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EARLY BLUE CRAB RECRUITMENT TO ALTERNATIVE NURSERY HABITATS IN MISSISSIPPI, USA

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ABSTRACT Although seagrass in the lower segments of estuaries provides good nursery habitat for blue crabs, the role of alternative inshore habitats for early blue crab recruitment is not well-known. Using suction sampling, we examined the recruitment dynamics of early blue crabs (*Callinectes* spp.) over a 10-wk study period at 7 sites representing potential nursery habitats, including 2 marsh edge sites, 2 subtidal unvegetated sites adjacent to salt marsh, 2 subtidal unvegetated sites adjacent to developed marsh, and 1 upestuary subtidal vegetated site. Abundances of small (<6.0 mm CW) and large (≥6.0 mm) juvenile crabs varied over the study period, mainly reflecting two monthly pulses of small crabs coinciding with the new moon phase. Early crabs were significantly more abundant from structured habitats than from subtidal unvegetated habitat; although small crabs were moderately abundant at subtidal unvegetated sites situated lower in the estuary. Large crabs were not abundant from subtidal unvegetated sites; whereas large crabs were abundant from sites with structured habitat. Subtidal unvegetated sites were characterized by crab size-distributions with single modes representing postsettlement crabs and with few large crabs; whereas structured habitats contained relatively more large crabs. However, crab size-distributions varied among structured habitats. Spatio-temporal variation in the early recruitment dynamics of blue crabs reflected temporal changes, such as lunar periodicity; landscape effects, such as proximity to currents; and habitat effects.

KEY WORDS: blue crab recruitment, *Callinectes*, nursery habitat

INTRODUCTION

Early blue crab recruitment involves an estuarine-dependent bipartite life-cycle consisting of a larval-supply phase as well as a postsettlement phase. High densities of postsettlement blue crabs commonly occur in vegetated and other structured habitats (Williams et al. 1990, Pile et al. 1996). For example, many studies of early blue crab recruitment focus on the role of submerged aquatic vegetation (SAV) as a nursery habitat. However, the blue crab postsettlement phase entails a sequence of ontogenetic shifts in movements and habitat use that are not fully understood (Orth & van Montfrans 1987, Pile et al. 1996, Pardieck et al. 1999). For example, Mense and Wenner (1989) found high densities of early juveniles in unvegetated sandy-mud substrate; early stages may even burrow in soft-sediments or seek refuge among the interstices of large particles in unvegetated sediments. Later juveniles also undertake movements from vegetated to unvegetated habitats. Movements of early juveniles from unvegetated sediments may even subsidize the supply of crabs to structured habitats (Rakocinski et al. 2003). In addition, upestuary movements of early crabs may also influence blue crab recruitment dynamics (Pardieck et al. 1999).

In Mississippi coastal waters, structured habitats such as seagrass and emergent fringing marsh are rapidly declining, whereas areal coverage by subtidal unvegetated habitat is high. Indeed, the estimated coverage by submerged aquatic vegetation (SAV) in Mississippi Sound has declined by ~85% over the last 30+ years (Moncreiff et al. 1998). In this region, fringing emergent vegetation is also rapidly declining due to shoreline development. In Chesapeake Bay, the historical decline in SAV has resulted in shifts by early crabs into shallow unvegetated habitats (Ruiz et al. 1993).

While SAV in the lower segments of estuaries clearly provides an important nursery habitat for early blue crabs, little is known about how alternative nursery habitats function in early crab recruitment within the US Gulf coast region. In a previous study in Mississippi Sound, we found considerable numbers of early postsettlement blue crabs from subtidal unvegetated sediments, suggesting that this habitat might subsidize nearby structured habitat (Rakocinski et al. 2003). Other patterns of postsettlement movement among different nursery habitats at various spatio-temporal scales may also influence early blue crab recruitment. Clearly, not enough is known about blue crab recruitment dynamics on the landscape scale in the US Gulf coast region.

