Probable Causes of Trends in Selected Living Resources in the Galveston Bay System

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Texans increasingly express their expectations for a clean environment in terms of entire ecosystems. Until recently, our tendency was to view environmental problems in isolated pieces we could understand—indeed this view was institutionalized (and seemingly immortalized) in an elaborate mosaic of fragmented jurisdictions. The Galveston Bay National Estuary Program (GBNEP) is a forerunner in elevating hands-on management of coastal environments to the level of the ecosystem; and in doing so, is encouraging an integration of traditionally disparate institutions.

The GBNEP was established under the authority of the Water Quality Act of 1987 to develop a *Comprehensive Conservation and Management Plan* (CCMP) for Galveston Bay. The purpose of the CCMP is to address threats to the Bay resulting from pollution, development, and overuse. To address these threats, five years of work commenced in 1990, consisting of three phases: (1) Identification of the specific problems facing the Bay; (2) A Bay-wide effort to compile data and information to describe status, trends, and probable causes related to the identified problems; and (3) Creation of the CCMP itself to enhance governance of the Bay at the ecosystem level. The GBNEP is accomplishing this work through a cooperative agreement between the U.S. EPA (Region 6) and the State of Texas (administered by the Texas Water Commission).

The structure of the GBNEP reflects a strong commitment to consensus-building among all Galveston Bay user groups, government agencies, and the public. The GBNEP "Management Conference" consists of six Governor-appointed committees with broad representation, totaling about one hundred individuals. Meetings of these committees are also open to the public, and public participation in policy-setting and in Bay management are considered strengths of the program. When submitted to the Governor of Texas in late 1994, the CCMP will reflect thousands of hours of involvement (much in the form of volunteer time) by individuals who in various ways use, enjoy, or help govern this vital coastal resource.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

This study had the purpose of determining the probable causes of trends in certain aquatic species and birds, reported in a previous work. The research was initiated as a series of meetings with the purpose of assembling a group of experts to review the data and literature. The participants in these meetings were generous with their time, their data, their bibliographies, and their suggestions as well as their professional opinions; in many ways they are the real authors of this manuscript. Our special thanks go to: **Carol Beardmore**, U.S. Fish and Wildlife Service (USFWS); **Lynn Benefield**, Texas Parks and Wildlife, Coastal Fisheries (TPWD/CF); **Brenda Bowling**, TPWD/CF; **David Brock**, Texas Water Development Board; **C. E. Bryan**, TPWD/CF; **Terry Cody**, TPWD/CF; **Ted Eubanks**, National Audubon Society; **Billy Fuls**, TPWD/CF; **Phil Glass**, USFWS; **Gary Graham**, TPWD Resource Protection (TPWD/RP); **Paul Hammerschmidt**, TPWD/CF; **Edward Klima**, National Marine Fisheries Service (NMFS); **Mike Lange**, USFWS; **Addison Lawrence**, Texas A&M University (TAMU); **Wen Lee**, TPWD/RP; **Lee Ann Linam**, TPWD/RP; **Larry McEachron**, TPWD/CF; **Robert McFarlane**, Galveston Bay National Estuary Program, Scientific and Technical Advisory Committee; **Teresa Ann McTigue**, NMFS; **Anita Morgan**, TPWD/RP; **Charles Moss**, TAMU Marine Advisory; **Dan Moulton**, TPWD Wildlife; **James Nance**, NMFS; **Jack Parker**, Consultant; **Harriet Perry**, Gulf Coast Research Laboratory, Ocean Springs, Mississippi; **Will Roach**, USFWS; **Peter Rubec**, TPWD/CF; **R. Douglas Slack**, TAMU; **Ray Telfair**, TPWD/RP; **Andy Tirpak**, TAMU/National Audubon Society; **Terry Turney**, TPWD Wildlife; **Tom Wagner**, TPWD/CF; and **Rex Wahl**, National Audubon Society.

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PROBABLE CAUSES OF TRENDS IN SELECTED LIVING RESOURCES IN THE GALVESTON BAY SYSTEM

Anne H. Walton
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I. EXECUTIVE SUMMARY

The Galveston Estuary became a participant in the National Estuary Program (NEP) in October 1988. The program is sponsored by the U.S. Environmental Protection Agency with the goal of maintaining estuaries in a healthy biological state while providing for other uses by developing a coordinated local, State and Federal management plan and program.

The diverse uses of the Galveston Estuary inevitably threaten the many species that depend on it. The most urbanized areas of Texas lie within the Galveston Estuary drainage (over 7,000,000 people; Ditton et al. 1989). Approximately half of the nation's chemical production and a third of its petroleum industry are located in the immediate vicinity of the Galveston Estuary. Fifty-one percent of the wastewater discharge permits issued in 1987 by the Texas Water Commission were in its watershed. Yet in 1989, the Galveston Estuary produced 24-38 percent (by weight) of the Texas coastwide commercial harvest of finfish, shrimp, crab, and oysters (Johns 1990) and almost 40 percent of the recreational harvest (Green et al. 1991).

This report is part of the effort to characterize the ecosystem of the Galveston Estuary. Its purpose is to investigate the probable causes of trends in the abundance of certain species, especially recent declines, as they relate to the overall health of the ecosystem. For some species, confining the discussion to a geographic scale as small as a single estuary may give a false impression of its population. But the primary question here is that of the health of the estuarine system, not the health of a particular species.

The species emphasized are those determined in an earlier study (Loeffler and Walton, 1992) to display chronic declines. The initial list of species to be studied was compiled by members of the Galveston Bay National Estuary Program Scientific and Technical Advisory Committee, with an emphasis on ecologically and commercially important organisms: finfish and shellfish, locally breeding birds, alligators, plankton, and open bay and marsh benthos. Oysters were studied elsewhere (Powell 1993). Statistically significant declining trends were most conspicuous for white shrimp, blue crab, and certain species of colonial waterbirds. These trends are discussed further in the present report.

Summary of conclusions

A decrease in the population of white shrimp (Penaeus setiferus) from 1982 through 1990 was documented by Osborn et al. (1992), but newly available monitoring data showed a rebound in 1991. The 1991-93 El Niño event and associated high inflows brought fresh water and nutrients into the estuary that were probably mostly responsible. Warm winters and changes in fishery regulations possibly also contributed to the white shrimp recovery. White shrimp are frequently more abundant after heavy rains and flooding, suggesting that the regulation of rivers to completely eliminate flooding might not be the best policy for a productive estuary.

Separate trend analyses of 20-mm size groups in bag seine and trawl data for blue crab (Callinectes sapidus) showed that smallest crab increased in numbers, whereas the largest size classes decreased. Overfishing was the most probable cause of the decline in large crab, possibly leading to an increase in small crab by reducing cannibalism. The trends may also have been affected by poorly-understood ecological changes.

Of all birds in the Galveston Estuary, colonial waterbirds were the best documented and potentially the best indicators of the health of the estuary. Declining trends in those colonial waterbirds that feed at the marsh-bay interface (Slack et al. in prep.) suggested that some problem in bay margin habitats may have affected bird populations: the loss of tidal marsh acreage, fluctuations in prey fish, pollution, or disease. A problem in nesting habitat was not implicated, but predation, disturbance of rookeries, and the loss of islands (to subsidence and erosion) place limitations on nesting birds.

The probable causes for the general decline in northern pintails and green-winged teal were probably outside of the Galveston Estuary, specifically the loss of wetland habitat in their breeding grounds on the Great Plains. Non-migratory mottled ducks were affected by the loss of freshwater marsh habitat in Texas.

Wildlife and fishery biologists have long recognized the importance of interannual wet and drought cycles on the biota of Texas. El Niño-Southern Oscillation (ENSO) cycles, a global phenomenon centered on the tropical Pacific Ocean, affected the climate in Texas and consequently the fishery species of Galveston Bay. The mild winters and high inflows of fresh water and nutrients associated with the most recent El Niño event were correlated with high populations of some species in 1991, especially white shrimp, grass shrimp, and some fish that feed on plankton (mullets and bay anchovy). The El Niño event of 1982-83 had a similar effect. The La Niña drought of 1988-89 correlated with low populations of some species, specifically blue crab and white shrimp, but with high populations of salinity-loving organisms such as brief squid.

Intensive shrimp trawling and the loss of wetlands certainly influenced living organisms, directly and by altering the distribution of nutrients within the estuary, though their effects were not obvious given the available data.

Recommendations

In the short term white shrimp and blue crab are probably protected by recent changes in fishing regulations. Wading birds, however, might be a warning of problems at the bay margin, and should be closely monitored for possible bioaccumulation of contaminants and other sources of morbidity and mortality. Bulkheading and development on or adjacent to tidal or fresh marsh should be prohibited. Provisions should be adopted to protect existing marsh or to allow new marsh to develop in recently-inundated areas.

Better data are needed on fishing practices and the seafood harvest, especially by crabbers and subsistence fishermen. Devices to reduce bycatch from shrimp trawling should be investigated and tested. There is also a lack of long-term, high-resolution data that would make it possible to relate trends in living resources directly to water and sediment quality, nutrient regime, and hydrological phenomena in the estuary and Gulf of Mexico. The role of seasonal and interannual variations in climate should be thoroughly investigated.

Sufficient freshwater inflow to the estuary must be maintained to maintain productivity. Regulation must be designed to take climatic fluctuation into consideration. Excessive regulation of the inflow regime should be avoided. Cycles of drought and flooding are natural to the estuary and are possibly necessary for maximum long-term productivity.

As recommended by Green (1992), the GBNEP created a committee to design an integrated sampling program to be used to track short-lived organisms (phyto- and zooplankton) as indicators of ambient estuarine quality and longer-lived organisms (larger shellfish and fishes) as indicators of long-term trends in quality. Some species of birds should also be included in an integrated monitoring program as indicators of the quantity and quality of mudflat (American oystercatcher), beach (Wilson's plover, least terns), or marsh (clapper rail, marsh wren) habitats, or of the health of the estuary in general (seaside sparrow).

This committee has the goal of refining a definition of estuarine health for the Galveston Estuary and determining how data from the proposed sampling program would successfully measure this health. This requires that careful thought be given to the way the estuarine ecosystem works. The committee must also recognize where and how sampling could be done that would not only address the question of population abundances but also why they change and whether humans have any control over the changes. The description of nutrient flux and estuarine energetics should be specifically addressed. The value of the Galveston Estuary requires this monitoring effort to assure its wildlife communities are not lost.

II. INTRODUCTION

The study documented by this report is part of the effort to characterize the ecosystem of the Galveston Bay estuarine system (including Galveston, Trinity, West, East, Christmas, Bastrop, and several other minor bays; hereafter referred to as the Galveston Estuary). Its purpose is to substantiate potential problems, as indicated by significant declines in species abundances, to evaluate the possible causes of the declines, to call attention to critical missing data, and to recommend possible management solutions or additional research.

This report represents the second part of a two-year project. The first phase concentrated on trend analyses for selected economically and ecologically important species: fourteen species of finfish and shellfish, eight species of birds, and alligators. Available data were summarized for open bay benthos, marsh benthos, and plankton. Oysters were studied elsewhere (Powell 1993). Results of the first phase of the study were published as "Status and Trends of Selected Living Resources in the Galveston Bay System" (Loeffler and Walton 1992).

Green (in Loeffler and Walton 1992) concluded that the overall health of the Galveston Estuary appears to be fair to good. Certain species, however, showed declining trends that were cause for concern: white shrimp and blue crab among fisheries species, certain colonial waterbirds (snowy egrets, roseate spoonbills, tricolored herons, and black skimmers), and some species of waterfowl (northern pintail, blue-winged teal, and mottled ducks).

The present report draws on the results of the first, and specifically focuses on underlying causes in addition to the documentation of trends. Factors that affect entire segments of the biota are discussed in Chapters III and IV. Chapters V, VI, and VII focus on those species that showed declines.

MATERIALS AND METHODS

Biological data sets

The standardized, fishery-independent Resource Monitoring Program conducted by the Fisheries and Wildlife Division of the Texas Parks and Wildlife Department (TPWD) provided most of the data used for aquatic species (the CF data set; Dailey et al. 1991). Details for sampling procedures are described in the TPWD Marine Resource Monitoring Operations Manual which is updated annually. Of the three gear types mentioned in this report, gill nets have been used in the Galveston Estuary since 1975-76, bag seines since 1977-78, and otter trawls since 1982-83.

Data for white and brown shrimp were collected by TPWD from 1963 through 1980 and transcribed onto computer files by the National Marine Fisheries Service (the

TPWD/NMFS data set). The data were taken using different methods from the CF data set but were useful for comparison, as discussed by Osborn et al. (1992). Historical trends for white shrimp are presented in Chapter V.

Recent years of commercial landings data for white shrimp were provided by the National Marine Fisheries Service. Landings data for blue crab came from the Texas Parks and Wildlife Department's Fisheries and Wildlife Division (Campbell et al. 1992). Recent and historical landings data, collected from Annual Reports of the Texas Parks and Wildlife Department and its ancestral agencies (the Texas Game, Fish and Oyster Commission and the Texas Game and Fish Commission), were described by Osborn (1992).

Of the data sets for birds, the most important to this report is the Texas Colonial Waterbird Survey, conducted annually during two weeks of the summer nesting season (Slack 1978, Texas Colonial Waterbird Society 1982, Martin 1989, Lange in review). Also mentioned are: the Mid-winter Waterfowl Transects, conducted from the air by the Texas Parks and Wildlife Department in cooperation with the U.S. Fish and Wildlife Service (Haskins 1990); Christmas Bird Counts, day-long tallies collected by a variety of means, sponsored by the National Audubon Society (Butcher 1990); and Shorebird Surveys of Bolivar Flats, conducted by the U.S. Fish and Wildlife Service. The data sets are described in greater detail by Slack et al. (in Loeffler and Walton 1992).

Several State and Federal agencies provided environmental data. These are described further in Chapter IV.

Statistical analysis

Numerical methods used with fisheries species follow those detailed in Osborn et al. (1992). Fisheries data permit the calculation of a Catch Per Unit Effort (CPUE), defined as the number of individuals caught per 0.03 hectare net area in the case of bag seine, or as per ten minutes net towing in the case of trawl. For aquatic species the results of trend analyses are shown as annual fitted values plus and minus the standard error, plotted with mean annual observed CPUE. Analysis of Deviance (ANODE) tables are presented in Appendix 1.

Size ranges and seasons used for the analysis of fisheries species in this report were chosen using the same reasoning described by Osborn et al. (1992): a size range was selected to represent the life stage of interest, and the data were confined to those months when individuals of that size are most abundant, to minimize zero catches and provide the best representation of geographic distribution. Data collected in 1991 became available during the course of this study and were included in analyses where possible.

Correlations between CPUE and environmental variables, described in Chapter III, were calculated using PROC CORR and PROC REG in SAS (PC Version 6.04). Only simple linear correlations are presented in Tables 1-3.

Work accomplished by Slack and others subsequent to the first phase of this project (1992) used detrended correspondence analysis, following the methodology of Spendelow et al. (1989), to recognize statistically significant within-community (structural) changes in assemblages of colonial waterbirds (Gawlik et al. 1992). Results of the analysis are discussed in Chapter VI.

For many phenomena that are reasonably expected to affect living resources, there were no data available of a duration, spatial coverage, and resolution comparable to that used to show population trends. For example, there is no routine monitoring for toxic organic compounds in the Galveston Bay System (Stanley 1989); expensive analytical procedures are used only for short-term studies or when there is reason to suspect a problem. Many "probable causes" are consequently not supported by a rigorous long-term correlation analysis. Because a cause is not ideally documented, however, does not mean it is not important. These situations are discussed in Chapter IV.

Species workshops

This study was initiated as a series of meetings with the purpose of assembling a group of experts to review the data. The participants in these meetings came from state and federal agencies, universities, conservation organizations, and private industry. The general approach during the workshops was similar: a presentation of the available data, a review of life history information from the literature, and a series of leading questions to guide discussion.

In all cases we attempted to address the following questions: What are the biases of data collection and analysis? What is the probability that the observed trends are artifacts rather than real biological phenomena? What is the probable temporal extent of the trends? Are the trends driven by a particular part of the Galveston Estuary? Are the trends unique to the Galveston Estuary or part of a larger phenomenon? Can the data be related to environmental factors, natural or human-induced? What are the possible consequences if the decline were to continue? And of course, what are the probable causes and possible remedies for the decline? The results of these discussions and follow-up studies were the foundations for Chapters V, VI, and VII.

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).

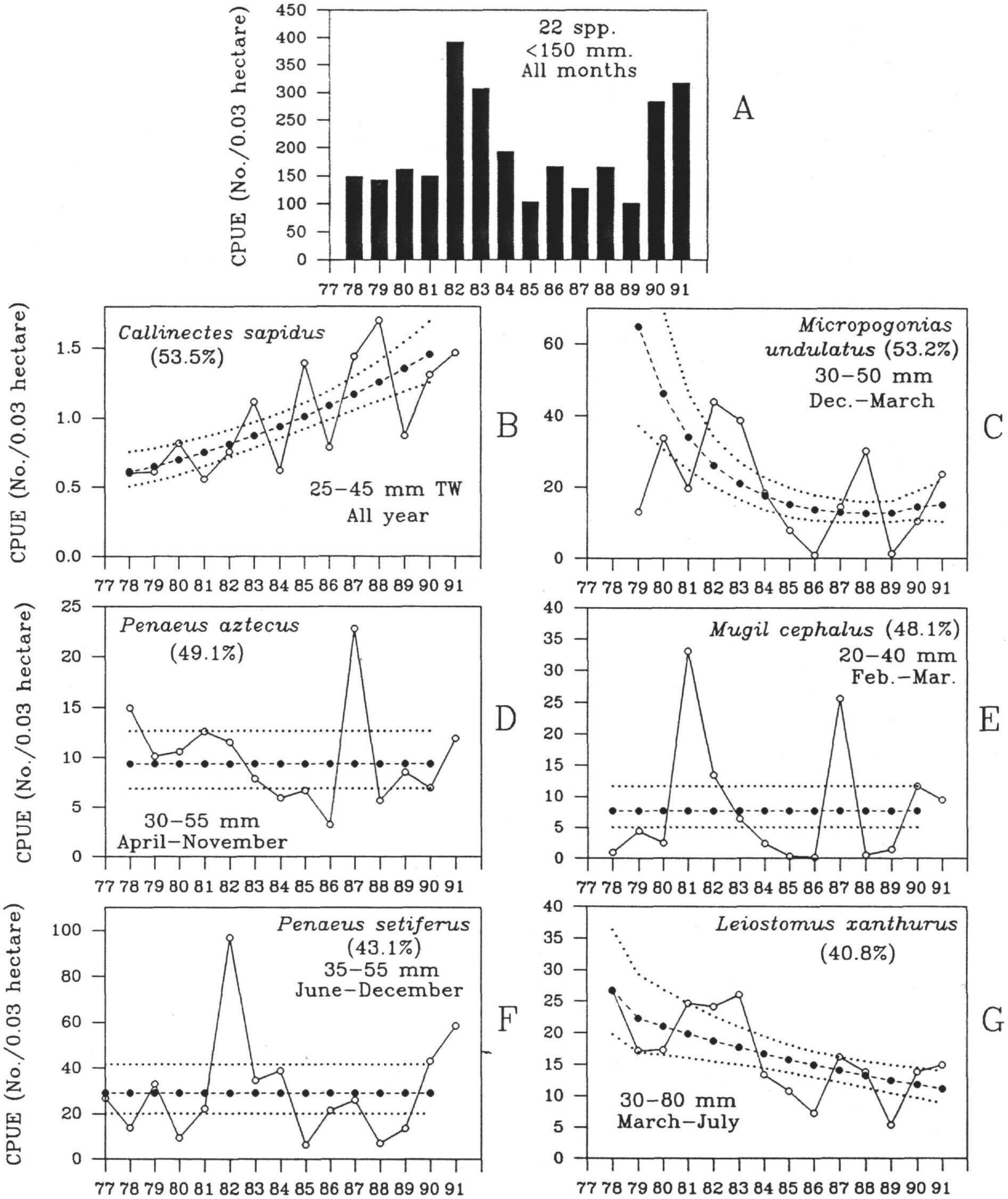


Figure 1. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for 22 most common species caught by bag seine. Percentage of samples containing that species in parentheses. A. Bar graph for all species present in over 10% of samples, <=150 mm TL. B. Blue crab. C. Atlantic croaker. D.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

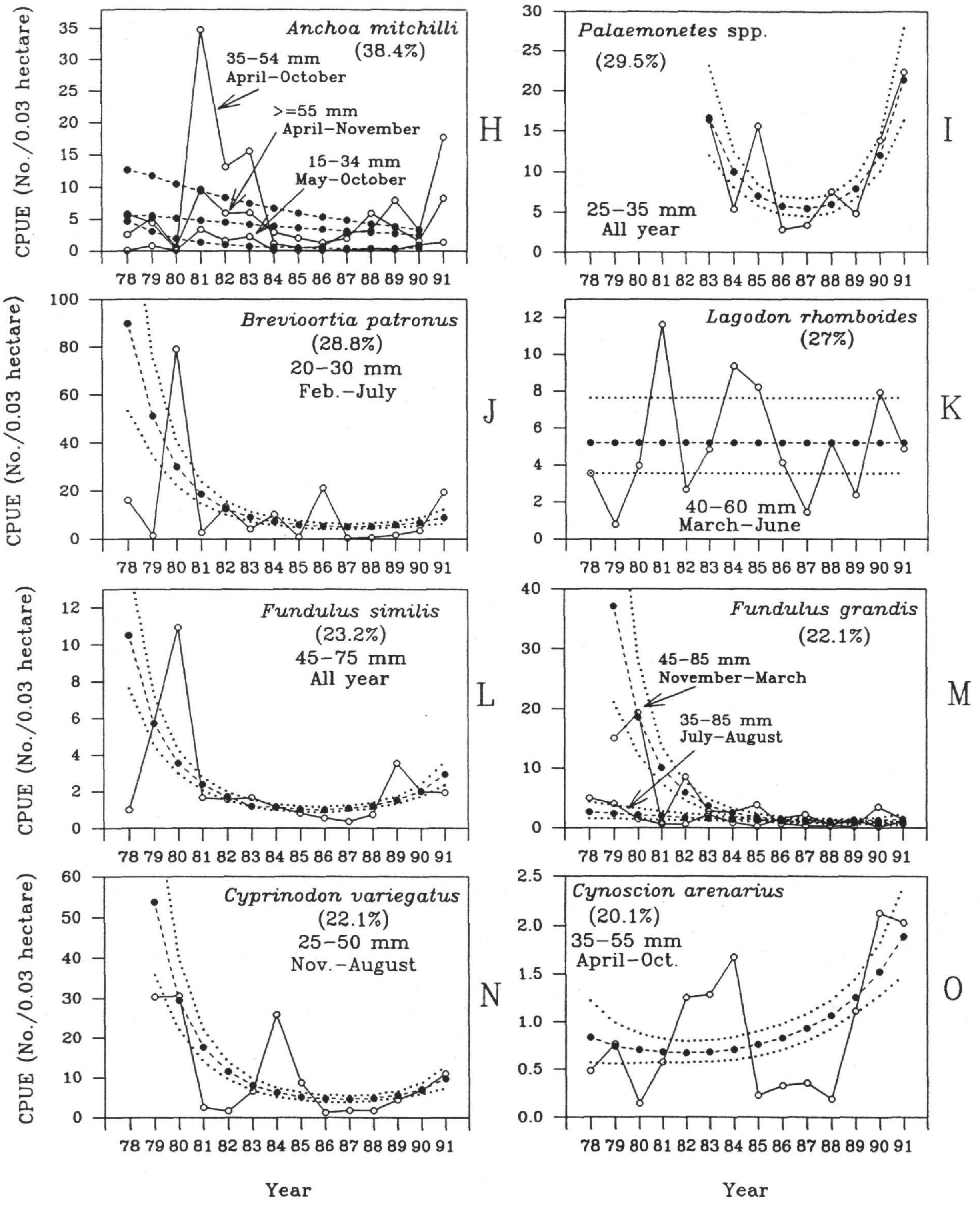


Figure 1 (continued). Mean annual CPUE with fitted values and confidence intervals (±S.E.) for most common species caught by bag seine. H. Bay anchovy. I. Grass shrimp. J. Gulf menhaden. K. Pinfish. L. Longnose killifish. M. Gulf killifish. N. Sheepshead minnow. O. Sand seatrout.

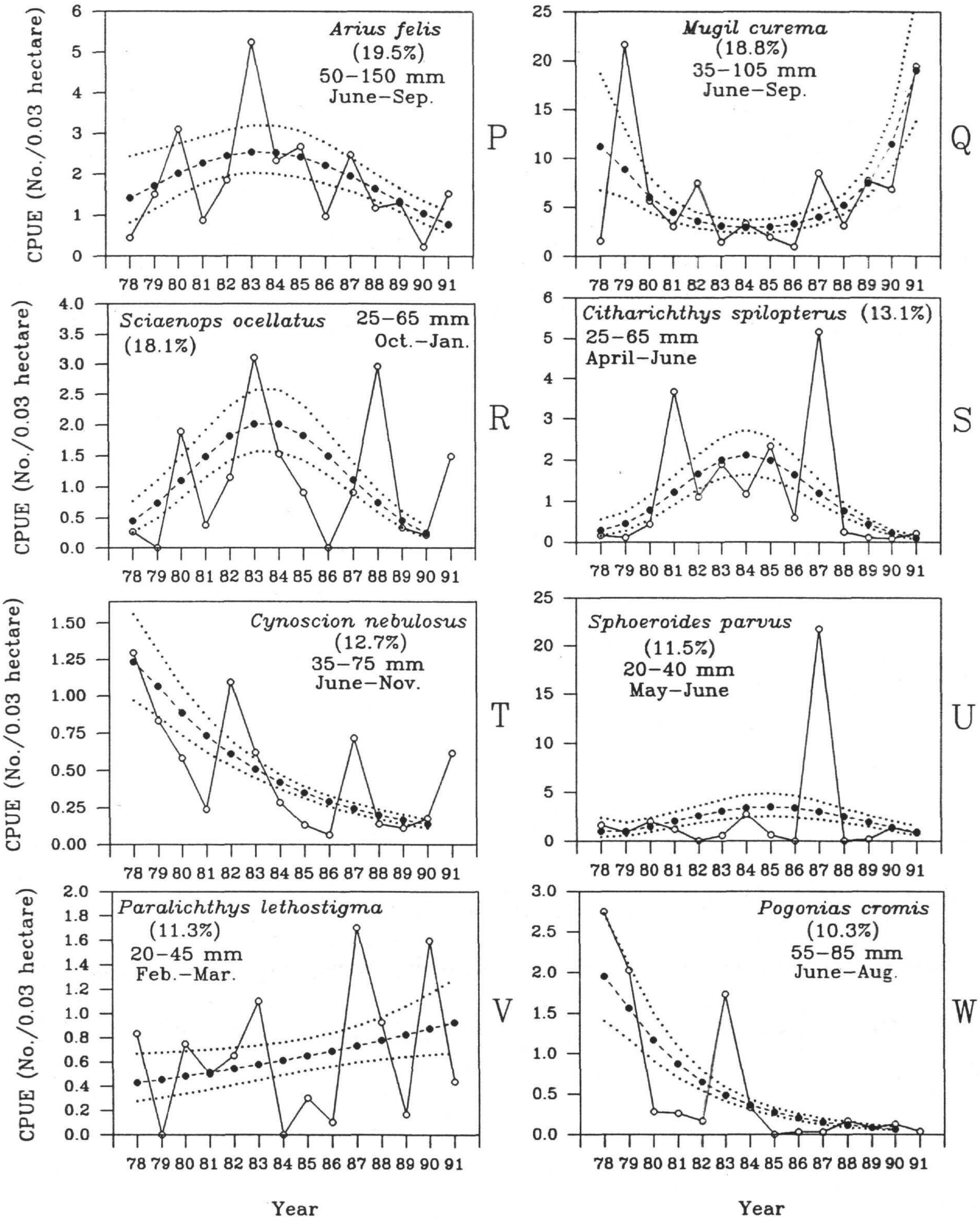


Figure 1 (continued). Mean annual CPUE with fitted values and confidence intervals (±S.E.) for most common species caught by bag seine. P. Hardhead catfish. Q. White mullet. R. Red drum. S. Bay whiff. T. Spotted seatrout. U. Least puffer. V. Southern flounder. W. Black drum.

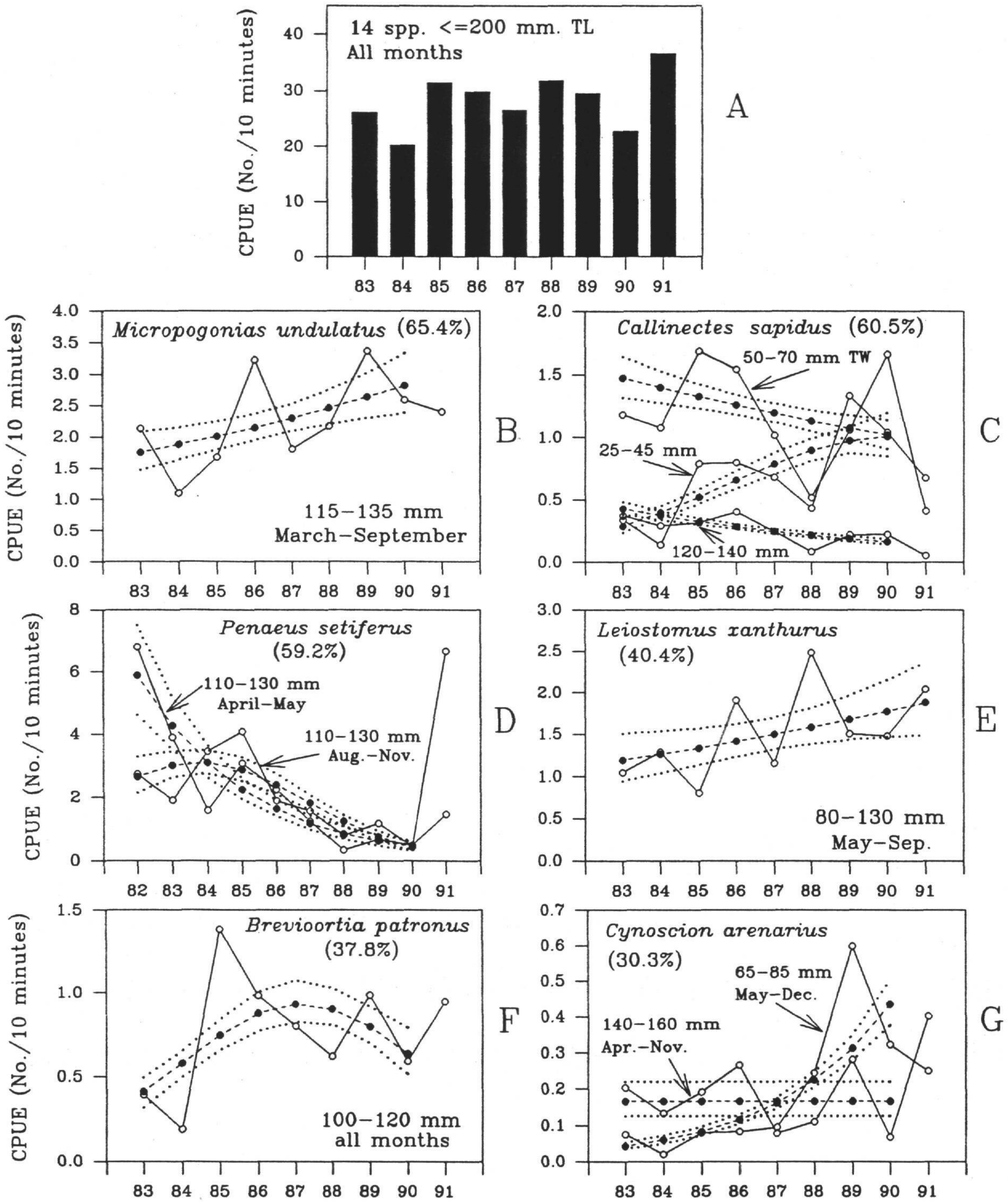


Figure 2. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for 14 most common species caught by trawl. Percentage of samples containing that species in parentheses. A. Bar graph for all spcies present in over 10% of samples, <=200 mm TL. B. Atlantic croaker. C. Blue crab. D. White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

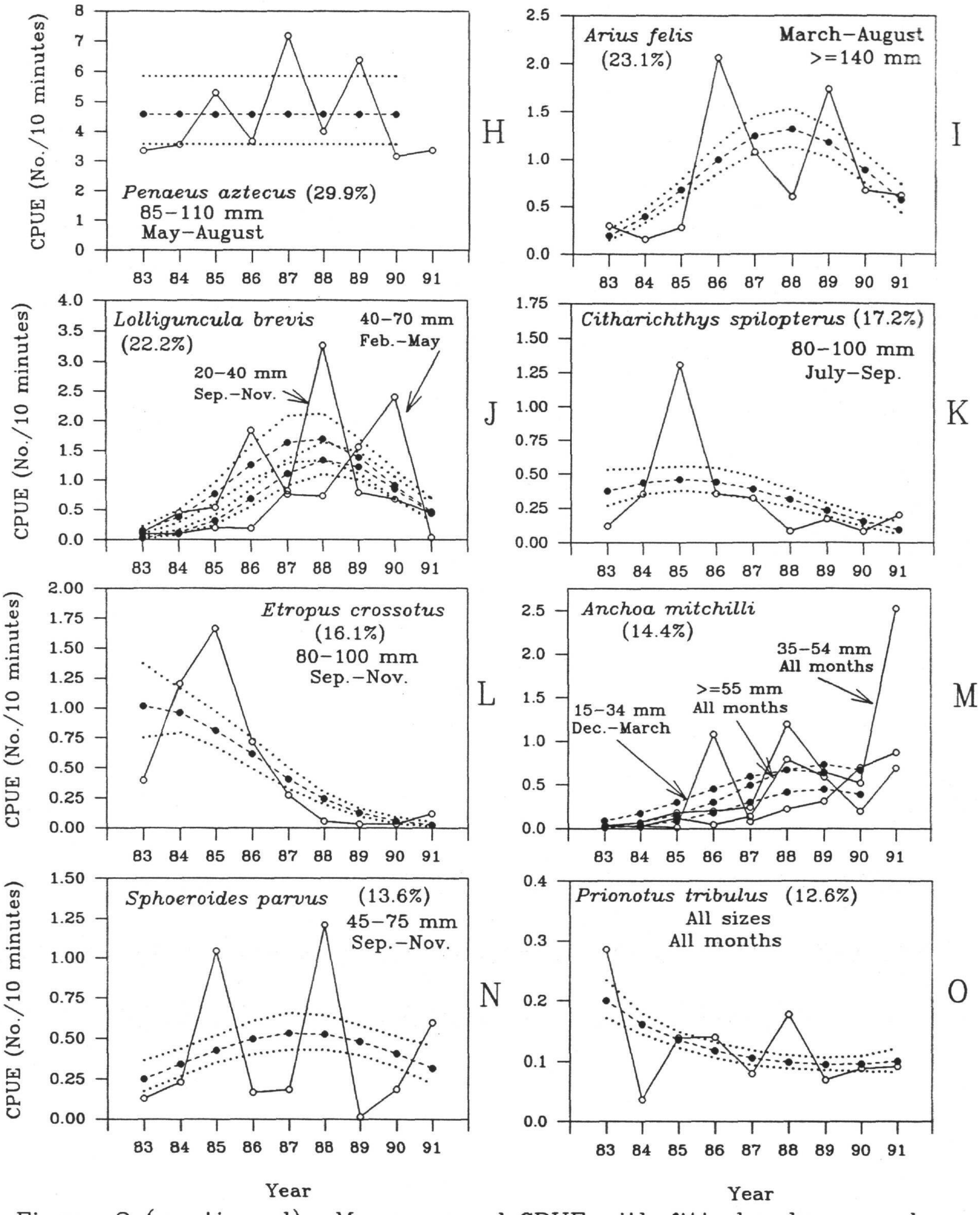


Figure 2 (continued). Mean annual CPUE with fitted values and confidence intervals (±S.E.) for most common species caught by trawl. H. Brown shrimp. I. Hardhead catfish. J. Brief squid. K. Bay whiff. L. Fringed flounder. M. Bay anchovy. N. Least puffer. O. Bighead searobin.

