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Long-Term Trawl Monitoring of White Shrimp, *Litopenaeus setiferus* (Linnaeus), Stocks within the ACE Basin National Estuarine Research Reserve, South Carolina

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ABSTRACT

DELANCEY, L.; WENNER, E., and JENKINS, J., 2008. Long-term trawl monitoring of white shrimp, *Litopenaeus setiferus* (Linnaeus), stocks within the ACE Basin National Estuarine Research Reserve, South Carolina. *Journal of Coastal Research,* SI(55), 193–199. West Palm Beach (Florida), ISSN 0749-0208.

Long-term trawl samples for white shrimp, *Litopenaeus setiferus,* collected within the Ashepoo, Combahee, Edisto Basin National Estuarine Research Reserve and adjacent waters were analyzed for trends in relative abundance and life history patterns. Milder winters are thought to have contributed to high population levels of white shrimp here, as seen along the rest of the southeastern coast of the United States. In addition to winter water temperature, regression analysis indicated a significant increase in salinity over time in the reserve and a significant relationship between percent saturation of dissolved oxygen and shrimp abundance in the summer. Relatively larger shrimp were collected in the spring and at open water locations in St. Helena Sound, reflective of normal growth and migration. Such baseline data should prove valuable for assessing future sustainability of shrimp stocks, especially if recent climatic trends of drought occur in the future.

ADDITIONAL INDEX WORDS: *Size frequency, abundance, penaeid, resource management, climatic conditions, estuary, water quality.*

INTRODUCTION

The most valuable commercial fishery in the southeastern United States is the harvest of penaeid shrimp. In South Carolina, this fishery is dominated by the white shrimp, *Litopenaeus setiferus* (Linnaeus), with combined commercial and recreational landings usually exceeding 1.8 million kg/y. These shrimp are most abundant in areas with extensive estuarine marshes, such as those along the South Carolina coast (WILLIAMS, 1955). After adult spawning in the spring, white shrimp are recruited as postlarvae to the estuaries and sounds of South Carolina in late spring and early summer, growing rapidly to juvenile and subadult stages in estuarine nursery areas (BEARDEN, 1961; MCKENZIE, 1981). Postlarvae seek habitats in shallow tidal creeks with muddy/sand substrate and plentiful organic debris. Juveniles prefer oligohaline and mesohaline areas but may be found along the entire estuarine salinity gradient (WENNER and BEATTY, 1993). Shrimp remain in these nursery habitats until late summer, when they begin to move into larger creeks and rivers in preparation for offshore migration (LINDNER and ANDERSON, 1956; WEYMOUTH, LINDNER, and ANDERSON, 1933). During this migration, they move progressively down the estuary into more saline waters. In mild winters, white shrimp can overwinter in deep, high-salinity areas, but their survival is dependent on temperature minima being >6 °C (FARMER, WHITAKER, and CHIPLEY, 1978).

Besides winter water temperature, the annual abundance of shrimp is also closely related to physical factors such as the amount of rainfall and meteorological events that influence recruitment to nursery areas (LAM *et al.,* 1989). Drastic changes in environmental conditions can negatively impact white shrimp recruitment and survival. In the past, a serious threat to populations of estuarine organisms has been the loss of nursery areas due to filling, dredging, and draining of critical marsh habitat (LINDALL and SALOMAN, 1977). More recently, escalating land use changes in upland areas adjacent to marshes have altered levels of freshwater runoff and created greater salinity variations that affect habitat suitability for white shrimp (HOLLAND *et al.,* 1997). Sampling within the Ashepoo-Combahee-Edisto (ACE) Basin National Estuarine Research Reserve (NERR) provides an opportunity to assess the shrimp resource within an area that has not been severely impacted by urban land use changes and major anthropogenic influences.

