III. CLIMATIC INFLUENCES ON FINFISH AND SHELLFISH POPULATIONS

An exploratory analysis of bag seine and trawl data shows El Niño-Southern Oscillation (ENSO) cycles affect some Galveston Bay fisheries species. Yearly bag seine catches show a significant linear correlation with the Southern Oscillation Index; the relationship is clearer than for local hydrological factors. ENSO's effect in Galveston Bay is probably related to a combination of factors, including higher inflows and mild winters during El Niño events, and droughts during the opposite phase. These environmental variables and their influence on interannual variability should be considered when evaluating trends in individual species or the possible effects of human activity.

Introduction

Figure 1 summarizes the results of trend analyses for the twenty-two species caught in over 10% of all bag seine samples in the Galveston Estuary. Figure 2 shows similar trend analyses for the fourteen species commonly sampled by trawl. These data were examined in an effort to recognize widespread trends (if any) and to determine what factors, environmental or anthropogenic, affect the biota as a whole and should be taken into account in the analysis of individual species.

As stated by Osborn et al. (1992), the species sampled in Galveston Bay display a mixture of trends: increases, decreases, no trend at all, or different trends for different life stages. The available data do not show widespread declines or concurrent changes that might indicate, for example, a serious pollution problem. Interannual variation in catch rate is nevertheless intriguing.

The bag seine data for some species show a four- or five-year periodicity (e.g. Figures 1 O, 1R, 1T). Years of peak abundance tend to coincide in several species, specifically in 1981-83, 1987-88, and 1990-91. These are years when El Niño conditions prevailed in the Eastern Pacific Ocean. It is visually apparent that El Niño-Southern Oscillation cycles (ENSO) or related large-scale climatic phenomena may influence catch rates, at least for some species.

It has not been demonstrated before that ENSO may affect Texas fisheries. It is not a surprise, however. The link between El Niño cycles and primary and secondary productivity on the Pacific coast of North America is well-documented (Baumgartner et al. 1985, Mysak 1986, Lange et al. 1990). Cyclicity in CPUE in the Gulf of Mexico was observed by Wilson et al. (1992), who described a four- or five-year cycle in the year-class strength of red drum and black drum in the northern Gulf. El Niño years are associated with unusually high rainfall and warm winters in the central U.S. (Ropelewski and Halpert 1986), especially along the Gulf of Mexico. The reverse phase, known as La Niña, is associated with drought (Trenberth et al. 1988). Tree rings from Mexico, the southwestern U.S., and Southern Great Plains provide a record of over 270 years of ENSO-related wet-dry cycles with a periodicity of 3-7 years (Blasing et al. 1988, Swetnam and Betancourt 1990, Stahle and Cleaveland 1993).

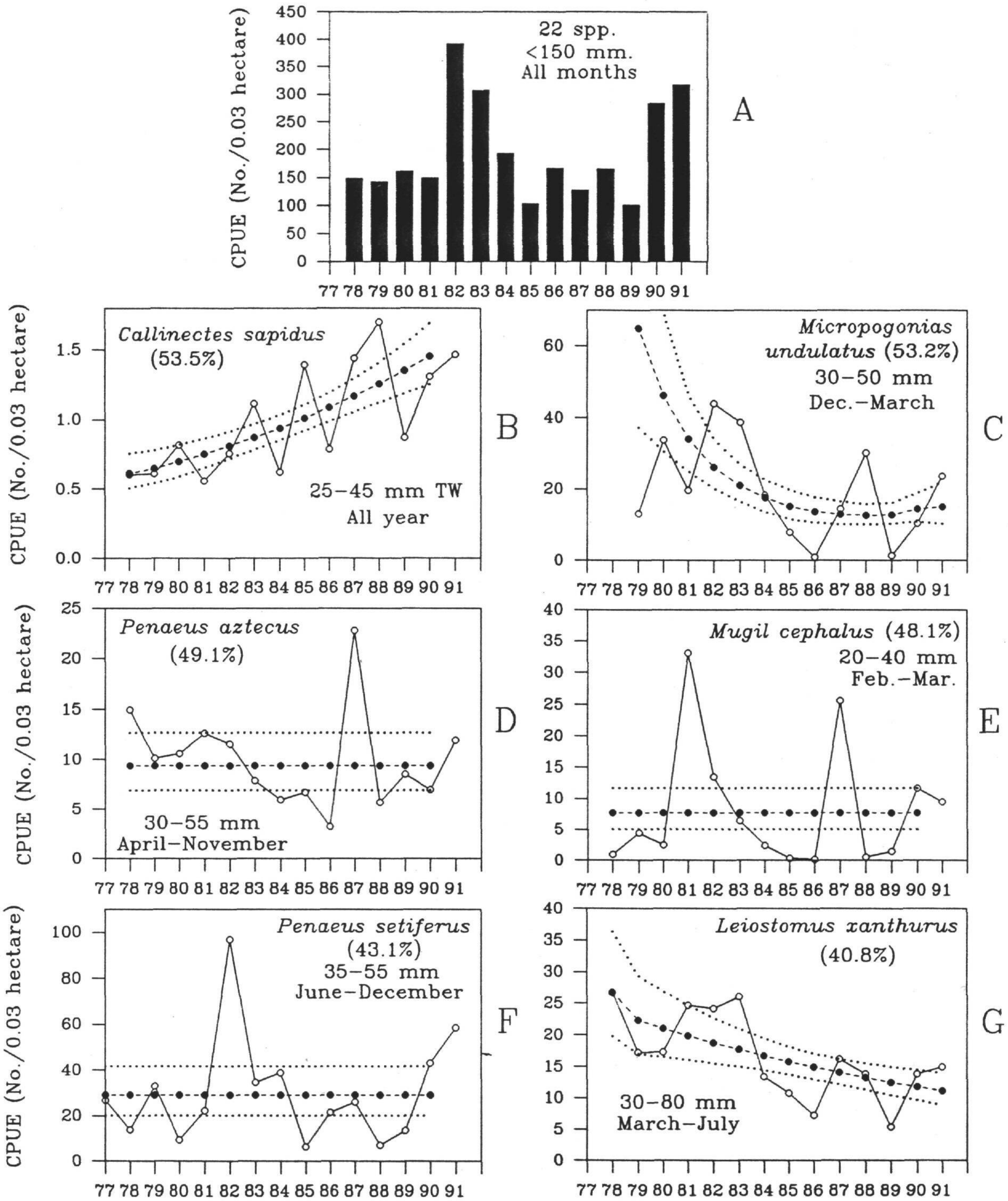

Figure 1. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for 22 most common species caught by bag seine. Percentage of samples containing that species in parentheses. A. Bar graph for all species present in over 10% of samples, <=150 mm TL. B. Blue crab. C. Atlantic croaker. D. Brown shrimp. E. Striped mullet. F. White shrimp. G. Spot.

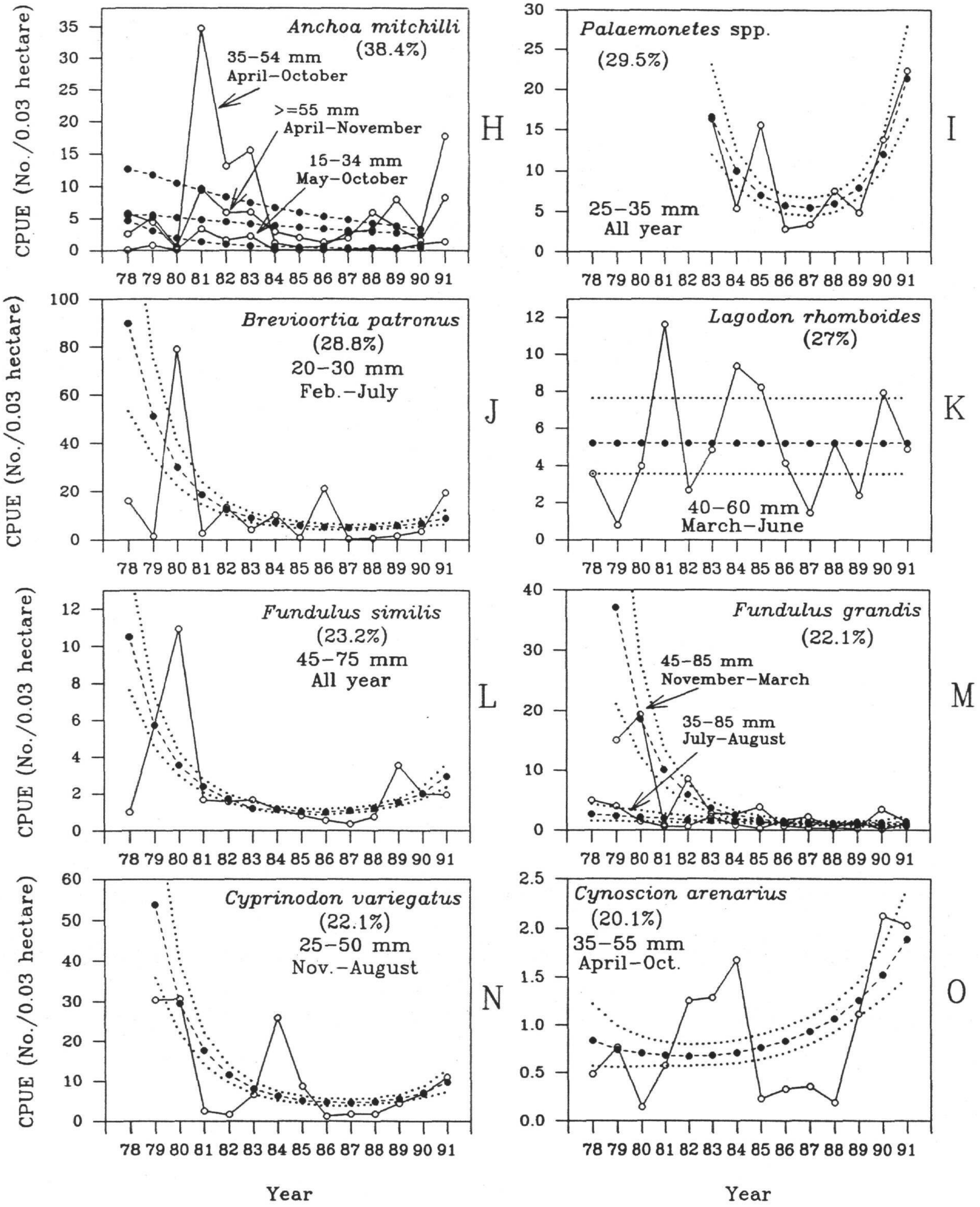

Figure 1 (continued). Mean annual CPUE with fitted values and confidence intervals (±S.E.) for most common species caught by bag seine. H. Bay anchovy. I. Grass shrimp. J. Gulf menhaden. K. Pinfish. L. Longnose killifish. M. Gulf killifish. N. Sheepshead minnow. O. Sand seatrout.