One approach to evaluating nursery value is to measure abundances of early stages occurring in different habitats over time. The value of a particular habitat is also dependent on its physiographic context. For example, the same kind of habitat may vary greatly in nursery potential depending on contextual features, such as position with respect to supply rates of early stages, hydroperiod, substrate, salinity, etc. The overall objective of this study is to examine variation in blue crab recruitment among seven inshore sites representing potential nursery habitats, including 2 marsh edge sites, 2 subtidal unvegetated sites adjacent to salt marsh, 2 subtidal unvegetated sites adjacent to developed marsh, and 1 upestuary subtidal vegetated site within the Mississippi Sound estuary over a 10-wk period during late summer and early autumn 1999. Specific objectives involved comparisons of: (1) abundances of postsettlement crabs (i.e., small crabs <6 mm CW) and early juvenile crabs (i.e., large crabs ≥6 mm CW) across six biweekly sample periods; (2) abundances of postsettlement crabs and early juvenile crabs among sites representing nursery habitats; (3) size distributions of early stages of blue crabs among sites representing nursery habitats.

MATERIALS AND METHODS

Study Area

Seven sites located among five shoreline locations were quantitatively sampled along a gradient of decreasing salinity running upestuary from Mississippi Sound to Old Fort Bayou (Fig. 1). These locations encompassed a range of habitat types for examining early blue crab recruitment. Marsh Point and Fort Bayou

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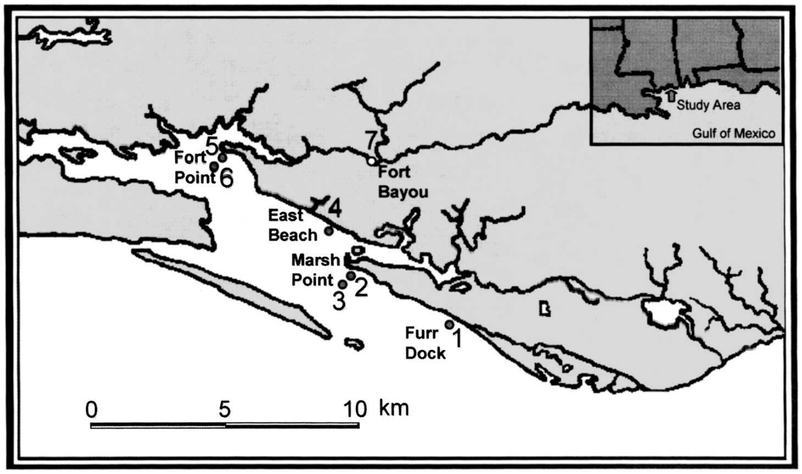

Figure 1. Map of the study area showing 7 sampling sites distributed among 5 locations along a transect running up-estuary into Fort Bayou from Mississippi Sound: site 1, Furr Dock–developed subtidal; sites 2 & 3, Marsh Point–marsh edge and marsh subtidal; site 4, East Beach–developed subtidal; sites 5 & 6, Fort Point–marsh edge and marsh subtidal; site 7, Fort Bayou–submerged vegetated.

Point (hereafter Fort Point) shorelines provided habitat structure in the form of fringing emergent vegetation (marsh edge) for early crab stages. The most seaward site was Furr Dock, located in Mississippi Sound near Pointe aux Chenes Road at 30°22′05″N and 88°46′37″W. Furr Dock was one of two locations used in a previous crab recruitment study (Rakocinski et al. 2003). Only subtidal unvegetated habitat (developed subtidal) (site 1) was sampled at this location, because the fringing marsh-edge had been replaced by residential development. The second location was further upestuary near Marsh Point at 30°23′09″N and 88°48′42″W. Both fringing marsh-edge (marsh edge) (site 2) and subtidal unvegetated (marsh subtidal) (site 3) sites were sampled at this unaltered location. The third location was on East Beach near a pier at 30°23′49N and 88°48′52″W. Only a subtidal unvegetated (developed subtidal) (site 4) site was sampled, because the marsh-edge was replaced by artificial beach at this location. The fourth location was at Fort Point near the mouth of Old Fort Bayou in Biloxi Bay, at 30°25′32N and 88°51′13″W. This location possessed a well-developed fringing marsh (marsh edge) consisting of emergent *Spartina* and *Juncus* and had a steeper shoreline profile than the Marsh Point location. Both marsh-edge (site 5) and subtidal unvegetated (marsh subtidal) (site 6) sites were sampled at this location. The most upestuary sampling location was situated in Old Fort Bayou at 30°25′17N and 88°48′14″W (hereafter Fort Bayou), where submerged beds of *Vallisneria* mixed with *Ruppia* were sampled (submerged vegetated) (site 7).