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

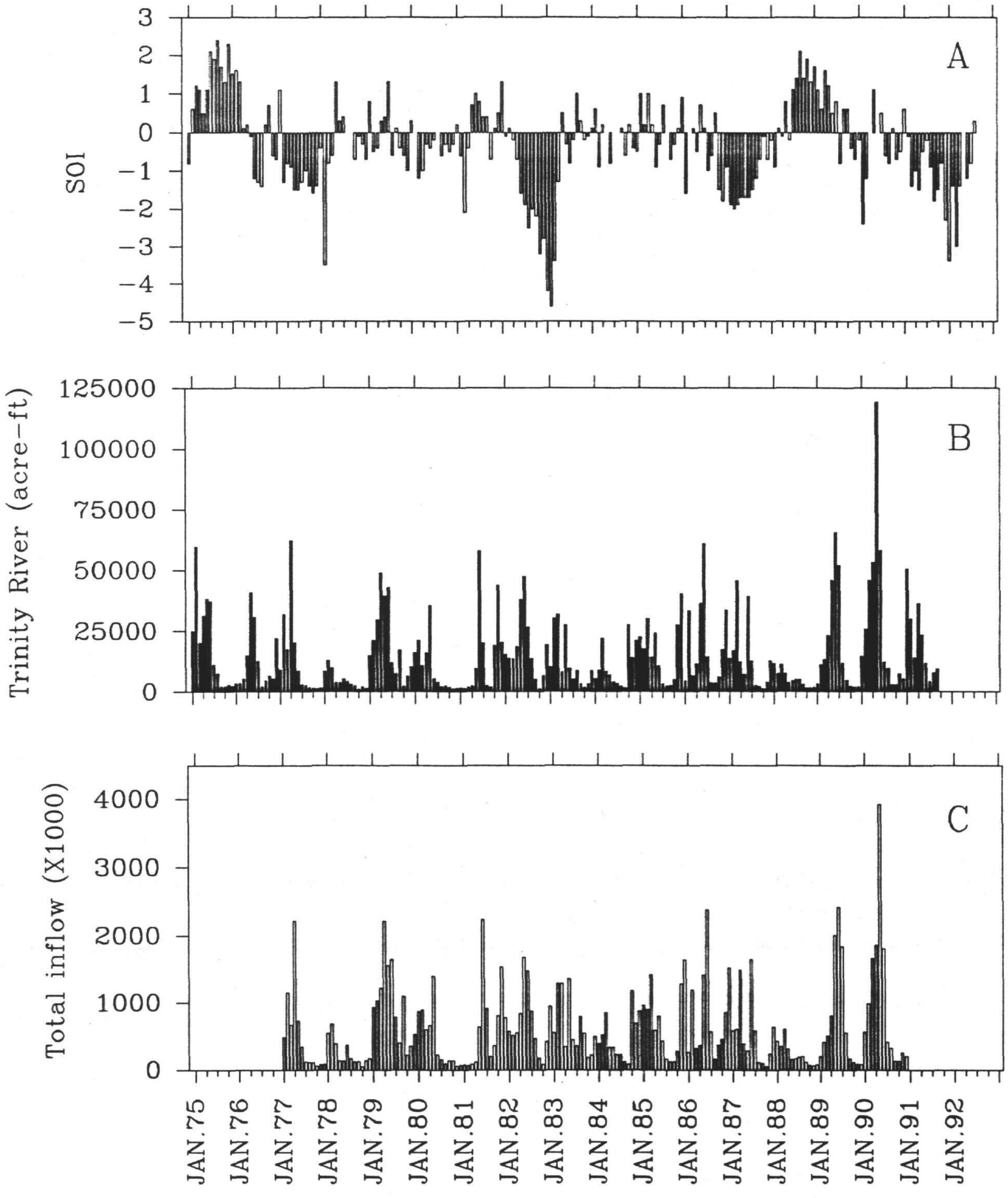


Figure 3. Time series for environmental variables used for correlation. A. Southern Oscillation Index. B. Trinity River inflows at Romayor gauge station. C. Total river inflows to Galveston Bay, including the Trinity River and twelve other streams.

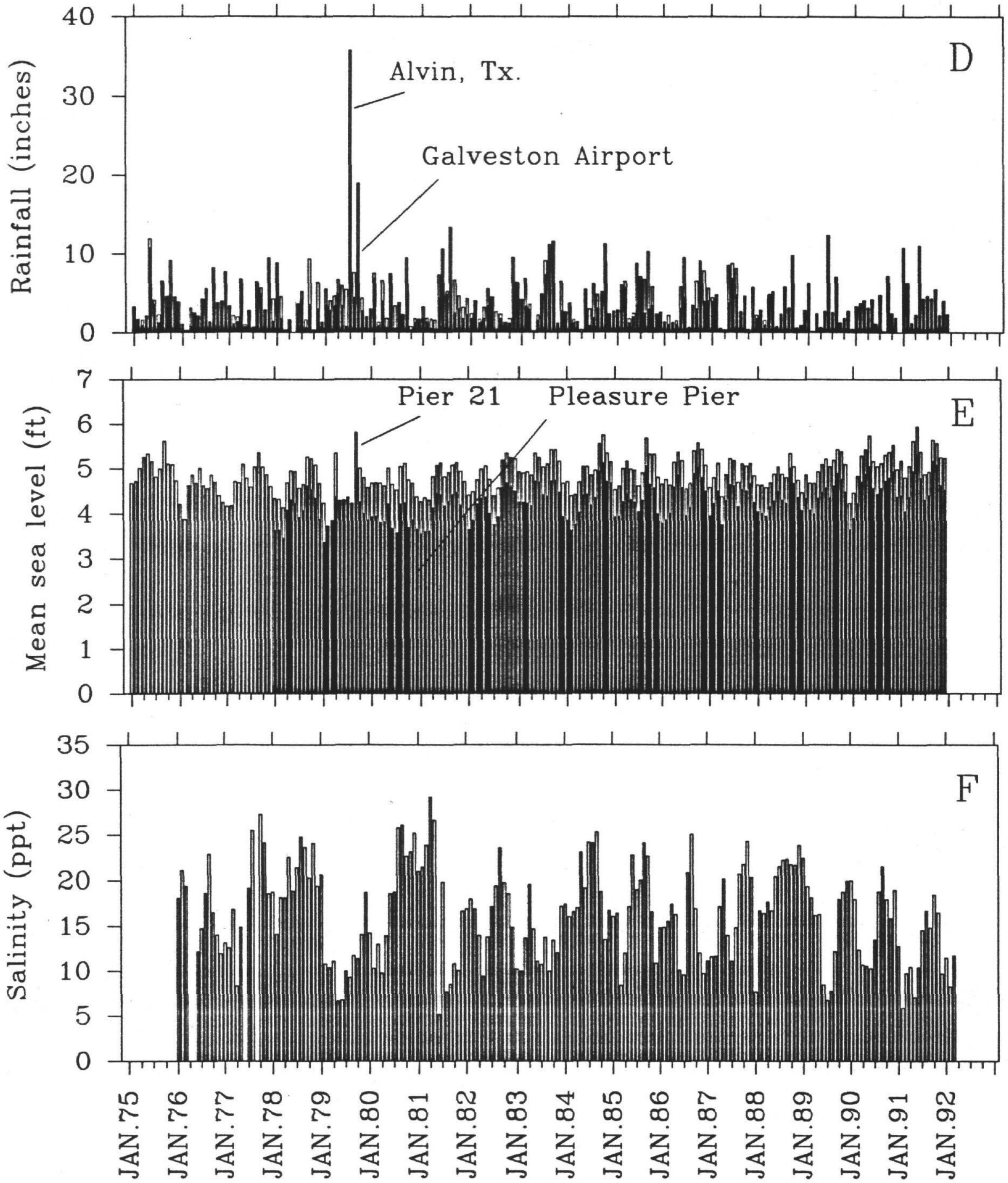


Figure 3 (continued). Time series for environmental variables used for correlation. D. Rainfall at Alvin, Texas and Galveston Airport. E. Mean sea level at Pier 21 (Galveston Channel) and Pleasure Pier, Galveston (Gulf of Mexico). F. Salinity, compiled from bag seine, gill net, and trawl samples.

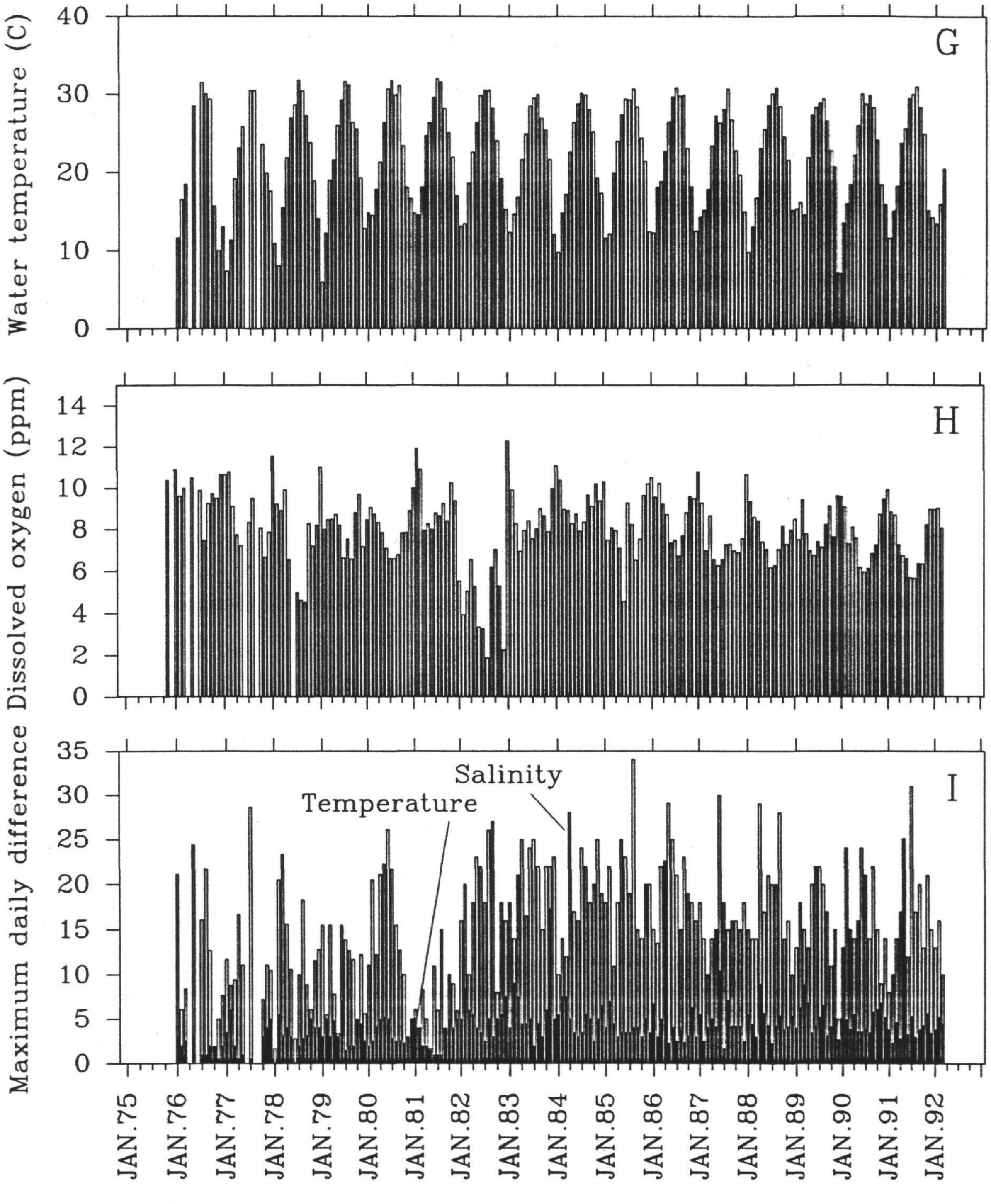


Figure 3 (continued). Time series for environmental variables used for correlation. G. Water temperature, compiled from bag seine, gill net, and trawl samples. H. Dissolved oxygen, compiled from bag seine, gill net, and trawl samples. I. Maximum daily difference per month in water temperature and salinity.

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.

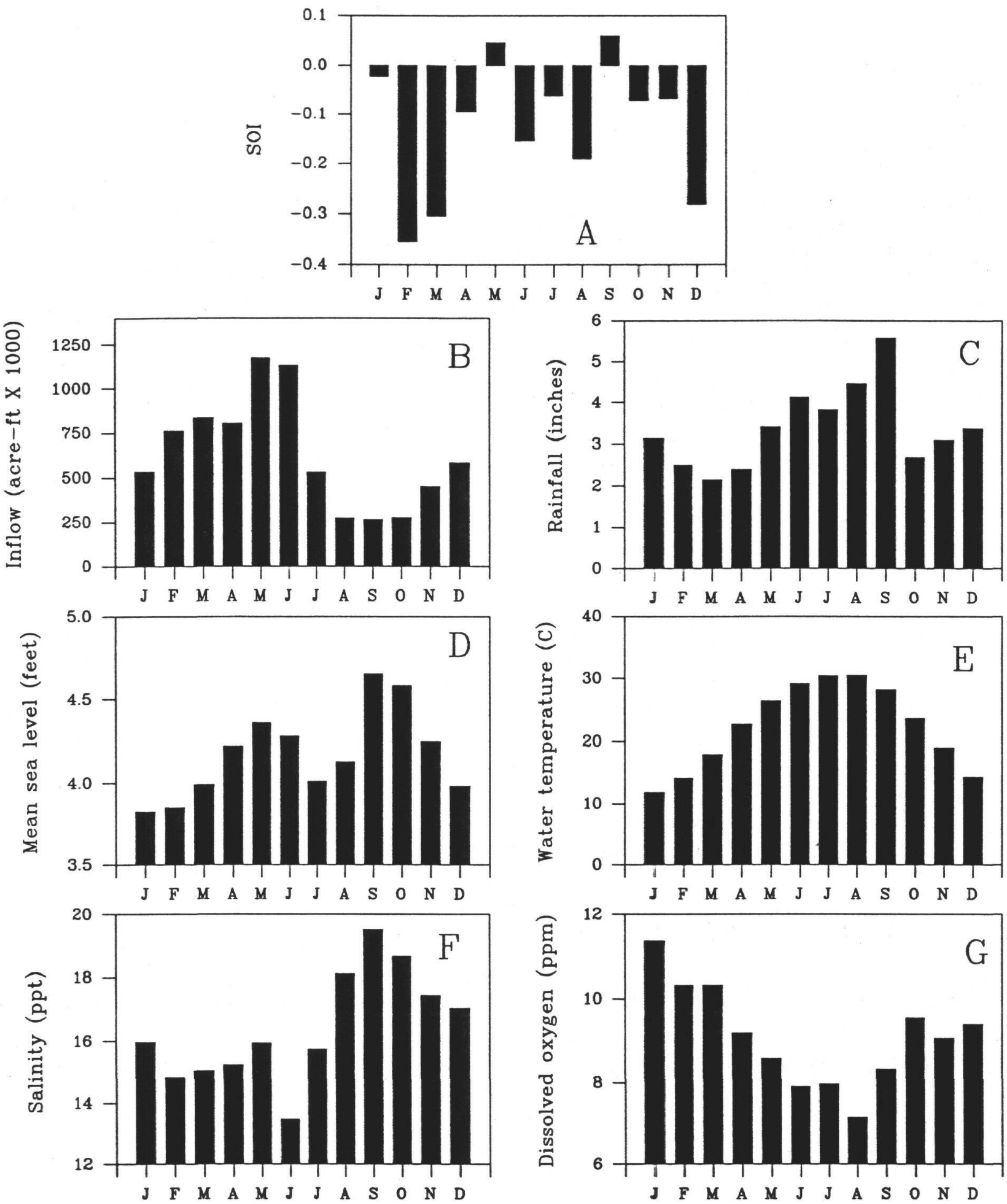
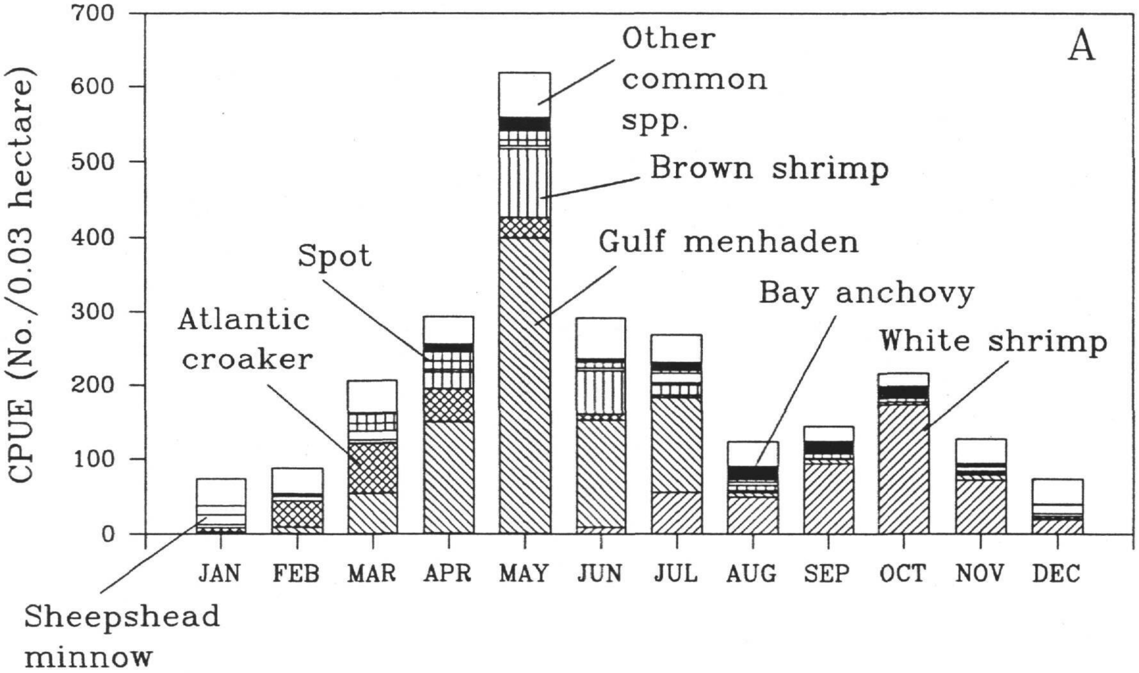


Figure 4. Monthly means for selected environmental variables. A. Southern Oscillation Index, 1970–1991. B. Total river inflow, 1977–1990. C. Rainfall at Galveston Airport, 1950–1991. D. Mean sea level at Pier 21, Galveston, 1980–1991. E. Water temperature, 1976–1991. F. Salinity, 1976–1991. G. Dissolved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



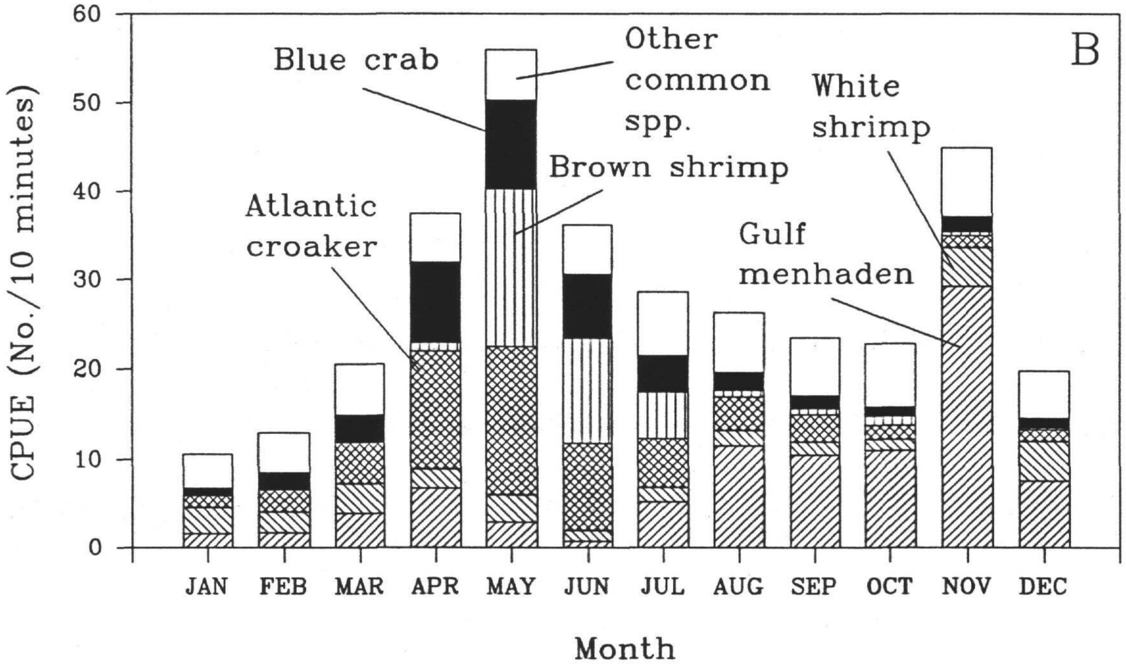


Figure 5. A. Monthly mean CPUE for 22 most common species caught by bag seine, <=150 mm TL, 1978–1991. B. Monthly mean CPUE for 14 most common species caught by trawl, <=200 mm TL, 1983–1991.

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.

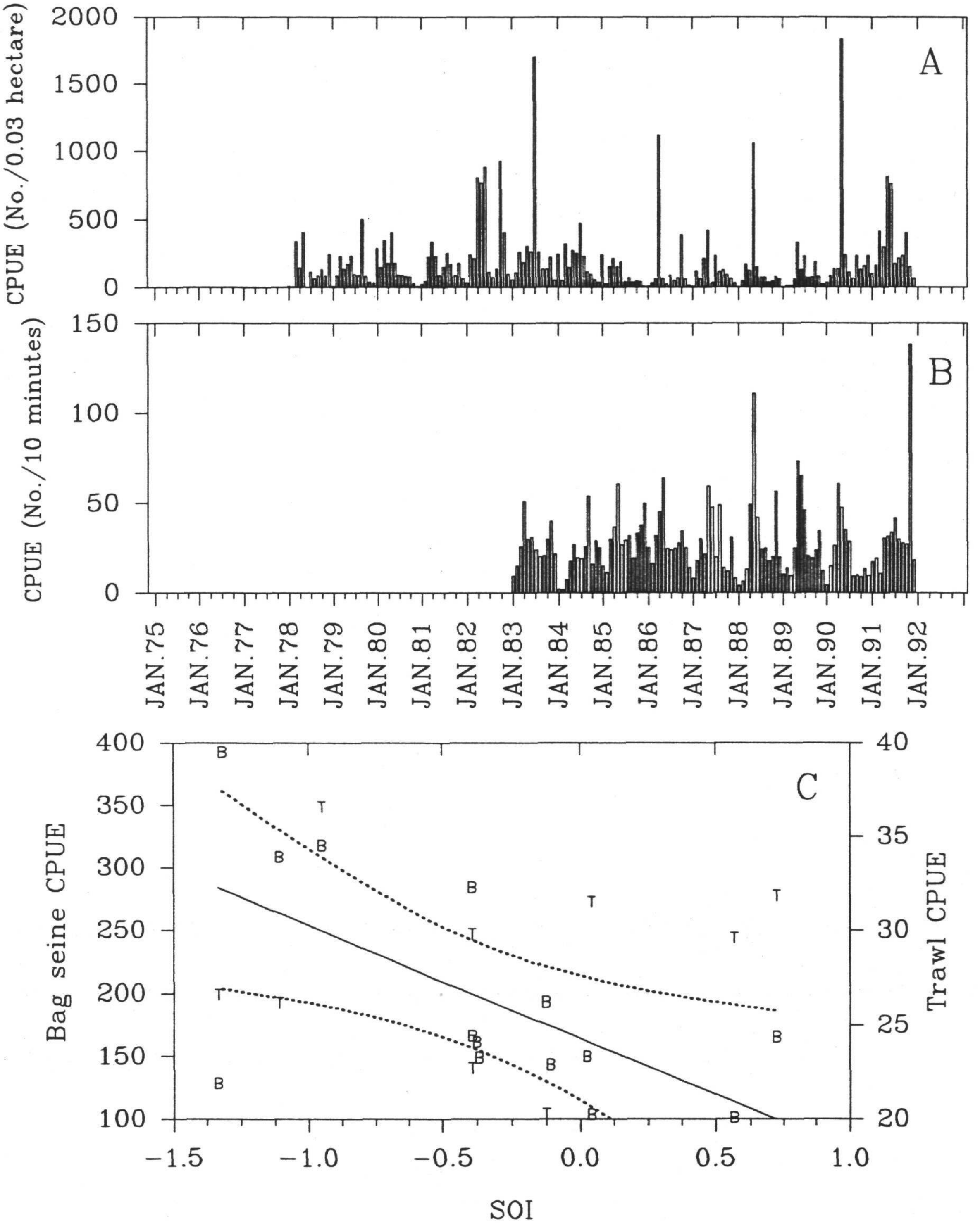


Figure 6. Mean monthly CPUE for (A) 22 most common species caught by bag seine, <=150 mm TL, and (B) 14 most common species caught by trawl, <=200 mm TL. C. Mean annual CPUE for bag seine (B) and trawl (T) data plotted against Southern Oscillation Index, with least-squares regression line for bag seine.

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.

IV. OTHER ENVIRONMENTAL FACTORS

This chapter discusses some of the natural and anthropogenic factors that affect a wide variety of organisms in the bay system: freshwater inflows, wetland loss, water and sediment quality, and shrimp trawling. Only inflow was amenable to direct quantitative comparison with fisheries species (Chapter III). This study did not reveal unambiguous effects for any of these factors, other than that they affect the biota in complex ways and should not be neglected in questions of management.

Freshwater inflows

Inflows and the timing of inflows are undeniably important to the estuarine biota (Texas Department of Water Resources 1981, Mueller and Matthews 1987, Longley in review). High secondary productivity after floods has been observed repeatedly on the Texas coast (e.g. Johnson 1974, Flint and Rabalais 1981). Catch rates in 1991 were moderate to high in spite of possibly severe freshets during 1990 and 1991 (Figures 1A, 2A). The reasons for the importance of inflows are complex, however, and covary with other parameters, such as salinity, nutrients, and water levels.

The most obvious effect of freshwater inflow is the alteration of salinity regime. Johnson et al. (1981) observed that small fishes and crustaceans were more abundant in an upper Galveston Bay nursery area during wet years, and speculated that part of the value of nursery grounds derives from low salinities, which repulse larger fishes and thereby reduce intense predation. Oysters are a good example of an organism that is increasingly vulnerable to predation and parasitism as salinity approaches that of seawater, though prolonged freshets can be fatal.

Ward and Armstrong (1992) documented a decline in salinity in Galveston Bay over the last three decades. The decline is not clearly associated with changes in inflows. The authors speculate that salinity may have changed over time in the Gulf of Mexico, or the interaction between Gulf and estuarine waters may be less intense than in the past.

High inflows also cause high water levels in the estuarine system, therefore large areas of flooded marsh, and a greater area of nursery habitat accessible to organisms (Childers et al. 1990). Rainfall can deliver non-point source runoff and debris to the estuary (Newell et al. 1992), but theoretically heavy inflows can also cleanse the estuarine system by flushing pollutants. Perhaps the most important effect of freshwater inflow is the contribution of nutrients to estuarine waters. Nutrients support the phytoplankton that form the base of the estuarine food web; Lee (in prep.) suggested that nursery grounds are valuable to juvenile shrimp because of the abundant food in those areas (diatoms and polychaetes). Rivers are responsible for most of the long-term contribution of nutrients to estuaries, especially nitrogen and silica (Nixon 1981).

Unlike the weather, inflows can be managed to some degree. Most of the streams entering the Galveston Estuary have some form of flood control structure, of which Lake

Livingston on the Trinity River is the largest. It is hypothetically possible to stabilize the estuarine salinity regime at an optimum level, for example for oyster production. If flushing and nutrient input are important mechanisms, however, the energy of periodic floods may be necessary for efficient delivery. Too much stability may lead to a long-term decline in an organism upon which oysters depend, or an increase in the density of predators on oysters. Therefore it is important to maintain some variability in inflows.

The negative aspect of freshwater inflow is that low salinities and/or imbalanced nutrient inputs may contribute to noxious plankton blooms. The dinoflagellate bloom offshore of Galveston Island in 1984 was ascribed to low salinity by Harper and Guillen (1989). The bloom caused fish kills along the Gulf shoreline but did not enter the Galveston Estuary proper. The 1986-87 red tide (coincident with a mild El Niño event) was similarly associated with heavy rainfall by Trebatoski (1988). This bloom also affected the Gulf and estuaries to the south, but not the Galveston Estuary.

Wetland loss

The acreage of nursery habitat (seagrass beds and intertidal vegetation) is directly related to an area's productivity of certain fisheries species, of which penaeid shrimp are the best documented (e.g. Turner 1977, Turner and Brody 1983). The loss of tidal marsh in the Galveston Bay area (mainly from relative sea level rise, bulkheading, and from development and other land use changes) has progressed for several decades. From the 1950s to 1989 there was a net loss of about 19 percent (32,400 acres) of the estuary's vegetated wetlands (White et al. 1993), most of it before the mid-1970s. Seagrass beds, for example, were formerly widespread on the shores of Galveston and Trinity Bays. The submerged vegetation failed to reestablish after Hurricane Carla in 1961 (Pulich and White 1990), in part because of ongoing coastal subsidence. With the loss of the seagrass biome, nursery habitat for unknown quantities of estuarine organisms was also lost.

The CF data set shows declines for few of the fisheries species that depend on wetland vegetation for nursery habitat (e.g. brown shrimp, Atlantic croaker; Figures 1C, 1D, 2B, 2H). Declines ascribable to wetland loss are not conspicuous probably because the time series available postdates the period of most rapid wetland loss, and the former abundance of marsh-dependent species is unknown. In addition, the work of Zimmmerman et al. (1990, 1991) suggests that the absence of wholesale declines should be viewed with caution. Many fisheries species may benefit from the temporary increase in complexity and/or productivity of drowning marsh as relative sea level rises. However, if sea level continues to rise at a rate greater than marsh accretion, drowned marshes will be replaced by relatively unproductive open bay bottom and fisheries production will probably decline.

The contrast between bag seine and trawl data (Figures 1, 2 and 6, Chapter III) suggests bay margin habitats and the mid-bay are unalike in their productivity and response to environmental variables. However they are by no means uncoupled. The quantities of organic detritus generated in bay-margin marsh environments (Zimmerman et al. 1991) are probably important to mid-bay consumers (Texas Department of Water Resources 1981). A decline in productivity at the margins could have serious consequences for the entire bay.

A less ambiguous indicator of the state of wetlands are those birds that feed in them and require fairly extensive high-quality habitat. Chapter VII discusses the declining trends in wading birds that feed at the marsh-bay interface. This may be an early warning of a potentially serious problem at the bay margin.

Water and sediment quality

Water quality, specifically nutrient load and dissolved oxygen, has improved substantially since the 1970s (Oppenheimer et al. 1973, Stanley 1989, Ward and Armstrong 1992). However, the estuary continues to receive nutrients, heavy metals, unknown quantities of toxic organic compounds, and other pollutants, especially from urban areas (Newell et al. 1992, Cain 1993, Crocker 1993, Armstrong and Ward in press). King (1989) reported that concentrations of DDE, DDD, and chlordane in Galveston Bay fish tissues are below the national average, but that PCB levels are 1.5 times higher than average. Carr et al. (1993) found significant toxicity in sediments in 12 out of 24 sampled stations in the Galveston Estuary, especially those adjacent to dredged material disposal areas or produced water separator platforms. Polluted sites near the Houston Ship Channel are commonly reported (e.g. King et al. 1987, Carr et al. 1993), and the EPA's Environmental Monitoring and Assessment Program (EMAP) found high fish pathology rates in 1991 in East Bay Bayou (Summers and Hornig 1993). Fish kills caused by hypoxia or pollution may be less common than in past years but continue to occur.

In spite of these other findings, this study did not reveal any trends in living resources that could be directly related to pollution. Desbonnet et al. (1991) similarly found that finfish stocks correlate more closely with climate, fishing pressure, economics, and management than with water quality trends. Unfortunately, fishery-independent monitoring began in the 1970s, when pollution was more severe than it is now. Therefore it is unknown to what extent the observed population trends reflect recovery or a failure to recover. Furthermore there may be localized areas that are intolerably polluted but are too small to affect a bay-wide trend analysis. Future studies using Geographic Information System (GIS) technology may reveal some "hot spots". In addition, the decline in some species of birds that feed at the marsh-bay interface (Chapter VII) suggests there may be a problem at the bay margin, and contamination of water or sediments is one possible explanation. Petroleum and its products are especially likely to concentrate at the estuarine margin and to remain entrapped in marsh sediments (Kennish 1992).

It is difficult to interpret the implications of the study of ambient water quality in the Galveston Estuary by Ward and Armstrong (1992). The investigators found declines in salinity, turbidity, nitrates, and chlorophyll a over the past three decades. The declines in total suspended solids and turbidity may indicate the estuary's eventual return to a clearer, healthier state. Declining chlorophyll a and nitrate load are probably associated, because phytoplankton are probably nitrogen-limited in the Galveston Estuary (Buskey

1992). These trends probably indicate the success of efforts to improve waste water treatment and reduce pollution. On the other hand, these water quality trends may also indicate a present or eventual decline in primary productivity (from reduced nutrient loading, wetland loss, or other causes) that could cause an eventual decline in other species. The causes and implications of these water quality trends should be investigated more thoroughly to ensure that future management is applied appropriately.

Trawling

Several species are known to be vulnerable to shrimp trawling: Atlantic croaker, blue crab, pinfish, spot, sand seatrout, hardhead catfish, and Gulf menhaden (Bryan et al. 1982, Chai 1991, Nance et al. 1993). It is surprising that none of these "bycatch species" (with the exception of blue crab, Chapter VI) showed clear declining trends in this study or that of Osborn et al. (1992). Figures 1C, 1G, 1J, and 1P show declining trends for croaker, spot, menhaden, and catfish in bag seine catches, but the declines are uncorroborated by trawl data (2B, 2E, 2F, and 2I).

Nevertheless it is hard to imagine that intensive shrimp trawling has no effect on the benthos or on bottom-feeders. At least one apparent fish kill, dominated by Atlantic croaker, was probably the result of discarding by commercial shrimpers (Harper and Guillen 1989). All bay bottom is trawled that can legally and physically be trawled, possibly many times during a year. If future monitoring data for 1993 or 1994 show an increase in the "bycatch species", the recent regulation of shrimping should be investigated as a probable cause. If future monitoring reveals a long-term decline in these species, additional regulation should be considered. Devices that economically permit bycatch species to escape from shrimp trawls should be investigated and tested.

V. WHITE SHRIMP

A strong linear decrease in trawl catches of white shrimp (Penaeus setiferus) from 1982 through 1990 was documented by Osborn et al. (1992), but newly available monitoring results for 1991 showed a rebound to 1983 levels (Figure 2D). The 1991 rebound probably resulted from two events: El Niño conditions during 1990-91 (associated with high freshwater inflows and mild winters), and new regulations that make shrimping illegal during two months in the summer in Texas waters. How much of each these factors contributed to the rebound cannot be determined because they occurred at the same time.

Geographic extent

Figures 7 and 8 show bag seine and trawl catches of white shrimp from all major bays in Texas. The largest catches as well as the strongest decline came from the Galveston Estuary, which is also the area of highest white shrimp abundance in Texas (Figure 7A, 8A). The decline was not unique to the Galveston Estuary nor was it confined to any one part of the system.

White shrimp caught by trawl also declined from 1982 through 1990 in three southern estuaries (Aransas, Corpus Christi, and Laguna Madre; Figures 8D, 8E, 8F). The rebound appeared to be coast-wide; white shrimp abundances for 1990 and/or 1991 appeared higher in both bag seine and trawl catches in most major bays. In the Gulf, however, only Statistical Zone 19 (offshore of San Antonio and Matagorda Bays) showed an analogous increase (Figure 9). Fishery-independent sampling in the Gulf has only been underway since 1986, so the available time series for Gulf data is very short.

It was no surprise that plots of the spatial distribution of CPUE (Osborn et al. 1992, figs. III.40, III.41, III.42, and III.43) show that white shrimp do not occur everywhere homogeneously. The estuary was subdivided spatially into areas of high and low catch rate using an analysis of variance. After two areas were identified, an analysis of deviance was performed in which Area was included as a categorical variable. The results show no differences in the slope or direction of the trends for the two areas (Figure 10). This indicates the 1982-90 decline was not confined to one part of the bay system.

Temporal extent and reliability

Differences in sample site selection and gear (Osborn et al. 1992) make it statistically inappropriate to directly compare the TPWD/NMFS historical data set (Figure 11A) with the CF data set (Figure 11B). By visual inspection white shrimp appeared to reach a maximum in 1980. There are no data for 1981, but juveniles (Figures 12A and 12B) and the spring catch of subadults (Figure 10B) in the CF data set showed a decline after the 1982 El Niño event. The fall catch of subadults (Figure 10C, 11B) declined after 1984.

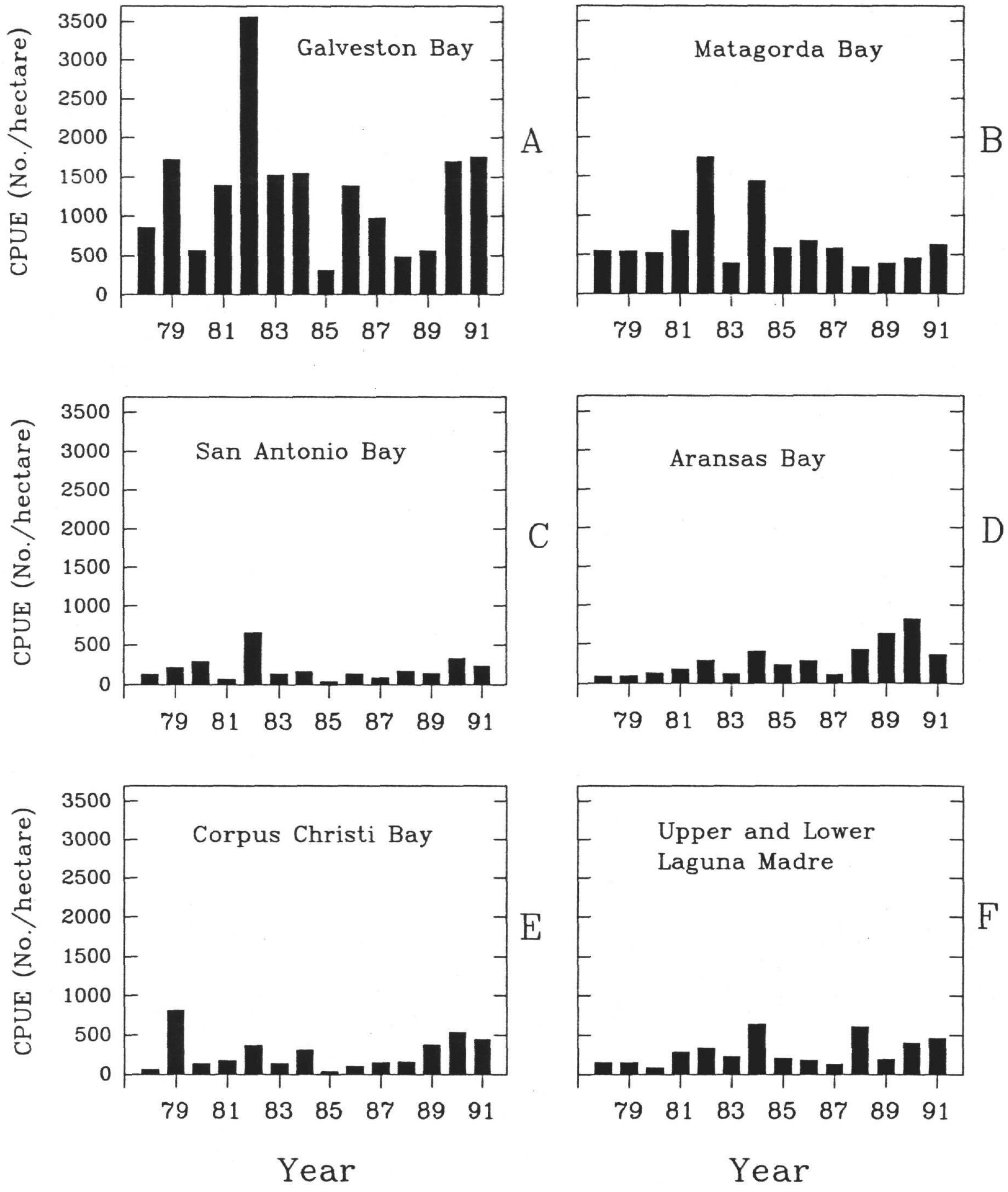


Figure 7. Mean annual CPUE for all sizes of white shrimp caught by bag seine in major estuaries in Texas. Data from Dailey et al. (1991) and McEachron (pers. comm.)

