STOCK ASSESSMENT OF BLUE CRAB (*Callinectes sapidus*) IN TEXAS COASTAL WATERS

by

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ABSTRACT

Texas blue crab stocks were assessed using fishery-independent and fishery-dependent monitoring data. Methods included trend analysis; a generalized fisheries model to identify development phases; regression and time series fitted surplus production models to estimate sustainable harvest levels; and a length-based mortality model to estimate instantaneous total mortality rate (Z). Long-term declines in abundance were observed, with commercial crab landings and catch-per-unit-effort at the lowest levels since the late 1960's. The fishery was characterized as "senescent" or declining from 1992 to 2005. Surplus production model results suggest an additional 15% reduction in fishing effort would be needed to achieve maximum sustainable yield. Z rates differed significantly among bay systems, with declining mortality found in Sabine Lake and East Matagorda Bay and increasing mortality in the upper Laguna Madre. A license management program for the commercial crab fishery has been in effect since 1998, reducing the number of licenses 28% from 1999 to 2005, yet harvest and abundance indices continue to decline. Management options to reduce fishing effort are listed, recommendations made, and future research priorities listed.

INTRODUCTION

The blue crab (*Callinectes sapidus* Rathbun) supports one of the largest commercial fisheries in Texas, surpassed only by shrimp and oysters in annual landings. From 2000 through 2004, an average of 2.3 million kg of crab worth $3.5 million, were harvested commercially from Texas coastal waters (Butler et al. in preparation). The number of commercial crab fishermen (fishing effort) during this same time period declined from 277 licensed commercial crab fishermen in 2000 to 218 in 2005. Commercial landings have declined since 1987, when 5.3 million kg of crab worth $4.5 million were landed. Fishery-independent monitoring trends and relative biomass estimates have been declining in recent years. Reasons for the observed declines in both abundance and commercial harvest of blue crabs in Texas are a combination of many factors: overfishing or overcapitalization (Hammerschmidt et al. 1998), shrimp trawl bycatch (Fuls et al. 2002), habitat loss or degradation (Hammerschmidt et al. 1998, Guillory et al. 2001), reduced freshwater inflow (Longley 1994, Hamlin 2005), etc.

Historically, the Texas blue crab fishery has been managed either by the Legislature or by the Texas Parks and Wildlife Commission (Commission) from authority granted by the Legislature (Texas Parks and Wildlife Department 2001). The Wildlife Conservation Act of 1983 (State of Texas 2005) granted regulatory authority to the Commission in all 18 coastal counties. In 1992, the Commission adopted the Texas Blue Crab Fishery Management Plan (Cody et al. 1992), which recommended management measures based on the best scientific information available to prevent overfishing. The Texas Parks and Wildlife Department (TPWD) has participated in regional crab fishery management throughout the Gulf of Mexico, with regional fishery management plans published in 1990 and 2001 (Steele and Perry 1990; Guillory et al. 2001). In 1997, House Bill 2542 created the Crab License Management Program. This law created a commercial crab fishing license, provisions for license transfer, license suspensions, license review board, and a voluntary license buyback program. In addition to the crab fishery, Texas currently has limited entry programs in place for the commercial shrimp, finfish, and oyster fisheries.

Current blue crab regulations include recreational and commercial licensing requirements; minimum size limit (5 in, 127 mm); prohibition on taking egg-bearing females;

trap design requirements including size restrictions, buoy marking, escape vent, and degradable panel specifications; trap limits (6-recreational, 200-commercial); trap spacing requirements; and a closed season each February designed to facilitate removal of derelict and abandoned (ghost) traps from coastal waters (Texas Parks and Wildlife Department 2006).

Blue crab are distributed throughout the Gulf of Mexico, and range in the western hemisphere from Nova Scotia to northern Argentina, including Bermuda and the Antilles (Williams 1974). Relatively few genetic characterization studies of blue crab in Texas have been conducted. McMillen-Jackson et al. (1994) reported wide-range genetic homogeneity from New York to Texas using electrophoretic allozyme analysis, while Kordos and Burton (1993) found significant spatial and temporal heterogeneity in Texas blue crab larvae and adults.

The blue crab is considered an “r-selected species” (Van Engel 1987), with certain life history traits (i.e. high fecundity, high inter-annual variation in abundance, rapid growth, early reproductive maturity, high natural mortality rates, and relatively short life span) suggestive of a density-independent spawner-recruit relationship (Guillory 1997). No stock recruit relationship has been quantified for the Gulf of Mexico blue crab fishery (Guillory et al. 2001).

Growth in blue crabs is discontinuous, occurring during ecdysis or molting; thus growth estimation is problematic. More (1969) noted a growth rate of 15.3-18.5 mm/month in Texas, while Hammerschmidt (1982) reported higher rates (21.4 and 25.2 mm/month for bag seine and bay trawl samples, respectively). Although size at age has not been determined for Gulf of Mexico blue crabs, size at maturity has been identified in Louisiana (Guillory and Hein 1997), Mississippi (H. Perry, personal communication) and Texas (Fisher 1999). Recent research from Chesapeake Bay (Ju et al. 1999, 2001, 2003; Ju and Harvey 2002) indicates the potential to accurately age blue crabs using metabolic byproducts (lipofuscins) found in crab eyestalks to determine population age structure.

Blue crabs have been described trophically as opportunistic benthic omnivores, and their food habits have been the focus of several studies (Darnell 1958, Tagatz 1968, Laughlin 1982, Alexander 1986). Predation on blue crabs varies with size, life history stage, and location. Over 60 species of finfish, as well as invertebrates, reptiles, birds (including the endangered whooping crane *Grus americana*) and mammals are documented predators of blue crab (Nelson et al. 1996, Guillory et al. 2001). Interspecific predation is an important source of mortality for early stage blue crabs.

The Texas shrimp trawl fishery may have significant impacts on blue crab mortality, especially during the juvenile stage and prior to recruitment stage into the trap fishery. Fuls et al. (2002) reported that blue crab and lesser blue crab (*Callinectes similis*) were the dominant invertebrates caught by commercial bay-shrimp fishermen during 1993-1995. Mean carapace width of blue crabs caught during the study ranged from 58 to 130 mm, averaging 80 mm. In 1995 the Texas legislature enacted the first bay and bait shrimp limited entry program, including a license buyback program. From 1996 through 2005, TPWD purchased 1,450 commercial shrimp boat licenses (746 bay and 704 bait) at a cost of approximately $9.1 million, or 45% of the licenses grandfathered into the fishery in 1995 (J. Cooke, personal communication). Additional conservation measures enacted in 2000 were designed to reduce overfishing, increase economic value of the fishery, and reduce shrimp trawl bycatch. Bay shrimp trawling effort for brown and pink shrimp increased 10-fold from 1966 to a peak effort in 1994 (Texas Parks and Wildlife Department 2002). Since then, bay effort for all shrimp species has declined substantially due in part to the license buyback program and economic conditions in the fishery.

Data on the Texas recreational blue crab catch and effort are sparse and have little value for fishery managers. Benefield (1968) estimated the annual recreational catch in Galveston Bay to be 15,039 kg, or 5.9% of the commercial catch in that system that year. Data from sport-boat anglers targeting and harvesting blue crabs were collected during routine fishery-independent creel surveys; however no estimates of either fishing effort or landings of blue crab were attempted. From 1983 to 2005, 70% of parties landing crabs and 88% of crabs landed were from the Sabine Lake and Galveston Bay systems (TPWD, unpublished data).

TPWD manages the coastal resources of the state through a long-term routine monitoring program. Fishery-independent monitoring data have been collected systematically in Texas estuaries using 182.9-m gill nets (since 1975), 18.3-m bag seines (since 1977), 6.1-m bay trawls (since 1982), and 6.1-m Gulf trawls since 1985 to assess trends in abundance and size of marine organisms captured (Martinez-Andrade et al. 2005). Methodology and results for this program are published regularly to assist resource managers in effective management of finfish and shellfish.

Commercial blue crab landings and ex-vessel value in Texas are monitored through the Marine Aquatic Products Report (MAPR), a mandatory self-reporting system used by seafood dealers. Beginning September 1, 2006, the MAPR system was replaced by the Texas Trip Ticket program, where dealers report landings from individual fishing trips, either on paper or electronically. Commercial crab fishing effort and catch-per-unit-effort (CPUE) data were not collected through the MAPR system, which hindered more precise management of this fishery. Effort data were collected by National Marine Fisheries Service port agents through 1992, from TPWD crab trap tag sales (1992-98), and from TPWD Commercial Crab Fisherman license sales (1999-present) (Guillory et al. 2001). The current TPWD license system provides an estimate of commercial crab fishing effort and CPUE.

Blue crab stock assessments have been hindered by several factors, including an inability to age individuals, uncertainty surrounding estimates of several key biological parameters, and inadequate commercial effort data. Ju et al. (1999, 2001) have recently developed lipofuscin-based aging techniques for blue crabs in Chesapeake Bay. However, these techniques have not been developed for application in the Gulf of Mexico. Blue crab stock assessments in Florida (Murphy et al. 2001), Delaware (Kahn 2003), and Chesapeake Bay (Miller et al. 2005) have been made using a catch survey model (Collie and Sissenwine 1983). This model bridges the gap between surplus production and age-structured models, but there are concerns about its application because of uncertainty in estimates of natural mortality and blue crab growth dynamics. Efforts to assess Gulf of Mexico blue crab stocks using a surplus production model (Csirke and Caddy 1983) were abandoned due to a lack of relationship between total mortality and landings in the Gulf of Mexico (G. Pellegrin, National Marine Fisheries Service, personal communication).

There has been some success modeling crab stocks using other surplus production models. Delaware Bay horseshoe crab (*Limulus polyphemus*) stocks were assessed successfully using a Schaefer-type surplus production model (Davis et al. 2006). This approach was able to determine important management benchmarks such as relative biomass (B/Bmsy) and relative fishing mortality (F/Fmsy), in spite of limited data and no prior stock assessment in place. Surplus production or biomass dynamic models are the simplest stock assessment models commonly used. They can be used with any level of detail in representation of population dynamics, including sections of the stock that are disaggregated spatially or by age (Hilborn and Walters 1992).

Objectives of this study were to:

1. Determine the developmental phase of the Texas commercial blue crab trap fishery using a generalized fishery model;
2. Document long-term trends in relative biomass, catch rate and mean size of blue crabs from TPWD routine fishery-independent monitoring data;
3. Document long-term trends in commercial blue crab landings, effort, and CPUE from TPWD fishery-dependent (MAPR) data, commercial license data, and other available sources;
4. Determine instantaneous total mortality (Z) of blue crab in the pre-recruit or juvenile stage using a length-based methodology and TPWD routine fishery-independent monitoring bay trawl data;
5. Estimate maximum sustainable yield (MSY) and optimal effort level (Emsy) for the blue crab trap fishery using surplus production models; and
6. Recommend future management measures and research needs to promote sustainable long-term yields of blue crabs in Texas.

MATERIALS AND METHODS

Generalized Fisheries Model

A generalized fisheries model (Caddy 1984) was used to describe Texas commercial blue crab landings (1960-2005) as the fishery progressed through four phases: undeveloped, developed, mature, and senescent. Implicit in this model is the concept that fishing effort drives the fishery from one phase to the next. Similar methods developed by Grainger and Garcia (1996) were used to calculate the rate of increase of yield, which varies significantly before the maximum long term yield is reached, or after it has been exceeded; the rate is zero for a stable fishery that is either non-developed or has reached its maximum production limit. Following their methodology, a third degree polynomial was fitted to the blue crab yield curve after transforming landings to a comparable Z-value, with a mean of 0 and standard deviation of 1. The slope of the fitted line between each successive year was used to determine the corresponding phase. Slopes that were greater than 0.05 were used to determine the developmental phase, slopes between -0.05 and 0.05 the undeveloped or mature phase, and slopes less than -0.05 the senescent phase.

Fishery-Independent Monitoring and Relative Biomass

TPWD Coastal Fisheries Division's fishery-independent monitoring data for blue crab caught in bag seine (1978-2005), bay trawl (1982-2005), Gulf trawl (1985-2005) and gill net (1983-2005) samples were used to examine annual trends in relative biomass, catch rate and mean size. These were evaluated using the linear regression routine in Microsoft® Excel 2003 SP2, where p values less than 0.05 and R^2 values greater than 0.25 were considered significant indications of long-term changes in the variable measured.