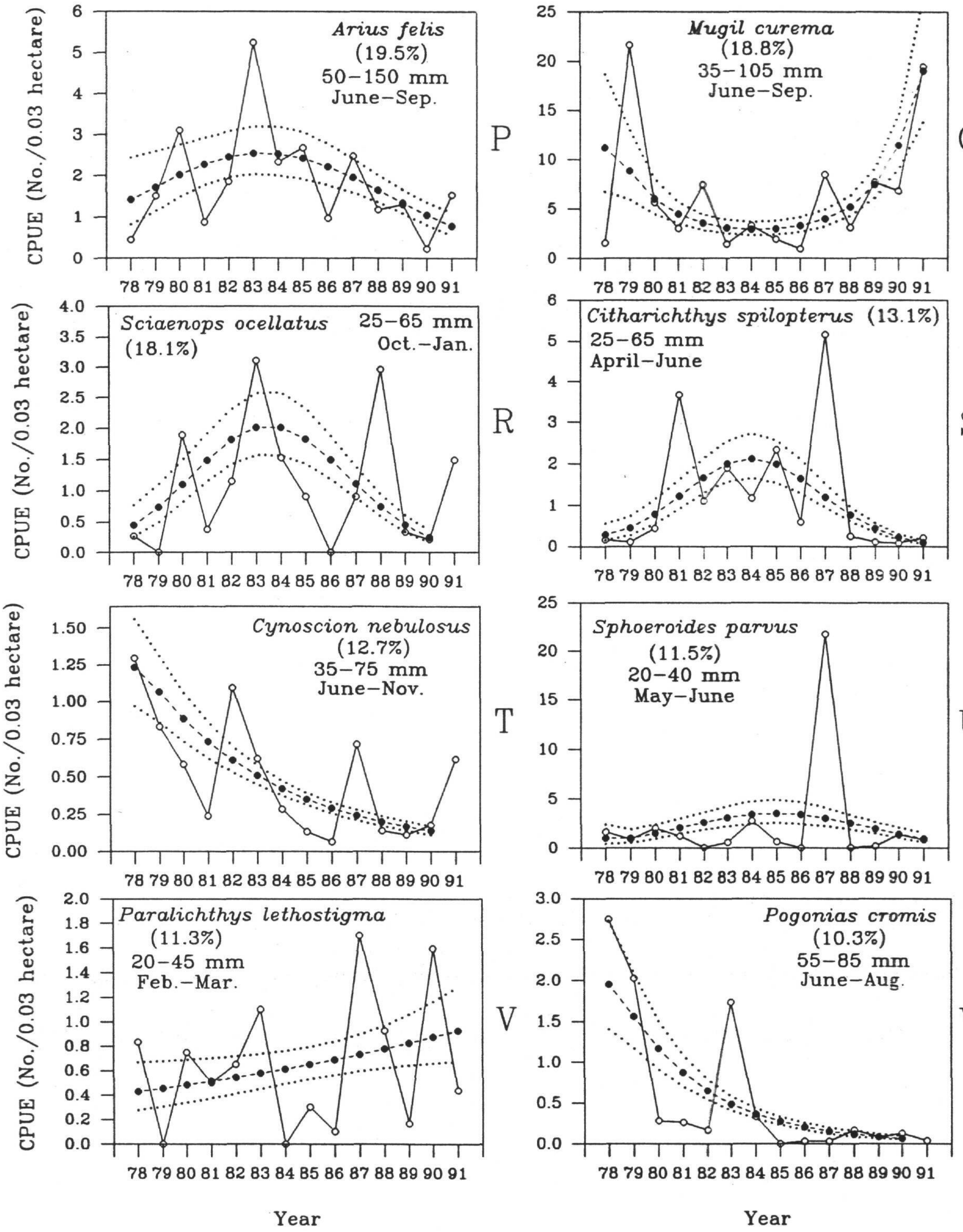

Figure 1 (continued). Mean annual CPUE with fitted values and confidence intervals (±S.E.) for most common species caught by bag seine. P. Hardhead catfish. Q. White mullet. R. Red drum. S. Bay whiff. T. Spotted seatrout. U. Least puffer. V. Southern flounder. W. Black drum.

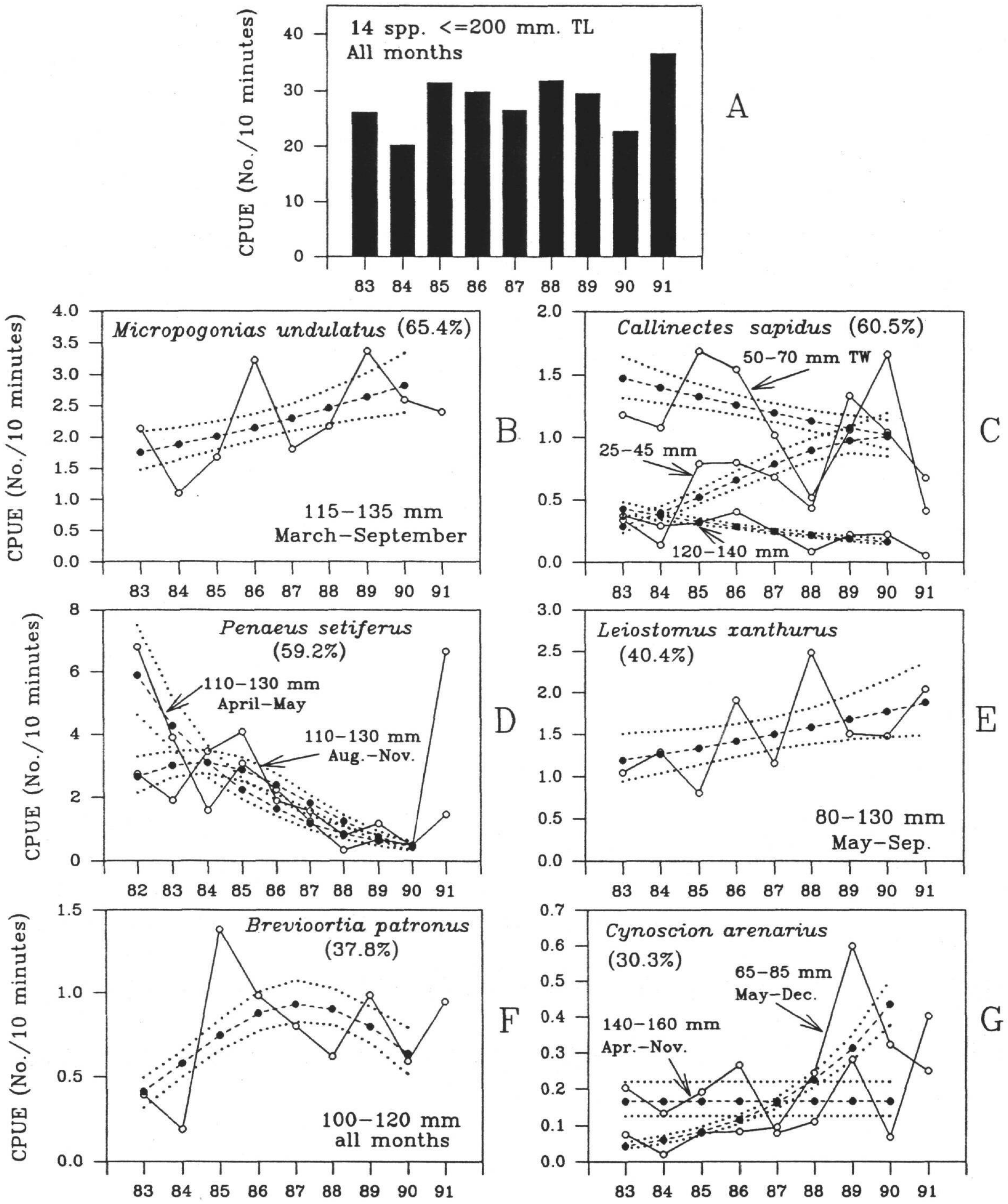

Figure 2. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for 14 most common species caught by trawl. Percentage of samples containing that species in parentheses. A. Bar graph for all spcies present in over 10% of samples, <=200 mm TL. B. Atlantic croaker. C. Blue crab. D. White shrimp. E. Spot. F. Gulf menhaden. G. Sand seatrout.

