2011

Seasonal Distribution and Abundance of Blue Crabs (*Callinectes sapidus*) in the Tampa Bay Estuary

Kerry E. Flaherty

Florida Fish and Wildlife Conservation Commission

Cameron B. Guenther

Florida Fish and Wildlife Conservation Commission

DOI: 10.18785/goms.2902.02

Follow this and additional works at: <https://aquila.usm.edu/goms>

Recommended Citation

Flaherty, K. E. and C. B. Guenther. 2011. Seasonal Distribution and Abundance of Blue Crabs (*Callinectes sapidus*) in the Tampa Bay Estuary. *Gulf of Mexico Science* 29 (2).

Retrieved from <https://aquila.usm.edu/goms/vol29/iss2/2>

This Article is brought to you for free and open access by The Aquila Digital Community. It has been accepted for inclusion in *Gulf of Mexico Science* by an authorized editor of The Aquila Digital Community. For more information, please contact Joshua.Cromwell@usm.edu.

Seasonal Distribution and Abundance of Blue Crabs (*Callinectes sapidus*) in the Tampa Bay Estuary

KERRY E. FLAHERTY¹ AND CAMERON B. GUENTHER²

Blue crabs (*Callinectes sapidus* (Rathbun)) are commercially important and are an integral part of the estuarine ecosystem as both predators and prey. Although adult blue crabs have been the focus of many studies, there is little published information on immature blue crab abundances, especially on the west Florida coast. The objectives of this study were to analyze the distributions and abundances of immature and adult blue crabs in the Tampa Bay estuary, specifically as they relate to 1) monthly and yearly trends in abundance and size, 2) timing of recruitment to the estuary, 3) sex- and size-determined distribution patterns, and 4) the influence of environmental factors, such as freshwater input. Catch rates, length frequencies, and indices of abundance were calculated for recruiting [≤ 20 -mm carapace widths (CW)], juvenile (21–80-mm CW), and adult (> 80 -mm CW) blue crabs caught during 1996 and 1997. Abundances of all size classes of blue crabs differed by region and month; juvenile and adult abundances were also significantly related to salinity. Immature crabs were collected in all months, confirming an extended spawning season, but there were elevated catches of recruiting blue crabs in February and September. Adults were caught year-round, with males generally being more abundant than females. Geographical regions close to the mouth of the bay had the highest densities of recruits, perhaps because of the supply of larvae being delivered to that area from offshore. With the use of monthly seine and river trawl data from an extended time period (1996–2004), annual variations in the abundance of immature and adult blue crabs were examined. A decline in the abundance of immature crabs collected in 21.3-m seines began after 1998, with a significant low occurring in 2002. A similar pattern was observed for adults collected in river trawls and by commercial fisheries. Unfavorable salinity regimes during this time period may have contributed to these abundance trends.

INTRODUCTION

Blue crabs (*Callinectes sapidus*) are an integral part of the estuarine ecosystem as both predators and prey. Recreationally important sport fish species such as black drum (*Pogonias cromis*; Silverman, 1979), red drum (*Sciaenops ocellatus*; Scharf and Schlicht, 2000), spotted seatrout (*Cynoscion nebulosus*; Tabb, 1961), common snook (*Centropomus undecimalis*; Blewett et al., 2006), and cobia (*Rachycentron canadum*; Meyer and Franks, 1996) have been known to feed on blue crabs. In turn, blue crabs prey upon mollusks, crustaceans, organic debris, and fishes (Tagatz, 1968a) and may also serve a valuable role in controlling populations of other estuarine species (Virstein, 1977). For example, Silliman and Bertness (2002) proposed that without the predatory control exerted by blue crabs, overgrazing by marsh periwinkles (*Littoraria irrorata*) on salt marsh cordgrass (*Spartina alterniflora*) could contribute to salt marsh die-offs.

Blue crabs are found from the Gulf of Maine to northern Argentina (Williams, 1974); throughout their range, maturation rates, spawning seasons, and the timing of recruitment to estuarine

systems vary. In the northern part of their U.S. range, blue crabs take up to 2 yr to mature (Van Engel, 1958), but in Florida, they may reach maturity by 12 mo (Tagatz, 1968b). Spawning generally begins in March through May and ends in August through October, depending on region, but in west-central Florida waters some spawning occurs in the winter (Steele and Bert, 1994). The larvae develop offshore in the plankton before recruiting to the estuaries as megalopae. Juveniles recruit in late summer in Chesapeake Bay (Orth and van Montfrans, 1987), from March through November in Charleston, South Carolina (Archambault et al., 1990), and are found year-round in Galveston Bay, Texas (Thomas et al., 1990) and Mississippi Sound (Stuck and Perry, 1981). Juveniles are also thought to inhabit west-central Florida estuaries throughout the year based on year-round spawning activity of adults (Steele and Bert, 1994), but few studies in this region have described the distribution of immature blue crabs.

Throughout their life history and ontogeny, blue crabs use differing habitats including riverine, estuarine, and near-shore environ-

ments. Adult males inhabit coastal river and estuarine systems with brackish waters (Tagatz, 1968a), and females seek out these same areas prior to their last molt, at which time mating occurs. After mating, females migrate to the lower reaches of the estuary or open waters to spawn (Cargo, 1958; Tagatz, 1968a; Oesterling and Adams, 1979; Steele and Bert, 1994), because early life stages require high salinity (Guillory et al., 2001). Typically, juveniles are found in shallow marshes or seagrass beds with brackish salinities (Orth and van Montfrans, 1987; Thomas et al., 1990). These habitats are distributed across a broad salinity gradient (i.e., seagrass beds, mangrove shorelines, and low-salinity rivers); therefore, habitat perturbations are likely to affect blue crab populations (Engel and Thayer, 1998). Specifically, blue crab survival and production have been positively related to habitat quality (Engel and Thayer, 1998; Guillory et al., 2001).

Valuable commercial and recreational fisheries for blue crabs exist along the Atlantic and gulf coasts of the United States. From 1996 to 2004, Florida's Gulf Coast commercial landings averaged 8.7 million pounds per year and were worth an estimated 6.9 million dollars annually [National Marine Fisheries Service (NMFS), 2007]. Annual gulf commercial landings peaked in 1998 at almost 13 million pounds, but catch per unit effort was beginning to decline (Steele and Bert, 1998). In 2001, commercial blue crab landings were the lowest on record (5 million pounds); since then landings have been slowly increasing (NMFS, 2007). Recreational harvest of blue crabs, which may be substantial, is not monitored (Murphy et al., 2007) making estimates of harvest problematic. Relating immature blue crab abundance and year class strength to trends in commercial landings may elucidate some of the factors influencing the variation in commercial catch.

Several studies on blue crab adult populations have been carried out in Florida (Tagatz, 1968a, 1968b; Oesterling and Adams, 1979; Steele, 1979; Laughlin, 1982; Steele, 1991; Steele and Bert, 1994; Wilber, 1994; Steele and Bert, 1998), but less attention has been paid to critical early life-history stages such as juveniles. Within Tampa Bay, Steele and Bert (1994) described blue crab abundances based on adult catch data collected by trapping, and a small-scale study by Yeager et al. (2007) compared whether juvenile blue crab abundance differed between naturally formed tidal creeks and man-made ditches in mangrove wetlands. To date, information on long-term trends in juvenile abundance has not been published for a west-coast Florida estuary.