Biomass was estimated by converting individual carapace widths (L) in each gear's draw, tow, or set to weight (W) using the length-weight relationship W=aLb, where parameters a (proportionality constant) and b (exponent) were estimated using combined sex averages (a = 0.000234, b = 2.707) from sex-specific width-weight parameters developed by Pullen and Trent (1970). Carapace width was measured from tip of lateral-most spine on one side to tip of lateral-most spine on other side.

Catch rates and mean size were calculated using the methodology referenced in Martinez-Andrade et al. (2005). Relative biomass was calculated by multiplying mean weight with catch rates. Spatial comparison of results by bay (e.g. Matagorda Bay) refer to the entire bay system.

Fishery-Dependent Monitoring

Fishery-dependent monitoring data were obtained from several sources. Commercial blue crab landings from 1972 to 2004 were obtained from Marine Aquatic Products Reports submitted monthly by Texas seafood dealers (Butler et al. in preparation). Commercial crab landings from 2005 were available from TPWD unpublished data (P. Campbell, personal communication). Numbers of commercial crab fishermen operating in Texas from 1960 to 1991 were obtained from NMFS port agent statistics (Guillory et al. 2001). TPWD crab trap tag sales and recipient names/addresses were used to estimate the number of crab fishermen operating from 1992 to 1998. Commercial Crab Fisherman licenses sold from 1999 to 2004 were used to determine fishing effort during these years. CPUE was reported as pounds landed per crab fisherman.

Surplus Production

Stocks were assessed by fitting a non-equilibrium logistic surplus production model (Schaefer 1954) to a time series of catch-per-crab fisherman data between 1967 and 2005. Commercial data prior to 1967 were excluded from the analysis because of large variation in CPUE indices. Initial estimates of Bt, K, q and r were derived using a multiple linear regression from the difference equation model developed by Hilborn and Walters (1992), written as

$$U_{t+1}/\,U_{t-1} = r - r/Kq * U_t - qE_t$$

where Ut = observed CPUE, K = carrying capacity, q = catchability, r = intrinsic growth rate, E_t = number of crab fishermen operating in year t, and Bt (biomass in year t) = Ut/q. These were then adjusted for a best model fit between the log-transformed observed and predicted ($\hat{U}_t$) catch-per-effort values using the least-squares method and the minimization routine available in Excel Solver:

$$\text{Minimize } (\ln(\hat{U}_t) - \ln(U_t))^2.$$

The maximum sustainable yield (MSY) and effort needed to achieve MSY (Emsy) were estimated using the model in Schaefer (1954), where MSY = rK/4 and Emsy = r/2q. Bootstrapping techniques (Efron 1979) were used to obtain confidence intervals around best fit parameters. One thousand bootstrap replicates were run using a Visual Basic sub-routine originally developed for use in Excel by Haddon (2001), but modified slightly to incorporate the Schaefer formula for biomass estimates. Each replicate consisted of randomly selecting residuals between observed and predicted catch-per-crab fisherman values, multiplying them by the observed values for each year to create a new pseudo data set, and then refitting the model. Means and 95 percentiles were calculated from the 1000 outputs of each parameter.

Instantaneous Total Mortality (Z)

Z was calculated using the length-based mortality estimate in Hoenig (1987) for populations where aging is not possible and reproduction occurs periodically throughout the year:

$$Z = K\ (L\infty\text{-}L)/L\text{-}L'$$

K and $L\infty$ are parameters of the von Bertalanffy growth equation, L is mean length of fish above L', where L' is the lower limit of length class in which animals are fully recruited into the bay trawl sampling gear. Growth parameters $L\infty = 276$ mm and $K = 0.663$ were taken from estimates calculated by Pellegrin et al. (2001) for blue crabs in the Gulf of Mexico. L' and L were calculated from fishery-independent bay trawl data with L' estimated at 60mm. The Excel linear regression routine was used to test for significant ($p < 0.05$) declining or increasing annual trends in mortality. The single factor ANOVA analysis tool in Excel was used to test for significant differences in the average mortality between bays.

RESULTS

Phases of Development

Based on a Caddy's generalized fishery model (Caddy 1984), the Texas commercial blue crab fishery went through a "developing" phase from 1960 to 1982. It was characterized as "mature" from 1983 to 1991, and has been "senescent" or declining from 1992 to 2005 (Figure 1). Peak landings of 11.7 million lb (5.3 million kg) occurred in 1987 during the mature phase, and landings of 3.1 million lb (1.4 million kg) in 2005 were the lowest in 38 years.

Fishery-Independent Monitoring and Relative Biomass Trends

Coastwide annual bag seine catch rates showed no significant trend from 1978-2005, ranging from 48/ha (1978) to 117/ha (1991), then generally declining to 62/ha in 2005 (Table 1). Mean CPUE for all years was highest in East Matagorda Bay (112/ha) and lowest in Matagorda Bay (44/ha); no areas showed significant trends in annual CPUE. Coastwide annual mean carapace width declined significantly from 1978-2005, ranging from 56 mm (1978) to 32 mm (1995, 2000), then rising to 36 mm in 2005 (Table 1). Mean width for all years was highest in Sabine Lake (52 mm) and lowest in Matagorda Bay (34 mm). Relative biomass declined significantly from 1978-2005, falling from 1.890 kg/ha (1979) to 0.475 kg/ha (2000), then rising to 0.720 kg/ha in 2005 (Table 2; Figure 2).

Coastwide annual bay trawl catch rates declined significantly from1982-2005, ranging from 25/h (1992, 1994) to 4/h in 2005 (Table 3). All bay systems except Sabine Lake showed declining trends in CPUE; these trends were significant in Galveston Bay, East Matagorda Bay, Aransas Bay, Corpus Christi Bay and lower Laguna Madre. Mean CPUE for all years was highest in San Antonio Bay (31.6/h) and lowest in Corpus Christi Bay (5.6/h). Coastwide annual mean carapace width showed no significant trend from 1982-2005, ranging from 62 mm (1992) to 89 mm (1984); mean width in 2005 was 81 mm (Table 3). Mean width varied among bay systems, with only the upper Laguna Madre showing a significant decrease in size. Mean width was highest in Sabine Lake (127 mm) and lowest in Galveston Bay and Aransas Bay (74 mm). Relative biomass declined significantly from 1982-2005, ranging from 1.201 kg/h (1982) to 0.256 kg/h (2005) (Table 4; Figure 3).

Coastwide annual gill net catch rates showed no significant trend from 1983-2005, declining from 0.16/h (1983) to 0.02/h (2000, 2001), then rising to 0.06/h in 2005 (Table 5). Coastwide annual mean carapace width showed no significant trend from 1983-2005, ranging from 156 mm (1999) to 138 mm (2005). Relative biomass declined significantly from 1983-2005, falling from 0.030 kg/h (1983) to 0.005 kg/h (2001), then rising to 0.020 kg/h (2005) (Table 6; Figure 4).

Coastwide annual gulf trawl catch rates in the Texas Territorial Sea (surf line to 16.7 km offshore) showed no significant trend from 1985-2005, ranging from 5.7/h (1991) to 0.6/h (1985): 2005 catch rate was 1.0/h (Table 7). Coastwide annual mean carapace width declined significantly from 1985-2005, ranging from 127 mm (1985) to 54 mm (2004); mean width in 2005 was 60 mm (Table 7). Relative biomass declined significantly from 1985-2005, falling from 0.284 kg/h (1986) to 0.026 kg/h (2000), then rising to 0.047 kg/h (2005) (Table 8; Figure 5).

Fishery-Dependent Monitoring Trends

Annual commercial landings of blue crab by bay system from 1972-2005 are listed in Table 9. Although Galveston Bay, San Antonio Bay, and Aransas Bay historically dominated landings throughout this period, Sabine Lake landings have increased in recent years. Since the late 1980s, landings from Galveston Bay south to Aransas Bay have declined steadily. Since 2001, only Sabine Lake (2000-02), San Antonio Bay (2002-04) and Aransas Bay (2002-04) have reported annual landings in excess of 450,000 kg (1 million lb). Since 1994, landings from Corpus Christi Bay south to lower Laguna Madre have accounted for less than 2% of coastwide landings.

Coastwide commercial landings rose from 1.3 million kg (2.9 million lb) in 1960 to a peak of 5.3 million kg (11.7 million lb) in 1987 (Table 9; Figure 6). Since then, landings have declined sharply to a low of 1.4 million kg (3.1 million lb) in 2005. During this same period ex-vessel value spiked at $4.5 million in 1998 and 2002, before dropping to $2.4 million in 2005. Since the late 1980's, commercial landings and CPUE (catch per licensed crab fisherman) have shown similar trends, with CPUE from 1994-2005 falling to the lowest rates in 46 years (Figure 6). Commercial fishing effort (no. of crab fishermen) rose sharply from 71 in 1960 to a peak of

345 in 1994 and 1997. Since then, TPWD limited entry and buyback programs have reduced effort to 218 crab fishermen in 2005.

Surplus Production

Initial model parameter inputs derived from regressing the difference equation were as follows: q = 0.001492, r = 0.66279, K = 27,224,457 (kg), B_{1967} = 24,172,518 (kg), MSY = 3,878,759 (kg) and E_{msy} = 222 crab fishermen (Figure 7). These parameters, adjusted for the best model fit using the least sum of squares method, were: q = 0.0017569, r = 0.653, K = 21,699,014 (kg), B_{1967} = 10,564,277 (kg), MSY = 3,541,549 (kg) and E_{msy} = 186 crab fishermen (Figure 8). All parameter estimates, including bootstrapping means with 95th percentile confidence intervals, are summarized in Table 10.

Instantaneous Total Mortality (Z)

Mean Z over the available data time series (1982-2005) from bay trawls were as follows: Sabine Lake = 0.53, Galveston = 1.03, East Matagorda = 0.78, Matagorda = 1.06, San Antonio = 1.17, Aransas = 1.09, Corpus Christi = 0.92, upper Laguna Madre = 0.90, lower Laguna Madre = 1.07, and coastwide = 1.06. Results from a single-factor ANOVA ($F = 35.1$, $F_{critical} = 1.98$) suggest mean Z differs significantly between bay systems. Z for each bay system and coastwide from 1982 to 2005 are presented in Table 11 and Figure 9. Declining trends in Z between 1982 and 2005 were detected at $\alpha = 0.05$ level of significance in Sabine Lake (slope = -0.006, p-value = 0.003, $R^2 = 0.398$) and East Matagorda (slope = -0.045, p-value < 0.001, $R^2 = 0.550$). An increasing trend in Z between 1982 and 2005 was detected at $\alpha = 0.05$ level of significance in the upper Laguna Madre (slope = 0.01, p-value =0.012, $R^2 = 0.255$).

DISCUSSION

Phases of Development

Trends in the Texas blue crab fishery closely resemble the phases included in the generalized fishery model (GFM) presented by Caddy (1984). The three stages of exploitation between 1960 and 2005, when viewed in relation to an almost linear expansion of effort from 1960 to 1997, suggest that the fishery was effort-driven from one phase to the next. The mature phase between 1983 and 1991 is of particular interest because landings during this time were near the maximum sustainable yield and the value corresponding to the top of the polynomial fitted curve (8,700,000 lbs) can be used as a close approximation. Fishing effort continued after this point, forcing the stock into a declining phase with landings in 2005 reaching the lowest level since 1968. Populations have since failed to rebound in spite of blue crab having r-selected characteristics (i.e. high fecundity and rapid growth). This model is useful for analyzing fisheries potential in situations where only landings data are available. Grainger and Garcia (1996) used the GFM to assess fisheries potential of the world's marine resources, concluding that in 1994, 35% of the world's fishery resources were in the senescent phase. Cuban marine fishery data from 1935-1995 were analyzed using GFM methods (Baisre 2000), concluding that 87.6% of the fisheries resources were at a critical stage, and that urgent action was needed to reduce effort so stocks could recover.

Fishery-Independent Monitoring and Relative Biomass Trends

Most of the fishery-independent monitoring time series begin near or during the mature phase of the commercial blue crab fishery, between 1983 and 1991, prior to the fishery entering a declining or senescent phase. While there was a clear downward trend in relative biomass indices for each gear that matched trends in the commercial fishery, trends using other measures were often inconclusive. For example, trends fitted to bag seine and Gulf trawl catch rates along with those fitted to annual mean size indices in gill nets and bay trawls proved to be insignificant and failed to detect any long-term decline. Using relative biomass as a measure of stock abundance has an advantage over other measures in that it monitors changes in size and abundance simultaneously. This provides a more salient view of the system in terms of biomass flows and fluxes, which are more conducive to understanding population dynamics in an ecosystem. Overall, it is clear that blue crab population abundance and biomass declined from the mid 1980's to the present.

