BA Dorf and M Fisher

Fishery-Independent Catch of Young-of-the-Year Red Snapper in the Texas Territorial Sea, 1985–2007

SEDAR31-RD08

1 March 2012

TITLE: Fishery-Independent Catch of Young-of-the-Year Red Snapper in the Texas Territorial Sea, 1985–2007

AUTHORS:

Barbara A. Dorf*

Mark Fisher

ADDRESSES:

Texas Parks and Wildlife Department

Coastal Fisheries Division

702 Navigation Circle

Rockport, Texas 78382-2779

USA

TELEPHONE: (361) 729-2328

FAX: (361) 729-1437

E-MAIL: Corresponding author: barbara.dorf@tpwd.state.tx.us

Abstract.—Between 1985-2007, Texas Parks and Wildlife conducted trawl surveys in the Texas Territorial Sea (TTS) near five passes to the Gulf of Mexico (Sabine, Bolivar, Matagorda, Aransas, and Brazos Santiago Passes) from shore out to 16.7 km within NOAA Fisheries Service statistical zones 17- 21. Sixteen trawl samples were collected monthly from randomly selected locations within each Gulf pass area (N = 21,353). A total of 7,688 red snapper (*Lutjanus campechanus*) were collected with mean total length of 90 mm (± 0.31 SE), and a coastwide mean catch/h of 2.1 (± 0.11 SE). Catches were low along the northern coast with 0.4% collected near Sabine Pass and Bolivar Pass, combined. Matagorda Pass, Aransas Pass, and Brazos Santiago Pass accounted for 16%, 43.8% and 39.8% of total catch, respectively. Monthly catches were lowest from January through April, increasing from May through August, peaking in September (8.1/h ± 0.67 SE), and decreasing through December. July – November accounted for 90% of total catch. Young-of-the-year were present from April – November at Matagorda Pass; from April – December at Aransas Pass; and throughout the year at Brazos Santiago Pass. The smallest young-of-the-year began to appear in large numbers in July at all three passes. Time series analysis revealed that catch is strongly seasonal, repeating from year to year, and positively related to water temperature. The Texas Territorial Sea is not uniform young-of-the-year habitat, and distinctly different regions are evident due to bathymetry and oceanography. Egg and larval advection from Mexico may play an important role in recruitment to the southern Texas Territorial Sea. Long-term increase in young-of-the-year red snapper from 2000 – 2007 is coincident with decreased commercial shrimp effort and use of bycatch reduction devices.

Red snapper are an important commercial and recreational fish in the Gulf of Mexico. In 2007, over 1,360 metric tons of commercially-fished red snapper, worth almost $9.6 million, were landed Gulfwide, with Texas accounting for 40.5% (551 metric tons) of the commercial catch that year. Conversely, the Gulf of Mexico recreational fishery landed almost 1.1 million red snapper Gulfwide that same year, with a total of only 5.4% (3.3%, federal; 2.1% state) caught off the Texas coast (NOAA Fisheries Service, Fisheries Statistics Division; Texas Parks and Wildlife Department). The NOAA Fisheries Service has determined that red snapper are overfished and undergoing overfishing (Gulf of Mexico Fishery Management Council, 2007). Stock assessments used to determine red snapper population recovery are currently lacking long-term, year round information on young-of-the-year from the western Gulf of Mexico. Published information on young-of-the-year red snapper in the western Gulf of Mexico includes only spring and fall Southeast Area Monitoring and Assessment Program (SEAMAP) resource surveys in the area between Brownsville, Texas and Mobile Bay, Alabama (Drass et al., 2002), as well as a number of other short-term studies (Moseley, 1966; Holt and Arnold, 1982; Rooker et al., 2004; Gazey et al., 2008).

The Texas summer closure, begun by adoption of the Texas Shrimp Conservation Act of 1959, completely closed the shrimp fishery in the Texas Territorial Sea (TTS), typically from May 15th through July 15th (Texas Parks and Wildlife Department, 2002). In 1981, a coordinated effort to close both state and federal waters became know as the “Texas Closure” (Gulf of Mexico Fishery Management Council, 1981). In 1985, the Texas Legislature gave the Texas Parks and Wildlife Commission authority to study, manage and regulate the shrimp fishery in Texas bays and the TTS within 16.7 km from shore after development of a Texas Shrimp Fishery Management Plan (Cody et al., 1989). That same year, the Texas Parks and Wildlife Department (TPWD) began standardized bottom trawl sampling in the near-shore Gulf of Mexico, an effort that has resulted in quantification of a number of commercially and recreationally important species in addition to the targeted shrimp.

In this paper, we quantify catch and size-frequency distribution of young-of-the-year red snapper collected during the TPWD bottom trawl survey in the TTS from 1985-2007. We also compare red snapper catch and total length among sampling areas and months.

Finally, we relate red snapper catch to depth, bottom-water temperature, salinity, dissolved oxygen and commercial shrimp fishing effort.

Methods

Sampling.—From 1985 through 2007, TPWD conducted bottom trawl surveys in the TTS, extending from the beach out to 16.7 km and within 24.1 km on either side of Sabine Pass, Bolivar Pass, Matagorda Pass, and Aransas Pass. A 48.2 km area surrounding Brazos Santiago Pass and extending to the Texas-Mexico border was also sampled. All samples were collected within NOAA Fisheries Service statistical zones 17–21 in water ≤ 40 m in depth (Figure 1).

Random sample locations were stratified by Gulf pass, and 16 samples $month^{-1} \cdot stratum^{-1}$ were collected. Sample tows were conducted at 4.8 km/h for 10 min parallel to the depth curve using otter trawls 5.7-m wide at the headrope and 7-m wide at the footrope, with 38-mm stretched nylon multifilament mesh throughout. Salinity, temperature, and dissolved oxygen were measured 0.3 m above the bottom for each trawl using YSI hand-held multiparameter instruments (Yellow Springs Instruments, Inc., Yellow Springs, Ohio; accuracy 0.1 ºC, 0.1 ppt, 0.1 mg/L, respectively). All fish were measured to the nearest millimeter total length (TL).

Analyses.—Catch-per-unit-effort (CPUE, red snapper catch/h), and size-frequency distributions were determined coastwide, annually, monthly and by Gulf area. We fitted a seasonal autoregressive time series regression model to the monthly mean coastwide trawl data to test the relationship between CPUE, oceanographic variables (bottom-water temperature, salinity, and dissolved oxygen), and depth. Also, the relationship between annual mean CPUE and annual commercial shrimping effort in the TTS, expressed as days fished, by statistical zone (provided by NOAA Fisheries, Galveston, Texas), was determined using nonlinear regression. Significance was determined at $\alpha = 0.05$.

Results

From 1985 through 2007, 7,688 red snapper were collected with a mean TL of 90 mm ± 0.31 SE, and ranging in size from 18–412 mm TL (Figure 2). Seventeen red snapper were >200 mm; these were assumed to be age-1 and were excluded from the analyses. All fish ≤ 200 mm TL were designated as young-of-the-year, although there may be some overlap with age-1 fish (Bradley and Bryan, 1975; Goodyear, 1995).

Of all young-of-the-year red snapper collected along the Texas coast, <1% were from the Sabine Pass and Bolivar Pass areas (Table 1). The largest proportion, 83.6%, came from the southern Texas coast, including the Aransas Pass and Brazos Santiago Pass areas (NOAA Fisheries Service statistical zones 20–21). The middle Texas coast at Matagorda Pass (NOAA Fisheries Service statistical zone 19) accounted for the remaining 16.0% of young-of-the-year.

Annual coastwide CPUE was variable with a generally-increasing trend (Figure 3). Coastwide mean CPUE was 2.1/h. Lowest mean CPUE values occurred from 1986 – 1988 (0.05/h), with peak CPUE in 2006 (8.0/h). Sampling in 1985 began in September, therefore CPUE is higher than would be expected if the entire year were sampled.