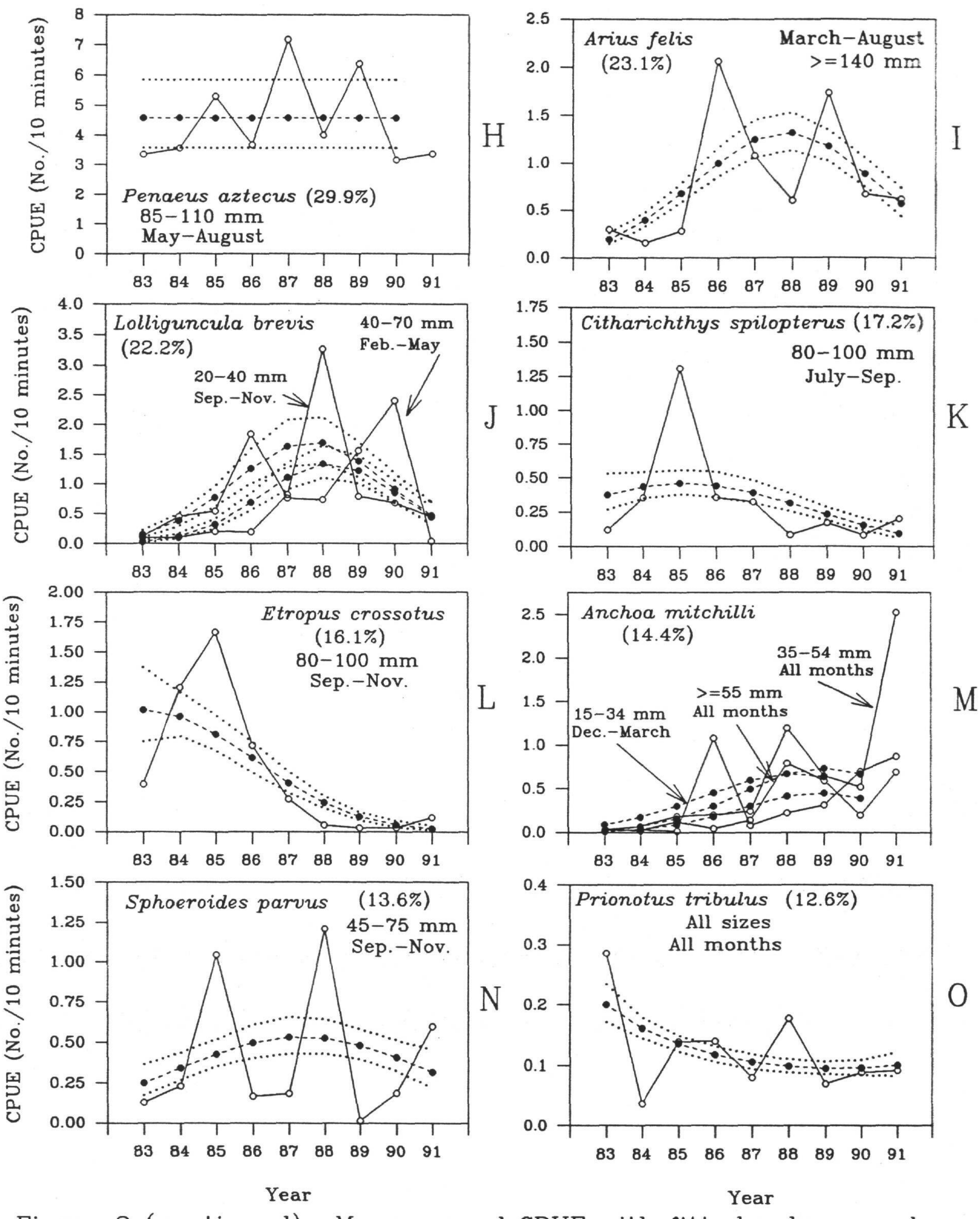

Figure 2 (continued). Mean annual CPUE with fitted values and confidence intervals (±S.E.) for most common species caught by trawl. H. Brown shrimp. I. Hardhead catfish. J. Brief squid. K. Bay whiff. L. Fringed flounder. M. Bay anchovy. N. Least puffer. O. Bighead searobin.

It has long been recognized that shrimp (especially white shrimp) thrive in and just after wet years (Gunter and Hildebrand 1954, Longley in review). Williams (1969) found an apparent association between white shrimp catch and mild winters. In contrast, low water levels in drought years may affect estuarine species by limiting the access of organisms to nursery marsh (Childers et al. 1990). Johnson et al. (1981) found that wet years favored young migratory fishes and crustaceans in Galveston Bay. Biomass in general is higher in wet years than in drought years (Montagna 1991). Powell et al. (1993) and Wilson et al. (1993) speculate that large-scale climate cycles, such as ENSO, affect the distribution of contaminants and parasites in oysters along the Gulf coast. Stanley (1989, Table 7.2) summarized U. S. Department of Commerce Annual Summary reports on Texas commercial landings to show that climatic events (and market economics) are the greatest influence on interannual variations in seafood catch.

The mechanism for El Niño's effect on the Texas Gulf coast is unclear. Climate cycles on such a large scale are expected to affect precipitation over a wide area, therefore to affect river inflow into an estuary and local precipitation (the major components of total inflow). ENSO may also affect the probability of extreme temperatures (freezes and heatwaves) or other weather events (tropical storm or unfavorable wind directions during larval migration). Inflows (Chapter IV) affect estuarine salinity and water level within the estuary, therefore the physiological state of organisms, primary productivity, the accessibility of the estuary to larvae immigrating from the Gulf, and their access to marsh habitat within the estuary. Heavy inflows during wet years may be important to flushing toxic materials from the estuary, though heavy runoff may bring in more non-point-source pollution. The detailed analysis necessary to identify the mechanism is beyond the capability of this preliminary study.

This chapter specifically addresses the following questions: can any trends in Galveston Bay organisms be related to environmental variables? Which of these environmental factors can be shown to be linked to ENSO in Galveston Bay? Which species are most strongly affected by ENSO? If possible, what is the mechanism of ENSO's influence? If ENSO is causally linked to the amount and timing of freshwater inflow into estuaries, the variation associated with it and its effects on fisheries should be taken into account by resource managers when proposing regulation.

Environmental data sets

Figure 3 shows recent data (monthly mean values) for some of the hydrological variables commonly linked to shellfish or finfish productivity and for which data were available. Figure 4 shows their seasonality as mean values by month. For those variables whose annual cycle differs from a calendar year (January-December), annual means were calculated using the twelve-month span beginning and ending at the months of that variable's lowest values. For comparison, Figure 5 shows the seasonality of the most common species caught by bag seine and trawl. Figure 6 shows the time series of CPUE for bag seine and trawl, and mean annual CPUE regressed against SOI.

(1) The Southern Oscillation Index (SOI) data set was provided by the National Weather Service (courtesy Vernon Kousky, Climate Analysis Center). The index is calculated using the values of barometric pressure and sea surface temperature at Tahiti and Darwin, Australia (Chelliah 1990, equation A2). For this study data were available from as early as 1882 through September 1992; only 1975-1992 are shown in Figure 3A.

The negative phase of the oscillation corresponds to El Niño events along the western coast of South America; the positive phase indicates La Niña. Figure 3A shows the severe El Niño of 1982-83, mild El Niño of 1986-87, La Niña of 1988-89, and moderate El Niño of 1990-92 (an event that continued through 1993).

Month-to-month variation in SOI is small relative to annual variation and there is no regular unimodal seasonality (Figure 4A). A calendar-year average of mean monthly SOI (January-December) was used in all correlations on an interannual scale.

(2) River inflow data were obtained from stream gauges maintained by the U. S. Geological Survey. Figure 3B shows inflows for the Trinity River (the largest single source of fresh water to Galveston Bay) at the Romayor gauge station. Figure 3C shows inflows of the Trinity River in combination with twelve other streams (total river inflow).

The monthly mean of total river inflow was used for correlation on a monthly scale (Table 1). For correlations on an interannual scale, mean total river inflow was calculated for January-December and for October-September (Figure 4B).

(3) Daily rainfall data were collected by the National Weather Service. Rainfall records from 1900 through 1988 at Alvin, Texas, were provided by Ruben Solis of the Texas Water Development Board. Records from 1950 through 1991 at the Galveston Airport were provided by the Texas Natural Resource Information Service. Both data sets have some gaps. Recent years of both data sets are shown in Figure 3D to show how monthly rainfall can vary from station to station, over a distance of 42 km (26 mi).

The Galveston Airport data set was used for correlation because it has the fewest missing data. Local rainfall is bimodally seasonal (Figure 4C); the heaviest rainfall is in summer (May-September), with a minor peak in winter (December-January). Annual mean rainfall was calculated for January-December and April-March.

(4) Tide gauge records were assembled by NOAA in cooperation with Corpus Christi State University and the Texas General Land Office. Mean monthly sea level data collected since 1908 at Pier 21 (on the Galveston Channel) and since 1958 at the Galveston Pleasure Pier (on the Gulf of Mexico) were provided by James Hubbard of the National Ocean Service. Both data sets have some gaps. Both data sets are shown in Figure 3E for comparison; though water level in the bay (Pier 21) is higher, the two data sets track each other closely.