Fishery-Dependent Trends

As with fishery-independent declines in abundance and biomass, declining commercial landings and CPUE are a concern to fishery managers in Texas. It is well documented that blue crab fishery landings are cyclic, and that fluctuations in landings have increased in recent years (Guillory et al. 2001). Causes of variability in landings may include economics, market demand, and processing capacity (Lyles 1976, Moss 1982); changes in fishing effort (Guillory et al. 1996); and interdependency with other fisheries and variations in year-class strength (Steele and Perry 1990). Reductions in freshwater inflow and habitat loss or degradation may also contribute somewhat to fluctuation in landings.

Surplus Production

Hilborn and Walters (1992) found that unrealistic results from surplus production models are generally not due to model failure, such as lack of age structure and time delays, but rather to errors in the data. Observational error in the annual catch-per-crab fisherman indices is probably high. Landings appear believable, but lack of effort data (i.e. number of traps and soak time) increases uncertainty in estimating the amount of effort exerted by one crab fisherman in any given year. Since the number of crab fishermen was the most dependable measure of effort available, it was assumed that the number of traps used and days spent crab fishing (effort exerted by one crab fisherman) was more or less constant over time. Variation around the true effort was certain to be higher in the early stages of the fishery's development when crab fishermen where known to have alternated between other fishing activities (Miller and Nichols

1985; Guillory et al. 2001). This appears to be less of a problem in later years when the fishery became more developed and effort stabilized. The amount of inaccurate or under-reported blue crab landings is unknown, and was considered constant over time (Butler et al. in preparation). Viewed in this way, effects of under-reporting on model results would only be a matter of scale and easily rectified. Were it determined for example that landings were under-reported by 20% on average, a simple solution would be to raise the determined MSY by a factor of the same percentage. A better solution would be to use the estimate of Emsy. This parameter does not change despite an increase or decrease in the magnitude of landings, provided the change is applied consistently across the time series. Bootstrap analysis was able to counter some of the effects of observation error and provide bounds for the derived parameters, but some of the large deviations between predicted and observed values like those seen in 1975-76 and 1979-80, were likely more than observation error and probably the result of another process not being captured in the model. Again, this becomes less of a problem for the model as the fishery continues to develop and large swings in recruitment and abundance are restricted.

Instantaneous Total Mortality (Z)

TPWD fishery-independent bay trawl data were used as input for the mortality model (Hoenig 1987), but these data may not fully represent mortality in the adult population. Mortality differed significantly between bays, which shows populations decline at different rates depending on location. This could be due to numerous causes; nevertheless, Z was lower in bay systems with less shrimp trawling (e.g., Sabine Lake and East Matagorda Bay). TPWD unpublished aerial survey data from 1994 to 2004 show considerably lower numbers of shrimp trawl vessels in these two bays on opening day of both spring and fall shrimping seasons. Mean annual Z values for Sabine Lake (0.53) and East Matagorda Bay (0.78) were much lower than for Galveston Bay (1.03) and Matagorda Bay (1.06) where shrimp trawling is more prevalent. Coastwide Z values follow a parabola shape that does not reveal any significant long-term decline using linear regression, but values after 1999 are lower on average than those in the preceding years, and this might reflect the reduction in the number of crab fishing licenses sold since 1998.

Management Recommendations

Resource managers should be concerned that crab populations have not rebounded despite a reduction in both crab trap and shrimp trawl effort. Numerous reasons exist for low populations, but results of this assessment point to one plausible explanation---excess effort. Stock abundance is at an all time low, production is reduced, and any surplus growth in the stock is quickly absorbed by the crab trap fishery, which is estimated at 15% above Emsy. While it is recognized that this and other models have limitations, finding ways to reduce effort would benefit the resource and ultimately the fishermen. Hilborn and Walters (1992) recommend adopting an adaptive management strategy to hedge against uncertainty in stock assessment models. These improve management policies by learning from the outcomes of different regulation changes and evolving new hypotheses and models as more new data become available. Management options for reducing effort include the following:

- Option 1: Maintain the status quo (i.e. allow limited entry, buybacks at current rate, and attrition to reduce effort).
- Option 2: Increase the required number and/or size of escape rings in traps.
- Option 3: Reduce trap limits from 200 to 150 per person.
- Option 4: Redirect funds and/or increase crab license fees, and dedicate increased revenue to crab license buybacks.
- Option 5: Establish a moratorium on crab license transfers.
- Option 6: Impose area closures.
- Option 7: Impose bag limit for recreational fishermen.

Pros and cons of these options are summarized in Table 12.

Future Research Priorities

There is no single cause for the observed decline in crab abundance; it is most likely due to a combination of ecological, environmental, and human-induced factors. This assessment recommends measures to reduce fishing effort because TPWD is charged with managing the state's resources. The following research priorities should lead to a better understanding of declines in abundance:

1. Develop models for ecosystem rather than single species management;
2. Assess impact of freshwater inflow on crab populations;
3. Assess impacts of habitat loss/degradation on crab populations;
4. Establish a cooperative study with commercial crab fishermen to quantify the difference in fishing power between traps with 6.03 cm, 6.19 cm and 6.35 cm escape rings;
5. Assess extent and magnitude of recreational blue crab harvest;
6. Evaluate compliance with regulations (i.e., possession of egg-bearing females, size limits, etc.);
7. Implement/evaluate a lipofuscin aging study for the Gulf area;
8. Evaluate Turtle Excluder Devices in crab traps;
9. Evaluate fishery-independent trawl and gill net blue crab sex and female maturity stage data (reinstated January 2006), and compare to data collected from 1983-87;
10. Quantify inshore shrimp fishing effort; and
11. Evaluate fishery-dependent Trip Ticket system data (available beginning January 2006) for obtaining improved effort data.

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Table 1. Annual mean catch rates (No./ha) and mean carapace widths (mm) of blue crab caught in Texas bays with 18.3-m bag seines by bay system and year during 1978-2005. ND = no data.

	Bay system																				
	Sabine Lake		Galveston		East Matagorda		Matagorda		San Antonio		Aransas		Corpus Christi		Upper Laguna Madre		Lower Laguna Madre		Coastwide	
Year	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width
1978	ND		66	52	ND		10	38	52	51	56	62	33	43	98	61	19	60	48	56
1979	ND		106	52	ND		27	51	76	49	84	62	166	43	90	48	56	54	84	51
1980	ND		122	54	ND		24	56	119	45	64	52	82	38	65	40	176	46	95	48
1981	ND		58	53	ND		43	44	51	54	88	45	85	40	42	58	173	35	76	43
1982	ND		101	48	ND		31	51	107	42	194	48	52	49	36	54	151	41	98	46
1983	ND		146	43	15	77	35	34	104	40	145	44	50	40	36	59	110	34	94	41
1984	ND		85	58	24	59	64	42	42	46	64	50	64	41	35	61	77	46	63	49
1985	ND		154	49	107	54	56	46	43	42	141	38	184	37	73	52	152	34	116	42
1986	37	79	90	55	86	55	52	52	62	46	30	48	77	40	23	45	91	41	62	49
1987	23	68	163	41	87	38	36	51	64	55	35	35	80	47	50	59	72	44	77	45
1988	44	64	160	46	138	31	29	36	48	42	54	35	89	45	38	43	78	37	78	42
1989	50	45	85	48	121	30	45	25	74	31	56	34	72	43	22	41	31	35	59	38
1990	66	47	141	44	94	46	74	31	98	30	83	35	149	42	37	51	68	40	94	40
1991	46	56	165	47	92	44	58	37	199	38	107	35	151	39	49	45	107	43	117	42
1992	36	55	90	36	54	37	45	26	117	30	129	35	163	38	105	58	129	35	102	37
1993	33	59	116	35	89	27	51	23	89	35	102	41	176	42	67	55	78	36	93	38
1994	27	51	89	38	176	26	96	22	27	34	91	27	208	39	113	47	130	32	101	34
1995	43	46	59	32	194	27	64	22	32	30	56	34	122	37	62	40	93	31	68	32
1996	84	41	106	36	136	25	38	27	39	30	37	33	119	33	48	39	100	27	72	33
1997	76	43	90	42	117	33	63	23	63	35	64	39	123	44	61	47	67	32	76	38
1998	59	57	107	43	129	33	48	27	75	37	51	36	102	38	41	45	81	33	74	38
1999	40	46	93	45	156	32	35	28	57	29	39	38	69	38	57	48	62	29	62	38
2000	113	35	95	35	141	26	44	22	36	31	35	34	65	34	15	35	30	30	54	32

Table 1. (Continued)

	Bay system																			
	Sabine Lake		Galveston		East Matagorda		Matagorda		San Antonio		Aransas		Corpus Christi		Upper Laguna Madre		Lower Laguna Madre		Coastwide	
Year	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width	No./ha	width
2001	36	46	88	36	219	37	36	23	77	32	50	36	95	33	26	41	59	25	64	33
2002	29	57	72	45	129	38	39	27	54	36	53	40	91	38	33	42	55	27	57	38
2003	41	45	70	39	101	41	31	30	71	29	87	39	114	35	49	54	99	46	71	39
2004	39	45	74	42	65	41	29	32	81	28	86	31	111	35	49	44	90	38	71	36
2005	47	51	72	45	110	26	20	30	65	32	78	32	97	33	45	41	61	28	62	36

Table 2. Relative biomass (kg/ha) of blue crab caught in Texas bays with 18.3-m bag seines by bay system and year (1978-2005). ND = no data.

	Bay system									
Year	Sabine Lake	Galveston	East Matagorda	Matagorda	San Antonio	Aransas	Corpus Christi	Upper Laguna Madre	Lower Laguna Madre	Coastwide
1978	ND	1.797	ND	0.119	1.151	1.840	0.531	1.883	0.392	1.161
1979	ND	2.616	ND	0.583	1.559	2.949	2.293	1.707	1.256	1.890
1980	ND	2.911	ND	0.720	1.854	1.533	0.868	0.574	1.987	1.640
1981	ND	1.863	ND	0.979	1.493	1.967	1.075	1.006	1.559	1.475
1982	ND	2.153	ND	0.740	1.661	3.477	1.042	0.677	1.609	1.705
1983	ND	2.694	0.980	0.517	1.373	2.354	0.770	0.943	0.973	1.497
1984	ND	2.791	0.641	1.008	0.657	1.421	0.912	0.859	0.994	1.370
1985	ND	2.854	3.168	1.234	0.527	1.617	1.514	1.242	1.301	1.656
1986	1.772	1.905	2.284	1.561	0.936	0.593	0.678	0.264	0.927	1.160
1987	0.878	2.770	1.193	1.032	1.574	0.329	1.055	0.969	1.202	1.379
1988	1.536	2.321	1.085	0.303	0.669	0.509	1.175	0.447	0.930	1.039
1989	0.899	1.752	1.172	0.170	0.554	0.716	0.767	0.237	0.332	0.758
1990	1.489	2.358	1.768	0.886	0.597	0.885	1.914	0.673	0.780	1.264
1991	1.276	2.911	1.812	1.124	1.784	1.026	1.608	0.756	1.397	1.623
1992	1.131	0.926	0.761	0.279	0.756	1.241	1.629	2.629	1.057	1.134
1993	1.103	1.165	0.747	0.196	0.855	1.343	2.035	1.542	0.901	1.087
1994	0.565	1.228	0.867	0.376	0.207	0.419	1.990	1.696	0.839	0.913
1995	0.881	0.563	1.389	0.331	0.304	0.813	1.033	0.617	0.590	0.610
1996	1.263	1.171	0.687	0.142	0.340	0.249	0.652	0.368	0.406	0.556
1997	1.337	1.397	1.438	0.260	0.797	1.218	1.920	0.931	0.603	1.024
1998	1.895	1.556	1.378	0.472	1.060	0.655	1.117	0.722	0.741	0.987
1999	0.914	1.745	1.815	0.286	0.540	0.606	0.715	1.011	0.448	0.861
2000	1.330	1.003	0.499	0.193	0.276	0.326	0.586	0.122	0.244	0.475

Table 2. (Continued)

Year	Bay system									Coastwide
	Sabine Lake	Galveston	East Matagorda	Matagorda	San Antonio	Aransas	Corpus Christi	Upper Laguna Madre	Lower Laguna Madre	
2001	0.730	0.925	2.149	0.215	0.483	0.607	0.644	0.267	0.261	0.552
2002	1.154	1.338	2.130	0.385	0.825	0.888	0.999	0.419	0.198	0.800
2003	0.953	0.892	1.990	0.255	0.429	0.982	0.980	1.154	1.511	0.896
2004	0.974	1.172	1.421	0.389	0.513	0.674	1.066	0.765	1.060	0.838
2005	1.494	1.370	0.542	0.203	0.674	0.627	0.888	0.500	0.254	0.720

Table 3. Annual mean catch rates (No./h) and mean carapace widths (mm) of blue crab caught in Texas bays with 6.1-m trawls by bay system and year during 1982-2005. ND = no data.

