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EFFECTS OF RIVER DISCHARGE AND MARINE ENVIRONMENTAL FACTORS ON THE BROWN SHRIMP FISHERY IN THE NORTHERN GULF OF MEXICO

By

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EFFECTS OF RIVER DISCHARGE AND MARINE ENVIRONMENTAL FACTORS ON THE BROWN SHRIMP FISHERY IN THE NORTHERN GULF OF MEXICO

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Regression analyses and delta-lognormal models were used to investigate whether river discharge and environmental variables significantly affected relative abundance of brown shrimp, *Farfantepenaeus aztecus*, in the northern Gulf of Mexico. Significant negative relationships were found between mean river flow during winter and spring months and catch rates (CPUE) off Texas, Louisiana and Mississippi/Alabama. However, during the same months significant positive relationships between CPUE and the variation in mean river discharge were found for each state. In Texas and Louisiana, delta-lognormal models revealed depth zone was the most significant variable ($P \leq 0.001$) in describing distribution, while time of day ($P \leq 0.001$) was most significant in describing CPUE and also distribution and CPUE in Mississippi/Alabama. These results suggest that brown shrimp relative abundance is effected by river discharge, while gulf-wide environmental variables exert no influence, except dissolved oxygen concentrations affecting distribution off Louisiana.

DEDICATION

I would like to dedicate my research and thesis to my Mom and Dad, who always encouraged me to pursue my dreams and to never settle for anything less than my best.

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CHAPTER I

INTRODUCTION

The waters of the northern Gulf of Mexico, which stretch from the Texas/Mexico border eastward to the Florida Keys, support some of the most productive and exploited fisheries in the United States (Lang *et al.* 1994; Rabalais *et al*. 1996; Chesney *et al.* 2000; Graham 2001). In 2007, three of the top six ports for total landed weight, and seven of the top 20 ports in dollar value of fish and invertebrates in the United States, were landed in the Gulf of Mexico (National Marine Fisheries Service Fisheries Statistics Division 2008a). Additionally, in 2007, 34% of the total recreational landings (by weight) in the United States came from the Gulf of Mexico (National Marine Fisheries Service Fisheries Statistics Division 2008b). The penaeid shrimp fishery is one of the more prevalent fisheries, with nearly 4 million metric tons landed between 1962 and 2006 (ca. 93% of all penaeid shrimp landed in the United States) (National Marine Fisheries Service Fisheries Statistics Division 2008b).

The brown shrimp (*Farfantepenaeus aztecus,* formerly *Penaeus aztecus*) fishery has dominated the northern Gulf of Mexico penaeid shrimp fishery. The fishery is divided into two components. The inshore fishery includes estuaries, marshes, canals and lagoons, whereas the offshore fishery comprises everything from the coastline seaward (Haas *et al*. 2001a). Brown shrimp account for 57% of total penaeid shrimp landings from 1962-2006 (National Marine Fisheries Service Fisheries Statistics Division 2008b). Texas and Louisiana have been the top two states in brown shrimp landings with historic averages of 46% and 37%, respectively (National Marine Fisheries Service Fisheries Statistics Division 2008b). Mississippi and Alabama have historically accounted for about 15% of total brown shrimp landings (National Marine Fisheries Service Fisheries Statistics Division 2008b).

Brown shrimp are estuarine dependent species, with adults generally spending most of their time offshore (Grimes 2001) (Figure 1). They are considered an annual species (Caillouet *et al.*1980), although some individual brown shrimp survive longer than a year (Sheridan *et al.*1989; Nance *et al.*1994). Spawning takes place in continental shelf waters (Cook and Lindner 1970), with a main peak occurring between September and November, and a smaller peak occurring between April and June (Rogers *et al.*1993). Fertilization occurs externally, with eggs generally hatching within 24 hours (Cook and Lindner 1970). Brown shrimp progress through several larval substages (nauplius, protozoeal and mysis) to a postlarval stage (Cook and Lindner 1970; Wiesepape *et al.* 1972). Peak immigration of postlarval brown shrimp (10-15 mm total length (TL)) into estuaries occurs in February and March (Zimmerman *et al.*1984; Rogers *et al.* 1993). Brown shrimp remain in estuaries until they become subadults (75-95 mm TL), which then begin to emigrate from the estuaries into continental shelf waters. This movement peaks between May and June (Parrack 1979; Matthews 1982).

The continental shelf waters inhabited by brown shrimp in the northern Gulf of Mexico are subject to several environmental stresses that can include local and regional weather patterns or events (i.e., tropical storms or hurricanes), offshore inputs (i.e., eddies breaking off the Loop Current) and coastal inputs (i.e., river discharge). While some of these stresses may be difficult to account for, others, such as river discharge, are readily available and can be incorporated into analyses.

The drainage area of all rivers that flow into the northern Gulf of Mexico encompasses approximately 55% of the continental U.S. in addition to parts of Canada (Graham 2001). The Mississippi River accounts for about 90% of freshwater input into the Gulf of Mexico (Rabalais *et al.* 1996). While most freshwater from the Mississippi-Atchafalaya River system flows to the Louisiana-Texas shelf, about one-third of the Mississippi River discharge flows eastward to the Mississippi-Alabama shelf (Wiseman and Sturges 1999). Besides the inputs from the Mississippi-Atchafalaya River system, numerous small river systems discharge into the northern Gulf of Mexico. While these rivers may provide a benefit to the system, it is difficult to discern because of the enormous amount of discharge from the Mississippi and Atchafalaya rivers. Areas east of the mouth of the Mississippi River also can be influenced by discharges mainly from the Mobile River system. Other significant inputs in this area include the Pearl and Pascagoula Rivers.

Fisheries production surrounding the Mississippi River delta has been historically high with 70-80% of total landings in the Gulf of Mexico coming from this region (Grimes 2001). Increased river discharge seems to be correlated to increases in marine primary production (Lohrenz *et al.* 1997; Daskalov 2003), and better opportunities for growth, survival, and recruitment of fish and invertebrate stocks in coastal zone marine environments (Lang *et al.* 1994; Grimes 2001; Lloret *et al.* 2004). Several studies (Bebars and Lasserre 1983; Barrera-Guevara 1990; Drinkwater and Frank 1994) have shown that when river flow is diminished or completely cut off (i.e., by construction of dams) declines in landings of marine fisheries may occur. However, reductions may be species specific. Diaz-Ochoa and Quiñones (2008) found that catch rates of white shrimp (*Litopenaeus occidentralis*) off of Buenaventura in the eastern tropical Pacific were significantly lower due to freshwater input.

One of the major areas of concern in the northern Gulf of Mexico is the annual formation of a large area of hypoxia (dissolved oxygen concentration < 2mg/L), which occurs adjacent to the outflow of the Mississippi and Atchafalaya rivers (Rabalais *et al.* 1996; Stanley and Wilson 2004). The area of the hypoxic zone varies annually and has recently reached 22,000 km^2 (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2004). Dissolved oxygen levels in the northern Gulf of Mexico also are strongly related to the amount of discharge of the Mississippi River and other major rivers as well as seasonal vertical stratification of the northern Gulf of Mexico waters (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2004). Duration of hypoxic conditions is generally dependent on many factors, including Mississippi River flow and local wind conditions (Stanley and Wilson 2004), but is usually most widespread in summer. However, outflows that contribute to the hypoxic zone in the northern Gulf of Mexico also enhance both the coastal and offshore fisheries (Chesney *et al*. 2000).

The National Marine Fisheries Service (NMFS) has been conducting groundfish surveys in the northern Gulf of Mexico since fall, 1972 (Nichols and Pellegrin 1989). Initially the survey (Fall Groundfish Survey) was centered in the north-central Gulf of Mexico (Atchafalaya Bay, Louisiana to Mobile Bay, Alabama) and was designed to address a decline in finfish stocks that supported the pet food industry (G. Pellegrin, NMFS, Pascagoula, MS, *personal communication*). Starting in 1981, a Summer Groundfish Survey was added to investigate brown shrimp stocks in the northern Gulf of Mexico. This survey was conducted as a component of the Southeast Area Monitoring and Assessment Program (SEAMAP) (Rester *et al.* 2002). However, the two surveys (Summer and Fall Groundfish) used different sampling methods to address specific requirements for their respective study. Beginning in 1987, a standardized SEAMAP protocol was used for both surveys to ensure compatibility of the data. For this reason, my investigation will be based on data collected from 1987-2005.

Considering the importance of fishery resources in the northern Gulf of Mexico, the understanding of how environmental and riverine factors might affect the fisheries is essential. Brown shrimp were chosen for this study due to their importance as part of the shrimp fishery within the northern Gulf of Mexico and their abundance within the survey data. Therefore, this study incorporates the following objectives:

- To determine if the relative abundance of brown shrimp differs seasonally
- To determine if number of severe weather events that made landfall significantly affected relative abundance of brown shrimp
- To determine if a relationship exists between the volume of discharge from the Mississippi, Atchafalaya, Pearl, Pascagoula and Mobile rivers and relative abundance of brown shrimp
- To determine if a relationship exists between distance from the Mississippi, Atchafalaya, Pearl, Pascagoula and Mobile rivers and relative abundance of brown shrimp
- To determine which, if any, marine environmental variables or descriptive sampling variables significantly affect the relative abundance of brown shrimp

From the information derived in pursuit of these objectives, I anticipate to gain a better understanding of how the abundance of brown shrimp relate to the freshwater inputs of the Mississippi/Atchafalaya river systems and other major river systems in the northern Gulf of Mexico. This study should help define marine environmental factors that may affect the relative abundance of brown shrimp in the northern Gulf of Mexico.

CHAPTER II

METHODS

Data Source

The dataset for this study was obtained from the NMFS Mississippi Laboratories in Pascagoula, Mississippi. It contained data from 8,474 usable trawl stations sampled between 1987 and 2005 (Table 1). A usable trawl station was defined as when no problems that could have affected the way the net fished occurred during the trawl. These problems included: the net hanging on bottom obstructions, the doors of the net crossing, the net tangling on deployment, or the codend not being secured properly. The stations were located within the northern Gulf of Mexico in an area that extended from the Texas/Mexico border eastward to the Alabama/Florida border, and covered water depths from 9 to 110 m (Figure 2). Areas with depths < 9 m were not sampled due to the draft limitations of the survey vessels.

Sample size differed among states with Texas and Louisiana having more trawl stations than Mississippi and Alabama. The total number of stations sampled per year ranged from 387 to 484, with 154 to 271 sampled during summer, and 164 to 265 sampled during fall. For this study, catches from Mississippi and Alabama were combined because of low sample size from each of the states, and one of the NMFS shrimp statistical zones (Figure 3) included portions of each state's water.

Data Collection

Sampling cruises were conducted by the NMFS Mississippi Laboratories during summer (June-July) and fall (October-November) between 1987 and 2005. Cruises primarily occurred aboard the National Oceanic and Atmospheric Administration (NOAA) Ship *Oregon II*. However, the NOAA Ship *Gordon Gunter* and R/V *Caretta* also were utilized to sample stations when logistical or weather-related problems arose, and the NOAA Ship *Oregon II* was unable to finish sampling all of the stations. In addition, most stations in Mississippi and Alabama were sampled using the Gulf Coast Research Laboratory R/V *Tommy Munro* and the Dauphin Island Sea Lab R/V *A.E. Verrill*. Table 2 describes the general characteristics of all the vessels utilized for sample collection.

For all vessels, standardized SEAMAP protocols (detailed below) were followed, with the same gear type being used. Comparative studies documented no differences in catch rates among research vessels (Pellegrin *et al.* 2004). Nichols and Pellegrin (1989) described the sampling design, with stations selected in a stratified random design, and with strata defined spatially by 1) shrimp statistical zones (Figure 3) 2) depth zone (Table 3), and 3) temporally by time of day (i.e., day or night). The shrimp statistical zones were derived from Kutkuhn (1962).

Bottom trawls used a 12.2-m semi-balloon shrimp trawl with a 12.8-m headrope and wooden doors that measured 2.4 m x 1 m. The trawls were towed at speeds between 2.5 and 3 knots. The net was composed of three different sections: wings, intermediate area, and codend with mesh sizes of 5.08 cm, 3.81 cm, and 4.13 cm, respectively. Trawls were conducted perpendicular to the depth zone to ensure that if species were distributed by depth, they would be represented in the sample (G. Pellegrin, NMFS, Pascagoula, MS, *personal communication*). The tow's length was determined by the time necessary to cover the required depth stratum at each station. However, a single tow's duration never exceeded 55 minutes because the nets did not have turtle-exclusion devices. If the entire depth zone was not covered during a single tow, the net was hauled up, emptied and then an additional tow was started at the point where the previous tow was terminated. This process continued until the entire depth zone was covered. At the end of each tow, the entire catch was brought on deck and total catch weight was recorded. All brown shrimp in the catch were counted and the total weight of brown shrimp was taken.

Environmental data were collected at each station with a conductivity-temperature-depth (CTD) meter (Seabird 911 system; Bellevue, WA). Before each tow began, the CTD meter was lowered over the side of the vessel and allowed 3 minutes to acclimate the sensors to water conditions and to flush out any residual Triton X, a solution used to clean the sensors. The CTD meter was then lowered to approximately 1-2 meters above the sea floor. Measurements of temperature (°C), dissolved oxygen (mg/L), salinity (ppt), and turbidity (% light transmission) were taken at the bottom, midway between the surface and bottom, and at the surface. At the beginning of each cruise, and once weekly thereafter, water samples were collected with Niskin bottles. Dissolved oxygen concentration was determined using Winkler titration to verify that the dissolved oxygen sensors were properly calibrated (G. Pellegrin, NMFS, Pascagoula, MS, *personal communication*).

Air temperature (°C) and barometric pressure (mb) were automatically obtained from the shipboard weather sensors at the time when the net was set out. Water color

(Forel-Ule scale), cloud cover (percentage of sky obscured and only during the day), wave height (m), sea state (Beaufort scale), and water clarity (Secchi depth, m and only during the day) also were recorded at each station. However, because of the subjective and therefore inconsistent nature of these measurements, water color, cloud cover, wave height, sea state and water clarity were excluded from the final analysis.

During the 19-year span of this study, there were numerous times (ca. 15%) when no measurements of temperature, salinity, dissolved oxygen or turbidity were collected due to CTD meter failures. These missing measurements resulted in some data being unavailable for use in later analysis. Therefore, the GENMOD procedure (SAS Institute Inc. 2007) was used to fit a generalized linear model (GLM) to the data set to estimate temperature, salinity, dissolved oxygen and turbidity measurements when they were missing. The GLM variables were estimated at the most finite level possible. Variables included in the GLM were season, year, shrimp statistical zone, depth zone and time of day. Comparisons among the modeled data and actual conditions were made and it was determined that the GLM was calculating acceptable temperature, salinity, dissolved oxygen and turbidity measurement estimates. Acceptable measurements of temperature, salinity, dissolved oxygen and turbidity were defined as no more than a 5% difference between the actual and modeled mean value for each statistical zone by year and season.

Seasonal Variation

The catch rate, expressed as mean number of brown shrimp collected per hour (CPUE), was calculated for each station. Catch rate, expressed as total weight of brown shrimp collected per hour, was considered as an option for CPUE. To examine a possible relationship between weight and number CPUEs, a Pearson product-movement correlation coefficient was calculated. The correlation coefficient (0.95) indicated that number and weight of brown shrimp CPUE were related closely. CPUE based on number of brown shrimp was chosen for the analyses. PROC GLM (SAS Institute Inc. 2007) was used to test for significant differences between the mean CPUE of the summer and fall cruises. Due to the unbalanced nature of the data, differing numbers of stations sampled during the summer and fall cruises, PROC GLM was chosen over PROC ANOVA for the analysis.

Effects of Severe Weather Events

Total number of severe weather events (tropical storms and hurricanes) was obtained for each state from the NOAA Coastal Services Center website. All severe weather events that either made landfall within the state's boundary or 50 kilometers of the state line were counted. The 50 km buffer around each state was selected because the size of the severe weather events could have affected that state even if direct landfall did not occur. PROC REG (SAS Institute Inc. 2007) was used to determine if the CPUE for a particular state and season was significantly affected by the number of severe weather events from the previous year for that state.

After individual regression analyses were run, they were examined to ensure that normality assumptions for parametric tests were met. Where necessary, the CPUE data were log-transformed to meet normality assumptions. Additionally, points identified as influential observations or outliers by using leverage values and studentized residuals, as outlined by Belsley *et al.* (1980), were dropped and the PROC REG was rerun to test for significance between CPUE and number of severe weather events from the previous year.

Relationships with River Discharge

Based on annual discharge values and available data, five major rivers that flow into the northern Gulf of Mexico were selected for analyses with the CPUE data. The five rivers chosen were the Mississippi, Atchafalaya, Pearl, Pascagoula and Mobile. However, there were no available discharge rates for the Mobile River. Therefore, discharge rates were obtained from the Alabama River and Tombigbee River at sites closest to where the two converge to form the Mobile River. The summation of these rates was assumed to be the discharge rate for the Mobile River.

Discharge rates from 1986 – 2005 were obtained from the United States Geological Survey (USGS) for the Mississippi, Pearl, Pascagoula, Alabama and Tombigbee rivers and from the United States Army Corps of Engineers (USACE) for the Atchafalaya River. The sites for the Mississippi River and Atchafalaya River were Tarbet Landing, Mississippi and Simmersport, Louisiana, respectively. Sites for the Pearl River and Pascagoula River were Bogalusa, Mississippi and Merrill, Mississippi. The sites for the Alabama River and Tombigbee River were Monroeville, Alabama and Coffeeville, Alabama, respectively.

The discharge rates obtained from the USGS and USACE differed slightly in form with the USGS providing discharge rates as a mean daily discharge and the USACE providing discharge rates as a daily instantaneous discharge. Mean daily discharge was defined as the mean value of all discharge values recorded in a given calendar day, while daily instantaneous discharge was defined as the discharge rate at 1301 hours on a given calendar day. All discharge rates were converted into m^3/s prior to analysis.