Annual CPUE trends were dominated by high CPUE near the Aransas Pass and Brazos Santiago Pass areas (Figure 4). The peak annual CPUE of 22/h occurred near Aransas Pass in 2006 and near Brazos Santiago Pass in 2004. In most years, the CPUE values in all five Gulf areas changed in a similar way. Exceptions included relatively high CPUEs near most middle and southern Gulf pass areas observed in 1989, 1995, and 2004, and low CPUEs near all areas except Aransas Pass in 1991 (9/h) and 2000 (13/h). In 2006, both Matagorda Pass and Aransas Pass areas had relatively high annual CPUEs (14/h and 22/h, respectively), while the Brazos Santiago Pass area CPUE remained relatively low.

July through November accounted for 90% of total catch. Monthly CPUEs were lowest from January through April. They increased from May through August, peaked in September (8.1/h), and decreased through December (Figure 5). The peak monthly CPUE occurred in September in Matagorda Pass and Aransas Pass and in October in Brazos Santiago Pass.

From January – March, numbers of young-of-the-year were too low to show a clear trend in mean total length (n=53) in the Brazos Santiago Pass area (Figure 6). From April through July, mean total length increased from 90 – 132 mm, and beginning in July, as numbers of young-of-the-year increased, a second group of smaller young-of-the-year began to appear in samples. A bimodal distribution continued from July through September, with the larger-sized mode gradually disappearing from samples. Mean total length remained relatively stable from September through December, increasing from 92 – 94 mm through November, and decreasing slightly in December to 88 mm. A similar trend occurred in the Aransas Pass area with low numbers of young-of-the-year present from December through April (n=19). From May through June, mean total length increased from 108 – 115 mm, and also beginning in July the second group of young-of-the-year began to appear in samples. The bimodal distribution continued through July, and from August through October mean total length increased from 82 – 93 mm, decreasing to 87 mm in November. In the Matagorda Pass area, low numbers of young-of-the-year were present from December through June (n=34). Small young-of-the-year began to appear in samples in July, and from July through October mean total length increased from 54 – 86 mm.

Oceanographic data

Mean bottom-water temperature (Figure 7A) ranged from 12.9°C in January near Sabine Pass to 29.8°C in August near Bolivar Pass. Highest temperatures occurred in August at Sabine Pass and Bolivar Pass and in September at Matagorda Pass, Aransas Pass, and Brazos Santiago Pass. Lowest temperatures for all areas occurred in January and February.

Mean bottom-salinity (Figure 7B) ranged from 22.9 ppt in May near Sabine Pass to 35.7 ppt in August near Brazos Santiago Pass. Salinity increased consistently from north to south along the coast, peaking in August for all areas and reaching minimum values in March near Brazos Santiago Pass, April near Aransas Pass, and in May near Sabine Pass, Bolivar Pass and Matagorda Pass.

Mean bottom-dissolved oxygen (Figure 7C) ranged from 5 mg/L in June to 9 mg/L in February near Bolivar Pass. Highest dissolved oxygen values for all areas occurred during the coldest months of January and February. Lowest values occurred in June for all areas except near Brazos Santiago Pass, where lowest dissolved oxygen values occurred in September.

Results of the time series regression indicate red snapper CPUE follows a second-order seasonal autoregressive process. The autoregressive parameters at lags 1 and 2 (months) were both significant, as was the seasonal (12 month) lag, indicating CPUE is dependent upon CPUE from the previous two months and that the same pattern recurs at the same time each year (Table 2). The residuals were uncorrelated, indicating that serial correlation had been adequately accounted for in the model. The data were stationary and no differencing was indicated by the Dickey-Fuller test (Dickey et al., 1984).

Of the three oceanographic regressors tested, only water temperature had a significant effect on CPUE. Water temperature was positively related to CPUE, indicating months with warmer than normal water temperatures tend to have higher red snapper CPUE than months with cooler temperatures. Figure 8 indicates that CPUE increases with water temperature, peaking around 30°C and then rapidly declining. Salinity and dissolved oxygen were not significantly correlated with CPUE.

Coastwide sampling depth ranged from 1.2 to 40 m with mean values increasing from north to south (7.6 – 18.6 m) reflecting the deepening and narrowing of the continental shelf. Catch rates for young-of-the-year red snapper were highest at depths of approximately 10 – 30 m.

Shrimp effort

Shrimp effort varied but generally increased from 1985-1995 (Figure 9). Peak effort in 1997 coincided with very low young-of-the-year red snapper CPUEs. Since 1997, shrimp effort has declined steadily, concurrent with increasing red snapper CPUE. When pooled over the entire time series, red snapper CPUE decreased exponentially with increased shrimp effort ($\text{CPUE} = 41.64 \cdot \text{Shrimp effort}^{-0.36}$; $F = 26.97$, $P<0.0001$, $R^2 = 0.385$) (Figure 10). While low shrimp effort did not always co-occur with high young-of-the-year CPUE, increased shrimp effort was almost always concurrent with low young-of-the-year CPUE.

Discussion

Catch

Differences in young-of-the-year red snapper abundance from the northern to southern Texas coast within the TTS may result from shallower depths along the northern coast compared to the southern coast. The continental shelf extends from the shoreline out to about 200 m depth, varying in width from 177 km off the Sabine River mouth at the northern end of the Texas coast, to 64.4 km off of the Rio Grande mouth at the southern end of the Texas coast (Lynch, 1954). Due to the narrower continental shelf along the southern Texas coast, the outer edge of the TTS is in closer proximity to deeper waters of the outer shelf, where red snapper larvae are more abundant (Lyczkowski-Shultz and Hanisko, 2007). Along the wider, northern Texas outer continental shelf, SEAMAP sampling in October - December 2002 (Rester et al., 2008) collected young-of-the-year red snapper when none were collected by TPWD sampling during the same period in the shallower TTS. Gutherz and Pellegrin (1988) noted that the greatest abundance of juvenile red snapper in resource assessment and commercial bycatch in the Gulf of Mexico from 1972 – 1981 were collected in the inshore 20-40 m depth range, primarily along the southern Texas coast in NOAA Fisheries Service statistical zones 19 - 21.

Peak red snapper catches in the present study were found from August – October (Figure 6). Samples collected by the NOAA Fisheries Service since 1985, during the fall groundfish survey (October – November) and summer SEAMAP surveys (June – July) in the TTS and Exclusive Economic Zone (EEZ), exclude the two high-abundance young-of-the-year red snapper months of August and September (Rester et al., 2007).

Relative young-of-the-year year-class strength was variable over the time period of this study (Figure 3). Strong year-classes were observed in 1989, 1995 and 2002-2004 for the Matagorda, Aransas, and Brazos Santiago Pass areas, and Aransas Pass had strong year classes in 1991, 2000, and 2006. Allman and Fitzhugh (2007) also observed the strong year-classes in 1989 and 1995, based on age progressions in the commercial and recreational landings from 1991 - 2002. Based on larval abundances in the western Gulf of Mexico, strong year-classes were not indicated in 1989 but were suggested in 1995, 2000, and 2003 (Hansiko et al., 2006). This geographic variability in year-class strength, particularly between the upper and lower Texas coast, indicates that recruitment processes influencing year-class strength may affect even relatively small areas of the Gulf of Mexico, but are often evident among multiple life history stages.

Two periods of low CPUEs, beginning in 1986 and 1996, co-occurred with coastwide red tide (toxic dinoflagellate, *Karenia brevis*) events along the Texas coast in September and October 1986 (Buskey et al., 1996), and in mid-September 1996 (Walsh et al., 2006). Current theory suggests that such blooms may originate offshore, where larval red snapper occur, before the bloom is transported into near shore coastal waters (Buskey et al., 1996; Tester and Steidinger, 1997; Villareal et al., 2001; Walsh et al., 2006). *K. brevis* has been shown to be present at greater concentrations in areas <50 m in depth than in deeper, offshore locations (Geesey and Tester, 1993). Although difficult to quantify without concurrent data, red tide could have affected the viability of offshore larvae or juveniles by direct toxicity or consumption of tainted prey, or may have affected adult spawning behavior during that time period (Riley et al., 1989; Prince et al., 2006). These periods of low CPUE lasted for several years after each coastwide red tide event, from 1986 through 1988 and 1996 through 1998 (Figure 3).