	Bay system																			
	Sabine Lake		Galveston		East Matagorda		Matagorda		San Antonio		Aransas		Corpus Christi		Upper Laguna Madre		Lower Laguna Madre		Coastwide	
Year	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width
1982	ND		28	90	ND		5	99	17	81	29	66	7	97	9	148	10	100	19	86
1983	ND		24	88	ND		10	86	21	80	40	81	2	95	7	113	12	96	18	86
1984	ND		19	92	ND		4	88	8	82	32	81	8	88	23	106	50	86	14	89
1985	ND		30	79	ND		10	85	19	76	23	72	5	115	20	103	36	86	20	80
1986	6	133	28	79	ND		13	85	19	85	25	78	14	88	8	100	15	85	20	82
1987	5	135	19	78	28	87	10	77	41	93	18	84	7	95	8	108	20	88	18	85
1988	5	137	9	71	13	91	3	77	90	75	59	63	7	88	7	98	18	84	23	73
1989	9	135	25	66	52	63	6	80	50	74	24	68	2	94	3	107	9	77	20	72
1990	6	98	32	72	15	79	4	90	40	69	17	71	14	96	5	93	34	91	22	75
1991	7	117	11	64	27	76	6	75	69	58	52	58	7	102	5	105	35	89	21	64
1992	7	139	8	77	2	102	7	65	107	54	39	56	10	81	26	110	28	98	25	62
1993	6	131	16	70	6	93	14	82	51	80	35	78	10	96	17	114	23	88	21	80
1994	4	146	16	74	3	90	23	85	72	47	26	72	3	66	21	83	25	93	25	66
1995	2	133	8	58	3	111	8	74	26	55	12	67	4	69	11	76	18	84	10	63
1996	9	107	15	60	7	107	16	82	14	75	10	72	5	78	4	86	13	87	13	72
1997	5	131	16	52	5	138	19	73	21	70	12	68	4	82	7	99	16	88	15	66
1998	11	126	21	65	8	122	13	76	15	86	20	77	6	83	9	99	13	86	16	74
1999	7	108	5	79	9	93	7	70	3	94	9	76	3	91	8	91	13	80	6	79
2000	4	148	10	71	4	59	6	72	6	84	8	77	2	94	2	92	6	76	7	75
2001	2	135	12	61	2	97	5	69	13	87	12	87	4	71	1	96	6	79	9	72
2002	5	111	10	71	6	132	4	98	10	79	20	77	3	101	2	73	4	81	8	79
2003	4	125	4	88	5	140	4	85	15	75	9	91	2	97	7	104	15	98	6	86
2004	8	128	5	76	3	144	5	89	18	74	8	83	3	69	2	88	3	101	7	80
2005	6	122	3	94	1	123	2	96	13	71	5	73	2	59	3	81	2	90	4	81

Table 4. Relative biomass (kg/h) of blue crab caught in Texas bays with 6.1-m trawls by bay system and year (1982-2005). ND = no data.

Year	Bay system									Coastwide
	Sabine Lake	Galveston	East Matagorda	Matagorda	San Antonio	Aransas	Corpus Christi	Upper Laguna Madre	Lower Laguna Madre	
1982	ND	1.987	ND	0.394	0.878	1.082	0.571	1.737	0.799	1.201
1983	ND	1.555	ND	0.565	1.078	2.321	0.195	0.770	0.919	1.186
1984	ND	1.371	ND	0.237	0.417	1.776	0.453	2.047	2.694	1.153
1985	ND	1.591	ND	0.573	0.856	0.949	0.565	1.726	2.021	1.132
1986	0.912	1.452	ND	0.743	1.113	1.216	0.880	0.667	0.832	1.066
1987	0.783	1.003	1.635	0.520	2.885	1.208	0.521	0.788	1.263	1.160
1988	0.897	0.410	0.859	0.163	3.552	1.957	0.472	0.599	0.992	1.116
1989	1.490	0.873	1.197	0.282	1.950	0.810	0.196	0.235	0.420	0.797
1990	0.601	1.179	0.701	0.280	1.381	0.686	0.989	0.308	2.080	0.942
1991	0.963	0.357	1.046	0.288	1.832	1.346	0.640	0.439	2.172	0.901
1992	1.193	0.452	0.214	0.245	2.315	0.861	0.561	2.750	2.266	1.048
1993	0.850	0.776	0.639	0.791	2.387	1.797	0.844	1.909	1.358	1.284
1994	0.860	0.739	0.240	1.301	1.205	1.106	0.143	1.143	1.620	0.982
1995	0.325	0.229	0.390	0.321	0.648	0.438	0.150	0.505	0.959	0.406
1996	1.093	0.388	0.743	0.795	0.616	0.433	0.225	0.254	0.723	0.518
1997	0.749	0.343	0.797	0.781	0.823	0.467	0.211	0.550	0.886	0.562
1998	1.718	0.763	1.042	0.662	0.902	1.051	0.369	0.724	0.812	0.798
1999	0.790	0.337	0.888	0.302	0.255	0.424	0.223	0.617	0.677	0.387
2000	0.734	0.432	0.260	0.254	0.424	0.413	0.161	0.138	0.335	0.346
2001	0.387	0.422	0.240	0.206	0.783	0.799	0.190	0.062	0.283	0.431
2002	0.629	0.465	0.940	0.374	0.535	1.120	0.268	0.067	0.237	0.512
2003	0.684	0.232	0.800	0.275	0.709	0.761	0.229	0.673	1.168	0.509
2004	1.298	0.314	0.614	0.386	0.786	0.478	0.140	0.186	0.290	0.416
2005	0.923	0.277	0.198	0.155	0.510	0.232	0.073	0.177	0.146	0.256

Table 5. Annual mean catch rates (No./h) and mean carapace widths (mm) of blue crab caught in Texas bays with 182.9-m gill nets (all meshes combined) by bay system and year (1983-2005) for spring and fall seasons combined. ND = no data.

	Bay system																				
	Sabine Lake		Galveston		East Matagorda		Matagorda		San Antonio		Aransas		Corpus Christi		Upper Laguna Madre		Lower Laguna Madre		Coastwide	
Year	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width
1983	ND		0.17	143	0.16	153	0.08	151	0.19	140	0.24	144	0.18	148	0.15	147	0.25	146	0.16	149
1984	ND		0.11	150	0.12	142	0.14	144	0.17	141	0.18	143	0.24	145	0.26	142	0.19	145	0.16	145
1985	ND		0.17	149	0.27	152	0.10	144	0.17	137	0.16	141	0.14	147	0.16	145	0.16	153	0.15	145
1986	0.22	148	0.18	151	0.31	133	0.11	143	0.09	141	0.09	143	0.06	149	0.03	147	0.06	148	0.12	147
1987	0.25	153	0.16	139	0.20	141	0.14	147	0.23	148	0.05	157	0.10	155	0.15	155	0.09	149	0.15	147
1988	0.23	155	0.12	146	0.11	153	0.04	136	0.06	139	0.06	147	0.07	146	0.02	123	0.06	152	0.08	143
1989	0.18	157	0.11	136	0.25	130	0.03	138	0.03	132	0.02	139	0.02	156	0.00	72	0.03	151	0.06	141
1990	0.20	150	0.13	144	0.18	133	0.11	143	0.14	139	0.09	140	0.12	139	0.04	128	0.14	141	0.12	142
1991	0.07	147	0.12	136	0.27	138	0.11	140	0.15	144	0.06	142	0.12	146	0.08	132	0.16	150	0.11	143
1992	0.10	156	0.09	152	0.09	143	0.05	149	0.06	134	0.06	141	0.15	149	0.31	143	0.07	149	0.09	148
1993	0.11	163	0.05	145	0.16	159	0.07	149	0.04	147	0.04	154	0.10	150	0.08	150	0.04	139	0.06	149
1994	0.06	159	0.04	148	0.11	154	0.03	148	0.04	139	0.02	152	0.04	155	0.03	111	0.02	128	0.04	148
1995	0.09	161	0.04	147	0.18	162	0.04	140	0.03	139	0.01	152	0.02	151	0.02	125	0.03	131	0.03	143
1996	0.10	151	0.05	141	0.11	153	0.03	139	0.02	162	0.02	148	0.02	157	0.02	141	0.04	149	0.04	147
1997	0.07	157	0.13	150	0.21	151	0.07	154	0.03	153	0.02	156	0.05	150	0.09	145	0.06	140	0.08	151
1998	0.10	157	0.07	148	0.14	155	0.05	154	0.07	153	0.02	149	0.03	147	0.12	154	0.05	131	0.06	151
1999	0.17	148	0.05	150	0.12	156	0.03	156	0.04	151	0.04	159	0.05	158	0.10	155	0.02	166	0.05	156
2000	0.08	158	0.02	155	0.04	155	0.01	160	0.01	144	0.02	151	0.01	152	0.00	150	0.00	146	0.02	155
2001	0.06	149	0.02	145	0.11	150	0.02	148	0.03	158	0.02	151	0.03	136	0.01	97	0.01	117	0.02	144
2002	0.11	146	0.07	142	0.19	150	0.05	141	0.07	151	0.04	148	0.05	153	0.01	141	0.00	116	0.06	144
2003	0.12	155	0.06	140	0.48	154	0.06	147	0.07	162	0.06	152	0.17	157	0.14	155	0.07	150	0.08	146
2004	0.16	154	0.19	69	0.29	155	0.08	156	0.03	149	0.03	147	0.05	153	0.07	167	0.00	160	0.10	148
2005	0.26	160	0.09	114	0.06	149	0.04	148	0.04	152	0.02	156	0.04	151	0.02	156	0.01	200	0.06	138

Table 6. Relative biomass (kg/h) of blue crab caught in Texas bays with 182.9-m gill nets (all meshes combined) by bay system and year (1983-2005) for spring and fall seasons combined. ND = no data.

	Bay system									
Year	Sabine Lake	Galveston	East Matagorda	Matagorda	San Antonio	Aransas	Corpus Christi	Upper Laguna Madre	Lower Laguna Madre	Coastwide
1983	ND	0.030	0.033	0.016	0.030	0.041	0.034	0.027	0.043	0.030
1984	ND	0.022	0.019	0.022	0.029	0.030	0.042	0.047	0.033	0.030
1985	ND	0.032	0.051	0.018	0.026	0.026	0.024	0.027	0.033	0.027
1986	0.041	0.035	0.043	0.020	0.014	0.015	0.012	0.004	0.012	0.028
1987	0.050	0.027	0.029	0.022	0.041	0.011	0.021	0.031	0.018	0.030
1988	0.049	0.023	0.022	0.005	0.010	0.011	0.013	0.003	0.012	0.022
1989	0.040	0.016	0.033	0.005	0.005	0.004	0.004	0.000	0.006	0.017
1990	0.039	0.023	0.025	0.018	0.023	0.014	0.019	0.005	0.022	0.022
1991	0.013	0.018	0.040	0.019	0.026	0.009	0.021	0.011	0.032	0.020
1992	0.021	0.017	0.016	0.009	0.008	0.010	0.027	0.052	0.013	0.023
1993	0.025	0.008	0.035	0.013	0.008	0.008	0.019	0.014	0.006	0.014
1994	0.014	0.007	0.023	0.006	0.006	0.004	0.008	0.003	0.003	0.007
1995	0.021	0.007	0.068	0.006	0.004	0.002	0.004	0.002	0.005	0.010
1996	0.019	0.008	0.021	0.005	0.004	0.003	0.004	0.002	0.007	0.008
1997	0.014	0.024	0.040	0.014	0.005	0.004	0.010	0.014	0.009	0.018
1998	0.023	0.014	0.029	0.011	0.014	0.004	0.005	0.024	0.007	0.014
1999	0.031	0.009	0.025	0.006	0.007	0.009	0.011	0.021	0.007	0.013
2000	0.018	0.004	0.009	0.002	0.003	0.003	0.003	0.001	0.001	0.007
2001	0.011	0.005	0.021	0.004	0.005	0.005	0.005	0.000	0.001	0.005
2002	0.020	0.013	0.035	0.009	0.014	0.007	0.011	0.002	0.000	0.012
2003	0.026	0.011	0.097	0.011	0.018	0.011	0.036	0.030	0.014	0.023
2004	0.033	0.014	0.061	0.016	0.007	0.005	0.010	0.018	0.001	0.016
2005	0.055	0.012	0.011	0.009	0.007	0.004	0.007	0.004	0.004	0.020

Table 7. Annual mean catch rates (No./h) and mean carapace widths (mm) of blue crab caught in the Texas Territorial Sea with 6.1-m trawls by gulf area and year (1985-2005). ND = no data.