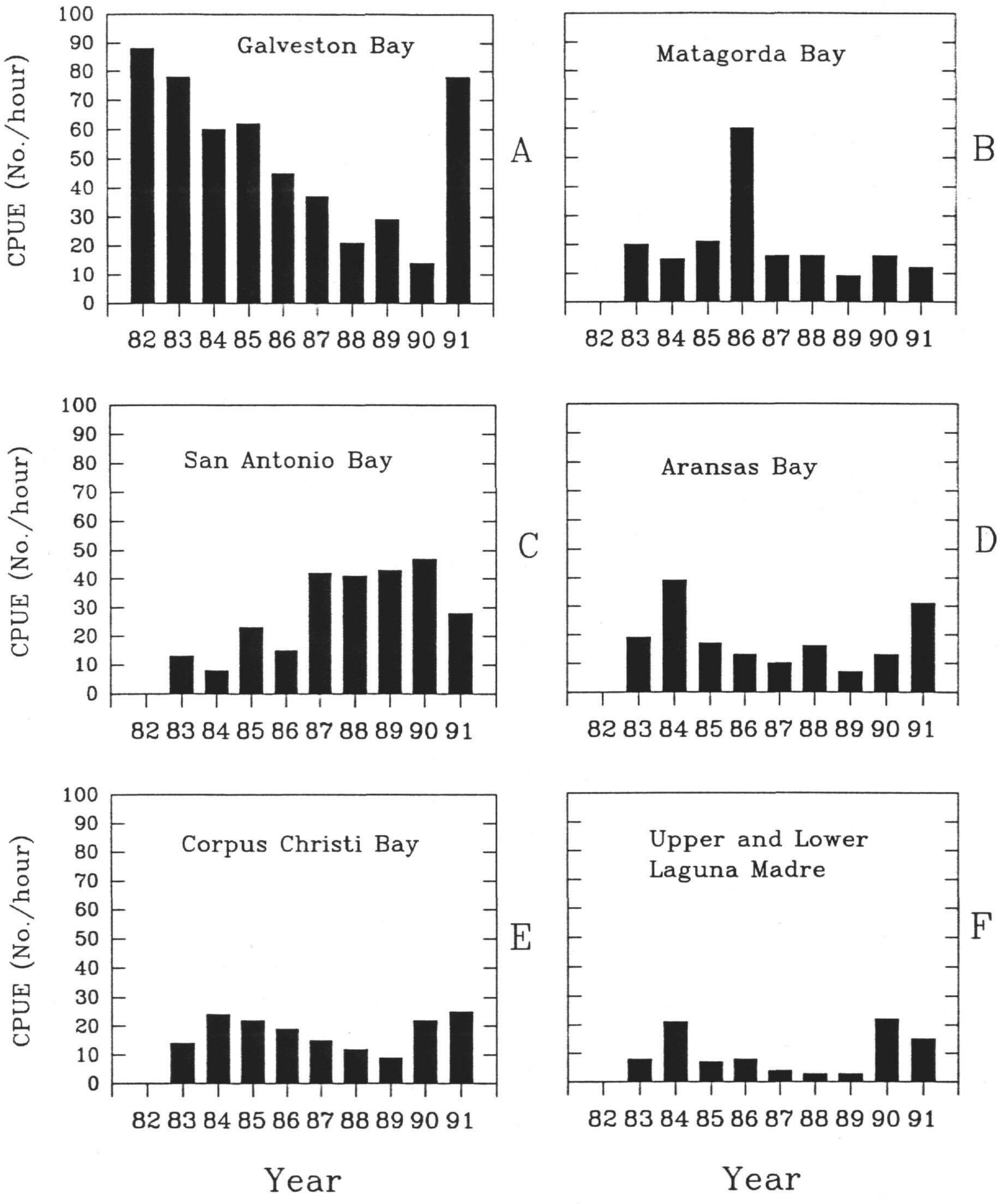


Figure 8. Mean annual CPUE for all sizes of white shrimp caught by trawl in major bays in Texas. Data from Dailey et al. (1991) and McEachron (pers. comm.).

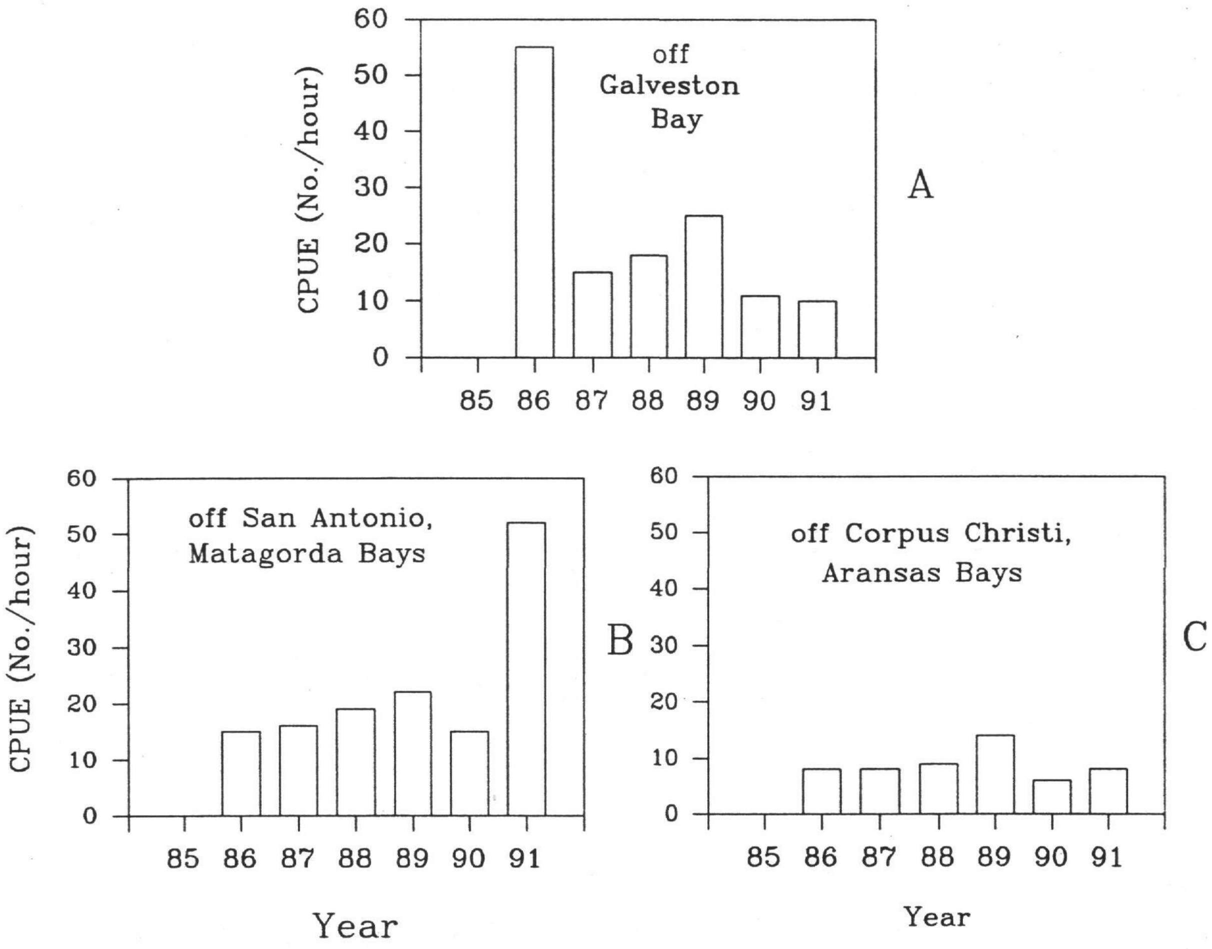


Figure 9. Mean annual CPUE for all sizes of white shrimp caught by trawl in the Gulf of Mexico. A. Statistical Zone 18. B. Statistical Zone 19. C. Statistical Zone 20. Data from Dailey et al. (1991) and McEachron (pers. comm.).

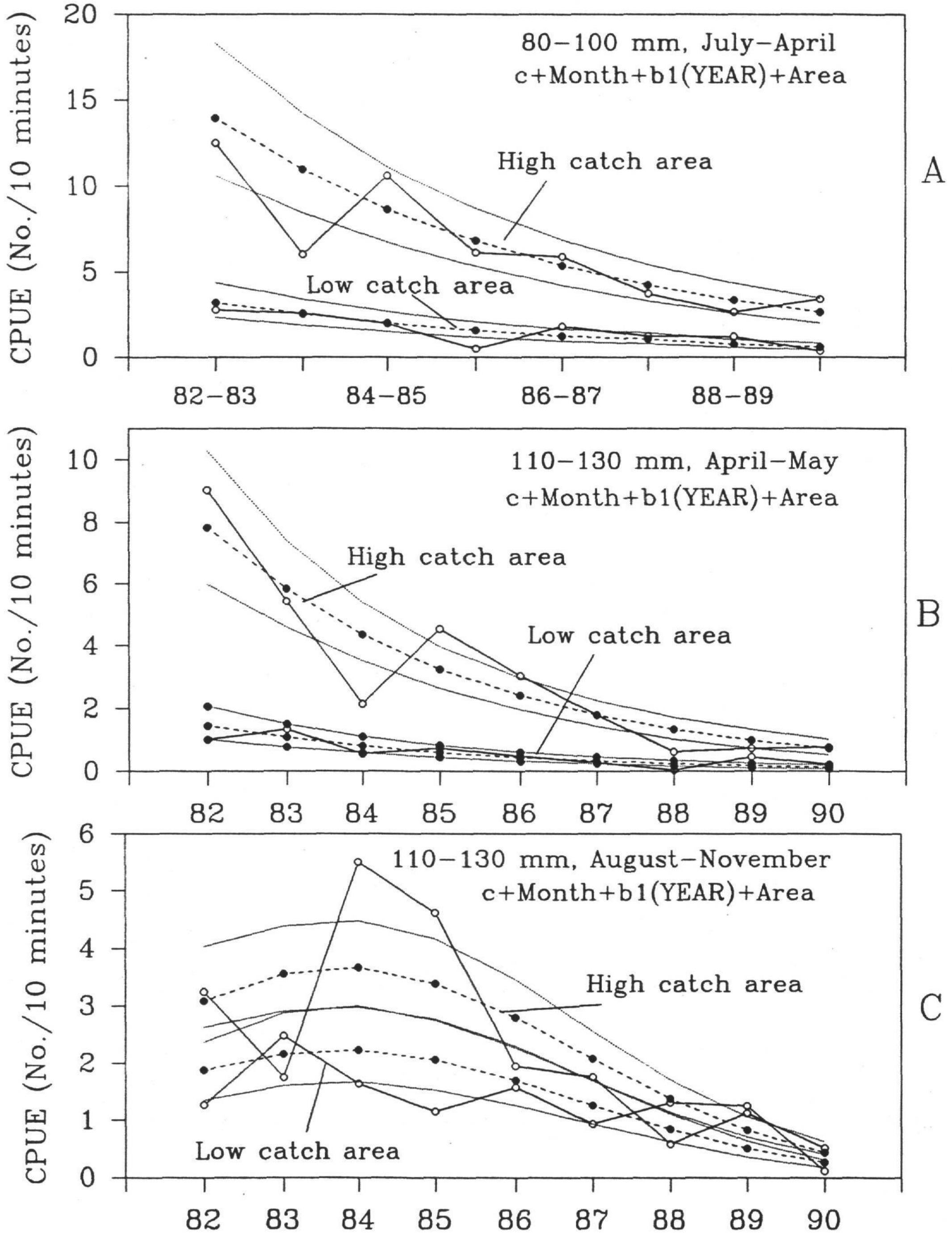


Figure 10. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for white shrimp caught by trawl in areas of high− and low−catch density. Area included in analysis of deviance as categorical variable. A. Juveniles, 80−100 mm, July−April. B. First−time spawners, 110−130 mm, spring C. First−time spawners, 110−130 mm, fall.

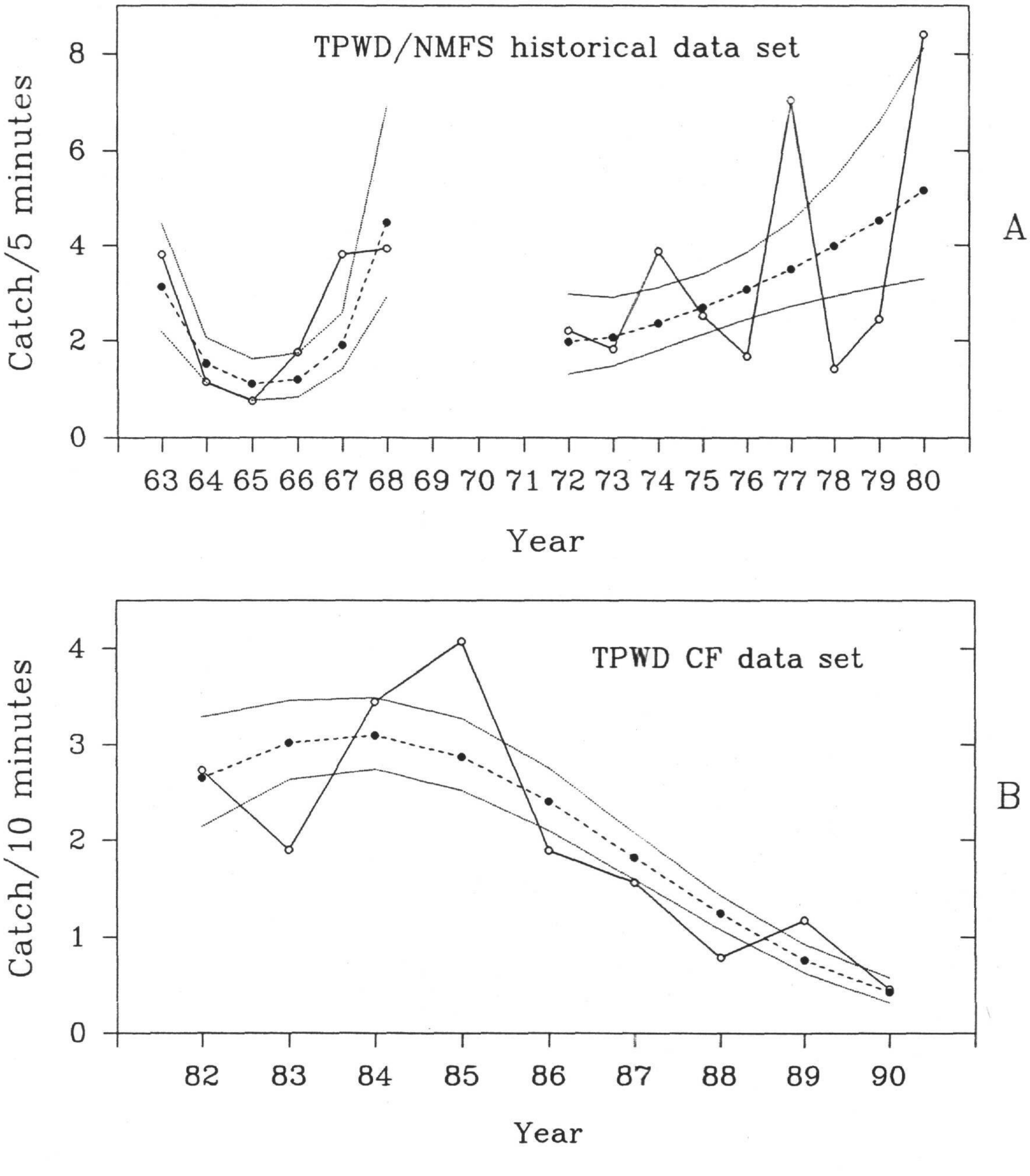


Figure 11. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for white shrimp, 110–130 mm TL, August–November. A. 1963–1968 and 1972–1980, TPWD/NMFS data set. B. 1982–1990, CF data set.

Bag seine data for young of the year showed no trend, while all size ranges caught by trawl showed declines until 1991. However, when bag seine data are confined to the years 1982-1990, the same years analyzed for trawl, the results show a nonlinear decline (Figure 12A). This suggests that trawl data and bag seine data are not as different as they appear. Trawl samples, however, are less constrained geographically and taken more frequently than bag seine samples.

The 1991 rebound and the recognition that white shrimp catches correlate with the Southern Oscillation Index (discussed in Chapter III), suggested that the declining trend in the trawl data was probably part of a larger, cyclical pattern, related to climatic cycles. However, the data may also indicate a real decline superimposed on natural population cycles. One reason not to dismiss the 1982-1990 decline is the possibility that it may indicate a problem with overfishing. Caillouet et al. (1980) observed a Gulf-wide decline in the size of white shrimp from 1959-1976, that continued through 1986 (Cody et al. 1989, Nance et al. 1989). The decline in size is suggestive of growth overfishing.

Harvest and regulation

Shrimpers are highly mobile and efficient. Shrimp boats have become larger and faster in recent years and selective pressure on shrimp is intense. The harvest of white shrimp takes place throughout the year within the estuary (most intensely during April-May and July-December), and until recently, within the nearshore Gulf of Mexico waters along the Texas Coast. This "inshore fishery" was often more intense than fishing offshore.

Until 1989, shallow Gulf waters (0-4 fathoms; 0-7.7 m) were open to trawling throughout the year, saltmarsh nursery areas were open to some bait shrimping, and bay waters could be trawled 24 hours a day. With the adoption of the 1989 Shrimp Management Plan (Cody et al. 1989), regulations designed to protect brown shrimp were changed to extend protection to white shrimp. Shrimping in jurisdictional nursery areas was banned in 1979, with the exception of those shrimpers who were "grandfathered". In 1989 the "grandfather" clause expired and nursery areas became completely closed to shrimping. In 1990, night fishing was banned in the bay during the spring season. In 1990 and 1991, the 0-4 fathom zone of the Gulf was included in the rest of the Texas closure and, for the first time, all shrimping in the Gulf off Texas was banned for two months during the summer. The rebound in white shrimp CPUE in 1990 and/or 1991 may be partially a result of these regulatory changes.

According to data provided by the National Marine Fisheries Service, the number of pounds of white shrimp harvested from Galveston Bay remained fairly steady during the 1970s and 1980s (Figure 13A), though the number of pounds per trip declined during the same time (Figure 13B). The CPUE decreased because effort increased while total harvest remained relatively constant. Reduced landings in 1989, 1990, and 1991 (affected by the regulatory changes discussed above) correspond to a small rebound in CPUE during 1990-1991. Mean size of the shrimp landed also increased. Landings (total pounds) of white shrimp from offshore Gulf waters for Texas as a whole decreased after 1984 but rebounded slightly in 1990 and 1991 (Figure 13C, filled circles).

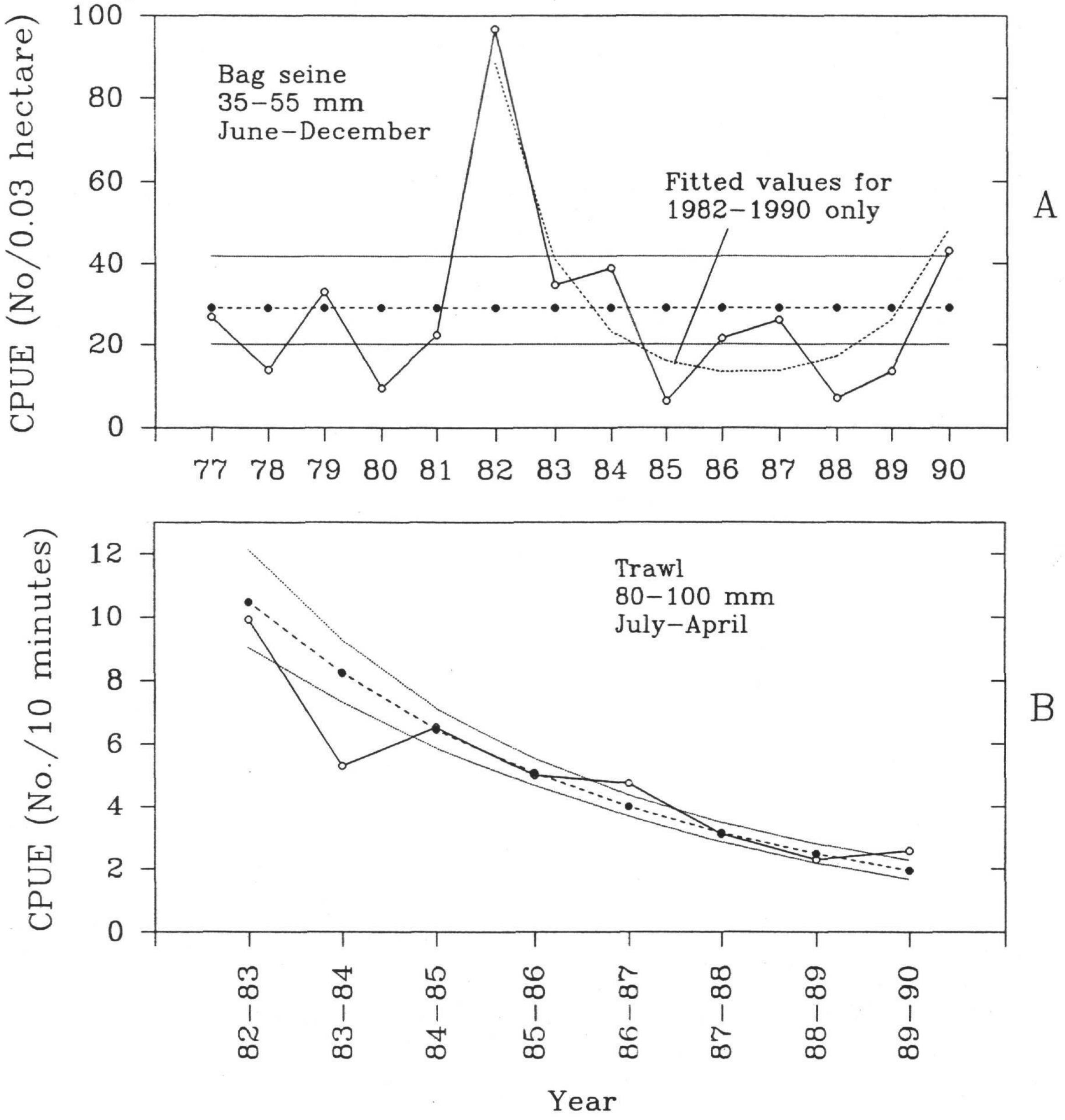


Figure 12. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for juvenile white shrimp. A. Young of the year caught by bag seine, 35–55 mm TL, June–December. Fitted values shown for 1977–90 and 1982–90. B. Juveniles caught by trawl, 80–100 mm TL, July–April, 1982–1990.

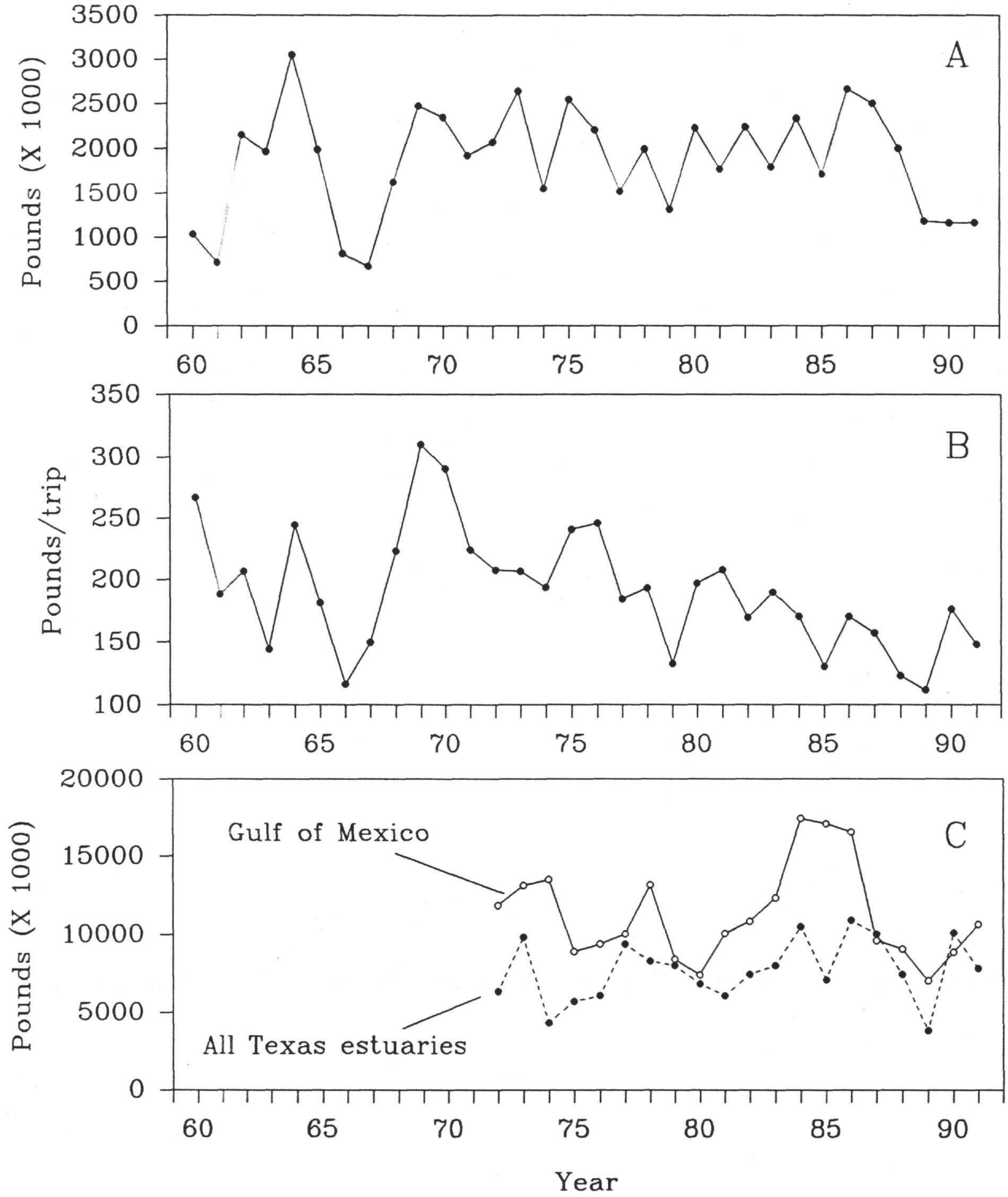


Figure 13. A. Annual commercial landings of white shrimp from the Galveston Estuary. B. Mean annual commercial CPUE (pounds per trip) of white shrimp from the Galveston Estuary. Data from National Marine Fisheries Service. C. Total annual white shrimp landings from Texas estuaries and Gulf of Mexico. Data from Campbell et al. 1992.

Probable causes of 1983-1990 decline

Obvious (but not all) candidates for the cause of the 1983-1990 decline are listed here in order of confidence and probability.

1) **Natural cycles** related to interannual variation in climate. As described in Chapter III, bag seine catches of white shrimp are correlated with El Niño-Southern Oscillation cycles, though the exact effect of large-scale climatic patterns on juvenile shrimp is unclear. The pattern for subadults caught by trawl (Figure 2D) is compatible with a peak during the severe El Niño of 1982-83, no response to the mild El Niño of 1986-87, a possible negative response to the La Niña of 1988-89, and another peak with the development of a moderate El Niño in 1991.

Spring trawl catches of large white shrimp (spawned during fall of the previous year) correlate with SOI on the 93 percent confidence level. This result is not statistically significant by most standards ($p<0.10$), and suspect because of the short time series. Nevertheless it suggests that the same environmental factors that favor juvenile white shrimp during an El Niño year also favor adults in mid-bay habitats.

2) **Overfishing**. This is an obvious probable cause of declining shrimp populations, given the intensity of the shrimp harvest (Figure 13) and the vulnerability of white shrimp in the nearshore Gulf. In addition, mariculturists have observed that relatively minor disturbances can interrupt white shrimp spawning or even cause gravid females to abort (Lawrence, pers. comm.). The harm caused by shrimping in the spawning area may not be restricted to those shrimp that are actually caught.

Changes in shrimping regulations, specifically the complete closure of Texas bays and the near-shore Gulf to shrimping for two months during the time of most intense white shrimp spawning (effective 1990), correlate with the 1991 rebound in white shrimp. However the effects of regulation cannot be separated from those of El Niño with the available data sets.

3) **Variation in freshwater inflow**. This is separated with difficulty from the El Niño-climate explanation. The relationship between inflows and large-scale climate cycles exists, though it is ambiguous. White shrimp abundances did not decline in step with freshwater inflows. However, high inflows are sometimes correlated with population peaks in white or brown shrimp during the following year (Gunter and Hildebrand 1954, Gunter and Edwards 1969). The influx of nutrients during wet years probably cause high productivity of diatoms, an important part of the white shrimp diet (McTigue and Zimmerman 1991). The heavy rains of 1990-1991 may also have affected shrimp populations by flushing contaminants from the estuary, causing low salinities that repel predators, or facilitating larval recruitment to marsh habitat (Chapter IV).

From 1980 through 1989, inflows averaged 442,000-822,000 acre-feet/month. During 1979 and 1990, in contrast, inflows averaged in excess of 1,000,000 acre-feet/month (Figure 3C). The apparent peak in the fall catch of large shrimp in 1980 (Figure 11A) and the 1991 rebound (Figure 2D) follow years of unusually high average inflows. A gradual decline in shrimp numbers may be a consequence of the relatively moderate inflows that prevailed between 1980 and 1989 and reduced cycling of the nutrients brought in during floods. After the construction of the Aswan Dam in 1965 eliminated Nile flooding, nutrient levels in the Delta region dropped, phytoplankton blooms declined, and shrimp populations in the southeastern Mediterranean also declined gradually (Aleem 1972, Wadie and Abdel Razek 1985). Excessive moderation of flow into Galveston Bay may have a similar effect.

4) **Interactions with other organisms**: disease, parasitism, competition, and non-human predation. There are few data available on shrimp morbidity. Brown shrimp (Penaeus aztecus), a possible competitor with white shrimp during at least part of the year, showed no significant trends during the same time periods (Figures 1D, 2H). It is unclear what other species are potential competitors because white shrimp occur in large numbers in the estuary at a season (late summer-winter) when other species are not highly abundant (Figure 5).

The success of restoration efforts for spotted seatrout and red drum raises the possibility that shrimp population trends are affected by trends in their predators. White shrimp are an important prey species (Muncy 1984). Potential predators on white shrimp include: Atlantic croaker (Figures 1C, 2A, 14A), southern flounder (Figures 1V, 14D), pinfish (Figures 1K, 14B), spot (Figures 1G, 2E), Gulf killifish (Figure 1M), spotted seatrout (Figures 1T, 14G, 14H) , and red drum (Figures 1R, 14E, 14F; Matlock and Garcia 1983, Minello, Zimmerman, and Czapla 1989, Minello, Zimmerman and Martinez 1989). Pinfish and spot both showed increases in adult populations while southern flounder showed no trend. Atlantic croaker, black drum, red drum, and spotted seatrout, the four species of Sciaenidae analyzed by Osborn et al. (1992), all showed increases in adult populations. Predation on white shrimp probably increased during the 1980s. How this natural predation compared to freshwater inflow, harvest by humans, or other factors is unknown.

5) **Water and sediment quality**. White shrimp are affected by pollution and have been affected in the Galveston Estuary in the past (Gordon et al. 1972). Water quality has improved in terms of dissolved oxygen and nutrient loading, but heavy metals and other sediment contaminants remain a problem locally (Chapter IV). A widespread pollution problem would be expected to affect other shrimp species as well, especially infaunal brown shrimp. Neither brown shrimp nor grass shrimp, however, show signs of decline (Figures 1D, 1 I, and 2H). The data do not indicate pollution was responsible for the decline in white shrimp (though the flushing and dilution effects of recent high inflows certainly have not been detrimental).

6) **Loss of habitat**. White et al. (1993) estimated a net loss of 19 percent of the Galveston Bay area's vegetated wetlands (32,400 acres) between the 1950s and 1989, of which the greatest proportion was probably intertidal marsh. Marsh and seagrass beds are prime nursery areas for juvenile white shrimp. However, lab experiments (Minello and Zimmerman 1985, Minello et al. 1990) show that white shrimp are not as strongly selective for vegetation as are brown shrimp, which do not show a decline. Drop

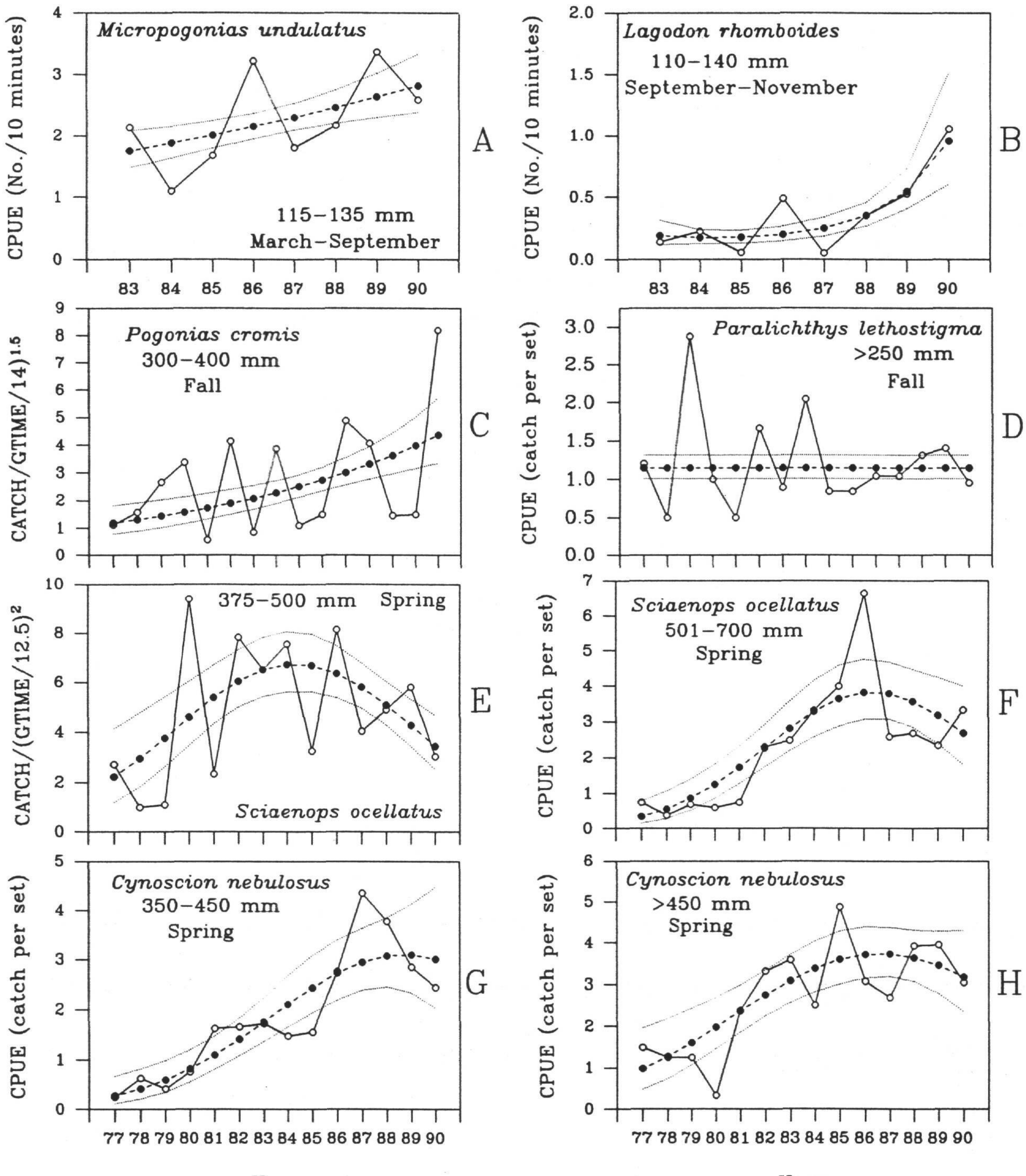


Figure 14. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for large size classes of 6 predatory fish species caught by trawl (A, B) and gill net (C–H). CPUE as defined in Osborn et al. (1992). A. Atlantic croaker. B. Pinfish. C. Black drum. D. Southern flounder. E, F. Red drum. G, H. Spotted seatrout.

samples in the field show white shrimp are common on bare substrate and less dense in marsh vegetation than other crustaceans (Zimmerman and Minello 1984). White shrimp nursery habitat is also crucial to other species, such as Atlantic croaker (Parker 1970, 1971), that do not show a decline (Figures 1D, 2B). Consequently wetland loss alone is probably not responsible for trends in white shrimp abundance. However, disturbance of spawning grounds in the Gulf (discussed above) is a form of habitat loss and may have been a contributing factor to the decline.