Mean River Discharge

In a preliminary analysis of the relationship between CPUE and river discharge, annual CPUE, separated by state, was regressed against mean annual discharge from a river that influenced a particular state's waters. Seasonal CPUE also was regressed against mean annual discharge from an appropriate river. These analyses resulted in no significant relationships. Therefore, a more finite approach utilizing mean monthly discharge was used in the regression analyses.

The CPUE data were again separated by state and season. For Louisiana and Texas, daily discharge values from the Mississippi and Atchafalaya rivers were combined and a mean discharge was calculated for all months. For Mississippi/Alabama, discharge values from the Pearl River, Pascagoula River and Mobile River were combined using the same method as the Mississippi and Atchafalaya rivers to produce a monthly mean discharge. In addition, discharge from the Mississippi River was tested against CPUE despite most of the water tends to flow westward (Morey *et al.* 2003). Monthly mean discharge tested against summer CPUE was based on those from August of the previous year through May of the current year. Monthly mean discharges tested against fall CPUE were those from August of the previous year through September of the current year.

PROC REG (SAS Institute Inc. 2007) was used to determine if any significant relationships existed between brown shrimp CPUE and monthly mean discharge for a given month. After the individual regression analyses were run, they were examined to ensure that all normality assumptions for parametric tests were met. Where necessary, the CPUE data were log-transformed to meet normality assumptions. Additionally, points identified as influential observations or outliers by using leverage values and studentized residuals, as outlined by Belsley *et al.* (1980), were dropped and the PROC REG was rerun to test for significance between CPUE and river discharge.

Relative Standard Error of River Discharge

Similar to the analyses between CPUE and mean annual discharge, preliminary analysis of the relationship between CPUE and the relative standard error of river discharge, annual CPUE was regressed against relative standard error of mean annual discharge from an appropriate river. Seasonal CPUE also was regressed against relative standard error of mean annual discharge from an appropriate river. However, these analyses resulted in no significant relationship. Therefore, a more finite approach utilizing relative standard error of monthly mean discharge values was used in the regression analyses.

In addition to testing for significance between CPUE and mean instantaneous daily discharge for all months, relative standard error of mean instantaneous daily discharge was tested to determine if there was significance with CPUE. For each month, a relative standard error was calculated and PROC REG (SAS Institute Inc. 2007) was run to test for significance. The same procedure outlined in the Mean River Discharge section was followed in addition to the assumption checking procedures.

Distance from Major River Mouths

For each station, a midpoint was calculated between the starting and ending positions of the tow. On stations with multiple tows, the starting and ending positions were defined as the starting position from the first tow and the ending position of the last tow, respectively. The first step was to convert latitudes and longitudes from degrees into radians. The latitude of the midpoint (*M*) was calculated as:

$$M = \arctan\left[\frac{\sin(slat) + \sin(elat)}{\sqrt{\left((\cos(slat) + \cos(elat) * \cos(dlon))^2 + (\cos(elat) * \sin(dlon))^2\right)}}\right] \quad (2\text{-}1)$$

where *slat* is the starting position's latitude, *elat* is the ending position's latitude and where:

$$dlon = elon - slon \quad (2\text{-}2)$$

where *elon* is the ending position's longitude and *slon* is the starting position's longitude. The longitude of the midpoint (*midlon*) was calculated as:

$$midlon = \arctan\left[\frac{\cos(elat) * \sin(dlon)}{\cos(slat) + \cos(elat) + \cos(dlon)}\right] \quad (2\text{-}3)$$

In the rare instance where either the starting or ending position of the tow was missing in the data set, the remaining position was used as the midpoint. Once the coordinates for the midpoint were calculated, a distance from the mouth of the river (*D)* was calculated as:

$$D = R * U \quad (2\text{-}4)$$

where *R* is the radius of the earth (6,367 km) and *U* was calculated as:

$$U = 2 * \arctan 2\left[\sqrt{a}, \sqrt{(1-a)}\right] \quad (2\text{-}5)$$

where:

$$a = \left(\sin\left(\frac{dlat}{2} \right) \right)^2 + \cos(slat) + \cos(elat) * \left(\sin\left(\frac{dlon}{2} \right) \right)^2 \tag{2-6}$$

where:

$$dlat = |elat - slat| \tag{2-7}$$

and:

$$dlon = |elon - slon| \tag{2-8}$$

where *elat* is the midpoint latitude of the station, *slat* is the latitude of the mouth of the river, *elon* is the midpoint longitude of the station and *slon* is the longitude of the mouth of the river. Catch rates were log-transformed to meet normality assumptions. PROC REG (SAS Institute Inc. 2007) then was used to test for correlation between CPUE by state and season, and distance from the mouth of the rivers. Stations that had a zero CPUE were removed from the analysis because they do not represent catch based on distance, but rather depth and species distribution (G. Pellegrin, NMFS, Pascagoula, MS, *personal communication*).

Annual Indices of Abundance

A delta-lognormal modeling approach was used to estimate relative abundance indices for brown shrimp (Lo *et al*. 1992; Ortiz 2006). The main advantage of using this approach was allowance for the probability of zero catch (Ortiz et al 2000). Stefánsson (1996) used this approach to analyze groundfish survey data and Porch and Scott (1994) found that using the delta-lognormal model yielded the most accurate abundance estimates when a large amount of zeros are present. The final model was built on two submodels that treated separately proportion of tows with a positive catch (i.e., where at least one shrimp was caught) and catch rates at stations with positive catches separately. Proportion of tows with a positive catch submodel assumed a binomial error distribution with a logit link function, whereas the catch rates of sets with positive catches submodel assumed a lognormal distribution with a log link function.

Two types of factors, class and continuous, could have been incorporated into both submodels. The class factors, which essentially described where and when the stations were sampled, included year, season, time of day, depth zone, and region. Season was classified as either summer or fall. Time of day was classified as either day or night. In Texas and Louisiana, region was classified as east, central and west designations (Figure 4). Due to the smaller area of sampling in Mississippi/Alabama, no regional divisions were used and, thus this area was treated as a single unit. Region was used instead of NMFS shrimp statistical zone because it better divided the state's waters into manageable areas, while also accounting for unique features within each state's waters, such as mouths of rivers and estuarine systems.

Continuous factors, which described the marine environment, included bottom temperature, salinity and dissolved oxygen concentration. These bottom parameter measurements were chosen because they, presumably, best defined the environment where the brown shrimp reside. Several factors were not included in the model analysis because of other missing data points or confounding factors (G. Ingram, NMFS, Pascagoula, MS, *personal communication*). These factors included turbidity, barometric pressure, and air temperature. Depth zone was chosen over depth because it provided a more finite spatial resolution (G. Ingram, NMFS, Pascagoula, MS, *personal communication*).

A SAS GENMOD procedure (SAS Institute Inc. 2007) that used a forward step-wise regression procedure was used to determine which of the factors and interaction terms significantly explained the variability in the submodels. First, a null model was run through the GENMOD procedure that contained none of the explanatory factors or interaction terms. From the null model, a base deviance per degree of freedom was obtained. Explanatory factors were then entered into the submodels one at a time and a deviance per degree of freedom was calculated for each factor. The factor with the greatest reduction in deviance per degree of freedom was then included in the submodel only if two conditions were met: 1) at least a 1% reduction in the deviance per degree of freedom and 2) the chi-square test of significance at the 5% level. The chi-square test statistic was used to test for significance of additional factors in the final model because the difference in deviance between two consecutive nested models follows a chi-square distribution (Ortiz 2006). The submodel was then rerun with the other factors to see if they should be included. This process continued until no terms that reduced the deviance per degree of freedom by more than 1% were found.

Once a set of individual factors were found for each submodel, possible first level interactions were evaluated using the same procedure as the fixed factors. Interaction terms were built from the individual factors present in their respective submodel. First level interaction were analyzed using PROC GLIMMIX and PROC MIXED (SAS Institute Inc. 2007) for the proportion of positive tows submodel and the catch rates of sets with positive catches submodel, respectively. The significance between nested submodels was evaluated using the likelihood ratio test. Goodness-of-fit criteria, which included Akaike’s Information Criteria (AIC), Schwarz's Bayesian Criteria (BIC) and

-2 * the residual log likelihood (-2RES Log), also were used to evaluate first level interactions, where lesser values indicated a better fitting model.

When the final set of factors was selected, the delta-lognormal index of relative abundance (I_y) as described by Lo *et al.* (1992) and adapted from Ingram *et al.* (2006) was estimated as:

$$I_y = c_y p_y, \tag{2-9}$$

where c_y is the estimate of mean CPUE for positive catches only for year y and p_y is the estimate of mean probability of occurrence during year y. Both c_y and p_y were estimated using GLMs. Data used to estimate abundance for positive catches (c) and probability of occurrence (p) were assumed to have a lognormal distribution and a binomial distribution, respectively, and modeled using the following equations:

$$\ln(c) = X\beta + \varepsilon \tag{2-10}$$

and

$$p = \frac{e^{X\beta+\varepsilon}}{1+e^{X\beta+\varepsilon}}, \text{ respectively,} \tag{2-11}$$

where c is a vector of the positive catch data, p is a vector of the presence/absence data, X is the design matrix for main effects, β is the parameter vector for main effects, and ε is a vector of independent normally distributed errors with expectation zero and variance σ^2. Therefore, c_y and p_y were estimated as least-squares means for each year along with their corresponding standard errors, SE(c_y) and SE(p_y), respectively. From these estimates, I_y was calculated, as in equation (2-9), and its variance calculated as:

$$V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y) + 2c_y p_y \mathrm{Cov}(c, p), \tag{2-12}$$

where:

$$\mathrm{Cov}(c, p) \approx \rho_{\mathrm{c,p}}\left[\mathrm{SE}\left(c_y\right)\mathrm{SE}\left(p_y\right)\right], \qquad (2\text{-}13)$$

and $\rho_{\mathrm{c,p}}$ denotes correlation of *c* and *p* among years.

CHAPTER III

RESULTS

Seasonal Variation

In the northern Gulf of Mexico, catch rates (CPUE) of brown shrimp were quite variable on spatial and temporal scales. Texas had the greatest yearly and seasonal variability for CPUE (Figures 5 and 6). The difference between summer and fall CPUE in Texas was significant ($P \leq 0.001$), with a CPUE of 468 and 82 shrimp per hour, for summer and fall, respectively. In Louisiana, there was no significant difference ($P = 0.91$) in the CPUE between summer and fall (means = 87 and 86 shrimp per hour, respectively). Annual means for summer CPUE (Figure 7) and fall CPUE (Figure 8) indicate high variability among years in Louisiana’s waters. In Mississippi/Alabama, there was a significant difference ($P =0.01$) in CPUE between summer and fall (means of 70 and 51 shrimp per hour, respectively). Yearly averages for summer and fall CPUE in Mississippi/Alabama are presented in Figures 9 and 10. There was a spike in summer CPUE during 2003, whereas the fall figure showed a steadier pattern for the CPUE among years.

Effects of Severe Weather Events

The total number of severe weather events that affected a state in a given year ranged between 0 and 4 (Table 4). In Texas, regression analyses suggest that there were no significant relationships between CPUE in summer (*P* = 0.25) nor in fall (*P* = 0.99) and number of severe weather events during the prior year. Louisiana, which had the greatest number of severe weather events during the study, also had no significant relationships between CPUE in summer (*P* = 0.15) or in fall (*P* = 0.69) and number of severe weather events during the prior year. In Mississippi and Alabama, which had the least number of severe weather events during the study period, no significant relationships between CPUE in the summer (*P* = 0.40) or fall (*P* = 0.33) and the number of severe weather events during the prior year were observed.

Relationships with River Discharge

Mean River Discharge

A negative, statistically weak, relationship (*P* = 0.08, R^2 = 0.1684) was found between mean Texas summer CPUE and monthly discharge from the Mississippi and Atchafalaya rivers during December of the previous year (Table 5). When a regression analysis between mean Texas summer CPUE and January's mean discharge from the Mississippi and Atchafalaya rivers was conducted, no significant relationship was found. However, when an influential observation was removed from the analysis, a significant negative relationship (*P* = 0.02, R^2 = 0.3067) between mean Texas summer CPUE and January's mean discharge from the Mississippi and Atchafalaya rivers emerged (Table 5). There was no significant relationship between mean fall CPUE from Texas and monthly discharge from the Mississippi and Atchafalaya rivers.

For the regressions conducted between Louisiana's summer CPUE and monthly discharge, the CPUE data needed to be log transformed to meet normality assumptions.

There is a significant negative relationship ($P = 0.04$, $R^2 = 0.2260$) between Louisiana's mean summer CPUE and April's monthly discharge from the Mississippi and Atchafalaya rivers (Table 5). A negative, statistically weak relationship ($P = 0.09$, $R^2 = 0.1624$) was found between Louisiana's mean summer CPUE and March's monthly discharge of the Mississippi and Atchafalaya rivers (Table 5). Analysis of mean fall CPUE from Louisiana and monthly discharge from the Mississippi and Atchafalaya rivers indicate no significant relationships.

For the regressions between Mississippi/Alabama's summer CPUE and monthly discharge, it was necessary to log-transform CPUE data to meet normality assumptions. There was no significant relationship between summer CPUE in Mississippi/Alabama and mean monthly discharge from the Mississippi River. In addition, there was no significant relationship between the combined mean monthly discharges from the Pearl, Pascagoula and Mobile rivers. Similarly, there was no significant relationship between fall CPUE in Mississippi/Alabama and mean monthly discharge from the Mississippi River. However, there was a significant positive relationship between fall CPUE ($P = 0.01$, $R^2 = 0.4746$) and combined mean monthly discharge from the Pearl, Pascagoula and Mobile rivers in September of the previous year (Table 5).

Relative Standard Error of River Discharge

A positive, statistically significant relationship ($P = 0.04$, $R^2 = 0.2191$) was found between Texas's summer CPUE and the relative standard error of mean monthly river discharge for December of the previous year (Table 6). In addition, a statistically weak, positive relationship ($P = 0.07$, $R^2 = 0.1808$) was found between Texas's summer CPUE and the relative standard error of mean monthly river discharge in January (Table 6). A significant, positive relationship ($P = 0.01$, $R^2 = 0.2186$) was found between fall CPUE in Texas and the relative standard error of mean monthly river discharge for February (Table 6). In Louisiana, the summer CPUE was found to have a significant positive relationship ($P \leq 0.001$, $R^2 = 0.5272$) with the relative standard error of mean monthly river discharge for February (Table 6). Additionally, the fall CPUE had a weakly significant, negative relationship ($P = 0.07$, $R^2 = 0.1750$) with the relative standard error of mean monthly river discharge for May (Table 6).

In Mississippi/Alabama, summer CPUE had a significant positive relationship with relative standard error of mean monthly river discharge from the Mississippi River for January ($P = 0.04$, $R^2 = 0.2121$; Table 6) and February ($P = 0.002$, $R^2 = 0.4412$; Table 6). In addition, summer CPUE had a significantly weak, positive relationship with the relative standard error of mean monthly river discharge from the Pearl, Pascagoula and Mobile rivers for March ($P= 0.09$, $R^2 = 0.1557$; Table 6). Analysis of fall CPUE in Mississippi/Alabama and relative standard error of mean monthly river discharge from the Mississippi River indicated no significant relationships for any months. However, analysis with the Pearl, Pascagoula and Mobile rivers showed a significant, positive relationship ($P = 0.03$, $R^{2\,=}\,0.2497$) with the relative standard error for October of the previous year and fall CPUE (Table 6).

Distance from Major River Mouths

Texas summer CPUE was related positively to distance from the Mississippi River ($P \leq 0.001$) and the Atchafalaya River ($P \leq 0.001$). However, the R^2 values, 0.0298 and 0.0250 respectively, indicated a very poor fit for the regression. Similar relationships existed for Texas fall CPUE for the Mississippi River ($P \leq 0.001$, $R^2=0.0210$) and Atchafalaya River ($P \leq 0.001$, $R^2=0.0337$). Louisiana summer and fall CPUE was related negatively to distance from the Mississippi River ($P \leq 0.001$, $R^2=0.0364$; $P \leq 0.001$ $R^2=0.0254$, respectively) and Atchafalaya River ($P \leq 0.001$, $R^2=0.0099$; $P \leq 0.001$ $R^2=0.0125$, respectively).

For Mississippi/Alabama, there were no significant relationships between distance from the Mississippi River ($P = 0.18$), Pascagoula River ($P = 0.17$) or Mobile River ($P = 0.92$) and summer CPUE. However, there was a significant positive relationship ($P \leq 0.001$) between distance from the Pearl River and Mississippi/Alabama summer CPUE, although the R^2 value (0.0309) indicates a poor model fit. Similar to the patterns in Texas, a significant negative relationship ($P \leq 0.001$) was observed between distance from the Mississippi River and Mississippi/Alabama's fall CPUE; however the R^2 value (0.0599) indicated a poor model fit. There also were significant positive relationships between distance from the Pearl, Pascagoula and Mobile rivers ($P \leq 0.001$ for all rivers) and Mississippi/Alabama fall CPUE; however, R^2 values ($R^2=0.0138$, $R^2=0.0523$, $R^2=0.0530$, respectively) indicated a poor fit. The poor fits for all the regressions seem to indicate that significance is apparently an artifact of the high number of samples collected in each state and not biologically significant.

Annual Indices of Abundance

The deviance table for Texas brown shrimp is shown in Table 7. For the proportion of positive catch submodel, the step-wise analysis of deviance indicated that depth zone, time of day, year and region were the significant explanatory factors. In the positive catch submodel, the significant explanatory factors were time of day, depth zone, season, year and region. None of the interaction terms evaluated for this submodel met the criteria for being included in the final model. For the positive catch submodel, time of day*depth zone and season*depth zone were significant explanatory interactions. An assessment of the interactions as random components in the mixed model is presented in Table 8. From the combination of the proportion of positive catch submodel and the positive catch submodel, the delta-lognormal indices of relative abundance for 1987-2005 are shown in Table 9. Comparisons between the standardized CPUE (modeled data) and the observed CPUE (Figure 11) indicated that, annually, there were inconsistencies present in the sampling coverage for Texas waters.