	Sabine Lake		Galveston		Port O'Connor		Port Aransas		Port Isabel		Coastwide	
Year	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width	No./h	width
1985	ND		0.5	105	0.8	134	0.7	127	0.3	144	0.6	127
1986	4.5	96	6.2	105	1.2	141	1.2	145	0.7	123	2.6	111
1987	3.2	96	0.8	112	1.7	105	0.5	142	0.3	141	1.3	106
1988	2.0	85	0.3	104	1.0	113	1.2	128	0.1	161	0.9	105
1989	3.7	61	2.5	72	0.7	130	0.3	134	0.3	146	1.5	77
1990	14.9	80	4.2	63	1.1	118	1.3	126	1.1	127	4.5	84
1991	18.9	72	6.3	58	1.0	102	1.8	112	0.2	121	5.7	73
1992	6.8	58	0.8	104	0.4	84	0.7	95	0.4	123	1.8	69
1993	4.8	78	0.7	83	1.8	116	1.3	130	0.6	102	1.8	95
1994	9.2	77	1.9	122	0.9	115	1.9	66	0.9	128	3.0	87
1995	8.0	65	1.1	61	0.2	120	0.6	122	0.3	122	2.0	70
1996	5.4	58	0.5	59	0.1	115	0.3	120	0.8	107	1.4	67
1997	15.2	67	3.0	65	0.5	83	0.6	107	1.0	124	4.1	71
1998	4.2	65	0.7	52	0.5	82	0.4	140	0.1	112	1.2	71
1999	1.7	68	1.4	63	0.4	115	0.8	103	0.3	140	0.9	82
2000	2.9	64	1.0	50	0.0	50	0.4	68	0.0	158	0.9	62
2001	3.0	63	1.7	74	0.1	105	0.4	121	0.4	136	1.1	76
2002	7.4	52	1.4	62	0.5	73	0.2	108	0.5	96	2.0	58
2003	2.1	50	0.7	74	0.3	134	0.5	117	0.7	130	0.9	81
2004	3.2	37	1.4	68	0.2	145	0.7	66	0.1	102	1.1	54
2005	3.6	38	0.8	130	0.1	133	0.2	94	0.1	158	1.0	60

Table 8. Relative biomass (kg/h) of blue crab caught in the Texas Territorial Sea with 6.1-m trawls by gulf area and year (1985-2005). ND = no data.

	Gulf area					
Year	Sabine Lake	Galveston	Port O'Connor	Port Aransas	Port Isabel	Coastwide
1985	ND	0.038	0.115	0.097	0.050	0.080
1986	0.337	0.640	0.183	0.197	0.087	0.284
1987	0.265	0.099	0.152	0.091	0.052	0.132
1988	0.129	0.035	0.114	0.164	0.014	0.092
1989	0.135	0.131	0.103	0.041	0.050	0.093
1990	0.840	0.124	0.131	0.168	0.138	0.280
1991	0.810	0.130	0.086	0.194	0.025	0.249
1992	0.185	0.087	0.027	0.054	0.046	0.080
1993	0.272	0.037	0.209	0.189	0.056	0.153
1994	0.428	0.256	0.101	0.084	0.110	0.196
1995	0.271	0.038	0.028	0.077	0.036	0.090
1996	0.143	0.012	0.015	0.042	0.074	0.057
1997	0.485	0.086	0.036	0.053	0.114	0.155
1998	0.150	0.008	0.026	0.066	0.009	0.052
1999	0.074	0.046	0.045	0.081	0.054	0.060
2000	0.091	0.015	0.000	0.017	0.007	0.026
2001	0.092	0.088	0.005	0.048	0.054	0.057
2002	0.155	0.048	0.035	0.022	0.040	0.060
2003	0.044	0.046	0.053	0.058	0.089	0.058
2004	0.017	0.066	0.046	0.036	0.013	0.035
2005	0.050	0.136	0.021	0.014	0.013	0.047

Table 9. Annual Texas commercial blue crab landings (kg x 1000), ex-vessel value ($ x 1000), and fishing effort (No. of licensed crab fishermen) by bay system and year (1960- 2005). ND = no data.

	Bay system												
Year	Sabine Lake	Galveston	East Matagorda	Matagorda	San Antonio	Aransas	Corpus Christi	Upper Laguna Madre	Lower Laguna Madre	Gulf	Coastwide	Ex-vessel Value	No. of crab fishermen
1960	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,300	177	71[a]
1961	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,304	178	76
1962	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2,029	289	89
1963	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,352	199	82
1964	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,127	175	87
1965	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,643	286	70
1966	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,260	228	72
1967	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,191	222	66
1968	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,852	329	81
1969	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2,877	599	95
1970	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2,506	509	102
1971	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2,635	567	90
1972	585	848	187	213	451	607	32	2	0	6	2,932	653	95
1973	616	929	376	133	390	577	19	0	5	76	3,121	830	126
1974	254	862	200	273	510	489	148	1	6	18	2,761	832	120
1975	282	826	264	162	698	405	57	4	2	18	2,718	948	152
1976	233	725	205	91	971	598	56	0	136	9	3,025	1,179	179
1977	103	833	151	96	990	1,018	47	58	442	5	3,742	1,947	167
1978	283	871	122	142	873	930	4	73	89	1	3,388	2,004	146
1979	74	886	89	309	1,216	1,105	23	12	55	0	3,770	2,146	97
1980	32	793	213	177	1,366	1,232	8	3	235	2	4,061	2,456	111
1981	33	277	38	167	1,456	806	4	0	370	3	3,153	1,929	112
1982	51	552	286	313	1,048	975	64	4	339	1	3,633	2,375	141

Table 9. (Continued)

Year	Bay system												
	Sabine Lake	Galveston	East Matagorda	Matagorda	San Antonio	Aransas	Corpus Christi	Upper Laguna Madre	Lower Laguna Madre	Gulf	Coastwide	Ex-vessel Value	No. of crab fishermen[a]
1983	78	639	289	362	1155	1138	105	5	217	16	4,005	3,250	131
1984	252	634	144	420	646	966	34	9	161	12	3,279	2,252	227
1985	306	983	71	449	1355	1012	60	42	117	14	4,410	3,310	195
1986	611	1368	2	542	778	425	398	34	104	38	4,301	3,171	223
1987	284	1262	2	510	2166	764	122	81	94	17	5,302	4,474	317
1988	201	1415	95	431	1244	1167	92	47	0	39	4,730	4,326	273
1989	556	1226	112	925	670	184	444	5	0	17	4,112	3,946	305
1990	337	865	7	836	1179	347	302	12	0	15	3,900	3,305	311
1991	316	695	137	443	736	394	51	2	6	5	2,784	2,277	215
1992	121	382	61	426	868	453	230	215	24	3	2,783	2,775	255
1993	396	826	28	579	785	674	442	29	0	1	3,759	3,961	269
1994	334	799	15	395	498	176	70	31	1	19	2,338	3,057	345
1995	580	526	367	298	598	224	23	3	5	1	2,625	4,062	327
1996	751	866	326	357	386	135	9	10	3	18	2,863	4,212	335
1997	897	893	1	437	799	155	9	1	11	12	3,213	4,347	345
1998	575	1102	129	407	705	108	26	2	112	3	3,170	4,549	318
1999	815	786	187	358	669	83	4	2	32	0	2,936	4,295	303
2000	691	462	102	227	558	56	1	0	5	9	2,111	3,301	277
2001	642	450	205	360	366	308	3	0	6	3	2,344	3,910	255
2002	710	443	227	365	871	537	24	0	8	0	3,192	4,523	230
2003	442	301	18	138	542	608	53	43	30	0	2,182	3,157	224
2004	321	163	0	102	714	462	24	0	10	0	1,799	2,663	222
2005	373	92	0	122	428	295	38	0	10	0	1,414	2,409	218

[a] Number of crab fishermen from NMFS port agents during 1960-1991, TPWD crab trap tag sales during 1992-1998, and TPWD crab fisherman license sales during 1999-present.

Table 10. Surplus production model parameters derived from two assessment methods (multiple linear regression and time series fitting) and bootstrap-derived means with 95th percentile confidence intervals.

Parameter	Assessment method		Bootstrap estimates		
	Multiple linear regression	Time series fitting	Lower confidence interval	Mean	Upper confidence interval
q	0.0011362	0.0017569	0.0009729	0.0016427	0.0022947
r	0.556	0.653	0.325	0.609	0.901
K	27,224,457	21,699,014	16,962,974	26,156,070	44,709,618
B_{1967}	24,172,518	10,564,277	7,089,573	13,025,780	27,724,484
MSY	3,878,759	3,541,549	3,163,356	3,481,401	3,718,528
Emsy	222	186	159	183	206

Table 11. Instantaneous total mortality (Z) for blue crab caught in Texas bays with 6.1-m trawls by bay system and year during 1982-2005. ND = no data.

	Bay system									
Year	Sabine Lake	Galveston	East Matagorda	Matagorda	San Antonio	Aransas	Corpus Christi	Upper Laguna Madre	Lower Laguna Madre	Coastwide
1982	ND	0.97	ND	0.97	1.08	1.08	0.97	0.50	0.99	0.99
1983	ND	1.01	ND	1.16	1.14	0.97	0.79	0.70	0.97	1.03
1984	ND	0.99	ND	0.99	1.16	1.04	1.12	0.93	1.16	1.03
1985	ND	1.04	ND	1.10	1.21	1.12	0.73	0.91	1.12	1.06
1986	0.65	1.06	ND	1.08	1.10	1.16	1.03	0.94	1.18	1.08
1987	0.57	1.04	1.16	1.06	1.01	0.88	0.88	0.83	1.03	0.99
1988	0.54	1.08	1.03	1.10	1.25	1.21	0.99	0.84	1.12	1.14
1989	0.54	1.12	1.62	1.16	1.25	1.28	0.81	0.85	1.18	1.14
1990	0.63	1.25	1.25	0.97	1.25	1.12	0.99	1.01	1.08	1.16
1991	0.59	1.16	1.42	1.10	1.25	1.21	0.88	0.81	1.03	1.12
1992	0.56	0.97	0.78	1.08	1.30	1.36	1.01	0.80	0.90	1.1
1993	0.56	0.94	0.55	1.04	1.21	1.06	0.79	0.74	1.08	1.03
1994	0.43	1.06	0.67	1.18	1.36	1.10	0.85	1.08	1.06	1.14
1995	0.49	1.08	0.54	1.23	1.30	1.14	1.08	1.16	1.10	1.18
1996	0.57	1.18	0.63	1.23	1.21	1.12	1.21	0.93	1.18	1.18
1997	0.51	1.18	0.52	1.21	1.18	1.18	0.90	0.94	1.14	1.16
1998	0.50	1.10	0.63	1.10	1.08	0.97	0.93	0.93	1.03	1.04
1999	0.57	0.84	0.57	1.01	0.91	1.14	0.81	0.94	1.16	0.93
2000	0.43	1.10	0.49	1.23	1.08	1.01	0.70	0.90	1.01	1.06
2001	0.52	0.99	0.67	1.12	1.06	1.01	1.08	0.90	1.30	1.03
2002	0.53	1.04	0.57	0.88	1.08	1.01	0.80	1.21	1.08	0.99
2003	0.48	0.94	0.56	0.72	1.14	0.85	0.65	0.88	0.97	0.91
2004	0.47	0.88	0.47	0.91	1.18	1.03	1.01	0.88	0.90	0.97
2005	0.49	0.72	0.61	0.87	1.33	1.03	0.97	1.04	1.03	0.97

Table 12. Pros and cons of management options to reduce commercial crab fishing effort in Texas.