The objectives of this study were to analyze a long-term fisheries-independent monitoring data set to describe the distributions and abundances of immature and adult blue crabs in the Tampa Bay estuary, specifically as they relate to 1) monthly and yearly trends in abundance and size, 2) timing of recruitment to the estuary, 3) sex- and size-determined distribution patterns, and 4) the influence of environmental factors, such as freshwater input. Annual trends in the abundance of immature and adult blue crabs collected during this study were then compared to the commercial catch during the same time period.

MATERIALS AND METHODS

Nekton sampling was conducted from 1996 through 2004 in the Tampa Bay estuary, located on the central gulf coast of Florida. Most of Tampa Bay is a relatively high-salinity estuary, with rivers providing a large portion of the fresh water to the bay (Lewis and Estevez, 1988). The middle and lower regions of Tampa Bay have the highest salinities, and the tidal portions of the rivers are typically mesohaline, depending on season. Because blue crab abundances have been shown to fluctuate with natural and anthropogenic variations in freshwater inflow (Wilber, 1994), freshwater inputs to or diversions from Tampa Bay may be vital to maintaining a healthy population of blue crabs. Tampa Bay was poststratified into four regions (Hillsborough Bay, Old Tampa Bay, Middle Bay, and Lower Bay), defined by salinity and habitat type (Lewis and Estevez, 1988), to determine spatial differences in abundance (Table 1). Three major rivers emptying into the bay (the Alafia, Little Manatee, and Manatee rivers) were treated as separate regions (Fig. 1). Annual freshwater input into Tampa Bay from 1996 through 2004 was estimated with the use of discharge data collected by water-stage recorders at two locations: the Alafia River at Lithia and the Little Manatee River at Wimauma (United States Geological Survey [USGS], 2008). Years were categorized into those with above average, average, and below-average river inflows with the use of 95% confidence intervals of mean inflows for the study period.

Blue crabs were collected with the use of a stratified random sampling design. Sampling sites were selected with the use of a grid that divided the estuary into cells 1 nautical mile (nmi) on a side; these were further divided into a microgrid of cells 0.1 nmi on a side. Microgrid cells were stratified according to depth and habitat and sampling locations were randomly

TABLE 1. Characteristics used in Lewis and Estevez (1988) to separate Tampa Bay, FL into four regions.

Region	Circulation	Water quality	Dissolved oxygen range (mg/liter)	Salinity (ppt)	Habitat types
Old Tampa Bay	Moderate	Declining	2.7–10.6	22.5 (mean), salinity range 5–10 parts per thousand > Hillsborough Bay (HB)	Moderate seagrass coverage and mangrove forest, some hard bottom, and extensive tidal marshes
Hillsborough Bay	Poor	Undesirable	0.9–11.6	20.9 (mean), the most freshwater input	Minimal seagrass coverage, tidal marshes, and mangrove forest
Middle Bay	Good	Good	1.1–8.1	25–33 (range)	Moderate seagrass coverage, tidal marshes, and mangrove forest
Lower Bay	Good	Good to excellent	1.4–8.5	25–33 (range)	Extensive seagrass coverage and mangrove forests, moderate tidal marshes

selected following a strict protocol (McMichael, 1991). Location, salinity [parts per thousand (ppt)], water temperature (°C), water depth (m), and habitat descriptions (shore type, bottom type, bottom vegetation type, and percent cover of bottom vegetation) were recorded at all sample sites.

Samples were collected with the use of 21.3-m (3.2-mm mesh) center-bag seines and 6.1-m (38-mm mesh) otter trawls with 3.2-mm stretch-mesh cod-end liner. The area (m²) sampled by each gear type was calculated from field trials for seines or from the distance towed (as determined by GPS coordinates) and a known size of the net mouth opening for trawls. The seine was used to capture smaller individuals of the faunal community in waters ranging in depth from 0.3 to 1.8 m and was deployed according to the habitat sampled: 1) offshore in open-water habitats, hauled a distance of 9.1 m with the seine wings held 15.5 m apart; 2) perpendicular to the shoreline, hauled a distance of 9.1 m with the seine wings held 15.5 m apart; and 3) along a shoreline from the stern of a boat in a semicircular pattern and retrieved onto shore. The offshore (method 1) and shoreline (method 2) sets were used to sample the bay regions, and the boat set (method 3) was used to sample riverine regions. Offshore sets (method 1) were stratified by the presence or absence of submerged aquatic vegetation within a grid cell, whereas boat sets (method 3) were stratified by the salinity gradient and the presence or absence of overhanging vegetation within a microgrid cell. Seines were used monthly in the bay and rivers from 1996 through 2004. Otter trawls, which typically capture larger blue crabs, were towed for approximately 0.1 nmi in river regions

and 0.2 nmi in bay regions. In rivers, otter trawls were used monthly throughout the sampling period (1996–2004), but were only used monthly from 1996 to 1997 in the bay. Therefore, data characterizing the full size range of blue crabs over the entire sampling area is restricted to this 2-yr period.

Blue crabs were counted and sexed, and carapace widths (CW) were measured to the nearest millimeter for up to 20 randomly selected individuals in each sample. For analysis purposes, all crabs less than or equal to 80-mm CW were labeled as immature based on published data by Steele and Bert (1994) and Archambault et al. (1990), which indicate that crabs less than 80-mm CW can be assumed to be immature. In order to look at the distribution and timing of recruitment to the estuary, two immature size classes were defined: recruits (≤ 20 -mm CW) and juveniles (21–80-mm CW). Individual variation in size at maturity likely resulted in some crabs labeled as adults (> 80 -mm CW) actually being immature and vice versa. We identified the sex of adult crabs in the field by noting the shape of the abdomen (Williams, 1974). Blue crabs infected by the parasitic sacculinid barnacle, *Loxothylacus texanus*, resemble mature female crabs even if immature or male (Hochberg et al., 1992; Messick and Sinderman, 1992), so these crabs were unsexed and labeled as parasitized.

Catch rates for each size class were calculated for immature crabs collected in seines and adults collected in otter trawls (monthly data from 1996 to 1997). Catch per unit effort (CPUE) was calculated based on number of crabs per set, log-transformed, and compared for differences by month and region for each size class. Kruskal–

Fig. 1. Location of the Tampa Bay estuary along the gulf coast of Florida (inset). The seven regions of the estuary are Old Tampa Bay (OTB), Hillsborough Bay (HB), middle bay (MB), lower bay (LB), Alafia River (AR), Little Manatee River (LMR), and Manatee River (MR). Spatial locations of 21.3-m seine (black dots) and 6.1-m otter trawl (gray dots) sampling sites from 1996–1997 are indicated on the map.

Wallis tests were used to detect seasonal differences in CPUE by region, because sample variances were heteroscedastic.

