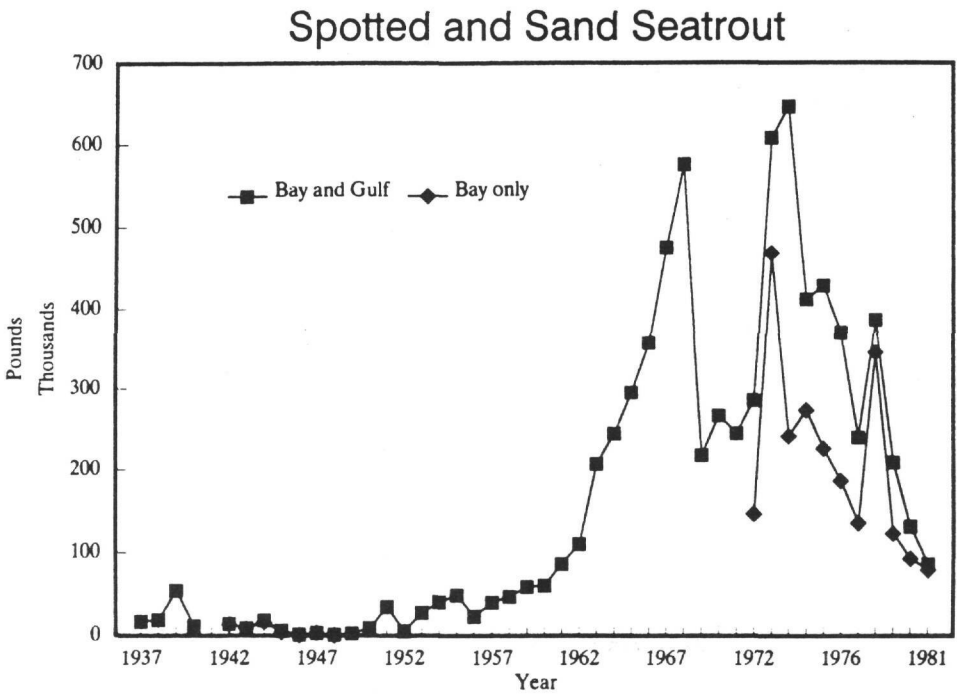

Figure III.3.10. Commercial landings (whole weight in pounds) of spotted and sand seatrout (Cynoscion spp.) in Galveston Bay, 1937-1989.

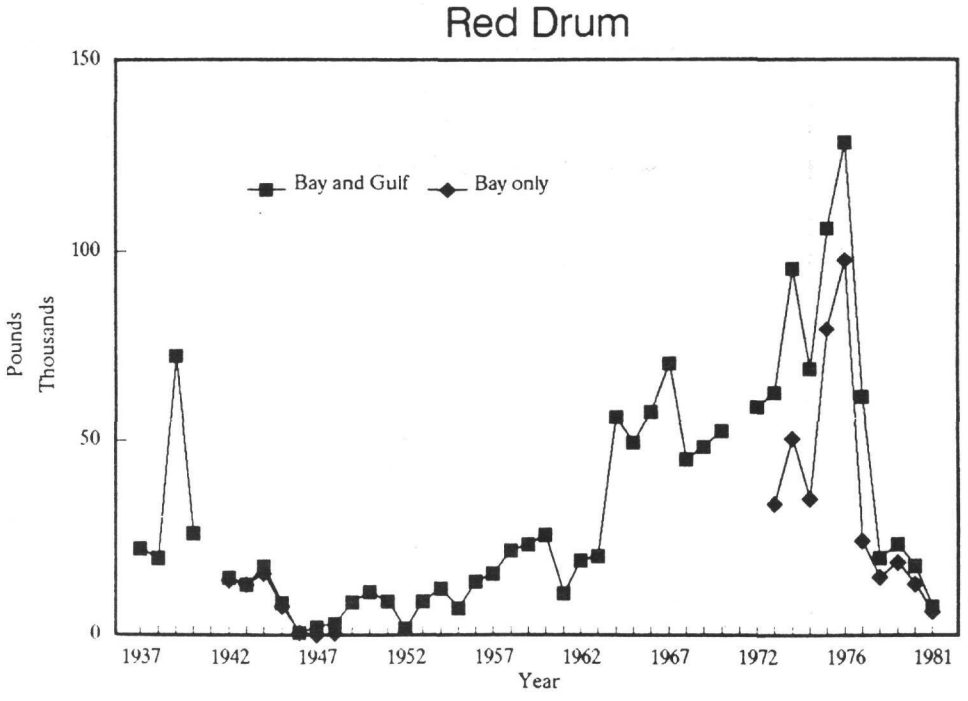

Figure III.3.11. Commercial landings (whole weight in pounds) of red drum (Sciaenops ocellatus) in Galveston Bay, 1937-1989.

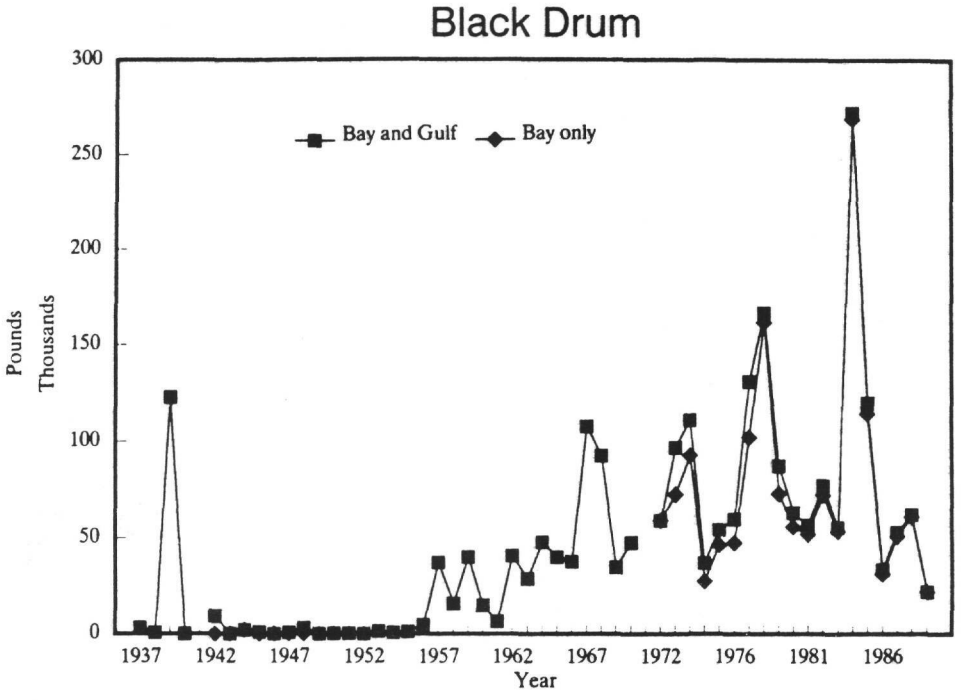

Figure III.3.12. Commercial landings (whole weight in pounds) of black drum (Pogonias cromis) in Galveston Bay, 1937-1989.