The effects of land subsidence are visually evident when the entire time series is considered. Relative sea level has increased ~20% since 1950. Turner (1991) used the

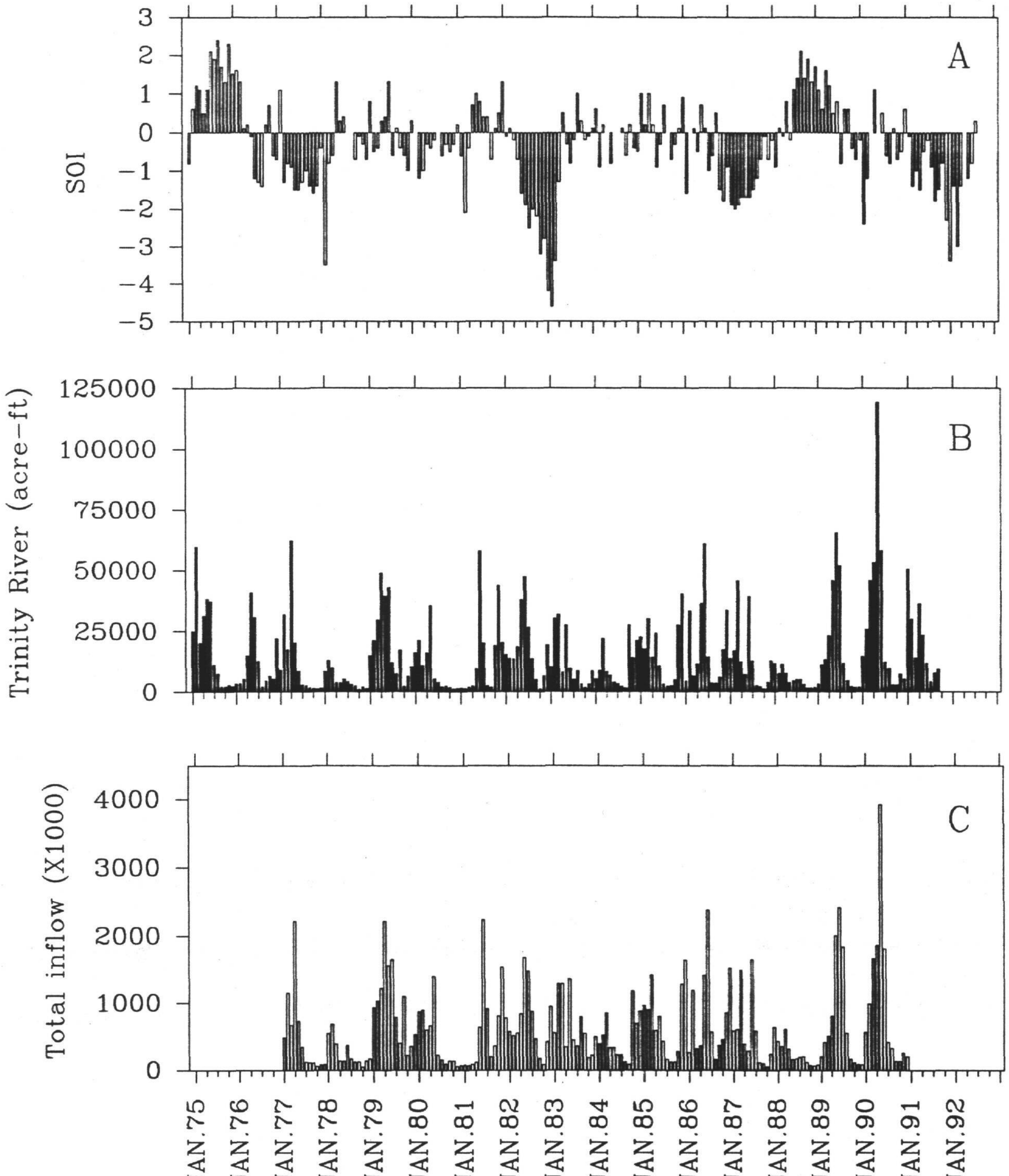

Figure 3. Time series for environmental variables used for correlation. A. Southern Oscillation Index. B. Trinity River inflows at Romayor gauge station. C. Total river inflows to Galveston Bay, including the Trinity River and twelve other streams.

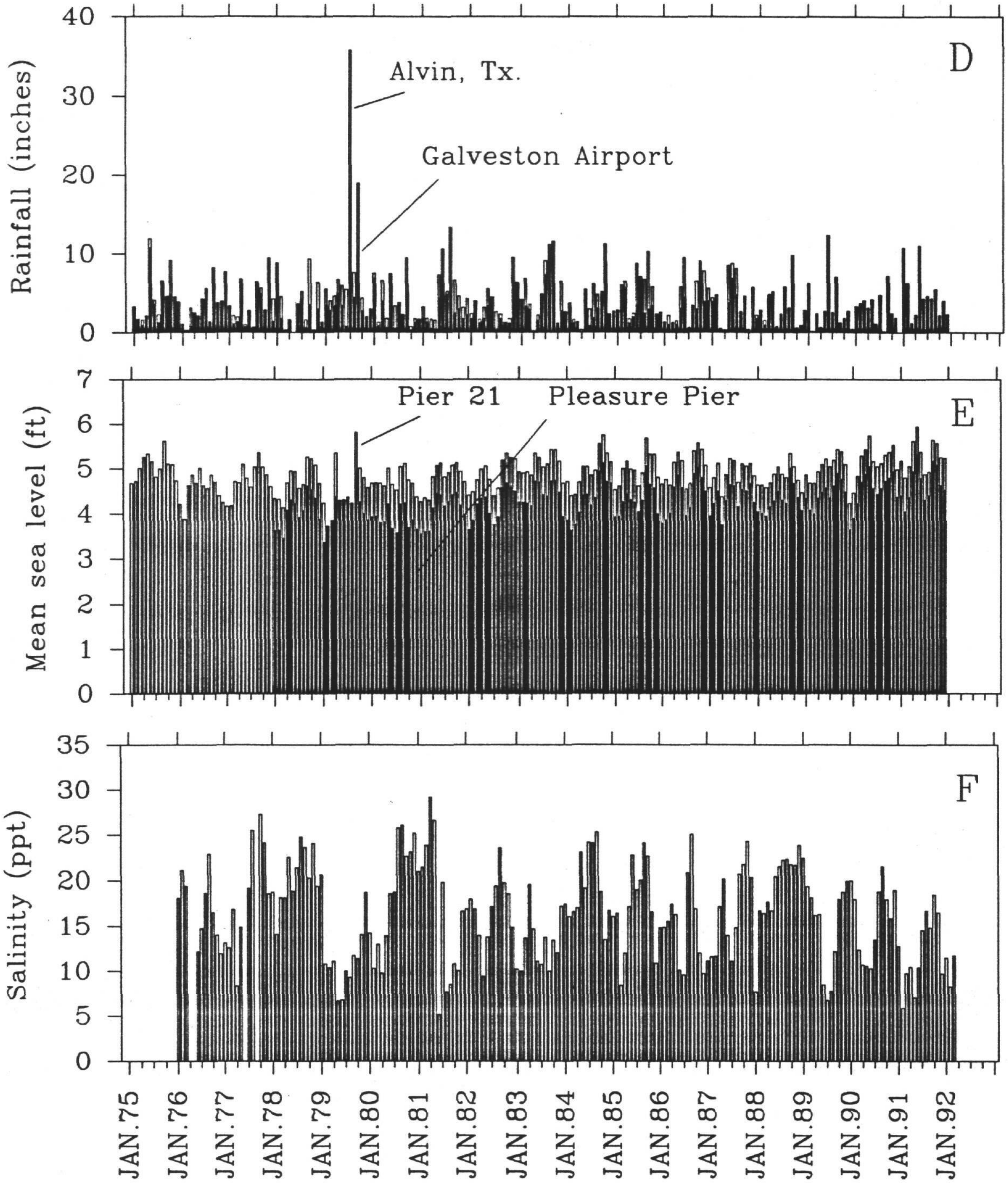

Figure 3 (continued). Time series for environmental variables used for correlation. D. Rainfall at Alvin, Texas and Galveston Airport. E. Mean sea level at Pier 21 (Galveston Channel) and Pleasure Pier, Galveston (Gulf of Mexico). F. Salinity, compiled from bag seine, gill net, and trawl samples.