During 1987-2005, brown shrimp were found annually in 75% to 91% of all stations sampled, with an average occurrence of 85% (Table 9). From the depth zone component of the proportion of positive catch submodel, there was a much lower odds of occurrence (18% - 84% reduction in the odds of occurrence) of brown shrimp at depths less than 18 m, with much higher odds of occurrence at depths greater than 18 m, and a peak around the 46 to 55 m depth zone. There also was a 79% reduction in the odds of occurrence of brown shrimp during the day compared to the night. Finally, the odds of occurrence in the east and west regions were identical. However, there was a 132% increase in the odds of occurrence in the central region.

From the positive catch submodel, highest catches occurred in depth zones between 20 and 32 m, with a peak around the 26 to 27 m and the 27 to 29 m depth zones. In addition, there was a 57% reduction of CPUE during the day when compared to CPUE at night. The positive catch submodel also shows that the positive catch rates are 10% higher during the fall. Regionally, there was a decrease in CPUE of 43% and 22% in the east and central regions, respectively, when compared to the west region. When the interaction term time of day*depth zone was incorporated into the model, it adjusted the parameter values for depth zone and day up for stations less than 16 m and down for all other depth zones. Depth zone*season, when incorporated into the model, had a reverse effect, adjusting the parameter values up for depth zones 46 – 55 m, 73 – 82 m, 82 – 91 m and 91 - 100 m and down for the fall season in all the other depth zones.

The deviance table for Louisiana brown shrimp is presented in Table 10. For the proportion of positive catch submodel, the step-wise analysis of deviance indicated that depth zone, bottom dissolved oxygen, time of day and year were the significant explanatory factors. In the positive catch submodel, the significant explanatory factors were time of day, depth zone, region and year. Of the interaction terms that were evaluated for the proportion of positive catch model, none met the criteria for being included in the final model. For the positive catch submodel, time of day*region and time of day*depth zone were significant explanatory interactions. An assessment of the interactions as random components in the mixed model is presented in Table 11. From the combination of the proportion of positive catch submodel and the positive catch submodel, the delta-lognormal indices of relative abundance for 1987-2005 are shown in Table 12. A comparison between the standardized CPUE (modeled data) and the observed CPUE (Figure 12) indicated that there was consistency in the sampling coverage from year to year in Louisiana waters.

From the proportion positive submodel, brown shrimp occurred between 66% and 91% of all the stations sampled in Louisiana, with an average yearly occurrence of 82% (Table 12). There was a much higher occurrence of brown shrimp in catches during the night (68% reduction in the odds of occurrence during the day). Brown shrimp showed a much lower occurrence in water < 35 m, with the highest occurrence occurring between 64 and 73 m depth zone. The proportion positive submodel indicated that for every mg/L increase in the amount of dissolved oxygen, there was a 49% increase in the odds of occurrence of brown shrimp.

From the positive catch submodel, there was a reduction in CPUE by 60% during the day. When compared to the west region, the CPUE in the east and central regions was 32% and 49% higher, respectively. The lowest CPUE occurred inshore of the 15 m depth zone and peaked around the 33-35 m depth zone. The interaction term, time of day*region adjusted the parameter values upwards for the east and central regions. Time of day*depth zone adjusted the parameter values during the day up in the 13 – 15 m depth zone and down in all the others.

The deviance table for Mississippi brown shrimp is presented in Table 13. For the proportion of positive catch submodel, the step-wise analysis of deviance indicated that time of day, depth zone and year were the significant explanatory factors. In the positive catch model, the significant explanatory factors were time of day and year. Of the interaction terms that were evaluated for the proportion of positive catch submodel and the positive catch submodel, none met the criteria for being included in the final model. From the combination of the proportion of positive catch submodel and the positive catch submodel, the delta-lognormal indices of relative abundance for 1987-

2005 are shown in Table 14. A comparison between the standardized CPUE (modeled data) and the observed CPUE (Figure 13) indicated that annually there was a lot of consistency present in the sampling coverage in Mississippi/Alabama waters.

From the proportion positive submodel, brown shrimp occurred in 34% to 77% of the stations in Mississippi and Alabama, with an average yearly occurrence of 61% (Table 14). There was a much higher occurrence of brown shrimp in the catch at night (78% reduction in odds of occurrence during the day). There were higher occurrences of brown shrimp at stations greater than 37 m in depth than in shallower stations. From the positive catch submodel, there was a reduction in the catch rates of 61% during the day.

CHAPTER IV

DISCUSSION

Brown Shrimp Fishery Characteristics

Due to a wide variety of factors that can affect the region at many scales, annual catches of brown shrimp in different locations can fluctuate dramatically. The life cycle of the brown shrimp introduces a greater level of complexity to management issues because of its life cycle movement between estuaries and the inshore/offshore habitats (Zimmerman *et al.* 2001). State regulations pertaining to the brown shrimp fishery in the northern Gulf of Mexico add another layer of complexity to management issues. Although the shrimp are not constrained by particular boundaries (i.e., state lines), they needed to be treated separately during the analysis. This necessity is exemplified by the extremely high catch rates observed in Texas waters during the summer survey.

During this survey, summer catch rates in Texas were several orders of magnitude greater than those in fall. When summer catch rates in Texas were compared to those in Louisiana and Mississippi/Alabama, a similar difference in magnitude was observed. However, fall catch rates in Texas, Louisiana and Mississippi/Alabama were similar to one another. A possible explanation for this difference is that the shrimp season is closed in Texas waters when the summer survey occurs, but is already open in the rest of the survey area. This closure of Texas waters began in 1981 when the Gulf of Mexico Shrimp Fishery Management Plan was implemented. The Texas closure was extended to

200 nautical miles to increase yield and eliminate waste caused by the discarding of undersized shrimp (Klima *et al.* 1987; Griffin *et al.*1993). As catch rates in the fall in Texas are very similar to those in Louisiana, it could be concluded that the high catch rates are a result of the closed season.

Riverine Significance

River Discharge

Increased river flow from the Mississippi and Atchafalaya rivers does not positively affect the brown shrimp fishery in Texas and Louisiana. Diop *et al.* (2007) found similar relationships between the flow of the Mississippi and Atchafalaya rivers and white shrimp (*Litopenaeus setiferus*) catch rates. The resulting significance between the discharge (means and variation) in December and January in Texas seems to be more of an indirect effect, whereas discharge (means and variation) from February to May in Louisiana appears to exert some direct effect.

The indirect affect occurring in Texas may be related to the immigration of postlarval brown shrimp into the estuaries. Morey *et al.* (2003) showed that the export pathway for fresh water is towards the west during the fall/winter and, ultimately, towards the south as a coastally trapped current along the Mexican coastline. This process could bring low salinity water to the Texas coast where it could be transported into the bays and estuaries or be blocking the migration of postlarvae into estuarine waters. Saoud and Davis (2003) suggest that postlarvae tolerance for lower salinity waters improves after 13 days of age and postlarvae younger than 13 days would not be able to survive in the low salinities found in many estuaries, thereby delaying their entrance. Shrimp postlarvae control their entrance into estuaries by swimming up into the incoming tide (Matthews *et al.* 1991; Rogers *et al.*1993), therefore this low salinity water could block them until the salinity increases, and thereby reduce their survival. Conversely, the high variation in flow could lead to gaps in the low salinity areas that were found to form when flow was low (Dinnel and Wiseman 1986; Morey *et al.* 2003). As a result pathways would open for the postlarvae to get through and enter the estuaries.

In Louisiana, the discharge from the Mississippi and Atchafalaya rivers may directly impact areas occupied by the several life stages of brown shrimp. Haas *et al.* (2001b) found several correlations between river flow (Mississippi and Atchafalaya rivers) and abundance of several life stages of brown shrimp. For all the life stages, river discharge from February to April was significant, a result which was very similar to the time that I found to be significant (March and April). The main difference was the positive relationship to April's flow, as compared to the negative relationship that I found for the same period. The difference could be related to the time shrimp entered into the estuaries. Most likely, the shrimp collected in my study are some of the first to enter the estuary and may be in a later life stage than those collected by Haas *et al.* (2001b). The role of variation in discharge amounts cannot be overlooked. Haas *et al.* (2001a) showed positive relationships between juvenile and adult abundance with temperature. Therefore, it is possible that high variation in discharge results in pulses of nutrient rich water, while not adversely affecting the water temperature with large quantities of cooler water. However, no measurements of nutrients were made during this study and the occurrence of these pulses of nutrient rich water is mainly speculative.

The waters off the coasts of Mississippi and Alabama appear to be affected differently by the river discharge than those off of the coasts of Texas and Louisiana. Part of this condition may be attributed to a reduced amount of freshwater entering the area, especially when compared to the discharges from the Mississippi and Atchafalaya rivers. This positive relationship is noteworthy because it is not only the sole positive relationship found with the mean discharge, but also is indicative of a lag effect. It is possible that the high influxes of fresh water act as signals for emigration from inshore waters to the gulf's deeper waters (Zein-Eldin and Renaud 1986). This activity would concentrate spawning populations of shrimp, possibly leading to increased numbers of shrimp the following year. This time frame also corresponds to peak brown shrimp spawning periods as reported by Rogers *et al.* (1993). This concentration of brown shrimp also occurs off the Texas coast in the fall, as evidenced by high brown shrimp catch rates during that season. However, the higher occurrences in deeper waters could be linked to the closure of the Exclusive Economic Zone (EEZ). Finally, the amount of freshwater entering this area is significantly less than the discharge from the Mississippi and Atchafalaya rivers. Therefore, high catch rates could be related to the amount of nutrients and other dissolved matter present in the discharge.

Shrimp catch rates in Mississippi/Alabama also are influenced by the variation in discharge of the Mississippi River. Discharge during similar months that were significant in the regressions of Texas and Louisiana also was found to be significant in this area Similar patterns exist with high catch rates being correlated with high variations in discharge. A significant relationship with variation in flow also exists from the combined discharge from the Mobile, Pascagoula and Pearl rivers in March. This occurrence corresponds to the time when early life stages of brown shrimp would be in the estuaries and subjected to the changes in temperature and salinity (Haas *et al*. 2001a, Haas *et al*. 2001b). Similar to the pattern observed for the Mississippi and Atchafalaya rivers, the greater catch rates are associated with high variations in discharge from the Mobile, Pascagoula and Pearl rivers.

Proximity to Rivers

While linear distance from the mouth of the rivers yielded questionable significance because of the extremely low R^2 values, proximity (related to region as defined in Figure 4) to the mouths of the rivers was observed to have a significant effect on catch rates. The eastern and central regions in Louisiana waters had the greatest positive catches and these regions coincide with the locations receiving direct discharge from the Mississippi and Atchafalaya rivers, respectively. Therefore, river flow likely has a positive influence on these fisheries, as evidenced in other studies (e.g. Grimes 2001). However, I contend that a threshold of river flow exists. At lower levels it can have a positive influence on shrimp catches, but becomes negative when the level of flow is too high.

The Hypoxic Zone

The size of the hypoxic zone in the northern Gulf of Mexico has been increasing during the past decade (Turner *et al.* 2006). This increased size has started to have a greater impact on the brown shrimp fishery in Louisiana, especially considering that up to 25% of the habitat can be lost (Craig *et al.* 2005). In addition, the large size has encroached on the waters off of the Texas coast on several occasions. The significant negative relationship between Louisiana's fall catch rates and May's variation in river discharge may be related to the size of the hypoxic zone, which previously has been correlated negatively to shrimp catches (Zimmerman *et al.* 1997; O'Connor and Whitall 2007). While low river discharges also have been linked significantly with smaller areas of hypoxia (Turner *et al.* 2006), it is possible that under conditions of low river discharge, offshore migration is less likely to be blocked (Zimmerman *et al.* 2001). During summer months when the hypoxic zone is most prevalent, high numbers of shrimp would tend to be stranded inshore of this area. As the hypoxic conditions begin to dissipate, the shrimp can move through the area that the hypoxic zone previously occupied. Once this occurs, the shrimp can recruit into the offshore fishery later that year.

Studies of the spatial distribution shifts of brown shrimp in relation to the hypoxic zone suggest that when confronted with areas of hypoxia, brown shrimp will move to both warmer inshore waters and cooler, deeper offshore waters with very high numbers remaining at the edges of hypoxic areas (Craig and Crowder 2005; Craig *et al.* 2005). With the lowest occurrence of brown shrimp in Louisiana located inshore of 35 m, there appears to be a wide area that becomes less suitable for them to inhabit. Due to a lack of data at stations with depths < 9 m, a more distinct pattern of abundance may be hidden where high densities of brown shrimp are found both inshore and offshore of the hypoxic zone (Craig and Crowder 2005). A more distinct pattern of abundance also may be obscured due to data collection methods. As the models are built upon measurement from the one CTD cast taken per station, it is unknown whether some of the tows crossed the edge of the hypoxic zone. With the evidence presented by Craig and Crowder (2005) and Craig *et al.* (2005), there could actually be high CPUE values associated with hypoxic conditions. Additionally, low CPUE values could be associated with normoxic conditions when most of the tow actually occurred in a hypoxic area. This issue is currently under review and will be addressed during future cruises (G. Pellegrin, NMFS, Pascagoula, MS, *personal communication*).

Other Environmental Influences

Time of day stands out as one of the more important factors affecting catch rates of brown shrimp, with night catches exceeding those during the day by a minimum of two times. This pattern reflects the fact that brown shrimp are primarily nocturnal and tend to bury themselves in soft substrate during the day (Cook and Linder 1970). Craig and Crowder (2005) also found the catch rates of brown shrimp to be significantly greater at night. Another reason could be that during the day the shrimp are able to detect and avoid the net better, which could also be a function of depth. Therefore, the shallower the water, the less chance at avoiding the net.

The insignificance between marine environmental variables and brown shrimp CPUE was not unique. In a study of their abundance in the Mississippi Sound, Riedel *et al.* (2008) found no relationship between abundance and temperature or salinity. In addition, when Zein-Eldin and Renaud (1986) summarized the inshore environmental effects of temperature and salinity regarding brown shrimp, they found brown shrimp were collected at temperatures ranging from 10-37 °C and salinities ranging from 0 to 45 ppt. The eurythermal and euryhaline nature of brown shrimp can be related back to its biology as an estuarine dependent species. However, Haas *et al.* (2001a) did find correlations between adult brown shrimp abundance and temperature and salinity, as were measured in the marshes and estuary, respectively. Measurements taken at these locations would have been controlling other factors such as growth rates, which have been found to increase with greater water temperatures (Minello *et al*. 1989) This type of correlation would not have been found with my data because my study examined the environmental conditions where the shrimp were captured. Finally, any trends would have been difficult to detect because the waters of the Gulf of Mexico tended to be very similar in temperature and salinity measurements.

Finding no significant relationship between number of severe weather events that entered the study area and catch rates was not totally unexpected. When these weather events passed through the study area, a good portion of the shrimp had already moved out of the inshore waters into the deeper offshore waters (Haas *et al.* 2001a). In addition, these severe weather events tend to affect the fishery infrastructure more than the brown shrimp. For example, in a Jackson county in Mississippi after Hurricane Katrina, two of the four processing plants were closed indefinitely (C. Armstrong, NMFS, Pascagoula, MS, *personal communication*). Posadas (2007) had assessed the full impact of Hurricane Katrina on the Mississippi coast seafood processors/dealers and estimated damages in excess of $100 million.

Management Implications

From the substantial difference in summer catch rates in the waters off Texas and all the other states and seasons, the question could be raised if restrictions similar to those in Texas could benefit other states in the coastal Gulf region. Watts and Pellegrin (1982) conducted a comparison of shrimp catch rates between 1980 (no closure) and 1981 (closure) and found a significant increase in shrimp catch rates in 1981. Several studies (Griffin *et al.*1993, Nance *et al.*1994) have examined the economic impacts of the Texas closure and what impact similar closures would have on a Gulf-wide basis. Their results suggest that overall net profits would increase, but would not be evenly distributed throughout the fishery. Mainly larger vessels would only be able to realize an increase in profit because of the higher flexibility to fish deeper (Nance *et al.*1994). However, before closures are implemented, more in-depth studies of brown shrimp distribution and life history should be conducted to assess the results and true validity on a more local scale, rather than applying a gulf-wide perspective. For example, LaFleur *et al.* (2005) suggested that the coastal region of Louisiana could see reductions of $45.9 million if shrimping disappeared from Terrebonne Parish, Louisiana.

Conclusions

Brown shrimp represent the most important stock of penaeid shrimp species in the northern Gulf of Mexico. By using the offshore waters and the estuaries and bays of the Gulf of Mexico during their life cycle, they are exposed to a wide range of environmental conditions. At the inception of this study, the hypothesis was that nutrients delivered to the northern Gulf of Mexico by the Mississippi River and other major rivers were a driving force that influenced brown shrimp catches and this cause and effect would be observed annually on a gulf-wide basis. However, I could find no conclusive evidence in the literature that directly linked riverine nutrient concentrations to river discharge, nor were nutrient measurements available for use in the analysis. A gulf-wide analysis could not be applied due to significant differences in catches in each state and during each season. These significant differences are mainly the result of the seasonal closure of Texas waters to shrimping during the survey. In addition, annual river discharges could not be used because brown shrimp would be most influenced during select times of the year rather than throughout the year.

Even though no direct link was apparent between river discharge and nutrient concentrations, analysis still indicated that a significant relationship existed between catch rates and river discharge. By applying a more finite approach, another factor that seems to drive the catches of brown shrimp emerged, the content of the discharge may not be as important as its physical characteristics, i.e., temperature and salinity. As previously stated, extended periods of high river discharge during the late winter and early spring adversely affect brown shrimp catches. The temperature of the discharge of river water can be the coldest of the year at a time when greater water temperatures in the estuaries are promoting faster growth that aids in securing a refuge from predation. The extended periods of high discharge could sufficiently lower the water temperature to reduce growth rates and thereby cause the brown shrimp to become more susceptible to predation. Predation in the estuaries previously has been shown to have a large impact on mortality of brown shrimp while they inhabit the estuaries (Minello and Zimmerman 1983, Minello *et al.* 1989). Overall, the time spent in the estuaries by early life stages of brown shrimp can substantially impact their catch rates.