Length–frequency data were pooled over the 2-yr period to assess seasonal differences in abundance, as date has been shown to be an accurate predictor of recruitment period (Allen

and Barker, 1990). Catch data from the crabs collected in seines and otter trawls were combined in the analysis to show a broader size spectrum of crabs collected. Length–frequency histograms were examined to determine the timing and size at which blue crabs fully recruited into the estuary. Percent length–

frequency distributions in 10-mm-CW size bins of adult male (>80 -mm CW), female (>80 -mm CW), and immature blue crabs (≤ 80 -mm CW) were calculated for each group and plotted.

The stratified random sampling design employed for this study generates count data, the distribution of which is bounded by zero, because it is not possible to detect a negative number of crabs. Often, the frequency distribution of these counts is highly nonnormal. In such cases, the use of statistical tests that assume normal distributions may be inappropriate. Generalized linear models based on the Gaussian distribution with a log transformation, Poisson, and negative binomial distributions were fit to the data and residual analyses and goodness of fit statistics were analyzed to determine the most appropriate model. Based on these analyses, the models based on the Poisson error distribution was deemed most appropriate. Factors and covariates included in the model were determined using backwards stepwise procedures and AIC (Akaike's information criterion) values. Variables were included in the model if they were statistically significant or if they improved the AIC value by more than four.

Abundance was calculated as the mean number of crabs per haul. Indices of abundance (IOA) for blue crabs were calculated with the use of a general linear model based on the Poisson distribution for the consistent monthly sampling in 1996–1997. The IOAs for each size class [recruits (≤ 20 -mm CW), juveniles (21–80-mm CW), and adults by sex (>80 -mm CW)] were calculated separately with the use of data collected during all months. Transformations were applied to the environmental variables prior to the analysis: Temperature and depth were log-transformed, and percent cover of bottom vegetation was arcsine transformed. Deployment method (for seines), year, region, month, salinity class (in 5-ppt increments), bottom vegetation type, and bottom type were treated as class variables. Temperature, depth, and percent cover of bottom vegetation were treated as covariates. If a class variable was significant, the adjusted means from the reduced model were calculated and transformed back to a linear scale by using their antilogarithms and are reported as estimates of abundance. Significant differences between the adjusted means were determined via Tukey-Kramer adjustment for multiple comparisons.

The same methodology was used for monthly data on immature crabs (≤ 80 -mm CW) collected in rivers and bay regions and adult crabs (>80 -mm CW) collected in rivers from 1996 through 2004 to estimate the relative annual abundance

of these size classes over a more extended time period. The indices of abundance for immature crabs were based on a peak recruitment period of August through March. These annual indices were then compared qualitatively against river inflow and Tampa Bay commercial landings [data for Hillsborough, Pinellas, and Manatee counties; Florida Fish and Wildlife Conservation Commission (FWC), 2005] reported as CPUE (number of crabs per trip) of adult blue crabs from 1996 through 2004. Analyses were performed with the use of R version 2.8.1 (R Development Core Team, 2008) or SAS version 9.1 (SAS Institute, 2006).

RESULTS

Annual patterns of river inflow varied significantly over the 9-yr study period. Mean daily river inflow for the Alafia and Little Manatee Rivers combined was extremely high for four water years (1997–1998, 2002–2003, 2003–2004, and 2004–2005; Fig. 2). The high 2004 inflows were related to heavy rainfall in the summer due to hurricanes, whereas the high inflows from 1997 to 1998 were associated with El Niño weather patterns in fall and winter (Schmidt et al., 2001). Three water years (1996–1997, 1999–2000, and 2001–2002) had low inflows at or below the 95% confidence interval of study-period mean inflows, some of which were attributable to La Niña conditions. The remaining years had inflows that were closer to historic means.

Baywide sampling (seines and trawls; 1996–1997).—A total of 1,655 seines and 704 trawls were completed in Tampa Bay from 1996 through 1997, with 1,531 and 828 of these hauls in bay and river regions, respectively (Fig. 1; Table 2). Blue crabs collected consisted of 522 recruits, 717 juveniles, 535 adult males, and 498 adult females. Of those crabs in the adult size range, there were an additional 16 that were parasitized and unable to be sexed. Immature blue crabs (≤ 80 -mm CW) made up the largest portion of the overall catch from August through April (Fig. 3). During January and February, recruits dominated the catch. This cohort appeared in the 80–110-mm CW size range by May and June. There was also a second peak of recruits in September that can be tracked to larger size classes in December (Fig. 3). In May–July, the majority of the catch consisted of adult crabs (Fig. 3). Of the adult crabs, males tended to be more abundant than females in the upper bay and rivers, but females were more abundant in lower regions of the bay. Overall, the majority of adults were captured in river regions, and males

Fig. 2. Mean annual river inflow for the Alafia and Little Manatee Rivers combined for water years (October–September) from 1996–2004. Bars represent the mean and error bars represent the standard error for each year. The horizontal line indicates the mean annual river flow over the study period and the dashed lines indicate the 95% confidence intervals.

in particular preferred these environments (Fig. 4).

The analysis (Kruskal-Wallis one-way ANOVAs) of monthly abundance patterns by region (Table 3) indicated significant differences for some regions, but not others. Monthly recruit abundances were significantly different for all bay regions and the Manatee River. Recruits were only found in these areas from August until May and peaks in abundance occurred earlier in the lower regions of the bay (Fig. 5). Juveniles showed distinct monthly differences in abundance in Old Tampa Bay, Lower Bay, and the Alafia River, and abundance patterns followed recruits temporally and spatially in most cases (Fig. 5). Adult males did not show significant monthly differences in any region except for the Alafia River, whereas females showed monthly variation in abundance in the Alafia River and Old Tampa Bay. Peaks in abundance in the Alafia River from March through May were evident in the Alafia River for both sexes (Fig. 6).

The generalized linear model explained 31.5% of the variability associated with blue crab abundance for recruits, 33.1% of the variability for juveniles, and 29.1% and 30.3% of the variability for male and female adults, respectively (Tables 4 and 5). The abundances of all blue crab size classes varied significantly with some factors (i.e., region and month), but only certain

size classes were influenced by others [i.e., year (recruits and adults), salinity (juveniles and adults), bottom type (recruits and adult males)]. Abundances of both immature size classes (recruits and juveniles) were influenced by gear deployment type, bottom vegetation type, temperature, and depth. Only juvenile abundances were positively correlated with the percentage of bottom covered in vegetation.

The abundances of all sizes of blue crabs varied significantly by the time of year (i.e., month; Tables 4 and 5). Peaks in abundance by month show a progression through the size classes over time (Fig. 7) and follow the trends evident in the length–frequency histograms. Highs in abundance were apparent in January and February for recruits, in February through March for juveniles, and in May for adults (Fig. 7). A second peak in abundance is seen in September for recruits and September and October for juveniles. Recruits were not collected in 21.3-m seines during June or July. Males and females have similar abundances through most months; however, males were higher in abundance in May and July and there was a slight increase in the proportion of females in the winter (November–January).

Regional differences in abundance were also significant for all sizes of blue crabs (Tables 4 and 5). Estimates of the abundance of recruits by

TABLE 2. Catch and effort data for blue crabs collected in Tampa Bay, FL, 1996–1997.