7) **Change in forage base**. Shifts in the food chain, such as a decline in the benthic marine worms or algae (especially diatoms) important to white shrimp survival and growth (McTigue and Zimmerman 1991), would be expected to affect other species as well. Unfortunately, the data to evaluate long-term changes in the biomass or composition of the benthos are not available.

Conclusions

It is important to distinguish natural climatically-influenced population cycles from the possible effects of overfishing. If ENSO is the predominating influence, a predicted switch to La Niña conditions during the latter half of 1993 (Keppenne and Ghil 1992) will result in low shrimp catches during 1993-94. If high inflows alone resulted in high catches of white shrimp, the resumption of normal inflows or drought conditions will result in declining shrimp catches until the next period of flooding. In either case, declines in dry years and increases after wet years are normal processes. If changes in fishing regulations are responsible for the high 1991 CPUE, then the rebound should be coastwide and long term.

A continued decline in white shrimp would be directly detrimental to a major commercial fishery. Other commercial and recreational fisheries would be indirectly affected in that a major food source would be removed for southern flounder, spotted seatrout, sand seatrout, and red drum.

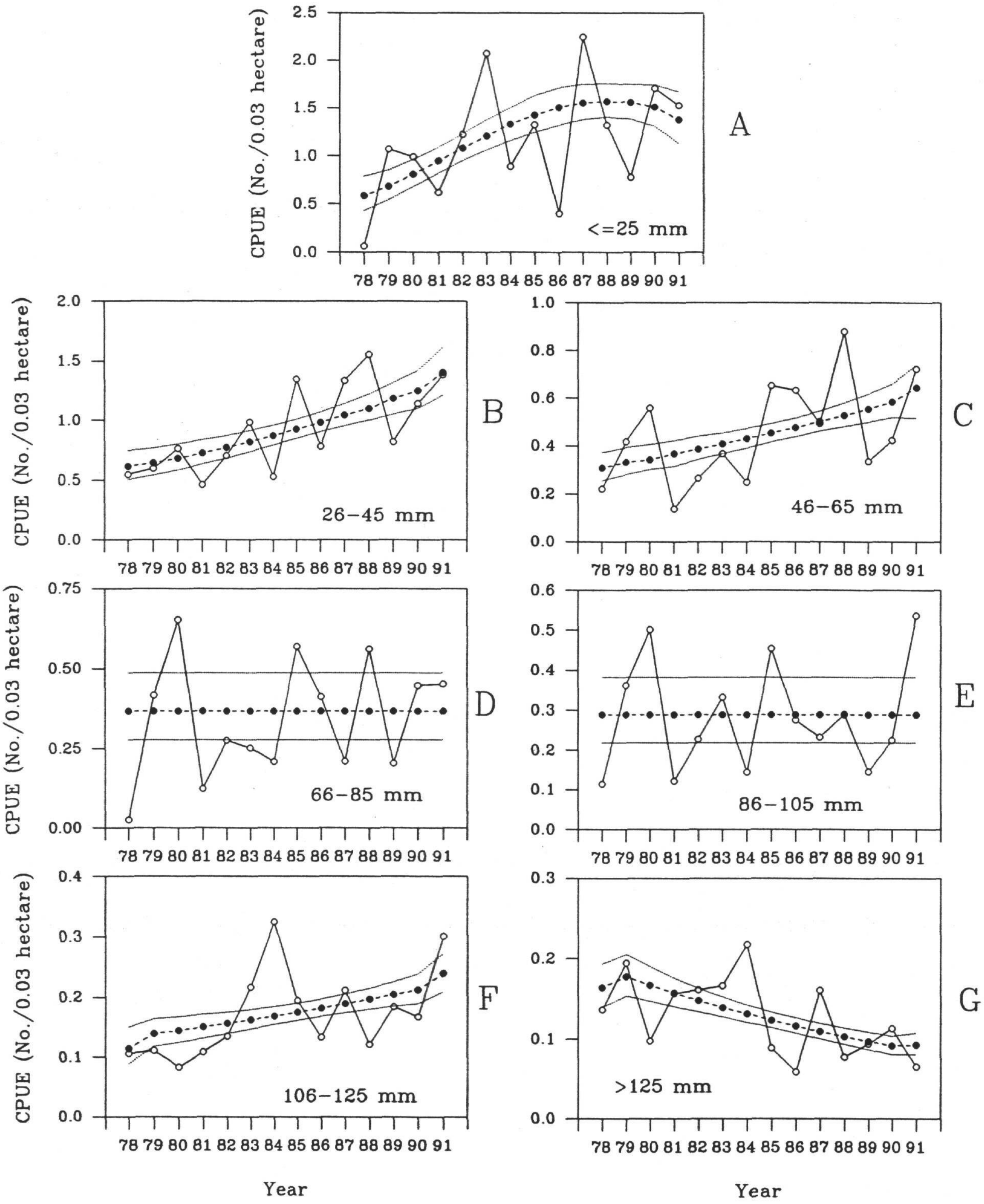


Figure 15. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for seven size classes of blue crab caught by bag seine.

VI. BLUE CRAB

Trend analyses on different 20-mm size groups in bag seine and trawl data (Figures 15, 16) for blue crab (Callinectes sapidus) showed that the smallest size classes increased in numbers, whereas the largest size classes decreased linearly. Though growth overfishing is the most probable cause of the decline in large crab, the trends may also have been affected by poorly-understood ecological changes such as increased predation and spatial shifts in habitat.

Trends in size-age groups

Blue crab are caught in substantial numbers throughout the year. Consequently all months were considered for trend analysis. Sample sizes were large enough that it was possible to subdivide the entire size range caught by bag seine and trawl into 20-mm size classes and perform trend analyses on them separately. Bag seine data showed a decline only in the largest size class of crab (> 125 mm total carapace width, TW) while smaller size classes increased or showed no trend, a pattern compatible with a directed (growth) overfishing hypothesis (Figure 15). In contrast, trawl data showed declines in intermediate size classes as small as the 46-65 mm group, though the decline was greatest for the market-size groups (Figure 16). The legal size limit for blue crab is five inches TW (127 mm), but there is anecdotal evidence for considerable illegal harvesting of undersized crab. "Market size" crab were considered to be all those greater than 115 mm TW.

The intriguing differences in pattern for bag seine and trawl results possibly reflect differing conditions in bay margin (bag seine) and mid-bay (trawl) habitats. This suggests intermediate-size crab may be making increased use of the bay margin in preference to the open bay. However, confining the bag seine data to the years 1982-91 (the same years as for trawl data and years of densest sampling) resulted in essentially the same pattern of trends for both data sets, suggesting the differences may be the result of examining two time series of different lengths.

Recruitment was not a problem. The smallest size classes sampled by both bag seine and trawl showed increases (Figures 15A, B, C and 16A). If megalopal blue crab are as widely dispersed and mobile off the Texas coast as they are in other parts of the Gulf of Mexico (Steele and Perry 1990), strong recruitment could continue even if the adult population in that bay were reduced.

Geographic extent and trends by sex

Considerable variation may be ascribed to local conditions. Drop-sampler data from a salt marsh in Galveston Island State Park showed opposite trends from those found here for bag seine (McTigue and Zimmerman, pers. comm.). Trawl data subdivided by bay zone (upper and lower estuary) yielded trends differing in shape and magnitude, but not in direction of slope, implying the overall declines are bay-wide rather than local

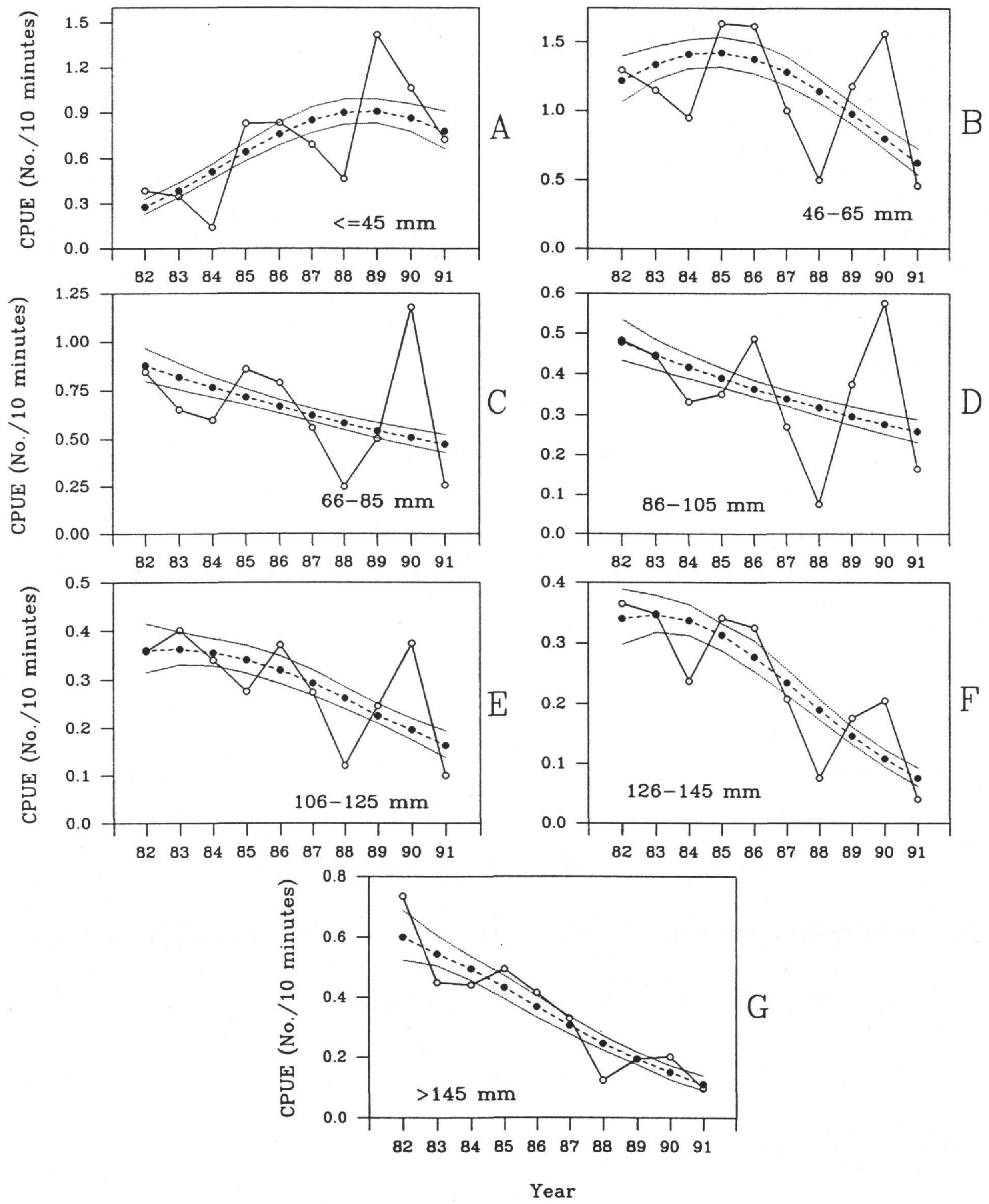


Figure 16. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for seven size classes of blue crab caught by trawl.

phenomena (Figure 17). There were greater slopes and a quadratic component to the trends in the upper bay (oligohaline-mesohaline), while the lower bay (mesohaline-polyhaline) showed gentler, linear trends.

The greater intensity of the decline in large crab in the upper bay zone raised the possibility of directed overfishing of male blue crab (Figure 17C). Female crabs are obliged to migrate to high-salinity waters in order to spawn but males are not (More 1969, Benefield and Linton 1990). Consequently males tend to concentrate in the fresher parts of estuaries where they are targeted by the fishery (Millikin and Williams 1984, McClintock and Marion 1990). Females outnumber males in the CF data set, especially in trawl samples. Sampling bias is also a possibility if adult male crab are concentrated far upriver and high in freshwater areas, where neither bag seine nor trawl samples are taken. Analyses of deviance revealed no significant differences in trends between males and females that would demonstrate directed overfishing of males. The available time series is short, however, because sex data were only recorded from 1982 through 1987. Neither are there obvious differences in the spatial distribution of the two sexes at any time of year that cannot be explained by a greater number of females in the data set (Figures 18, 19, 20).

More crab are landed from the Galveston Estuary than any other in Texas (Hammerschmidt 1985). Because the Galveston Estuary is the largest in Texas, calculations of coastwide trends, weighted by estuarine area, revealed a coastwide decline in the size of blue crab that influenced the Blue Crab Management Plan (Cody et al. 1992). However, a comparison of trends among all Texas estuaries (Figures 21, 22) showed analogous declines in the larger sizes of blue crab only in Aransas Bay (Figure 22D) and the Upper Laguna Madre (Figure 22F). These estuaries are sufficiently different from Galveston, both physically and economically, that the population trends of concern here should be considered unique to the Galveston Estuary.

Though recruitment was apparently strong in the Galveston Estuary, Figures 21-22 suggest there may be cause for concern in San Antonio Bay or the Laguna Madre.

Temporal extent and reliability

How long blue crab have been declining is unknown because a historical fishery-independent data set (previous to 1977) for blue crab is not available. The CF data indicate the observed trends have prevailed at least since 1978 or 1979 (Figure 15).

It is possible that the observed trends are merely the downward portion of a cyclical pattern, or that (as discussed for white shrimp) a real decline may be superimposed on natural population cycles. The discussion here continues on the assumption that the trends are affected by human activity.

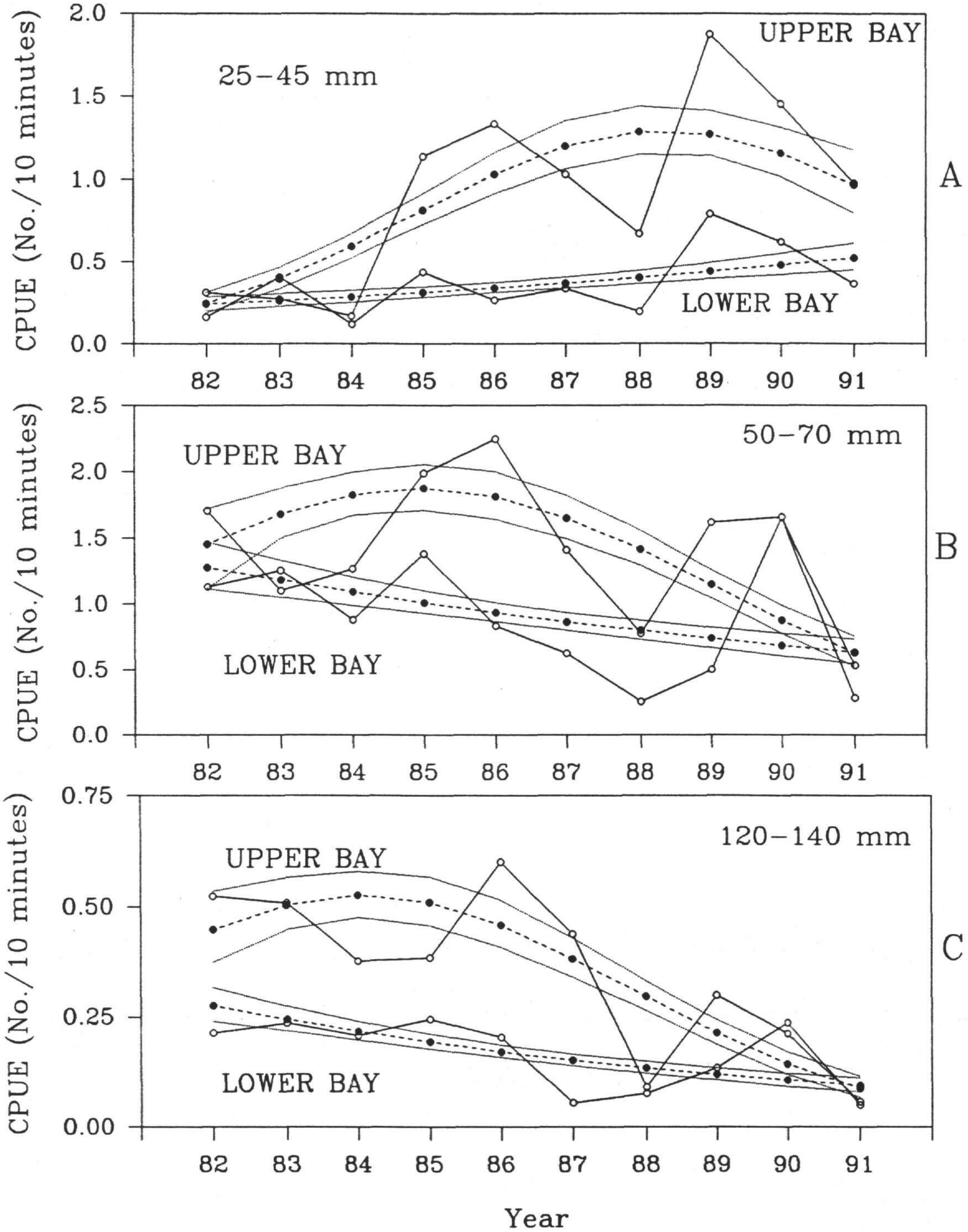
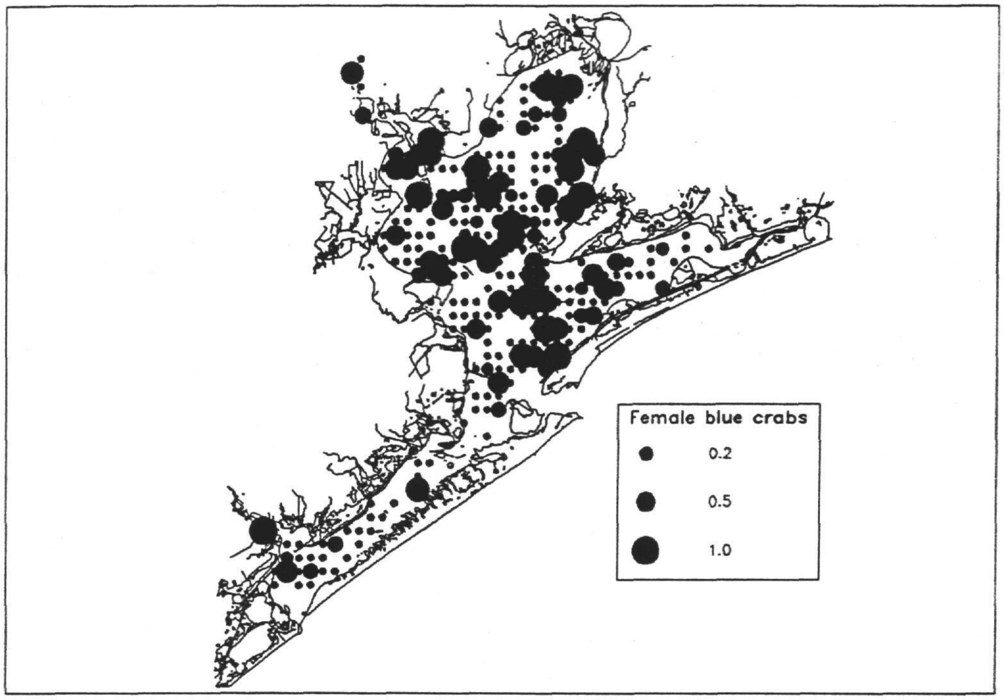
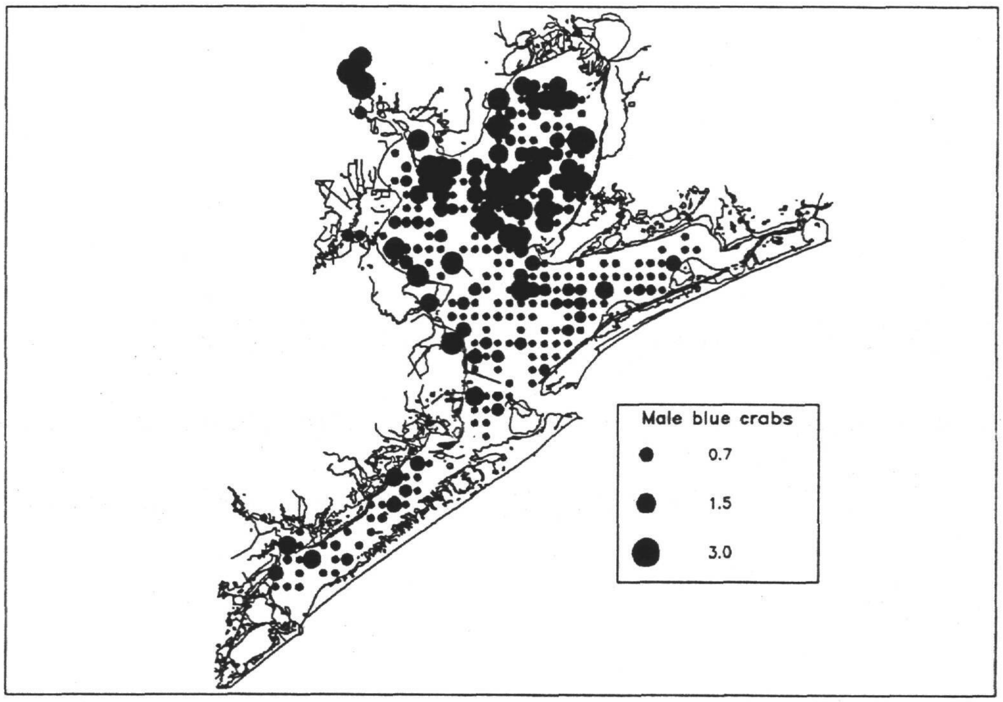


Figure 17. Mean annual CPUE with fitted values and confidence intervals (±S.E.) for blue crab caught by trawl in upper and lower zones of Galveston Estuary. A. Young of the year, 25–45 mm TW, all months. B. Juveniles, 50–70 mm, all months. C. First-time spawners, 120–140 mm, all months.

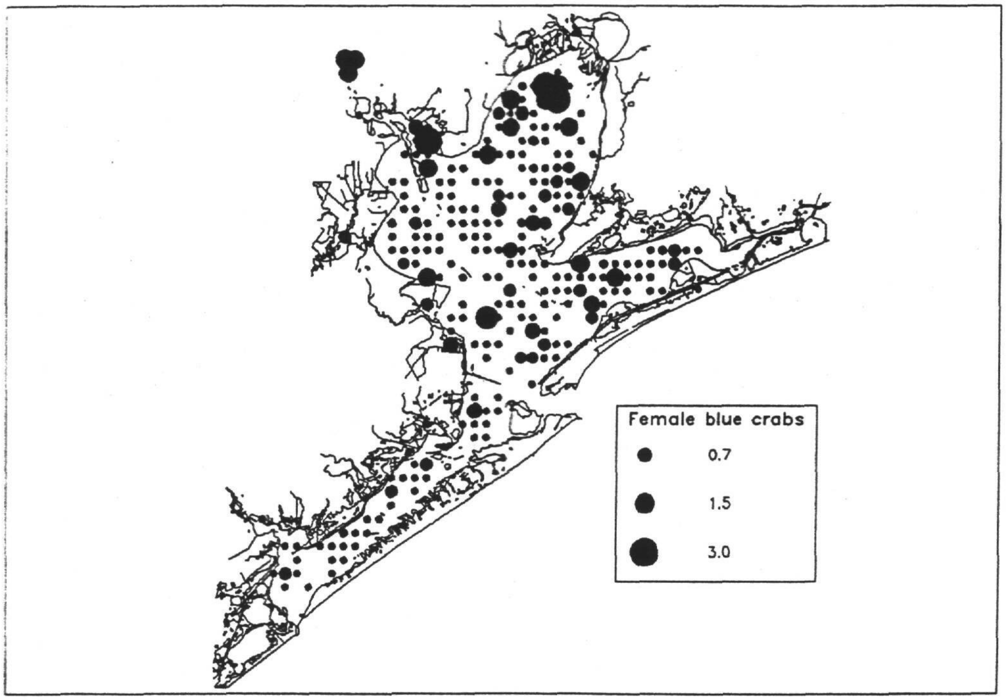


A



B

Figure 18. Spatial distribution of adult (>120 mm TW) blue crab within the Galveston Estuary, March–July. Trawl data pooled from 1982–1987. Circles size proportional to mean CPUE. A. Females. B. Males.



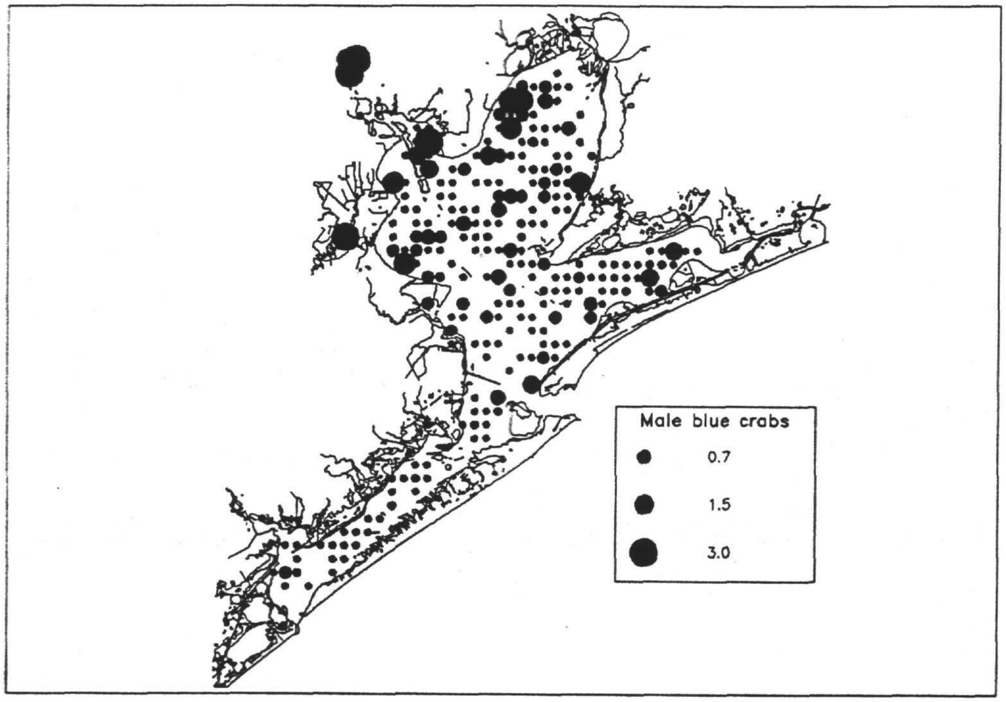
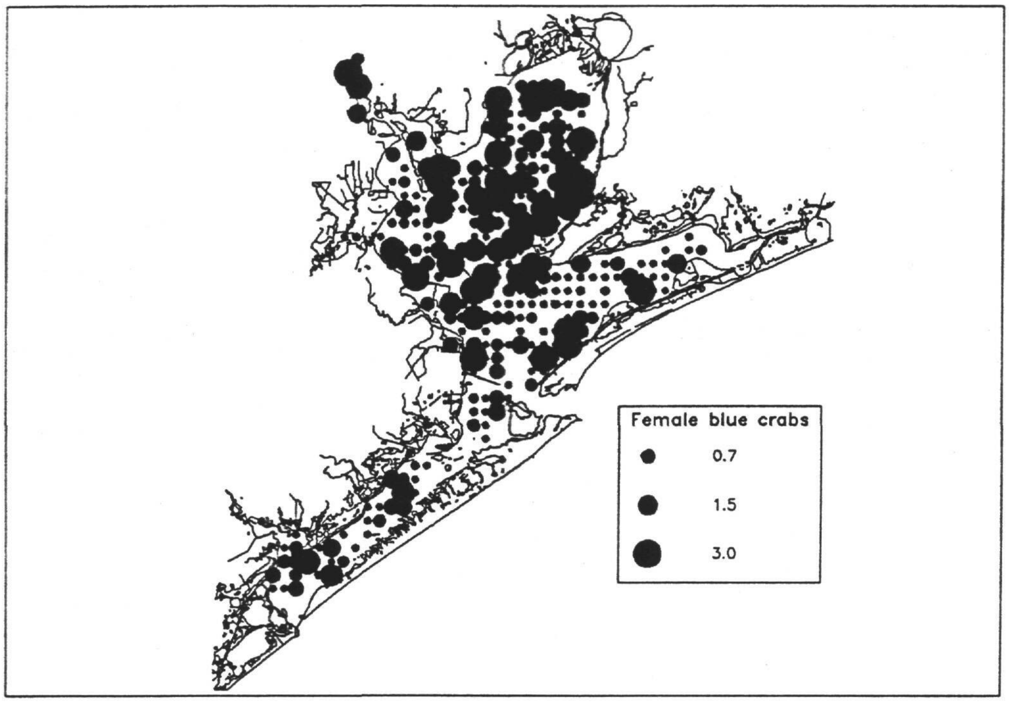
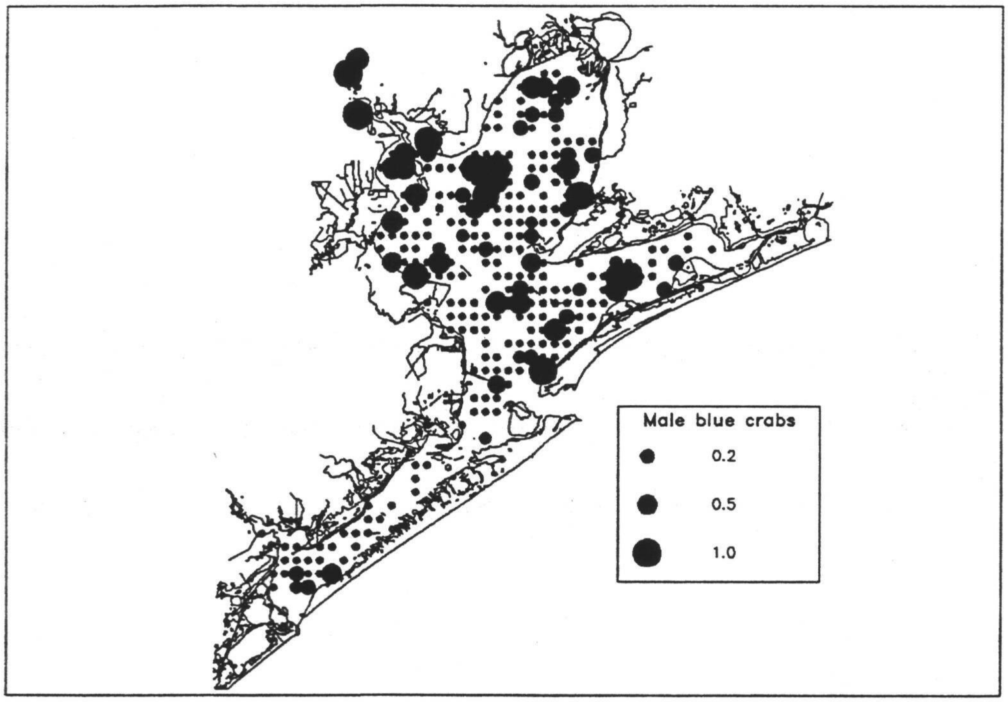


Figure 19. Spatial distribution of adult (>120 mm TW) blue crab within the Galveston Estuary, August–October. Trawl data pooled from 1982–1987. Circles size proportional to mean CPUE. A. Females. B. Males.



A



B

Figure 20. Spatial distribution of adult (>120 mm TW) blue crab within the Galveston Estuary, November–February. Trawl data pooled from 1982–1987. Circles size proportional to mean CPUE. A. Females. B. Males.

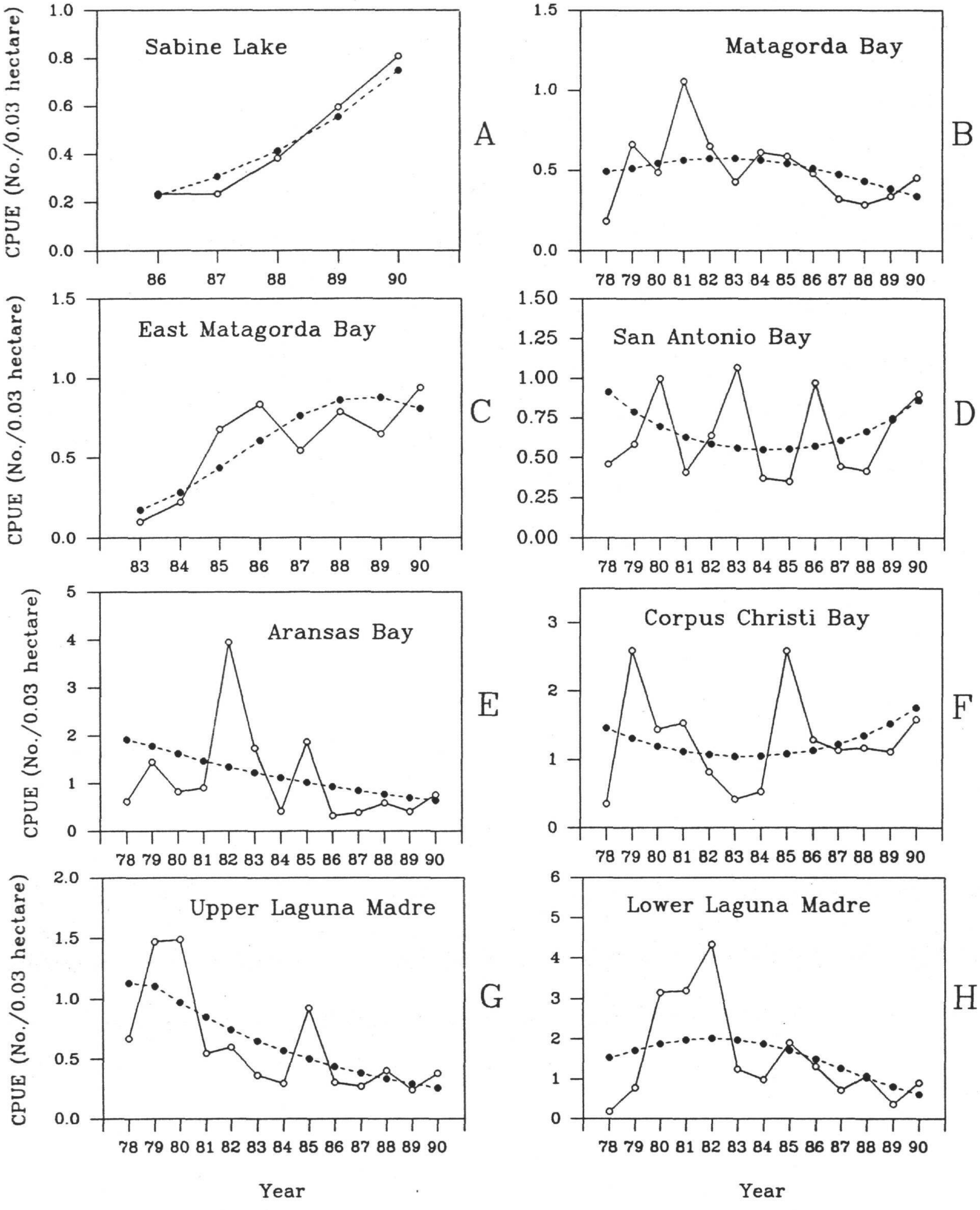


Figure 21. Mean annual CPUE with fitted values for blue crab caught by bag seine, 25–45 mm, all months, in all major Texas estuaries other than Galveston.

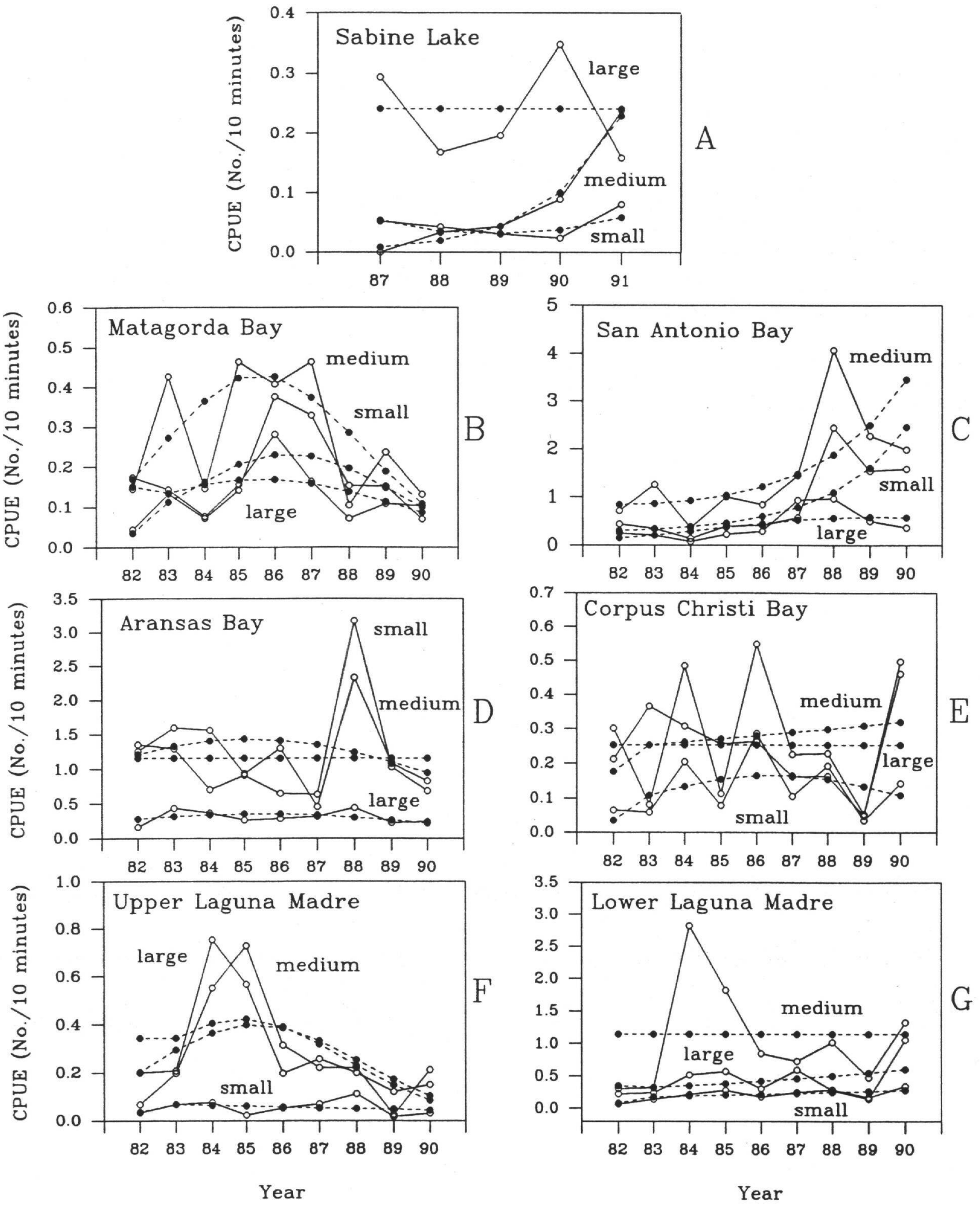


Figure 22. Mean annual CPUE with fitted values for small (25–45 mm TW), medium (50–70 mm), and large (120–140 mm) blue crab caught by trawl, all months, in all major estuaries other than Galveston.