Field Sampling

Each sampling event consisted of three suction samples taken parallel with the shoreline, except four samples were taken at most sites on the first sampling date. Samples were taken 25 m apart at marsh-edge sites and 50 m apart at subtidal unvegetated sites; but distances from the shoreline varied at the submerged vegetated site. Subtidal unvegetated samples were taken at depths from 90–100 cm, thus distances of samples from shore varied somewhat with the tide. At marsh-edge sites, samples were relatively shallow, but depths also varied somewhat with tidal conditions. Depths of samples within submerged vegetation at the Fort Bayou location (site 7) varied from 30–100 cm, depending on tidal conditions.

Suction sampling was conducted during the late summer/early autumn in 1999, every 2 wk from August 24, 1999 to November 3, 1999 at all seven sites. Field work ensued over 13 dates, yielding a total of 130 1.77 m^2 suction samples (4 per site for sites 1–4 on first date and 3 per site thereafter). Early stages of blue crabs were collected using a venturi suction head attached to a 5-hp gas 2″ centrifugal water pump (Orth & van Montfrans 1987, Rakocinski et al. 2003). The suction head was used to vacuum the substrate and structured habitat within a 1.77 m^2 circular drop-net with 1-mm mesh sides. The area of bottom enclosed by the drop net as well as all associated vegetation within the drop net was thoroughly suctioned through a 1-mm mesh bag. All retained materials, including early crabs, were fixed in 10% formalin and labeled. Suction samples were preserved in 10% formalin separately and returned to the GCRL for processing.

Suction samples also were accompanied by environmental information, including weather conditions, GPS coordinates, time-of-sampling, salinity, water temperature, dissolved oxygen, depth, shore distance, and sediment characteristics. Water quality variables were measured once for each set of samples from a site, whereas structural habitat features were recorded for each sample. Habitat structure variables were also measured, including depth, distance from the shoreline, substrate, SAV cover, and the number of *Spartina* stems.

Laboratory Methods

Suction sample contents were stained with dilute Rose Bengal before crabs and other associated organisms were sorted using a WILD stereo-microscope. Because marsh edge and SAV samples contained large amounts of detrital and vascular plant material, contents of these samples were passed through a series of nested sieves and the size fractions processed separately. Subtidal unvegetated samples were sorted as one fraction because they contained much less extraneous material. Target organisms were identified whenever possible as either *Callinectes sapidus* or *C. similis*, and carapace widths (CW) measured to the nearest 0.01 mm using a dial calipers.

Data Analysis

Mean abundances (±1 se) of the three (or four 1.77 m^2) suction samples per site-event for both small and large crabs were graphically compared across sample periods for the seven sites. Size categories of early crabs were classified: postsettlement, or "small" crabs, were those with CW <6 mm, whereas early juvenile, or "large" crabs, were those with CW ≥6 mm (Rakocinski et al. 2003). Seventy-nine unmeasured damaged *Callinectes* spp. specimens were assigned to small and large size classes proportionately to measured crabs for specific site-events. Early postsettlement stages of all *Callinectes* specimens were pooled for comparisons of abundances, because *C. similis* made up a low proportion (3.1%) of the total number of blue crabs.