Region and gear	No. of hauls	Size class	No. crabs	Catch per unit effort (No. per haul)	Standard error
Hillsborough Bay					
21.3-m seines	135	Recruits	37	0.274	0.112
		Juveniles	118	0.874	0.422
6.1-m otter trawls	42	Adult males	36	0.857	0.337
		Adult females	48	1.143	0.440
Subtotal	177		239		
Old Tampa Bay					
21.3-m seines	291	Recruits	65	0.223	0.136
		Juveniles	188	0.646	0.218
6.1-m otter trawls	85	Adult males	68	0.800	0.275
		Adult females	53	0.624	0.167
Subtotal	376		374		
Middle Bay					
21.3-m seines	241	Recruits	126	0.523	0.161
		Juveniles	87	0.361	0.071
6.1-m otter trawls	123	Adult males	34	0.276	0.105
		Adult females	29	0.236	0.105
Subtotal	364		276		
Lower Bay					
21.3-m seines	456	Recruits	182	0.399	0.157
		Juveniles	183	0.401	0.078
6.1-m otter trawls	158	Adult males	90	0.570	0.140
		Adult females	121	0.766	0.266
		Parasitized	6	–	–
Subtotal	614		582		
Alafia River					
21.3-m seines	162	Recruits	33	0.204	0.076
		Juveniles	35	0.216	0.054
6.1-m otter trawls	60	Adult males	105	1.750	0.397
		Adult females	64	1.067	0.286
Subtotal	222		237		
Little Manatee River					
21.3-m seines	188	Recruits	22	0.117	0.040
		Juveniles	25	0.133	0.031
6.1-m otter trawls	130	Adult males	114	0.877	0.218
		Adult females	69	0.531	0.096
		Parasitized	1		
Subtotal	318		231		
Manatee River					
21.3-m seines	182	Recruits	57	0.313	0.100
		Juveniles	81	0.445	0.123
6.1-m otter trawls	106	Adult males	88	0.830	0.163
		Adult females	114	1.075	0.207
		Parasitized	9		
Subtotal	288		349		
Grand total	2,359		2,288

Fig. 3. Monthly length frequency histograms (10-mm CW increments) of immature blue crabs (≤ 80 -mm CW; white bars), adult females (gray bars), and adult males (black bars) collected with 21.3-m seines and 6.1-m otter trawls during 1996–1997 in Tampa Bay, FL. I: number of immature blue crabs; F: number of females; M: number of males.

region were highest in the Manatee River, Middle Bay, and the Lower Bay, which are located closest to the Gulf of Mexico (Fig. 8). Higher numbers of juveniles were caught per set in the bay versus river regions, and abundances were more evenly distributed throughout the bay regions as compared to recruit abundances. Adults were most abundant in the Lower Bay, Hillsborough Bay, Alafia River, and Manatee River. Females were more abundant in regions

closer to the mouth of the bay (Lower Bay and Manatee River), and males were more commonly caught in Old Tampa Bay and the rivers further from the Gulf of Mexico.

Salinity had a significant influence on the distribution of juvenile and adult blue crabs (Tables 4 and 5). Juveniles were more abundant in areas of lower salinity (0–5 ppt; Fig. 9) than in higher salinity (26–35 ppt), and abundance estimates were extremely variable for the >35-

Fig. 4. The number of adult male (A) and female (B) blue crabs caught with 6.1-m otter trawls during 1996–1997 in Tampa Bay, FL. Gray circles represent females, black boxes represent males, and small dots represent zero catches.

ppt range. This high variability was caused by two juveniles being caught in one of only six seine hauls that had salinities within this range. Male and female adult blue crabs had similar abundances for most salinity classes, but a clear difference in abundance was shown at the high end of the salinity range, where females were more abundant (Fig. 9).

The abundances of immature blue crabs were influenced by habitat type and environmental conditions. Both size classes were influenced by the type of dominant bottom vegetation (algae, seagrass, or none) present at the sampling site and were most abundant in sites dominated by

algae than areas with no vegetation. Juveniles were also more abundant in sites dominated by seagrass, and abundance was positively correlated with the percentage of bottom covered by vegetation (Fig. 10). The abundance of recruits was influenced by type of substrate present at the sampling site; recruits were most abundant in areas with a mud substrate. The abundances of both size classes were correlated positively with water temperature and negatively with depth.

Long-term sampling [seines (baywide), trawls (rivers), 1996–2004].—From 1996 through 2004, the abundances of immature (≤ 80 -mm CW) and

TABLE 3. Results from Kruskal-Wallis tests comparing monthly variation in catch per unit effort (CPUE) over region by size class of blue crabs (1996–1997).

Region	Recruits		Juveniles		Adult males		Adult females	
	χ^2	<i>p</i> value	χ^2	<i>P</i> value	χ^2	<i>p</i> value	χ^2	<i>p</i> value
Hillsborough Bay	22.01	0.024	9.37	0.588	13.66	0.190	17.79	0.059
Old Tampa Bay	20.56	0.038	26.04	0.006	18.04	0.081	25.37	0.008
Middle Bay	26.17	0.006	11.38	0.412	14.18	0.223	14.41	0.211
Lower Bay	43.43	<0.001	20.39	0.040	11.69	0.388	11.09	0.435
Alafia River	14.93	0.186	35.11	<0.001	29.29	0.002	20.14	0.044
Little Manatee River	17.16	0.103	13.56	0.258	17.80	0.086	17.26	0.100
Manatee River	24.36	0.011	18.77	0.066	9.19	0.605	12.26	0.344

Fig. 5. Monthly mean catch per unit effort of recruiting (black bars) and juvenile (gray bars) blue crabs by region (1996–1997). Bars represent the mean and error bars represent the standard error.

adult (>80 -mm CW, sexes combined) blue crabs were significantly influenced by year, region, month, bottom type, salinity class, and depth (Table 6). Abundances of immature crabs also varied by gear deployment type, bottom vegetation type, and temperature. The generalized linear model explained 22.1 and 22.3% of the variability associated with immature and adult blue crab abundance, respectively, during this extended study period. From 1996 through 2004, yearly differences in the abundances of immature and adult blue crabs were apparent. Relative abundance declined after 1998, with a significant low in abundance in 2002 (Fig. 11). When comparing the abundance data from our study for immature and adult blue crabs with that of

commercial CPUE data (adults only) from Tampa Bay, the peaks and lows in abundance were remarkably similar. In some instances, commercial CPUE lagged behind adult abundance measured independently. Large peaks in immature blue crab abundance were seen a year after high mean river inflows (1998 and 2003), and these peaks extended into the adult population as well. Tampa Bay commercial landings were also high in 1998 (0.90 million pounds), but the largest peak occurred in 1996 (1.14 million pounds; FWC, 2005). Another peak in immature blue crab abundance in 2000 does not correspond to a preceding high river inflow year, but does follow 2 yr of elevated catches of adult blue crabs in the rivers and commercially (1998 and 1999).

Fig. 6. Monthly mean catch per unit effort of adult male (gray bars) and female (black bars) blue crabs by region (1996–1997). Bars represent the mean and error bars represent the standard error.