Once they enter the offshore waters of the northern Gulf of Mexico, brown shrimp catches were principally influenced by temporal and spatial characteristics, i.e., time of day and depth zone. The one exception to the spatial distribution was the occurrence of brown shrimp when they encounter areas of low dissolved oxygen concentrations in the hypoxic zone off the Louisiana coast. The apparent lack of significance of other marine environmental factors can be explained by the eurythermal and euryhaline physiology of this species.

Future research should focus on the early life stages of brown shrimp in the estuarine systems. This research should consider the physical characteristics, i.e., temperature, salinity and nutrient concentrations, of these systems. Since river discharge has been shown to play a significant role in the relative abundance of brown shrimp, measurement of the content of the discharge, in addition to its physical characteristics, is advisable. Direct measurements of the content of the discharge combined with measures of the amount of discharge, may yield important predictive relationships. This additional information would improve overall understanding of the mechanisms affecting the dynamics of brown shrimp stocks in the northern Gulf of Mexico.

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TABLES

Table 1. Number of stations sampled for brown shrimp, *Farfantepenaeus aztecus*, as part of the Southeast Area Monitoring and Assessment Program in summer and fall in the continental shelf waters of the northern Gulf of Mexico in waters off of Texas (TX) Louisiana (LA) and Mississippi/Alabama (MS/AL) from 1987 through 2005 (Total N=8,474).

	Summer				Fall				
Year	TX	LA	MS/AL	Seasonal Total	TX	LA	MS/AL	Seasonal Total	Yearly Total
1987	88	90	93	271	51	77	36	164	435
1988	91	54	75	220	91	90	36	217	437
1989	88	53	66	207	90	90	51	231	438
1990	87	85	70	242	86	89	58	233	475
1991	91	91	50	232	90	89	53	232	464
1992	88	91	47	226	92	87	38	217	443
1993	87	87	47	221	87	90	78	255	476
1994	90	86	64	240	88	91	65	244	484
1995	87	88	47	222	90	86	50	226	448
1996	89	85	48	222	92	90	51	233	455
1997	90	73	44	207	87	93	47	227	434
1998	89	80	40	209	90	91	44	225	434
1999	90	89	46	225	91	91	50	232	457
2000	89	82	50	221	88	91	46	225	446
2001	57	59	38	154	93	91	49	233	387
2002	91	92	46	229	92	91	55	238	467
2003	91	46	46	183	91	92	82	265	448
2004	86	91	43	220	89	73	47	209	429
2005	82	67	36	185	88	98	46	232	417

Table 2. General characteristics of all survey vessels used during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program conducted in the waters off of Texas, Louisiana, Mississippi and Alabama from 1987-2005. NOAA (National Oceanic and Atmospheric Administration) GCRL (Gulf Coast Research Lab) DISL (Dauphin Island Sea Lab).

Vessel	Affiliation	Length (m)	Breadth (m)	Draft (m)	Displacement (gross tons)	Location of Net
NOAA Ship *Oregon II*	NOAA	51.8	10.4	4.3	952	Port side
NOAA Ship *Gordon Gunter*	NOAA	68.3	13.1	4.9	2,328	Stern
R/V *Caretta*	NOAA	17.5	5.2	2.4	N/A	Port side
R/V *Tommy Munro*	GCRL	29.7	7.6.	2.7.	159	Starboard side
R/V *A.E. Verrill*	DISL	19.8	5.6	1.8	70	Stern

Table 3. Summary of the different depth zones sampled during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program from 1987 through 2005. Depth zone refers to the two digit starting and ending depth sampled in fathoms based on the original survey design. Minimum Depth and Maximum Depths represent the corresponding depth in meters of each depth zone.

Depth Zone	Minimum Depth (m)	Maximum Depth (m)
0506	9.14	10.97
0607	10.97	12.80
0708	12.80	14.63
0809	14.63	16.46
0910	16.46	18.29
1011	18.29	20.12
1112	20.12	21.95
1213	21.95	23.77
1314	23.77	25.60
1415	25.60	27.43
1516	27.43	29.26
1617	29.26	31.09
1718	31.09	32.92
1819	32.92	34.75
1920	34.75	36.58
2022	36.58	40.23
2225	40.23	45.72
2530	45.72	54.86
3035	54.86	64.00
3540	64.00	73.15
4045	73.15	82.30
4550	82.30	91.44
5060	91.44	109.73

Table 4. Total number of tropical storms and hurricanes that made direct landfall in Texas, Louisiana and Mississippi/Alabama or were within 50 kilometers of the respective state line during the time period of 1986 – 2005.

Year	Texas	Louisiana	Mississippi/Alabama
1986	1	1	0
1987	1	1	0
1988	0	2	1
1989	3	3	1
1990	0	0	0
1991	0	0	0
1992	0	1	1
1993	2	0	0
1994	0	0	0
1995	1	1	1
1996	0	0	0
1997	0	1	1
1998	2	3	2
1999	1	0	0
2000	0	0	0
2001	1	0	0
2002	1	4	4
2003	3	1	1
2004	1	2	1
2005	2	3	4

Table 5. Breakdown of significant linear regressions found between catch per unit of effort (CPUE) of brown shrimp, *Farfantepenaeus aztecus*, (number of shrimp per hour) and monthly mean discharge of a particular river or group of rivers. State describes where the brown shrimp were collected as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005 with a 12.2 m semi-balloon shrimp trawl. Season denotes the time of year when the brown shrimp were collected. River describes which river discharge was used (MSAT – combined discharge from the Mississippi and Atchafalaya rivers, PPM – combined discharge from the Pearl, Pascagoula and Mobile rivers, MSR – discharge from the Mississippi River). Month describes the time frame of discharge that was used (L denotes that the data used was from the previous year). *P* and R^2 describe the P-value and R^2 values, respectively from the regression analysis. Relationship describes the direction of the relationship between CPUE and mean river discharge for a given month.

State	Season	River	Month	*P*	R^2	Relationship
Texas	Summer	MSAT	December (L)	0.08	0.1684	Negative
Texas	Summer	MSAT	January	0.02	0.3067	Negative
Louisiana	Summer	MSAT	April	0.04	0.2260	Negative
Louisiana	Summer	MSAT	March	0.09	0.1624	Negative
Mississippi-Alabama	Fall	PPM	September (L)	0.01	0.4746	Positive

Table 6. Breakdown of significant regressions found between catch per unit of effort (CPUE) of brown shrimp, *Farfantepenaeus aztecus*, (number of shrimp per hour) collected during the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005 and the relative standard error of mean monthly discharge of a particular river or group of rivers. State and season describe which CPUE was used. River describes which river discharge was used (MSAT – combined discharge from the Mississippi and Atchafalaya rivers, PPM – combined discharge from the Pearl, Pascagoula and Mobile rivers, MSR – discharge from the Mississippi River). Month describes the time frame of discharge that was used (L denotes that the data used was from the previous year). *P* and R^2 describe the P-value and R^2 values, respectively from the regression analysis. Relationship describes the direction of the relationship between CPUE and relative standard of river discharge for a given month.

State	Season	River	Month	*P*	R^2	Relationship
Texas	Summer	MSAT	December (L)	0.04	0.2191	Positive
Texas	Summer	MSAT	January	0.07	0.1808	Positive
Texas	Fall	MSAT	February	0.01	0.3186	Positive
Louisiana	Summer	MSAT	February	<0.001	0.5272	Positive
Louisiana	Fall	MSAT	May	0.07	0.1750	Negative
Mississippi-Alabama	Summer	MSR	January	0.04	0.2151	Positive
Mississippi-Alabama	Summer	MSR	February	0.002	0.4412	Positive
Mississippi-Alabama	Summer	PPM	March	0.09	0.1557	Positive
Mississippi-Alabama	Fall	PPM	October (L)	0.03	0.2497	Positive

Table 7. Deviance summary table showing the stepwise addition of explanatory factors to the 1) proportion of positive catch submodel and 2) the positive catch submodel for brown shrimp, *Farfantepenaeus aztecus*, in Texas during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program. Percentage difference refers to the total percentage of difference between the model with the explanatory variables and the null model. DZ refers to depth zone, TOD refers to time of day, and REGION refers to the western, central or eastern area of the state's waters.

Factors for Proportion Positive Submodel	Degrees of freedom	Deviance	Deviance per degrees of freedom	Percentage difference	*P*
NULL	3316	2809.2775	0.8472		
DZ	3294	2434.2885	0.7390	12.77	<0.001
DZ+TOD	3293	2275.7937	0.6911	18.43	<0.001
DZ+TOD+YEAR	3275	2206.0263	0.6736	20.49	<0.001
DZ+TOD+YEAR+REGION	3273	2169.8971	0.6630	21.75	<0.001

Factors for Positive Catch Submodel	Degrees of freedom	Deviance	Deviance per degrees of freedom	Percentage difference	*P*
NULL	2817	10347.7004	3.6733		
TOD	2816	8146.1761	2.8928	21.25	<0.001
TOD+DZ	2794	6607.6340	2.3649	35.62	<0.001
TOD+DZ+SEASON	2793	5945.8669	2.1288	42.05	<0.001
TOD+DZ+SEASON+YEAR	2775	5518.7603	1.9887	45.86	<0.001
TOD+DZ+SEASON+YEAR+REGION	2773	5397.6251	1.9465	47.01	<0.001
TOD+DZ+SEASON+YEAR+REGION+TOD*DZ	2751	5121.3300	1.8616	49.32	<0.001
TOD+DZ+SEASON+YEAR+REGION+TOD*DZ+SEASON*DZ	2729	4878.0859	1.7875	51.34	<0.001

Table 8. Analysis of first level interactions for inclusion in the positive catch submodel for brown shrimp, *Farfantepenaeus aztecus*, in Texas during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program. -2 RES Log Likelihood (-2 RES LL), Akaike's Information Criteria (AIC) and Schwartz's Bayesian Criterion (BIC) represent goodness of fit criteria used to assess how the first level interactions affected the overall model. *P* refers to the likelihood ratio test, which tests the significance between nested models. TOD refers to time of day, DZ refers to depth zone, and REGION refers to the western, central or eastern area of the state's waters. All significant indicates that the fixed factors (time of day, depth zone, season, year and region) remained significant at alpha=0.05.

Factors	-2 RES LL	AIC	BIC	*P*	Fixed Factors
TOD+DZ+SEASON+YEAR+REGION	10032.5	10070.5	10183.4		
TOD+DZ+SEASON+YEAR+REGION+TOD*DZ	9843.7	9881.7	9994.6	0.003	all significant
TOD+DZ+SEASON+YEAR+REGION+TOD*DZ+SEASON*DZ	9731.6	9733.6	9739.5	0.013	all significant

Table 9. Delta-lognormal indices of relative abundance (I_y) (number of shrimp per hour) of brown shrimp, *Farfantepenaeus aztecus*, in Texas during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program from 1987-2005 with their respective coefficient of variation (CV) and the upper (UCL) and lower (LCL) 95% confidence intervals. Total number of stations sampled (n), total number of stations where brown shrimp were caught (m) and the nominal frequency of occurrence (f) are listed for each year.

Year	n	m	f	I_y	CV	LCL	UCL
1987	139	106	0.7626	67.5105	0.1424	50.8498	89.6301
1988	182	136	0.7473	44.6801	0.1256	34.7911	57.3800
1989	178	140	0.7865	99.6020	0.1219	78.1225	126.9871
1990	173	142	0.8208	132.2714	0.1177	104.6101	167.2469
1991	181	149	0.8232	172.2799	0.1144	137.1542	216.4014
1992	180	151	0.8389	66.9597	0.1151	53.2312	84.2288
1993	174	142	0.8161	88.7268	0.1217	69.6194	113.0782
1994	178	155	0.8708	126.1974	0.1119	100.9636	157.7379
1995	177	154	0.8701	187.5746	0.1119	150.0694	234.4530
1996	181	165	0.9116	79.5537	0.1084	64.0885	98.7507
1997	177	158	0.8927	126.9185	0.1103	101.8575	158.1456
1998	179	161	0.8994	157.7389	0.1109	126.4425	196.7815
1999	181	161	0.8895	174.5629	0.1095	140.3293	217.1480
2000	177	159	0.8983	247.8122	0.1098	199.0890	308.4595
2001	150	129	0.8600	161.5580	0.1229	126.4723	206.3772
2002	183	153	0.8361	156.1306	0.1132	124.5773	195.6758
2003	182	163	0.8956	124.2855	0.1089	100.0257	154.4291
2004	175	154	0.8800	209.6105	0.1117	167.7476	261.9205
2005	170	140	0.8235	131.4534	0.1184	103.8126	166.4538

Table 10. Deviance summary table showing the stepwise addition of explanatory factors to the 1) proportion of positive catch submodel and 2) the positive catch submodel for brown shrimp, *Farfantepenaeus aztecus*, in Louisiana during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program. Percentage difference refers to the total percentage of difference between the model with the explanatory variables and the null model. DZ refers to depth zone, OXYBOTM refers to the bottom dissolved oxygen, TOD refers to time of day, and REGION refers to the western, central or eastern area of the state's waters.

Factors for Proportion Positive Submodel	Degrees of freedom	Deviance	Deviance per degrees of freedom	Percentage difference	*P*
NULL	3178	2959.7402	0.9313		
DZ	3156	2557.6019	0.8104	12.98	<0.001
DZ+OXYBOTM	3155	2447.5079	0.7758	16.70	<0.001
DZ+OXYBOTM+TOD	3154	2337.5608	0.7411	20.42	<0.001
DZ+OXYBOTM+TOD+YEAR	3136	2215.7431	0.7066	24.13	<0.001

Factors for Positive Catch Submodel	Degrees of freedom	Deviance	Deviance per degrees of freedom	Percentage difference	*P*
NULL	2618	6787.8876	2.5928		
TOD	2617	5344.4035	2.0422	21.24	<0.001
TOD+DZ	2595	4716.3612	1.8175	29.90	<0.001
TOD+DZ+REGION	2593	4532.5655	1.7480	32.58	<0.001
TOD+DZ+REGION+YEAR	2575	4329.6996	1.6814	35.15	<0.001
TOD+DZ+REGION+YEAR+TOD*REGION	2573	4179.6634	1.6244	37.35	<0.001
TOD+DZ+REGION+YEAR+TOD*REGION+TOD*DZ	2551	4075.5723	1.5976	38.38	<0.001

Table 11. Analysis of first level interactions for inclusion in the positive catch submodel for brown shrimp, *Farfantepenaeus aztecus*, in Texas during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program. -2 RES Log Likelihood (-2 RES LL), Akaike's Information Criteria (AIC) and Schwartz's Bayesian Criterion (BIC) represent goodness of fit criteria used to assess how the first level interactions affected the overall model. *P* refers to the likelihood ratio test, which tests the significance between nested models. TOD refers to time of day, DZ refers to depth zone, and REGION refers to the western, central or eastern area of the state's waters. All significant indicates that the fixed factors (time of day, depth zone, region and year) remained significant at alpha=0.05.

Factors	-2 RES LL	AIC	BIC	*P*	Fixed Factors
TOD+DZ+REGION+YEAR	8855.6	8893.6	9005.1		
TOD+DZ+REGION+YEAR+TOD*REGION	8808.8	8846.8	8958.4	0.003	all significant
TOD+DZ+REGION+YEAR+TOD*REGION+TOD*DZ	8694.5	8732.5	8844.0	<0.001	all significant

Table 12. Delta-lognormal indices of relative abundance (I_y) (number of shrimp per hour) of brown shrimp, *Farfantepenaeus aztecus*, in Louisiana during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program from 1987-2005 with their respective coefficient of variation (CV) and the upper (UCL) and lower (LCL) 95% confidence intervals. Total number of stations sampled (n), total number of stations where brown shrimp were caught (m) and the nominal frequency of occurrence (f) are listed for each year.

Year	n	m	f	I_y	CV	LCL	UCL
1987	167	144	0.8623	56.9623	0.1196	44.8824	72.2935
1988	144	95	0.6597	28.9227	0.1837	20.0914	41.6359
1989	143	112	0.7832	49.4064	0.1223	38.7203	63.0417
1990	174	139	0.7989	68.7928	0.1220	53.9420	87.7321
1991	180	142	0.7889	75.3279	0.1117	60.2888	94.1185
1992	178	147	0.8258	45.1087	0.1081	36.3631	55.9575
1993	177	137	0.7740	63.7907	0.1092	51.3089	79.3088
1994	177	142	0.8023	49.9346	0.0985	41.0220	60.7835
1995	174	140	0.8046	86.4992	0.0987	71.0385	105.3249
1996	175	138	0.7886	80.7343	0.1143	64.2846	101.3933
1997	166	135	0.8133	39.3325	0.1027	32.0454	48.2768
1998	171	153	0.8947	48.6911	0.0976	40.0731	59.1625
1999	180	154	0.8556	70.4713	0.0937	58.4513	84.9630
2000	173	148	0.8555	123.5213	0.1244	96.4032	158.2676
2001	150	125	0.8333	63.6657	0.1324	48.9099	82.8733
2002	183	158	0.8634	64.6909	0.0913	53.9172	77.6174
2003	138	126	0.9130	91.8834	0.1245	71.7012	117.7465
2004	164	138	0.8415	106.4807	0.1162	84.4681	134.2298
2005	165	146	0.8849	139.6876	0.1286	108.1118	180.4858

Table 13. Deviance summary table showing the stepwise addition of explanatory factors to the 1) proportion of positive catch submodel and 2) the positive catch submodel for brown shrimp, *Farfantepenaeus aztecus*, in Mississippi/Alabama during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program. Percentage difference refers to the total percentage of difference between the model with the explanatory variables and the null model. TOD refers to time of day and DZ refers to depth zone.