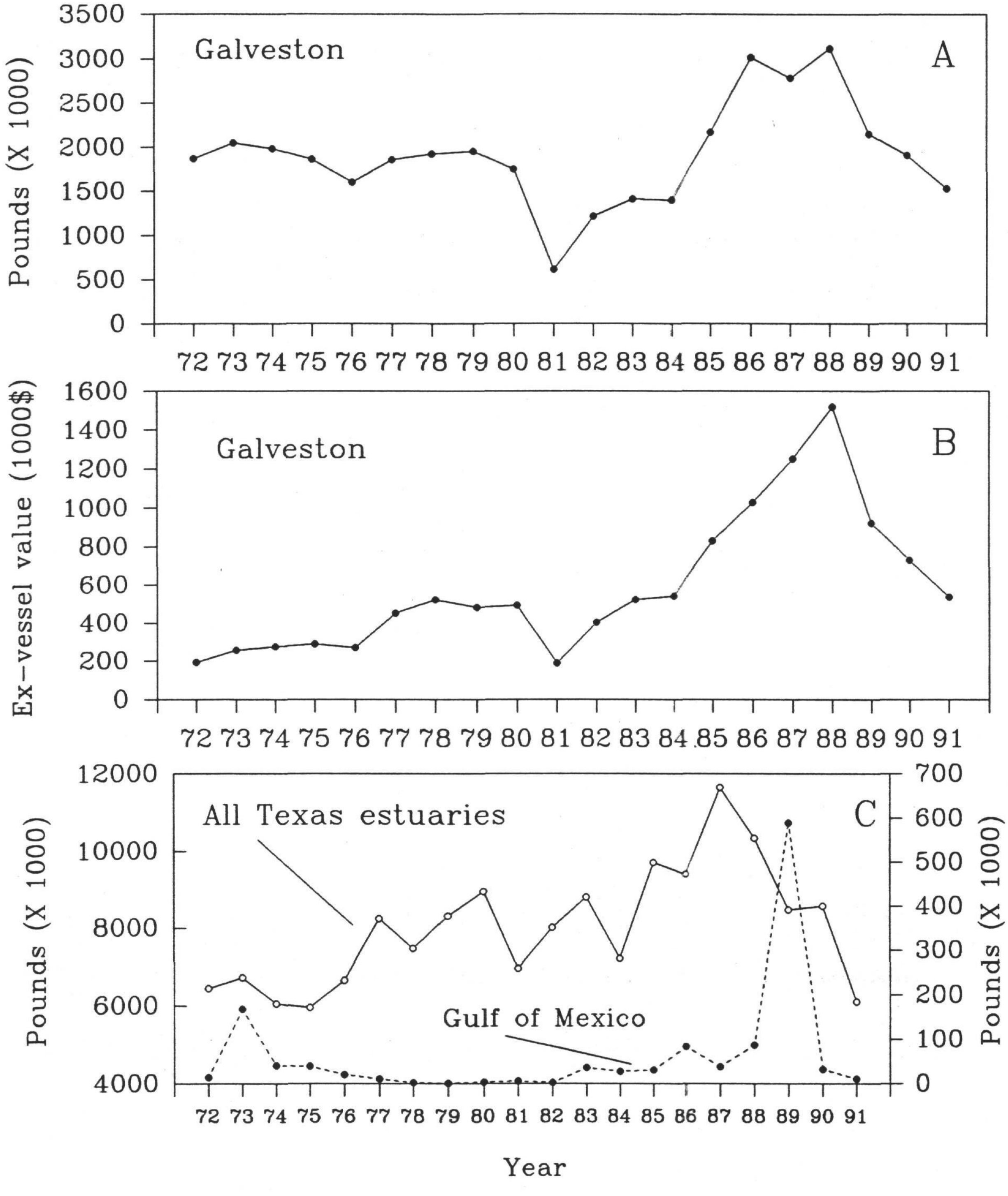


Figure 23. A. Annual commercial landings of blue crab from the Galveston Estuary. B. Ex-vessel value of blue crab landed from the Galveston Estuary. C. Total annual blue crab landings from all Texas estuaries (left axis, hollow circles) and from Gulf of Mexico (right axis, filled circles). Data from Campbell et al. 1992.

Harvest and regulation

Commercial landings of blue crab in the Galveston Estuary increased during the last thirty years (Osborn 1992) as the price of blue crab steadily increased (Figure 23B). Aerial surveys indicate the number of crab traps in Texas bays roughly doubled from 1977-78 to 1985 (Hammerschmidt and Benefield 1986). It requires little capital to enter commercial crabbing relative to other fisheries. Data on recreational or bait crabbing are sparse, though the literature mentions these as important components of the blue crab fishery (Cody et al. 1992). Anecdotal evidence suggests that crab, taken legally and illegally, are popular with visitors and are an important food source for coastal residents. Jaworski (1972) estimated that the actual crab harvest in Louisiana may be twice as high as that indicated by landings records. Perry et al. (1984) also observed that reported commercial landings are probably less accurate than similar data for other fisheries, as a consequence of unrecorded direct sales to fish markets and the public.

Regulations affecting the harvest of blue crab are relatively simple and few: crab traps must be tagged, the number of crab traps is limited per fisherman and in certain areas, gear and gear size are restricted, sponge crabs (egg-bearing females) may not be retained, and crab smaller than five inches (127 mm TW) may not be retained, except for bait. There are no seasons or bag limits and few areas are restricted. Crabs are used as bait mainly by black drum fishermen and account for a very small proportion of the bait fishery; less than 1% of sport-boat fishermen reported using crab for bait during 1983-90 (Cody et al. 1992).

Probable causes

Possible causes for the declines in larger blue crab are listed here in order of confidence and probability. The list is not necessarily comprehensive.

1) **Overfishing**. Overfishing can result from the excessive legal harvesting of adults, excessive black-market harvesting of sublegal-size crab, excessive legal harvesting of juveniles for bait, excessive recreational harvesting (legal and illegal), or ghost fishing (abandoned crab traps).

The bait fishery is probably minor (Cody et al. 1992). Black market crabbing and ghost fishing, though known to occur perhaps extensively, are poorly documented. Data on the recreational harvest are also sparse and estimates of the impact of the recreational fishery vary widely (Cody et al. 1992). Useful data are available only for the commercial harvest of market-size crab, which show that crab are increasingly valuable and exploited with increasing intensity coastwide (Figure 23C). Market-size populations of blue crab may be declining in step.

Given that larger blue crab (>60 mm) are cannibalistic on small blue crab, the number of juveniles may be increasing as their predators decline (discussed below). It is also possible that the harvest of market-size blue crab is sufficiently intense to impose selection for small size, as has been proposed for other fisheries (Nelson and Soulé 1987).

2) **Natural (non-human) predation**. Many of the same predators that consume white shrimp also eat blue crab: Atlantic croaker (Figures 1C, 2B, 14A), southern flounder (Figures 1V, 14D), spot (Figures 1G, 2E), red drum (Figures 1R, 14E, 14F), spotted seatrout (Figures 1T, 14G, 14H), black drum (Figures 1W, 14C) and pinfish (Figures 1K, 14B; Matlock and Garcia 1983, Millikin and Williams 1984, Thomas et al. 1990, Steele and Perry 1990). Other predators include raccoons, birds (clapper rail, great blue heron, and mergansers), and larger blue crab (Darnell 1958, Millikin and Williams 1984, Steele and Perry 1990).

Pinfish, spot, spotted seatrout, red drum, and black drum increased in population in recent years. Predation on small blue crab by fish probably increased, though predation on small crab by larger blue crab probably decreased. How this natural predation compared to the harvest by humans or other human-induced factors is unknown.

3) **Natural cycles** and natural environmental effects. The time series is not long enough to demonstrate a periodicity greater than two or three years. Though many environmental variables are known to affect blue crab (e.g. temperature, salinity, wind direction at the time of megalopal migration into the estuary), most short-term events have only short-term or local effects. Low harvests and low bag seine catches in 1981 probably resulted from low recruitment that year, but did not affect the overall trend. Available climatic data (Chapter III) show little correspondence with blue crab CPUE data.

4) **Variation in freshwater inflow**. Blue crab thrive at low salinities and occur in greatest numbers in estuaries receiving substantial fresh water inflow (More 1969). However, salt water is a limiting factor because a salinity near that of sea water is a physiological requirement for spawning (More 1969). Records of river inflow to the Galveston Estuary (Figures 3B, 3C) suggest a possible relationship between inflow and blue crab recruitment, in that low trawl catches of blue crab during 1988 may be related to a dry year (associated with a La Niña event). However, the decline in the largest sizes of blue crab continued in spite of high inflows during 1989-1991.

5) **Increased morbidity** (disease and parasites). Blue crab pathologies are relatively well-documented (Millikin and Williams 1984), though their incidence in the Galveston Estuary is not. The CF data set records observations of infestation by Loxothylacus texanus (a sacculinid barnacle) only from 1982 through 1987. There is no obvious trend (Figure 24). Anecdotal evidence (McTigue, pers. comm.; Wardle, pers. comm.) suggests sacculinid infections are localized, and the rate of infection may be reduced in 1991-1992 as a consequence of high freshwater inflows (Ragan and Matherne 1974). Though crab morbidity may be a factor in observed population trends, the available data do not show it.

6) **Loss of wetland habitat and SAV**. Wetlands, especially submerged aquatic vegetation, are heavily used by juvenile blue crab (Orth and van Montfrans 1990).

Wetland loss has undoubtedly affected blue crab, though the most rapid loss of vegetated wetlands in the Galveston Estuary (discussed in Chapter IV) occurred mostly before the period of CF sampling. Wetland loss alone does not explain the pattern of trends in various size classes because juveniles show an increase at the same time that adults, which use vegetated wetlands less intensely, declined.

7) Mortality or habitat disturbance caused by **shrimp trawling**. Blue crab are one of the most common species captured by trawling (Figure 2C) and a well-documented "bycatch species" (Bryan et al. 1982, Nance et al. 1993). Blue crab are also one of the species most likely to survive being trawled, exposed to air, and discarded, by virtue of their hard carapace and resistance to dehydration. Other "bycatch species" (Nance et al. 1993) include Atlantic croaker (Figure 2B), Gulf menhaden (Figure 2F), sand seatrout (Figure 2G), bay anchovy (Figure 2M), spot (Figure 2F), and brief squid (Figure 2J), of which only squid show a possible decline. Though direct mortality caused by shrimp trawling is likely to affect other species before blue crab, the possible role of habitat disturbance is unknown.

8) **Water quality**. Blue crab are "hard to kill" and adaptable to a variety of habitats relative to other species. Pollution is more likely to affect other species before blue crab, because the crab hepatopancreas is effective at removing common toxins (Millikin and Williams 1984). The study of toxic contamination in food organisms by Brooks et al. (1992) found blue crab to be less contaminated than oysters, spotted seatrout, black drum, or southern flounder.

9) **Change in forage base**. A food supply problem would similarly appear in other species before blue crab, which are classified as detritivores, omnivores, or opportunistic carnivores depending on ontogenetic stage or food availability. Large blue crab are relatively unspecialized carnivores that consume a variety of fish, crustaceans, mollusks, and annelids (Perry et al. 1984, Alexander 1986, Steele and Perry 1990, Fitz and Wiegert 1991).

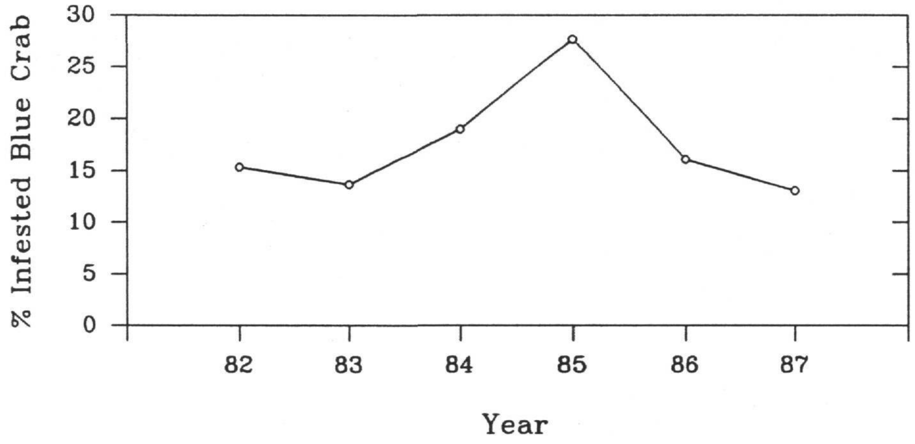


Figure 24. Annual percentage of blue crab in trawl samples parasitized by *L. texanus* (out of all crab typed).

Discussion and conclusions

The data presently available suggest directed growth overfishing to be the greatest influence on observed blue crab population trends. This conclusion is qualitative, however, because blue crab are exceptionally complicated among fisheries species. Their life cycle is complex, there is a surprising number of unanswered questions about blue crab biology for such a ubiquitous species, and the many aspects of the harvest are relatively poorly documented.

A separate, but possibly related, question from the decline in market-size adults is the apparent increase in intermediate-size blue crab in bag seine catches (Figure 15) associated with decreases in the same size classes in trawl catches (Figure 16). Bay margin habitat may be increasingly favored relative to open-bay habitat because of spatial shifts in food supply. As an alternative explanation, an increase in mortality among large blue crab (probably human-induced) may result in decreased mortality (by cannibalism) and increased availability of resources (by reduced competition) for the smaller size classes.

The study of ambient water quality in Galveston Bay by Ward and Armstrong (1992) shows a decline in total suspended solids (TSS; turbidity), nitrates, and chlorophyll a over the past thirty years. As discussed in Chapter IV, these trends probably demonstrate that regulation of industry has been successful in reducing nutrient loading (Stanley 1989). In light of the trends in blue crab, they may also indicate a slow decline in primary productivity in mid-bay regions while bay margins remain relatively productive. Zimmerman et al. (1991) suggested that drowning coastal marsh is even more productive than stable marsh, so young blue crab may be taking advantage of the temporary benefits of relative sea level rise. The long-term effects of declining TSS are unknown. Drowning marsh will eventually be replaced by open-bay bottom, with unknown, but probably unfavorable, consequences for blue crab.

A continued decline in large blue crab will eventually lead to a collapse of the commercial fishery in the Galveston Estuary and probably an intensification of crabbing pressure elsewhere. The ecological consequences of a reduction or disappearance of large blue crab are the subject of speculation. Small blue crab are probably more heavily preyed upon than large blue crab, so continued high recruitment would probably ensure the presence of an important food item for many species of fish and birds. However, a severe decline in adult blue crab would probably affect recruitment eventually, especially if the declines extend beyond the Galveston Estuary. There are probably food items that are only available to predation or scavenging by crab of some minimum size, but the possible effects of the absence of the predator or scavenger are unknown.

VI. BIRDS

Of all birds in the Galveston Estuary area, colonial waterbirds are the best documented and potentially the best indicators of the health of the estuary. They are highly visible, sensitive to environmental changes in nesting or feeding habitat, and high on the food chain (therefore likely to bioaccumulate contaminants). Declining trends in those colonial waterbirds that feed at the marsh-bay interface suggest recent reductions in tidal marsh habitat and/or habitat quality and/or marsh prey species. The probable causes for the general decline in northern pintails and green-winged teal probably lie beyond the Galveston Estuary, but declines in non-migratory mottled ducks are driven by conditions within Texas, such as salt water intrusion into nesting habitat.

Given the high mobility of birds, it is inappropriate to evaluate the health of a species based on data from a geographic area as small as a single estuary. However, when the question concerns the health of the estuary (not of a species), birds are appropriate indicators.

COLONIAL WATERBIRDS

Trend analyses by Slack et al.

The initial study by Slack et al. (1992), "Status and Trends of Selected Vertebrate Resources in the Galveston Estuary: Birds and Alligators", showed a decreasing trend in total numbers of certain colonial waterbirds based on data from the Texas Colonial Waterbird Survey: snowy egrets, Egretta thula; black skimmers, Rynchops niger; tricolored herons, Egretta tricolor; and roseate spoonbills, Ajaia ajaja (Figures 25, 26, 27, 28). There was also a decrease in the number of birds per colony for these species plus great egrets (Casmerodius albus; Figure 29), suggesting a change in the structure of the colonial waterbird community. Olivaceous cormorants (Phalacrocorax brasilianus) were exceptional among colonial waterbirds in showing an increase (Figure 30). Among the waterfowl, mottled ducks (Anas fulvigula), northern pintails (Anas acuta), and blue-winged teal (Anas discors) declined in abundance based on the Mid-winter Waterfowl Transects (Figures 31, 32, 33), reflecting a widespread trend that has been cause for concern on the national level (Figure 34). At least six species of shorebirds appeared to be stable or possibly increasing.

Subsequent work by Slack et al. (in prep.) focused on the Texas Colonial Waterbird Survey, the most robust data set available on estuarine birds. There was no significant trend in the total numbers of birds and little or no trend in species richness from 1973 through 1990. However, a detrended correspondence analysis (using the methodology of Spendelow et al. 1989) revealed significant changes in species and habitat associations. Birds with similar population trends fell into three different groups, each with similar feeding habitats.

1) An inland group (little blue herons, white ibises, cattle egrets, white-faced ibises, and great blue herons) was composed of freshwater marsh feeders and generalists. There was no significant change in the number of individuals or the percentage of them in the community overall. The number of colonies containing these species increased, but in those colonies where they are present, their proportion in the colony decreased.

2) An open-water group (royal terns, Caspian terns, olivaceous cormorants, Forster's terns, and Sandwich terns) was mainly composed of open-bay fish-eating birds. The number of individuals, the number of colonies occupied by them, and the number of them in the community overall increased. The percentage of their representation in the colony showed no significant change. Black-crowned night herons, though marsh-feeding birds, unexpectedly clustered with this open-water group.

3) A marsh group (tricolored herons, snowy egrets, black skimmers, roseate spoonbills, and great egrets) was made up of birds that feed on small fish and invertebrates at the marsh-bay interface. This group declined both in total numbers and the proportion the composed in those colonies where they occur. The number of colonies containing them increased but the mean colony size decreased (Figures 25, 26, 27, 28, 29). All these are wading birds except black skimmers, which fell into this group probably because they feed in nearshore areas where the water surface is smooth rather than in rougher open bay waters.

Least terns were outliers in this analysis, probably because they are more opportunistic nesters than strictly colonial and are therefore difficult to count accurately. Laughing gulls are generalists that showed no population trend and were not associated with declining species.

Slack et al. (in prep.) concluded that feeding habitat, not nesting habitat, was probably the controlling factor in the observed trends, because most of the colonial waterbird species nest together. The decline in marsh-feeding birds is probably correlated with wetland loss. Although nesting habitat is not suspected of being the controlling factor in the Galveston Estuary, it can be crucial on a more local scale (Mike Lange, pers. comm.). The problems of waterbird colonies in the Galveston Estuary area are well documented: rookeries have been lost to subsidence or erosion, disturbed by humans, invaded by fire ants, or decimated by mammalian predators. Nesting habitat is undeniably important, though not necessarily a driving force of the estuary-wide trend.

Reliability and temporal extent

Texas Colonial Waterbird Survey data have been analyzed independently by Glass (1992), Telfair (in press), and Lange (in review). Their analyses corroborate the results of Slack et al. (in prep.). The decline in black skimmers has also been observed elsewhere (King and Krynitsky 1986).

Telfair (in press) concentrated on inland bird colonies and the possible influence of the cattle egret on colony life span. He found that excluding colonies for which there were incomplete censuses (mainly inland colonies) changed the magnitude, but not the slope,

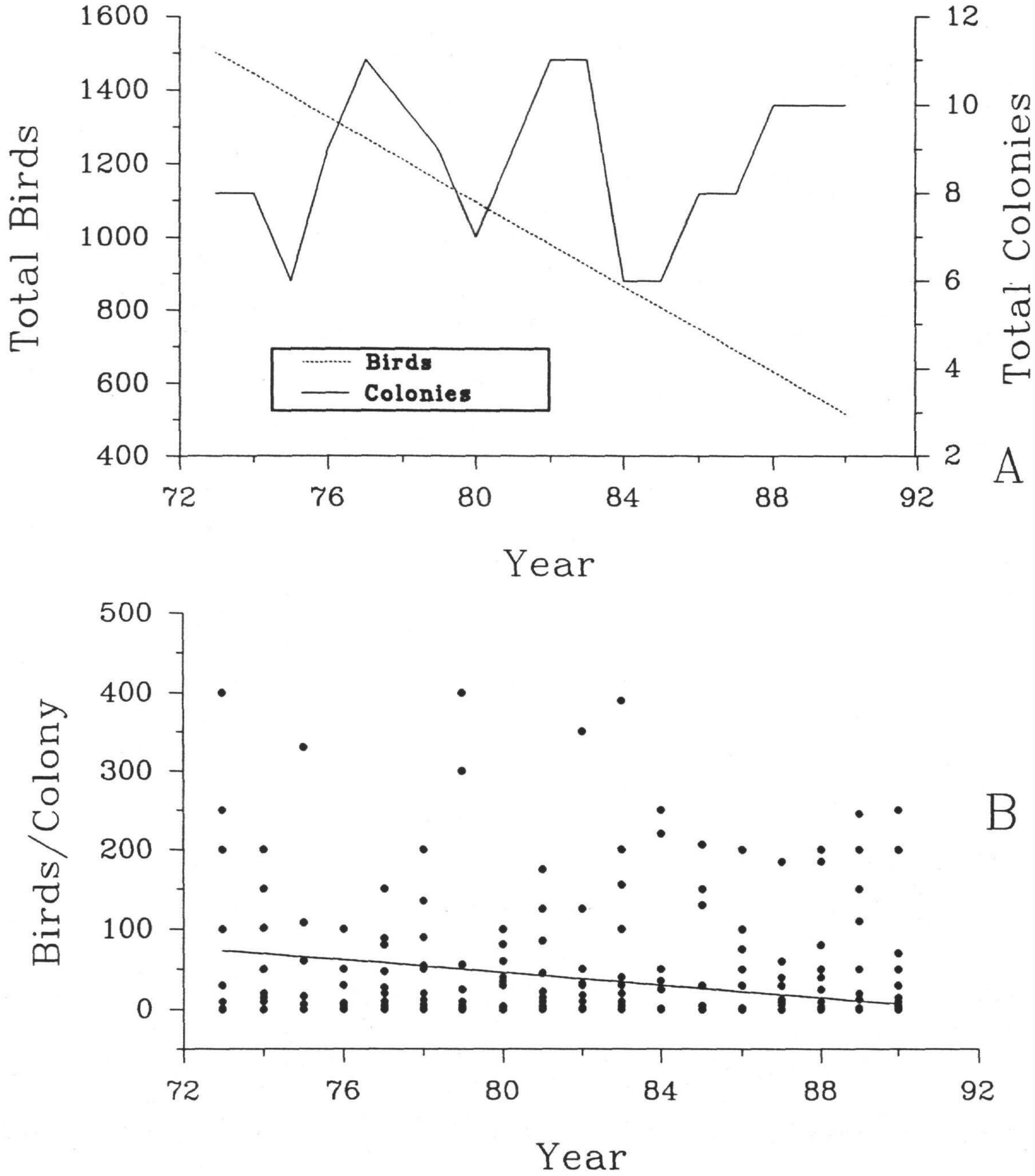


Figure 25. A. Trend in snowy egrets per year (N=18) and the number of colonies containing snowy egrets from 1973 to 1990 during Texas Colonial Waterbird Surveys. B. Individual colony counts and trend in snowy egrets per colony from 1973 to 1990 (N=516) during Texas Colonial Waterbird Surveys. From Slack et al. (1992).

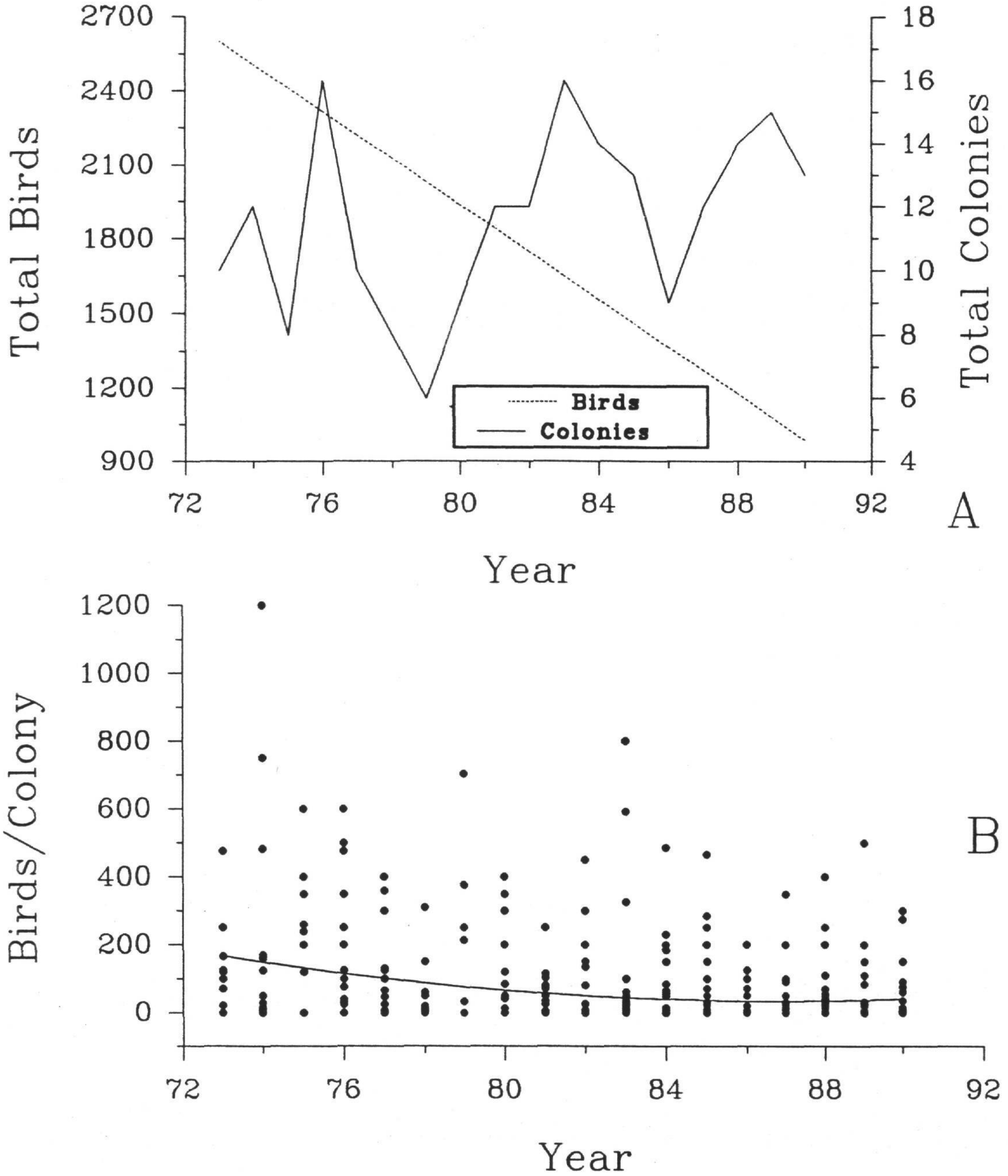


Figure 26. Trend in numbers of black skimmers per year (N=18) and the number of colonies containing black skimmers from 1973 to 1990 during Texas Colonial Waterbird Surveys. B. Individual colony counts and trend in numbers of black skimmers per colony from 1973 to 1990 (N=516) during Texas Colonial Waterbird Surveys. From Slack et al. (1992).

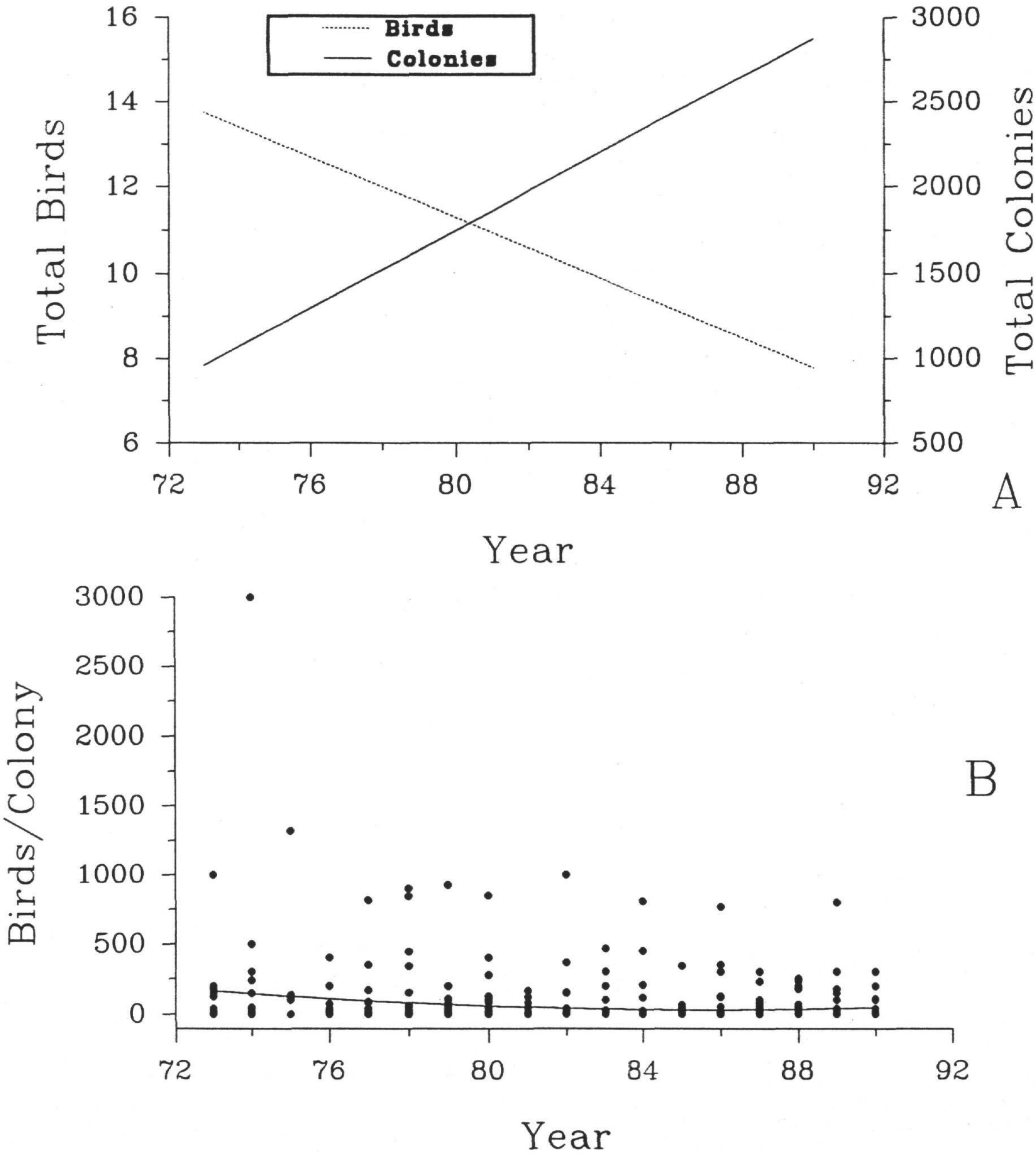


Figure 27. A. Trend in tricolored herons per year (N=18) and the trend in numbers of colonies containing tricolored herons from 1973 to 1990 during Texas Colonial Waterbird Surveys. B. Individual colony counts and trend in tricolored herons per colony from 1973 to 1990 (N=516) during Texas Colonial Waterbird Surveys. From Slack et al. (1992).

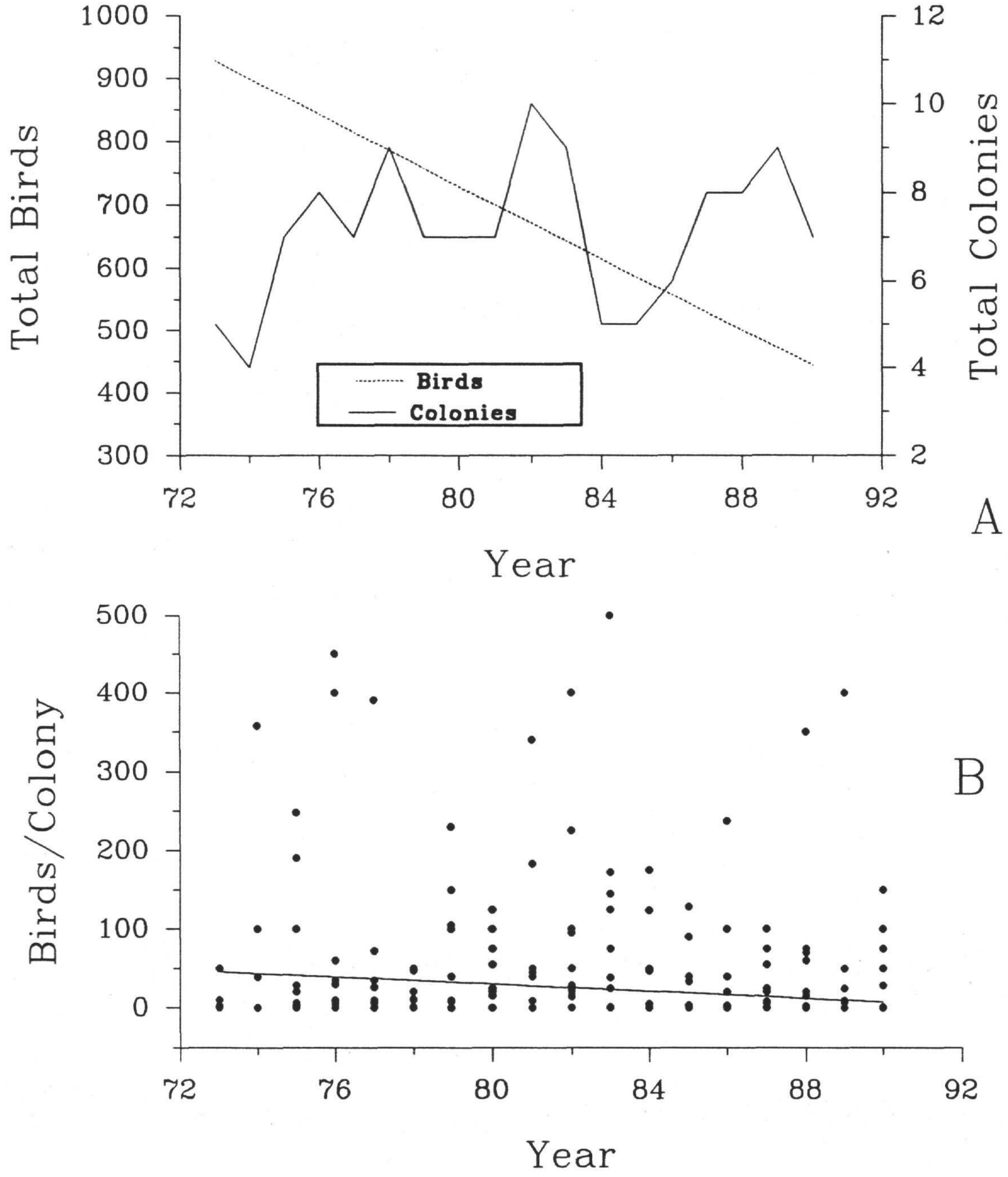


Figure 28. A. Total number of roseate spoonbills per year (N=18) and the number of colonies containing roseate spoonbills from 1973 to 1990 during Texas Colonial Waterbird Surveys. B. Individual colony counts and trend in roseate spoonbills per colony from 1973 to 1990 (N=516) during Texas Colonial Waterbird Surveys. From Slack et al. (1992).