DISCUSSION

This study provides a comprehensive view of the distribution and abundance of a wide size range of blue crabs in the Tampa Bay estuary. A comparison of the blue crab population data in this study to other Tampa Bay–specific studies is problematic because of individual biases in gear selectivity [baited traps (Steele and Bert, 1994) vs. seines and trawls] or limited temporal and spatial sampling distribution (Yeager et al., 2007), but several conclusions resulting from these studies are in agreement. Recruiting or juvenile blue crabs were collected in the Tampa Bay estuary in all months, confirming the existence of an extended spawning season (March–October and some year-round spawn-

ing) proposed by Steele and Bert (1994). The year-round presence of small crabs in Tampa Bay supports the idea that blue crab populations in the Gulf of Mexico are not limited seasonally by the number of recruits (Steele and Perry, 1990). Data collected regarding the recruitment timing of blue crabs have been a valuable tool in a recent blue crab stock assessment for the state of Florida (Murphy et al., 2007).

The timing of peaks in recruitment and the temporal changes in abundances of differing size classes also agreed with previous studies in the area. Recruits had two peaks in abundance: a large one in January and February and a smaller one in September. Cohorts can be tracked throughout the year and through spatial shifts toward the upper bay regions through a clear

TABLE 4. Reduced Poisson models of abundances of immature blue crabs collected in 21.3-m seines in Tampa Bay, FL, 1996–1997.

Size and source	Explained deviance	df	Deviance	Residual df	Residual deviance
Recruits (≤ 20 -mm CW)	31.5				
Year**		1	18.66	1,614	1,797.97
Month**		11	365.12	1,620	2,126.96
Deployment type**		2	219.60	1,618	1,907.36
Region**		6	100.36	1,631	2,492.08
Bottom type**		2	35.93	1,615	1,816.63
Bottom vegetation type*		2	9.49	1,611	1,775.31
Log (temperature + 1)**		1	13.17	1,613	1,784.80
Log (depth + 1)**		1	54.80	1,617	1,852.56
Juveniles (21–80-mm CW)	33.05				
Year ^a		1	3.33	1,561	3,029.22
Month**		11	307.81	1,562	3,032.55
Deployment type**		2	441.27	1,559	2,587.95
Region**		6	147.74	1,573	3,340.37
Salinity class**		7	46.13	1,550	2,423.05
Bottom vegetation type**		2	118.76	1,557	2,469.18
Log (temperature + 1)*		1	9.97	1,549	2,413.08
Log (depth + 1)**		1	35.29	1,548	2,377.80
Arcsine (bottom vegetation percent cover)**		1	42.56	1,547	2,335.24

^a Not significant.* $P < 0.01$.** $P < 0.001$.

succession of peaks in length frequency and abundance. A short-term study investigating several small tidal tributaries of Tampa Bay from December through May also found a high abundance of recruits (modal size 10–20-mm CW) in winter (December–February) and of juveniles (modal size 30–50-mm CW) in March–

May (Yeager et al., 2007). High numbers of juvenile crabs (> 25 -mm CW) were also found in traps in March–May and in October–November in a current blue crab trapping study in Tampa Bay (A. McMillen-Jackson, pers. comm.). Adults were more abundant during the summer months, with male blue crabs having a higher

TABLE 5. Reduced Poisson models of abundances of adult blue crabs (> 80 -mm CW) collected in 6.1-m otter trawls in Tampa Bay, FL, 1996–1997.

Size and source	Explained deviance	df	Deviance	Residual df	Residual deviance
Males	29.1				
Year**		1	82.94	669	1,350.80
Month**		11	308.36	670	1,433.74
Region**		6	112.42	681	1,742.09
Salinity class*		7	20.86	659	1,316.67
Bottom type*		3	13.26	666	1,337.53
Log (temperature + 1) ^a		1	0.54	658	1,316.14
Log (depth + 1) ^a		1	1.48	657	1,314.65
Females	30.3				
Year**		1	18.47	669	1,440.83
Month**		11	217.34	670	1,459.30
Region**		6	91.537	681	1,676.63
Salinity class**		7	206.997	662	1,233.84
Log (temperature + 1) ^a		1	0.0737	661	1,233.76
Log (depth + 1) ^a		1	0.87	660	1,232.90

^a Not significant.* $P < 0.01$.** $P < 0.001$.

Fig. 7. Adjusted abundance estimates for recruits (≤ 20 -mm CW), juveniles (21–80-mm CW), and adult blue crabs (> 80 -mm CW) collected during 1996–1997 in Tampa Bay, FL, by month. The boxes represent the 25th–75th percentiles, the error bars represent the 10th–90th percentiles, and the line indicates the median estimate. Refer to Tables 4 and 5 for the ANCOVA results of the models used.

abundance in the estuary and a higher affinity for lower salinity, confirming their role as permanent estuarine and riverine inhabitants, as suggested by Steele and Bert (1994). Female blue crabs were found in higher numbers during the winter, as in previous studies (Steele and Bert, 1994), coinciding with their annual migration along the west coast of Florida (Oesterling and Adams, 1979; Steele, 1991). The additional information provided by this fisheries-indepen-

dent monitoring study is a valuable asset to and verification of population data collected in the trapping program.

In addition to abundance varying temporally, differential habitat use by sex and size class within the estuary was apparent and influenced by habitat suitability or migration that occurs after recruitment into the estuary. Many studies have shown that juveniles have increased survival and growth rates in areas where seagrass area or

Fig. 8. Adjusted abundance estimates for recruiting (≤ 20 -mm CW), juvenile (21–80-mm CW), and male and female (> 80 -mm CW) blue crabs collected during 1996–1997 in Tampa Bay, FL, by region (region abbreviations defined in Fig. 1). The boxes represent the 25th–75th percentiles, the error bars represent the 10th–90th percentiles, and the line indicates the median estimate. Refer to Tables 4 and 5 for the Poisson GLM results.

marsh vegetation is available (Orth and van Montfrans, 1987; Thomas et al., 1990). Results from this study concur with previous findings from other geographic locations; the presence and increasing percent cover of bottom vegetation positively influenced the abundance of immature blue crabs. Algal habitats, in particular, appear to be a preferred habitat for immature blue crabs. Drift algae has previously been shown to harbor several estuarine fish

species in high abundances (Rydene and Matheson, 2003) and to serve as nursery habitat for juvenile blue crabs (Falls, 2008). Lower abundances of immature crabs in seagrass habitats as opposed to algal habitats may be a result of regional differences, not habitat selectivity. Hillsborough Bay and Old Tampa Bay have less extensive seagrass beds but can have large amounts of drift algae supporting high abundances of juveniles. Meise and Stehlik (2003)

Fig. 9. Adjusted abundance estimates for juvenile (21–80-mm CW), and male and female (>80-mm CW) blue crabs during 1996–1997 in Tampa Bay, Florida, by salinity class. The boxes represent the 25th–75th percentiles, the error bars represent the 10th–90th percentiles, and the line indicates the median estimate. Refer to Tables 4 and 5 for the Poisson GLM results.