Oceanographic Factors

Water temperatures remained lower in the Brazos Santiago Pass area than anywhere along the Texas coast from May through August (Figure 7A). This is due to seasonal up-coast circulation and prevailing southeast winds, occurring from middle May to early August, which generate corresponding upwelling of cooler offshore water (Zavala-Hidalgo et al., 2003; Zavala-Hidalgo et al., 2006). Down-coast circulation resumes in September and upwelling ceases. Water temperatures in the Aransas Pass and Brazos Santiago Pass areas reach their maximum in September, with maximum temperatures at Santiago Pass in October (Figure 7A), all coincident with highest young-of-the-year CPUEs. Along of the remainder of the Texas coast maximum surface water temperatures occur in July and August (Zavala-Hidalgo et al., 2006), with maximum bottom-water temperatures occurring in August.

Our seasonal autoregressive time series regression analysis indicated that bottom temperature was the only significant hydrologic variable tested, with warmer temperatures associated with higher young-of-the-year red snapper catch. This relationship suggests that young-of-the-year red snapper move closer inshore during periods of warmer water temperatures such as those occurring in the Matagorda Pass and Aransas Pass areas in August and September, and in the Brazos Santiago Pass area in September and October.

In the Brazos Santiago Pass area, seasonal up-coast circulation from middle May to early August may transport larvae northward from the outer continental shelf of Mexico to Texas, with young-of-the-year moving inshore from the outer Texas shelf in response to warmer water temperatures in September and October. A similar offshore-onshore movement by juvenile red snapper in response to warmer water temperatures was suggested by Bradley and Bryan (1975) in commercial shrimp data, and Gutherz and Pellegrin (1988) in National Marine Fisheries Service bottom fish and SEAMAP survey data.

Gallaway et al. (1999) defines environmental suitability indices for juvenile red snapper based on NMFS fall groundfish and summer SEAMAP surveys, including salinities of 34 – 35 ppt and dissolved oxygen levels of > 5 mg/L. Salinities along the northern Texas coast (Sabine Pass and Bolivar Pass) are mostly below 30 ppt and could be a factor in the low numbers of young-of-the-year red snapper collected (Figure 7B). Although low dissolved oxygen levels were not recorded in this study, reduced numbers of young-of-the-year red snapper along the northern Texas coast could be affected by areas of hypoxic bottom-water with dissolved oxygen levels of 2 mg/L or less, such as those recorded during the summers of 1993 – 1996 from Louisiana and as far as the west end of Galveston Bay (Gallaway et al., 1999) and Matagorda Bay (DiMarco et al., 2008).

Life history

Based on examination of adult gonads, red snapper are reported to spawn from April through October (Fitzhugh et al., 2004) or November (Bradley and Bryan, 1975) in areas all along the Texas outer continental shelf (Collins et al., 1980; Collins et al., 2001; Lyczkowski-Shultz and Hanisko, 2007). Larvae have been collected on the outer continental shelf beginning in May, reaching highest numbers in July and September, and present through November (Hansiko et al., 2006; Lyczkowski-Shultz and Hanisko, 2007; Lyczkowski-Shultz, NOAA Southeast Fisheries Science Center, National Marine Fisheries Service, Mississippi Laboratories, Pascagoula, Mississippi, personal communication). Rooker et al. (2004) predicted hatch dates along the northern Texas coast from April – August, peaking in May – June.

Young-of-the-year red snapper in the present study were collected off of Matagorda Pass from April through November; off Aransas Pass from April through December, and off Brazos Santiago Pass throughout the year. An overall age – length relationship for young-of-the-year 20 – 80 mm standard length and estimated post-settlement growth rate of approximately 0.8 mm/d from the upper Texas coast (Rooker et al., 2004), suggests that spawning probably begins in February along the northern and middle coast and occurs throughout the year in the Brazos Santiago Pass area.

Long-shore currents vary over the course of the year. From middle August through early May, long-shore currents run from north to south, and are primarily wind driven and enhanced by Mississippi-Atchafalaya River discharge. From middle May to early August, the current reverses and upcoast circulation occurs (Li et al., 1997; Zavala-Hidalgo et al., 2003). Although no data on red snapper spawning in Mexico are currently available, it is likely that red snapper spawn along all Gulf of Mexico outer continental shelf areas, including Mexico. Larvae spawned on the Tamaulipas-Veracruz shelf and carried onto the Texas continental shelf by seasonally variable long-shore currents could contribute to juveniles collected in the Aransas Pass and Brazos Santiago Pass areas from August through October.

Shrimp fishing effort

The commercial shrimp fishery has been shown to be a source of young-of-the-year red snapper mortality through bycatch of small red snapper (Gutherz and Pellegrin, 1988; Gallaway and Cole, 1999; Schirripa, 1999), although shrimp effort has been decreasing since its peak in 1997 due to economic and fishery management factors. Rising operating expenses related to increased fuel prices, decreased market prices, competition from farm-raised imports, and fleet overcapitalization, have resulted in the inability of many in the commercial shrimp fleet to make a profit (Gillig et al., 2001).

However, the shrimp fishery is open from July – November, when 90% of young-of-the-year red snapper were collected (Figure 5). The remainder of the year, from December through mid-July, the shrimp fishery in the TTS is effectively closed over most of the Texas coast to commercial shrimp trawls by seasonal area closures (Texas Parks and Wildlife Department, 2008) and other measures designed to allow shrimp to move from estuaries to the open Gulf and grow to a larger, more profitable size prior to harvest.

Several investigators have reported that shrimp trawl bycatch combined with commercial and recreational hook and line fishing have contributed to declines of red snapper populations in the Gulf of Mexico. Gutherz and Pellegrin (1988) noted that 63% of juvenile red snapper in Gulf of Mexico commercial bycatch from 1972 – 1981 were collected along the Texas coast from September – November in NOAA Fisheries Service statistical zones 19 - 21 . Gazey et al. (2008) observed that western Gulf of Mexico shrimp trawl bycatch is dominated by young-of-the-year red snapper during September – April. Bradley and Bryan (1975) noted that the combination of juvenile shrimp trawl bycatch with commercial (and recreational) hook and line fishing caused declines in commercial red snapper catches. Bycatch reduction devices (BRDs) were required in the TTS shrimp fleet in 2001 to reduce bycatch of non-target animals such as young-of-the-year red snapper (Texas Parks and Wildlife Department, 2002). Although beneficial, many BRD designs have been shown to be less effective than anticipated in reducing red snapper bycatch (Gallaway et al., 1998; Engaas et al., 1999; Gallaway and Cole, 1999).

Conclusions

The long-term increase in young-of-the-year red snapper concurrent with the decrease in commercial shrimp effort implies a linkage through by-catch and implementation of BRDs in the Gulf of Mexico. The TTS continental shelf is not uniform young-of-the-year red snapper habitat, but distinctly different regions are apparent due to bathymetry and oceanography. The southern TTS boundary with Mexico is open and has evidence of possible larval advection northward from Mexico and a unique annual temperature pattern. Depending on settlement times, flux of eggs and larvae from the south may play an important role in recruitment to the southern TTS.

Acknowledgements

This study was funded by the Texas Parks and Wildlife Department. The authors wish to thank all of the Texas Parks and Wildlife Department technicians, biologists, and ecosystem leaders who were responsible for sample acquisition and processing. The authors would also like to express our appreciation to Perry Trial, Tracy Villareal, and the three anonymous reviewers. Their input greatly improved the quality of the manuscript.