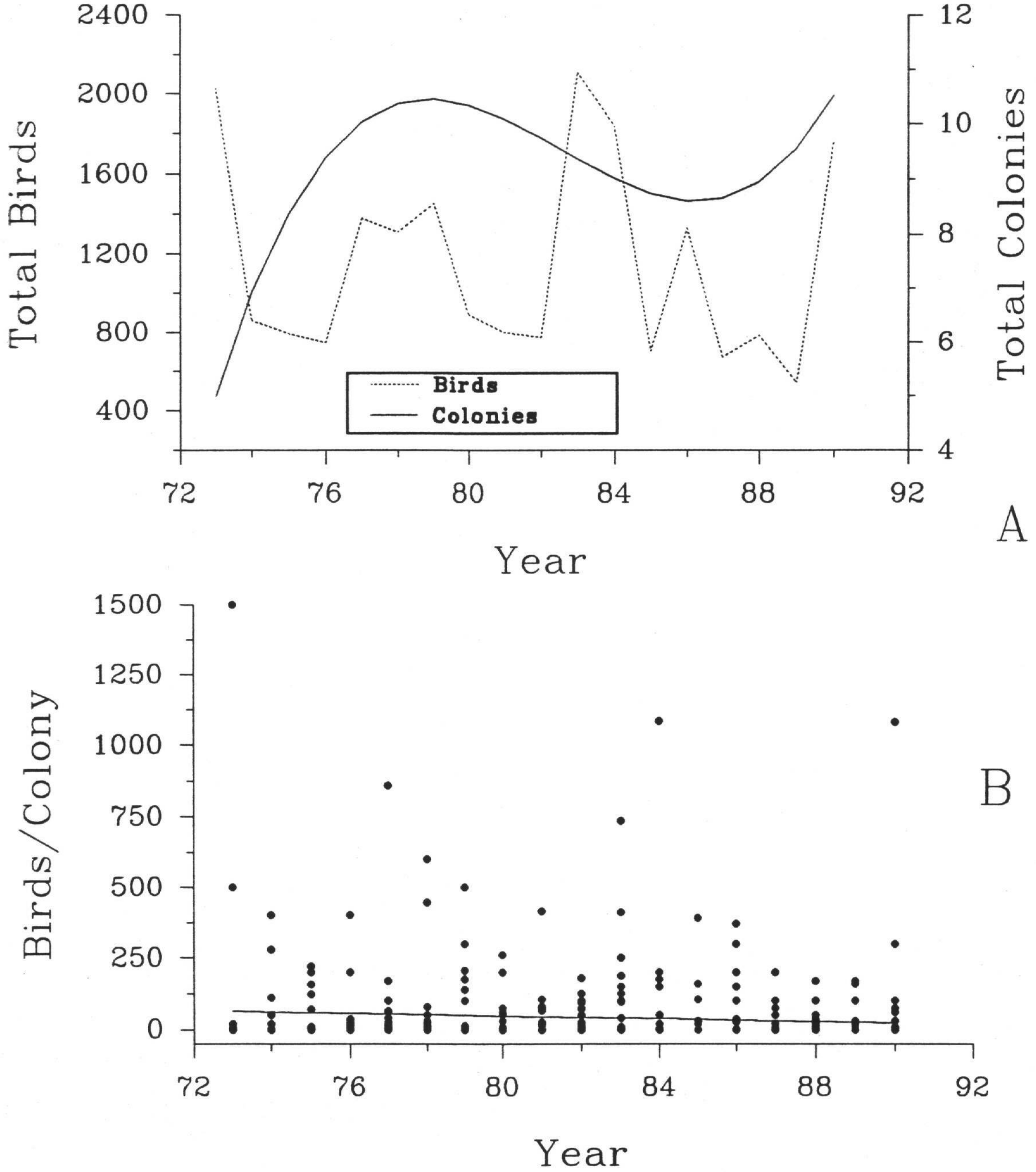


Figure 29. A. Total number of great egrets per year (N=18) and the trend in number of colonies containing great egrets from 1973 to 1990 during Texas Colonial Waterbird Surveys. B. Individual colony counts and mean number of great egrets per colony from 1973 to 1990 (N=516) during Texas Colonial Waterbird Surveys. From Slack et al. (1992).

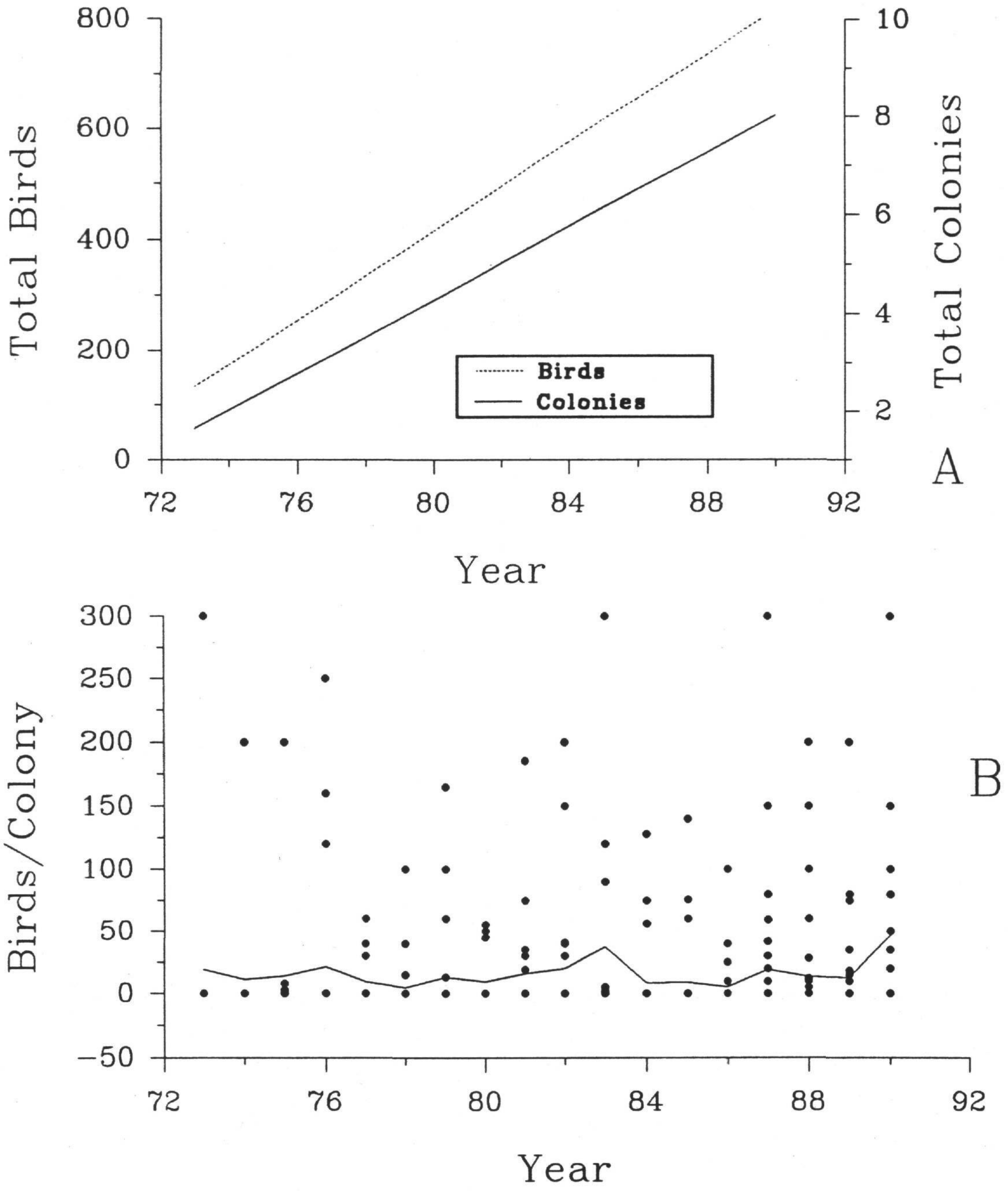


Figure 30. A. Trend in olivaceous cormorants per year (N=18) and the trend in number of colonies containing olivaceous cormorants from 1973 to 1990 during Texas Colonial Waterbird Surveys. B. Individual colony counts and mean number of olivaceous cormorants per colony from 1973 to 1990 (N=516) during Texas Colonial Waterbird Surveys. From Slack et al. (1992).

of the trends in colony number and colony size, lending credence to the conclusion that the number of colonies has generally increased. The increase in the number of colonies observed for both the open-water and the marsh group may also be the result of sampling bias, as more small colonies are discovered and added to the data base.

The true magnitude and exact timing of the trends are unknown because the time span covered by the Texas Colonial Waterbird Survey (1973 through 1990) may not be long enough to show its entire extent. The declines could be a normal life cycle of which only the downward portion was sampled. For long-lived organisms such as birds, a time series of several decades may be required in order to distinguish population cycles from superimposed trends. Historical sources (e.g. Strecker 1912, Williams 1938) mention the presence of species of birds no longer found in the Galveston Estuary region. At the least, it is valid to conclude that there has been long-term structural change in the bird community in the Galveston Estuary area.

Geographic extent

Birds are highly mobile organisms with patchy areal distributions. Colonies shift widely in space and time. Whether a species shows an increase, a decrease, or variation with little pattern depends largely on the size of the area covered, and larger population trends may be obscured by focusing on too small a scale (a single colony, a single refuge, a single estuarine system, or a single state). However, confining the geographic scale to the estuarine level is not inappropriate if it is recognized that the question being addressed is that of the health of the estuarine system, not the health of a species.

Probable causes

Possible causes for the declines in marsh-feeding birds are listed here in order of confidence and probability. The list is not comprehensive.

1) **Decrease in quantity of feeding habitat**. The loss of tidal wetlands is the most likely explanation for declining trends in marsh-feeding birds. As discussed in Chapter IV, roughly 19 percent of the Galveston Estuary's vegetated wetlands were lost between the 1950s and 1989 (White et al. 1993). Most of the loss probably occurred before the period of record of the Texas Colonial Waterbird Survey, but the trends shown in Figures 25-29 may reflect ongoing wetland loss and lagged effects on long-lived organisms.

2) **Decrease in quality of feeding habitat**. It is also possible that pollutants concentrate in the waters, sediments, or resident organisms of bay margin feeding habitat. Waterbirds are effective bioaccumulators of a variety of contaminants (King 1989). Buoyant materials, such as oil and grease, tend to concentrate in intertidal areas and could be specifically detrimental to wading birds and skimmers. In addition to the well-publicized oil spills, oil and grease are a large component of non-point source pollution (Newell et al. 1992) and are routinely released during activities related to oil transportation (Kennish 1992). King and Krynitsky (1986) found higher levels of DDE (a metabolite of the banned pesticide DDT) in black skimmers than in cormorants or

gulls, at levels known to cause reproductive problems in some species. White et al. (1984) found high residues of DDE in black skimmer eggs from the southern and mid-coast region of Texas. Oil field effluent is another potential source of contamination. Though there is no direct evidence that bird populations on an estuary-wide scale have been affected by pollution, it would be surprising if they were not.

3) **Decrease in food supply**. The quantity of prey fish is a special aspect of the quality of feeding habitat that can be tested using CF data. Bag seine samples probably approximate the prey available to birds feeding at the bay margin, though there is no control for the predator's bias or the prey's predator avoidance mechanisms. Figure 1A shows a general decline in small fish abundance in bag seine catches from 1982 through 1989, possibly corresponding to the declines in marsh-feeding birds between 1983 and 1990 (Figures 25-29). Figure 2A shows the CPUE for the 14 common species caught by trawl in the open bay (confined to individuals under 200 mm). The numbers of fish caught by trawl remained relatively constant and may correlate with the steady or increasing trends observed among birds that feed over open water.

These generalities must be interpreted with caution because detailed diet information for waterbirds, especially in coastal areas, is scarce. Wading birds apparently consume a wide variety of fresh, salt, and brackish water fish and invertebrates (Oberholser 1974, Telfair et al. 1982, King 1989). Killifish and sheepshead minnow, among the most important prey species to herons (Rex Wahl pers. comm.), declined over the 1978-1991 period (Figures 1L, 1M, 1N) though their numbers were fairly constant after 1980. A study by Morrison et al. (1977) showed the diet of nestling olivaceous cormorants in Sabine Lake to be dominated by sheepshead minnow (Figure 1N), striped mullet (Figure 1E), Atlantic croaker (Figure 1C), and sailfin molly, species that show no trend or declines between 1978 and 1991. The population of olivaceous cormorant nevertheless increased (Figure 30).

A closer examination of Figures 25-30 shows that peaks in the number of birds per colony tend to coincide in 1973-74 and 1983-84, during and following El Niño events. The possibility that ENSO affects bird populations is especially conspicuous for olivaceous cormorants (Figure 30), whose greatest numbers occur in the El Niño years 1973, 1983, 1987, and 1990. If ENSO affects fish populations and if food supply limits the abundance of wading birds, the high numbers of small fish in 1990-91 should result in a resurgence of birds feeding on them in 1992 or 1993.

4) **Increase in morbidity**. The role of disease, whether naturally occurring or aggravated by human activity, has received little attention. Spalding (1990, 1991) suggested the proliferation of parasitic nematodes in nutrient-rich eutrophic waters contributed to die-offs of wading birds in Florida. There is at least one report (Rex Wahl pers. comm.) of a die-off of black skimmer chicks in the Galveston Estuary area in 1989-90, caused by starvation or possibly parasitic infection. There are no data to demonstrate a disease problem in the Galveston Estuary, but the possibility should be investigated.

5) **Decrease in quantity or quality of nesting habitat**. Many factors can be deleterious to single colonies: inundation and erosion from rising relative sea level; wetland drainage or sedimentation creating a connection between a bird island and the mainland, allowing invasion by raccoons or other predators; changing vegetation, caused by cattle egret guano or by normal succession (Telfair in press). Increased predator density associated with human activity (e.g. feral dogs and cats, garbage-eating raccoons) and direct disturbance by humans may also contribute to a decline in the number or size of bird colonies. Fire ants are locally a problem and should definitely be monitored, though premature or incorrect treatment for fire ants may cause worse problems (such as disturbance, contamination, or the resurgence of ectoparasites).

All the factors above are undoubtedly important locally. However, they would be expected to affect all colonial waterbirds that nest together, not just those with similar feeding habitat. The proposed creation of new nesting islands for colonial waterbirds (Glass 1992) would probably be favorable for colonial waterbirds in general but should not be pursued at the expense of vegetated wetland habitat.

6) **Natural cycles**. The recognition that bird populations may be linked to small fish populations (cause 3 above) and climate cycles raises the possibility that the perceived declines are driven by high counts early in the available time series. Given a longer time series, there may be no net trend. However, visual inspection of the variability in Figures 25B, 26B, 27B, 28B, and 29B suggests that authentic declines may be superimposed on ENSO-related variation. Black skimmers are the most dramatic example because the peaks in birds/colony declined steadily (Figure 26), in spite of the relative strength of the climatic events. Olivaceous cormorants peaked during the El Niño years 1983, 1987, and 1990, but black skimmers did not.

WATERFOWL

A discussion of declines in waterfowl is necessarily general, in part because local monitoring has been less effective than for colonial waterbirds. Waterfowl are monitored by the Mid-winter Waterfowl Transects, providing reputable data but only available for the past five years; and by the Mid-winter Waterfowl Cruise Count, a good source of long-term records but impractical for trend analysis because there is no control for effort.

Mottled ducks, northern pintails, and blue-winged teal showed a decline in population (Figures 31, 32, 33). Only mottled duck are not migratory. Northern pintails and blue-winged teal have been declining nationwide since the 1950s (Figure 34). These species are probably most strongly affected by factors outside of Texas, such as the loss of small wetlands to agriculture and development in their breeding grounds on the Great Plains (e.g. Pederson et al. 1989), or conditions in Central and South American wintering grounds (Stutzenbaker and Weller 1989). There is little definitive evidence, however. The most probable local cause of declining waterfowl populations is the loss of freshwater marsh habitat (discussed in Chapter IV). White et al. (1993) estimate that

35,600 acres of fresh marsh in the Galveston Bay region were lost between the 1950s and 1989, most of them drained and converted to uplands.

Other factors possibly contributing to waterfowl population trends on the Texas Gulf Coastal Plain are numerous but hard to quantify (Cain and Feierabend 1988). Though Cain (1988) detailed the problem of contaminated wintering waterfowl habitat, Hobaugh et al. (1989) reported that controls on the use of pesticides resulted in a decrease in pesticide-related mortality in Texas since the 1970s. Avian cholera may have caused die-offs of waterfowl with increasing frequency through the 1980s on the rice prairies of Texas (Hobaugh et al. 1989), though the factors contributing to the severity of the disease and its possible effect on population levels are unclear. The ingestion of lead shot was probably a problem for several species of waterfowl, especially mottled ducks (Moulton et al. 1988). The regulated use of steel shot instead of lead has probably reduced the degree of lead toxicity. However, such measures probably will not immediately restore mottled duck populations.

It is interesting that while some species of ducks show declines (Slack et al. 1992), geese have generally increased (Haskins 1990). Geese appear to be more efficient in using the winter rice fields of Texas than are ducks (Bateman et al. 1988, Hobaugh et al. 1989). They also adapt to a variety of breeding habitats, whereas ducks are more closely tied to aquatic habitats (Pederson et al. 1989). While those ducks that breed in the prairie pothole country are losing their wetlands to farming, snow geese breed in the Arctic, beyond intense competition with agriculture. Possibly the decline in ducks is favorable to geese. The numbers of geese on the Texas Gulf coast will probably decline as rice farming is lost to other land uses, specifically to development (Bateman et al. 1988). Furthermore, snow geese may be increasing to the point where populations will decline because of overcrowded breeding grounds.

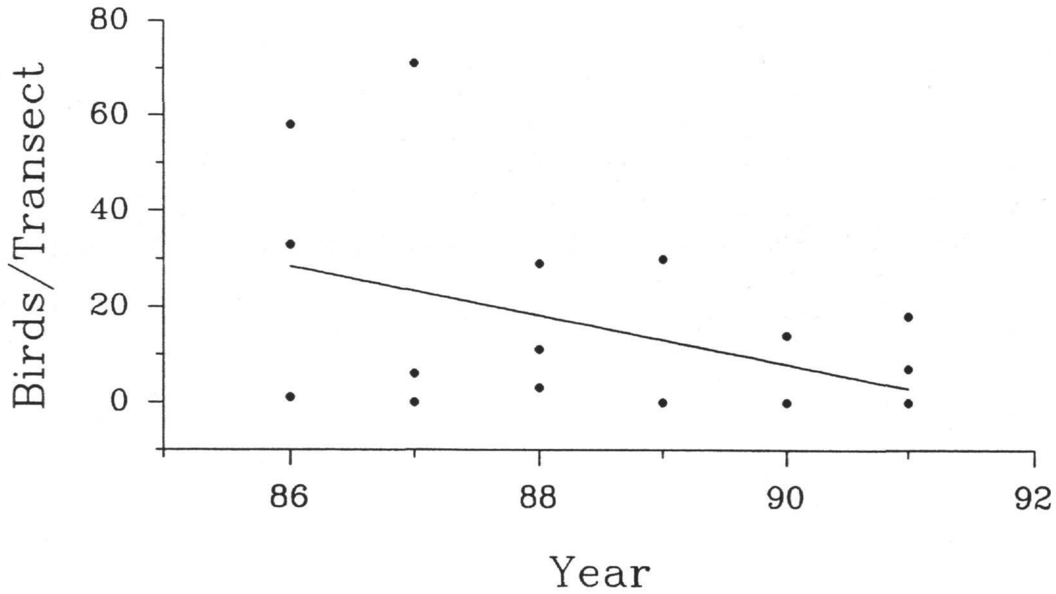


Figure 31. Individual counts and trend in mottled ducks from 1986 to 1991 (N=18) during Mid-winter Waterfowl Transects. From Slack et al. (1992).

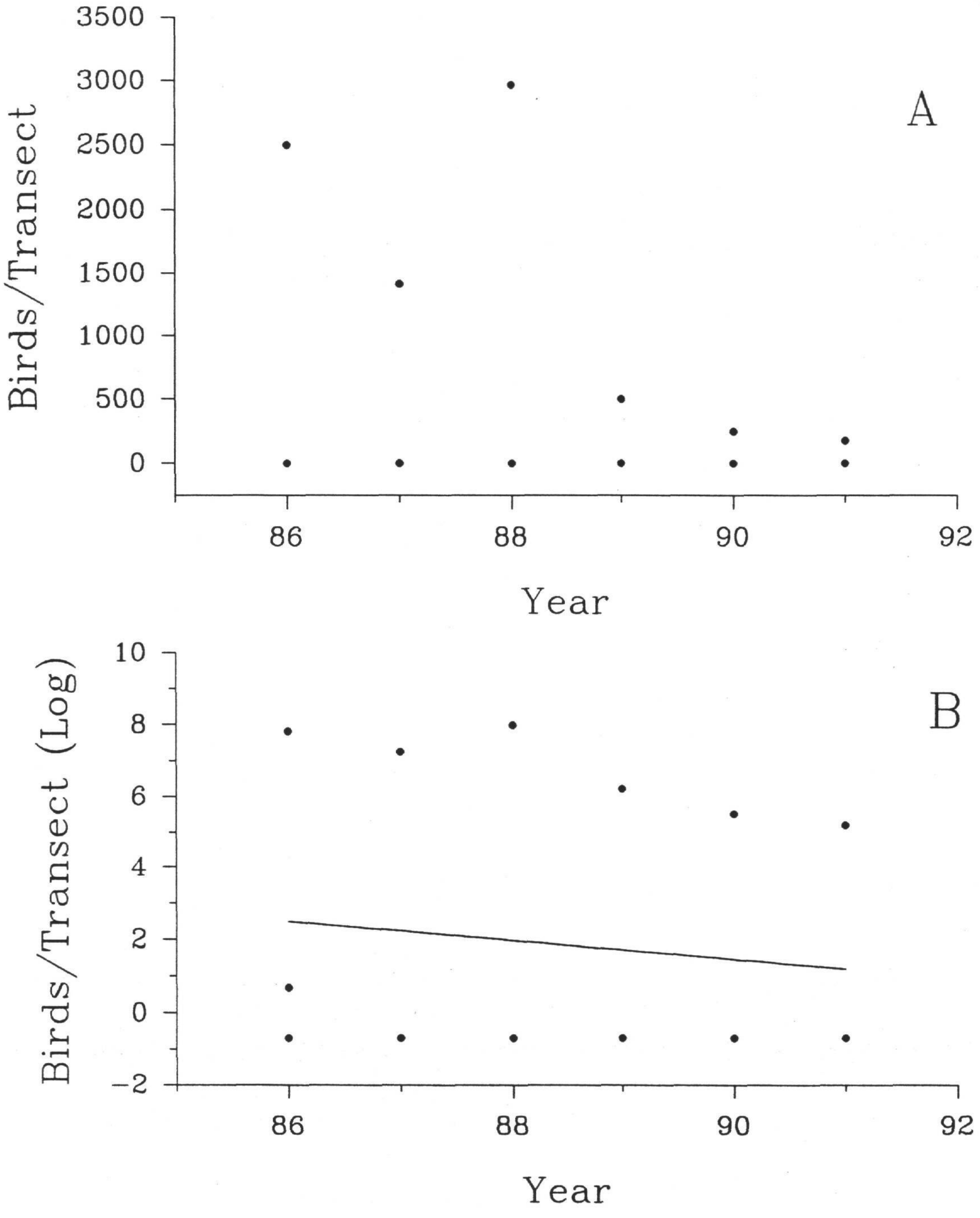
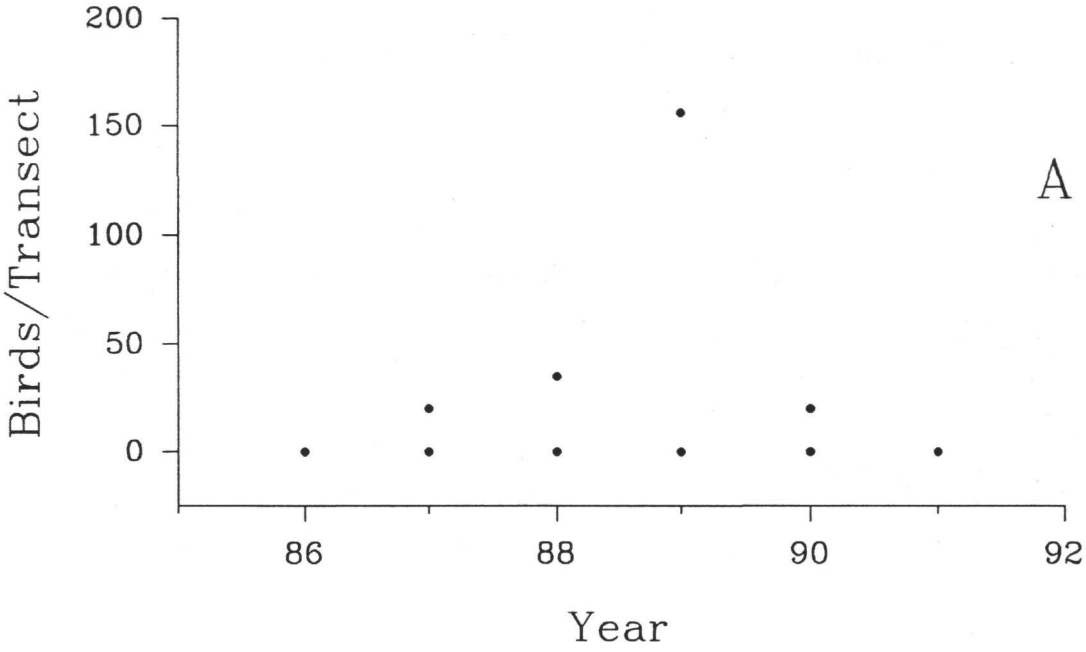


Figure 32. A. Numbers of northern pintails per transect from 1986 to 1991 (N=18) during Mid-winter Waterfowl Transects. B. Trend in northern pintails from 1986 to 1991 (N=18) during Mid-winter Waterfowl Transects. From Slack et al. (1992).



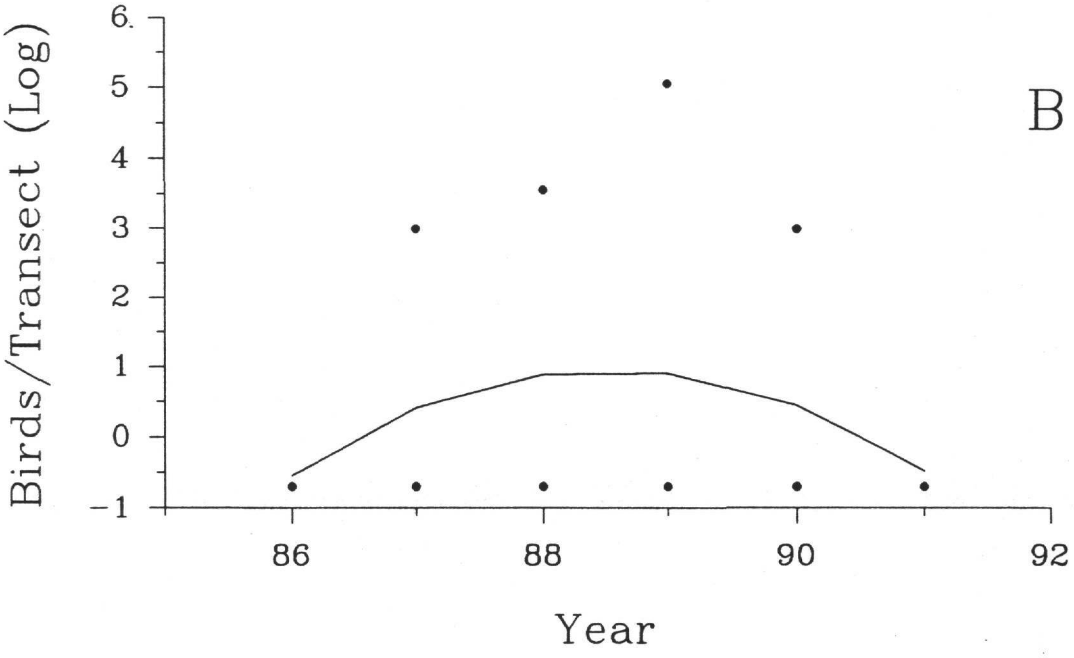


Figure 33. Numbers of blue−winged teal per transect from 1986 to 1991 (N=18) during Mid−winter Waterfowl Transects. B. Trend in blue−winged teal from 1986 to 1991 (N=18) during Mid−winter Waterfowl Transects. From Slack et al. (1992).

SHOREBIRDS

Slack et al. (1992) reported a possible increase in shorebird populations based on data from the Christmas Bird Counts and the Bolivar Flats Shorebird Surveys. The Christmas Bird Count data should be interpreted with caution, however, because of the high variability in effort. The Bolivar Flats Shorebird Surveys also indicate there has been at least a local increase. However, Neill (1992) reported a loss of shorebird habitats throughout North America during the 1970s and 1980s, and declines in shorebird populations in north-central Texas over the last 10 years.

DISCUSSION AND CONCLUSIONS

Birds are relatively conspicuous members of the estuarine community and have a record as indicators of environmental problems. Declining brown pelican, osprey, and falcon populations in the 1960s raised alarms about the bioaccumulation of pesticides and led to the nationwide ban on DDT. Royal terns and brown pelicans both feed on open-water fish and both show strong increases in their use of the Galveston Estuary in recent years (Slack pers. comm.). This is probably the result of reduced pesticide pollution (Stanley 1989).

Wading birds are valuable as estuarine indicator species. The eggs and chicks of herons and egrets have been used to test for contaminants (specifically, DDE and PCBs) as part of the National Contaminant Biomonitoring Program (Custer et al. 1991), because of their high trophic level, relatively regular nesting habits, and tendency to bioaccumulate contaminants. The decline in marsh-feeding birds documented by Slack et al. (in prep.) is cause for concern. Unlike the declines in waterfowl, marsh-feeding birds are probably responding to relatively local stresses. The most probable causes are local (estuary-wide) wetland loss (from bulkheading, subsidence, and development) and/or contamination. Background data on parasitization and contaminant body burden in birds throughout the bay would be relatively inexpensive to acquire and potentially revealing. Black skimmers should be specifically targeted for such a study.

The disappearance of waterbird colonies could have serious consequences for nutrient cycling in the estuary. Powell et al. (1991) showed that seagrasses in a Florida estuary increased in biomass as a consequence of nutrient input from bird colonies. Other birds also probably play important, but poorly understood, roles in the estuarine food web. Continued declines in birds, especially waterfowl, will disappoint birdwatchers and hunters, and adversely affect the area's tourist industry.

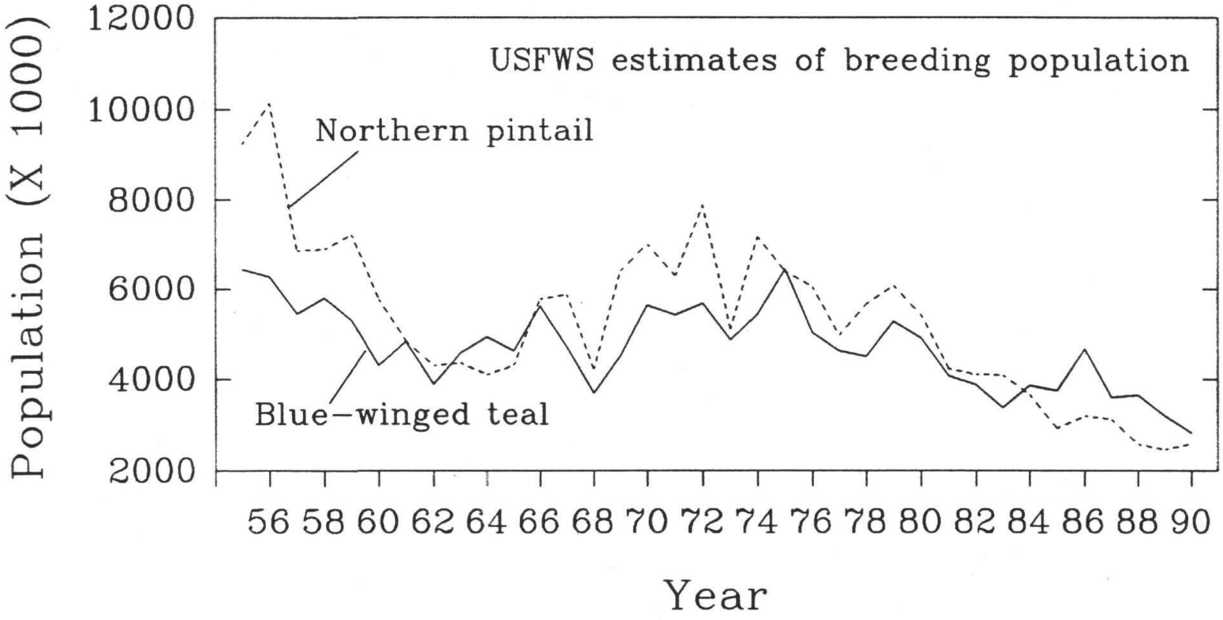


Figure 34. Annual population estimates for northern pintails and blue–winged teal in North America. Data from U. S. Fish and Wildlife Service.

VIII. CONCLUSIONS AND RECOMMENDATIONS

White shrimp

The 1983-1990 decline in white shrimp was probably part of a natural, climatically-influenced population cycle, or the result of overharvesting. Recent regulation of the shrimping industry should be monitored to ensure that sufficient protection of the white shrimp resource is in place. The causes of any future decline should be investigated rigorously. The effects of recent regulatory changes cannot be separated from the beneficial effects of high freshwater inflows and mild winters associated with the recent El Niño event. River inflows should not be regulated to the extent that natural variability in inflows (periodic floods) are eliminated, which would probably have the effect of reducing long-term shrimp productivity.

Blue crab

The potential problem represented by declines in blue crab populations has also been recognized by the Texas Parks and Wildlife Department in the formulation of the Texas Blue Crab Fishery Management Plan (Cody et al. 1992). The Plan recommended that certain measures be considered for adoption as Department regulations: that crab trap tending be confined to daylight hours, that rules pertaining to the spacing and marking of crab traps (now in effect locally) be extended coastwide, that the seizure of abandoned crab traps be authorized, and that escape vents be used on all traps to reduce bycatch. In addition, the Plan recommended present monitoring efforts be maintained and expanded and data collected to assess the current allocation of the blue crab resource among user groups.

Government and private organizations at all levels can contribute towards the reduction in wasteful crabbing practices. The recent establishment of a trap identification system (trap tagging and floats) will provide more precise effort data and reduce the number of stolen, lost, and abandoned crab traps (Cody et al. 1992). However, law enforcement will have to be intensified if illegal crabbing is widespread. Efforts to remove debris from coastal areas should place an emphasis on recovering abandoned crab traps. The use of biodegradable panels on traps should be promoted to reduce ghost fishing. Above all, the public should be educated that blue crab are not an unlimited resource.

Birds

The declining trends among wading birds that feed at the marsh-bay interface may be an early warning of a potentially serious problem with tidal wetlands, whether the ultimate cause lies in tidal marsh acreage, pollution, small fish populations, or disease. Bird morbidity and contamination of bay margin habitats should be specifically investigated. A background study on rates of parasitization and contaminant body burden in birds (especially black skimmers) throughout the estuary would be relatively inexpensive to perform.

Birds are valuable indicator species because they have relatively slow population turnover, require more extensive high-quality habitat than do most fisheries species, and are sensitive to many contaminants. Most species are not hunted by man, and therefore are not affected by one major source of interannual variation. As birds are important to the health of the bay, the bay is important to the health of birds; the Galveston Estuary is nationally important to the survival of the piping plover.

The following species have been recommended for monitoring (Eubanks, Ortego, pers. comm.):

1) The American oyster catcher and the seaside sparrow are non-migratory, obligate estuarine species. A decline in these species indicates a decline in estuarine health. The oyster catcher inhabits oyster reefs and mud flats and is not common, but is easy to recognize. The seaside sparrow, found on the edges of Spartina alterniflora marsh, is fairly common, though difficult to survey becuase of its small size and cryptic coloration.

2) Certain obligate marsh-dwelling birds should be monitored as indicators of the state of marsh communities: the clapper rail, associated with Spartina alterniflora; the black rail, an obligate associate of Spartina spartinae (but possibly hard to monitor because of its obscure coloration); and the marsh wren, associated with Phragmites and other tall emergent grasses.

3) Wilson's plover and least terns should be monitored as indicators of beach environments. Both breed on Galveston Island and are affected by development in the area.

4) Less appropriate indicator species are those that move frequently between inland and coastal areas, such as the little blue heron, or are exclusively coastal but highly migratory, such as the reddish egret.

5) Shorebirds should be monitored because so little is known about the status of their populations. Programs associated with the Salt Bayou Project are now being designed to count and identify birds along transects flown by helicopter (B. Ortego, pers. comm.). This method is relatively economical, but will be biased towards those birds that are large and easy to identify.

Other factors

There are aspects of the seafood harvest that are not documented by existing means of collecting data. This is especially true of those fishermen that do not use boat ramps or keep licensed boats, including a large portion of the recreational and subsistence fishermen. Landings and effort by the commercial fishery should be documented independently of self-reporting. Overflights, spot checking of fish markets and roadside seafood sellers, and spot interviews of recreational and subsistence fishermen should be continued. The management implications of any data recovered this way should also be addressed.

The causes and implications of the trends in water quality parameters reported by Ward and Armstrong (1992), declines in turbidity, nitrates, and chlorophyll a, should be investigated thoroughly. Declining primary productivity may be associated with a positive reduction in nutrient loading from wastewater or runoff, but may also indicate wetland loss is affecting the ecosystem as a whole. The consequences of not understanding the causes of these trends and their effects on the estuarine ecosystem are potentially sever, both ecologically and economically.

The reduction of variation in freshwater inflows involves more than the alteration of the salinity regime. The role of freshwater inflows in nutrient cycling is one of the most important estuarine processes. The effects of seasonal and interannual variation in inflows should be investigated in the context of a thorough study of climate effects on the Galveston Bay biota and the role of large-scale climatic phenomena. There are many scenarios for future climate change; to be prepared for change, the existing system needs to be as well understood as possible.

An ideal sampling program?

The GBNEP created a committee with the purpose of designing a comprehensive sampling program to monitor changes in the estuarine biota. Ideally, the committee should coordinate existing private and governmental sampling programs (including the CF program) to reduce duplication of effort and to address gaps in information. A monitoring program will be needed well beyond the duration of the Galveston Bay National Estuary Program (to be completed in fall 1994), and should also involve rigorous analysis of the data collected, with the goal of assuring the health of the Galveston Estuary.