Factors for Proportion Positive Submodel	Degrees of freedom	Deviance	Deviance per degrees of freedom	Percentage difference	*P*
NULL	1977	2655.6427	1.3433		
TOD	1976	2462.2114	1.2461	7.24	<0.001
TOD+YEAR	1958	2371.6455	1.2113	9.83	<0.001
TOD+YEAR+DZ	1936	2272.4780	1.1738	12.62	<0.001

Factors for Positive Catch Submodel	Degrees of freedom	Deviance	Deviance per degrees of freedom	Percentage difference	*P*
NULL	1194	3117.6948	2.6111		
TOD	1193	2885.3993	2.4186	7.37	<0.001
TOD+YEAR	1175	2699.3893	2.2974	12.02	<0.001

Table 14. Delta-lognormal indices of relative abundance (I_y) (number of shrimp per hour) of brown shrimp, *Farfantepenaeus aztecus*, in Mississippi/Alabama during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program from 1987-2005 with their respective coefficient of variation (CV) and the upper (UCL) and lower (LCL) 95% confidence intervals. Total number of stations sampled (n), total number of stations where brown shrimp were caught (m) and the nominal frequency of occurrence (f) are listed for each year.

Year	n	m	f	I_y	CV	LCL	UCL
1987	129	61	0.4729	28.6237	0.2252	18.3469	44.6569
1988	111	38	0.3423	8.9274	0.2793	5.1604	15.4439
1989	117	68	0.5812	82.5691	0.1955	56.0524	121.6300
1990	128	71	0.5547	51.9142	0.1859	35.9105	75.0502
1991	103	71	0.6893	56.4584	0.1792	39.5670	80.5608
1992	85	47	0.5529	38.5886	0.2195	25.0080	59.5441
1993	125	72	0.5760	37.0690	0.1805	25.9135	53.0268
1994	129	75	0.5814	31.8018	0.1808	22.2155	45.5247
1995	97	68	0.7010	63.7622	0.2018	42.7612	95.0773
1996	99	67	0.6768	31.8176	0.1881	21.9146	46.1956
1997	91	60	0.6593	53.9024	0.2012	36.1911	80.2812
1998	84	63	0.7500	63.6324	0.1918	43.5079	93.0653
1999	96	55	0.5729	161.3735	0.2830	92.6192	281.1665
2000	96	62	0.6458	79.3508	0.1944	53.9801	116.6457
2001	87	49	0.5632	92.9461	0.2618	55.5331	155.5643
2002	101	78	0.7723	97.1462	0.1845	67.3797	140.0628
2003	128	86	0.6719	215.3332	0.2082	142.6158	325.1277
2004	90	52	0.5778	76.1762	0.2525	46.3344	125.2377
2005	82	52	0.6342	63.5275	0.2267	40.5959	99.4128

FIGURES

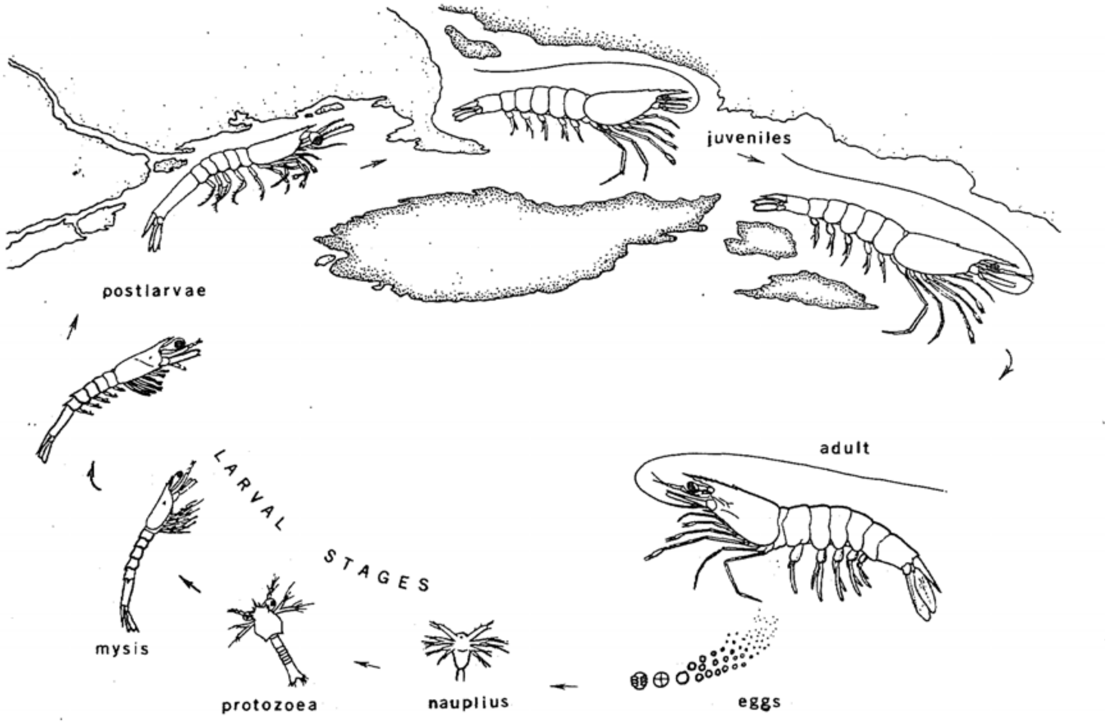

Figure 1. Depiction of the annual life cycle of brown shrimp, *Farfantepenaeus aztecus*, that shows the movement between the offshore waters of the Gulf of Mexico and it's estuarine systems (figure from Fischer *et al.* 1981).

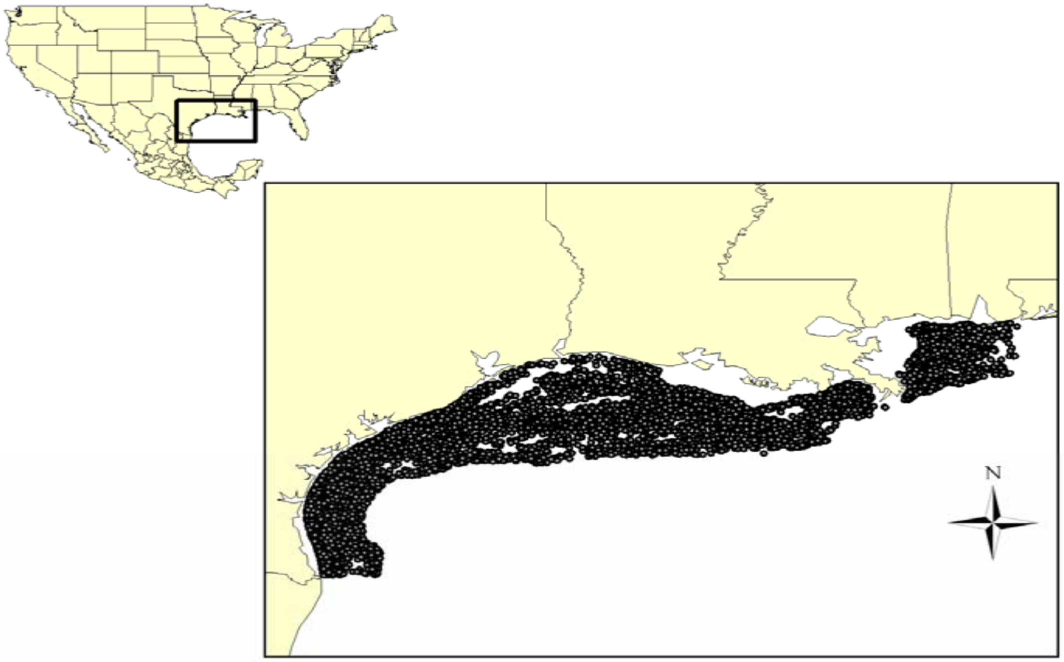

Figure 2. An exploded view of the northern Gulf of Mexico where trawls were conducted between 1987 and 2005 during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program. The study area encompasses the continental shelf waters from the Texas/Mexico border eastward to the Alabama/Florida border. Each circle (N = 8,474) represents the location where a trawl was successfully completed.

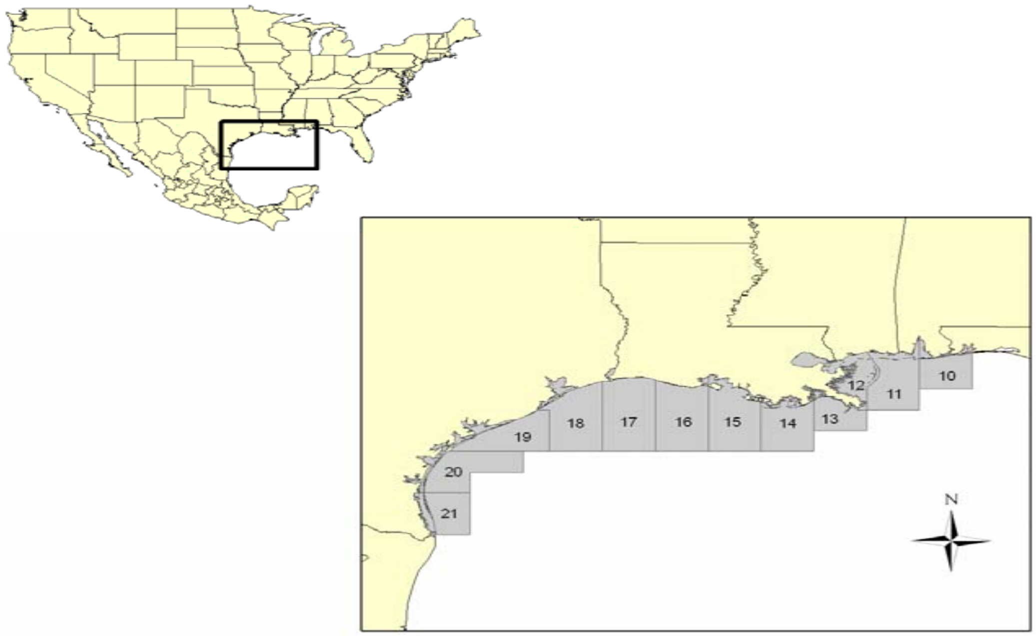

Figure 3. The breakdown of the continental shelf waters of the northern Gulf of Mexico into shrimp statistical zones that were sampled during Summer and Fall Groundfish Surveys as part of the Southeast Area Monitoring and Assessment Program between 1987 and 2005. Shrimp statistical zone 12 was not sampled during this study because of the limited draft of the survey vessels.

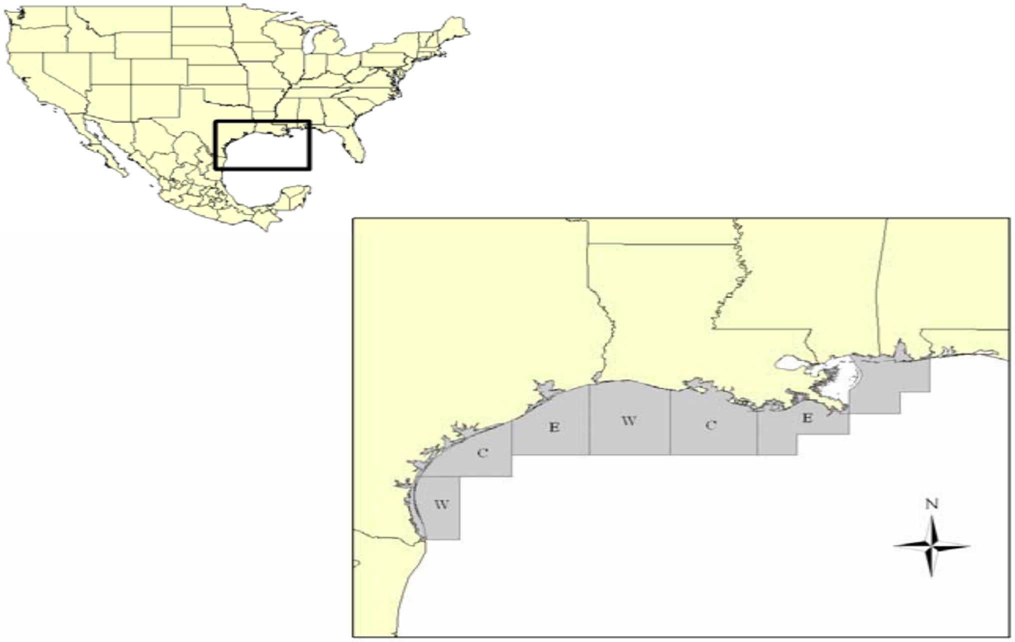

Figure 4. The breakdown of the continental shelf waters of the northern Gulf of Mexico into regions for Summer and Fall Groundfish Surveys conducted as part of the Southeast Area Monitoring and Assessment Program between 1987 and 2005. Note that the area off of Mississippi and Alabama was not divided because of the relatively small size of the area. W denotes the western section, C denotes the central section and E denotes the eastern section.

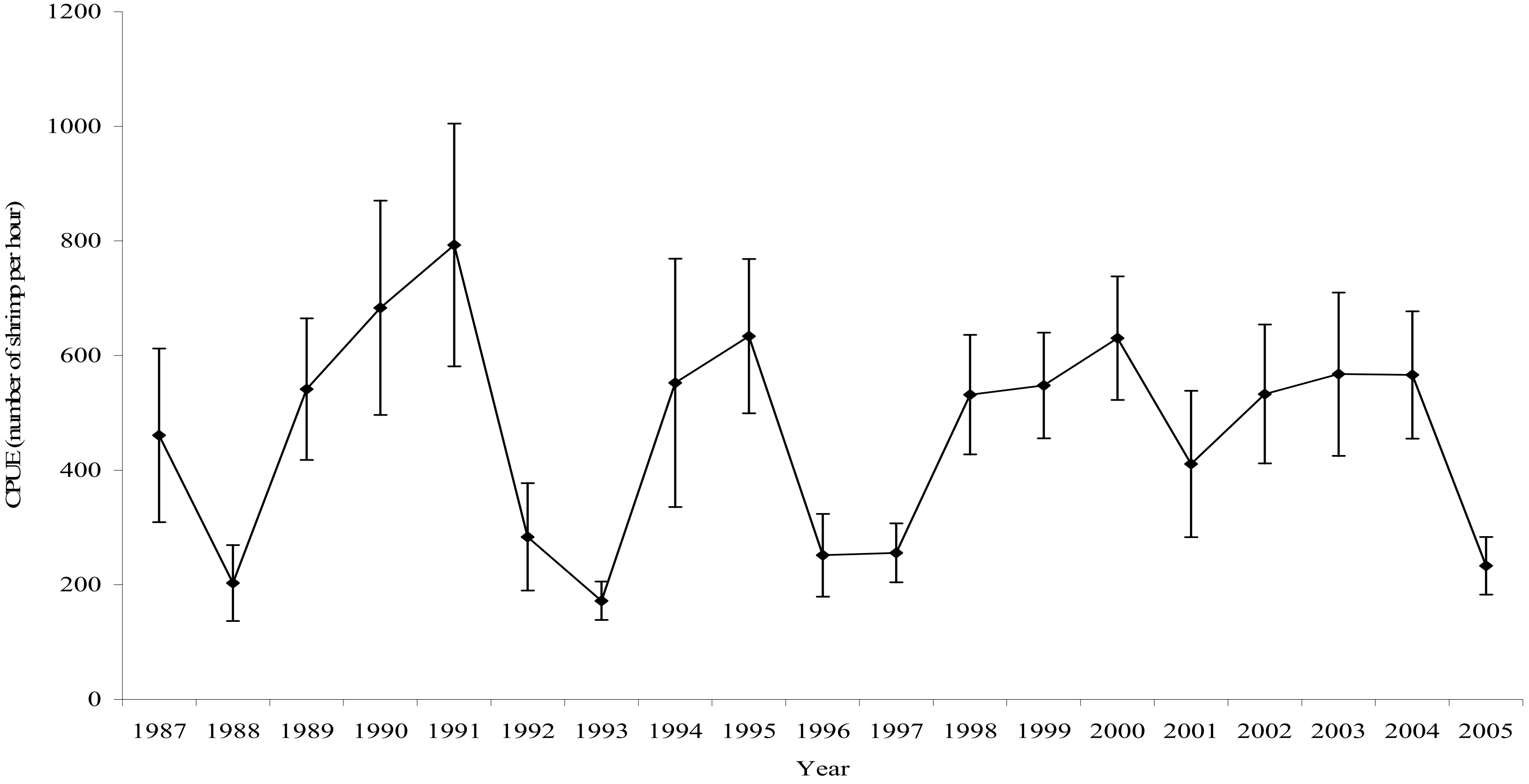

Figure 5. Catch rates (CPUE) of brown shrimp, *Farfantepenaeus aztecus*, collected using a 12.2 m semi-balloon shrimp trawl off of the coast of Texas during Summer Groundfish Survey as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005. Bars represent standard errors.