found that juvenile blue crab abundance was not significantly different in habitats with and without cover, implying that other factors may be important in determining abundance. Recruiting crabs were more abundant in habitats with mud substrate, confirming findings from previous studies (Livingston et al., 1976; Perry and Stuck, 1982). Greater abundances of recruiting crabs in mud habitats may be related to habitat suitability (for refuge) or food availability. Seitz et al. (2005) observed increased growth of juvenile blue crabs in muddy upriver areas that had high densities of clams. The distribution of different size classes of blue crabs within the estuary indicates that as juveniles develop, they begin to show a preference for riverine environments. The high abundance of recruiting blue crabs in the Manatee River and the lower bay regions may be due to the close proximity of these regions to the mouth of the bay (Etherington and Eggleston, 2000), where larvae spawned in the Gulf of Mexico tend to settle out. The upper bay regions (Hillsborough Bay and Old Tampa Bay), with lower average

salinities, also had the lowest abundances of recruiting blue crabs, most likely due to the greater distance from the larval supply in the Gulf of Mexico. Pardieck et al. (1999) found that the presence of postlarvae and small recruits within an estuary is more influenced by larval supply and water-column transport, whereas the presence of juvenile blue crabs is influenced by habitat suitability, such as seagrass type. Adult male and juvenile blue crabs were more abundant in lower-salinity areas, concurring with previous studies (Steele and Perry, 1990). The relationship between regions within the bay, salinity, and habitat type complicates the interpretation of regional differences in blue crab abundances (i.e., separating the importance of habitat from that of region).

Freshwater inflow is known to influence blue crab abundance. Wilber (1994) demonstrated that the commercial landings of blue crabs from north Florida were closely linked to freshwater inflows, and the present study agrees with similar findings in the literature that juvenile and adult male crabs are more abundant in lower-salinity

Fig. 10. Adjusted abundance estimates for recruiting (≤ 20 -mm CW) and juvenile (21–80-mm CW) blue crabs collected during 1996–1997 in Tampa Bay, FL, by bottom vegetation type. The dots represent the adjusted means and the error bars represent the standard errors. Refer to Tables 4 and 5 for the Poisson GLM results.

environments (Steele and Bert, 1994; Thomas et al., 1990; Archambault et al., 1990). Immature and adult blue crab indices of abundance and commercial landings were high in Tampa Bay in

1998 in association with increased rainfall and river flows during the 1997–1998 El Nino event (Schmidt et al., 2001). This El Nino event was followed by lower-than-average river inflow from late 1998 through the beginning of 2002, which corresponds to a low in the abundance of immature blue crabs in 2002. Reduced rainfall and freshwater diversions have the potential to affect recruitment and survival of young crabs into the estuary adversely. Salinity gradients aid in the active and passive transport of pelagic larvae into estuaries (McConaughy, 1988); during drought years these gradients are lessened and may possibly disrupt or preclude settlement. From 1998 to 2001, commercial landings in the Tampa Bay estuary declined to record low levels (FWC, 2005), and concurrently adult blue crabs in rivers exhibited decreased abundances in 2002. From 2003 to 2004, however, there was a drastic increase in blue crab recruitment and a steady rise in adult abundance and commercial landings that may be linked to an increase in river inflow above historic means during the same time period. A recent stock assessment of the blue crab in Florida (Murphy et al., 2007) also indicates that the stock size increased during this time period. Long-term trawling data from the north-central Gulf of Mexico has also shown general trends of increasing blue crab abundance with high river inflow during this time period (Rubio, 2009).

TABLE 6. Reduced Poisson models of abundances of immature blue crabs collected in 21.3-m seines from August through March in all Tampa Bay, FL, regions and adult crabs collected from all months in 6.1-m otter trawls in Tampa Bay rivers, 1996–2004.

Size and source	Explained deviance	df	Deviance	Residual df	Residual deviance
Immature (≤ 80 -mm CW)	22.1				
Year**		8	615.43	3,216	8,016.17
Month**		7	225.52	3,226	8,928.18
Deployment type**		2	296.58	3,224	8,631.60
Region**		6	440.06	3,233	9,153.7
Salinity class**		7	221.23	3,205	7,645.99
Bottom type**		2	121.27	3,212	7,867.22
Bottom vegetation type**		2	27.70	3,214	7,988.49
Log (temperature + 1)*		1	9.16	3,204	7,636.83
Log (depth + 1)**		1	161.10	3,203	7,475.73
Adults (> 80 -mm CW)	22.3				
Year**		8	284.6227	1,153	4,778.854
Month**		11	435.0295	1,161	5,063.477
Region**		2	510.3084	1,172	5,498.506
Salinity class**		7	48.06508	1,144	4,720.585
Bottom*		2	10.20392	1,151	4,768.65
Log (temperature + 1) ^a		1	0.362634	1,143	4,720.222
Log (depth + 1)**		1	51.45117	1,142	4,668.771

^a Not significant.

* $P < 0.01$.

** $P < 0.001$.

Fig. 11. Adjusted abundance estimates for immature (≤ 80 -mm CW; gray boxes) and adult (> 80 -mm CW; white boxes) blue crabs caught during 1996–2004 in Tampa Bay, FL, by year. The boxes represent the 25th–75th percentiles, the error bars represent the 10th–90th percentiles, and the line indicates the median estimate. Commercial CPUE for the Tampa Bay area is plotted with the adult abundance estimates, and mean river inflow and standard error is plotted with the immature abundance estimates. Refer to Table 6 for the Poisson GLM results.

Other factors that may influence populations of blue crabs, especially the mortality of recruits into the estuary, include disease and predation (Etherington et al., 2003). Parasites such as *Hematodinium perezii* and *Loxothylacus texanus* are capable of causing mortality or terminating reproduction, respectively, therefore affecting the population and leading to decreased abundance (Hochberg et al., 1992; Messick and Sinderman, 1992; Shields and Squyers, 1999; Messick and Shields, 2000; Gruebl et al., 2002). A very low proportion of blue crabs were found to

have visual abnormalities or parasites in this study, so disease probably had a limited effect on abundance during this time period. Mortality from predation may differ among regions, and cannibalism by larger crabs located in higher abundance in the upper bay and rivers may also influence recruit abundance (Hines and Ruiz, 1995). Increasing depths can also increase mortality since shallow areas provide refuge from predation (Ruiz et al., 1993; Dittel et al., 1995). The findings of this study would suggest that these shallow-water habitats are serving as refugia

in Tampa Bay as abundances of small crabs were significantly and negatively correlated with depth.

The diversity of parameters influencing blue crab abundance precludes naming one as an overall driving factor. However, salinity preferences of blue crabs underscore the importance of maintaining minimum water flows in coastal rivers throughout their range. Water authorities have been diverting river water to urban areas for human use, and these actions can and do alter salinity gradients in rivers, especially during droughts. As a result of reduced salinity gradients, larval transport, settlement, and survival of blue crabs may be impacted, leading to lower annual abundances of blue crabs. Although the control mechanisms on blue crab populations are likely much more complex, a combination of fishing pressure and unfavorable salinity regimes due to reduced river inflow in conjunction with water diversions may have contributed to both the decline of the commercial landings and the declines in the fisheries-independent monitoring indices of annual abundance from 1998 to 2002. The blue crab population in Tampa Bay recovered quickly from these lows in abundance after periods of increased freshwater inflow, suggesting that increased freshwater input may provide suitable conditions for recovery.