Among-site differences in abundances of early crabs were addressed with paired *t*-tests between designated groups of sites: (1) total numbers of crabs between upper and lower subtidal unvegetated sites; (2) numbers of small crabs between subtidal unvegetated and structured habitat sites; (3) total numbers of crabs between subtidal unvegetated and structured habitat sites; and (4) total numbers of crabs between Marsh Point and Fort Point marsh-edge sites. Paired *t*-tests consisted of matched sets of observations pooled for the two groups of concern over the six sample periods. Numbers of crabs were combined (as per sample means) for all drop samples for each site-event, and then log transformed (ln n +1) before averaging for each group and sampling date. Paired *t*-tests addressed whether mean differences between paired group values were significant (Green & Salkind 2000). Rejection levels were controlled for familywise error rate at 0.05 for the four tests using the sequential Bonferroni procedure (Peres Neto 1999). SPSS for Windows Release 11.0.1 (SPSS, Inc.) was used for the paired *t*-tests.

Two fully-factorial 3-way ANOVAs in which location, habitat, and sample period served as factors were conducted separately on abundances of small and large crabs from the Marsh Point and Fort Point locations, where both marsh subtidal and marsh edge habitats were sampled. Log transformed (ln n +1) numbers of crabs from each suction sample were entered into the ANOVAs using SPSS for Windows Release 11.0.1 (SPSS, Inc.). Terms for all 2- and 3-way interactions, as well as for the three main effects were included in the models. Equality of error variance was tested using the Levene test.

Size distributions of *C. sapidus* falling within 1-mm size intervals (i.e., CW) were pooled for each site across the six sample periods. Four comparisons were made between composite size distributions representing designated groups of sites using Kolmogorov-Smirnov (K-S) two-sample tests (Siegel 1956): (1) two lower versus 2 upper subtidal unvegetated sites; (2) 4 subtidal unvegetated versus three structured habitat sites; (3) Marsh Point versus Fort Point marsh-edge sites; and (4) Marsh Point marsh edge site versus the Old Fort Bayou submerged vegetated site. An effective rejection level of 0.05 was maintained using a corrected *P* value of 0.0125, based on the number of tests (i.e., 0.05/4 tests).

RESULTS

Site Comparisons

Site characteristics reflected habitat differences (Table 1). Salinity varied spatially from the highest (26.8 ppt) to the lowest (15.8 ppt) levels along the transect running between the Furr Dock and Old Fort Bayou locations. Salinity was less consistent where values were low, for example, salinity ranged from 11.9 to 21.0 at the most upestuary location (i.e., Fort Bayou). Water temperature was fairly similar among the seven sites, ranging from 25.1°C to 27.2°C. Within-site temperature ranges reflected a cooling trend across the study period; water temperature reached 33.0°C at the beginning of the study period and fell to 17.4°C at the end of the study period. Dissolved oxygen levels varied inversely with water temperature and ranged from 3.80–8.10 mg/L.

Site-specific hydrographic variation was reflected by differences in depth profiles (Table 1). Because sample depth was kept relatively constant (i.e., 0.89–0.96 m) among the four subtidal unvegetated sites, mean seaward distances of samples at these sites showed that the East Beach location had the shallowest depth profile (mean distance = 105.9 m), whereas the Fort Point location had the steepest profile (mean distance = 40.2 m). Furr Dock and Marsh Point locations had intermediate profile slopes (mean distance = 56.9 and 66.0 m, respectively). Moreover, depths and distances of samples from shore differed between the two marsh-edge sites, reflecting the longer hydroperiod at the Fort Point–marsh edge site compared with the Marsh Point–marsh-edge site.

TABLE 1.

Summary of site characteristics (mean ± 1 se/range); typically n = 6 for salinity, water temperature, and dissolved oxygen; n, 18 or 19 for other variables.