The shrimp fishery has been important historically in the ACE Basin region. The white shrimp resource in South Carolina waters is routinely monitored and its harvest regulated by the South Carolina Department of Natural Resources (SCDNR). Such established long-term surveys provide a baseline of information that has the potential to enhance our

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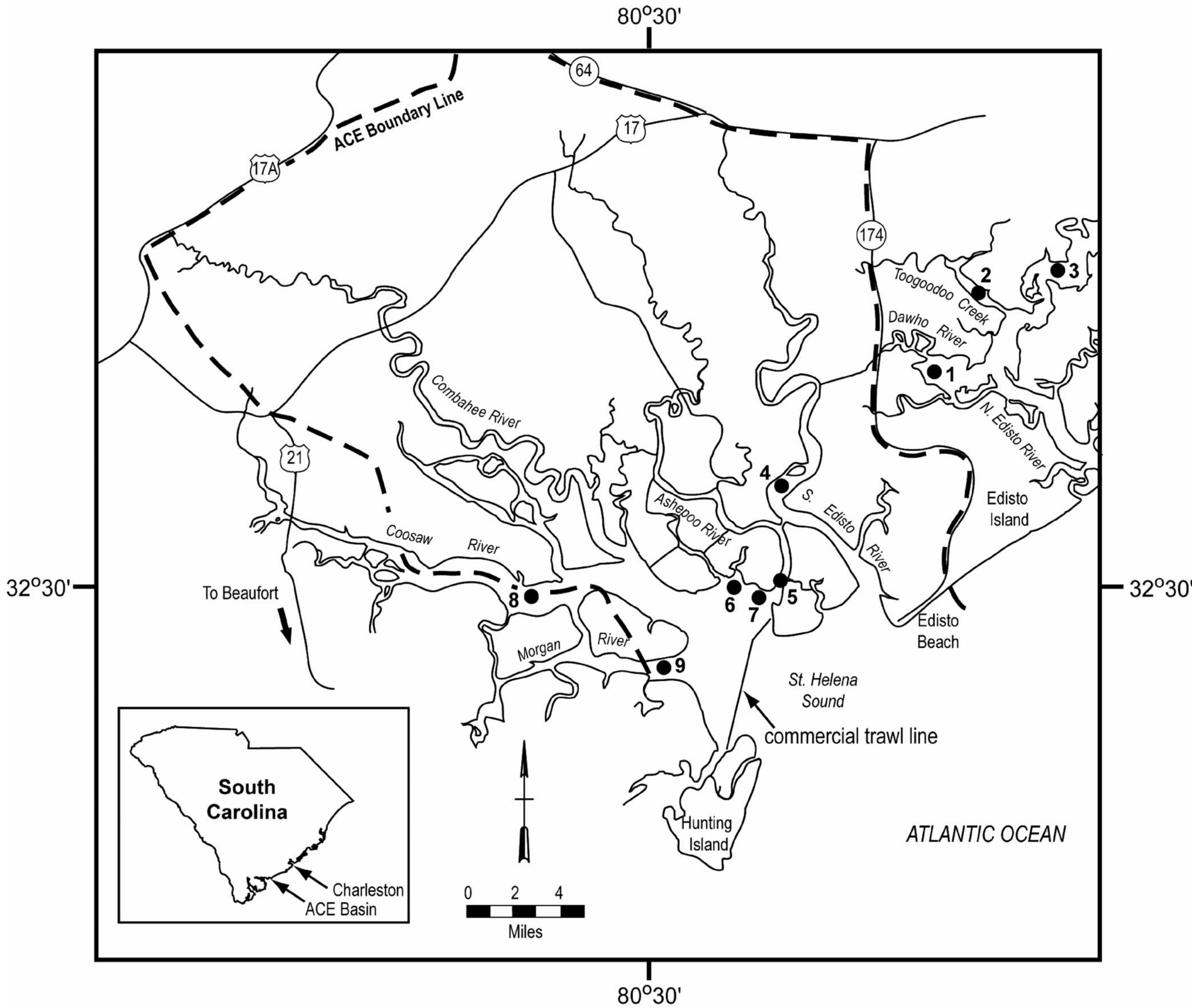

Figure 1. Map of the study area in the vicinity of the ACE (Ashepoo, Combahee, and Edisto Rivers) Basin National Estuarine Research Reserve. Research trawl stations are numbered. The legal commercial trawling area is seaward of the indicated line.