Pros and cons	Management options [a]						
	1	2	3	4	5	6	7
Pros							
Immediate effort reduction		x	x	x		x	x
Reduce user conflicts				x		x	x
Reduce mortality on sub-legal sized crabs		x				x	
Reduce bycatch mortality in traps		x x	x			x	
Protect critical grow out and spawning areas						x	
Cons							
Delayed stock recovery	x						
Added costs to fisherman						x	
Requires additional data		x		x			x
Increased enforcement problems	x			x		x	x

[a] Management options were defined as follows:

- Option 1: Maintain the status quo (i.e. allow limited entry, buybacks at current rate, and attrition to reduce effort).
- Option 2: Increase the required number and/or size of escape rings in traps.
- Option 3: Reduce trap limits from 200 to 150 per person.
- Option 4: Redirect funds and/or increase crab license fees, and dedicate increased revenue to crab license buybacks.
- Option 5: Establish a moratorium on crab license transfers.
- Option 6: Impose area closures.
- Option 7: Impose bag limit for recreational fishermen.

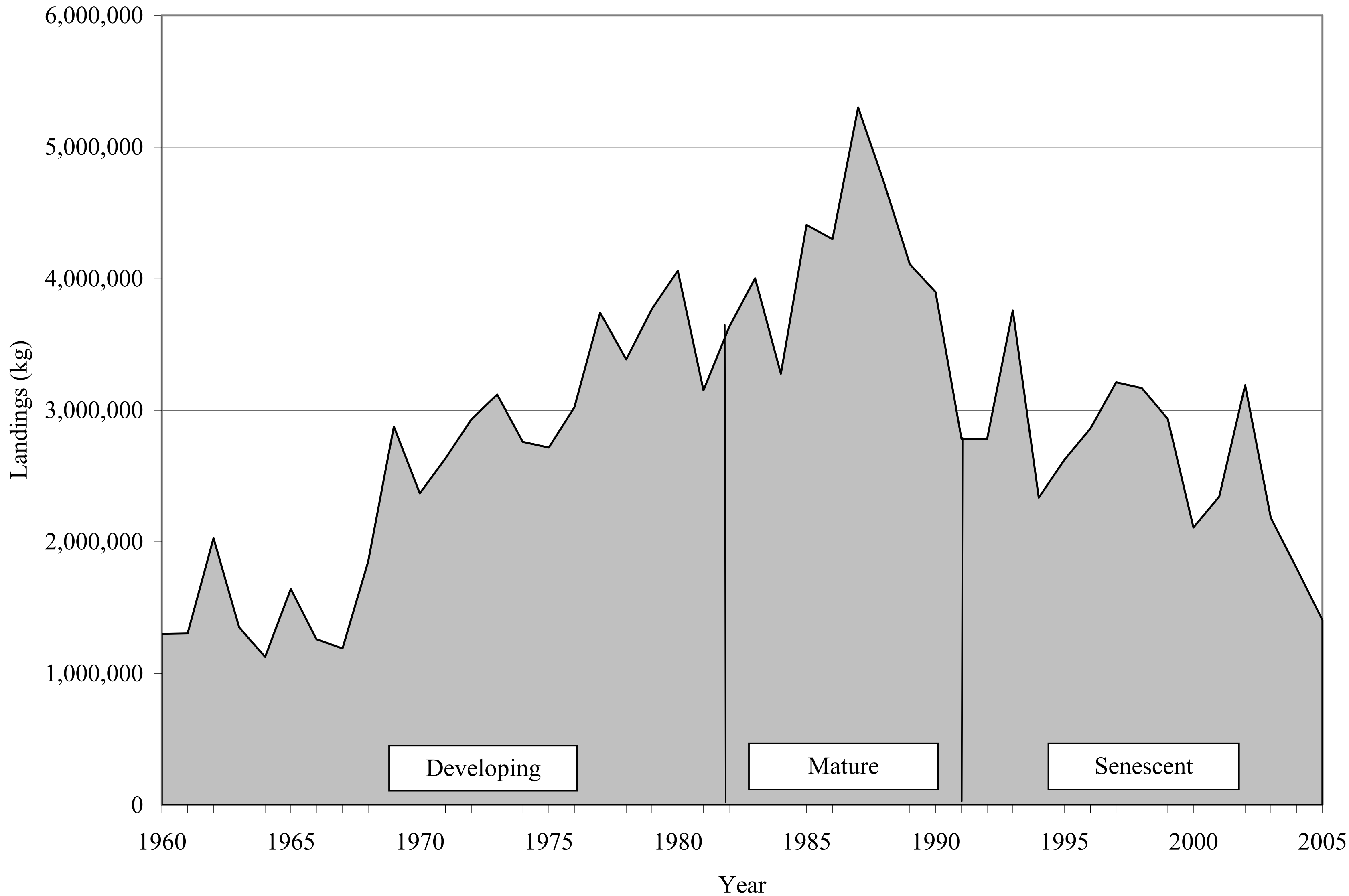

Figure 1. Stages of development in the Texas commercial blue crab fishery from 1960 to 2005.

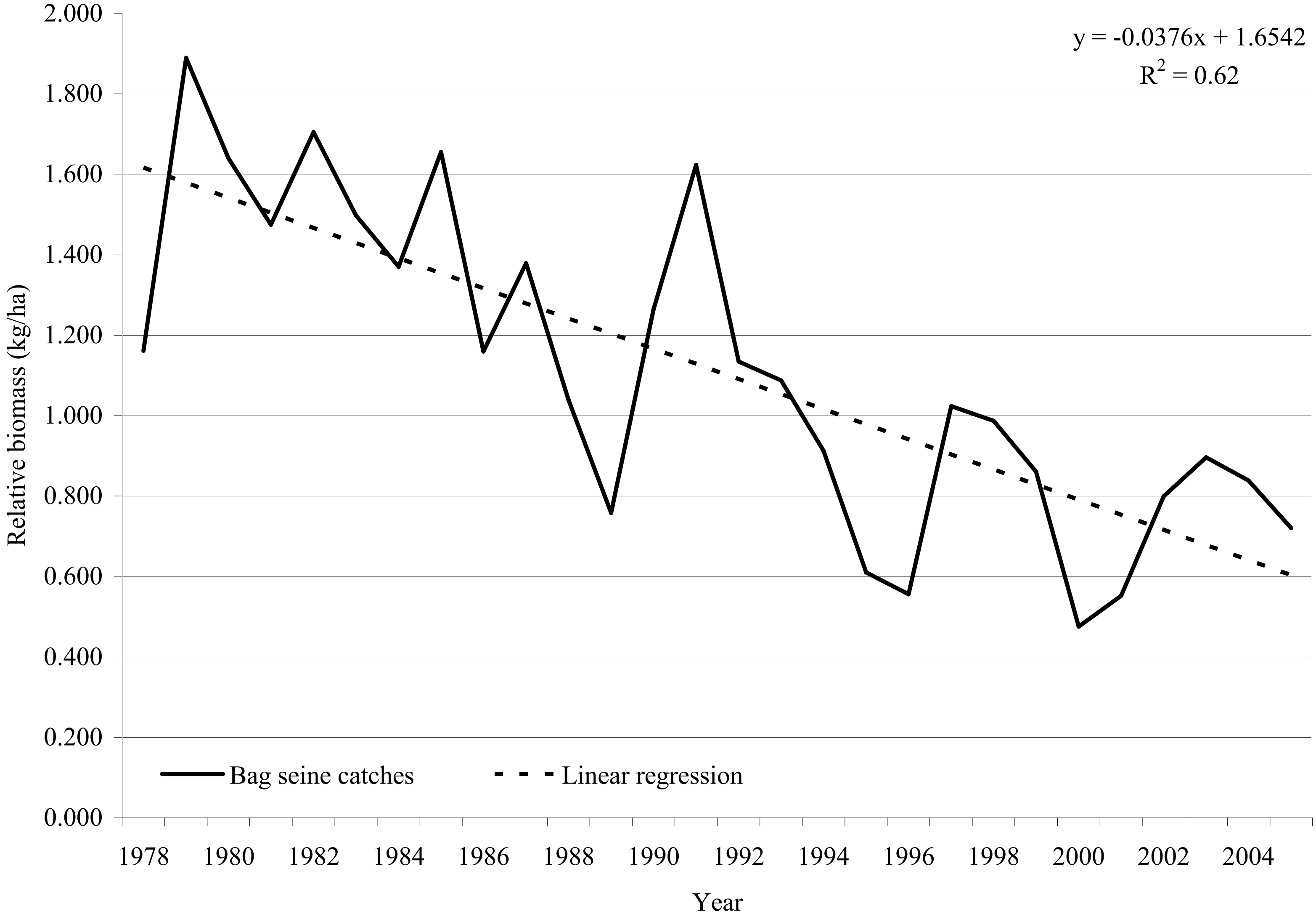

Figure 2. Annual coastwide relative biomass of blue crab caught in Texas bays with 18.3-m bag seines during 1978-2005.

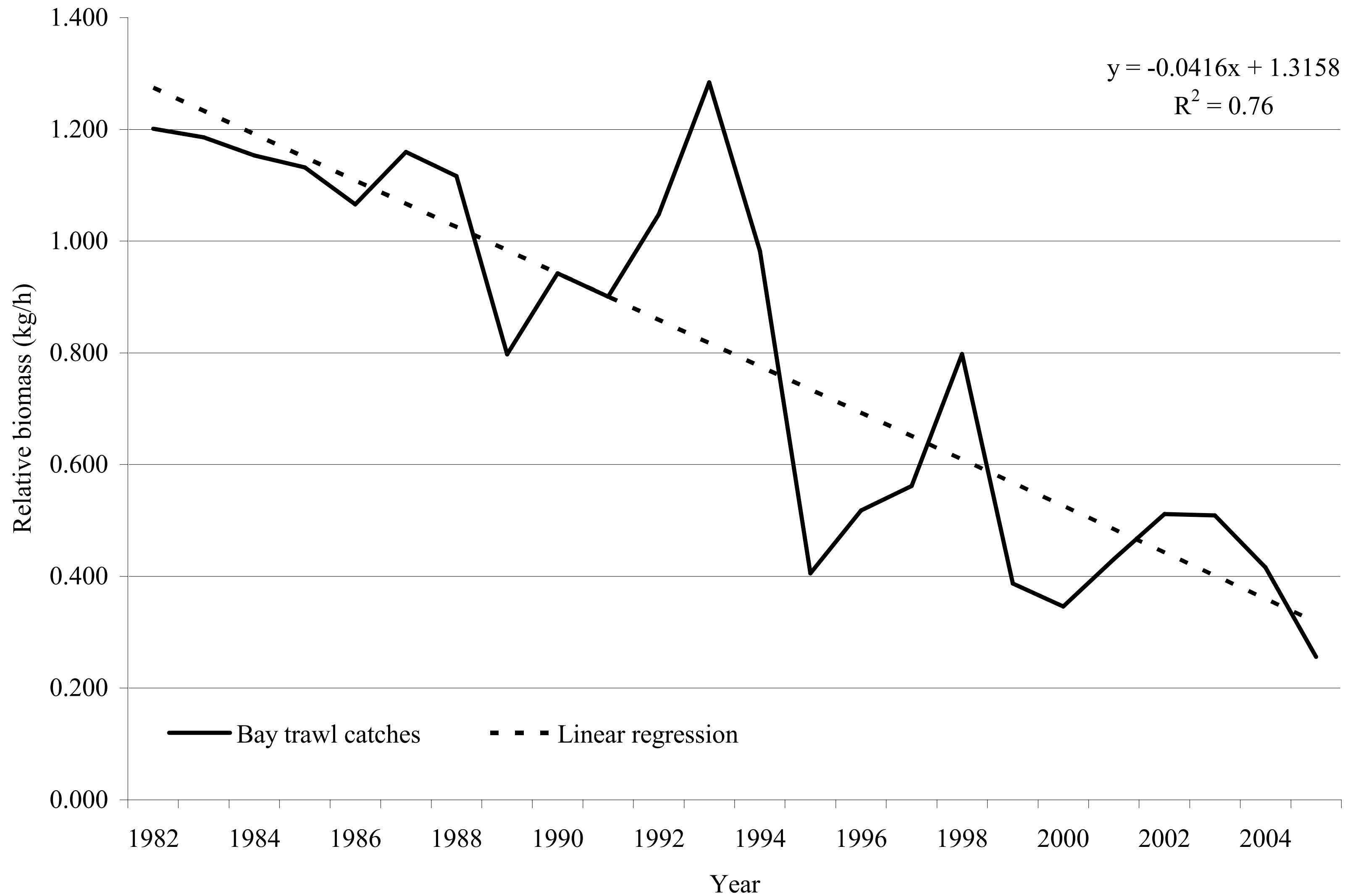

Figure 3. Annual coastwide relative biomass of blue crab caught in Texas bays with 6.1-m trawls during 1982-2005.