	Salin (ppt)	Temp (°C)	DO (mg/l)	Depth (m)	Dist (m)	Substr	Stems	% SAV
Site 1	26.8 ± 0.7	25.9 ± 1.8	5.58 ± 0.38	0.96 ± 0.01	56.9 ± 4.3	silt/sand/mud	0	0
	24.3–28.8	17.9–30.9	4.13–6.45	0.90–1.05	25–90			
Site 2	25.8 ± 1.0	25.1 ± 2.1	6.00 ± 0.38	0.16 ± 0.02	0.7 ± 0.2	sand/shell/detr	94.3 ± 9.4	0
	22.9–28.8	17.4–32.0	5.22–7.52	0.05–0.30	0–2.5		15–154	
Site 3	25.6 ± 1.1	25.6 ± 2.1	5.69 ± 0.34	0.94 ± 0.01	66.0 ± 6.1	silt/sand/mud/tubes	0	0
	22.6–29.1	17.7–32.0	4.97–7.31	0.85–1.05	27–111			
Site 4	25.0 ± 1.0	27.2 ± 1.9	6.03 ± 0.54	0.89 ± 0.02	105.9 ± 12.5	silt/sand/mud	0	0
	22.3–28.6	18.4–33.0	4.15–8.10	0.80–1.10	34–185			
Site 5	20.5 ± 1.0	25.9 ± 1.2	5.58 ± 0.55	0.48 ± 0.03	2.8 ± 0.3	shell/detr/mud	64.5 ± 11.4	0
	18.3–23.8	23.1–30.7	4.10–7.32	0.22–0.68	1–6		25–210	
Site 6	21.1 ± 0.7	26.2 ± 1.4	5.94 ± 0.38	0.92 ± 0.01	40.2 ± 4.2	silt/sand/mud	0	0
	19.2–23.2	22.5–31.6	4.85–7.30	0.90–1.00	19–87			
Site 7	15.8 ± 1.4	25.3 ± 2.3	5.38 ± 0.58	0.72 ± 0.05	34.9 ± 4.4	mud/detr/silt	0	70%
	11.9–21.0	18.8–32.2	3.80–7.95	0.40–1.00	2–68			40 to 100%

(Salin, salinity; Temp, water temperature; DO, dissolved oxygen; Dist, distance from shoreline; Substr, substrate; Stems, number of emergent *Spartina* stems; % SAV, submerged aquatic vegetation cover (i.e., *Vallisneria/Ruppia*).

The mean depth of samples was 0.16 m and the mean distance was 0.7 m at the latter site; whereas the mean depth of samples was 0.48 m and the mean distance was 2.8 m at the former site. Samples came from emergent *Spartina* stems at both of these sites.

Sediments were similar among the four subtidal unvegetated sites, consisting mainly of a shallow layer (1–2 cm) of silt overlying muddy sand (Table 1). Worm tubes (i.e., *Diopatra*) along with associated debris potentially provided cover for small crabs at the Marsh Point–subtidal marsh site. The predominance of shell hash within the sediment matrix at the Fort Point–marsh edge site provided abundant refuge for small crabs. The dominant sediment component at the Marsh Point–marsh edge site was sand with small amounts of shell hash. Marsh Point–marsh edge samples contained a higher mean density of emergent *Spartina* stems than Fort Point–marsh edge samples (i.e., 94.3 vs. 64.5 per sample). Finally, habitat structure consisting of submerged aquatic vegetation (SAV) (*Vallisneria*/*Ruppia*) occurred at the Fort Bayou location, where SAV coverage averaged 70%. The dominant sediment component at this location was soft mud.

Crab Abundance

The 130 1.77-m^2 (= 230 m^2) suction samples yielded a total of 2,431 (10.6 per m^2) blue crabs, including 1,458 (60%) small (i.e., <6.0 mm CW) and 973 (40%) large (i.e., ≥6.0 mm) crabs. *Callinectes sapidus* made up 92.2% of the small crabs and 94.8% of the large crabs, whereas *C. similis* made up 3.7% and 2.3% of the small and large crabs, respectively. Unidentified damaged blue crabs made up 3.6% of the total number of blue crabs.