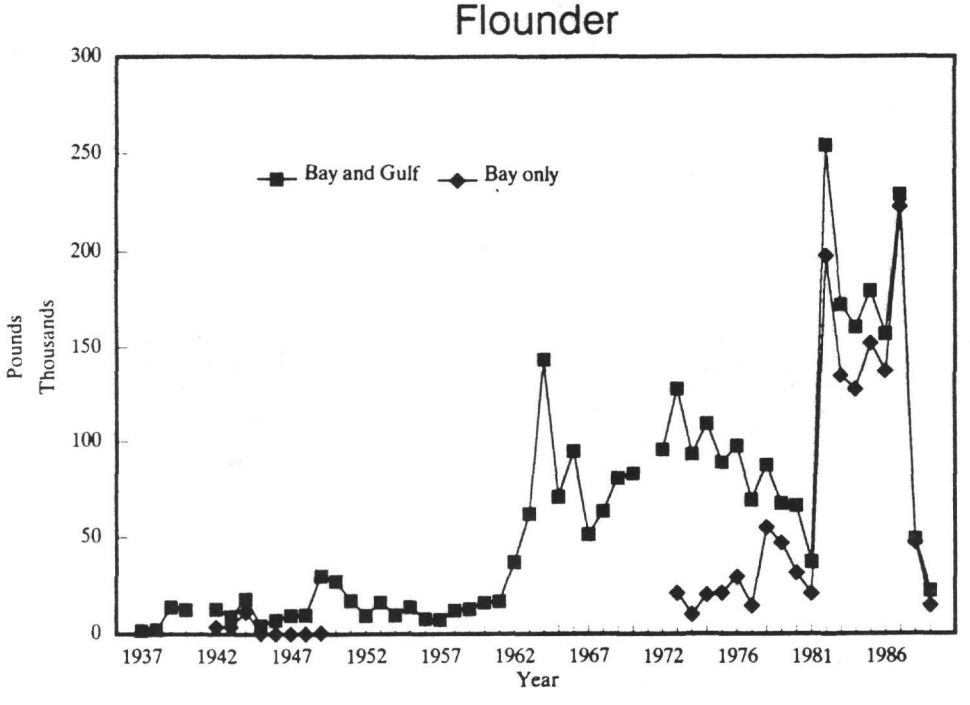

Figure III.3.13. Commercial landings (whole weight in pounds) of flounder (Paralichthys spp.) in Galveston Bay, 1937-1989.

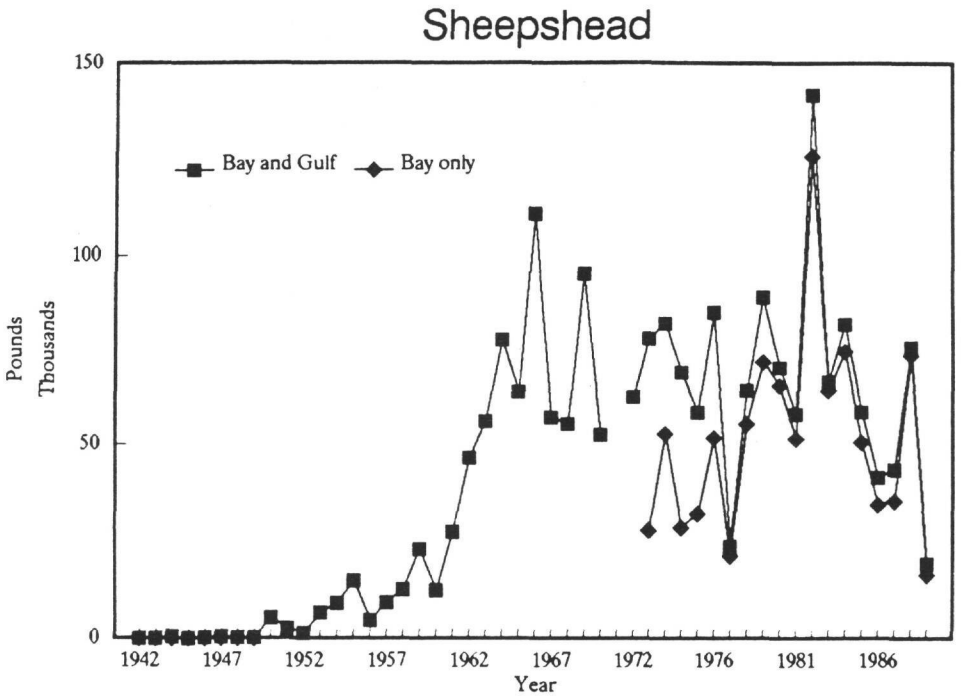

Figure III.3.14. Commercial landings (whole weight in pounds) of sheepshead (Archosargus probatocephalus) in Galveston Bay, 1942-1989.

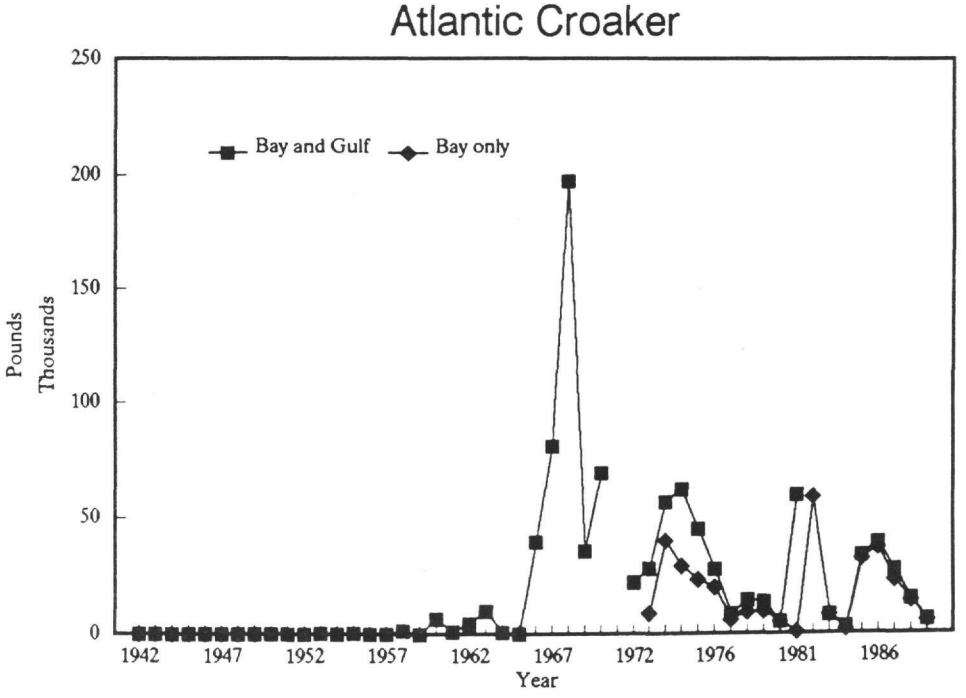

Figure III.3.15. Commercial landings (whole weight in pounds) of Atlantic croaker (Micropogonias undulatus) in Galveston Bay, 1942-1989.