knowledge of factors that influence production within estuarine systems. Previous studies have emphasized aspects of the shrimp trawling fishery, including composition of bycatch, sea turtle excluder device testing, timing of shrimp migration, and maturation of shrimp before trawl season openings (DeLancey *et al.*, 2005; Lunz, 1955; Wenner, S.C. Wildlife and Marine Resources Department unpublished report, 1987; Whitaker, DeLancey, and Jenkins, 1989). This article presents information on the temporal and spatial abundance of white shrimp collected from a long-term trawl survey within the vicinity of the ACE Basin NERR. Although trawls have been shown to be relatively inefficient sampling devices for estimating abundance (Watson, Workman, and Hataway, 1992; Wennhage, Gibson, and Robb, 1997), their usage historically was to approximate and predict commercial trawl catch in the commercial shrimp fishery and represents a long-term, repeated sampling effort. Such data are not currently available from more efficient gear and statistically robust sampling schemes that have been used to estimate shrimp population density, such as those employed in South Carolina (Wenner And Wenner, 1993) and in the Gulf of Mexico (*e.g.,* Howe, Wallace, and Rikard, 1998; Rozas, 1992) in short-term studies.

METHODS

Sampling stations were located within the North and South Edisto River systems and St. Helena Sound of South Carolina (Figure 1). The current sampling scheme has been used by the SCDNR since 1979. Sampling cruises were conducted in

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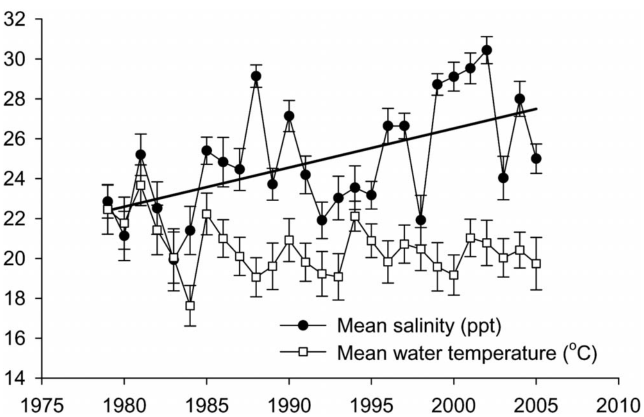

Figure 2. Annual mean and standard error for bottom water temperature and salinity collected during research trawl sampling in the ACE Basin, 1979–2005.

March, April, August–September, and November–December. Otter trawls (6.2-m headrope × 2.5-cm stretch mesh) were towed for 15 minutes, with penaeid shrimp sorted, counted, weighed, and a random subsample of 50 individuals measured to total length in millimeters. Bottom water temperature and salinity measurements were taken after each tow by stem thermometer, hand refractometer, or a portable YSI Model 85 meter (±0.1 °C, ±1 ppt, respectively). Additional hydrographic variables that were used to supplement data taken during trawl collections included daily water temperature from Fort Johnson on Charleston Harbor, South Carolina (DeLancey *et al.,* 2005) and salinity and dissolved oxygen from a continuous water quality monitoring station in the ACE Basin NERR (Sanger *et al.,* 2002; Wenner *et al.,* 2004).

Mean catch per tow (CPUE) of white shrimp was calculated for each year, season, and station. Season was defined for spring as collections in March–April, summer as August–September, and fall as November–December. CPUE was transformed [$\log_{10}(x + 1)$] to satisfy assumptions of normality and homogeneous variances (Sokal and Rohlf, 1981; SPSS, 2004) for testing factors with analysis of variance (ANOVA). Factors were tested individually because sample sizes were unequal and the design was unbalanced, which precluded use of multiple factor designs. The nonparametric Kruskal-Wallis (KW) test was used when transformation failed to meet assumptions. Differences between the mean total length of shrimp by year, season, and station were compared with the nonparametric KW test. Statistical results were considered significant at the $p \leq 0.05$ level. Regression analyses were performed to explore relationships between physical factors, CPUE, and shrimp size, and to examine trends in variables with time.