Abundances of small juvenile crabs fluctuated much more than large juvenile crabs during the study period (Fig. 2). Distinct peaks in abundances of small crabs appeared at some of the sites on September 7 and October 5 (i.e., 2nd and 4th sample periods), presumably reflecting monthly pulses of postsettlement crabs during the study period (Fig. 2A, Fig. 2B). These pulses coincided with the new moon periods in September (Sep 8) and October (Oct 8) and followed the August (Aug 24) and September (Sep 22) full moon periods by 2 wk. The widest differences in densities of small and large crabs were on the second sample date, when small crabs were clearly more abundant (grand mean ± 1 SE = 13.67 ± 8.69 m^2 small vs. 3.50 ± 2.21 m^2 large) and on the sixth sample date, when large crabs were actually more abundant (grand mean ± 1 SE = 1.48 ± 1.08 m^2 small vs. 3.34 ± 1.95 m^2 large).

Site-specific temporal changes in crab abundance underscored the overall temporal pattern. On 7 September, densities of small crabs reached up to 15.25 m^2 at one of the four subtidal sites (Marsh Point–marsh subtidal) and up to 64.78 m^2 at one (Fort Point–marsh edge) of the three structured-habitat sites (i.e., fringing marsh or SAV). Again on 5 October, densities of small crabs reached 18.83 m^2 and 26.55 m^2 at the same subtidal (Marsh Point–marsh subtidal) and structured habitat sites (Fort Point–marsh edge). Although temporal variation in the abundance of large crabs was not marked, relatively high densities of large crabs from marsh edge sites as high as 14.50 m^2 at Marsh Point and 20.53 m^2 at Fort Point on September 21 likely reflected growth and survival of the September 7 cohort of small crabs (Fig. 2).