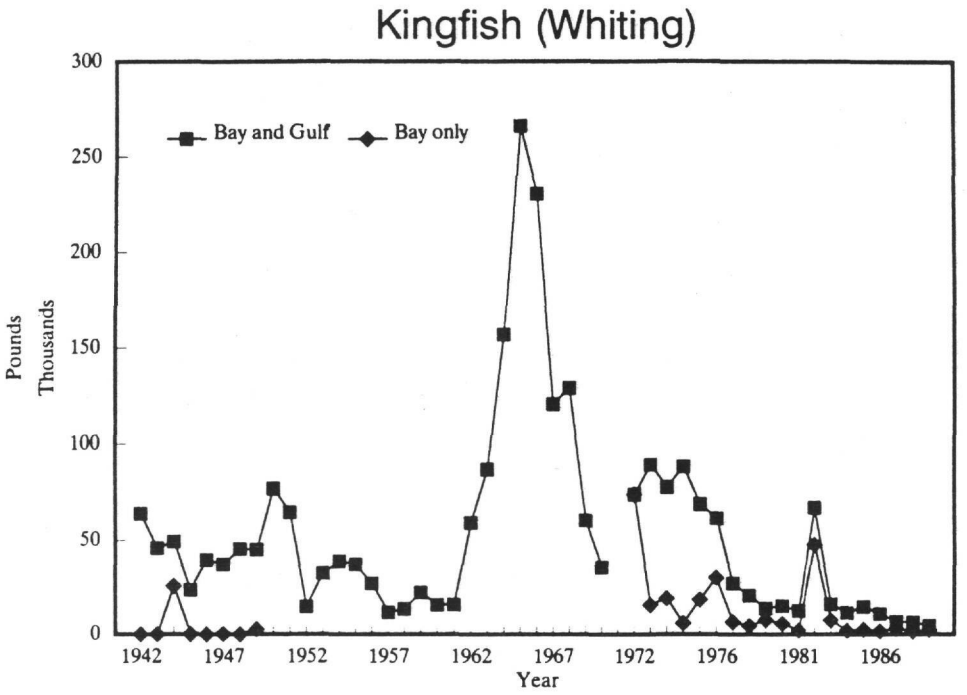

Figure III.3.16. Commercial landings (whole weight in pounds) of kingfish (whiting; Menticirrhus spp.) in Galveston Bay, 1942-1989.

Figure III.3.17. Commercial landings (whole weight in pounds) of unclassified food and scrap in Galveston Bay, 1942-1989.

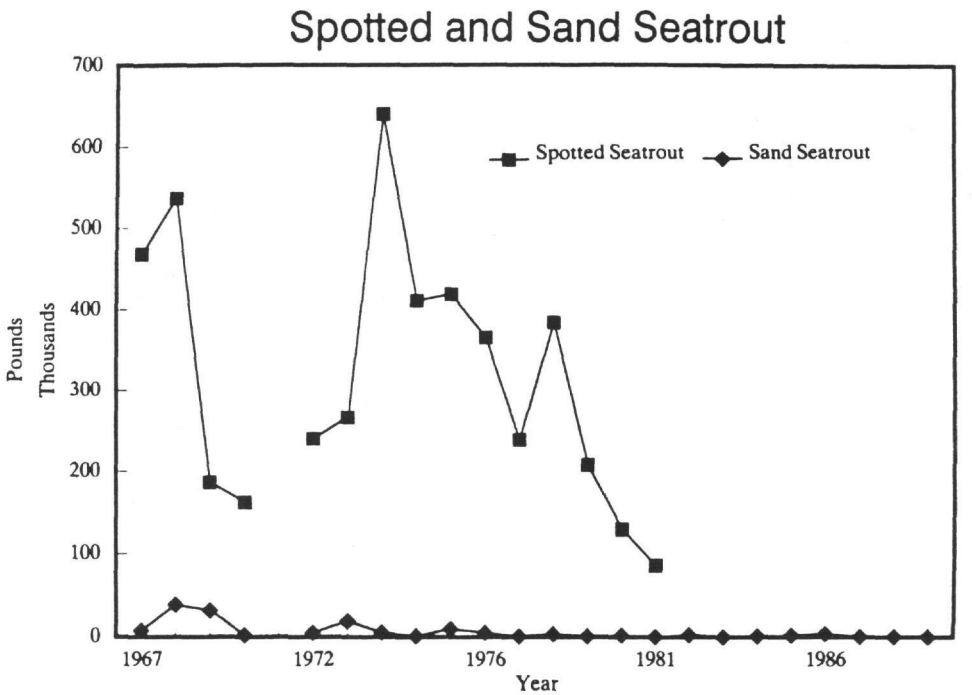

Figure III.3.18. Commercial landings (whole weight in pounds) of spotted and sand seatrout (Cynoscion spp.), by species, in Galveston Bay, 1967-1989.

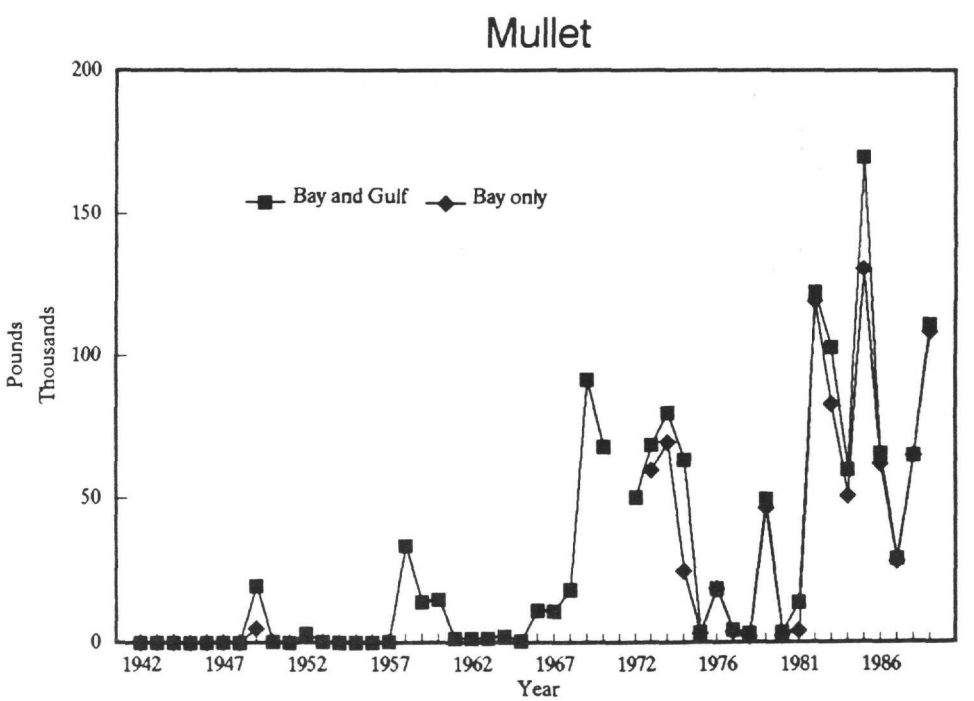

Figure III.3.19. Commercial landings (whole weight in pounds) of mullet (Mugil spp.) in Galveston Bay, 1942-1989.