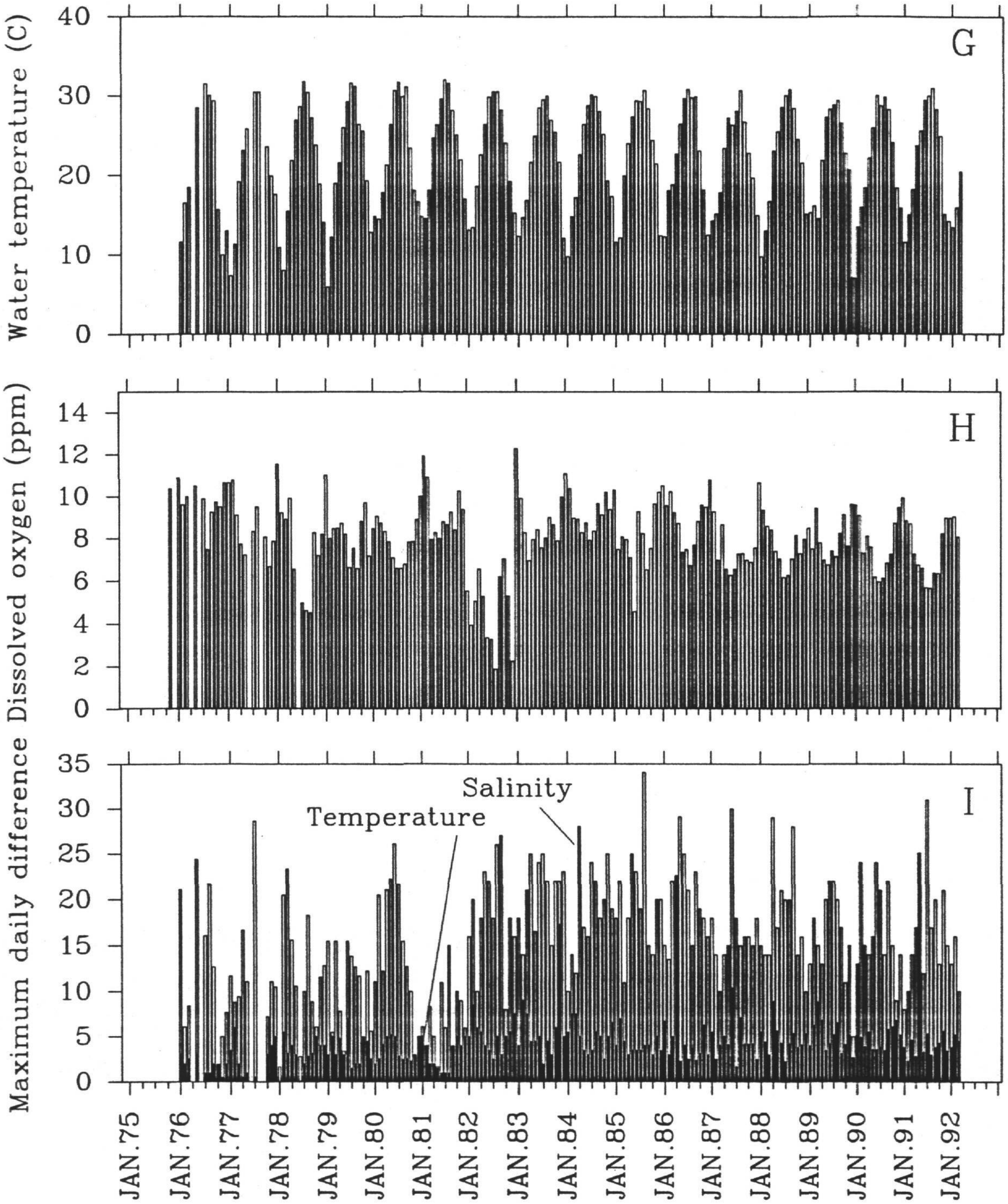

Figure 3 (continued). Time series for environmental variables used for correlation. G. Water temperature, compiled from bag seine, gill net, and trawl samples. H. Dissolved oxygen, compiled from bag seine, gill net, and trawl samples. I. Maximum daily difference per month in water temperature and salinity.

Pier 21 time series to document subsidence and sea level rise in the northern Gulf of Mexico. In the time series segment used for correlation (1975-1991; Figure 3E) the increase in water level is small, so the data were not corrected for subsidence. However, the increase may bias the results in some cases.

Only the records for the bay (Pier 21) were used for correlation. Figure 4D shows the highest water levels occur in September (the month of peak rainfall), with a minor peak in May (the month of peak river inflows). Annual mean sea level was calculated for January-December only.

(5) Salinity, water temperature, and dissolved oxygen (DO) records were compiled from the CF data set (Figures 3F, 3G, 3H). The data used for correlation were collected during bag seine, trawl, and gill net sampling. Consequently the data are more geographically complete than other available data sets, in that all minor bays and both mid-bay and bay margin environments are represented. However, sampling is not highly regular. There is a stronger representation of data from the bay margin during spring and fall gill netting seasons. The number of samples per month varies from 8 (all bag seine samples from the first years of the monitoring program) to 144 (during gill netting season in recent years). Because samples are taken at random sites, not fixed stations, any month's samples can be biased geographically, especially if the sample size is low. Monthly means of all records were calculated in order to minimize this geographic bias and the varying monthly sample size, and only these means were used for correlation. However, the data could be skewed in unrecognized ways.

Dissolved oxygen records are frequently unreliable. Values over 12 mg/l, indicating supersaturated conditions at the temperatures and salinities probable in Galveston Bay, are common. Oxygen supersaturation is possible in Galveston Bay, especially in the surf zone, but many values are sufficiently high to indicate probable instrumentation errors (Whitledge, McEachron, pers. comm.). All values over 13 were deleted from the data set. During 1987 many samples were measured with a probe without correction for salinity and temperature; they too have been deleted. Consequently the sample size per month for DO is not large, and some of the readings may still be incorrect. The correlations shown for DO should be viewed with caution.

Annual mean temperature was calculated for January-December only (Figure 4E). Salinity was calculated for January-December and June-May (Figure 4F), and DO for January-December and August-July (Figure 4G).

(6) Temperature and salinity alone may have less effect on living organisms than sudden changes in temperature and salinity. Special data sets were constructed in an effort to identify freezes, heat waves, and freshets, or at least those times when the temperature or salinity gradient in the bay was most extreme. All records of bag seine, trawl, and gill net samples taken during the same day were compared. When temperature or salinity records taken during the same day, usually from a considerable distance apart, are widely different, it probably indicates a fast-moving environmental event. The greatest such daily difference in any month was retained in the data sets.

The resulting data sets (Figure 3 I) have the same problems as the original temperature and salinity data sets, with even smaller sample sizes because multiple samples were not taken every day. The data do not show any false freezes or freshets (extreme events not documented independently), but do not have sufficient resolution to clearly show all known events. For example, the freezes of December 1983, February 1989, and December 1989 (McEachron et al. in prep.) are not obvious in Figure 3 I (though unusually low temperatures for December 1989 appear in Figure 3G). Neither are the freshets of the summers of 1979 or 1989 (Hofstetter 1981, Bowling 1992), though average salinities in those seasons appear low in Figure 3F. Correlations based on these data are shown in Table 1 but should be viewed with caution.

Correlation results

Tables 1, 2, and 3 show the results of simple bivariate linear correlations (Pearson's r) between the environmental variables described above and bag seine and trawl CPUE. Correlations significant at the 95 percent probability level are shown in **bold**. Scatter plots (such as Figure 6C) were also examined visually.

Table 1 shows that mean monthly CPUE correlates with that month's river inflows, sea level, temperature, and dissolved oxygen, but not with SOI or rainfall. For the most part this reflects simple seasonality. Figures 5 and 4 show that both bag seine and trawl catches are highest in late spring and summer, when temperatures are high, river inflows (and therefore water levels) are highest, and dissolved oxygen is lowest (therefore a negative correlation). The correlations imply that the bulk of the Galveston Bay biota is adapted to use the estuarine environment during months of highest inflow and when the greatest area is inundated.

Monthly bag seine CPUE correlates negatively with salinity, indicating the highest catches at the bay margin occur in months of low salinity. No similar effect appears for trawl data, either because mid-bay environments are more moderated, or because the bimodal seasonality of trawl catches (peaks in both May and November) is not matched by bimodality in salinity (lowest in May-August).

Bag seine CPUE correlates positively with the months of greatest temperature differences, because high bag seine catches occur during April and May when the weather is unsettled and the daily temperature range is large. Similarly, trawl data correlate with months of greatest salinity differences (April-August), months of high inflow and/or rainfall. These data, limited as they are, do not show that heat waves, freezes, or freshets have a devastating effect on the entire community.

On an interannual scale different factors prevail. Of all the environmental factors tested, the single best predictor of a year's bag seine catch is mean annual SOI (Table 2, first line; Figure 6C). Dissolved oxygen also correlates significantly with CPUE, probably because years of high biomass are years of high oxygen demand, therefore low DO levels.