ACKNOWLEDGMENTS

We thank all of the biologists and staff of the Fisheries Independent Monitoring Program at the Fish and Wildlife Research Institute (FWRI) in St. Petersburg, FL for their dedication to sampling and data processing. Special recognition goes to Richard Lehnert, Justin Krebs, and Theodore Switzer for advice on analyses; Anne McMillen-Jackson of the Crustacean Biology Group, FWRI, Joe O'Hop of the Fisheries Dependent Monitoring Program, FWRI, and the National Marine Fisheries Service, Fisheries Statistics Section for personal communications including raw data; and Debbie Leffler and Robert McMichael, Jr. for their support and assistance. Comments from Anne McMillen-Jackson, Sue Gerhart, Debbie Leffler, Robert McMichael, Jr., Jim Quinn, and Judy Colvocoresses greatly improved the quality of this manuscript. This project was supported in part by proceeds from state of Florida saltwater recreational fishing licenses and by funding from the Department of the Interior, U.S. Fish and Wildlife Service, Federal Aid for Sportfish Restoration Project Number F-43. The statements, findings, views, conclusions, and recommendations contained in this document are

those of the authors and do not necessarily reflect the views of the U.S. Department of Interior and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

LITERATURE CITED

- ALLEN, D. M., AND D. L. BARKER. 1990. Interannual variations in larval fish recruitment to estuarine epibenthic habitats. *Mar. Ecol. Prog. Ser.* 63:113–125.
- ARCHAMBAULT, J. A., E. L. WENNER, AND J. D. WHITAKER. 1990. Life history and abundance of blue crab, *Callinectes sapidus* Rathbun, at Charleston Harbor, South Carolina. *Bull. Mar. Sci.* 46:145–158.
- BLEWETT, D. A., R. A. HENSLEY, AND P. W. STEVENS. 2006. Feeding habits of common snook, *Centropomus undecimalis*, in Charlotte Harbor, Florida. *Gulf Carib. Res.* 18:1–13.
- CARGO, D. G. 1958. The migration of adult female blue crabs, *Callinectes sapidus* Rathbun, in Chincoteague Bay and adjacent waters. *J. Mar. Res.* 16:180–191.
- DITTEL, A. I., A. H. HINES, G. M. RUIZ, AND K. K. RUFFIN. 1995. Effects of shallow water refuge on behavior and density-dependent mortality of juvenile blue crabs in Chesapeake Bay. *Bull. Mar. Sci.* 57(3):902–916.
- ENGEL, D. W., AND G. W. THAYER. 1998. Effects of habitat alteration on blue crabs. *J. Shellfish Res.* 17:579–585.
- ETHERINGTON, L. L., AND D. B. EGGLESTON. 2000. Large-scale blue crab recruitment: Linking postlarval transport, post-settlement planktonic dispersal, and multiple nursery habitats. *Mar. Ecol. Prog. Ser.* 204:179–198.
- , ———, AND W. T. STOCKHAUSEN. 2003. Partitioning loss rates of early juvenile blue crabs from seagrass habitats into mortality and emigration. *Bull. Mar. Sci.* 72:371–391.
- FALLS, J. A. 2008. The survival benefit of benthic macroalgae *Gracilaria vermiculophylla* as an alternative nursery habitat for juvenile blue crabs. Master's thesis, The College of William and Mary, Williamsburg, VA.
- FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION (FWC). 2005. Commercial fisheries landings in Florida. http://research.myfwc.com/features/view_article.asp?id=19224. Accessed December 19, 2005.
- GRUEBL, T., M. E. FRISCHER, M. SHEPPARD, M. NEUMANN, A. N. MAURER, AND R. F. LEE. 2002. Development of an 18S rRNA gene-targeted PCR-based diagnostic for the blue crab parasite *Hematodinium* sp. *Dis. Aquat. Org.* 49:61–70.
- GUILLORY, V., H. PERRY, AND S. VANDERKOOY (EDS.). 2001. The blue crab fishery of the Gulf of Mexico, United States: A regional management plan. Gulf States Marine Fisheries Commission, Ocean Springs, MS. 306 p.
- HINES, A. H., AND G. M. RUIZ. 1995. Temporal variation in juvenile blue crab mortality: nearshore shallows and cannibalism in Chesapeake Bay. *Bull. Mar. Sci.* 57:884–901.