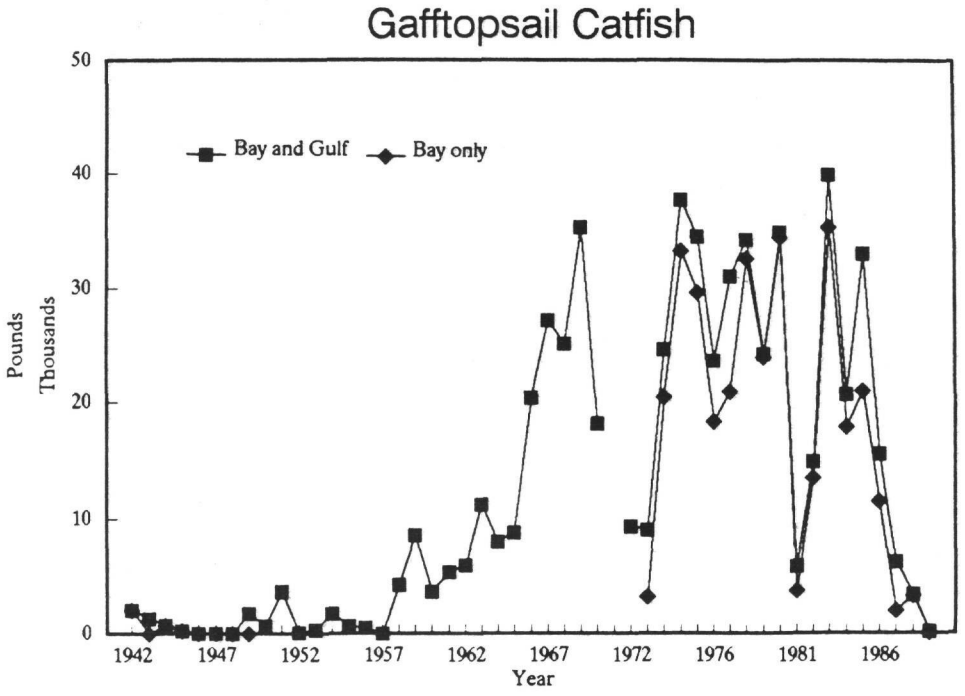

Figure III.3.20. Commercial landings (whole weight in pounds) of gafftopsail catfish (Bagre marinus) in Galveston Bay, 1942-1989.

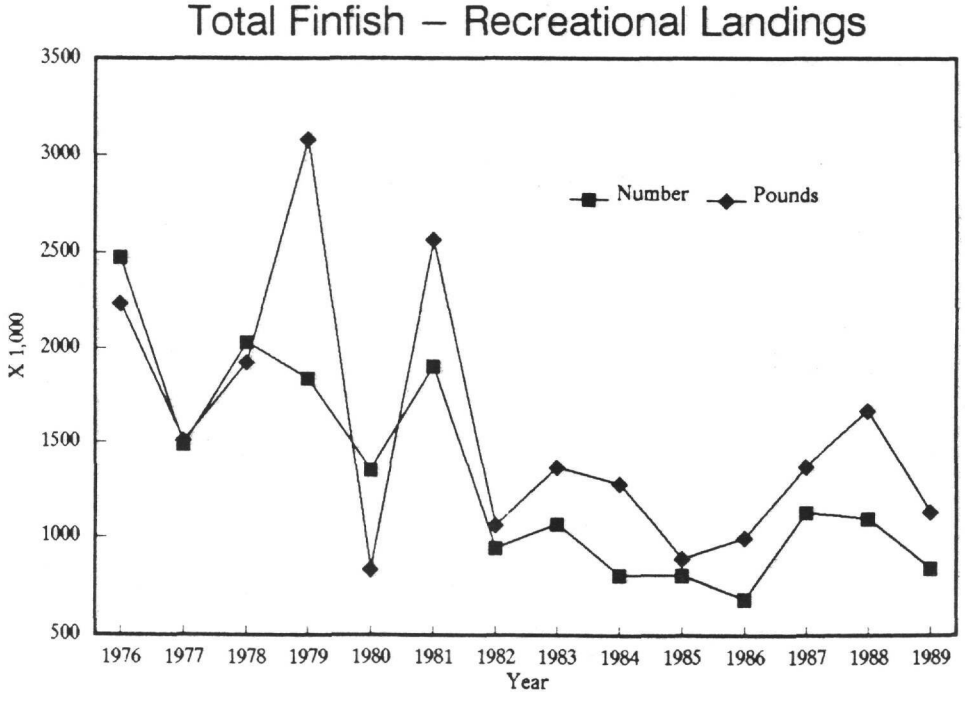

Figure III.3.21. Recreational landings (numbers of fish and whole weight in pounds) of all finfish caught by private sport-boat fishermen in Galveston Bay, 1976-1989.

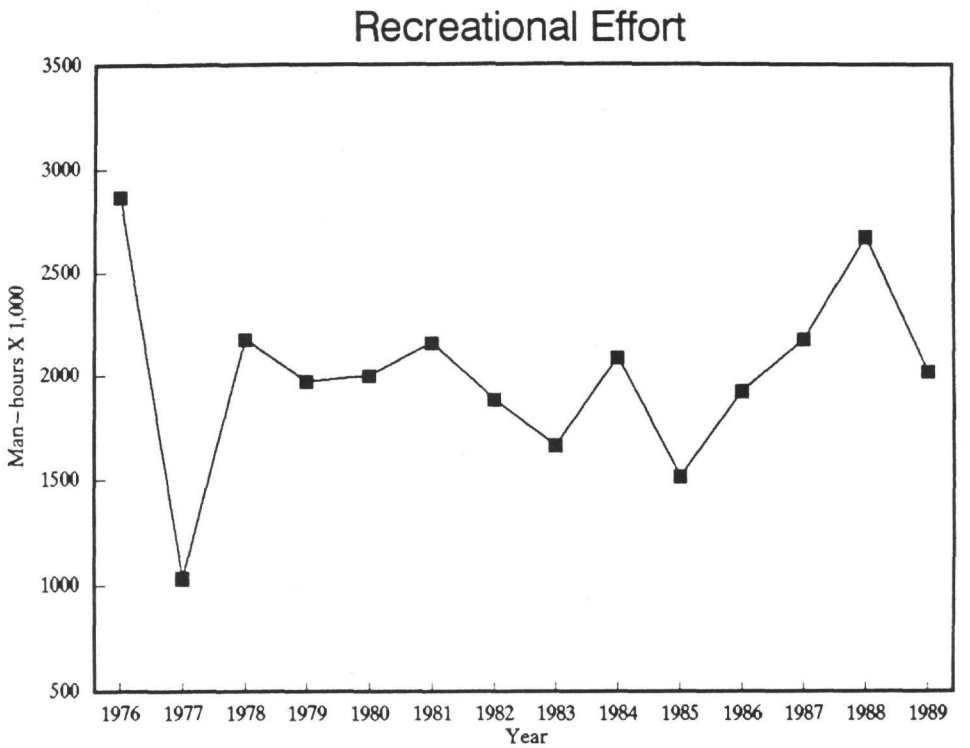

Figure III.3.22. Recreational effort (man-hours) expended by private sport-boat fishermen in Galveston Bay, 1976-1989.