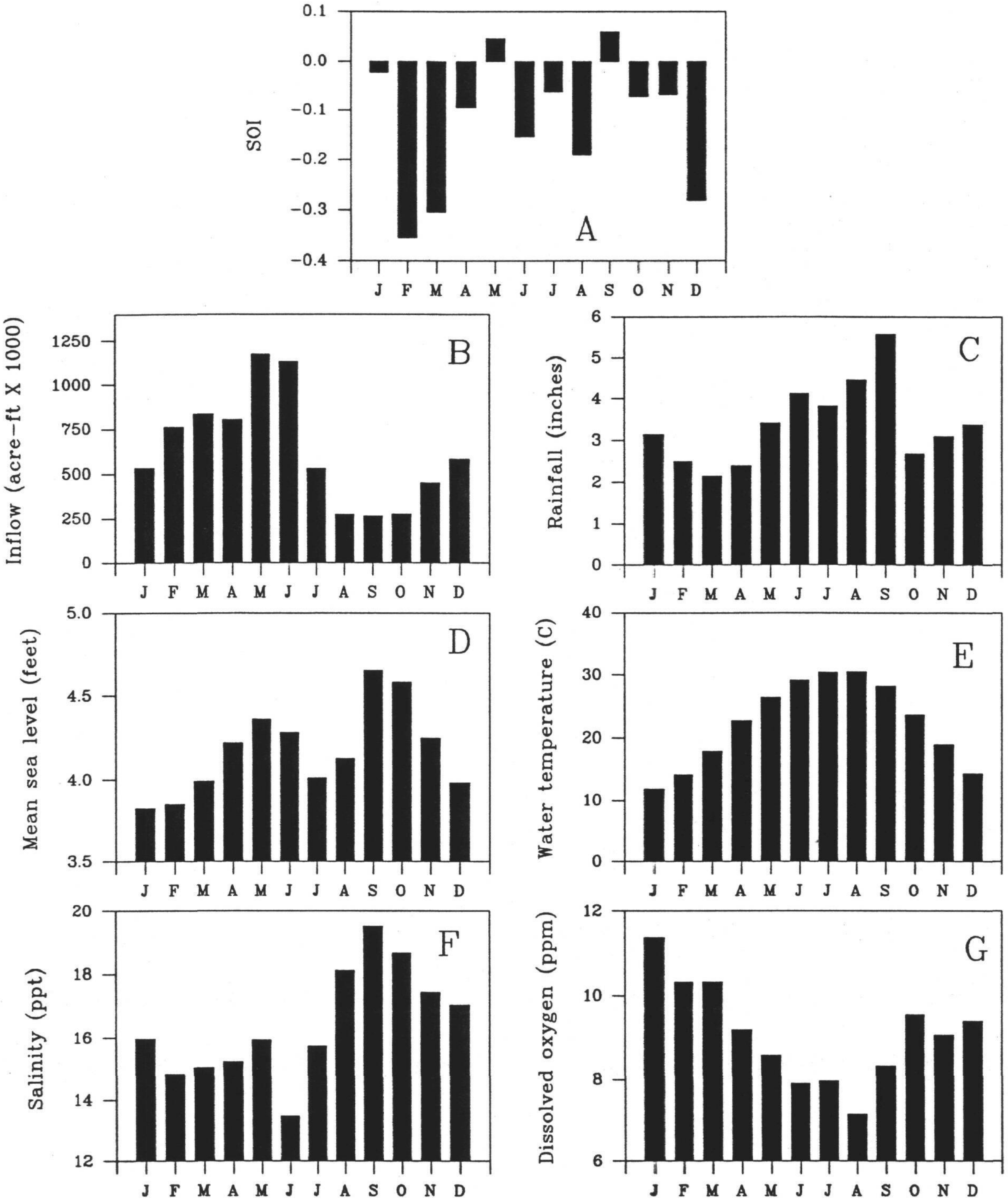

Figure 4. Monthly means for selected environmental variables. A. Southern Oscillation Index, 1970–1991. B. Total river inflow, 1977–1990. C. Rainfall at Galveston Airport, 1950–1991. D. Mean sea level at Pier 21, Galveston, 1980–1991. E. Water temperature, 1976–1991. F. Salinity, 1976–1991. G. Dissolved oxygen, 1976–1991.

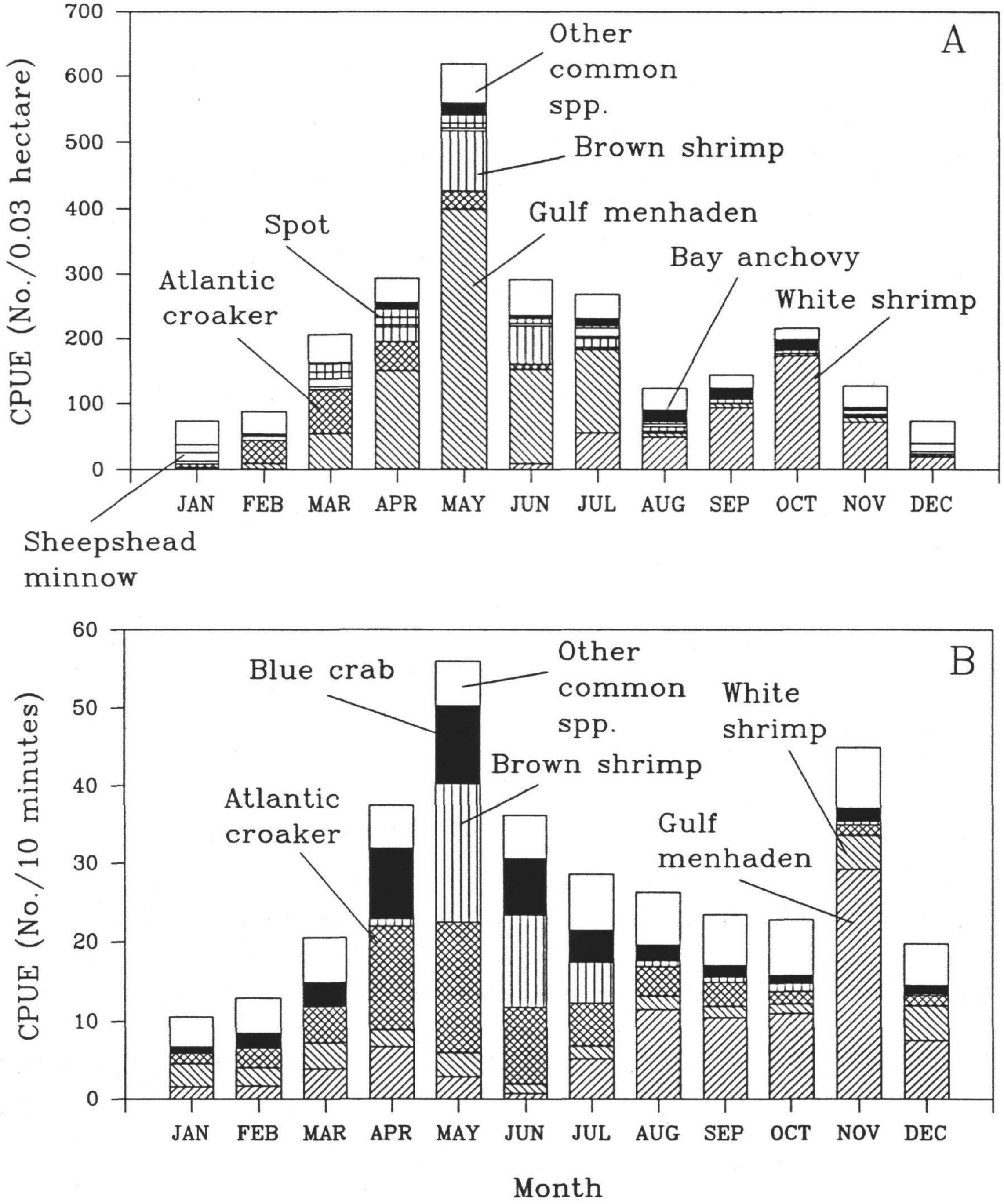

Figure 5. A. Monthly mean CPUE for 22 most common species caught by bag seine, <=150 mm TL, 1978–1991. B. Monthly mean CPUE for 14 most common species caught by trawl, <=200 mm TL, 1983–1991.

TABLE 1. CORRELATIONS OF CPUE WITH ENVIRONMENTAL VARIABLES BY MONTH. PEARSON'S R/PROBABILITY. CORRELATIONS SIGNIFICANT AT 95% PROBABILITY LEVEL IN **BOLD**.

	SOI	MEAN GAGED INFLOW	TOTAL RAINFALL	MEAN SEA LEVEL	MEAN SALINITY	MEAN TEMP	MEAN DISSOLVED OXYGEN	MAXIMUM DAILY TEMP. DIFF.	MAXIMUM DAILY SALINITY DIFF.
BAG SEINE (1978-91) 22 SPP.	-0.03/0.70	**0.26/0.001**	0.08/0.31	**0.26/0.001**	**-0.16/0.03**	**0.23/0.003**	**-0.18/0.02**	**0.19/0.01**	0.10/0.19
TRAWL (1983-1991) 14 SSP.	0.13/0.18	**0.27/0.008**	0.02/0.86	**0.22/0.02**	-0.04/0.69	**0.29/0.003**	**-0.27/0.005**	0.08/0.41	**0.30/0.002**
SOI	1.0/0.0	0.025/0.75	0.05/0.45	-0.04/0.59	0.09/0.22	0.11/0.13	-0.06/0.42	-0.07/0.32	-0.06/0.43

No environmental variables correlated significantly with the annual trawl catch (Table 3). Lag times of 1 month to 2 years were systematically tested without revealing any significant results. The shorter time series for trawl sampling may obscure real interannual differences; the suite of organisms caught by trawl may not respond with the same consistency as those in bag seine; or the effects of environmental events may be less severe in the moderated mid-bay habitats than at the bay margin.

In contrast, the results of the preliminary analysis of bag seine data warrant a closer examination of individual species. Mean annual CPUE was calculated for the 22 most common bag seine species using the same size range-season combinations used for trend analysis (Figure 1). CPUE was regressed against annual means of environmental variables, calculated both over a calendar year (January-December) and as annual cycles. Consequently some of the correlations shown on Table 2 are lagged (indicated with an asterisk *): that is, one or more of the months used to calculate CPUE postdate the period of the environmental variable. No effort was made to systematically test all possible lag times, which lies beyond the scope of this exploratory study.

The three species that correlate significantly with SOI are all important to the commercial and recreational fishery: white shrimp, red drum, and spotted seatrout. White shrimp also correlate negatively with DO, but the two fish species do not correlate with any other environmental variable.

River inflows, rainfall, water level, and salinity are expected to covary. No species correlates significantly with river inflow at the 95% probability level, though white mullet correlate at the 92% level. White mullet also correlate with rainfall and salinity. Grass shrimp correlate with both rainfall and water level, giving credence to the hypothesis that marsh-dependent species are limited by access to wetlands. Sand seatrout also correlate with water level. Juvenile Gulf menhaden and adult bay anchovy correlate significantly with rainfall; the other size classes of bay anchovy correlate marginally with rainfall or salinity. It is interesting that all these species feed on diatoms and/or zooplankton.