Such a program should track short-lived organisms (phyto- or zooplankton) as measures of ambient estuarine quality, and longer-lived organisms (larger shellfish, fishes, and birds) as measures of trends in estuarine quality. In addition to the birds listed above, certain aquatic organisms should be specifically monitored: oysters and spotted seatrout, because they spend all or most of their lives in a single estuary; and abundant species such as shrimp, menhaden, and blue crab, because of their economic importance and role in the food web. These and the organisms discussed in Loeffler and Walton (1992) are among the most conspicuous and best-documented members of the estuarine biota. Other organisms are undoubtedly important to the estuarine ecosystem but have received little attention, such as ctenophores, cnidarians such as cabbage heads, insects, and bay benthos in general. Organisms should be routinely counted, measured, and checked for anomalies. Habitat parameters should be routinely recorded (water quality measurements, sediment composition and friability, vegetation type). Samples should be spot-checked for contaminants and nutrient levels in a manner that can be directly related to the sampling of fish and birds. Monitoring should specifically address nutrient cycling and community relationships.

The methodology of the ideal sampling program should be diverse to address a variety of scales. The best monitoring program is one that can account for local habitats and communities, as well as changes in single species, throughout an estuary. Thanks to remote sensing technology, it is now possible to inventory the vast emergent part of the estuarine drainage and to quantify vegetation types and substrate with less manpower than required by ground surveying. Remote monitoring is reasonably accurate if combined with extensive ground truthing and field work. Plans for this kind of program are being discussed in association with the Salt Bayou Project and should be coordinated with other efforts to monitor the estuary. Though remote sensing cannot be applied in detail to submerged habitats, it is being profitably applied to the mapping of circulation patterns. The estuary should be routinely surveyed by helicopter or plane to monitor fishing and shrimping activity, and to count large organisms such as marine mammals, turtles, and birds.

Data collection should be directed at measuring the health of the estuary and the factors that influence it most strongly. The committee should carefully consider the definition of estuarine health, because this should be integrated with the goals of bay-wide management efforts. An understanding of estuarine health would require the adequate description of the structure and function of all components of the estuarine ecosystem, many of which (discussed above) are unknown.

As part of the bay's yearly physical check-up, the committee should assemble and distribute a yearly (or more frequently, if necessary) report on the state of health of the estuary. Such reports could direct attention to problems as they develop and before they become severe. If any suspicious conditions are found, the reports should pose a tentative diagnosis, recommend further testing, and suggest treatment. The intrinsic interest of the Galveston Estuary and its value to the Texas economy require that its health be taken seriously.

REFERENCES

Aleem, A. A. 1972. Effect of river outflow management on marine life. Marine Biology 15:200-208.

Alexander, S. K. 1986. Diet of the blue crab, Callinectes sapidus Rathbun, from nearshore habitats of Galveston Island, Texas. Texas Journal of Science 38:85-89.

Armstrong, N. E., and G. H. Ward. in press. Point sources loading characterization of Galveston Bay. Galveston Bay National Estuary Program.

Bateman, H. A., T. Joanen, and C. D. Stutzenbaker. 1988. History and status of midcontinent snow geese on their Gulf Coast winter range. p. 495-515 in M. W. Weller (ed.): Waterfowl in Winter. University of Minnesota Press, Minneapolis, Minnesota.

Baumgartner, T., V. Ferreira-Bartrine, H. Schrader, and A. Soutar. 1985. A 20-year varve record of siliceous phytoplankton variability in the central Gulf of California. Marine Geology 64:113-129.

Benefield, R. L., and T. L. Linton. 1990. Movement of blue crabs in Trinity Bay. Texas Parks and Wildlife Department Management Data Series 16. Austin, Texas. 6 p.

Blasing, T. J., D. W. Stahle, and D. N. Duvick. 1988. Tree ring-based reconstruction of annual precipitation in the south-central United States from 1750 to 1980. Water Resources Research 24:163-171.

Bowling, B. G. 1992. Rehabilitation of public oyster reefs damaged by a natural disaster in Galveston Bay. Texas Parks and Wildlife Department Management Data Series 84. Austin, Texas. 6 p.

Brooks, J. M., T. L. Wade, M. C. Dennicutt II, D. A. Wiesenburg, D. Wilkinson, T. J. McDonald, and S. J. McDonald. 1992. Toxic contaminant characterization of aquatic organisms in Galveston Bay: a pilot study. Galveston Bay National Estuary Program Publication GBNEP-20. Houston, Texas. 341 p.

Bryan, C. E., T. J. Cody, and G. C. Matlock. 1982. Organisms captured by the commercial shrimp fleet. Texas Parks and Wildlife Department Technical Series 31. Austin, Texas. 26 p.

Buskey, E. J. 1992. Characterization of plankton from Galveston Bay. p. 347-375 in C. Loeffler and A. Walton (eds.): Status and Trends of Selected Living Resources in the Galveston Bay System. Galveston Bay National Estuary Program Publication 19. Houston, Texas.

Butcher, G. S. 1990. Audubon Christmas Bird Counts. p. 5-13 in J. R. Sauer and S. Droege (eds.): Survey Designs and Statistical Methods for the Estimation of Avian Population Trends. U.S. Fish and Wildlife Service Biological Reports 90(1).

Caillouet, C. W., F. J. Patella and W. B. Jackson. 1980. Trends toward decreasing size of brown shrimp, Penaeus aztecus, and white shrimp, Penaeus setiferus, in reported annual catches from Texas and Louisiana. Fishery Bulletin 77:985-989.

Cain, B. W. 1988. Wintering waterfowl habitat in Texas: shrinking and contaminated. p. 583-596 in M. W. Weller (ed.): Waterfowl in Winter. University of Minnesota Press, Minneapolis, Minnesota.

Cain, B. W. 1993. Contaminant assessment of the Upper Texas Coast. p. 103-108 in R. W. Jensen, R. W. Kiesling and F. S. Shipley (eds.): Proceedings, The Second State of the Bay Symposium, February 4-6, 1993. Galveston Bay National Estuary Program Publication GBNEP-23. Houston, Texas.

Cain, B. W., and J. S. Feierabend. 1988. Workshop summary: toxins, disease, and lead poisoning. p. 609-612 in M. W. Weller (ed.): Waterfowl in Winter. University of Minnesota Press, Minneapolis, Minnesota.

Campbell, P., T. Storck, V. Price and L. Robinson. 1992. Trends in Texas commercial fishery landings, 1972-1991. Texas Parks and Wildlife Department Management Data Series 86. Austin, Texas. 108 p.

Carr, R. S., D. C. Chapman, and C. L. Howard. 1993. Survey of Galveston Bay bottom sediments and benthic communities. p. 83-94 in R. W. Jensen, R. W. Kiesling and F. S. Shipley (eds.): Proceedings, The Second State of the Bay Symposium, February 4-6, 1993. Galveston Bay National Estuary Program Publication GBNEP-23. Houston, Texas.

Chai, P. 1991. Fish bycatch by trawls in Texas waters. American Fisheries Society Annual Meeting, September 8-10, 1991, San Antonio, Texas. Abstracts:109-110.

Chelliah, M. 1990. The global climate for June-August 1989: a season of near normal conditions in the tropical Pacific. Journal of Climate 3:138-162.

Childers, D. L., J. W. Day, and R. A. Muller. 1990. Relating climatological forcing to coastal water levels in Louisiana estuaries and the potential importance of El Niño-Southern Oscillation events. Climate Research 1:31-42.

Cody, T. J., R. P. Campbell, P. C. Hammerschmidt, G. C. Matlock, C. E. Bryan, J. E. Clark, and L. S. Procarione. 1989. Texas Shrimp Fishery Management Plan. Source document. Texas Parks and Wildlife Department Fishery Management Plan Series 2. Austin, Texas. 261 p.

Cody, T. J., T. Wagner, C. E. Bryan, L. W. McEachron, R. Rayburn, B. Bowling, and J. Mambretti. 1992. Fishery management plan for the blue crab fishery in Texas waters. Texas Parks and Wildlife Department Fishery Management Plan Series 4. Austin, Texas. 27 p.

Crocker, P. A. 1993. Water quality trends for the Houston Ship Channel. p. 27-32 in R. W. Jensen, R. W. Kiesling and F. S. Shipley (eds.): Proceedings, The Second State of the Bay Symposium, February 4-6, 1993. Galveston Bay National Estuary Program Publication GBNEP-23. Houston, Texas.

Custer, T. W., B. A. Rattner, H. M. Ohlendorf, and M. J. Melancon. 1991. Herons and egrets as proposed indicators of estuarine contamination in the United States. Acta XX Congressus Internationalis Ornithologici:2474-2479.

Dailey, J. A., Kana, J. C., and McEachron, L. W. 1991. Trends in relative abundance and size of selected finfishes and shellfishes along the Texas coast: November 1975-December 1990. Texas Parks and Wildlife Department Management Data Series 74. Austin, Texas. 128 p.

Darnell, R. 1958. Food habits of fishes and larger invertebrates of Lake Ponchartrain, Louisiana, an estuarine community. Publications of the Institute of Marine Science, University of Texas 5:353-416.

Desbonnet, A., M. Eatough, V. Lee, J. Cogan, and D. Stanley. 1991. Correlations between water quality and fisheries trends in six major U.S. estuaries. 11th International Estuarine Research Conference, November 10-14, 1991, San Francisco. Abstracts:34.

Ditton, R. B., D. K. Loomis, D. R. Fesenmaier, M. O. Osborn, D. Hollin, and J. W. Kolb. 1989. Galveston Bay and the surrounding area; human uses, production and economic values. p. 53-65 in Galveston Bay: Issues, Resources, Status and Management. NOAA Estuary-of-the-Month Seminar Series 13.

Fitz, H. C., and R. G. Wiegert. 1991. Utilization of the intertidal zone of a salt marsh by the blue crab Callinectes sapidus: density, return frequency, and feeding habits. Marine Ecology Progress Series 76:249-260.

Flint, R. W., and S. C. Rabalais. 1981. Estuarine benthic community dynamics related to freshwater inflow to the Corpus Christi Bay estuary. p. 489-508 in R. D. Cross and D. L. Williams (eds.): Proceedings of the National Symposium on Freshwater Inflow to Estuaries. Volume I. U. S. Fish and Wildlife Service FWS/OBS-81-14.

Gawlik, D. E., R. D. Slack, J. A. Thomas, and D. N. Harpole. 1992. Structural changes in the colonial waterbird community of Galveston Bay Estuary. Cooper Ornithological Meetings, June 1992. Program.

Glass, P. 1992. An analysis of the advisability and need of creating new colonial waterbird nesting islands in Galveston Bay, Texas. Appendix to: Fish and Wildlife Coordination Act Report, Houston-Galveston Navigation Channels, Texas Project. Draft. U.S. Fish and Wildlife Service. Houston, Texas.

Gordon, K. G., J. Gillespie, W. B. Brogden, and C. H. Oppenheimer. 1972. Shrimp bioassay of Galveston Bay waters. Chapter III in C. H. Oppenheimer, W. B. Brogden, and K. G. Gordon (eds.): Toxicity Studies of Galveston Bay Project. University of Texas Marine Science Institute. Port Aransas, Texas.

Green, A. W. 1992. Executive summary. p. 1-9 in C. Loeffler and A. Walton (eds.): Status and Trends of Selected Living Resources in the Galveston Bay System. Galveston Bay National Estuary Program Publication 19. Houston, Texas.

Green, L. M., R. P. Campbell, and K. W. Spiller. 1991. Trends in finfish landings, and social and economic characteristics of sport-boat fishermen in Texas marine waters, May 1974 - May 1989. Texas Parks and Wildlife Department Management Data Series 56. Austin, Texas. 103 p.

Gunter, G., and J. C. Edwards. 1969. The relation of rainfall and fresh water drainage to the production of penaeid shrimp (Penaeus fluviatilis Say and Penaeus aztecus Ives) in Texas and Louisiana waters. p. 875-892 in M. N. Mistakidis (ed.): Proceedings of the World Scientific Conference on the Biology and Culture of Shrimp and Prawns. FAO Fisheries Report No. 57, Vol. 3.

Gunter, G., and H. H. Hildebrand. 1954. The relation of rainfall of the state and catch of the marine shrimp (Penaeus setiferus) in Texas waters. Bulletin of Marine Science of the Gulf and Caribbean 4:95-103.

Hammerschmidt, P. C. 1985. Relative blue crab abundance in Texas coastal waters. Journal of Shellfish Research 5:9-11.

Hammerschmidt, P. C., and R. L. Benefield. 1986. Number and distribution of crab traps in Texas bays. Texas Parks and Wildlife Department Management Data Series 92. Austin, Texas. 7 p.

Harper, D. E., Jr., and G. Guillen. 1989. Occurrence of a dinoflagellate bloom associated with an influx of low salinity water at Galveston, Texas, and coincident mortalities of demersal fish and benthic invertebrates. Contributions in Marine Science 31:147-161.

Haskins, J. 1990. Analyses of selected Mid-winter Waterfowl Survey data (1955-1990): Region 2. U. S. Fish and Wildlife Service. Albuquerque, New Mexico. 76 p.

Hobaugh, W. C., C. D. Stutzenbaker, and E. L. Flickinger. 1989. The rice prairies. p. 367-383 in L. M. Smith, R. L. Pederson, and R. M. Kaminski (eds.): Habitat Management for Migrating and Wintering Waterfowl in North America. Texas Tech Press, Lubbock, Texas.

Hofstetter, R. P. 1981. Rehabilitation of public oyster reefs damaged or destroyed by a natural disaster. Texas Parks and Wildlife Department Management Data Series 21. Austin, Texas. 9 p.

Jaworski, E. 1972. The blue crab fishery in Barataria Estuary. Sea Grant Publication LSU-SG-72-01. Baton Rouge, Louisiana. 112 p.

Johns, M. A. 1990. Trends in Texas commercial fishery landings, 1972-1989. Texas Parks and Wildlife Department Management Data Series 37. Austin, Texas.

Johnson, D. R., K. Strawn, and W. H. Neill. 1981. Rainfall-related trends in the structure of a fish-crustacean community in Texas' Galveston Bay system. p. 335-349 in R. D. Cross and D. L. Williams (eds.): Proceedings of the National Symposium on Freshwater Inflow to Estuaries. Volume II. U. S. Fish and Wildlife Service FWS/OBS-81/04.

Johnson, R. B., Jr. 1974. Ecological changes associated with the industrialization of Cedar Bayou and Trinity Bay, Texas. Texas Parks and Wildlife Department Technical Series 16. Austin, Texas. 79 p.

Kennish, M. J. 1992. Ecology of Estuaries: Anthropogenic Effects. CRC Press, Boca Raton, Louisiana.

Keppenne, C. L., and M. Ghil. 1992. Extreme weather events. Nature 358:547.

King, K. A. 1989. Food habits and organochlorine contaminants in the diet of olivaceous cormorants in Galveston Bay, Texas. The Southwestern Naturalist 34:338-343.

King, K. A., and A. J. Krynitsky. 1986. Population trends, reproductive success, and organochlorine chemical contaminants in waterbirds nesting in Galveston Bay, Texas. Archives of Environmental Contamination and Toxicology 15:367-376.

King, K. A., C. J. Stafford, B. W. Cain, A. J. Mueller, and H. D. Hall. 1987. Industrial, agricultural, and petroleum contaminants in cormorants wintering near the Houston Ship Channel, Texas, USA. Colonial Waterbirds 10:93-99.

Lange, C. B., S. K. Burke, and W. H. Berger. 1990. Biological production off southern California is linked to climate change. Climate Change 16:319-329.

Lange, M. L. In review. Texas Colonial Waterbird Colonies: 1973-1990 Census Summary, Atlas, and Trends. U. S. Fish and Wildlife Service.

Loeffler, C., and A. Walton (eds.). 1992. Status and Trends of Selected Living Resources in the Galveston Bay System. Galveston Bay National Estuary Program Publication 19. Houston, Texas. 452 p.

Longley, W. L. (ed.). In review. Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs. Texas Water Development Board and Texas Parks and Wildlife Department. Austin, Texas.

Martin, C. 1989. Texas colonial waterbird summary -- 1989. Special Administrative Report. Texas Parks and Wildlife Department. Austin, Texas.

Matlock, G. C., and M. A. Garcia. 1983. Stomach contents of selected fishes from Texas bays. Contributions in Marine Science 26:95-110.

McClintock, J. B., and K. R. Marion. 1990. The habitat utilization, population dynamics, reproductive biology and nutrition of the blue crab Callinectes sapidus in Weeks Bay, Alabama: important implications for fisheries. NOAA Technical Memorandum. 62 p.

McTigue, T. A., and R. J. Zimmerman. 1991. A model of food resource utilization by two fisheries species in marsh and unvegetated habitats. American Fisheries Society Annual Meeting, September 8-12, San Antonio, Texas. Abstracts:110-111.

Millikin, M. R., and Williams, A. B. 1984. Synopsis of biological data on the blue crab, Callinectes sapidus Rathbun. FAO Fisheries Synopsis 138. NOAA Technical Report NMFS 1. 38 p.

Minello, T. J., and Zimmerman, R. J. 1985. Differential selection for vegetative structure between juvenile brown shrimp (Penaeus aztecus) and white shrimp (P. setiferus), and implications in predator-prey relationships. Estuarine, Coastal and Shelf Science 20:707-716.

Minello, T. J., R. J. Zimmerman, and P. A. Barrick. 1990. Experimental studies in selection for vegetative structure by penaeid shrimp. NOAA Technical Memorandum NMFS-SEFC-237. Galveston, Texas. 30 p.

Minello, T. J., R. J. Zimmerman, and T. E. Czapla. 1989. Habitat-related differences in diets of small fishes in Lavaca Bay, Texas, 1985-1986. NOAA Technical Memorandum NMFS-SEFC-236. Galveston, Texas. 16 p.

Minello, T. J., R. J. Zimmerman, and E. X. Martinez. 1989. Mortality of young brown shrimp Penaeus aztecus in estuarine nurseries. Transactions of the American Fisheries Society 118:693-708.

Montagna, P. A. 1991. Relationship between climate, freshwater inflow, and benthos in Texas estuaries. 11th Annual Estuarine Research Conference, November 10-14, 1991, San Francisco. Abstracts:95.

More, W. R. 1969. A study of the blue crab in Texas. Texas Parks and Wildlife Department Technical Series 1. Austin, Texas. 31 p.

Morrison, M. L., E. Shaley, Jr., and R. D. Slack. 1977. The food of nestling cormorants. The Southwestern Naturalist 22:321-326.

Moulton, D. W., C. D. Frentress, C. D. Stutzenbaker, D. S. Lobpries, and W. C. Brownless. 1988. Ingestion of shotshell pellets by waterfowl wintering in Texas. p. 597-607 in M. W. Weller (ed.): Waterfowl in Winter. University of Minnesota Press, Minneapolis, Minnesota.

Mueller, A. J., and G. A. Matthews. 1987. Freshwater inflow needs of the Matagorda Bay system with focus on penaeid shrimp. NOAA Technical Memorandum NMFS-SEFC-189. Galveston, Texas. 97 p.

Muncy, R. J. 1984. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico): white shrimp. U. S. Fish and Wildlife Service FWS/OBS-82/11.20. Slidell, Louisiana. 19 p.

Mysak, L. A. 1986. El Niño, interannual variability and fisheries in the northeast Pacific Ocean. Canadian Journal of Fisheries and Aquatic Science 43:464-497.

Nance, J. M., E. F. Klima, and T. E. Czapla. 1989. Gulf of Mexico shrimp stock assessment workshop. NOAA Technical Memorandum NMFS-SEFC-239. Galveston, Texas. 23 p.

Nance, J., E. Martinez, D. Emiliani, J. Davis, L. Rathmell and Z. Zein-Eldin. 1993. Shrimp trawl bycatch in the Galveston Bay System. p. 249-253 in R. W. Jensen, R. W. Kiesling and F. S. Shipley (eds.): Proceedings, The Second State of the Bay Symposium, February 4-6, 1993. Galveston Bay National Estuary Program Publication GBNEP-23. Houston, Texas.

Neill, R. L. 1992. Recent trends in shorebird migration for north-central Texas. The Southwestern Naturalist 37:87-88.

Nelson, K., and M. Soulé. 1987. Genetical conservation of exploited fishes. p. 345-418 in N. Ryman and F. Utter (eds.): Population Genetics and Fishery Management. Washington Sea Grant Program, University of Washington Press, Seattle.

Newell, C. J., H. S. Rifani, and P. P. Bedient. 1992. Characterization of non-point sources and loadings to Galveston Bay. Galveston Bay National Estuary Program Publication GBNEP-15. Houston, Texas. 221 pp.

Nixon, S. W. 1981. Freshwater inputs and estuarine productivity. p. 31-57 in R. D. Cross and D. L. Williams (eds.): Proceedings of the National Symposium on Freshwater Inflow to Estuaries. Volume I. U. S. Fish and Wildlife Service FWS/OBS-81/04.

Oberholser, H. C. 1974. E. B. Kincaid, Jr., ed. The Bird Life of Texas. Volume I. University of Texas Press, Austin, Texas. 530 pp.

Oppenheimer, C. H., W. B. Brogden, and K. G. Gordon (eds.). 1973. Toxicity Studies of Galveston Bay Project, Sept. 1, 1971 to Dec. 1, 1972. Final report to the Texas Water Quality Board, Galveston Bay Study Program, for contract IAC (72-73) 183. University of Texas Marine Science Institute. Port Aransas, Texas.

Orth, R. J., and J. van Montfrans. 1991. Seagrass beds as critical nursery areas for the blue crab, Callinectes sapidus. American Fisheries Society Annual Meeting, September 8-12, 1991, San Antonio, Texas. Abstracts:115.

Osborn, M. 1992. Appendix 3: Commercial and recreational fisheries landings. p. 232-261 in C. Loeffler and A. Walton (eds.): Status and Trends of Selected Living Resources in the Galveston Bay System. Galveston Bay National Estuary Program Publications 19. Houston, Texas.

Osborn, M., A. Green, P. Chai, J. Lin, A. Morgan, P. Rubec, S. Spanyers, and A. Walton. 1992. Fisheries. p. 12-264 in C. Loeffler and A. Walton (eds.): Status and Trends of Selected Living Resources in the Galveston Bay System. Galveston Bay National Estuary Program Publications 19. Houston, Texas.

Parker, J. C. 1970. Distribution of juvenile brown shrimp (Penaeus aztecus Ives) in Galveston Bay, Texas, as related to certain hydrographic features and salinity. Contributions to Marine Science 15:1-12.

Parker, J. C. 1971. The biology of the spot, Leiostomus xanthurus Lacepede, and the Atlantic croaker, Micropogon undulatus (Linnaeus), in two Gulf of Mexico nursery areas. NOAA Sea Grant Publication TAMU-GS-71-210. Galveston, Texas. 182 p.

Pederson, R. L., D. G. Jorde, and S. G. Simpson. 1989. Northern Great Plains. p. 281-310 in L. M. Smith, R. L. Pederson, and R. M. Kaminski (eds.): Habitat Management for Migrating and Wintering Waterfowl in North America. Texas Tech Press, Lubbock, Texas.

Perry, H. M. (ed.), G. Adkins, R. Condrey, P. C. Hammerschmidt, S. Heath, J. R. Herring, C. Moss, and G. Perkins. 1984. A profile of the blue crab fishery of the Gulf of Mexico. Gulf States Marine Fisheries Commission Publication 9. Ocean Springs, Mississippi. 80 p.

Powell, E. N. 1993. Status and trends analysis of oyster reef habitat in Galveston Bay. p. 207-209 in R. W. Jensen, R. W. Kiesling and F. S. Shipley (eds.): Proceedings, The Second State of the Bay Symposium, February 4-6, 1993. Galveston Bay National Estuary Program Publication GBNEP-23. Houston, Texas.

Powell, E. N., J. D. Gauthier, E. A. Wilson, A. Nelson, R. R. Fay, and J. M. Brooks. 1993. Oyster disease and climate change. Are yearly changes in Perkinsus marinus parasitism in oysters (Crassostrea virginica) controlled by climate cycles in the Gulf of Mexico? PSZNI Marine Ecology 13:243-270.

Powell, G. V. N., J. W. Fourqurean, W. J. Kenworthy, and J. C. Zieman. 1991. Bird colonies cause seagrass enrichment in a subtropical estuary: observational and experimental evidence. Estuarine, Coastal and Shelf Science 32:567-579.

Pulich, W. M., and W. A. White. 1990. Decline of submerged vegetation in the Galveston Bay System: chronology and relationships to physical processes. University of Texas at Austin Bureau of Economic Geology. Austin, Texas. 27 p.

Ragan, J. G. and B. A. Matherne. 1974. Studies on Loxothylacus texanus. p. 185-203 in R. L. Amborski, M. A. Hood and R. R. Miller (eds.): Proceedings Gulf Coast Regional Symposium on Diseased Marine Animals. Sea Grant Publication LSU-SG-74-05, Louisiana State University. Baton Rouge, Louisiana.

Ropelewski, C. F., and M. S. Halpert. 1986. North American precipitation and temperature patterns associated with the El Niño/Southern Oscillation (ENSO). Monthly Weather Review 114:2352-2362.

Slack, R. D. 1978. The Texas Colonial Waterbird Survey. Proceedings National Audubon Society, Cornell University Conference on the Amateur and North American Ornithology. National Audubon Society.

Slack, R. D., D. Gawlik, D. Harpole, and J. Thomas. 1992. Status and trends of selected vertebrate resources in the Galveston Estuary: birds and alligators. p. 265-346 in C. Loeffler and A. Walton (eds.): Status and Trends of Selected Living Resources in the Galveston Bay System. Galveston Bay National Estuary Program Publication 19. Houston, Texas.

Spalding, M. G. 1990. Antemortem diagnosis of Eustrongylidosis in wading birds (Ciconiformes). Colonial Waterbirds 13:75-77.

Spalding, M. G. 1991. Water bird diseases. p. 177-181 in Coastal Nongame Workshop, Southeast Region, Gainesville, Florida.

Spendelow, J. A., R. M. Erwin, and B. K. Williams. 1989. Patterns of species co-occurrence of nesting colonial Ciconiiformes in Atlantic Coast estuarine areas. Colonial Waterbirds 12:51-59.

Stahle, D. W., and M. K. Cleaveland. 1993. Southern Oscillation extremes reconstructed from tree rings of the Sierra Madre Occidental and Southern Great Plains. Journal of Climate 6:129-140.

Stanley, D. W. 1989. Historical trends in water quality and fisheries resources in Galveston Bay, Texas. Draft Report to National Ocean Pollution Program Office (NOAA, Rockville, MD). Institute for Coastal and Marine Resources, East Carolina University, Greenville, North Carolina.

Steele, P., and H. M. Perry (eds.). 1990. The blue crab fishery of the Gulf of Mexico, United States: a regional management plan. Gulf States Marine Fisheries Commission 21. Ocean Springs, Mississippi.

Strecker, J. K. 1912. The birds of Texas: an annotated check list. Baylor University Bulletin 15(1). Waco, Texas.

Stutzenbaker, C. D., and M. W. Weller. 1989. The Texas coast. p. 385-405 in L. M. Smith, R. L. Pederson, and R. M. Kaminski (eds.): Habitat Management for Migrating and Wintering Waterfowl in North America. Texas Tech Press, Lubbock, Texas.

Summers, K., and E. Hornig. Potential toxicity concerns for Galveston Bay: results from the Environmental Monitoring and Assessment Program (EMAP). p. 99-101 in R. W. Jensen, R. W. Kiesling and F. S. Shipley (eds.): Proceedings, The Second State of the Bay Symposium, February 4-6, 1993. Galveston Bay National Estuary Program Publication GBNEP-23. Houston, Texas.

Swetnam, T. W., and J. L. Betancourt. 1990. Fire-Southern Oscillation relations in the southwestern United States. Science 249:1017-1020.

Telfair, R. C. II. in press. Cattle egret (Bubulcus ibis) population trends and dynamics in Texas (1954-1990). Texas Parks and Wildlife Department. Austin, Texas.

Telfair, R. C. II, C. D. Frentress, and B. G. Davis. 1982. Food of fledgling olivaceous cormorants (Phalacrocorax olivaceus) in East Central Texas. Bulletin of the Texas Ornithological Society 15:16-18.

Texas Colonial Waterbird Society. 1982. An Atlas and Census of Texas Waterbird Colonies 1973-1980. Caesar Kleberg Wildlife Research Institute. Kingsville, Texas.

Texas Department of Water Resources. 1981. Trinity-San Jacinto Estuary: a study of the influences of freshwater inflows. TPWR LP-113. Austin, Texas.

Thomas, J. L., R. J. Zimmerman, and T. J. Minello. 1990. Abundance patterns of juvenile blue crabs (Callinectes sapidus) in nursery habitats of two Texas bays. Bulletin of Marine Science 46:115-125.

Trebatoski, B. 1988. Observations on the 1986-1987 Texas red tide (Ptychodiscus brevis). Texas Water Commission Report 88-02. Austin, Texas. 48 p.

Trenberth, K. E., G. W. Branstator, and P. A. Arkin. 1988. Origins of the 1988 North American drought. Science 242:1640-1645.

Turner, R. E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Transactions of the American Fisheries Society 106:411-416.

Turner, R. E. 1991. Tide gauge records, water level rise, and subsidence in the northern Gulf of Mexico. Estuaries 14:139-147.

Turner, R. E., and M. S. Brody. 1983. Habitat suitability index models: northern Gulf of Mexico brown shrimp and white shrimp. U.S. Fish and Wildlife Service FWS/OBS-82/10.54. Slidell, Louisiana. 24 p.

Wadie, W. F., and Abdel Razek, F. A. 1985. The effects of damming on the shrimp population in the south-eastern part of the Mediterranean Sea. Fisheries Research 3:323-335.

Ward, G. H., and N. E. Armstrong. 1992. Ambient water and sediment quality of Galveston Bay: present status and historical trends. Galveston Bay National Estuary Program Publication GBNEP-22. Houston, Texas. 181 p.

White, D. H., C. A. Mitchell, and D. M. Swineford. 1984. Reproductive success of black skimmers in Texas relative to environmental pollutants. Journal of Field Ornithology 55:18-30.

White, W. A., T. A. Tremblay, E. G. Wermund, and L. R. Handley. 1993. Trends and status of wetland and aquatic habitats, Galveston Bay, Texas. p. 201-205 in R. W. Jensen, R. W. Kiesling and F. S. Shipley (eds.): Proceedings, The Second State of the Bay Symposium, February 4-6, 1993. Galveston Bay National Estuary Program Publication GBNEP-23. Houston, Texas.

Williams, A. B. 1969. Penaeid shrimp catch and heat summation, an apparent relationship. p. 643-656 in M. N. Mistakidis (ed.): Proceedings of the World Scientific Conference on the Biology and Cultutre of Shrimps and Prawns. FAO Fisheries Reports No. 57, vol. 3.

Williams, G. G. 1938. Notes on the waterbirds of the upper Texas coast. The Auk 55:62-70.

Wilson, C. A., D. W. Beckman, D. L. Nieland, and A. L. Stanley. 1992. The variation of year-class strength and annual reproductive output of red drum, Sciaenops ocellatus, and black drum, Pogonias cromis, from the northern Gulf of Mexico; and age structure and reproductive potential of the northern Gulf of Mexico offshore population of red drum not vulnerable to purse seine capture: the missing fish? Final report. Marine Fisheries Initiative (MARFIN) Program LSU-CFI-92-2. Baton Rouge, Louisiana.

Wilson, E. A., E. N. Powell, T. L. Wade, R. J. Taylor, B. J. Presley, and J. M. Brooks. 1993. Spatial and temporal distributions of contaminant body burden and disease in Gulf of Mexico oyster populations: the role of local and large-scale climatic controls. Hegolander Meeresuntersuchungen 46:201-235.

Zimmerman, R. J., and T. J. Minello. 1984. Densities of Penaeus aztecus, Penaeus setiferus, and other natant macrofauna in a Texas salt marsh. Estuaries 7:421-433.

Zimmerman, R. J., T. J. Minello, M. C. Castiglione, and D. L. Smith. 1990. Utilization of marsh and associated habitats along a salinity gradient in Galveston Bay. NOAA Technical Memorandum NMFS-SEFC-250. Galveston, Texas. 68 p.

Zimmerman, R. J., T. J. Minello, E. F. Klima, and J. M. Nance. 1991. Effects of accelerated sea-level rise on coastal secondary production. p. 110-124 in H. S. Bolton (ed.): Coastal Wetlands. American Society of Civil Engineers, New York.

APPENDIX 1. TREND ANALYSIS TABLES (ANODE AND ANOVA)

Table 4. Analysis of deviance for blue crab caught by bag seine, 25-45 mm TW, January-December, 1978-1990 (Figure 1B).

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 5. Analysis of deviance for Atlantic croaker caught by bag seine, 30-50 mm, December-March, 1977-1991 (Figure 1C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	160.12	53.37	42.34	<0.001
YEAR					
Linear	1	14.03	14.03	11.13	<0.001
Quadratic	1	6.47	6.47	5.13	<0.025
Other	10	83.05	8.31	6.59	<0.001
Month x Year	36	160.75	4.47	3.54	<0.001
Corrected error	423	533.14	1.26		

Table 6. Analysis of deviance for brown shrimp caught by bag seine, 30-55 mm, April-November, 1978-1990 (Figure 1D).

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 7. Analysis of deviance for striped mullet caught by bag seine, 20-40 mm, February-March, 1978-1990 (Figure 1E).

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 8. Analysis of deviance for white shrimp caught by bag seine, 35-55 mm, June-December, 1977-1990 (Figure 1F, 12A).

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 9. Analysis of deviance for spot caught by bag seine, 35-80 mm, March-July, 1978-1991 (Figure 1G).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	4	142.70	35.67	25.22	<0.001
YEAR					
Linear	1	15.23	15.23	10.76	0.001
Quadratic	1	1.58	1.58	1.11	>0.25
Other	11	25.9	2.35	1.66	>0.05
Month x Year	51	213.3	4.18	2.96	<0.001
Corrected error	600	848.9	1.41		

Table 10. Analysis of deviance for bay anchovy caught by bag seine, 15-34 mm, May-October, 1978-1990 (Figure 1H).

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 11. Analysis of deviance for bay anchovy caught by bag seine, 35-54 mm, April-October, 1978-1990 (Figure 1H).

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 12. Analysis of deviance for bay anchovy caught by bag seine, >=55 mm, April-November, 1978-1990 (Figure 1H).

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 13. Analysis of deviance for grass shrimp caught by bag seine, 25-35 mm, January-December, 1983-1991 (Figure 1I).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	81	7.36	5.78	<0.001
YEAR					
Linear	1	6.73	6.73	5.29	<0.025
Quadratic	1	48.26	48.26	37.89	<0.001
Other	6	26.3	4.38	3.44	<0.005
Month x Year	88	578.30	6.57	5.16	<0.001
Corrected error	1136	1446.80	1.27		

Table 14. Analysis of deviance for Gulf menhaden caught by bag seine, 20-30 mm, February-July, 1978-1991 (Figure 1J).

Source of variation	D.F.	Deviance	M.D.	F	P
Month	5	127.70	25.54	20.20	<0.001
YEAR					
Linear	1	14.82	14.82	11.72	<0.001
Quadratic	1	9.64	9.64	7.62	0.005
Other	11	187.20	17.02	13.46	<0.001
Month x Year	64	357.4	5.58	4.42	<0.001
Corrected error	499	631.0	1.26		

Table 15. Analysis of deviance for juvenile pinfish caught by bag seine, 40-60 mm, March-June, 1978-1991 (Figure 1K).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	72.69	24.23	19.48	<0.001
YEAR					
Linear	1	1.56	1.56	1.26	>0.25
Quadratic	1	3.271	3.271	2.62	>0.10
Other	11	40.77	3.71	2.98	<0.001
Month x Year	38	131.91	3.47	2.80	<0.001
Corrected error	424	527.51	1.24		

Table 16. Analysis of deviance for longnose killifish caught by bag seine, 45-75 mm, January-December, 1978-1991 (Figure 1L).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	84.30	7.66	7.32	<0.001
YEAR					
Linear	1	12.26	12.26	11.71	<0.001
Quadratic	1	63.85	63.85	60.99	<0.001
Other	11	124.40	11.309	10.89	<0.001
Month x Year	142	577.50	4.07	3.88	<0.001
Corrected error	1241	1299.20	1.05		

Table 17. Analysis of deviance for Gulf killifish caught by bag seine, 35-85 mm, July-August, 1978-1991 (Figure 1M).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	1	5.77	5.77	6.41	<0.025
YEAR					
Linear	1	11.00	11.00	12.22	<0.001
Quadratic	1	.61	.61	.68	>0.25
Other	11	34.09	3.10	3.44	<0.001
Month x Year	13	44.55	3.43	3.81	<0.001
Corrected error	229	206.11	.90		

Table 18. Analysis of deviance for Gulf killifish caught by bag seine, 45-85 mm, November-March, 1978-1991 (Figure 1M).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	4	25.87	6.47	5.52	<0.001
YEAR					
Linear	1	92.4	92.4	78.91	<0.001
Quadratic	1	24.88	24.88	21.25	<0.001
Other	10	69.90	6.99	5.97	<0.001
Month x Year	48	197.31	4.11	3.52	<0.001
Corrected error	510	597.13	1.17		

Table 19. Analysis of deviance for sheepshead minnow caught by bag seine, 25-50 mm, November-August, 1978-1991 (Figure 1N).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	9	237.6	26.40	21.81	<0.001
YEAR					
Linear	1	38.38	38.38	31.70	<0.001
Quadratic	1	59.91	59.91	49.48	<0.001
Other	10	139.80	13.98	11.55	<0.001
Month x Year	108	539.90	5.00	4.13	<0.001
Corrected error	987	1195	1.21		

Table 20. Analysis of deviance for sand seatrout caught by bag seine, 35-55 mm, April-October, 1978-1991 (Figure 1 O).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	6	75.59	12.60	13.00	<0.001
YEAR					
Linear	1	27.15	27.15	28.00	<0.001
Quadratic	1	5.37	5.37	5.54	<0.01
Other	11	128.56	11.68	12.05	<0.001
Month x Year	77	270.17	3.51	3.62	<0.001
Corrected error	647	627.27	0.97		

Table 21. Analysis of deviance for hardhead catfish caught by bag seine, 50-150 mm, June-September, 1978-1991 (Figure 1P).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	22.87	7.62	7.90	<0.001
YEAR					
Linear	1	12.98	12.98	13.45	<0.001
Quadratic	1	10.55	10.55	10.93	<0.001
Other	11	61.31	5.57	5.77	<0.001
Month x Year	38	133.46	3.51	3.64	<0.001
Corrected error	475	458.52	.97		

Table 22. Analysis of deviance for white mullet caught by bag seine, 35-105 mm, June-September, 1978-1991 (Figure 1Q).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	157.46	52.49	36.46	<0.001
YEAR					
Linear	1	23.90	23.90	16.60	<0.001
Quadratic	1	57.34	57.34	39.83	<0.001
Other	11	83.12	7.56	5.25	<0.001
Month x Year	88	148.87	1.69	1.17	>0.10
Corrected error	422	607.58	1.44		

Table 23. Analysis of deviance for red drum caught by bag seine, 25-65 mm, October-January, 1977-1991 (Figure 1R).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	66.63	22.21	22.75	<0.001
YEAR					
Linear	1	10.27	10.27	10.52	<0.005
Quadratic	1	6.38	6.38	6.54	0.01
Other	11	100.18	9.11	9.33	<0.001
Month x Year	39	103.34	2.65	2.71	<0.001
Corrected error	323	315.33	.98		

Table 24. Analysis of deviance for bay whiff caught by bag seine, 25-65 mm, April-June, 1978-1991 (Figure 1S).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	2	0.30	0.15	.152	>0.75
YEAR					
Linear	1	18.60	18.60	18.85	<0.001
Quadratic	1	40.38	40.38	40.93	<0.001
Other	11	69.49	6.32	6.40	<0.001
Month x Year	25	113.98	4.56	4.62	<0.001
Corrected error	239	235.83	.99		

Table 25. Analysis of deviance for spotted seatrout caught by bag seine, 35-75 mm, June-November, 1978-1990 (Figure 1T).