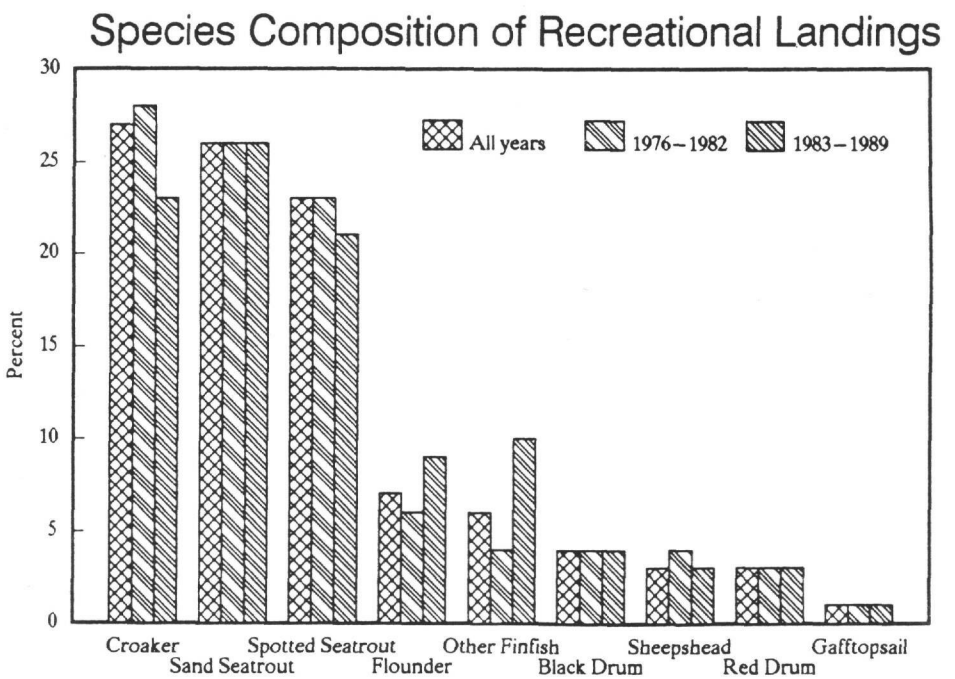

Figure III.3.23. Species composition, by numbers of fish, of recreational finfish landings caught by private sport-boat fishermen in Galveston Bay from 1976 to 1989 from 1976 to 1982, and from 1983 to 1989.

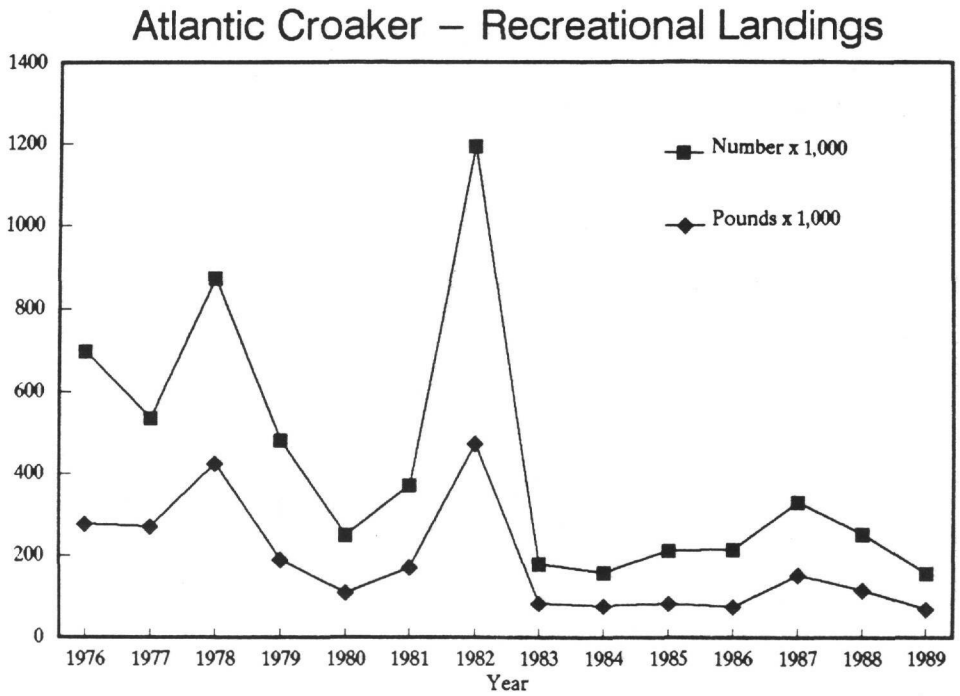

Figure III.3.24. Recreational landings (numbers of fish and whole weight in pounds) of Atlantic croaker (Micropogonias undulatus) caught by private sport-boat fishermen in Galveston Bay, 1976-1989.

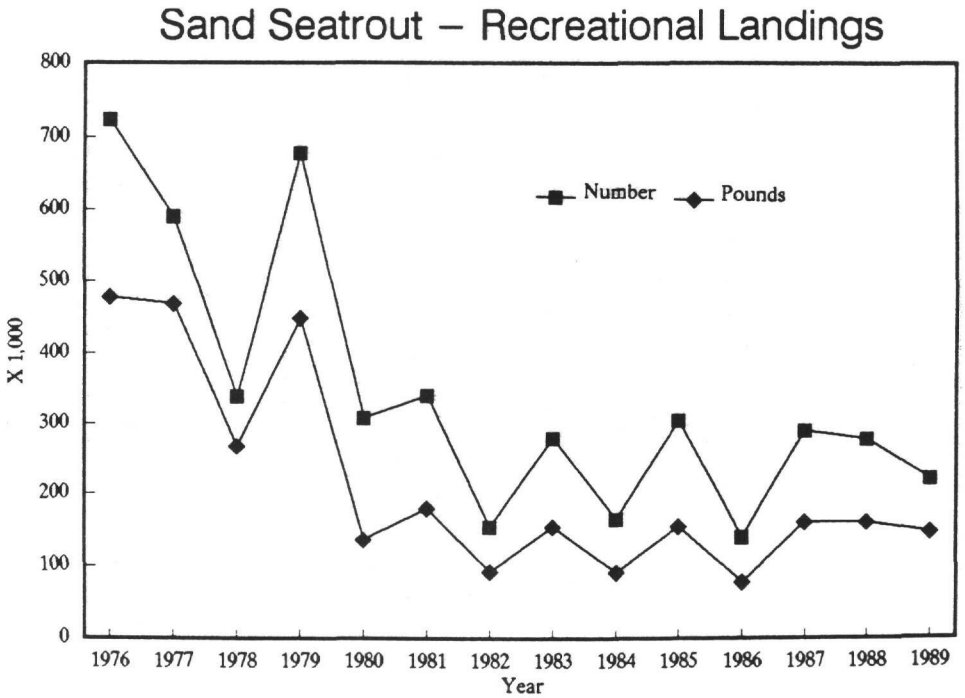

Figure III.3.25. Recreational landings (numbers of fish and whole weight in pounds) of sand seatrout (Cynoscion arenarius) caught by private sport-boat fishermen in Galveston Bay, 1976-1989.