There is a positive correlation between mean annual temperature and the CPUE of juvenile pinfish, but a negative correlation for small Gulf killifish, sheepshead minnow, and black drum. The analyzed season for pinfish is in the spring (when mild temperatures would be expected to favor growth), but for the three latter species includes the summer months (when high temperatures can be fatal). Pinfish also correlate positively with DO. Atlantic croaker, white shrimp, and the bag seine assemblage as a whole correlate negatively with DO, probably because years of high productivity (Atlantic croaker and white shrimp being major components of the biomass) are years of high oxygen demand.

The absence of a significant correlation in this analysis does not mean a variable does not have an effect. (1) The relationship may not be linear (as demonstrated for inflows and commercial catches of several fisheries species; Longley in review); (2) the effect may be stronger on another life stage than the one analyzed; (3) the effect may be lagged

TABLE 2. CORRELATIONS OF BAG SEINE CPUE WITH ENVIRONMENTAL VARIABLES, BY YEAR. PEARSON'S R/PROBABILITY. PERIOD OF RECORD, SEASONS, AND SIZE RANGES AS IN FIGURE 1. CORRELATIONS SIGNIFICANT AT 95% PROBABILITY LEVEL IN **BOLD**.

	SOI (JAN-DEC)	MEAN GAGED INFLOW (JAN-DEC)	MEAN GAGED INFLOW (OCT-SEP)	TOTAL RAINFALL, GALVESTON (JAN-DEC)	TOTAL RAINFALL, GALVESTON (APR-MAR)	MEAN SEA LEVEL GALVESTON (JAN-DEC)	MEAN SALINITY (JAN-DEC)	MEAN SALINITY (JUN-MAY)	MEAN TEMP (JAN-DEC)	MEAN DISSOLVED OXYGEN (JAN-DEC)	MEAN DISSOLVED OXYGEN (AUG-JULY)
22 SPP. (JAN-DEC)	**-0.63/0.02**	0.35/0.22	0.31/0.30*	0.17/0.55	0.22/0.45*	0.43/0.13	-0.30/0.29	-0.40/0.15	0.11/0.7	**-0.54/0.05**	**-0.63/0.01***
BLUE CRAB (JAN-DEC)	0.06/0.84	-0.12/0.68	0.08/0.80*	-0.05/0.87	0.01/0.97*	0.24/0.42	0.06/0.85	-0.30/0.32*	0.06/0.85	-0.11/0.71	-0.15/0.62*
ATLANTIC CROAKER (DEC-MAR)	-0.49/0.09*	0.39/0.19*	-0.29/0.37	0.28/0.36*	0.40/0.18	-0.14/0.66*	-0.38/0.20*	-0.46/0.11	0.38/0.20*	-0.26/0.39*	**-.61/0.03***
BROWN SHRIMP (APR-NOV)	-0.50/0.08	-0.23/0.45	-0.10/0.75*	-0.13/0.67	-0.22/0.47	-0.44/0.14	0.11/0.71	0.01/0.96*	-0.09/0.78	-0.28/0.36	-0.10/0.73*
STRIPED MULLET (FEB-MAR)	-0.38/0.20	0.14/0.65	0.64/0.84	0.12/0.70	-0.28/0.36	-0.12/0.69	-0.10/0.73	0.16/0.61	0.52/0.07	-0.03/0.91	0.001/0.99
WHITE SHRIMP (JUNE-DEC)	**-0.61/0.03**	0.34/0.25	0.43/0.15*	-0.04/0.90	0.22/0.47	0.21/0.48	-0.20/0.51	-0.29/0.34	0.11/0.72	**-0.65/0.02**	**-0.55/0.05***
SPOT (MAR-JUL)	-0.46/0.09	-0.29/0.34	-0.29/0.34	0.07/0.81	0.07/0.83*	-0.37/0.19	0.10/0.74	0.06/0.83*	0.12/0.69	-0.21/0.47	-0.33/0.25
BAY ANCHOVY (SM) (MAY-OCT)	-0.21/0.48	0.23/0.44	0.07/0.82*	0.49/0.09	0.51/0.08	0.006/0.98	-0.36/0.23	0.31/0.30*	0.45/0.12	0.06/0.86	-0.30/0.32*
BAY ANCHOVY (MED) (APR-OCT)	-0.07/0.82	0.06/0.85	-0.13/0.67*	0.35/0.24	0.39/0.19	-0.20/0.51	-0.17/0.57	0.54/0.06*	0.41/0.16	0.10/0.74	-0.16/0.61*
BAY ANCHOVY (LG) (APR-NOV)	0.12/0.70	-0.02/0.94	-0.18/0.55*	0.53/0.06	**0.58/0.04**	-0.21/0.49	-0.21/0.48	0.48/0.10*	0.21/0.48	0.04/0.90	-0.30/0.32*
GRASS SHRIMP (JAN-DEC)	-0.30/0.43	0.27/0.51	0.20/0.63*	**0.80/0.009**	0.27/0.49*	**0.71/0.03**	-0.58/0.10	-0.42/0.26*	0.06/0.87	-0.34/0.38	-0.47/0.20*
GULF MENHADEN (FEB-JUL)	-0.13/0.65	-0.27/0.37	-0.17/0.58	-0.25/0.39	**0.65/0.01***	-0.29/0.31	0.22/0.45	-0.44/0.12*	0.30/0.29	-0.09/0.75	0.04/0.88
PINFISH (MAR-JUN)	0.29/0.30	-0.05/0.87	-0.36/0.23	-0.06/0.85	-0.09/0.75*	0.08/0.79	0.29/0.31	0.24/0.42*	**0.64/0.01**	0.47/0.09	**0.52/0.05**

	SOI (JAN-DEC)	INFLOW (JAN-DEC)	INFLOW (OCT-SEP)	RAINFALL (JAN-DEC)	RAINFALL (APR-MAR)	SEA LEVEL (JAN-DEC)	SALINITY (JAN-DEC)	SALINITY (JUN-MAY)	TEMP (JAN-DEC)	D.O. (JAN-DEC)	D.O. (AUG-JULY)
LONGNOSEKILLIFISH (JAN-DEC)	0.11/0.72	0.06/0.86	0.08/0.80*	0.09/0.75	0.39/0.17*	-0.27/0.35	-0.08/0.77	-0.29/0.32	0.10/0.74	-0.006/0.98	-0.15/0.61*
GULF KILLIFISH (SM) (JUL-AUG)	-0.13/0.65	-0.16/0.61	-0.11/0.72	0.08/0.79	0.06/0.84	-0.29/0.32	-0.07/0.80	-0.12/0.69	**-0.63/0.01**	0.08/0.80	-0.02/0.95*
GULF KILLIFISH (LG) (NOV-MAR)	0.12/0.71*	0.09/0.78*	0.16/0.61	0.39/0.18*	0.41/0.16	-0.27/0.38*	-0.20/0.51*	-0.41/0.17	-0.38/0.20*	0.04/0.72*	-0.23/0.44
SHEEPSHEADMINNOW (NOV-AUG)	-0.13/0.66*	0.05/0.86*	-0.11/0.73	0.40/0.18*	0.34/0.25*	0.07/0.82*	-0.32/0.29*	-0.31/0.30*	**-0.66/0.01***	0.04/0.89*	0.17/0.58*
SAND SEATROUT (APR-OCT)	-0.28/0.33	0.45/0.12	0.35/0.24*	0.28/0.33	0.38/0.21	**0.74/0.002**	-0.39/0.17	-0.35/0.22*	-0.15/0.62	-0.13/0.65	-0.27/0.35*
HARDHEAD CATFISH (JUN-SEP)	-0.39/0.17	-0.10/0.74	0.02/0.96	0.26/0.36	-0.02/0.95	0.06/0.84	-0.20/0.49	0.27/0.38	0.01/0.98	0.10/0.73	-0.32/0.26*
WHITE MULLET (JUN-SEP)	-0.17/0.56	0.50/0.08	0.50/0.08	**0.65/0.01**	0.53/0.06	0.39/0.17	**-0.66/0.01**	-0.37/0.21	-0.29/0.31	-0.23/0.43	-0.12/0.69*
RED DRUM (OCT-JAN)	**-0.64/0.01**	0.39/0.17*	-0.37/0.21	0.17/0.57*	0.29/0.32	0.23/0.42	-0.43/0.13*	-0.40/0.15	0.25/0.39	-0.47/0.09	-0.39/0.16
BAY WHIFF (APR-JUL)	-0.43/0.13	-0.10/0.73	-0.08/0.79	-0.02/0.96	0.09/0.78	-0.20/0.50	0.03/0.92	0.12/0.69	0.35/0.22	0.14/0.64	0.12/0.69
SPOTTED SEATROUT (JUN-NOV)	**-0.58/0.04**	-0.23/0.44	-0.08/0.80*	-0.09/0.78	-0.17/0.57	-0.44/0.14	0.07/0.82	0.08/0.80	-0.34/0.25	-0.53/0.06	-0.42/0.15*
LEAST PUFFER (MAY-JUN)	-0.44/0.12	-0.13/0.67	0.03/0.92	-0.18/0.55	-0.18/0.56	-0.09/0.74	0.09/0.77	-0.19/0.52	-0.04/0.89	-0.04/0.91	0.14/0.64
BLACK DRUM (JUN-AUG)	-0.13/0.68	-0.15/0.62	-0.19/0.54	0.30/0.32	0.18/0.56	-0.18/0.56	-0.15/0.63	-0.17/0.59	**-0.57/0.04**	0.09/0.78	-0.16/0.61*
SOUTHERN FLOUNDER (FEB-MAR)	-0.42/0.13	-0.15/0.63	0.07/0.83	-0.24/0.40	0.19/0.51	-0.02/0.96	-0.13/0.65	-0.32/0.26	0.04/0.91	-0.25/0.38	-0.26/0.38
SOI (JAN-DEC)	1.0/0.000	-0.09/077	*0.68/0.01	0.12/0.61	*0.07/0.77	-0.23/0.40	0.35/0.16	*0.07/0.79	0.26/0.31	0.35/0.16	*-0.08/0.79

* DATA LAGGED: PERIOD OF HYDROLOGICAL VARIABLE PRECEDES SPECIES SEASON.