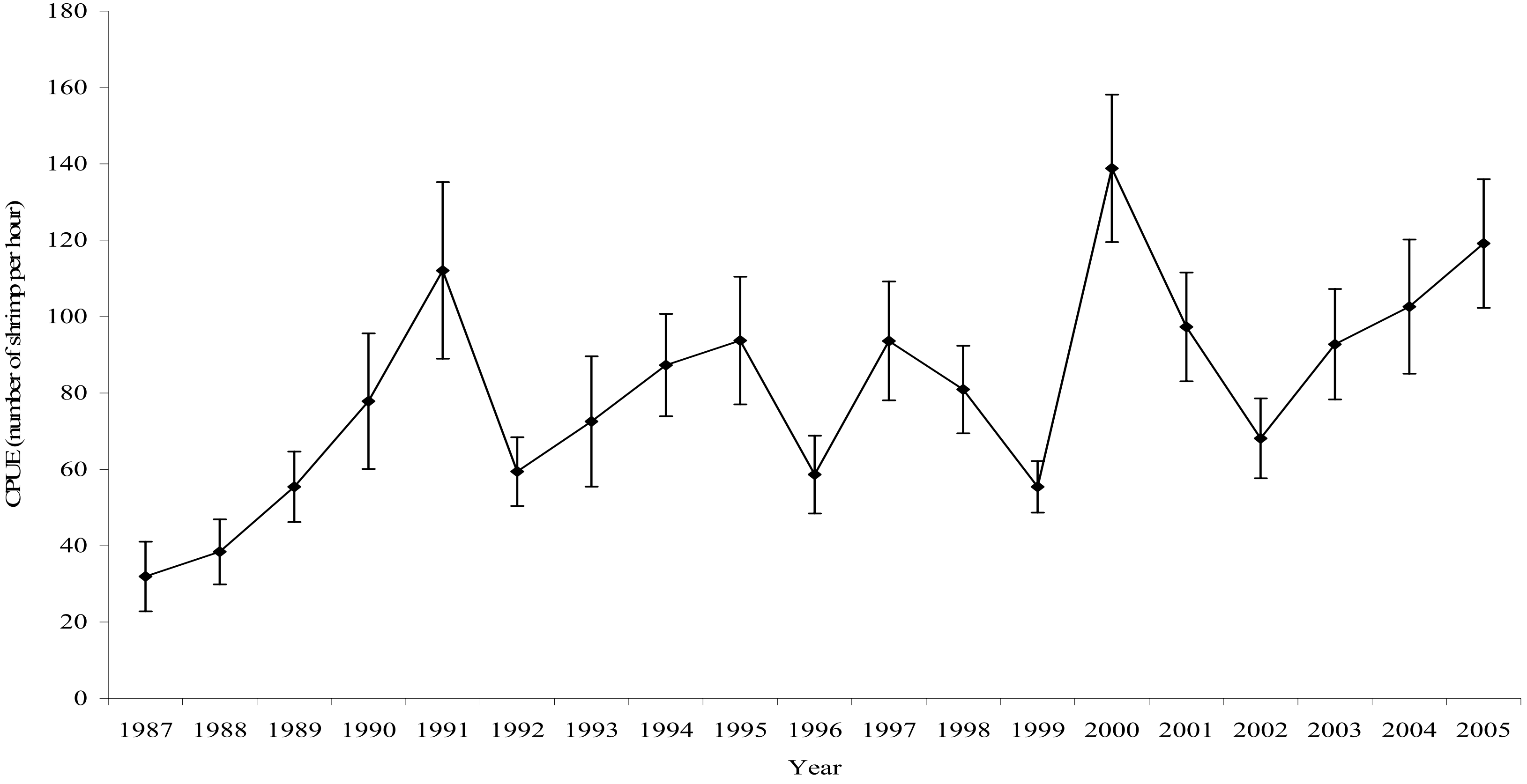

Figure 6. Catch rates (CPUE) of brown shrimp, *Farfantepenaeus aztecus*, collected using a 12.2 m semi-balloon shrimp trawl off of the coast of Texas during Fall Groundfish Survey as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005. Bars represent standard errors.

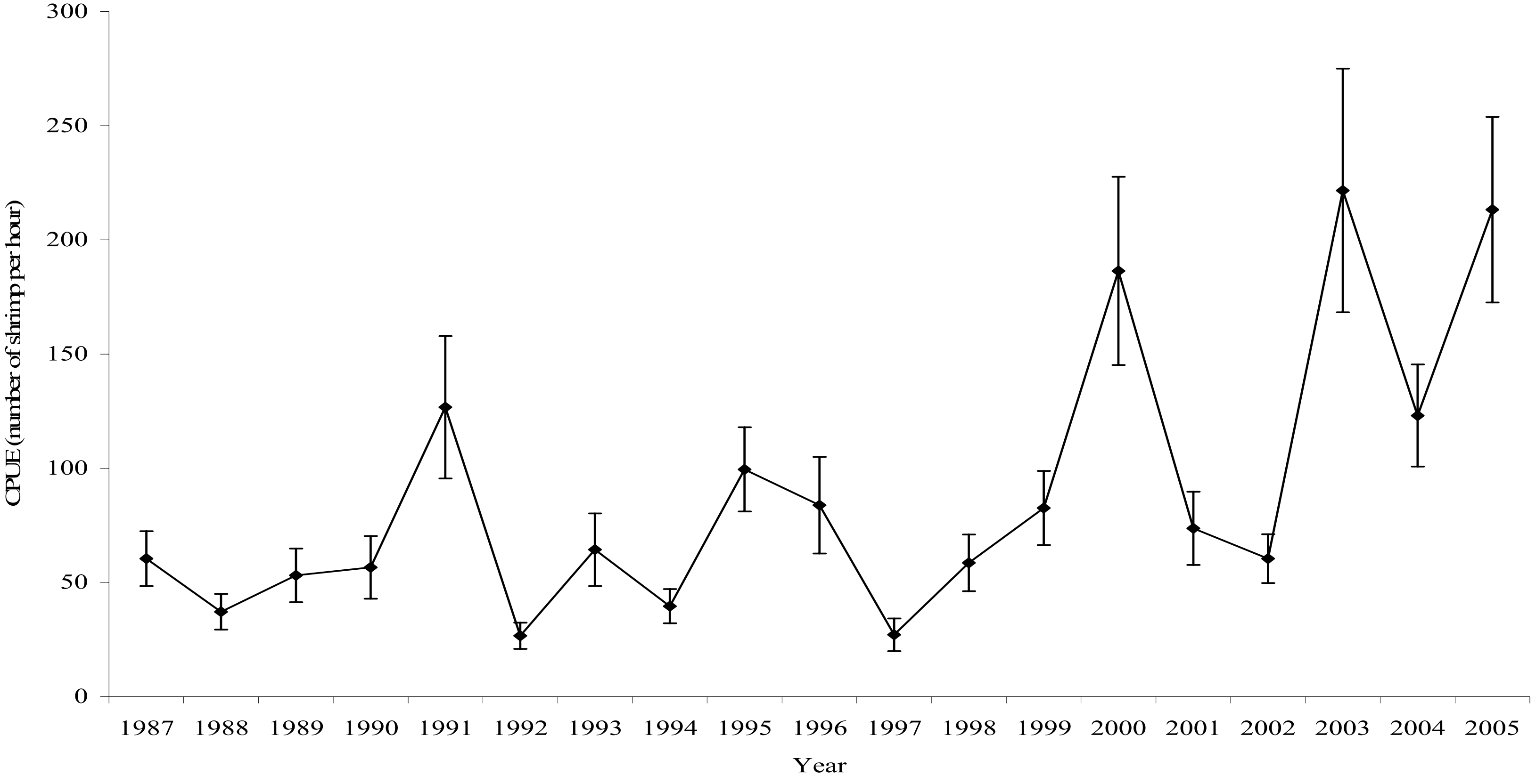

Figure 7. Catch rates (CPUE) of brown shrimp, *Farfantepenaeus aztecus*, collected using a 12.2 m semi-balloon shrimp trawl off of the coast of Louisiana during Summer Groundfish Survey as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005. Bars represent standard errors.

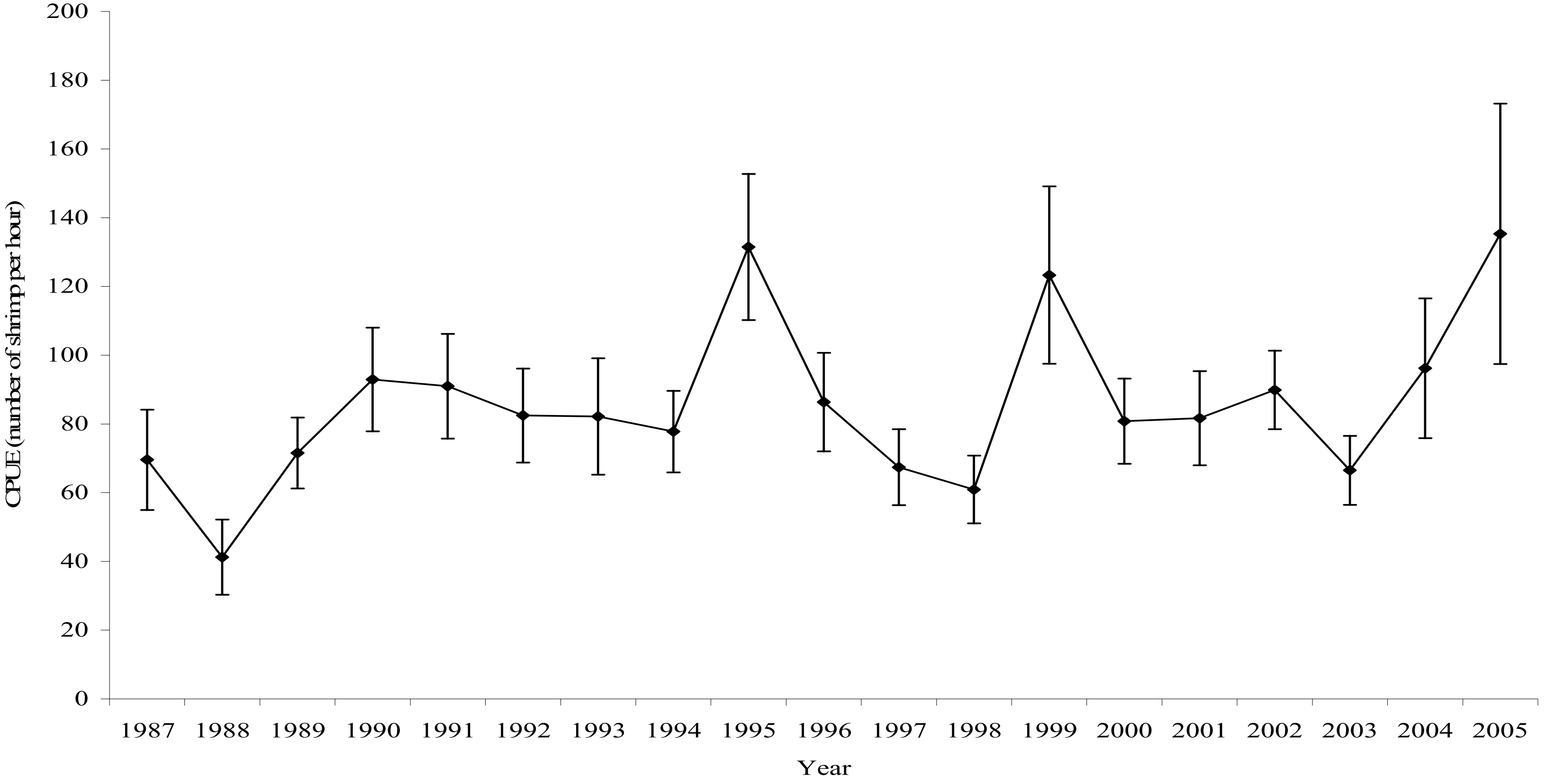

Figure 8. Catch rates (CPUE) of brown shrimp, *Farfantepenaeus aztecus*, collected using a 12.2 m semi-balloon shrimp trawl off of the coast of Louisiana during Fall Groundfish Survey as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005. Bars represent standard errors.

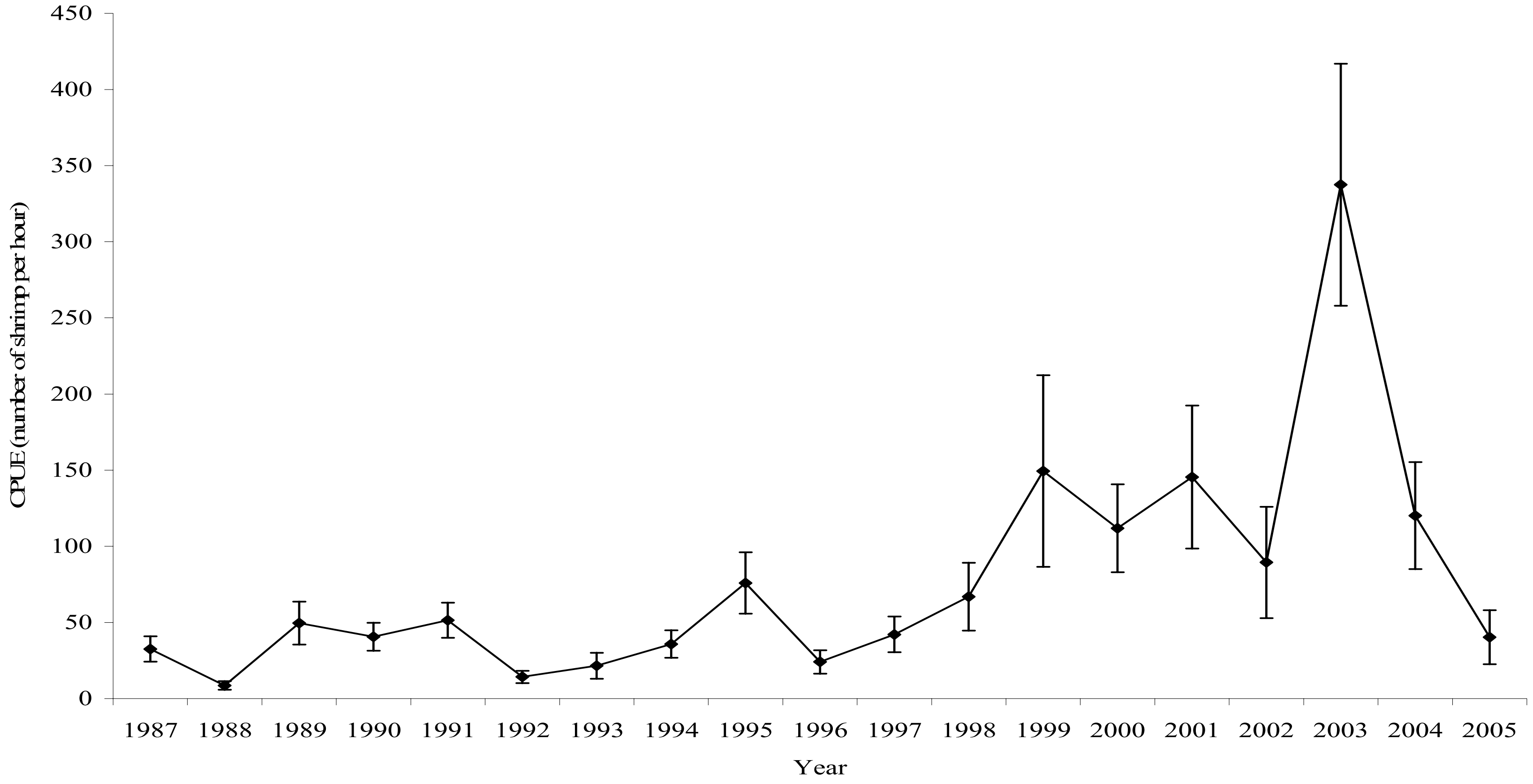

Figure 9. Catch rates (CPUE) of brown shrimp, *Farfantepenaeus aztecus*, collected using a 12.2 m semi-balloon shrimp trawl off of the coast of Mississippi/Alabama during Summer Groundfish Survey as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005. Bars represent standard errors.

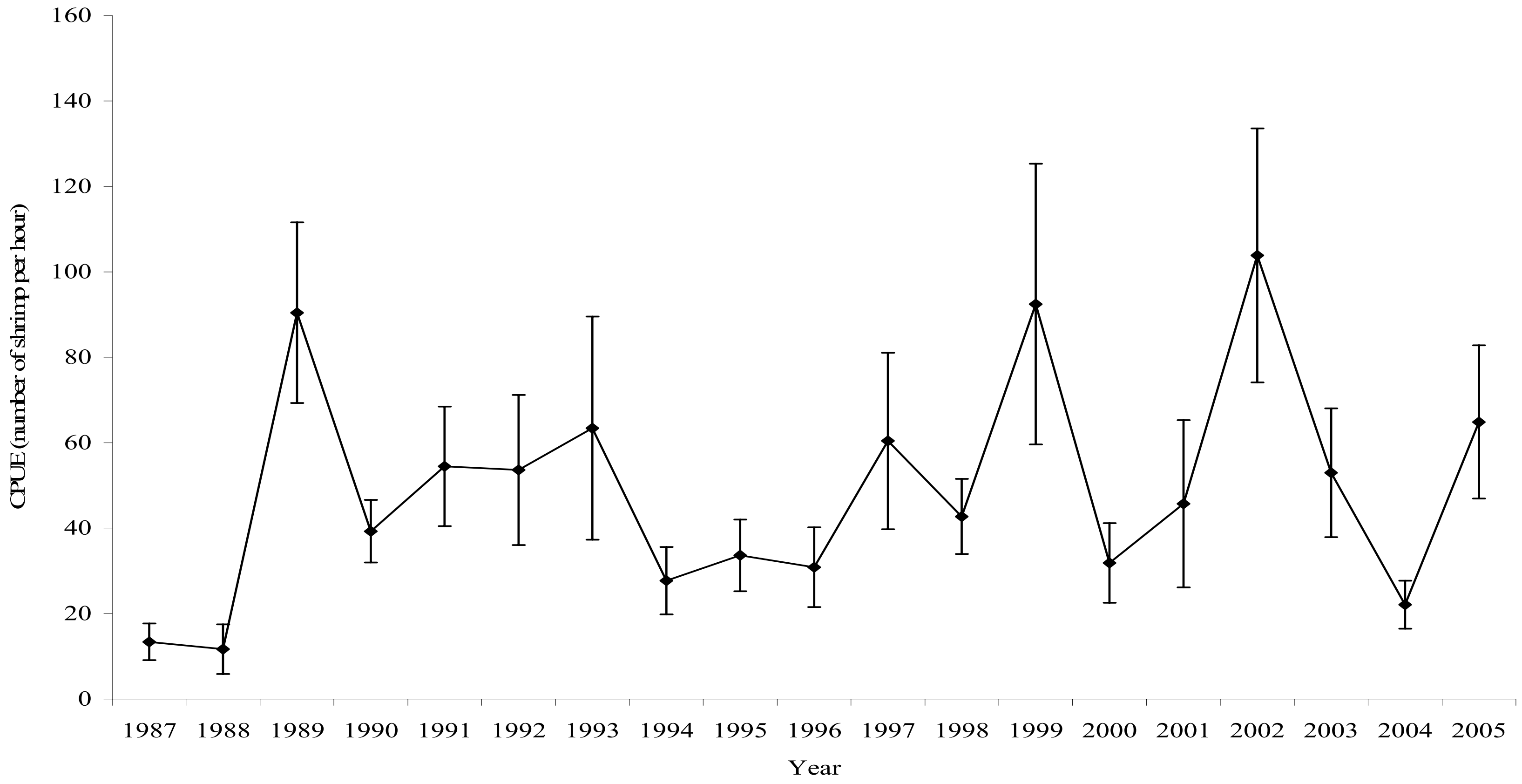

Figure 10. Catch rates (CPUE) of brown shrimp, *Farfantepenaeus aztecus*, collected using a 12.2 m semi-balloon shrimp trawl off of the coast of Mississippi/Alabama during Fall Groundfish Survey as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005. Bars represent standard errors.