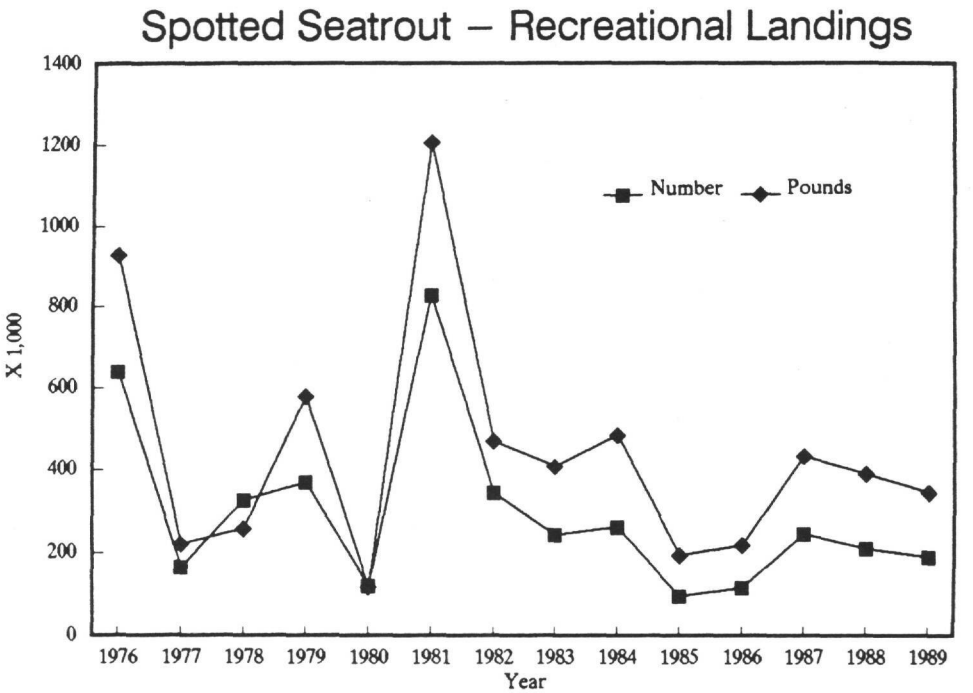

Figure III.3.26. Recreational landings (numbers of fish and whole weight in pounds) of spotted seatrout (Cynoscion nebulosus) caught by private sport-boat fishermen in Galveston Bay, 1976-1989.

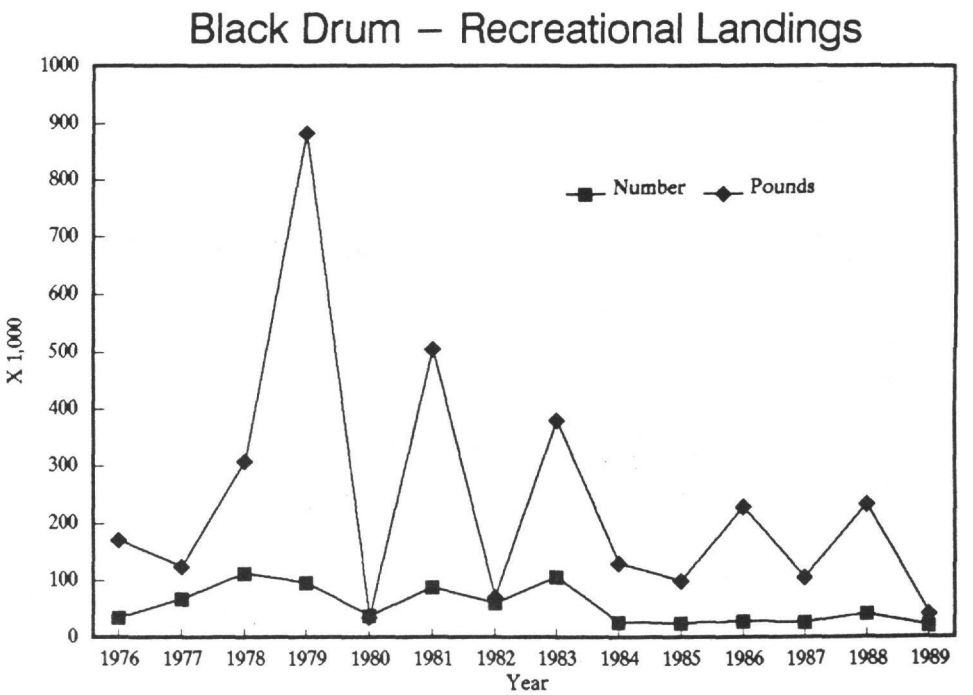

Figure III.3.27. Recreational landings (numbers of fish and whole weight in pounds) of black drum (Pogonias cromis) caught by private sport-boat fishermen in Galveston Bay, 1976-1989.

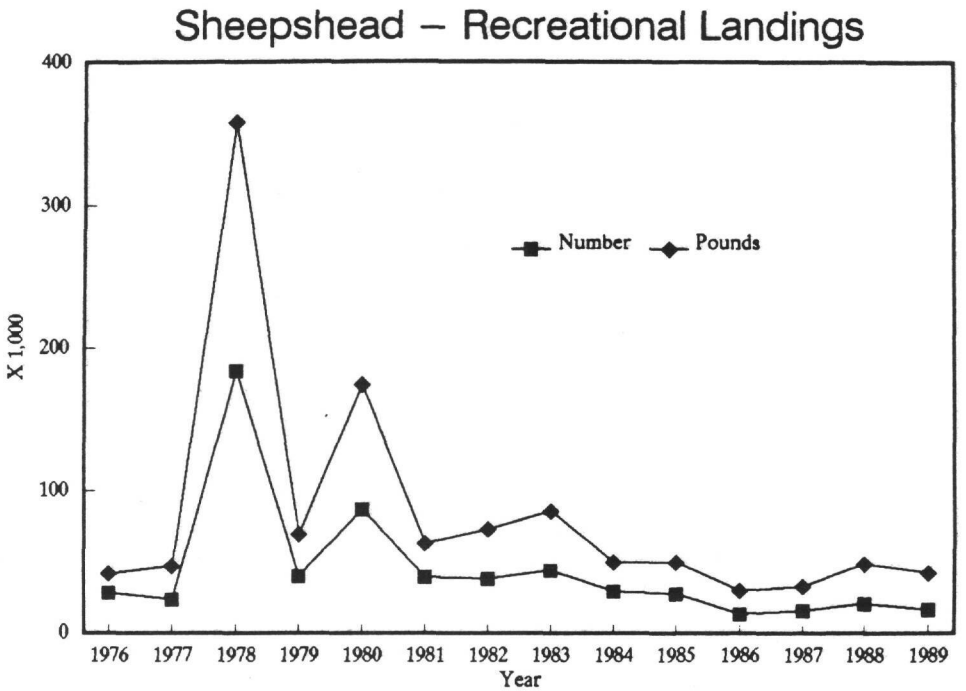

Figure III.3.28. Recreational landings (numbers of fish and whole weight in pounds) of sheepshead (Archosargus probatocephalus) caught by private sport-boat fishermen in Galveston Bay, 1976-1989.

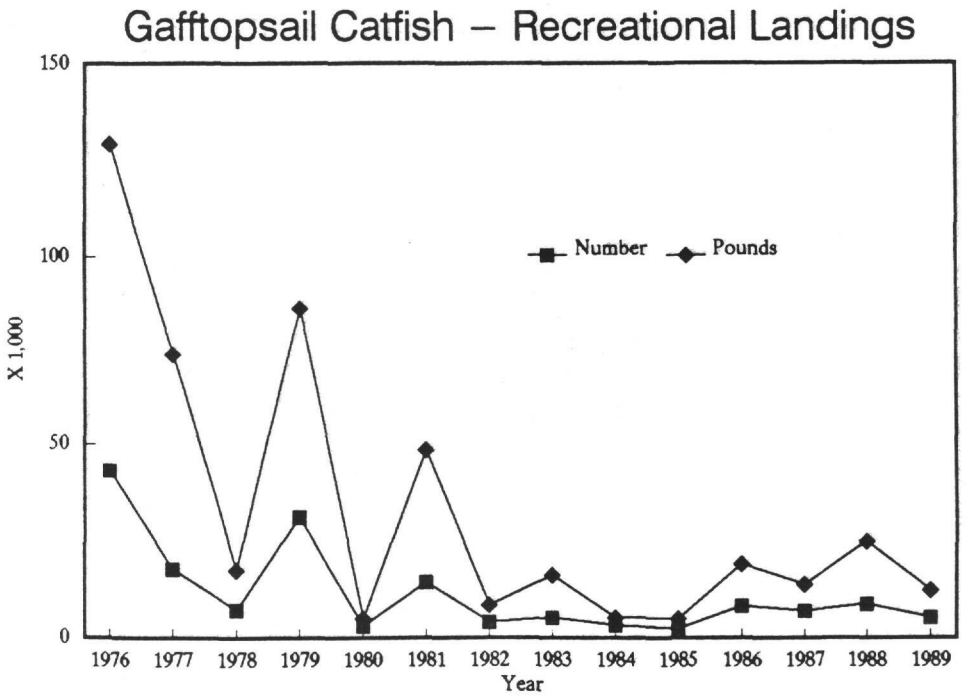

Figure III.3.29. Recreational landings (numbers of fish and whole weight in pounds) of gafftopsail catfish (Bagre marinus) caught by private sport-boat fishermen in Galveston Bay, 1976-1989.