- HOCHBERG, R. J., T. M. BERT, P. STEELE, AND S. D. BROWN. 1992. Parasitization of *Loxothylacus texanus* on *Callinectes sapidus*: aspects of population biology and effects on host morphology. *Bull. Mar. Sci.* 50(1):117–132.
- LAUGHLIN, R. A. 1982. Feeding habits of the blue crab, *Callinectes sapidus* Rathbun, in the Apalachicola estuary, Florida. *Bull. Mar. Sci.* 32:807–822.
- LEWIS, R. R., AND ESTEVEZ, E. D. 1988. Ecology of Tampa Bay, Florida: An estuarine profile. U.S. Department of the Interior, Fish and Wildlife Service, Biol. Rep. 85(7.18):132.
- LIVINGSTON, R. J., G. J. KOBYLINSKI, F. G. LEWIS III, AND P. F. SHERIDAN. 1976. Long-term fluctuations of epibenthic fish and invertebrate populations in Apalachicola Bay, Florida. *Fish. Bull.* 74(2):311–321.
- MC CONAUGHIA, J. R. 1988. Export and reinvasion of larvae as regulators of estuarine decapod populations. *Am. Fish. Soc. Symp.* 3:90–103.
- MC MICHAEL, R. H. 1991. Florida's marine fisheries-independent monitoring program. In: *Proceedings, Tampa Bay Area Scientific Information Symposium 2 (BASIS)*. 1991 February 27–March 1, Tampa, FL. S. F. Treat and P. A. Clark (eds.) 528 p.
- MEISE, C. J., AND L. L. STEHLIK. 2003. Habitat use, temporal abundance variability, and diet of blue crabs from a New Jersey estuarine system. *Estuar. Coasts* 26(3):731–745.
- MESSICK, G. A., AND J. D. SHIELDS. 2000. Epizootiology of the parasitic dinoflagellate *Hematodinium* sp. in the American blue crab *Callinectes sapidus*. *Dis. Aquat. Org.* 43(2):139–152.
- , AND C. J. SINDERMAN. 1992. Synopsis of principal diseases of the blue crab, *Callinectes sapidus*, NOAA Tech. Memo No. NMFS-F/NEC-88. U.S. Department of Commerce, Washington, DC.
- MEYER, G. H., AND J. S. FRANKS. 1996. Food of Cobia, *Rachycentron canadum*, from the North central Gulf of Mexico. *Gulf Res. Rep.* 9:161–167.
- MURPHY, M. D., A. L. McMILLEN-JACKSON, AND B. MAHMOUDI. 2007. Astock assessment for blue crab, in Florida waters. Report to the Florida Fish and Wildlife Commission, Division of Marine Fisheries Management, in-house report 2007-006, June 22, 2007.
- NATIONAL MARINE FISHERIES SERVICE (NMFS). 2007. NMFS commercial fishery landings data. <http://www.st.nmfs.noaa.gov/st1/commercial/index.html>. Accessed June 22, 2007.
- OESTERLING, M. J., AND C. A. ADAMS. 1979. Migration of blue crabs along Florida's Gulf Coast. *Proceedings of the Blue Crab Colloquium*, October 1979. pp. 37–57.
- ORTH, R. J., AND J. VAN MONTRANS. 1987. Utilization of a seagrass meadow and tidal marsh creek by blue crabs *Callinectes sapidus*. I. Seasonal and annual variations in abundance with emphasis on post-settlement juveniles. *Mar. Ecol. Prog. Ser.* 41:283–294.
- PARDIECK, R. A., R. J. ORTH, R. J. DIAZ, AND R. N. LIPCIUS. 1999. Ontogenetic changes in habitat use by post-larvae and young juveniles of the blue crab. *Mar. Ecol. Prog. Ser.* 186:227–238.
- PERRY, H. M., AND K. C. STUCK. 1982. The life history of the blue crab in Mississippi with notes on larval distribution, p. 17–22. In: H. M. Perry and W. A. Van Engel (eds.), *Proceedings Blue Crab Colloquium*, Publication 7, Gulf States Marine Fisheries Commission, Ocean Springs, MS.
- R DEVELOPMENT CORE TEAM. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <http://www.R-project.org>.
- RUBIO, G. H. S. 2009. Oceanic-atmospheric modes of variability and their effect on river flow and blue crab (*Callinectes sapidus*) abundance in the northcentral Gulf of Mexico. Ph.D. diss., University of Southern Mississippi, Hattiesburg, MS.
- RUIZ, G. M., A. H. HINES, AND M. H. POSEY. 1993. Shallow water as a refuge habitat for fish and crustaceans in non-vegetated estuaries: an example from Chesapeake Bay. *Mar. Ecol. Prog. Ser.* 99:1–16.
- RYDENE, D. A., AND R. E. MATHESON, JR. 2003. Diurnal fish density in relation to seagrass and drift algae cover in Tampa Bay, Florida. *Gulf Mex. Sci.* 21(1):35–58.
- SAS INSTITUTE, INC. 2006. Base SAS® 9.1.3 procedures guide. 2d ed., Vols. 1–4. SAS Institute Inc., Cary, NC.
- SCHARF, F. S., AND K. K. SCHLICHT. 2000. Feeding habits of red drum (*Sciaenops ocellatus*) in Galveston Bay, Texas: Seasonal diet variation and predator–prey size relationships. *Estuaries* 23:128–139.
- SCHMIDT, N., E. K. LIPP, J. B. ROSE, AND M. E. LUTHER. 2001. ENSO influences on seasonal rainfall and river discharge in Florida. *J. Climate* 14:615–628.
- SEITZ, R. D., R. N. LIPCIUS, AND M. S. SEEBO. 2005. Food availability and growth of the blue crab in seagrass and unvegetated nurseries of Chesapeake Bay. *J. Mar. Bio. Ecol.* 319:57–68.
- SHIELDS, J. D., AND C. M. SQUYARS. 1999. Mortality and hematology of blue crabs, *Callinectes sapidus*, experimentally infected with the parasitic dinoflagellate *Hematodinium perezii*. *Fish. Bull.* 98:139–152.
- SILLIMAN, B. R., AND M. D. BERTNESS. 2002. A trophic cascade regulates salt marsh primary production. *Proc. Natl. Acad. Sci. U.S.A.* 16:10500–10505.
- SILVERMAN, M. J. 1979. Biological and fisheries data on black drum, *Pogonias cromis* (Linnaeus). U.S. Department of Commerce National Marine Fisheries Service North East Fisheries Center. NOAA Tech. Ser. 22. 35 p.
- STEELE, P. 1979. A synopsis of the biology of the blue crab *Callinectes sapidus* Rathbun in Florida, p. 29–35. In: *Proceedings Blue Crab Colloquium*. H. M. Perry and W. A. Van Engel (eds.), Publication 7, Gulf States Marine Fisheries Commission, Ocean Springs, MS.
- . 1991. Population dynamics and migration of the blue crab, *Callinectes sapidus* Rathbun, in the eastern Gulf of Mexico. *Proc. Gulf Caribb. Fish Inst.* 40:241–244.
- , AND T. M. BERT. 1994. Population ecology of the blue crab, *Callinectes sapidus* Rathbun, in a subtropical estuary: population structure, aspects of reproduction, and habitat partitioning. *Fla. Mar. Res. Publ.* 54:1–24.
- , AND ———. 1998. The Florida blue crab fishery: History, status, and management. *J. Shellfish Res.* 17:441–449.
- , AND ——— (EDS.). 1990. The blue crab fishery of the Gulf of Mexico United States: a regional

- management plan. Gulf States Marine Fisheries Commission Rep. No. 21 Ocean Springs, MS. 180 p.
- STUCK, K. C., AND H. M. PERRY. 1981. Observations on the distribution and seasonality of portunid megalopae in Mississippi waters. Gulf Res. Rep. 7:93–95.
- TABB, D. C. 1961. A contribution to the biology of the spotted seatrout, *Cynoscion nebulosus* (Cuvier) of East-Central Florida. State of Florida, Board of Conservation Technical Series No. 35. 24 p.
- TAGATZ, M. E. 1968a. Biology of the blue crab, *Callinectes sapidus* Rathbun, in the St. Johns River, Florida. Fish. Bull. 67:17–33.
- . 1968b. Growth of juvenile blue crabs, *Callinectes sapidus* Rathbun, in the St. Johns River, Florida. Fish. Bull. 67:281–288.
- THOMAS, J. L., R. J. ZIMMERMAN, AND T. J. MINELLO. 1990. Abundance patterns of juvenile blue crabs (*Callinectes sapidus*) in nursery habitats of two Texas bays. Bull. Mar. Sci. 46:115–125.
- UNITED STATES GEOLOGICAL SURVEY (USGS). 2008. USGS Water Data for the Nation. <http://waterdata.usgs.gov/nwis/>. Accessed June 14, 2008.
- VAN ENGEL, W. A. 1958. The blue crab and its fishery in Chesapeake Bay: Part I—Reproduction, early development, growth and maturation. Comm. Fish. Rev. 20:6–17.
- VIRNSTEIN, R. W. 1977. The importance of predation by crabs and fishes on benthic infauna in Chesapeake Bay. Ecology 58:1199–1217.
- WILBER, D. H. 1994. The influence of Apalachicola River flows on blue crab, *Callinectes sapidus*, in north Florida. Fish. Bull. 92:180–188.
- WILLIAMS, A. B. 1974. The swimming crabs of the genus *Callinectes* (Decapoda: Portunidae). Fish. Bull. 72:685–798.
- YEAGER, L. A., J. M. KREBS, A. B. BRAME, AND C. C. McIVOR. 2007. Juvenile blue crab abundances in natural and man-made tidal channels in mangrove habitat, Tampa Bay, Florida USA. Bull. Mar. Sci. 80(3):555–565.
- FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION, FISH AND WILDLIFE RESEARCH INSTITUTE, 100 EIGHTH AVENUE, SE, ST. PETERSBURG, FLORIDA 33701. Date accepted: August 11, 2011