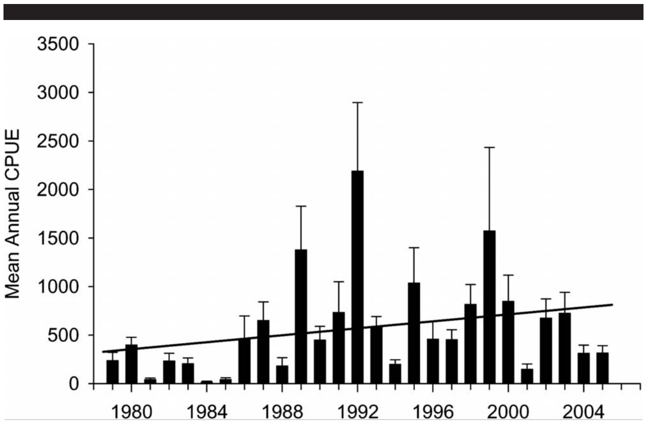

Figure 3. Annual mean catch per trawl tow (CPUE) and standard error for white shrimp, *Litopenaeus setiferus,* collected in the vicinity of the ACE Basin, 1979–2005. The regression line indicates an increasing, although statistically insignificant trend ($p = 0.05$).

RESULTS

The mean annual water temperature in the ACE Basin NERR fluctuated without an apparent trend over time ($r^2 = 0.11$; $F = 3.05$, $p = 0.09$). The time series reflected a 4-year decline from 1981 to 1984, which represented the lowest temperatures in the dataset (Figure 2). Mean annual salinity demonstrated a significant increasing trend ($r^2 = 0.30$; $F = 10.5$, $p = 0.003$) with time, with 4 consecutive years above 28 ppt, beginning in 1999 (Figure 2). Data collected from water quality monitoring stations in the ACE Basin NERR also indicated an increase in average salinity for the period 1998–2003.

The annual CPUE of white shrimp during the time period 1979–2005 varied by as much as two orders of magnitude (Figure 3), generally increasing after 1985. Statistically significant differences in CPUE were detected between years (DF = 26/897, $F = 12.4$, $p = 0.00$, ANOVA) (Figure 3), time of year ($\chi^2 = 238.2$, $p = 0.00$, KW), and stations (DF = 8/897, $F = 8.1$, $p = 0.00$, ANOVA), respectively (Table 1).

White shrimp were most abundant in 1992 and 1999, respectively, with relatively greater numbers overall being taken in fall than in spring. Shrimp were most abundant in proximity to river mouths (station 9) or the confluence of several rivers (stations 1 and 8) (Figure 1).

Regression analyses revealed a significant relationship between January water temperature collected in Charleston Harbor and subsequent shrimp CPUE in March in the ACE Basin ($p = 0.00$) (Figure 4). The regression of the CPUE of white shrimp taken in August *vs.* the percent saturation of dissolved oxygen measured during July–August at a NERR water quality monitoring station situated in a tidal creek on the South Edisto River for 1995–2005 was also significant ($p = 0.02$) (Figure 5). Other nonsignificant regressions that were examined included annual CPUE over time, annual CPUE *vs.* salinity and water temperature measurements taken during trawl sampling, and CPUE in fall *vs.* summer dissolved oxygen measured at NERR monitoring stations.

Mean total length of white shrimp was statistically different for time of year, by year, and by station ($\chi^2 = 1188.8$, 3811.4, and 2880.3, respectively, $p = 0.00$, KW). An increase in the size of shrimp occurred in spring, whereas relatively smaller shrimp were collected in autumn (Figure 6). Gener-

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Table 1. *Mean catch per tow ($\log_{10} x + 1$), standard error of mean, number of tows (*n*), mean total length (mm), standard error of mean, and number measured (*n*) for white shrimp,* Litopenaeus setiferus*, by station, collected in the vicinity of the ACE Basin, 1979–2005.*