References

Allman, R. J. and G. R. Fitzhugh. 2007. Temporal age progressions and relative year-class strength of Gulf of Mexico red snapper. Pages 311-328. Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Bradley, E. and C. E. Bryan. 1975. Life history and fishery of the red snapper (*Lutjanus campechanus*) in the northwestern Gulf of Mexico: 1970-1974. Proceedings of the Gulf and Caribbean Fisheries Institute 27:77-106.

Buskey, E. J., J. Stewart, J. Peterson and C. Collumb. 1996. Current status and historical trends of brown tide and red tide phytoplankton blooms in the Corpus Christi Bay National Estuary Program study area. Texas Natural Resource Conservation Commission, CCBNEP-07. 174 pp., Austin, Texas.

Cody, T. J., R. P. Campbell, P. C. Hammerschmidt, G. C. Matlock, C. E. Bryan, J. E. Clark and L. S. Procarione. 1989. Texas shrimp fishery management plan: Source document. Fishery Management Plan Series No. 2. 261 pp. Texas Parks and Wildlife Department, Austin, Texas.

Collins, L. A., J. H. Finucane and L. E. Barger. 1980. Description of larval and juvenile red snapper, *Lutjanus campechanus*. Fishery Bulletin 77(4):965-974.

Collins, L. A., G. R. Fitzhugh, L. Mourand, L. A. Lombardi, W. T. Walling, Jr., W. A. Fable, Jr., M. R. Burnett and R. J. Allman. 2001. Preliminary results from a continuing study of spawning and fecundity in the red snapper (Lutjanidae: *Lutjanus campechanus*) from the Gulf of Mexico, 1998-1999. Proceedings of the Gulf and Caribbean Fisheries Institute 52:34-47.

Dickey, D. A., D. P. Hasza and W. A. Fuller. 1984. Testing for unit roots in seasonal time series. Journal of the American Statistical Association 79(386):355-367.

DiMarco, S. F., T. Dellapenna, D. Shormann, W. Denton, M. K. Howard, N. May and A. S. Quigg. 2008. Hypoxia formation along coastal Texas due to Brazos River flooding: Summer 2007. 2008 Ocean Sciences Meeting: From the Watershed to the Global Ocean, Orlando, FL (USA), 2-7 Mar 2008.

Drass, D. M., J. Lyczkowski-Shultz and P. J. Bond. 2002. Distribution of red snapper larvae in the northern Gulf of Mexico, 1982-1994. Pages 333 *in* McKay, M., Nides, J. & Vigil, D., editors. Proceedings: Gulf of Mexico fish and fisheries: Bringing together new and recent research, October 2000. OCS Reports. U.S. Minerals Management Service No. 2002-004. 674 pp. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana.

Engaas, A., D. Foster, B. D. Hataway, J. W. Watson and I. Workman. 1999. The behavioral response of juvenile red snapper (*Lutjanus campechanus*) to shrimp trawls that utilize water flow modifications to induce escapement. Marine Technology Society Journal 33(2):43-50.

Fitzhugh, G. R., M. S. Duncan, L. A. Collins, W. T. Walling and D. W. Oliver. 2004. Characterization of red snapper (*Lutjanus campechanus*) reproduction: 2004 Gulf of Mexico SEDAR, SEDAR7-DW-35, National Marine Fisheries Service, Southeastern Fisheries Science Center, Panama City, Florida.

Gallaway, B. J. and J. G. Cole. 1999. Reduction of juvenile red snapper bycatch in the U.S. Gulf of Mexico shrimp trawl fishery. North American Journal of Fisheries Management 19(2):342-355.

Gallaway, B. J., J. G. Cole, R. Meyer and P. Roscigno. 1999. Delineation of essential habitat for juvenile red snapper in the northwestern Gulf of Mexico. Transactions of the American Fisheries Society 128(4):713-726.

Gallaway, B. J., M. Longnecker, J. G. Cole and R. M. Meyer. 1998. Estimates of shrimp trawl bycatch of red snapper (*Lutjanus campechanus*) in the Gulf of Mexico. Pages 817-839 *in* Funk, F., Quinn, T. J., II, Heifetz, J., Ianelli, J. N., Powers, J. E., Schweigert, J. F., Sullivan, P. J. & Zhang, C.-I., editors. Fishery Stock Assessment Models. Alaska Sea Grant College Program Report No. AK-SG-98-01, Fairbanks, AK.

Gazey, W. J., B. J. Gallaway, J. G. Cole and D. A. Fournier. 2008. Age composition, growth and density-dependent mortality in juvenile red snapper estimated from observer data from the Gulf of Mexico penaeid shrimp fishery. North American Journal of Fisheries Management 28(6):1828-1842.

Geesey, M. E. and P. A. Tester. 1993. *Gymnodinium breve* : Ubiquitous in Gulf of Mexico waters. Pages 251-255 *in* Smayda, T. J. & Shimizu, Y., editors. Toxic Phytoplankton Blooms in the Sea. Elsevier Science Publishers B.V., New York.

Gillig, D., W. L. Griffin and T. Ozuna, Jr. 2001. A bioeconomic assessment of Gulf of Mexico red snapper management policies. Transactions of the American Fisheries Society 130(1):117-129.

Goodyear, C. P. 1995. Red snapper in U.S. waters of the Gulf of Mexico. Southeast Fisheries Science Center, Miami Laboratory, Coastal Resources Division, MIA-95/96-05. 118 p., Miami, Florida.

Gulf of Mexico Fishery Management Council. 1981. Fishery Management Plan for the Shrimp Fishery of the Gulf of Mexico, United States Waters (includes Amendments 1 and 2), Gulf of Mexico Fishery Management Council, Tampa, Florida. 250 pp.

Gulf of Mexico Fishery Management Council. 2007. Final Amendment 27 to the Reef Fish Fishery Management Plan and Amendment 14 to the Shrimp Fishery Management Plan (including Supplemental Environmental Impact Statement, Regulatory Impact Review, and Regulatory Flexibility Act Analysis), Tampa, Florida. 438 pp.

Gutherz, E. J. and G. J. Pellegrin. 1988. Estimate of the catch of red snapper, *Lutjanus campechanus*, by shrimp trawlers in the U.S. Gulf of Mexico. Marine Fisheries Review 50(1):17-25.

Hansiko, D. S., J. Lyczkowski-Shultz and G. W. Ingram. 2006. Indices of larval red snapper occurrence and abundance for use in stock assessment. Pages 285-300 *in* Patterson, W. F., III, Jr., J. H. C., Fitzhugh, G. R. & Nieland, D. L., editors. Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60. American Fisheries Society, Bethesda, Maryland.

Holt, S. A. and C. R. Arnold. 1982. Growth of juvenile red snapper *Lutjanus campechanus*, in the northwestern Gulf of Mexico. Fishery Bulletin 80(3):644-648.

Li, Y., W. D. Nowlin, Jr. and R. O. Reid. 1997. Mean hydrographic fields and their interannual variability over the Texas-Louisiana continental shelf in spring, summer, and fall. Journal of Geophysical Research 102(C1):1027-1049.

Lyczkowski-Shultz, J. and D. S. Hanisko. 2007. A time series of observations of red snapper larvae form SEAMAP surveys 1982-2003: Seasonal occurrence, distribution, abundance, and size. Pages 3-23 *in* Patterson, W. F., III, J.H. Cowan Jr., Fitzhugh, G. R. & Nieland, D. L., editors. Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Lynch, S. A. 1954. Geology of the Gulf of Mexico. Pages 67-86 *in* Gulf of Mexico: Its origin, waters, and marine life. Fishery Bulletin 55:604.

Moseley, F. N. 1966. Biology of the red snapper, *Lutjanus aya* Bloch, of the northwestern Gulf of Mexico. Publications of the Institute of Marine Science 11:90-101.