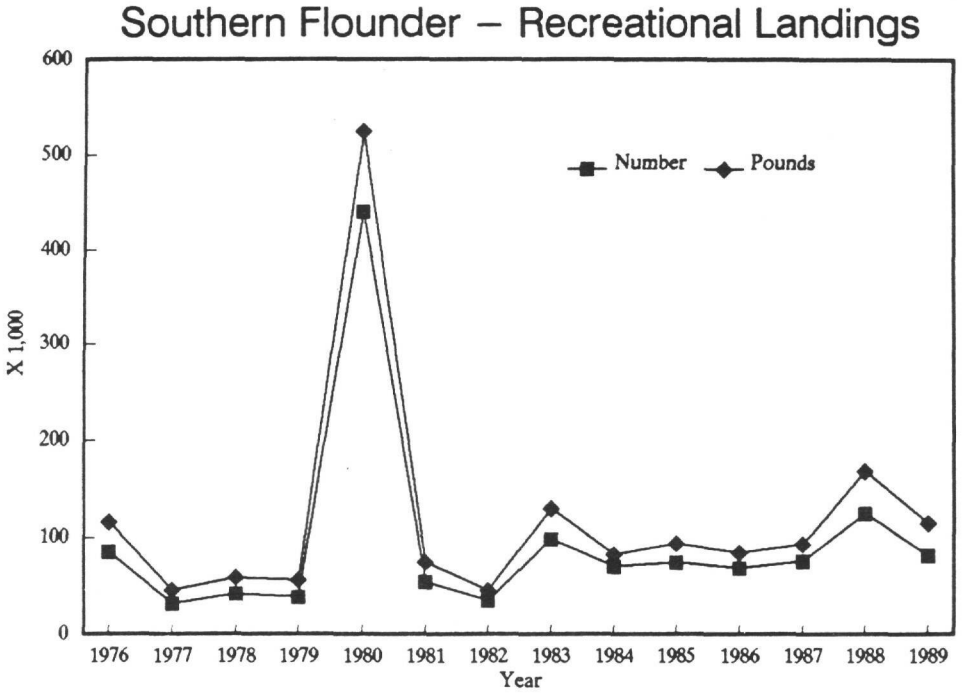

Figure III.3.30. Recreational landings (numbers of fish and whole weight in pounds) of southern flounder (Paralichthys lethostigma) caught by private sport-boat fishermen in Galveston Bay, 1976-1989.

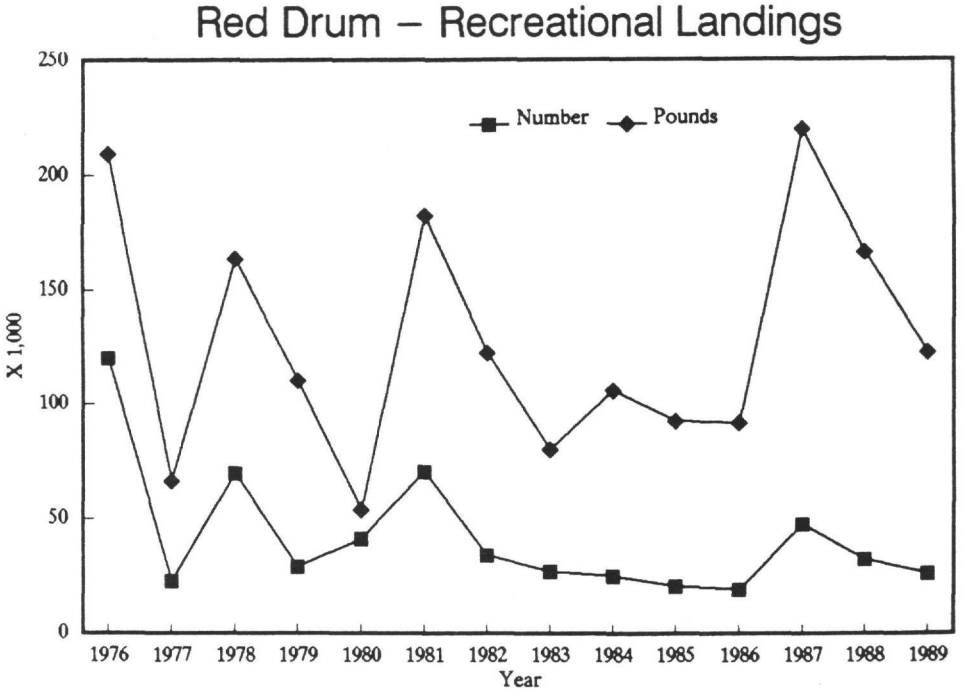

Figure III.3.31. Recreational landings (numbers of fish and whole weight in pounds) of red drum (Sciaenops ocellatus) caught by private sport-boat fishermen in Galveston Bay, 1976-1989.

DISCUSSION

Commercial shrimp, crab and oyster landings in the Galveston Estuary showed increases in the 1980s; however, commercial and recreational finfish landings peaked in the 1960s and 1970s, and have declined since then. Increased commercial fishing pressure and changes in technology are probably responsible for the increases in shellfish landings (Quast et al. 1988; Cody et al. 1989; Cody et al. in preparation), while commercial and recreational fishing pressure, environmental events (such as the 1983 freeze and the 1986 red tide), and major changes in fishing regulations designed to decrease fishing pressure on declining stocks are responsible for recent decreases in finfish landings (Maddux et al. 1989). In the oyster fishery, oyster tongs were the primary gear used prior to 1960; the introduction and widespread use of dredges greatly increased the harvest after 1960 (Quast et al. 1988). The development of the otter trawls after 1917, the adoption of "double-rigged" trawls in the 1950s and 1960s, and exploration of deeper, offshore Gulf waters caused large increases in the shrimp harvest (Cody et al. 1989). In the crab fishery, the primary gear used prior to the 1940s was the trotline; crab traps were introduced during the 1940s (Cody et al. in preparation). According to NMFS estimates, the number of crab fishermen was about 150 in 1976, a little over 100 in 1980, doubled to over 200 in 1984, and increased to over 300 in 1987 (Cody et al. in preparation).