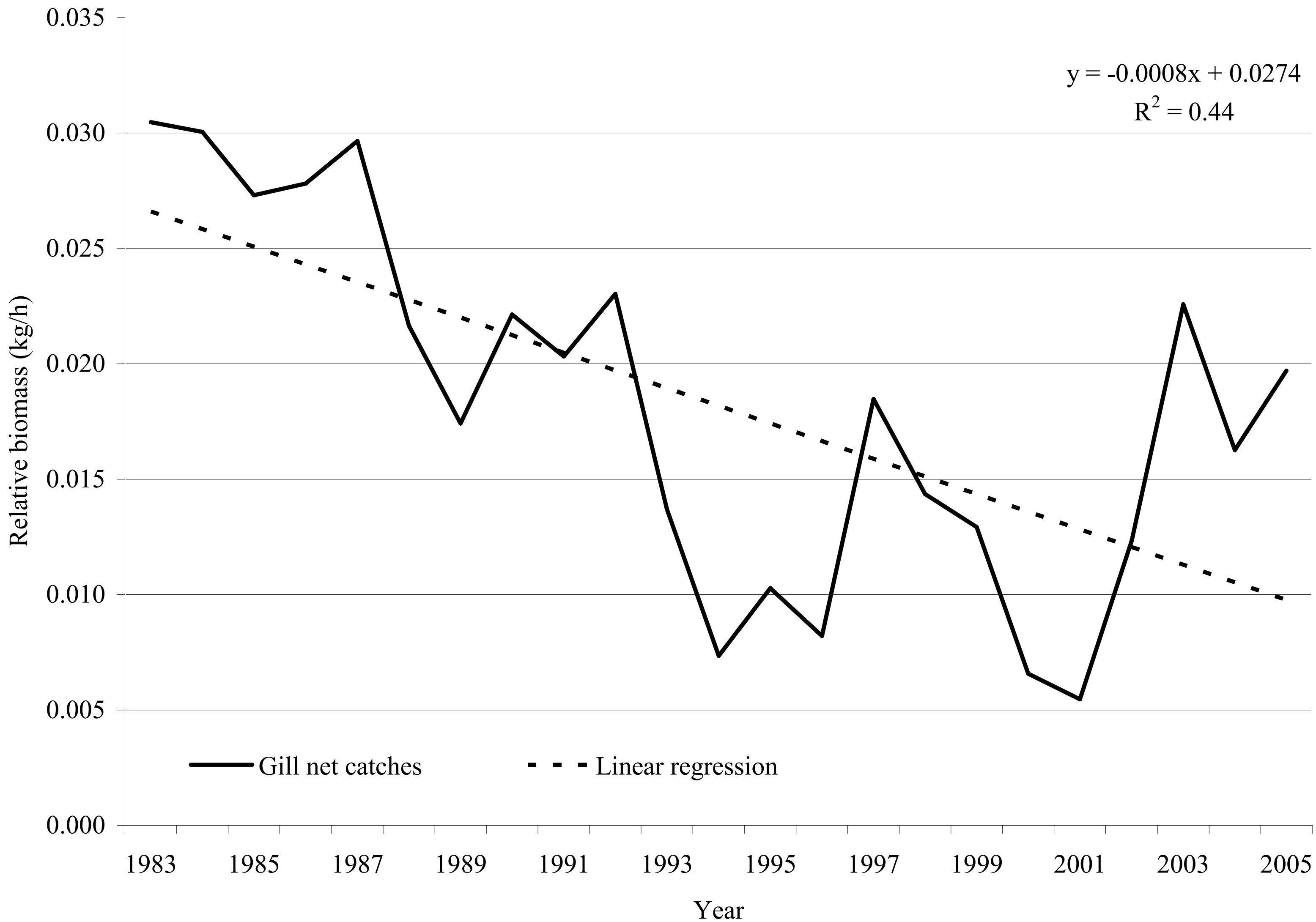

Figure 4. Annual coastwide relative biomass of blue crab caught in Texas bays with 182.9-m gill nets during 1983-2005.

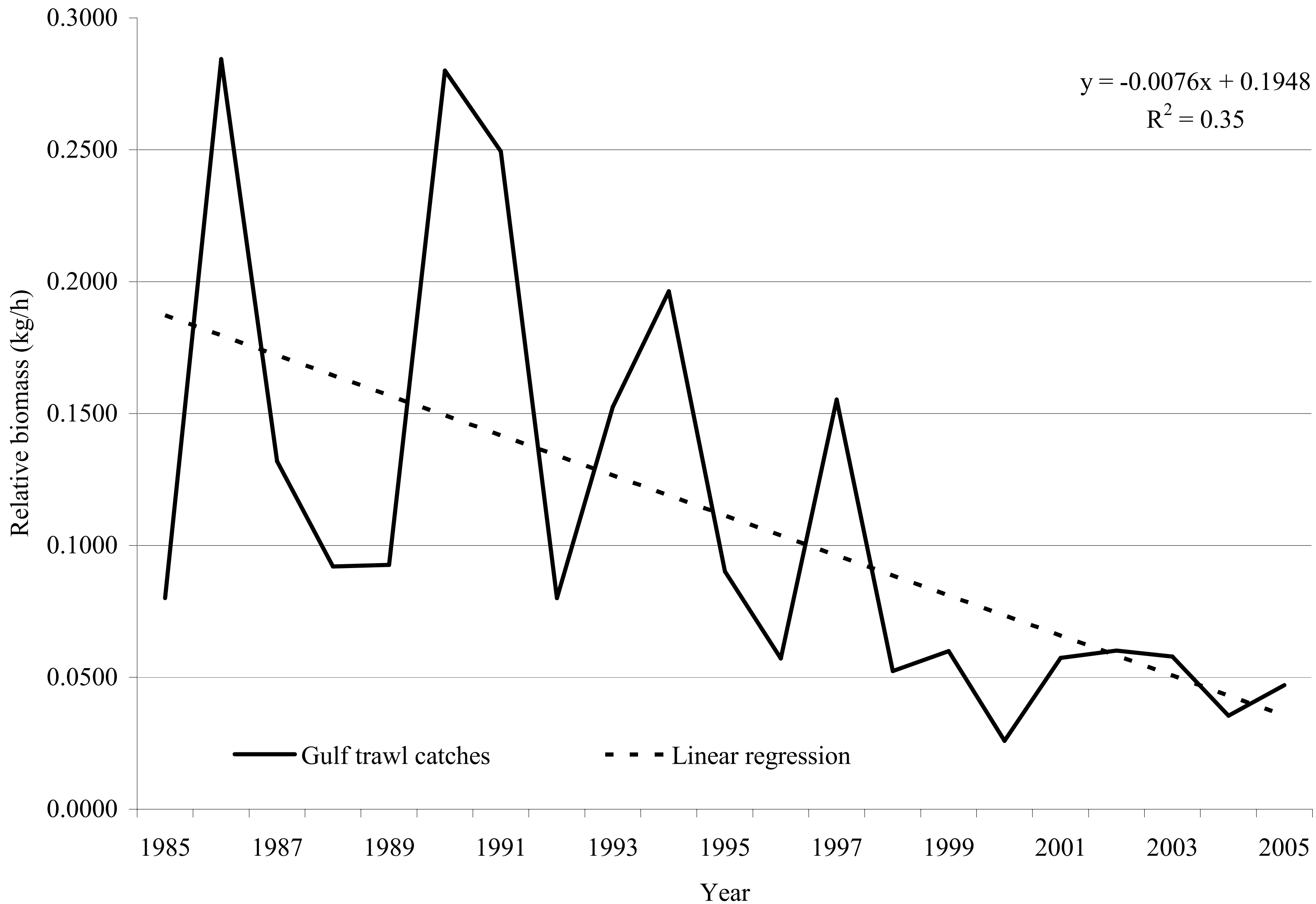

Figure 5. Annual coastwide relative biomass of blue crab caught in the Texas Territorial Sea with 6.1-m trawls during 1985-2005.

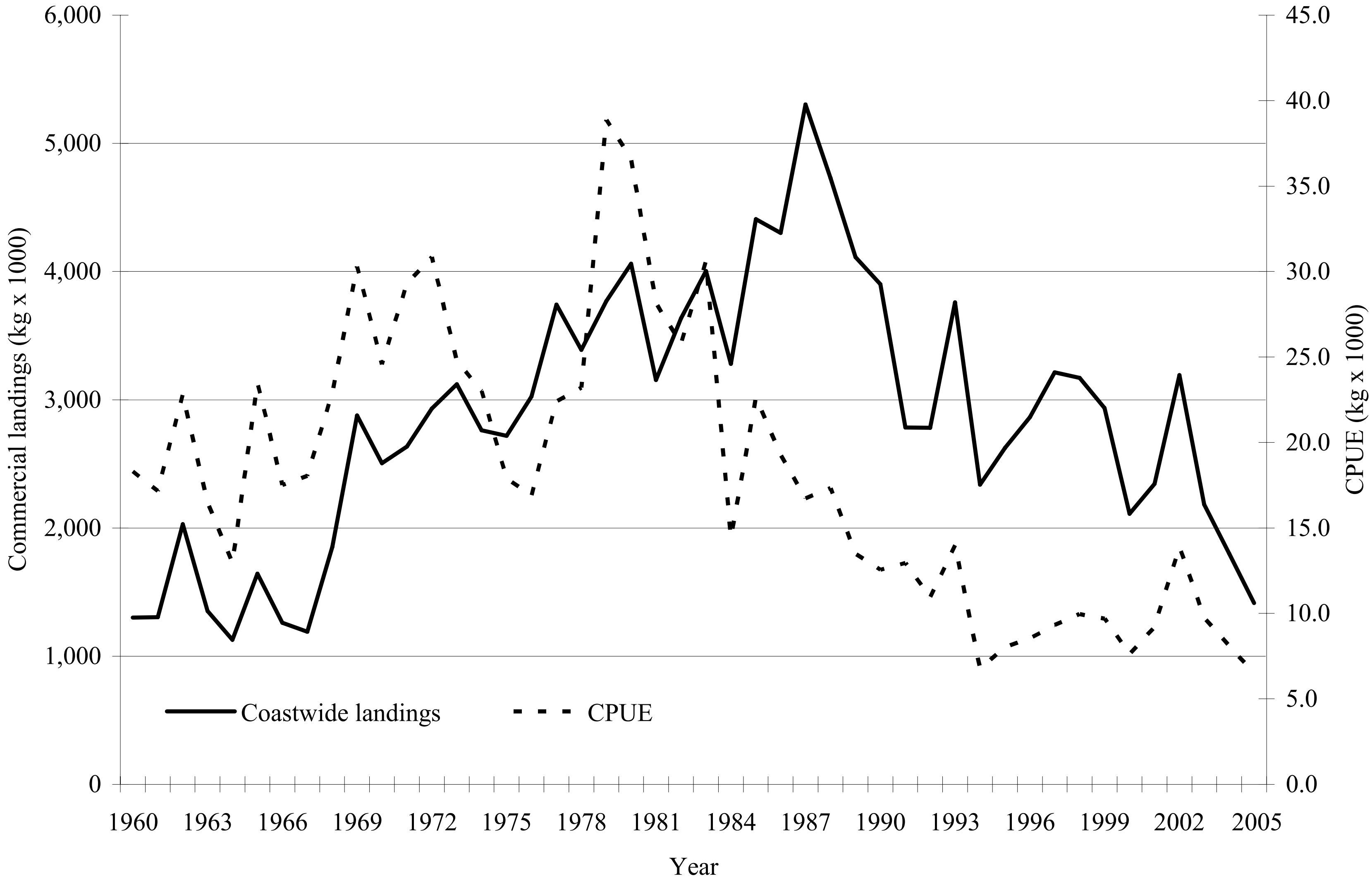

Figure 6. Annual Texas commercial blue crab landings and CPUE (catch per crab fisherman) during 1960-2005