Prince, E. K., L. Lettieri, K. J. McCurdy and J. Kubanek. 2006. Fitness consequences for copepods feeding on a red tide dinoflagellate: deciphering the effects of nutritional value, toxicity, and feeding behavior. Oecologia 147(3):479-488.

Rester, J. K., Nathaniel Sanders Jr. and B. Pellegrin. 2008. SEAMAP environmental and biological atlas of the Gulf of Mexico, 2002. Gulf States Marine Fisheries Commission, No. 156:1-264, Ocean Springs, MS.

Rester, J. K., M. Paine and E. O. Serrano. 2007. Annual report of the Southeast Area Monitoring and Assessment Program (SEAMAP). Gulf States Marine Fisheries Commission, No. 152:1-117, Ocean Springs, MS.

Riley, C. M., S. A. Holt, G. J. Holt, E. J. Buskey and C. R. Arnold. 1989. Mortality of larval red drum (*Sciaenops ocellatus*) associated with a *Ptychodiscus brevis* red tide. Contributions in Marine Science 31:137-146.

Rooker, J. R., A. Landry, Jr., B. W. Geary and J. A. Harper. 2004. Assessment of a shell bank and associated substrates as nursery habitat of postsettlement red snapper. Estuarine Coastal and Shelf Science 59(4):653-661.

Schirripa, M. J. 1999. Management trade-offs between the directed and undirected fisheries of red snapper (*Lutjanus campechanus*) in the U.S. Gulf of Mexico. Proceedings of the International Conference on Integrated Fisheries Monitoring, Sydney, Australia, 1-5 Feb 1999. Food and Agriculture Organization, Rome. pp. 223-230.

Tester, P. A. and K. A. Steidinger. 1997. *Gymnodinium breve* red tide blooms: Initiation, transport, and consequences of surface circulation. Limnology and Oceanography 42(5, pt. 2):1039-1051.

Texas Parks and Wildlife Department. 2002. The Texas shrimp fishery: A report to the Governor and the 77th Legislature of Texas (Executive summary). PWD RP V3400-657 (8/02). Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, Texas. 60 pp.

Texas Parks and Wildlife Department. 2008. 2008-2009 Texas Commercial Fishing Guide, Effective Sept. 1, 2008, Expires Aug. 31, 2009. PWD BK V3400-074 (7/08). Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, Texas 78744. 37 pp.

Villareal, T. A., M. A. Brainard and L. W. McEachron. 2001. *Gymnodinium breve* (Dinophyceae) in the western Gulf of Mexico: Resident versus advected populations as a seed stock for blooms. 9th International Conference on Harmful Algal Blooms, Hobart (Australia), 7-11 Feb 2000, Hallegraeff, G.M., Blackbum, S.I., Bolch, C.J. and Lewis, R.J. (eds). Intergovemmental Oceanographic Commission of UNESCO, Paris (France). Pages 153-156

Walsh, J. J., J. K. Jolliff, B. P. Darrow, J. M. Lenes, S. P. Milroy, A. Remsen, D. A. Dieterle, K. L. Carder, F. R. Chen, G. A. Vargo, R. H. Weisberg, K. A. Fanning, F. E. Muller-Karger, E. Shinn, K. A. Steidinger, C. A. Heil, C. R. Tomas, J. S. Prospero, T. N. Lee, G. J. Kirkpatrick, T. E. Whitledge, D. A. Stockwell, T. A. Villareal, A. E. Jochens and P. S. Bontempi. 2006. Red tides in the Gulf of Mexico: Where, when, and why? Journal of Geophysical Research 111:C11003, doi:11010.11029/12004JC002813.

Zavala-Hidalgo, J., A. Gallegos-García, B. Martínez-López, S. L. Morey and J. J. O'Brien. 2006. Seasonal upwelling on the western and southern shelves of the Gulf of Mexico. Ocean Dynamics 56:333-338, DOI:310.1007/s10236-10006-10072-10233.

Zavala-Hidalgo, J., S. L. Morey and J. J. O'Brien. 2003. Seasonal circulation on the western shelf of the Gulf of Mexico using a high-resolution numerical model. Journal of Geophysical Research 108(C12, 3389):DOI:10.1029/2003JC001879, 002003.

TABLES

Table 1.— Count and proportion of young-of-the-year red snapper collected in the Texas Territorial Sea in the TPWD bottom trawl survey from 1985–2007 partitioned by Gulf area and NOAA Fisheries Service statistical zone.

Gulf area	NFS statistical area	Count	Percentage
Sabine Pass	17	1	0
Bolivar Pass	18	34	0.4
Matagorda Pass	19	1,227	16.0
Aransas Pass	20	3,360	43.8
Brazos Santiago Pass	21	3,049	39.8

Table 2.—Seasonal autoregressive time series regression model of monthly mean coastwide TPWD bottom trawl survey data from 1985–2007, collected in the Texas Territorial Sea, to test the relationship between young-of-the-year red snapper CPUE and hydrologic variables. $R^2 = 0.449$. Asterisk indicates significance at $p<0.05$.

Variable	Parameter	t value	P>t
Intercept	-6.172	-0.94	0.349
Autoregressive lag 1	0.644	10.31	<0.01*
Autoregressive lag 2	0.178	2.8	0.006*
Autoregressive lag 12	0.109	2.09	0.038*
Temperature	0.295	2.58	0.011*
Salinity	0.093	0.74	0.46
Dissolved oxygen	-0.161	-0.4	0.686

FIGURE CAPTIONS

Figure 1. —NOAA Fisheries Service statistical zones 17–21 and TPWD Gulf of Mexico sampling areas (shaded rectangles) which extend from the beach out to 16.7 km and within 24.1 km on either side of passes. At Brazos Santiago Pass, sampling occurred in an area 48.2 km north from the Texas-Mexico border.

Figure 2. —Length-frequency distribution in 10 mm size classes of young-of-the-year red snapper collected from 1985-2007 in the Texas Territorial Sea by the TPWD bottom trawl survey. Red snapper >200 mm TL (n = 17) were excluded.

Figure 3.— Coastwide and by Gulf area annual mean (+ SE) catch/h, of young-of-the-year red snapper collected from the Texas Territorial Sea in the TPWD bottom trawl survey from 1985–2007.

Figure 4. — Annual mean catch/h, of young-of-the-year snapper collected in each Gulf pass area in the Texas Territorial Sea during the TPWD bottom trawl survey from 1985 – 2007. Sabine Pass (n = 1) and Bolivar Pass (n = 34) were excluded. Symbols: Matagorda Pass (triangle), Aransas Pass (circle), and Brazos Santiago Pass (square).

Figure 5.— Coastwide monthly mean (+SE) catch/h of young-or-the-year red snapper collected from the Texas Territorial Sea in the TPWD bottom trawl survey from 1985–2007.

Figure 6.— Monthly mean TL (mm), by 10 mm size class, of young-or-the-year red snapper collected in the Brazos Santiago Pass, Aransas Pass, and Matagorda Pass areas of the Texas Territorial Sea in the TPWD bottom trawl survey from 1985–2007.

Figure 7.— Relationship between month, Gulf area and oceanographic variables (± SE) for young-of-the-year red snapper collected from the Texas Territorial Sea in the TPWD bottom trawl survey from 1985–2007. (A) Mean bottom-water temperature (°C);

(B) Mean bottom-salinity (ppt); (C) Mean bottom-dissolved oxygen (mg/L). Symbols: Sabine Pass (star), Bolivar Pass (diamond), Matagorda Pass (triangle), Aransas Pass (circle), Brazos Santiago Pass (square).

Figure 8.— Relationship between coastwide mean catch/h and bottom-water temperature (°C) for young-of-the-year red snapper collected from the Texas Territorial Sea in the TPWD bottom trawl survey from 1985–2007.