Station Location	Station Code	Catch per Tow	Standard Error	*n*	Mean Length	Standard Error	*n*
Dawho River	1	2.31	0.099	101	108.03	0.277	3928
Toogoodoo River	2	1.72	0.115	92	111.19	0.339	2747
Martins Point	3	2.01	0.108	89	115.01	0.334	3240
South Edisto River	4	1.78	0.100	106	107.08	0.292	3592
Ashepoo River	5	1.88	0.087	110	112.18	0.260	4014
Rock Creek	6	1.66	0.095	108	122.20	0.290	3419
Combahee Slough	7	1.73	0.106	72	127.18	0.360	2229
Coosaw River	8	2.15	0.097	115	113.23	0.275	4512
Morgan River	9	2.14	0.096	104	115.65	0.267	4275

ally, white shrimp were larger in years of low relative abundance, with a significant inverse relationship noted between the mean annual CPUE of shrimp and the mean annual total length ($r^2 = 0.30$; $F = 10.62$, $p = 0.003$) (Figure 7). The mean size of shrimp was smaller in riverine stations than in open sound stations ($\chi^2 = 2880.3$, DF = 8, $p = 0.00$, KW) (Figure 1, Table 1).

DISCUSSION

The positive effect of mild winters and conversely the negative effects of harsh winters on white shrimp stocks have been well documented (DeLancey *et al.,* 2005; Lam, Whitaker, and Lee, 1989; Williams, 1970); therefore it is not surprising that the data collected in this study reflect previous observations made on white shrimp. Since the mid-1980s, the majority of the winters in the southeastern United States have been mild, and in general, global temperatures have been warming (NOAA, 2006). Through the period 1987–2000, white shrimp commercial landings along the U.S. southeastern Atlantic coast exceeded 4.5 million kg/y, with a decline after the relatively cold winter of 2001 (NOAA Fisheries, 2006). Water temperatures falling below 8 °C in winter have been shown to be lethal to white shrimp (Joyce, 1965; McKenzie, 1981).

The increasing trend in salinity seen in this study reflects long-term changes in rainfall amount and subsequent river discharge, especially during the period 1999–2002, when a multiyear drought occurred in South Carolina and Georgia (Kiuchi, 2002; Verity, Alber, and Bricker, 2006). A potential increase in freshwater usage in upstream river areas by future development may continue this trend. Although no significant relationship was noted between salinity and the catch of white shrimp in this study, previous authors have stated that populations of the species seem to be positively affected by relatively higher amounts of freshwater inflow (Gunter and Hildebrand, 1954; Lam, Whitaker, and Lee, 1989). If the trend toward drier, more saline conditions persist, it may well impact the productivity of white shrimp stocks in the future and will warrant continued monitoring. Although not demonstrated for shrimp, increased salinity conditions are thought to have led to the proliferation of a marine parasitic dinoflagellate lethal to the blue crab, *Callinectes sapidus,* and a protistan (*Perkinsus marinus*) infecting oysters on the U.S. east coast (Ford and Tripp, 1996; Lee, 2000; Messick and Shields, 2000).

The apparent relationship between the percent saturation of dissolved oxygen and summer catches of white shrimp seen in this study raises further questions. A recent study has doc-

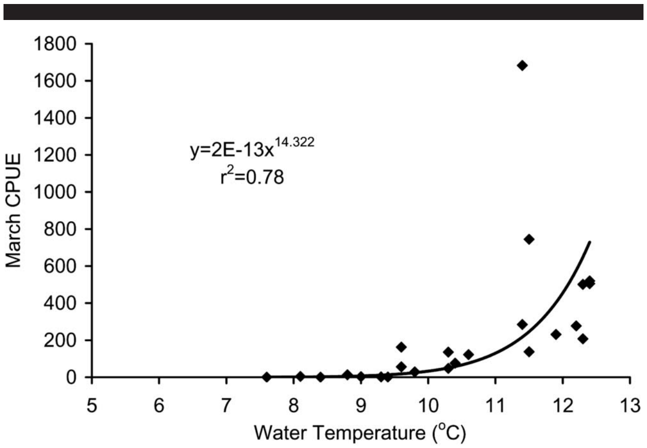

Figure 4. Regression of mean water temperature measured during January in Charleston Harbor, South Carolina, *vs.* mean catch per tow of white shrimp, *Litopenaeus setiferus,* taken in March in the vicinity of the ACE Basin NERR, 1979–2005.