In the 1970s red drum and spotted seatrout were in high demand by both consumers and recreational fishermen, were bringing a higher dollar per pound than other finfish, and were heavily targeted by commercial fishermen using efficient gill and trammel nets. Concern about overfishing prompted fishing restrictions in the late 1970s and finally the commercial sale of these species was banned beginning September 1981. The increases in landings of mullet, flounder, and black drum after 1981 probably reflect commercial fishermen shifting from red drum and spotted seatrout to other species. Recently a lucrative market developed for mullet roe, but recent regulations intended to protect spawning mullet have been implemented.

Recreational landings are affected by shifts in effort for economic reasons, such as gas price increases, decreases in fish availability caused by substantial fishing effort, and environmental events that are perceived as lowering catch rates by killing fish (Maddux et al. 1989). Catch rates are also affected by fishermen's knowledge and geographic residence (Matlock 1983). The large immigration into Texas in the 1980s with resulting increases in coastal populations may have changed the overall composition of recreational fishermen and their landings and catch rates. Changes in regulations also affect recreational landings (Meador and Green 1986); the many bag and size limits implemented in the 1980s (Anonymous 1984, 1986, 1988, 1990) have certainly affected sport-fishermen's harvest, but should ultimately improve the quality of their fishing experience.

Besides changes in fishing effort and gears, economics, etc., there may be other reasons that shellfish have not shown as serious a decline as finfish. Most of the shellfish species are shorter-lived, with earlier reproduction, than most of the commercially and recreationally important finfish species, so that they are more robust with respect to fishing pressure. Finfish landings seemed to have reached their maximum in the 1970s,

and effort and harvest could have exceeded the amount necessary to sustain maximum sustainable yield. Shellfish fisheries probably are currently reaching or exceeding levels of optimum effort (Quast et al. 1988; Cody et al. 1989, In preparation). Oyster landings have declined in the most recent years, the shrimp fishery is overcapitalized, and catch rates in the crab fishery are declining. Recent implementation of regulations designed to achieve management objectives in the Texas Oyster and Shrimp Fishery Management Plans (Quast et al. 1988, Cody et al. 1989) should help to maintain and restore those fisheries while achieving optimum yield. Management Plans are now being developed for commercially and recreationally important finfish species, and the Crab Management Plan is in the public review stage.

When no independent monitoring data are available, landings data are sometimes used as indicators of trends in the status of fish stock; however, this is not a desirable situation because landings are greatly influenced by economic and technological factors and do not always reflect the condition of fish stocks. Inaccurate or incomplete self-reporting by commercial fishermen has been documented, though it occurs to an unknown degree (Contas et al. undated, Bockstael 1980, Richkus et al. 1980, Green and Thompson 1981, Ferguson 1986, Matlock 1986, Campbell et al. 1990), and varies with many sociological and economic factors. Deficiencies in reporting requirements and subsequent enforcement also affect the utility of commercial landings data (Johns 1990). Changes in fishing regulations affect both commercial and recreational landings. Texas designed and tested a commercial sampling survey in the 1980s to obtain more reliable commercial landings estimates as well as additional biological, sociological, and economic data (Lahr et al. 1987, unpublished data); however, current budget and manpower constraints do not allow complete implementation of the survey.

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APPENDIX 4. STATEMENTS BY CONSULTING STATISTICIANS

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Jane and Roland Blumberg Centennial Professor
DAVID V HINKLEY

Mr A Green
Resource Protection Division
Texas Parks & Wildlife Department
4200 Smith School Road
Austin TX 78744

August 23 1991

Dear Mr Green

In response to your request, I am writing an overall assessment of the statistical methods which have been applied to analyses of data collected in the coastal fisheries study.

The data available on fish populations are integer counts of catches. For the statistical analysis of such data the authoritative text is the 1989 publication *Generalized Linear Models* authored by P. McCullagh & J. A. Nelder: the second of these authors also coauthored the corresponding software package GLIM. The statistical analysis by TPWD staff has followed the methodology described in this book, using GLIM for numerical calculations, with advice from me on options.

An important feature of the fisheries catch data is over-dispersion relative to the standard Poisson frequency model, and correct allowance has been made for this by careful determination of, and use of, the form of data variation - which is similar to that for Negative Binomial frequency models.

Proper diagnostic checking methods have been applied, both to verify assumptions of the statistical analysis and to check for atypical values.

The focus of the statistical analysis has been on detection of long-term trends in catch rates. The general strategy was to fit trend curves, after allowance for seasonal variation when possible, followed by statistical assessment of whether or not those curves show real trends as opposed to spurious trends due to random variation. This strategy is standard and has been correctly applied. For certain species other forms of trend (e.g., step-up or step-down) have been diagnosed by appropriate inspection of statistical graphs and corresponding comparisons of annual means.

In summary, it is my judgement that the appropriate state-of-the-art statistical techniques have been used in the data analysis in this study. Where my advice has been sought and given, I believe that it has been correctly applied.

Yours sincerely,

David V Hinkley

September 10th, 1991

Mr. Al Green
Texas Parks & Wildlife

SUBJECT: Review of Methodology

Dear Mr. Green:

I have been asked to give my professional opinion of the statistical methodology used in the current contract between Texas Parks and Wildlife Department and the Environmental Protection Agency. For the past year, I have been a consulting statistician on the portion of this contract that deals with detection and estimation of temporal trends in fish populations in Galveston Bay over the past 14 years. During the course of my consultancy, I have participated in meetings and discussions, suggested and directed analyses, interpreted results, and reviewed documents relating to trends and trend methodology for the subject contract. In my opinion, the statistical methodology used by TPWD on this contract and reported in the contract report is appropriate and reasonable for the purpose of detecting and estimating temporal trends in the species data that were available.

It should be noted that the analysis was limited to identifying the existence of trends and estimating their magnitudes. No attempt was made to accomplish the more difficult task of associating causative factors with trends, although some possibilities are suggested by the analytical results and briefly hinted at in the contract report. That was deemed beyond the scope of the present study. In general, the signal (trend) in the data is weak compared with the noise (random component) and takes different forms from one species to another and from one sampling technique to another. This renders difficult the task of developping tight, subject-matter-rooted models.

Nevertheless, TPWD staff did a fine job of coping with potential problems of seasonality, longitudinal studies of the same cohorts, specificity of sampling technique to organism size, autocorrelation in the time series, standardizing CPUE, and (with Dr. Hinkley's assistance -- see his separate review) dealing with mixtures of Poisson distributed errors (the negative binomial model). I believe the latter is probably an innovation in fisheries work that is likely to create considerable professional interest.

I have two modest suggestions for sampling methodology. First, I think it may be advisable to revise the policy of measuring only the first 19 individuals of a species that are caught and merely counting the remainder. It seems to me that the gain in information to be obtained from measuring all caught individuals clearly outweighs the additional effort involved in measuring them, particularly in view of the effort and pains taken to catch them. Second, I think it may be advisable to revisit the issue of sample site selection. Currently, sites are selected at random in Galveston Bay. Thus the variation in catch includes a component due to site-to-site variation, as well as components due to different seasons, different catch times, etc. So if the catch increases next month, it is not altogether clear whether the increase is due to a trend or to a selection of more favorable sites. I think that the spatial variation maps provided in the contract report suggest that catch may vary in a systematic manner across Galveston Bay. Thus site selection may be a significant factor in catch rates. Therefore, there may be some gains to be achieved in terms of detectability of trends by stratifying the Bay into areas of high and low catch rates for site selection. For species having a significant catch gradient across the Bay, a stratified sample design will be more efficient than a simple random selection of sites.

Sincerely,

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cc: Dr. David Hinkley