Figure 9.— Coastwide annual mean catch/h (bar) of young-of-the-year red snapper collected from the Texas Territorial Sea in the TPWD bottom trawl survey and shrimp effort as days fished/1,000 (line) from 1985–2007. Shrimp effort data from the Texas Territorial Sea were obtained from the NOAA Fisheries Service for statistical zones 18-21.

Figure 10.— Coastwide mean catch/h of young-of-the-year red snapper collected from the Texas Territorial Sea (TTS) in the TPWD bottom trawl survey versus mean shrimp effort as days fished from 1985–2007, by statistical zone ($CPUE = 41.64 \cdot \text{Shrimp effort}^{-0.36}$; $F = 26.97$, $P<0.0001$, $R^2 = 0.385$). Each point represents an annual value for each statistical zone. Shrimp effort data from the Texas Territorial Sea were obtained from the NOAA Fisheries Service, Galveston, Texas, for statistical zones 18-21 and were not available for 2007.

FIGURES

Figure 1.

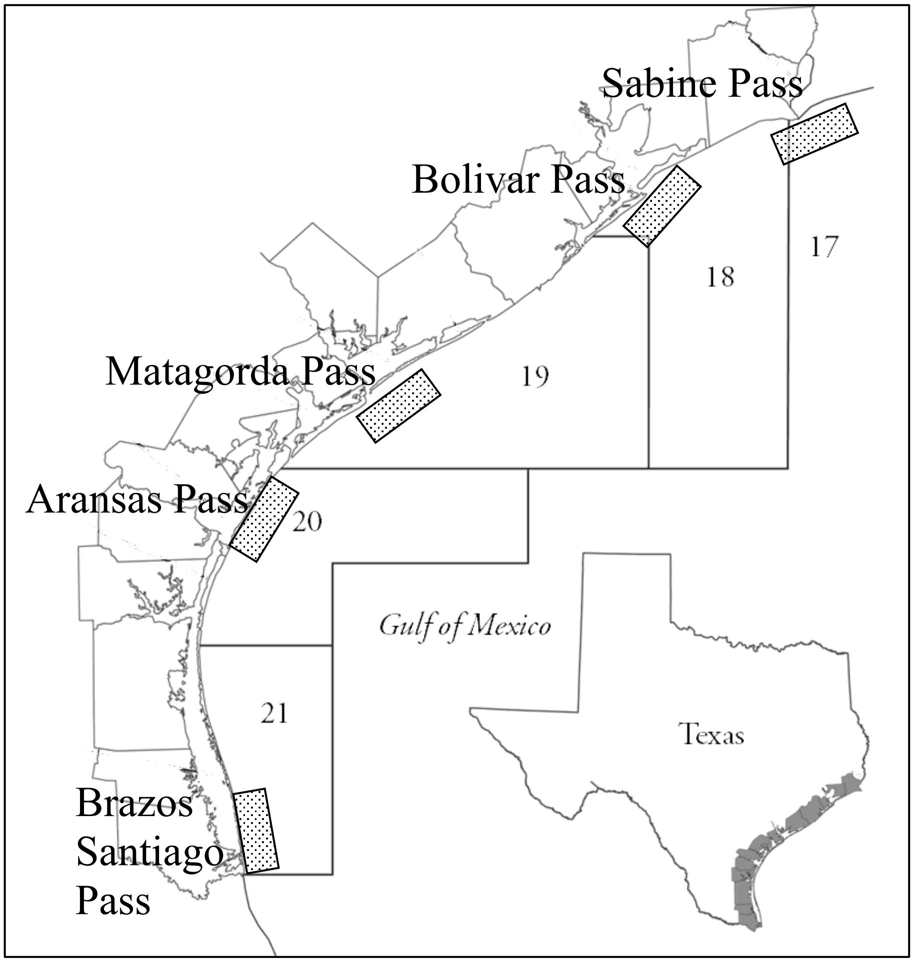


Figure 2.

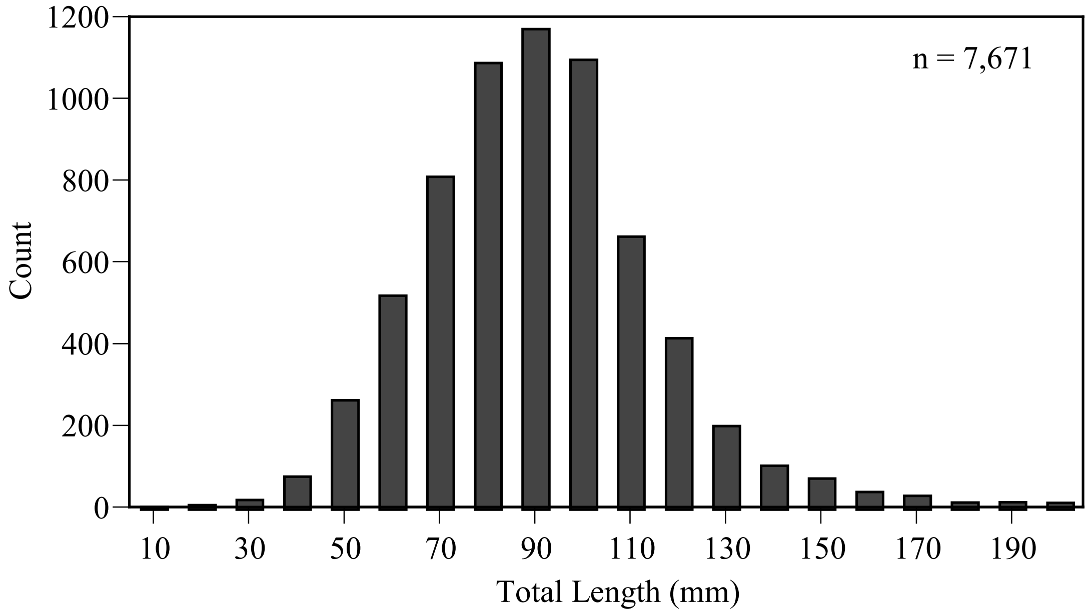


Figure 3.

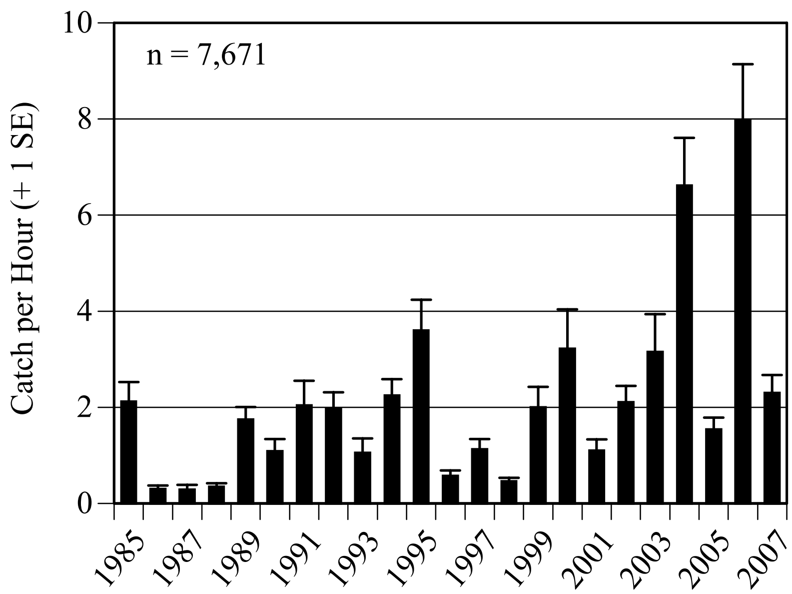


Figure. 4.