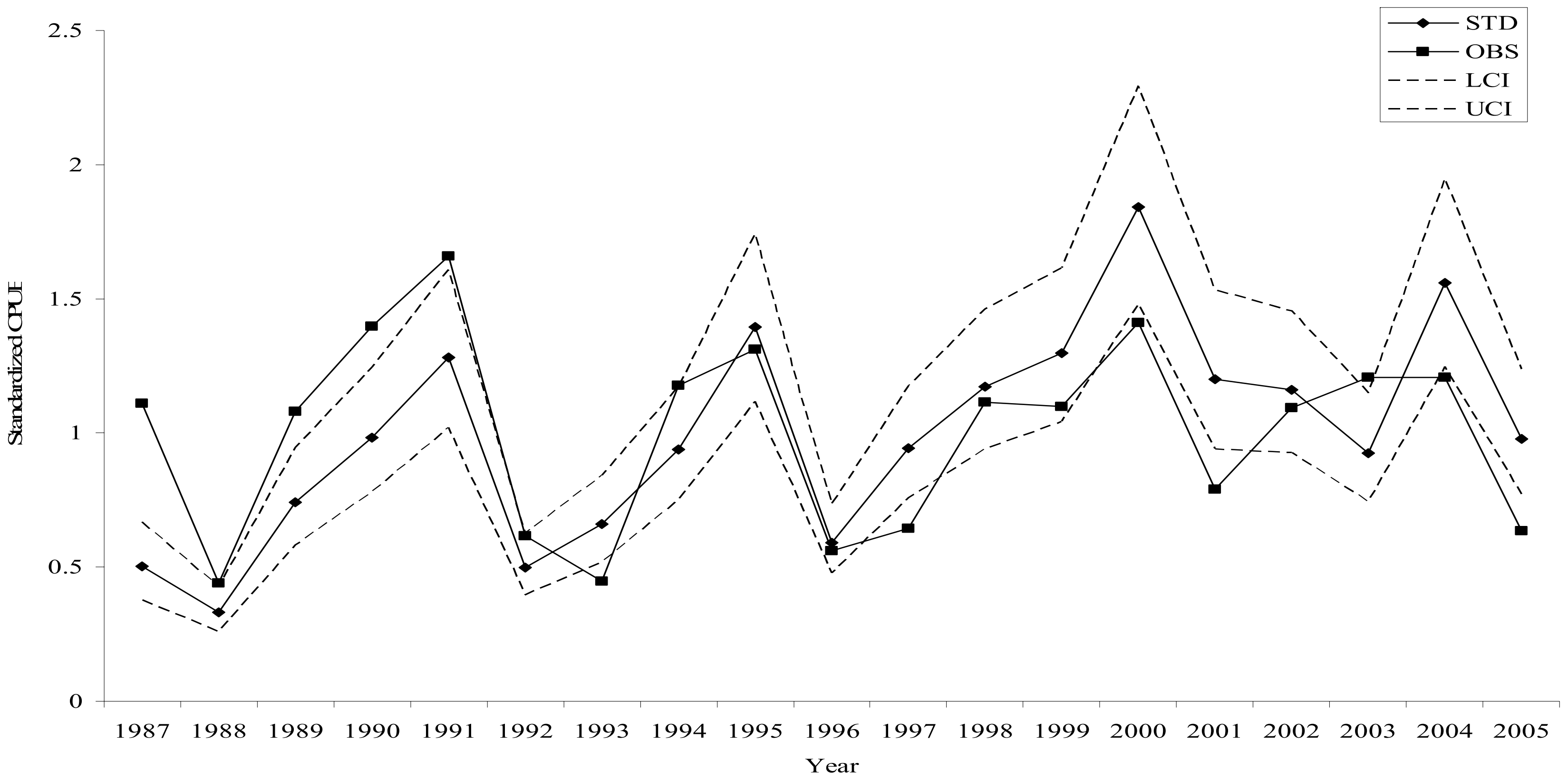

Figure 11. Standardized relative indices of abundance and nominal catch rates for brown shrimp, *Farfantepenaeus aztecus*, collected using a 12.2 m semi-balloon shrimp trawl off of the coast of Texas as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005. Dotted lines indicate the estimated 95% confidence intervals for the standardized catch rates.

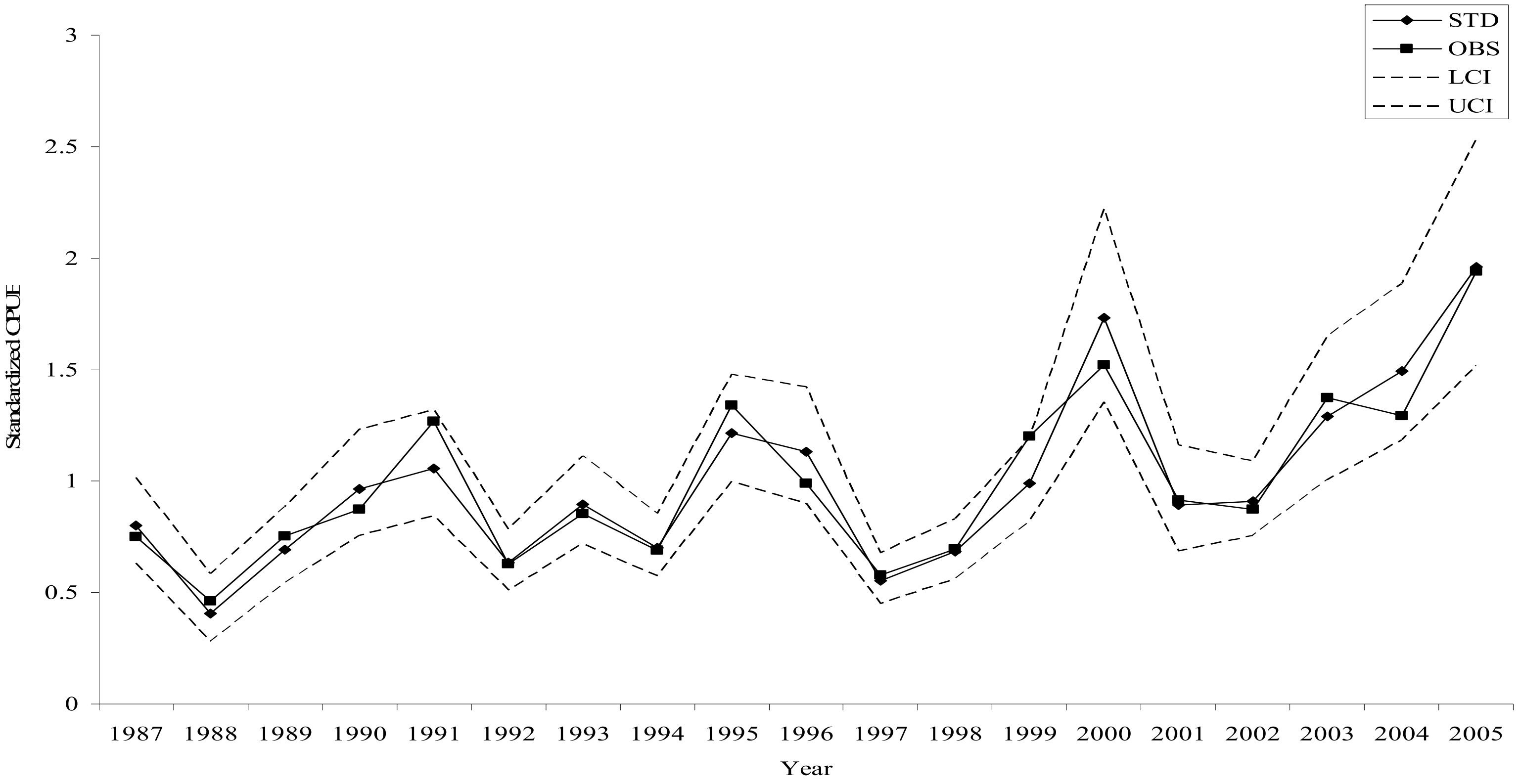

Figure 12. Standardized relative indices of abundance and nominal catch rates for brown shrimp, *Farfantepenaeus aztecus*, collected using a 12.2 m semi-balloon shrimp trawl off of the coast of Louisiana as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005. Dotted lines indicate the estimated 95% confidence intervals for the standardized catch rates.

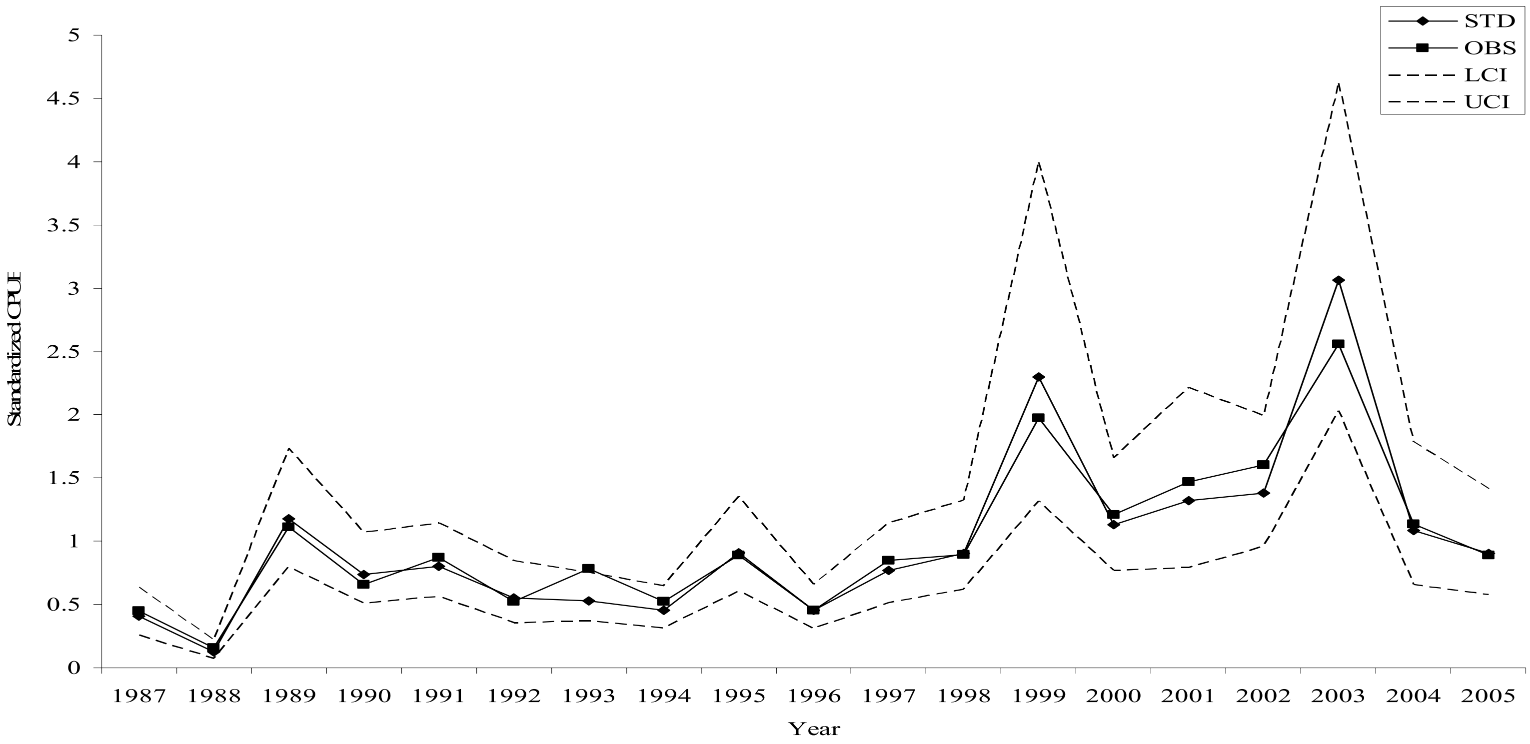

Figure 13. Standardized relative indices of abundance and nominal catch rates for brown shrimp, *Farfantepenaeus aztecus*, collected using a 12.2 m semi-balloon shrimp trawl off of the coast of Mississippi/Alabama as part of the Southeast Area Monitoring and Assessment Program conducted by the National Marine Fisheries Service from 1987-2005. Dotted lines indicate the estimated 95% confidence intervals for the standardized catch rates.

APPENDIX A

SEASONAL AND YEARLY CPUE OF BROWN SHRIMP FOR TEXAS, LOUISIANA AND MISSISSIPPI/ALABAMA COLLECTED FROM 1987 TO 2005 DURING THE SUMMER AND FALL GROUNDFISH SURVEYS CONDUCTED BY THE NATIONAL MARINE FISHERIES SERVICE, PASCAGOULA LABORATORY, MISSISSIPPI, USA.

	Texas			Louisiana			Mississippi/Alabama		
Year	Summer	Fall	Total	Summer	Fall	Total	Summer	Fall	Total
1987	460.87	31.94	303.49	60.44	69.56	64.64	32.50	13.38	27.16
1988	202.98	38.40	120.69	37.18	41.25	39.72	8.55	11.67	9.56
1989	541.46	55.43	295.71	53.14	71.52	64.71	49.58	90.43	67.39
1990	683.41	77.85	382.38	56.58	92.94	75.18	40.59	39.27	39.99
1991	792.97	112.10	454.42	126.72	90.98	109.05	51.39	54.45	52.97
1992	283.58	59.40	169.00	26.67	82.46	53.94	14.19	53.61	31.81
1993	172.14	72.53	122.34	64.36	82.19	73.43	21.48	63.39	47.63
1994	552.37	87.28	322.44	39.57	77.78	59.22	35.73	27.69	31.68
1995	633.97	93.71	359.26	99.54	131.46	115.32	75.90	33.64	54.12
1996	251.48	58.64	153.46	83.85	86.38	85.15	24.07	30.85	27.57
1997	255.74	93.62	176.05	27.12	67.42	49.70	42.14	60.41	51.58
1998	531.73	80.93	305.07	58.58	60.91	59.82	66.87	42.72	54.22
1999	547.95	55.41	300.32	82.62	123.30	103.18	149.38	92.43	119.72
2000	630.46	138.82	386.03	186.42	80.77	130.85	111.79	31.84	73.48
2001	410.77	97.33	216.44	73.73	81.67	78.55	145.50	45.70	89.29
2002	532.91	68.12	299.24	60.48	89.89	75.10	89.35	103.83	97.23
2003	567.61	92.74	330.18	221.64	66.49	118.21	337.44	52.97	155.20
2004	566.29	102.61	330.48	123.07	96.20	111.11	120.16	22.08	68.94
2005	233.02	119.15	174.08	213.23	135.31	166.95	40.25	64.85	54.05
Survey Mean	467.97	81.78	274.00	86.52	85.80	86.13	70.08	50.75	60.48

APPENDIX B

AVERAGE MONTHLY DISCHARGE RATES (m^3/s) FOR THE MISSISSIPPI RIVER FOR JANUARY THROUGH DECEMBER RECORDED AT TARBET LANDING, MS FROM 1986 TO 2005

Year	January	February	March	April	May	June	July	August	September	October	November	December
1986	11767.02	16764.58	16968.19	15461.00	14254.34	17703.69	11818.17	7530.45	6361.85	17785.72	18690.06	21319.85
1987	13862.47	14034.03	24157.92	19638.68	12433.84	10901.99	9359.17	5867.98	5687.91	4697.86	6464.74	10980.54
1988	22875.29	21569.89	17700.77	19293.21	9357.35	4990.37	3603.55	3790.80	3720.83	4132.43	6170.24	10685.50
1989	20390.87	19966.41	30057.88	25284.11	17274.19	19234.69	19851.02	8395.49	9311.52	9309.85	8419.54	7366.95
1990	11927.79	25135.25	28165.21	22899.83	25288.77	31420.37	16049.26	10057.96	8562.07	8605.58	8526.20	12928.01
1991	33547.24	24135.06	24855.80	26516.84	30767.62	20793.06	10486.37	6674.55	6261.80	5758.37	10128.94	20201.79
1992	17500.72	12276.82	18726.57	15729.06	12928.01	11507.97	11232.65	13687.08	8196.78	7630.93	9855.21	20095.83
1993	24066.58	19441.54	24385.37	31085.29	32293.08	21400.93	19301.13	22612.37	15292.04	16838.48	14075.36	21403.88
1994	13786.65	23133.85	28176.18	27119.99	29493.37	12055.43	11036.26	8130.59	6551.57	6573.16	9096.32	14224.19
1995	13318.97	15607.64	18835.27	14300.95	21898.97	31135.32	17722.69	11176.02	6983.88	6658.11	8486.56	8247.51
1996	10542.09	17271.32	14881.87	16772.07	24336.05	27804.31	13838.72	11171.45	7576.64	9263.26	14596.39	23097.41
1997	17761.06	22828.43	35276.40	32705.01	21972.05	21336.74	15187.88	8268.52	6532.70	6210.52	7214.19	9074.18
1998	21288.79	20595.45	24320.52	26224.23	28227.33	17138.30	19071.85	11082.85	6386.39	8810.19	10684.89	11388.85
1999	15176.00	29994.62	22175.74	19339.46	23184.19	16125.50	14555.77	8037.42	4998.87	4749.92	4520.31	6775.03
2000	6395.04	6219.94	13987.61	16694.67	11168.71	11944.05	14076.21	7321.28	5110.25	5332.70	6830.97	9172.83
2001	9962.96	17383.51	27962.43	19581.10	14527.46	19232.80	11015.25	7865.69	6270.29	7675.69	7478.48	20953.55
2002	15428.11	20703.66	15869.31	27889.26	24453.88	23685.15	9700.80	6715.66	6274.07	9075.09	10141.21	11543.23
2003	15184.22	11722.16	23777.93	14365.14	20252.94	20526.88	12510.57	9947.43	8766.90	7184.26	8307.22	14353.90
2004	16368.05	19114.85	19782.51	15637.51	18129.18	22098.47	17994.90	9043.12	9562.60	9674.31	14925.81	25284.20
2005	26636.10	26473.22	18096.29	18792.95	12210.96	10332.82	8307.80	5320.83	6697.88	5593.95	5331.12	6331.10