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		

Table 26. Analysis of deviance for least puffer caught by bag seine, 20-40 mm, May-June, 1978-1991 (Figure 1U).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	1	0.02	0.02	0.02	>0.75
YEAR					
Linear	1	0.07	0.07	0.07	>0.75
Quadratic	1	11.14	11.14	10.64	>0.001
Other	11	112.64	10.24	9.78	<0.001
Month x Year	12	39.07	3.26	3.11	<0.001
Corrected error	176	184.18	1.04		

Table 27. Analysis of deviance for southern flounder caught by bag seine, 20-45 mm, February-March, 1978-1991 (Figure 1V).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	1	4.56	4.56	4.88	<0.025
YEAR					
Linear	1	3.90	3.90	4.17	<0.05
Quadratic	1	0.33	0.33	0.35	>0.50
Other	11	65.62	5.97	6.39	<0.001
Month x Year	13	49.40	3.80	4.07	<0.001
Corrected error	109	177.49	0.93		

Table 28. Analysis of deviance for black drum caught by bag seine, 55-85 mm, June-August, 1978-1990 (Figure 1W).

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 29. Analysis of deviance for Atlantic croaker caught by trawl, 115-135 mm, March-September, 1983-1990 (Figure 2B, 14A).

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		

Table 30. Analysis of deviance for blue crab caught by trawl, 25-45 mm TW, January-December, 1983-1990 (Figure 2C).

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 31. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1983-1990 (Figure 2C).

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 32. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1983-1990 (Figure 2C).

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		

Table 33. Analysis of deviance for white shrimp caught by trawl, 110-130 mm, April-May, 1982-1990 (Figure 2D).

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 34. Analysis of deviance for white shrimp caught by trawl, 110-130 mm, August-November, 1982-1990 (Figures 2D, 11B).

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		

Table 35. Analysis of deviance for spot caught by trawl, 80-130 mm, May-September, 1983-1991 (Figure 2E).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	4	23.86	5.97	7.64	<0.001
YEAR					
Linear	1	3.58	3.58	4.58	<0.05
Quadratic	1	0.49	0.49	0.63	>0.25
Other	6	14.04	2.34	3.00	<0.01
Month x Year	32	136.82	4.27	5.48	<0.001
Corrected error	817	637.34	0.78		

Table 36. Analysis of deviance for Gulf menhaden caught by trawl, 110-120 mm, January-December, 1983-1990 (Figure 2F).

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 37. Analysis of deviance for sand seatrout caught by trawl, 65-85 mm, May-December, 1983-1990 (Figure 2G).

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 38. Analysis of deviance for sand seatrout caught by trawl, 140-160 mm, April-November, 1983-1990 (Figure 2G).

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 39. Analysis of deviance for brown shrimp caught by trawl, 85-110mm, May-August, 1983-1990 (Figure 2H).

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		

Table 40. Analysis of deviance for hardhead catfish caught by trawl, >=140 mm, March-August, 1983-1991 (Figure 2 I).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	5	49.62	9.92	12.94	<0.001
YEAR					
Linear	1	18.15	18.15	23.63	<0.001
Quadratic	1	52.10	52.10	67.84	<0.001
Other	6	54.44	9.07	11.81	<0.001
Month x Year	40	142.26	3.56	4.63	<0.001
Corrected error	988	758.81	0.77		

Table 41. Analysis of deviance for brief squid caught by trawl, 20-40 mm, September-November, 1983-1991 (Figure 2J).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	2	6.76	3.38	4.62	0.01
YEAR					
Linear	1	39.37	39.37	53.84	<0.001
Quadratic	1	61.21	61.21	83.70	<0.001
Other	6	45.06	7.51	10.27	<0.001
Month x Year	16	70.69	4.42	6.04	<0.001
Corrected error	438	320.30	.73		

Table 42. Analysis of deviance for brief squid caught by trawl, 40-70 mm, February-May, 1983-1991 (Figure 2J).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	3	56.00	18.67	26.97	<0.001
YEAR					
Linear	1	7.85	7.85	11.35	<0.001
Quadratic	1	24.01	24.01	34.69	<0.001
Other	6	47.86	7.98	11.53	<0.001
Month x Year	24	97.44	4.06	5.87	<0.001
Corrected error	570	394.51	0.69		

Table 43. Analysis of deviance for bay whiff caught by trawl, 80-100 mm, July-September, 1983-1991 (Figure 2K).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	2	0.07	0.03	0.05	>0.75
YEAR					
Linear	1	21.21	21.21	31.879	<0.001
Quadratic	1	5.34	5.34	8.03	<0.005
Other	6	55.73	9.29	13.96	<0.001
Month x Year	16	51.64	3.23	4.85	<0.001
Corrected error	456	303.39	.67		

Table 44. Analysis of deviance for fringed flounder caught by trawl, 80-100 mm, September-November, 1983-1991 (Figure 2L).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	2	3.03	1.515	2.39	>0.05
YEAR					
Linear	1	87.18	87.18	137.41	<0.001
Quadratic	1	6.97	6.97	10.99	<0.001
Other	6	49.21	8.20	12.92	<0.001
Month x Year	16	34.38	2.15	3.39	<0.001
Corrected error	419	265.82	0.63		

Table 45. Analysis of deviance for bay anchovy caught by trawl, 15-34 mm, December-March, 1983-1990 (Figure 2M).

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 46. Analysis of deviance for bay anchovy caught by trawl, 35-54 mm, January-December, 1983-1990 (Figure 2M).

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 47. Analysis of deviance for bay anchovy caught by trawl, >=55 mm, January-December, 1983-1990 (Figure 2M).

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		

Table 48. Analysis of deviance for least puffer caught by trawl, 45-75 mm, September-November, 1983-1991 (Figure 2N).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	2	15.32	7.66	12.73	<0.001
YEAR					
Linear	1	0.03	0.03	0.06	>0.75
Quadratic	1	4.23	4.23	7.02	<0.005
Other	6	75.30	12.55	20.86	<0.001
Month x Year	16	40.57	2.54	4.22	<0.001
Corrected error	400	240.67	0.60		

Table 49. Analysis of deviance for bighead searobin caught by trawl, all sizes, January-December, 1983-1991 (Figure 2 O).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	195.60	17.78	37.21	<0.001
YEAR					
Linear	1	11.87	11.87	24.84	<0.001
Quadratic	1	2.37	2.37	4.96	<0.05
Other	6	38.23	6.37	13.33	<0.001
Month x Year	88	125.69	1.43	2.99	<0.001
Corrected error	1350	645.11	0.48		

Table 50. Analysis of deviance for white shrimp caught by trawl, 80-100 mm, July-April, 1982-1990, using Area as a categorical variable (Figure 10A).

Source of Variation	D.F.	Deviance	M.D.	F	P
Area	1	144.80	144.80	149.28	<0.001
Month	9	433.30	48.14	49.63	<0.001
YEAR					
Linear	1	149.40	149.40	154.02	<0.001
Quadratic	1	1.50	1.50	1.55	>0.01
Other	5	83.80	16.76	17.28	<0.001
Month x Year	63	382.10	6.07	6.26	<0.001
Corrected error	1444	1403.0	0.97		

Table 51. Analysis of deviance for white shrimp caught by trawl, 110-130 mm, April-May, 1982-1990, using Area as a categorical variable (Figure 10B).

Source of Variation	D.F.	Deviance	M.D.	F	P
Area	1	75.14	75.14	85.39	<0.001
Month	1	10.38	10.38	11.80	<0.001
YEAR					
Linear	1	109.68	109.68	124.64	<0.001
Quadratic	1	0.00	0.00	0.00	>0.75
Other	6	21.77	3.63	4.12	<0.001
Month x Year	12	28.81	2.40	2.73	<0.001
Corrected error	342	300.00	0.88		

Table 52. Analysis of deviance for white shrimp caught by trawl, 110-130 mm, August-November, 1982-1990, using Area as a categorical variable (Figure 10C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Area	1	13.23	13.23	13.78	<0.001
Month	3	33.58	11.19	11.66	<0.001
YEAR					
Linear	1	117.11	117.11	121.99	<0.001
Quadratic	1	38.95	38.95	40.57	<0.001
Other	6	52.81	8.80	9.17	<0.001
Month x Year	24	143.01	5.96	6.21	<0.001
Corrected error	684	659.83	0.96		

Table 53. Analysis of deviance for white shrimp caught by trawl, 110-130 mm, August to November, 1963-1968, from TPWD/NMFS data (Figure 11A).

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 54. Analysis of deviance for white shrimp caught by trawl, 110-130 mm, August to November, 1972-1980, from TPWD/NMFS data (Figure 11A).

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		

Analysis of deviance for white shrimp caught by trawl, 110-130 mm, August-November, 1982-1990 (Figure 11B): see Table 34.

Analysis of deviance for white shrimp caught by bag seine, 35-55 mm, June-December, 1977-1990 (Figure 12A): see Table 8.

Table 55. Analysis of deviance for white shrimp caught by trawl, 80-100 mm, July-April, 1982-1990 (Figure 12B).

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		

Analysis of deviance for Atlantic croaker caught by trawl, 115-135 mm, March-September, 1983-1990 (Figure 14A): see Table 29.

Table 56. Analysis of deviance for pinfish caught by trawl, 110-140 mm, September-November, 1983-1990 (Figure 14B).

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		

Table 57. Analysis of deviance for black drum caught by 300-400 mm, fall season, 1975-1989 (Figure 14C). $CPUE=CATCH/(GTIME/14)^{1.5}$.

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

Table 58. Analysis of deviance table for southern floun by gill net, >250 mm, fall season, 1975-1989 (Figure 14 CPUE = catch/set.

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

Table 59. Analysis of deviance for red drum caught by 375-500 mm, spring season, 1977-1990 (Figure 14E). $CPUE=CATCH/(GTIME/12.5)^{2}$.

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

Table 60. Analysis of deviance for red drum caught by gill net, 501-700 mm, spring season, 1977-1990 (Figure 14F). 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		

Table 61. Analysis of deviance for spotted seatrout caught by gill net, 350-450 mm, spring season, 1977-1990 (Figure 14G). 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 62. Analysis of deviance for spotted seatrout caught by gill net, >450 mm, spring season, 1977-1990 (Figure 14H). 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		

Table 63. Analysis of deviance for blue crab caught by bag seine, <=25 mm TW, January-December, 1978-1991 (Figure 15A).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	168.5	15.07	13.96	<0.001
YEAR					
Linear	1	21.23	21.23	19.67	<0.001
Quadratic	1	8.50	8.50	7.88	0.005
Other	11	69.00	6.27	5.81	<0.001
Month x Year	141	441.90	3.13	2.90	<0.001
Corrected error	1356	1463.70	1.08		

Table 64. Analysis of deviance for blue crab caught by bag seine, 26-45 mm, January-December, 1978-1991 (Figure 15B).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	228.9	20.81	21.46	<0.001
YEAR					
Linear	1	21.74	21.74	22.47	<0.001
Quadratic	1	2.66	2.66	2.74	0.10
Other	10	30.10	2.74	2.82	0.001
Month x Year	141	361.10	2.56	2.64	<0.001
Corrected error	1338	1297.60	0.97		

Table 65. Analysis of deviance for blue crab caught by bag seine, 46-65 mm, January-December, 1978-1991 (Figure 15C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	218.50	19.86	23.85	<0.001
YEAR					
Linear	1	11.93	11.93	14.32	<0.001
Quadratic	1	0.32	0.32	0.39	>0.50
Other	11	41.00	3.73	4.47	<0.001
Month x Year	141	349.00	2.47	2.97	<0.001
Corrected error	1107	922.10	0.83		

Table 66. Analysis of deviance for blue crab caught by bag seine, 66-85 mm, January-December, 1978-1991 (Figure 15D).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	155.90	14.17	18.41	<0.001
YEAR					
Linear	1	1.17	1.17	1.51	>0.10
Quadratic	1	0.10	0.10	0.14	>0.50
Other	10	47.80	4.34	5.64	<0.001
Month x Year	141	322.40	2.28	2.97	<0.001
Corrected error	1108	852.90	0.77		

Table 67. Analysis of deviance for blue crab caught by bag seine, 86-105 mm, January-December, 1978-1991 (Figure 15E).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	134.50	12.23	16.47	<0.001
YEAR					
Linear	1	1.22	1.22	1.65	>0.10
Quadratic	1	0.01	0.01	0.02	>0.75
Other	11	51.30	4.66	6.28	<0.001
Month x Year	141	310.60	2.20	2.96	<0.001
Corrected error	1068	792.80	0.74		

Table 68. Analysis of deviance for blue crab caught by bag seine, 106-125 mm, January-December, 1978-1991 (Figure 15F).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	176.10	16.009	21.19	<0.001
YEAR					
Linear	1	4.71	4.71	6.23	<0.025
Quadratic	1	1.89	1.89	2.51	>0.10
Other	10	18.40	1.67	2.21	0.01
Month x Year	141	273.51	2.94	2.57	<0.001
Corrected error	816	616.49	0.76		

Table 69. Analysis of deviance for blue crab caught by bag seine, >125 mm, January-December, 1978-1991 (Figure 15G).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	154.63	14.06	21.01	<.001
YEAR					
Linear	1	9.43	9.43	14.10	<0.001
Quadratic	1	1.08	1.08	1.61	>0.10
Other	11	17.55	1.60	2.39	<0.01
Month x Year	141	218.01	1.55	2.31	<0.001
Corrected error	703	470.27	0.669		

Table 70. Analysis of deviance for blue crab caught by trawl, <=45 mm, January-December, 1982-1991 (Figure 16A).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	345.10	31.37	40.26	<0.001
YEAR					
Linear	1	52.31	52.31	67.13	<0.001
Quadratic	1	21.16	21.16	27.15	<0.001
Other	7	130.60	18.66	23.94	<0.001
Month x Year	99	429.00	4.33	5.56	<0.001
Corrected error	2172	1692.40	0.78		

Table 71. Analysis of deviance for blue crab caught by trawl, 46-65 mm, January-December, 1982-1991 (Figure 16B).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	918.20	83.47	104.04	<0.001
YEAR					
Linear	1	24.81	24.81	35.41	<0.001
Quadratic	1	16.51	16.51	20.58	<0.001
Other	7	80.01	11.43	14.25	<0.001
Month x Year	99	316.20	3.19	3.98	<0.001
Corrected error	2224	1784.30	0.80		

Table 72. Analysis of deviance for blue crab caught by trawl, 66-85 mm, January-December, 1982-1991 (Figure 16C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	1108.60	100.78	135.74	<0.001
YEAR					
Linear	1	25.09	25.09	33.80	<0.001
Quadratic	1	0.99	0.99	1.33	0.25
Other	7	99.30	14.19	19.10	<0.001
Month x Year	99	321.00	3.24	4.37	<0.001
Corrected error	1996	1481.90	.74		

Table 73. Analysis of deviance for blue crab caught by trawl, 86-105 mm, January-December, 1982-1991 (Figure 16D).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	755.10	68.65	99.15	<0.001
YEAR					
Linear	1	19.45	19.45	28.09	<0.001
Quadratic	1	0.02	0.02	0.03	>0.75
Other	7	83.40	11.91	17.21	<0.001
Month x Year	99	326.60	3.30	4.76	<0.001
Corrected error	1711	1184.50	.69		

Table 74. Analysis of deviance for blue crab caught by trawl, 106-125 mm, January-December, 1982-1991 (Figure 16E).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	456.50	41.50	63.77	<0.001
YEAR					
Linear	1	27.77	27.77	42.67	<0.001
Quadratic	1	2.97	2.97	4.56	<0.05
Other	7	48.70	6.96	10.69	<0.001
Month x Year	99	230.20	2.32	3.57	<0.001
Corrected error	1901	1237.10	0.65		

Table 75. Analysis of deviance for blue crab caught by trawl, 126-145 mm, January-December, 1982-1991 (Figure 16F).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	433.40	39.40	63.02	<0.001
YEAR					
Linear	1	71.55	71.55	114.45	<0.001
Quadratic	1	9.80	9.80	15.68	<0.001
Other	7	38.50	5.50	8.80	<0.001
Month x Year	99	225.70	2.28	3.65	<0.001
Corrected error	1653	1033.40	0.62		

Table 76. Analysis of deviance for blue crab caught by trawl, >145 mm, January-December, 1982-1991 (Figure 16G).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	204.10	18.55	27.90	<0.001
YEAR					
Linear	1	132.70	132.70	199.52	<0.001
Quadratic	1	4.23	4.23	6.37	<0.025
Other	7	22.10	3.16	4.75	<0.001
Month x Year	99	208.00	2.10	3.16	<0.001
Corrected error	2129	1416.00	.66		

Table 77. Analysis of deviance for blue crab caught by trawl, 25--45 mm, January-December, 1982-1991, in the upper zone of the Galveston Estuary (Figure 17A).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	237.40	21.58	21.13	<0.001
YEAR					
Linear	1	57.67	57.67	56.46	<0.001
Quadratic	1	34.51	34.51	33.78	<0.001
Other	7	87.80	12.54	12.28	<0.001
Month x Year	99	461.50	4.66	4.56	<0.001
Corrected error	899	918.30	1.02		

Table 78. Analysis of deviance for blue crab caught by trawl, 25--45 mm, January-December, 1982-1991, in the lower zone of the Galveston Estuary (Figure 17A).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	213.30	19.39	17.08	<0.001
YEAR					
Linear	1	16.50	16.50	14.53	<0.001
Quadratic	1	3.20	3.20	2.82	>0.05
Other	7	73.40	10.48	9.24	<0.001
Month x Year	99	280.80	2.84	2.50	<0.001
Corrected error	774	878.50	1.13		

Table 79. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1982-1991, in the upper zone of the Galveston Estuary (Figure 17B).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	780.30	70.94	71.50	<0.001
YEAR					
Linear	1	29.54	29.54	29.77	<0.001
Quadratic	1	24.08	24.08	24.27	<0.001
Other	7	62.40	8.91	8.98	<0.001
Month x Year	99	340.00	3.43	3.46	<0.001
Corrected error	962	954.40	0.992		

Table 80. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1982-1991, in the lower zone of the Galveston Estuary (Figure 17B).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	595.60	54.14	53.25	<0.001
YEAR					
Linear	1	19.98	19.98	19.65	<0.001
Quadratic	1	0.01	0.01	0.01	>0.75
Other	7	73.50	10.50	10.33	<0.001
Month x Year	99	242.80	2.45	2.41	<0.001
Corrected error	864	878.50	1.02		

Table 81. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1982-1991, in the upper zone of the Galveston Estuary (Figure 17C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	282.85	25.71	27.20	<0.001
YEAR					
Linear	1	58.04	58.04	61.37	<0.001
Quadratic	1	19.93	19.93	21.07	<0.001
Other	7	37.43	5.35	5.65	<0.001
Month x Year	99	246.75	2.49	2.63	<0.001
Corrected error	692	654.40	0.95		

Table 82. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1982-1991, in the lower zone of the Galveston Estuary (Figure 17C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	299.54	27.23	44.17	<0.001
YEAR					
Linear	1	19.02	19.02	30.85	<0.001
Quadratic	1	0.09	0.09	0.14	>0.50
Other	7	28.23	4.03	6.54	<0.001
Month x Year	99	153.38	1.55	2.51	<0.001
Corrected error	684	421.66	0.62		

Table 83. Analysis of deviance for blue crab caught by bag seine, 25-45 mm, January-December, 1986-1990, in Sabine Lake (Figure 21A).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	87.40	7.95	12.22	<0.001
YEAR					
Linear	1	24.72	24.72	38.03	<0.001
Quadratic	1	1.35	1.35	2.08	>0.10
Other	2	1.11	0.55	0.85	>0.25
Month x Year	44	117.65	2.67	2.67	<0.001
Corrected error	643	420.45	.65		

Table 84. Analysis of deviance for blue crab caught by bag seine, 25-45 mm, January-December, 1978-1990, in Matagorda Bay (Figure 21B).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	218.8	19.89	28.42	<0.001
YEAR					
Linear	1	7.50	7.50	10.71	<0.005
Quadratic	1	4.30	4.30	6.14	<0.025
Other	10	40.60	4.06	5.80	<0.001
Month x Year	131	400.60	3.06	4.37	<0.001
Corrected error	1292	907.10	0.70		

Table 85. Analysis of deviance for blue crab caught by bag seine, 25-45 mm, January-December, 1983-1990, in East Matagorda Bay (Figure 21C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	140.50	12.77	15.77	<0.001
YEAR					
Linear	1	49.10	49.10	60.62	<0.001
Quadratic	1	15.0	15.0	18.52	<0.001
Other	5	23.40	4.68	5.78	<0.001
Month x Year	76	242.00	3.18	3.93	<0.001
Corrected error	953	771.60	0.81		

Table 86. Analysis of deviance for blue crab caught by bag seine, 25-45 mm, January-December, 1978-1990, in San Antonio Bay (Figure 21D).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	203.80	18.53	24.38	<0.001
YEAR					
Linear	1	0.80	0.80	1.05	>0.25
Quadratic	1	9.70	9.70	12.76	<0.001
Other	10	39.70	3.97	5.22	<0.001
Month x Year	131	385.60	2.94	3.87	<0.001
Corrected error	1299	987.10	0.76		

Table 87. Analysis of deviance for blue crab caught by bag seine, 25-45 mm, January-December, 1978-1990, in Aransas Bay (Figure 21E).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	112.80	10.25	11.03	<0.001
YEAR					
Linear	1	44.10	44.10	47.42	<0.001
Quadratic	1	1.30	1.30	1.40	>0.25
Other	10	142.10	14.21	15.28	<0.001
Month x Year	131	410.90	3.14	3.37	<0.001
Corrected error	1308	1214.40	0.93		

Table 88. Analysis of deviance for blue crab caught by bag seine, 25-45 mm, January-December, 1978-1990, in Corpus Christi Bay (Figure 21F).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	194.10	17.65	18.38	<0.001
YEAR					
Linear	1	3.80	3.80	3.96	<0.05
Quadratic	1	7.50	7.50	7.81	<0.01
Other	10	99.0	9.90	10.31	<0.01
Month x Year	131	446.10	3.41	3.55	<0.001
Corrected error	1311	1260.40	0.96		

Table 89. Analysis of deviance for blue crab caught by bag seine, 25-45 mm, January-December, 1978-1990, in the Upper Laguna Madre (Figure 21G).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	291.20	26.47	41.36	<0.001
YEAR					
Linear	1	63.50	63.50	99.22	<0.001
Quadratic	1	2.40	2.40	3.75	>0.05
Other	10	49.40	4.94	7.72	<0.001
Month x Year	131	324.10	2.47	99.22	<0.001
Corrected error	1281	824.70	0.64		

Table 90. Analysis of deviance for blue crab caught by bag seine, 25-45 mm, January-December, 1978-1990, in the Lower Laguna Madre (Figure 21H).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	255.20	23.20	24.68	<0.001
YEAR					
Linear	1	59.00	59.00	62.77	<0.001
Quadratic	1	16.90	16.90	17.98	<0.001
Other	10	151.30	15.31	16.10	<0.001
Month x Year	131	451.90	3.45	3.67	<0.001
Corrected error	1312	1239.40	0.94		

Table 91. Analysis of deviance for blue crab caught by trawl, 25-45 mm, January-December, 1987-1991, in Sabine Lake (Figure 22A).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	17.68	1.61	3.58	>0.05
YEAR					
Linear	1	56.93	56.93	126.51	<0.001
Quadratic	1	0.30	0.30	0.67	>0.25
Other	2	62.46	31.23	69.40	<0.001
Month x Year	44	120.81	2.75	6.10	<0.001
Corrected error	983	444.01	0.45		

Table 92. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1987-91, in Sabine Lake (Figure 22A).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	34.57	3.14	22.45	<0.001
YEAR					
Linear	1	0.00	0.00	0.00	>0.75
Quadratic	1	2.20	2.20	15.71	<0.001
Other	2	2.54	1.27	9.07	<0.001
Month x Year	44	64.04	1.46	10.40	<0.001
Corrected error	985	138.68	0.14		

Table 93. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1987-1991, in Sabine Lake (Figure 22A).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	57.93	5.27	10.75	<0.001
YEAR					
Linear	1	0.01	0.01	0.02	>0.75
Quadratic	1	0.31	0.31	0.63	>0.25
Other	2	15.25	7.63	15.56	<0.001
Month x Year	44	111.02	2.52	5.15	<0.001
Corrected error	1007	494.48	0.49		

Table 94. Analysis of deviance for blue crab caught by trawl, 25-45 mm, January-December, 1982-1990, in Matagorda Bay (Figure 22B).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	173.49	15.77	46.39	<0.001
YEAR					
Linear	1	0.66	0.66	1.94	>0.10
Quadratic	1	21.84	21.84	64.24	<0.001
Other	6	16.36	2.73	8.02	<0.001
Month x Year	84	255.71	3.04	8.95	<0.001
Corrected error	1942	655.80	0.34		

Table 95. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1982-90, in Matagorda Bay (Figure 22B).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	266.00	24.18	56.24	<0.001
YEAR					
Linear	1	6.50	6.50	15.12	<0.001
Quadratic	1	38.60	38.60	89.77	<0.001
Other	6	44.20	7.37	17.13	<0.001
Month x Year	84	237.40	2.83	6.57	<0.001
Corrected error	1949	839.00	0.43		

Table 96. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1982-1990, in Matagorda Bay (Figure 22B).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	374.18	34.02	97.19	<0.001
YEAR					
Linear	1	1.00	1.00	2.86	>0.05
Quadratic	1	9.16	9.16	26.17	<0.001
Other	6	33.01	5.50	15.72	<0.001
Month x Year	84	124.72	1.48	4.24	<0.001
Corrected error	1938	685.7	0.35		

Table 97. Analysis of deviance for blue crab caught by trawl, 25-45 mm, January-December, 1982-1990, in San Antonio Bay (Figure 22C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	515.40	46.85	70.99	<0.001
YEAR					
Linear	1	195.40	195.40	296.06	<0.001
Quadratic	1	6.80	6.80	10.30	<0.005
Other	6	74.50	12.42	18.81	<0.001
Month x Year	88	257.80	2.93	4.44	<0.001
Corrected error	2043	1355.40	0.66		

Table 98. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1982-90, in San Antonio Bay (Figure 22C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	663.60	60.33	72.68	<0.001
YEAR					
Linear	1	121.40	121.40	146.2	<0.001
Quadratic	1	8.90	8.90	10.72	<0.005
Other	6	102.90	17.15	20.66	<0.001
Month x Year	88	250.80	2.85	3.43	<0.001
Corrected error	2049	1700.60	0.83		

Table 99. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1982-1990, in San Antonio Bay (Figure 22C).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	329.70	29.97	46.11	<0.001
YEAR					
Linear	1	84.40	84.40	129.85	<0.001
Quadratic	1	12.60	12.60	19.38	<0.001
Other	6	128.40	21.40	32.92	<0.001
Month x Year	88	185.90	2.11	3.25	<0.001
Corrected error	2043	1318.5	0.65		

Table 100. Analysis of deviance for blue crab caught by trawl, 25-45 mm, January-December, 1982-1990, in Aransas Bay (Figure 22D).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	739.10	67.19	95.99	<0.001
YEAR					
Linear	1	1.80	1.80	2.57	<0.10
Quadratic	1	0.60	0.60	0.86	>0.25
Other	6	149.10	24.85	35.50	<0.001
Month x Year	88	426.30	4.84	6.92	<0.001
Corrected error	2048	1440.80	0.70		

Table 101. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1982-90, in Aransas Bay (Figure 22D).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	859.40	78.13	95.28	<0.001
YEAR					
Linear	1	3.60	3.60	4.39	<0.05
Quadratic	1	6.60	6.60	8.05	<0.005
Other	6	129.90	21.65	26.40	<0.001
Month x Year	88	393.90	4.48	5.46	<0.001
Corrected error	2049	1681.4	0.82		

Table 102. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1982-1990, in Aransas Bay (Figure 22D).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	318.4	28.95	48.24	<0.001
YEAR					
Linear	1	2.70	2.70	4.50	<0.05
Quadratic	1	8.10	8.10	13.50	<0.001
Other	6	40.20	6.70	11.17	<0.001
Month x Year	88	287.50	3.27	5.45	<0.001
Corrected error	2036	1225.90	0.60		

Table 103. Analysis of deviance for blue crab caught by trawl, 25-45 mm, January-December, 1982-1990, in Corpus Christi Bay (Figure 22E).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	239.63	21.78	75.12	<0.001
YEAR					
Linear	1	0.58	0.58	2.00	>0.10
Quadratic	1	6.90	6.90	23.79	<0.001
Other	6	50.52	8.42	29.03	<0.001
Month x Year	84	190.17	2.26	7.81	<0.001
Corrected error	2282	670.2	0.29		

Table 104. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1982-90, in Corpus Christi Bay (Figure 22E).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	570.10	51.83	140.07	<0.001
YEAR					
Linear	1	2.20	2.20	6.95	<0.025
Quadratic	1	0.10	0.10	0.27	>0.50
Other	6	128.50	21.42	57.88	<0.001
Month x Year	84	195.70	2.33	6.30	<0.001
Corrected error	2278	831.70	0.37		

Table 105. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1982-1990, in Corpus Christi Bay (Figure 22E).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	588.40	53.49	118.87	<0.001
YEAR					
Linear	1	0.30	0.30	0.67	>0.25
Quadratic	1	0.90	0.90	2.00	>0.10
Other	6	84.80	14.15	31.44	<0.001
Month x Year	84	204.20	2.43	5.40	<0.001
Corrected error	2291	1033.10	0.45		

Table 106. Analysis of deviance for blue crab caught by trawl, 25-45 mm, January-December, 1982-1990, in the Upper Laguna Madre (Figure 22F).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	53.40	4.85	26.97	<0.001
YEAR					
Linear	1	1.04	1.04	5.78	<0.025
Quadratic	1	0.52	0.52	2.89	>0.50
Other	6	14.06	2.34	13.02	<0.001
Month x Year	84	85.92	1.02	5.98	0.001
Corrected error	861	154.34	0.18		

Table 107. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1982-90, in the Upper Laguna Madre (Figure 22F).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	185.72	16.88	43.29	<0.001
YEAR					
Linear	1	9.27	9.27	23.77	<0.001
Quadratic	1	12.20	12.20	31.28	<0.001
Other	6	40.60	6.77	17.35	<0.001
Month x Year	84	148.93	1.77	4.55	<0.001
Corrected error	884	345.35	0.39		

Table 108. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1982-1990, in the Upper Laguna Madre (Figure 22F).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	122.47	11.13	21.83	<0.001
YEAR					
Linear	1	20.14	20.14	39.49	<0.001
Quadratic	1	19.07	19.07	37.39	<0.001
Other	6	41.82	6.97	13.67	<0.001
Month x Year	84	174.84	2.08	4.08	<0.001
Corrected error	899	456.79	0.51		

Table 109. Analysis of deviance for blue crab caught by trawl, 25-45 mm, January-December, 1982-1990, in the Lower Laguna Madre (Figure 22G).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	123.29	11.21	25.47	<0.001
YEAR					
Linear	1	3.98	3.98	9.05	<0.005
Quadratic	1	0.17	0.17	0.39	>0.50
Other	6	7.87	1.31	2.98	<0.01
Month x Year	84	244.19	2.91	6.61	0.001
Corrected error	890	392.49	0.44		

Table 110. Analysis of deviance for blue crab caught by trawl, 50-70 mm, January-December, 1982-90, in the Lower Laguna Madre (Figure 22G).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	623.70	56.70	70.00	<0.001
YEAR					
Linear	1	0.36	0.36	0.44	<0.001
Quadratic	1	2.29	2.29	2.83	>0.05
Other	6	92.17	15.36	18.97	<0.001
Month x Year	84	150.20	1.79	2.21	<0.001
Corrected error	911	737.10	0.81		

Table 111. Analysis of deviance for blue crab caught by trawl, 120-140 mm, January-December, 1982-1990, in the Lower Laguna Madre (Figure 22G).

Source of Variation	D.F.	Deviance	M.D.	F	P
Month	11	223.87	20.35	27.14	<0.001
YEAR					
Linear	1	16.31	16.31	21.75	<0.001
Quadratic	1	0	0	0	>0.75
Other	6	86.79	14.47	19.29	<0.001
Month x Year	84	153.53	1.83	2.44	<0.001
Corrected error	920	691.70	0.75		

Table 112. Analysis of variance table for snowy egrets (Figure 25). TCWS data. From Slack et al. (1992).

	r^2	df	F	P	Parameter Estimate
Total Birds					
Model	0.28	1	6.33	0.023	
Year		1	6.33	0.023	-57.91
Birds/Colony					
Model	0.02	1	11.83	<0.001	
Year		1	11.83	<0.001	-3.91

Table 113. Analysis of variance table for black skimmers (Figure 26). TCWS data. From Slack et al. (1992).

	r^2	df	F	P	Parameter Estimate
Total Birds					
Model	0.27	1	5.98	0.026	
Year		1	5.98	0.026	-95.08
Birds/Colony					
Model	0.07	1	18.77	<0.001	
Year		1	7.78	0.006	-120.90
Year^2		1	6.95	0.009	0.70

Table 114. Analysis of variance table for tricolored herons (Figure 27). TCWS data. From Slack et al. (1992).

	r^2	df	F	P	Parameter Estimate
Total Birds					
Model	0.27	1	5.83	0.028	
Year		1	5.83	0.028	-87.81
Number of Colonies					
Model	0.44	1	12.46	0.003	
Year		1	12.46	0.003	0.45
Birds/Colony					
Model	0.03	2	8.53	<0.001	
Year		1	5.08	0.025	-143.13
Year^2		1	4.65	0.031	0.83

Table 115. Analysis of variance table for roseate spoonbills (Figure 28). TCWS data. From Slack et al. (1992).

	r^2	df	F	P	Parameter Estimate
Total Birds					
Model	0.30	1	6.77	0.019	
Year		1	6.77	0.019	-28.51
Birds/Colony					
Model	0.02	1	9.51	0.002	
Year		1	9.51	0.002	-2.25

Table 116. Analysis of variance table for great egrets (Figure 29). TCWS data. From Slack et al. (1992).

	r^2	df	F	P	Parameter Estimate
Number of Colonies					
Model	0.44	3	3.65	0.039	
Year		1	6.47	0.023	190.18
$Year^2$		1	6.31	0.025	-2.31
$Year^3$		1	6.15	0.027	0.01
Birds/Colony					
Model	0.01	1	4.23	0.040	
Year		1	4.23	0.040	-2.35

Table 117. Analysis of variance table for olivaceous cormorants (Figure 30). TCWS data. From Slack et al. (1992).

	r^2	df	F	P	Parameter Estimate
Total Birds					
Model	0.27	1	5.87	0.028	
Year		1	5.87	0.028	40.24
Number of Colonies					
Model	0.59	1	23.39	<0.001	
Year		1	23.39	<0.001	0.37

Table 118. Analysis of variance table for mottled ducks (Figure 31). Mid-winter Waterfowl Transects data. From Slack et al. (1992).

	r^2	df	F	P	Parameter Estimate
Model	0.74	3	13.15	<0.001	
Transect		2	14.88	<0.001	
Year		1	9.68	0.008	-5.11
Year*Transect		2	5.44	0.021	

Table 119. Analysis of variance table for northern pintails (Figure 32). Mid-winter Waterfowl Transects data. From Slack et al. (1992).

	r^2	df	F	P	Parameter Estimate
Model (log)	0.98	3	189.77	<0.001	
Transect		2	280.01	<0.001	
Year		1	9.30	0.008	-0.26
Year*Transect		2	7.93	0.006	

Table 120. Analysis of variance table for blue-winged teal (Figure 33). Mid-winter Waterfowl Transects data. From Slack et al. (1992).

	r^2	df	F	P	Parameter Estimate
Model (log)	0.69	4	7.23	0.003	
Transect		2	11.43	0.001	
Year		1	6.07	0.029	49.89
$Year^2$		1	6.07	0.029	-0.28
Year*Transect		2	0.00	0.995	