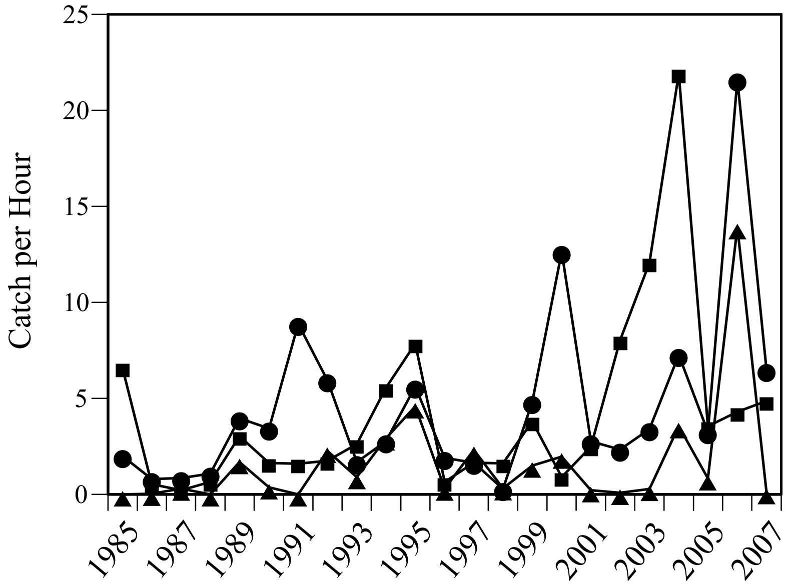


Figure 5.

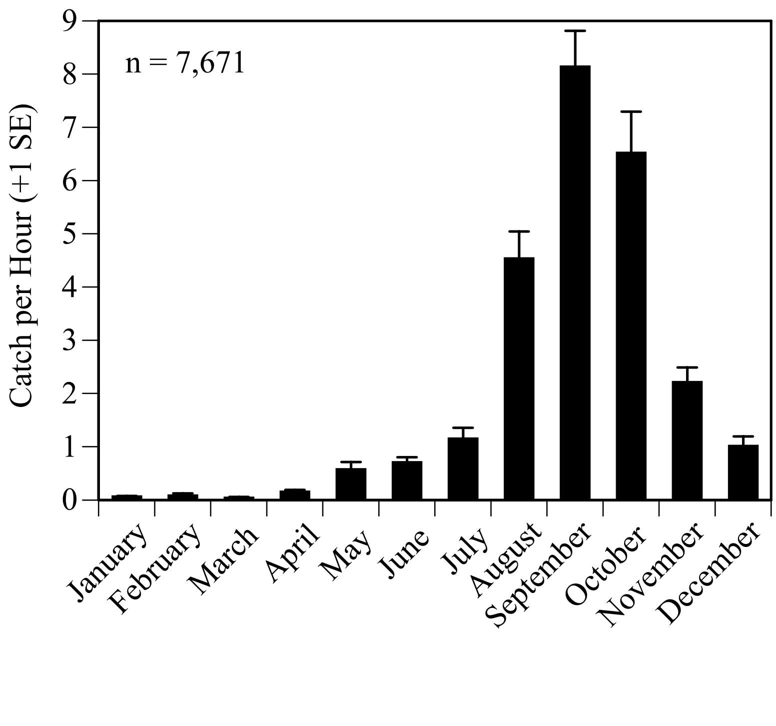


Figure 6.

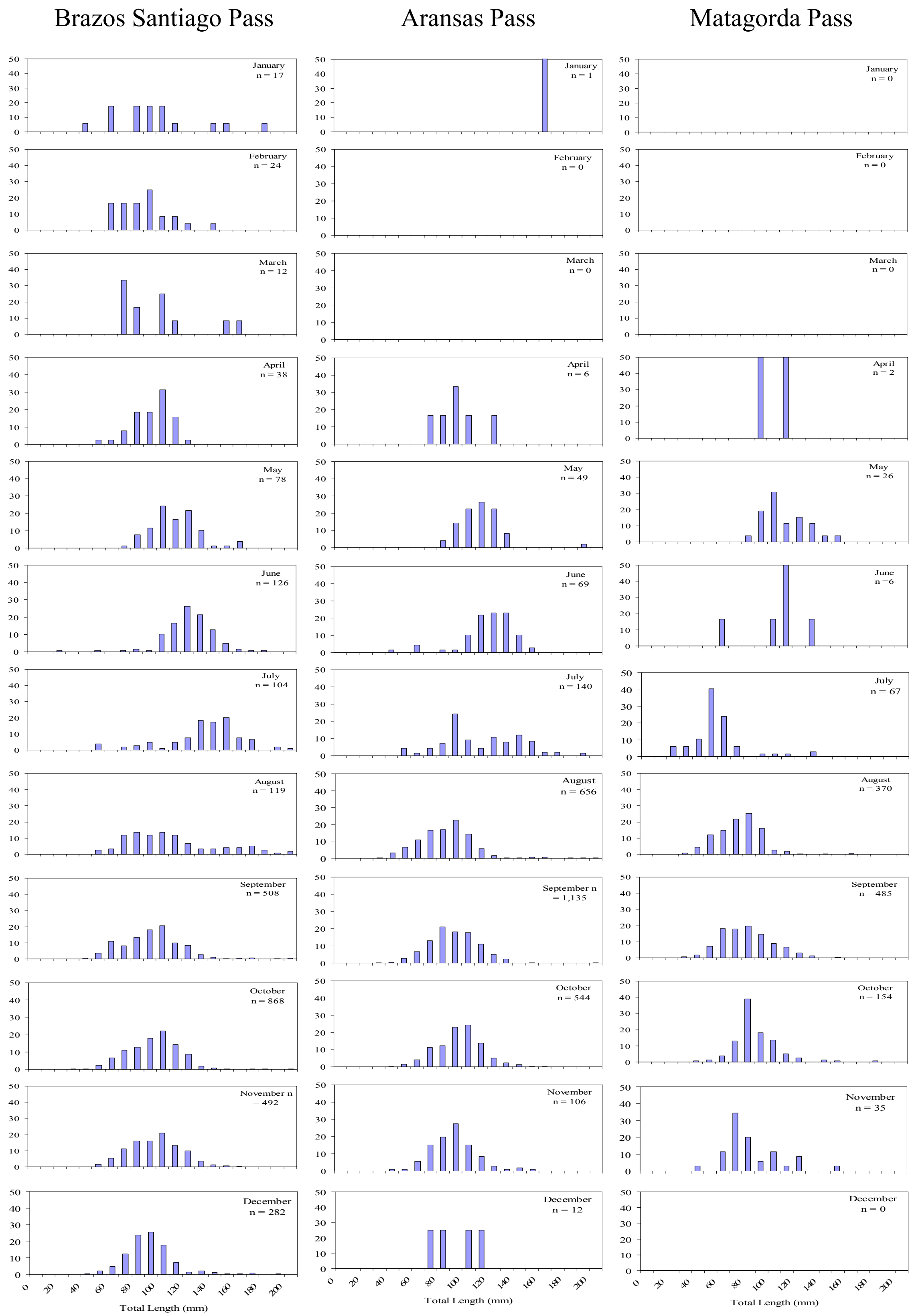
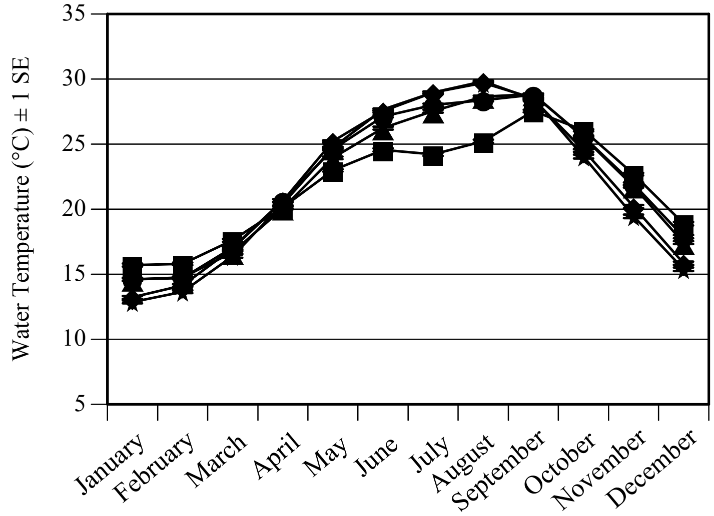
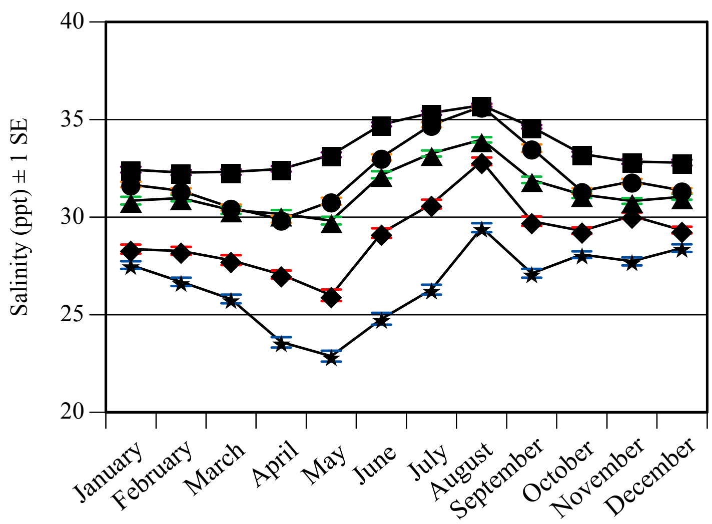