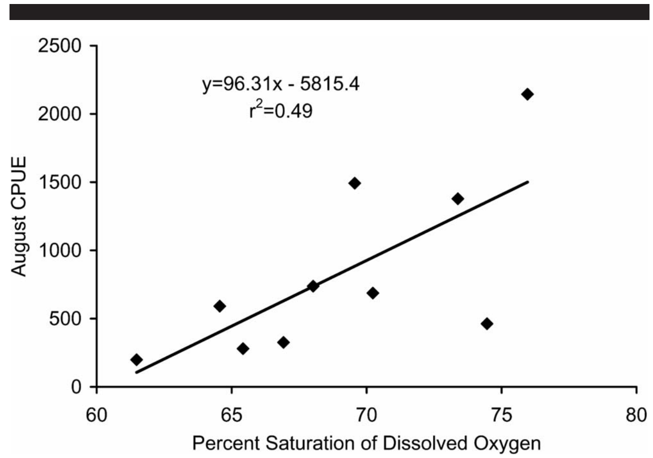

Figure 5. Regression of mean percent dissolved oxygen measured during July and August at St. Pierre Creek, South Carolina, *vs.* mean catch per tow of white shrimp, *Litopenaeus setiferus,* taken during August in the vicinity of the ACE Basin NERR, 1995–2005.

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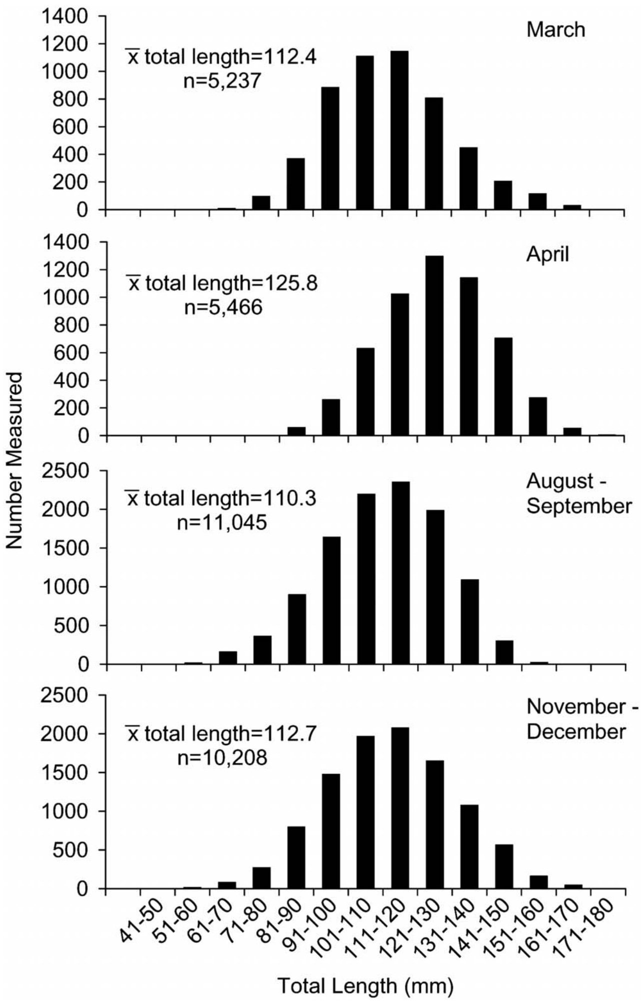

Figure 6. Total length frequency of white shrimp, *Litopenaeus setiferus,* collected in the vicinity of the ACE Basin, 1979–2005, by month.