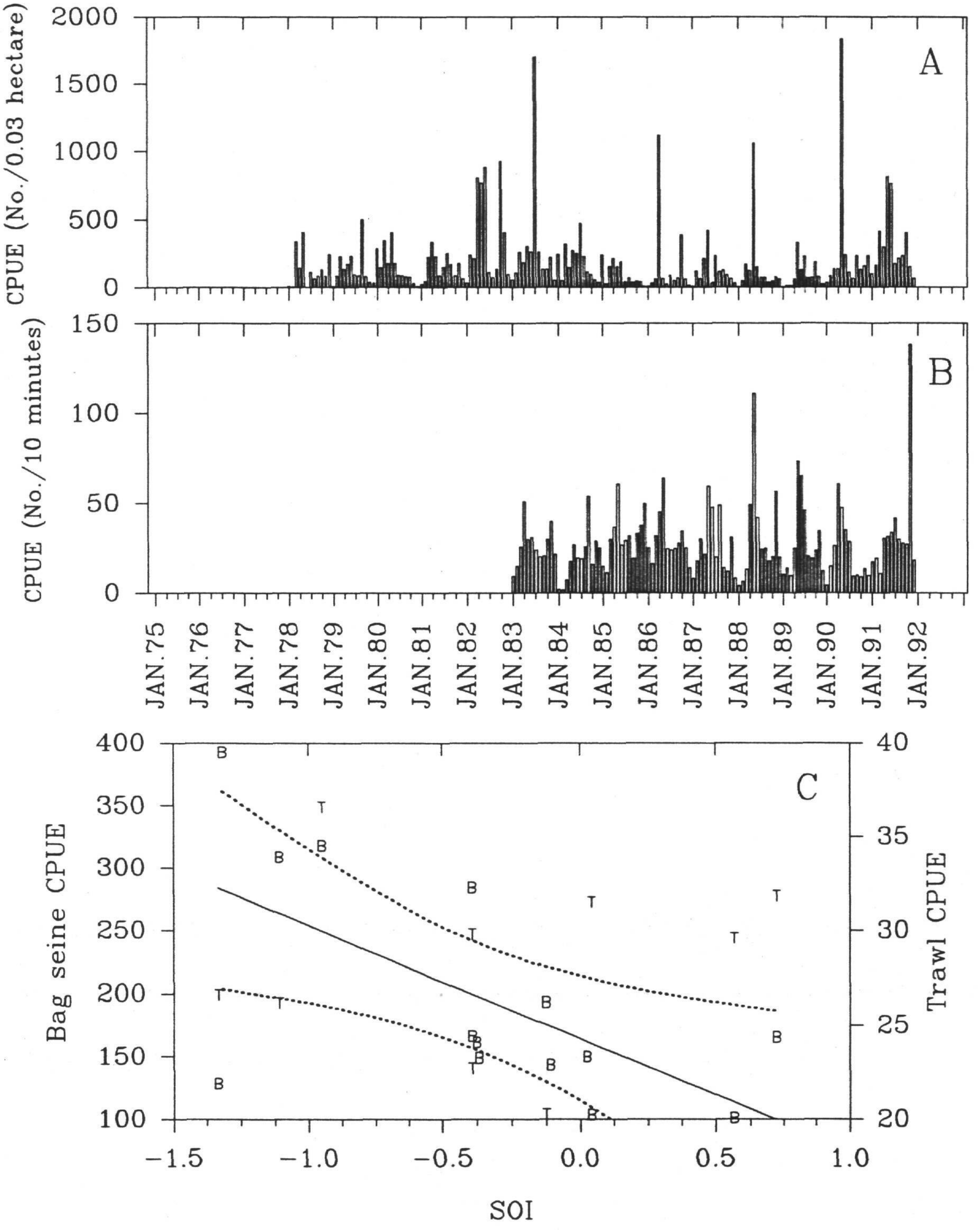

Figure 6. Mean monthly CPUE for (A) 22 most common species caught by bag seine, <=150 mm TL, and (B) 14 most common species caught by trawl, <=200 mm TL. C. Mean annual CPUE for bag seine (B) and trawl (T) data plotted against Southern Oscillation Index, with least-squares regression line for bag seine.

by a period of time not considered; or, (4) the effect may be strongest in combination with other variables.

Galveston Bay environmental variables were regressed against SOI in an effort to reveal the possible mechanism of ENSO in Texas (Table 2, bottom line). Only lagged inflows (October-September) correlate significantly with SOI. The correlation is positive, that is, El Niño years are followed by low inflows. Linear correlations of SOI with summer only (April-September) and winter only (October-March) inflow, rainfall, and water level were not significant. Neither do lagged inflows correlate with any of the species that correlate with SOI. This demonstrates the complexity of the covarying phenomena represented by ENSO. The role of freshwater inflows are discussed in greater detail in Chapter IV.

The effects of ENSO on living resources

Though the pool of bag seine species and certain abundant species (such as white shrimp) show their highest abundance during El Niño events, the effect is not the same for all species. Figures 1D, 1E, 1S, 1U, and 1V show peaks during the mild El Niño of 1987-88 but not during the severe event of 1982-83. This suggests that some aspect of El Niño's effect - such as higher water levels and access to marsh - may benefit the community as a whole, but that other aspects (such as reduced salinity) do not favor some species.

Trawl data for all species individually were not regressed against environmental variables because there were no significant correlations using all species pooled, and because results are suspect given the short time series. Visual inspection of Figure 2 shows that the highest abundance of white shrimp (Figure 2D) occurs during El Niño years (though the mild El Niño of 1987-88 had little effect); the low CPUE for blue crab in 1988 (Figure 2C) may be related to the 1988-89 La Niña event; and brief squid, a high-salinity Gulf species (Figure 2J), was most abundant during the La Niña event and least abundant in El Niño years.

Interannual climate cycles are probably integral to the estuary's productivity. However, it is not clear to what extent ENSO directly affects the Texas fishery. Trawl data do not show a mass response to El Niño events. Bag seine data do, but it is not always certain that high recruitment to bag seine samples corresponds to large catches of adult fish in later years. The fishery-independent data for white shrimp show a strong relationship with ENSO, but commercial catches do not (Chapter IV).

The effects of ENSO vary among estuaries. There may be stronger relationship between net inflows and ENSO in the estuaries of south Texas than for Galveston Bay. In Louisiana, where inflows are consistently higher and salinities lower, maximum biological productivity occurs under moderate conditions, not during El Niño events. Childers et al. (1990) found the highest commercial CPUE of shrimp in Louisiana estuaries occurred in years with intermediate water levels. Wilson et al. (1992) found that the dominant year classes of red drum and black drum in the northern Gulf were spawned in 1966, 1970, 1974, and 1979. All these years follow El Niño years.

TABLE 3. CORRELATIONS OF TRAWL CPUE WITH ENVIRONMENTAL VARIABLES, BY YEAR. PEARSON'S R/PROBABILITY. NO CORRELATIONS SIGNIFICANT AT 95% PROBABILITY LEVEL.

	SOI	MEAN GAGED INFLOW	TOTAL RAINFALL	MEAN SEA LEVEL	MEAN SALINITY	MEAN TEMP	DISSOLVED OXYGEN
14 SPP. NO LAG	0.14/0.72	-0.25/0.55	-0.36/0.35	0.05/0.90	-0.35/0.36	-0.15/0.71	-0.49/0.18
14 SPP. 1 MO. LAG	0.17/0.66	-0.23/0.57	0.42/0.27	0.19/0.63	-0.28/0.47	0.63/0.07	-0.50/0.17
14 SPP. 2 MO. LAG	0.17/0.65	-0.20/0.63	0.32/0.41	0.30/0.44	-0.28/0.47	0.54/0.13	-0.44/0.24
14 SPP. 3 MO. LAG	0.16/0.68	-0.07/0.86	0.39/0.31	0.32/0.40	-0.26/0.50	0.47/0.20	-0.48/0.20
14 SPP. 6 MO. LAG	0.10/0.80	-0.31/0.45	0.13/0.75	0.33/0.38	0.25/0.52	0.34/0.38	-0.25/0.52
14 SPP. 12 MO. LAG	0.02/0.95	0.03/0.94	0.51/0.16	0.08/0.84	0.58/0.10	0.54/0.14	-0.02/0.96
14 SPP. 18 MO. LAG	0.09/0.81	0.25/0.52	0.07/0.86	0.31/0.42	-0.46/0.21	-0.45/0.22	0.62/0.07
14 SPP. 24 MO. LAG	0.10/0.80	0.44/0.24	-0.46/0.21	0.71/0.03	-0.54/0.13	-0.46/0.21	0.59/0.09

Conclusion

The most striking result of these analyses is that bag seine CPUE in Galveston Bay is more clearly related to hydrological data measured in the South Pacific (SOI) than to those measured in Texas. The details of the mechanism remain unclear, however. ENSO affects a combination of factors, probably in a nonlinear fashion, and complicated by an array of lag times. It cannot be ruled out that the strongest effects may be on factors not tested, such as conditions in the Gulf. ENSO can be thought of as a summary of covarying local conditions (including freshwater inflow and temperature) that remain unspecified on a local level.