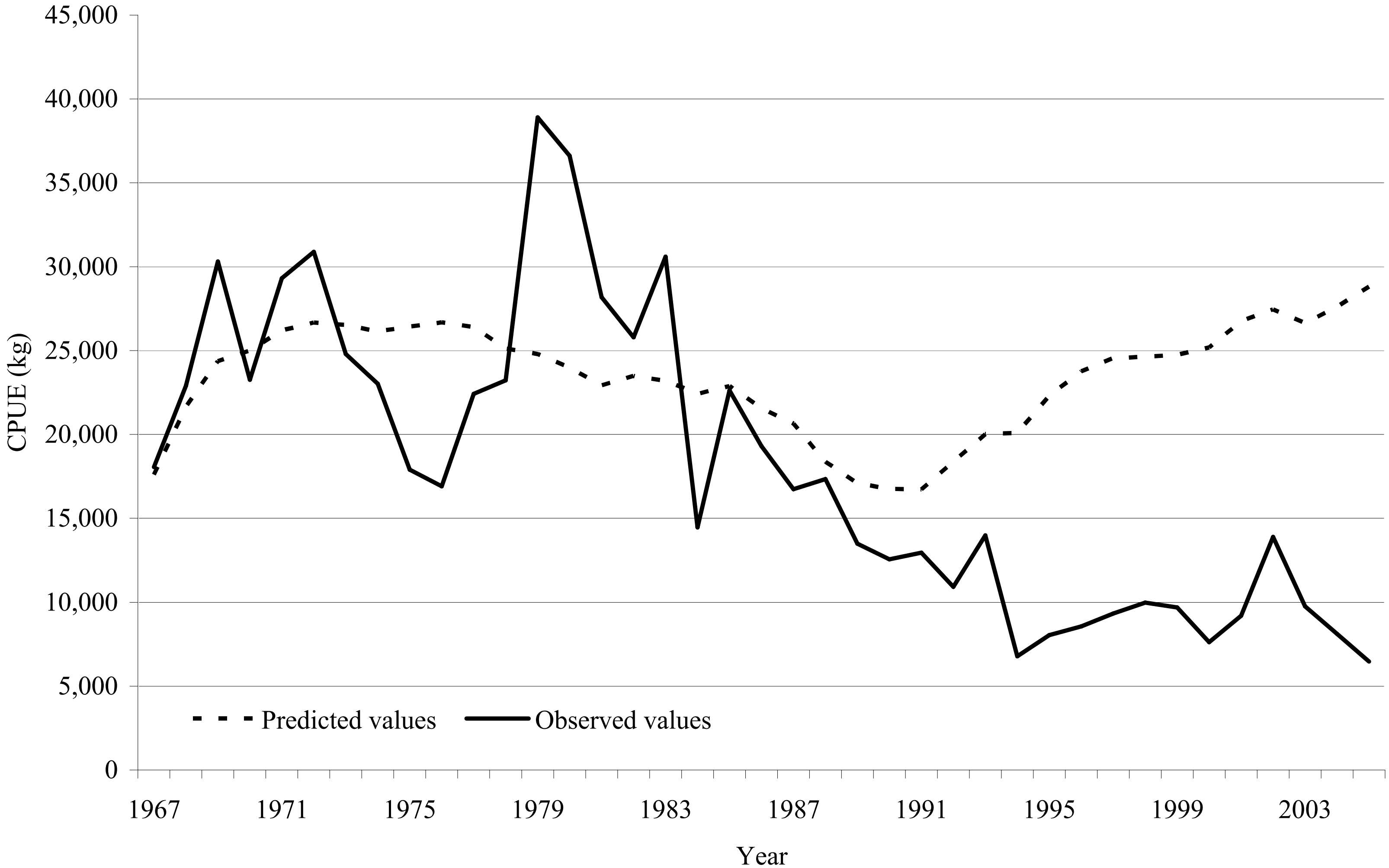

Figure 7. Observed versus predicted catch-per-crab fisherman in Texas during 1967-2005 using initial regression parameters.

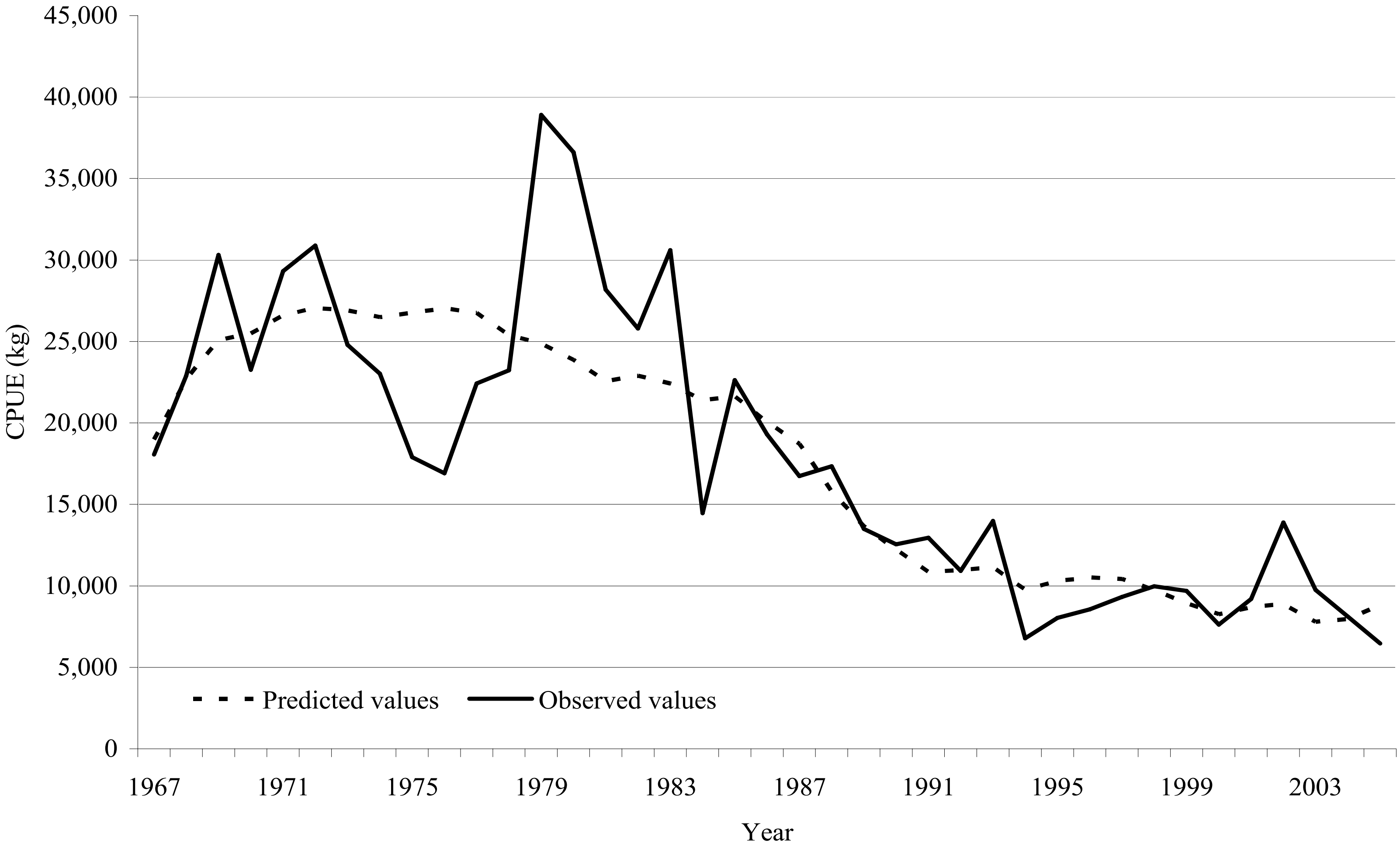

Figure 8. Observed versus predicted catch-per-crab fisherman in Texas during 1967-2005 after adjusting initial regression parameters using time series fitting.

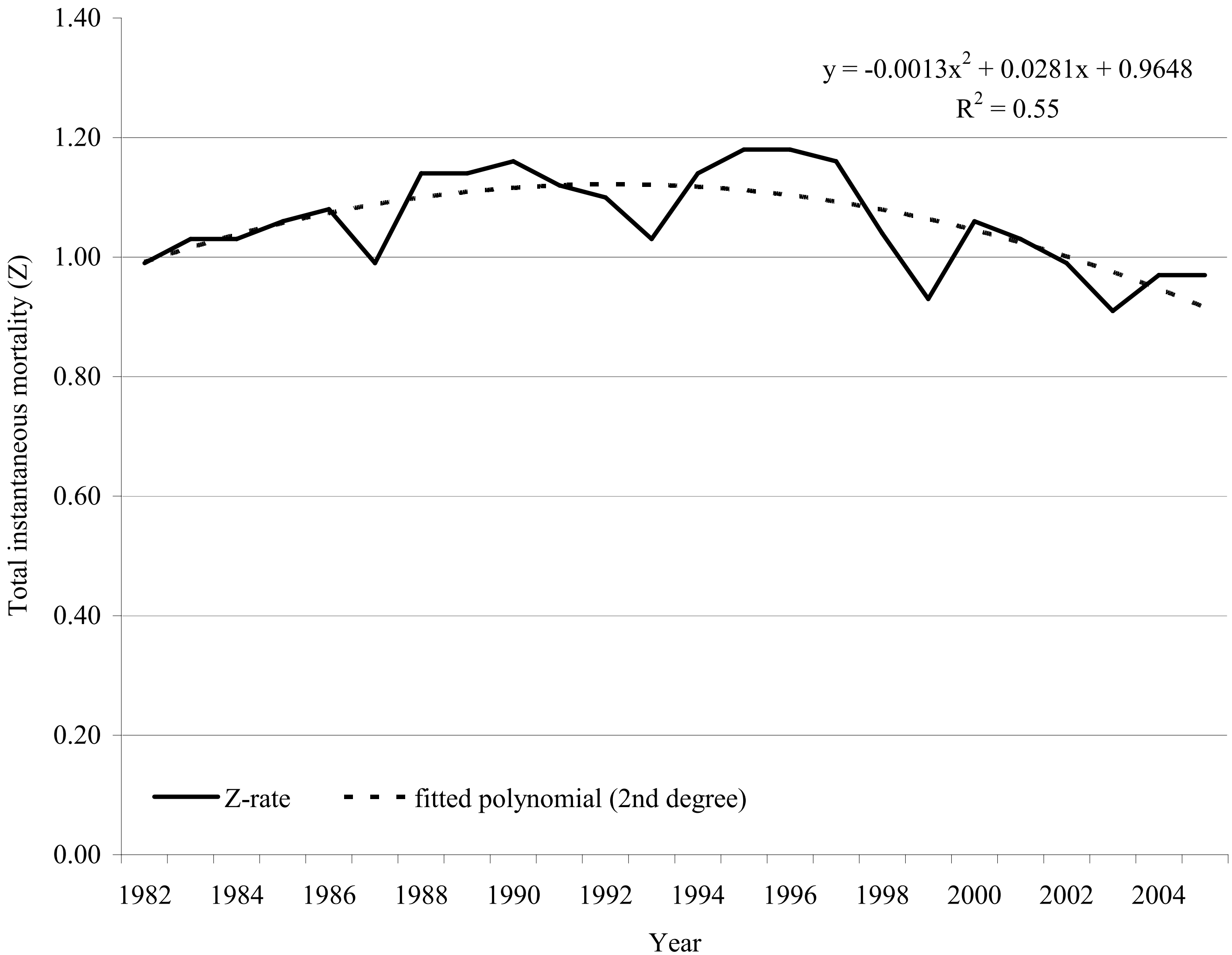

Figure 9. Coastwide mortality (Z) for blue crab caught in Texas bays with 6.1-m trawls during 1982-2005.

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