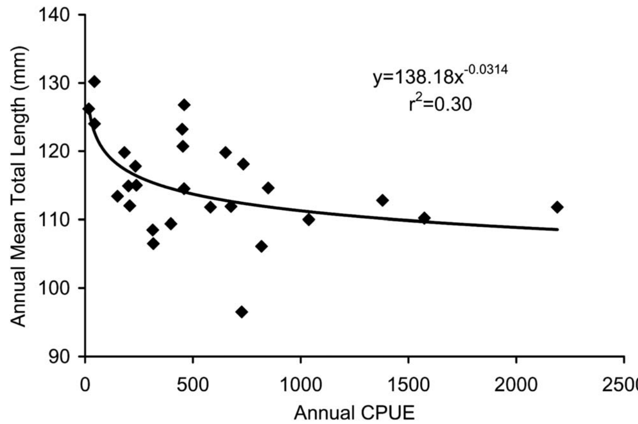

Figure 7. Regression of annual mean catch per tow *vs.* annual mean total length of white shrimp, *Litopenaeus setiferus,* taken in the vicinity of the ACE Basin NERR, 1979–2005.

umented an apparent decline in dissolved oxygen in coastal estuaries in Georgia (VERITY, ALBER, and BRICKER, 2006). What effects such a decline may have on shrimp stocks in these areas are unknown and may be difficult to demonstrate because of the natural variability of the populations (ALLEN *et al.,* 1997). At the least, further declines in water quality (dissolved oxygen) in estuarine nurseries may cause premature displacement of growing shrimp into deeper areas or avoidance of shallow creek areas critical to their survival (RENAUD, 1986; WENNER and BEATTY, 1993).

Shrimp collected in spring represent potential spawners that have survived the winter (LINDER and ANDERSON, 1956; WEYMOUTH, LINDNER, and ANDERSON, 1933). These individuals undergo rapid growth in the spring and represent the largest individuals collected during the year. Their progeny are the shrimp taken in late summer and fall. Differences in the average size of white shrimp observed at stations in this study reflect distribution related to basic life history. Smaller shrimp were collected in rivers, often adjacent to tidal creeks (Table 1), which have been shown to be important nursery areas (WENNER and BEATTY, 1993; WILLIAMS, 1955). As shrimp grow, they gradually move into sound locations (Stations 6 and 7 in Figure 1) (LINDNER and COOK, 1970; WHITAKER, DELANCEY, and JENKINS, 1989).

Observations from this study suggest that the annual size of penaeid shrimp may be negatively affected by increased relative abundance. This has been noted by various authors (CAILLOUET *et al.,* 1976; NANCE, KLIMA, and CZAPLA, 1989; PÉREZ-CASTEÑEDA and DEFEO, 2005), presumably reflective of increased competition for resources such as food and space.

The ACE Basin NERR can be considered a microcosm for trends and issues representative of estuaries in the southeastern United States. There has been a decline in commercial shrimping effort in the region due to low market prices and high fuel costs (SCDNR, 2007); an increase in recreational shrimping in St. Helena Sound (BYRD, 2006; LOW, 1992); the appearance of "black gill" disease in shrimp, thought to be enhanced by stress from high summer temperatures and excessive rainfall (DELANCEY *et al.,* 2003; GEER, 2003); and the establishment of an exotic species of the red alga, *Gracilaria,* that has fouled commercial shrimp trawls (FRESHWATER *et al.,* 2006; J. NORRIS, U.S. National Museum, personal communication). Continued baseline monitoring in conjunction with short-term intensive studies will be necessary to document these and other potential changes to shrimp populations in the ACE Basin NERR. Future efforts will include modeling of shrimp populations utilizing more detailed water quality data being collected by the NERRS program. As new modeling approaches become available, regional stock assessments should be feasible for shrimp stocks in the southeastern United States (HAAS *et al.,* 2001).

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Maddox, among many others, who assisted with field sampling. K. Swanson assisted with figure and manuscript preparation. A. Dukes supplied salinity and dissolved oxygen data. This manuscript is dedicated to the memory of Nan Jenkins.

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