APPENDIX C

AVERAGE MONTHLY DISCHARGE RATES (m^3/s) FOR THE MISSISSIPPI AND ATCHAFALAYA RIVERS COMBINED FOR JANUARY THROUGH DECEMBER RECORDED AT TARBET LANDING, MS AND SIMMERSPORT, LA, RESPECTIVELY FROM 1986 TO 2005

Year	January	February	March	April	May	June	July	August	September	October	November	December
1986	16803.76	24000.55	24241.96	22167.37	20459.38	25357.74	16890.54	10540.26	8931.13	25465.98	26775.47	30492.68
1987	19795.30	20110.02	34565.74	28063.88	17826.83	15616.74	13180.12	8390.92	8146.76	6727.53	9471.99	15571.53
1988	32721.06	30802.12	25303.39	27547.57	13414.88	7119.80	5086.98	5329.96	5255.61	5878.03	8798.99	15332.20
1989	29105.15	28615.18	42987.71	36117.19	24703.25	27540.97	28370.74	11959.76	13273.99	13308.92	11975.19	10500.07
1990	17093.33	35817.78	40255.59	32718.23	36033.64	44969.04	22941.21	14368.52	12250.81	12322.40	12215.89	18456.19
1991	48060.08	34352.38	35484.66	37881.33	43580.54	30034.74	15071.87	9509.89	8773.50	7988.09	14703.99	29089.62
1992	25033.01	17592.57	26666.25	22411.84	18555.76	16423.77	16009.07	19589.78	11696.75	10920.25	14066.87	28698.67
1993	34388.53	27759.61	34845.25	44446.12	46231.36	30518.01	27523.97	32304.04	21847.39	24044.66	20086.08	30626.04
1994	19749.63	32991.15	40239.15	38728.01	42109.89	17278.94	15776.14	11609.91	9361.55	9445.95	12954.01	20316.88
1995	19052.67	22279.29	26894.61	20537.26	31263.63	44481.05	25329.88	15924.12	9941.10	9494.36	12123.39	11767.02
1996	15032.59	24726.47	21262.30	24412.90	34646.12	39506.72	19646.41	15958.83	10868.01	13255.02	20779.85	33006.48
1997	25368.24	32624.04	50400.33	46738.84	31358.62	30478.37	21711.71	11801.73	9306.80	8912.50	10322.43	12927.10
1998	30422.34	29405.02	34748.42	37464.13	40359.73	24470.47	27222.54	15843.73	9119.91	12601.91	15250.51	16257.52
1999	21667.87	42868.67	31679.24	27596.65	33135.28	23057.46	20779.08	11466.50	7147.17	6796.96	6442.08	9689.84
2000	9137.21	8871.96	20237.41	23832.40	15935.99	17021.26	20061.12	10407.81	7325.57	7575.21	9730.61	13100.65
2001	14903.80	24617.45	39685.60	27803.37	20866.78	27313.49	15733.21	10655.46	8961.34	10217.85	9621.29	29898.94
2002	22037.81	29575.93	22671.75	39847.47	35616.20	33361.02	13642.33	9585.71	8973.61	12984.64	14449.14	16482.23
2003	21699.84	16731.21	34278.91	20200.29	28941.64	29324.93	17877.06	14207.75	12523.60	10268.97	11856.26	20505.05
2004	23420.77	27275.96	28218.19	22471.31	25800.30	31537.42	25749.15	12912.48	13647.78	13835.98	21319.75	36126.82
2005	37979.29	37929.40	25870.64	26806.61	17473.32	14733.26	11848.32	7595.31	9640.94	7947.90	7639.89	9014.81

APPENDIX D

AVERAGE MONTHLY DISCHARGE RATES (m^3/s) FOR THE MOBILE (CALCULATED FROM THE DISCHARGE RATES FROM THE TOMBIGBEE AND ALABAMA RIVERS), PASCAGOULA AND PEARL RIVERS COMBINED FOR JANUARY THROUGH DECEMBER RECORDED AT COFFEEVILLE, AL , MONROEVILLE, MS, MERRILL, MS AND BOGAL USA, MS, RESPECTIVELY FROM 1986 TO 2005

Year	January	February	March	April	May	June	July	August	September	October	November	December
1986	1165.31	1782.35	2386.77	665.80	754.72	999.75	452.44	387.69	374.98	444.37	2254.93	3856.77
1987	4861.83	4910.44	6811.75	1727.65	1176.07	1074.49	780.07	733.80	426.20	320.85	407.26	690.26
1988	1990.16	2456.86	1558.73	2284.88	532.66	372.37	503.88	380.37	1271.22	929.98	1880.10	1474.00
1989	5050.66	2687.95	5507.44	4093.96	2204.32	4056.25	4100.11	890.43	785.51	1696.67	2233.21	3278.46
1990	7468.43	11400.36	8585.03	2473.05	2466.31	1287.73	690.50	489.55	388.57	418.54	527.45	1972.57
1991	2882.75	4721.87	5332.26	5710.88	9485.60	3337.07	1282.52	744.98	759.90	532.74	1034.24	2344.93
1992	3345.53	4180.61	3269.97	1739.99	625.11	1072.99	732.45	1088.85	1157.25	588.39	3415.73	4334.31
1993	6909.09	3642.14	4041.83	3625.79	1977.14	839.88	1081.67	744.01	516.02	426.54	1439.06	1479.18
1994	2756.74	6580.63	4561.20	5335.55	1060.19	1077.59	2533.05	983.72	794.92	1246.93	1043.30	2989.44
1995	2639.57	3944.76	6488.27	2959.31	1687.78	837.16	548.69	625.97	363.69	1990.97	2641.35	3445.27
1996	3764.08	5607.71	5255.94	3404.75	1155.26	910.84	787.98	833.91	863.14	679.20	1167.41	2435.68
1997	3982.77	4968.60	4986.60	2399.07	3491.75	4317.05	1906.66	963.17	551.44	984.74	1499.90	2835.92
1998	7310.60	6145.06	6556.11	3356.91	1416.65	846.81	842.53	731.62	728.09	803.19	586.84	1279.80
1999	3176.50	5039.00	3805.16	1576.74	1042.93	1099.00	1469.66	404.98	328.36	495.37	408.96	608.22
2000	1137.32	811.09	2095.93	4065.58	562.75	425.33	325.90	311.25	288.60	256.25	713.09	984.51
2001	2415.24	3211.39	8401.71	3695.52	791.60	1967.53	846.33	1026.91	1849.92	1349.95	740.40	3502.60
2002	3249.36	3365.36	2862.22	2288.13	1536.76	520.21	637.11	518.91	1006.90	2046.52	3478.00	4417.60
2003	2543.67	4939.01	5967.21	4003.68	5479.50	3220.56	3850.43	2005.23	994.95	662.75	1228.49	1726.84
2004	2339.17	6601.41	2869.33	1039.97	1206.28	1750.03	1935.79	678.67	1518.80	1020.08	3117.68	5036.17
2005	2147.18	4272.11	3437.49	5680.10	1342.12	2406.30	2959.94	1284.53	1543.08			

APPENDIX E

RELATIVE STANDARD ERRORS OF THE MEAN MONTHLY DISCHARGE RATES (m^3/s) FOR THE MISSISSIPPI RIVER FOR JANUARY THROUGH DECEMBER RECORDED AT TARBET LANDING, MS FROM 1986 TO 2005

Year	January	February	March	April	May	June	July	August	September	October	November	December
1986	0.0506	0.0504	0.0272	0.0202	0.0267	0.0211	0.0135	0.0226	0.0100	0.0536	0.0083	0.0193
1987	0.0216	0.0137	0.0231	0.0070	0.0583	0.0221	0.0199	0.0170	0.0131	0.0214	0.0709	0.0474
1988	0.0330	0.0143	0.0173	0.0265	0.0482	0.0372	0.0203	0.0170	0.0078	0.0154	0.0991	0.0644
1989	0.0355	0.0430	0.0132	0.0163	0.0344	0.0160	0.0414	0.0355	0.0278	0.0244	0.0262	0.0377
1990	0.0629	0.0301	0.0136	0.0223	0.0230	0.0204	0.0382	0.0255	0.0135	0.0273	0.0173	0.0625
1991	0.0198	0.0325	0.0208	0.0173	0.0132	0.0322	0.0337	0.0104	0.0056	0.0139	0.0225	0.0357
1992	0.0189	0.0151	0.0214	0.0410	0.0434	0.0231	0.0213	0.0301	0.0144	0.0462	0.0711	0.0192
1993	0.0085	0.0304	0.0203	0.0148	0.0069	0.0254	0.0115	0.0056	0.0258	0.0307	0.0593	0.0211
1994	0.0309	0.0170	0.0051	0.0114	0.0204	0.0352	0.0084	0.0315	0.0279	0.0206	0.0378	0.0297
1995	0.0648	0.0422	0.0276	0.0375	0.0148	0.0098	0.0482	0.0243	0.0251	0.0142	0.0384	0.0206
1996	0.0388	0.0349	0.0245	0.0229	0.0194	0.0077	0.0530	0.0292	0.0185	0.0341	0.0366	0.0091
1997	0.0272	0.0166	0.0328	0.0316	0.0260	0.0208	0.0601	0.0166	0.0282	0.0096	0.0137	0.0318
1998	0.0562	0.0267	0.0100	0.0081	0.0166	0.0213	0.0277	0.0218	0.0175	0.0500	0.0325	0.0333
1999	0.0410	0.0193	0.0295	0.0146	0.0175	0.0155	0.0246	0.0265	0.0175	0.0137	0.0142	0.0479
2000	0.0403	0.0933	0.0394	0.0226	0.0379	0.0341	0.0428	0.0237	0.0213	0.0156	0.0484	0.0460
2001	0.0415	0.0507	0.0183	0.0202	0.0285	0.0173	0.0309	0.0276	0.0217	0.0430	0.0400	0.0459
2002	0.0688	0.0361	0.0577	0.0206	0.0166	0.0452	0.0303	0.0170	0.0235	0.0157	0.0153	0.0729
2003	0.0547	0.0999	0.0298	0.0175	0.0550	0.0387	0.0264	0.0259	0.0463	0.0228	0.0663	0.0208
2004	0.0247	0.0344	0.0326	0.0148	0.0245	0.0208	0.0474	0.0310	0.0272	0.0404	0.0250	0.0220
2005	0.0396	0.0367	0.0382	0.0316	0.0320	0.0262	0.0167	0.0187	0.0289	0.0182	0.0254	0.0215

APPENDIX F

RELATIVE STANDARD ERRORS OF THE MEAN MONTHLY DISCHARGE RATES (m^3/s) FOR THE MISSISSIPPI AND ATCHAFALAYA RIVERS COMBINED FOR JANUARY THROUGH DECEMBER RECORDED AT TARBET LANDING, MS AND SIMMERSPORT, LA, RESPECTIVELY FROM 1986 TO 2005

Year	January	February	March	April	May	June	July	August	September	October	November	December
1986	0.0506	0.0498	0.0271	0.0198	0.0268	0.0205	0.0136	0.0252	0.0112	0.0536	0.0082	0.0194
1987	0.0216	0.0140	0.0230	0.0071	0.0586	0.0224	0.0170	0.0164	0.0131	0.0223	0.0716	0.0473
1988	0.0331	0.0144	0.0172	0.0267	0.0473	0.0383	0.0207	0.0175	0.0084	0.0151	0.0995	0.0636
1989	0.0360	0.0438	0.0130	0.0162	0.0346	0.0161	0.0413	0.0360	0.0280	0.0242	0.0263	0.0380
1990	0.0621	0.0303	0.0136	0.0223	0.0229	0.0205	0.0378	0.0256	0.0143	0.0275	0.0186	0.0617
1991	0.0204	0.0323	0.0208	0.0174	0.0135	0.0310	0.0346	0.0102	0.0066	0.0142	0.0235	0.0348
1992	0.0187	0.0144	0.0218	0.0413	0.0431	0.0238	0.0205	0.0299	0.0135	0.0451	0.0713	0.0191
1993	0.0084	0.0303	0.0204	0.0149	0.0069	0.0255	0.0118	0.0055	0.0259	0.0303	0.0589	0.0210
1994	0.0316	0.0174	0.0052	0.0113	0.0198	0.0356	0.0083	0.0312	0.0278	0.0198	0.0382	0.0298
1995	0.0645	0.0422	0.0270	0.0374	0.0148	0.0100	0.0486	0.0240	0.0245	0.0140	0.0388	0.0212
1996	0.0383	0.0350	0.0251	0.0241	0.0198	0.0085	0.0530	0.0292	0.0187	0.0327	0.0370	0.0094
1997	0.0272	0.0168	0.0328	0.0313	0.0258	0.0209	0.0600	0.0167	0.0286	0.0095	0.0141	0.0315
1998	0.0566	0.0268	0.0099	0.0081	0.0165	0.0219	0.0276	0.0222	0.0178	0.0492	0.0322	0.0330
1999	0.0411	0.0195	0.0297	0.0148	0.0177	0.0152	0.0244	0.0267	0.0178	0.0139	0.0145	0.0476
2000	0.0411	0.0930	0.0378	0.0227	0.0380	0.0342	0.0426	0.0241	0.0226	0.0153	0.0484	0.0464
2001	0.0354	0.0509	0.0182	0.0207	0.0255	0.0165	0.0308	0.0385	0.0210	0.0460	0.0355	0.0462
2002	0.0689	0.0363	0.0576	0.0207	0.0176	0.0472	0.0285	0.0165	0.0237	0.0151	0.0153	0.0724
2003	0.0549	0.0999	0.0309	0.0171	0.0550	0.0389	0.0281	0.0258	0.0466	0.0228	0.0667	0.0211
2004	0.0251	0.0343	0.0324	0.0156	0.0241	0.0207	0.0475	0.0307	0.0272	0.0415	0.0248	0.0221
2005	0.0393	0.0376	0.0378	0.0317	0.0320	0.0268	0.0167	0.0186	0.0282	0.0175	0.0277	0.0215

APPENDIX G

RELATIVE STANDARD ERRORS OF THE MEAN MONTHLY DISCHARGE RATES (m^3/s) FOR THE MOBILE (CALCULATED FROM THE DISCHARGE RATES FROM THE TOMBIGBEE AND ALABAMA RIVERS), PASCAGOULA AND PEARL RIVERS COMBINED FOR JANUARY THROUGH DECEMBER RECORDED AT COFFEEVILLE, AL, MONROEVILLE, MS, MERRILL, MS AND BOGALUSA, MS, RESPECTIVELY FROM 1986 TO 2005

Year	January	February	March	April	May	June	July	August	September	October	November	December
1986	0.0735	0.0806	0.1375	0.0447	0.1258	0.0848	0.0301	0.0228	0.0348	0.0622	0.2174	0.0793
1987	0.1480	0.0522	0.0854	0.1155	0.0510	0.0868	0.0962	0.1028	0.0244	0.0081	0.0487	0.0807
1988	0.1288	0.0897	0.0669	0.0771	0.0431	0.0158	0.0504	0.0257	0.1252	0.1319	0.1135	0.0815
1989	0.0742	0.0734	0.0734	0.1141	0.0550	0.0972	0.0811	0.0644	0.0674	0.1011	0.0717	0.0849
1990	0.0756	0.0518	0.0589	0.0828	0.0838	0.0893	0.0365	0.0258	0.0194	0.0461	0.0596	0.1768
1991	0.0797	0.1648	0.1403	0.0534	0.0462	0.1146	0.0731	0.0183	0.0500	0.0332	0.1214	0.0755
1992	0.0728	0.0873	0.0472	0.1000	0.0261	0.0868	0.0395	0.1107	0.1000	0.0228	0.0927	0.0757
1993	0.0786	0.0595	0.0458	0.0713	0.0650	0.0564	0.0687	0.0775	0.0217	0.0624	0.1127	0.0635
1994	0.1203	0.0539	0.0707	0.0748	0.0590	0.0756	0.0600	0.0744	0.0713	0.0538	0.0956	0.0800
1995	0.0718	0.1103	0.0854	0.1604	0.1313	0.0850	0.0272	0.0722	0.0372	0.1575	0.0984	0.1127
1996	0.0921	0.0940	0.0659	0.0667	0.1046	0.0545	0.0687	0.0741	0.0571	0.0797	0.0548	0.0718
1997	0.0611	0.0416	0.0934	0.1249	0.1243	0.0415	0.0788	0.0411	0.0518	0.1636	0.0679	0.1164
1998	0.0659	0.0380	0.0814	0.0570	0.0816	0.0712	0.0654	0.0570	0.2220	0.1899	0.0668	0.1267
1999	0.1044	0.1428	0.0868	0.0636	0.1166	0.1741	0.1237	0.0346	0.0333	0.1176	0.0328	0.0616
2000	0.0828	0.0666	0.1248	0.1362	0.0417	0.0247	0.0194	0.0216	0.0158	0.0175	0.1007	0.1285
2001	0.1340	0.0667	0.0513	0.1265	0.0470	0.1139	0.0649	0.0893	0.1405	0.1588	0.1399	0.0980
2002	0.1346	0.0921	0.0838	0.1117	0.1262	0.0395	0.0326	0.0460	0.2550	0.0730	0.0649	0.0956
2003	0.1244	0.0985	0.0814	0.0999	0.0490	0.0746	0.1089	0.0804	0.0581	0.0446	0.1619	0.0760
2004	0.0619	0.0842	0.1074	0.0517	0.0800	0.0800	0.1219	0.0499	0.1649	0.1013	0.1209	0.0605
2005	0.0727	0.0504	0.0658	0.0988	0.1148	0.1113	0.1206	0.0774	0.1320			