Brazos Santiago Pass
Aransas Pass
Matagorda Pass
January n = 17
February n = 24
March n = 12
April n = 38
May n = 78
June n = 126
July n = 104
August n = 119
September n = 508
October n = 868
November n = 492
December n = 282
January n = 1
February n = 0
March n = 0
April n = 6
May n = 49
June n = 69
July n = 140
August n = 656
September n = 1,135
October n = 544
November n = 106
December n = 12
January n = 0
February n = 0
March n = 0
April n = 2
May n = 26
June n =6
July n = 67
August n = 370
September n = 485
October n = 154
November n = 35
December n = 0
Total Length (mm)
Total Length (mm)
Total Length (mm)

Figure 7.

A.


Water Temperature (°C) ± 1 SE
35
30
25
20
15
10
5
January
February
March
April
May
June
July
August
September
October
November
December

B.


Salinity (ppt) ± 1 SE
40
35
30
25
20
January
February
March
April
May
June
July
August
September
October
November
December

C.

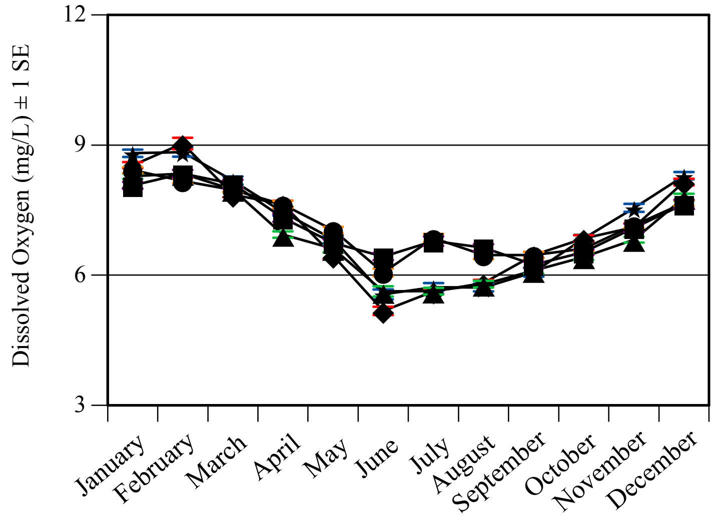

12
9
6
3
Dissolved Oxygen (mg/L) ± 1 SE
January
February
March
April
May
June
July
August
September
October
November
December

Figure 8.

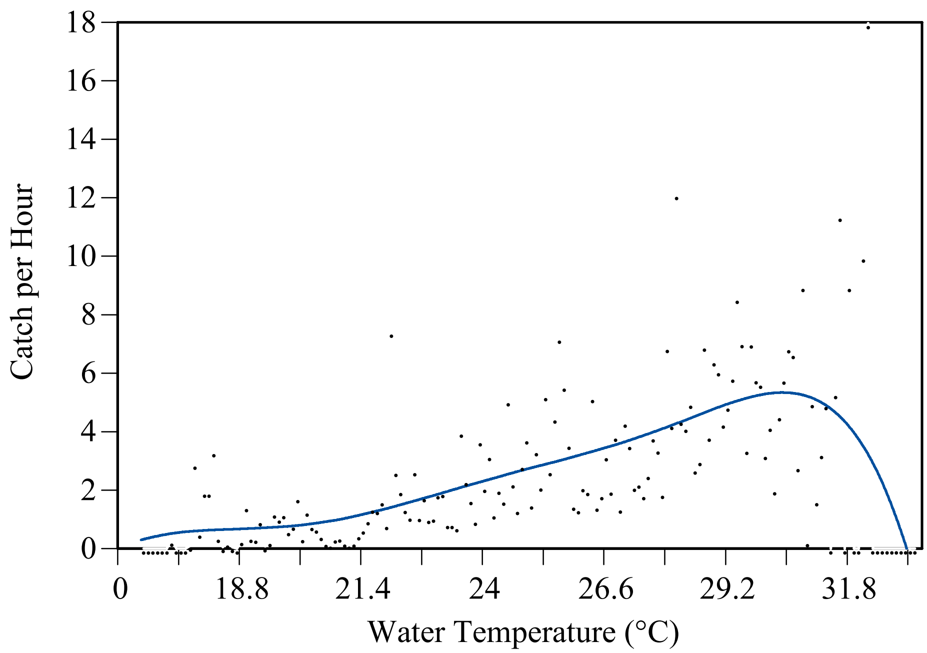

18
16
14
12
10
8
6
4
2
0
Catch per Hour
0
18.8
21.4
24
26.6
29.2
31.8
Water Temperature (°C)

Figure 9.

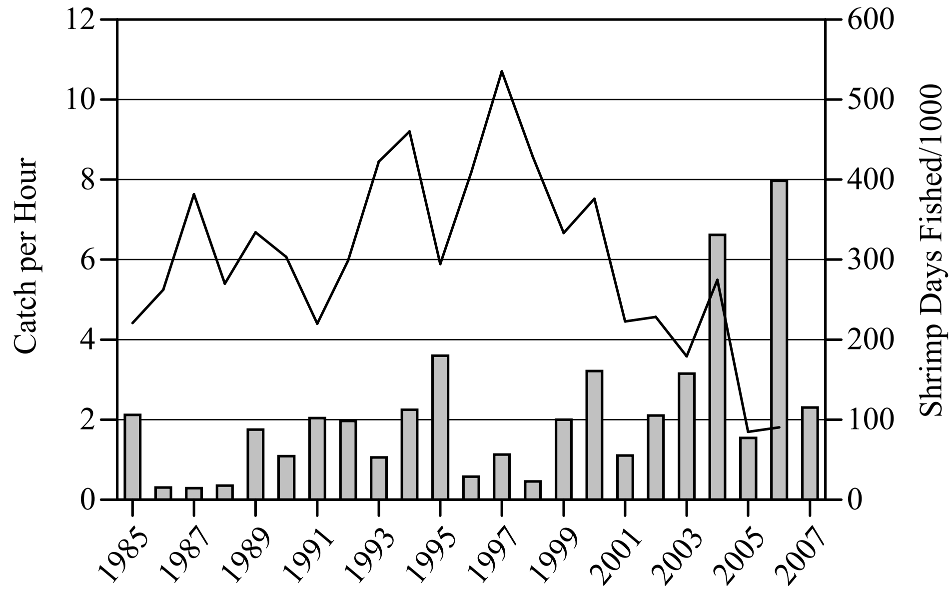


Figure 10.