Spatial variation in abundances of early crabs reflected land-

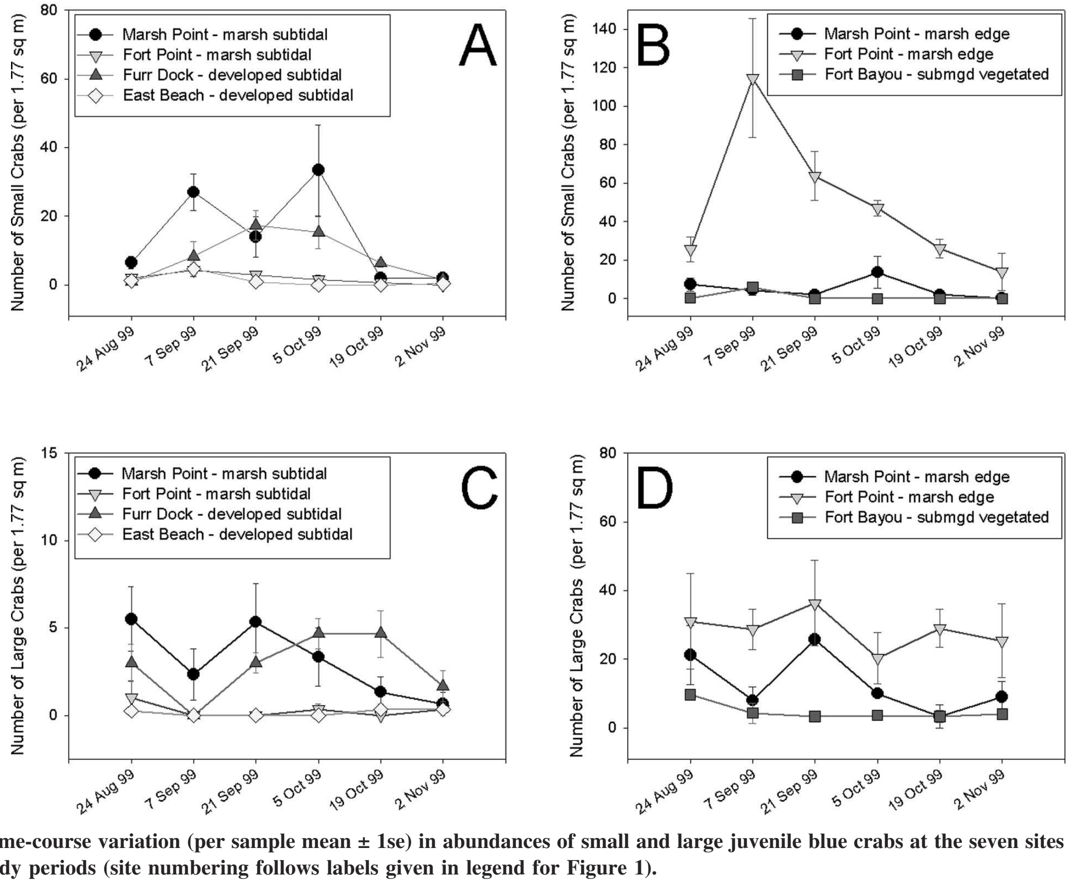

Figure 2. Time-course variation (per sample mean ± 1se) in abundances of small and large juvenile blue crabs at the seven sites across the six biweekly study periods (site numbering follows labels given in legend for Figure 1).

scape, habitat, and site-specific differences. Crabs were much more abundant at the two lower subtidal unvegetated sites than at the two subtidal unvegetated sites located further upestuary (paired-$t = 5.310$; $P = 0.003$ vs. 0.025 Bonferroni critical value). Generally, abundances of early crabs were much greater from structured habitat sites than from subtidal unvegetated sites (paired-$t = 13.470$; $P < 0.001$ vs. 0.0125 Bonferroni critical value); although differences in abundances of small crabs were not nearly as great between subtidal unvegetated and structured habitats (paired-$t = 3.198$; $P = 0.024$ vs. 0.05 Bonferroni critical value). Low abundances of large crabs generally occurred at the four subtidal unvegetated sites, where densities never reached above 3.11 m^2 (Fig. 2C); whereas large crabs were much more abundant among the structured-habitat sites, where densities reached up to 20.53 m^2 (Fig. 2D). The Fort Point–marsh edge site yielded much higher abundances of early crabs than the Marsh Point–marsh edge site (paired-$t = 6.592$; $P = 0.001$ vs. 0.0167 Bonferroni critical value).

Analysis of Variance on abundances of small and large crabs included data from the two locations where both marsh edge and adjacent subtidal habitat were sampled. Levene tests showed that error variance in log transformed abundances of small crabs was homogeneous ($F = 1.683$; $P > 0.05$); however, the error variance of log transformed abundances of large crabs was moderately heterogeneous ($F = 3.23$; $P < 0.001$). Although all three main effects of location, habitat, and sample period were significant ($F > 10.0$; $P < 0.005$) for small crabs, a significant 2-way interaction ($F = 118.2$; $P < 0.001$) precluded direct interpretation of the location and habitat main effects. Strong temporal variation in small crab abundance was evidenced by a significant sample period effect ($F = 13.5$; $P < 0.001$), which was not confounded by any interactions. No other interaction effects were significant within this fully factorial 3-way model.

At Marsh Point, densities of small crabs were greater in adjacent subtidal habitat than at the marsh edge (grand mean ± 1 SE $= 8.00 \pm 3.07\ m^2$ vs. $2.79 \pm 1.13\ m^2$), whereas at Fort Point, densities of small crabs were much higher in the marsh edge than in adjacent subtidal habitat (grand mean ± 1 SE $= 27.40 \pm 8.53\ m^2$ vs. $1.10 \pm 0.36\ m^2$). Furthermore, subtidal densities of small crabs were greater at Marsh Point than at Fort Point; and conversely, marsh edge densities were greater at Fort Point than at Marsh Point.

Like was seen for small crabs, a significant 2-way interaction ($F = 34.0$; $P < 0.001$) precluded direct interpretation of the location and habitat main effects for large crabs. However, the location main effect was nonsignificant ($F = 0.132$; $P = 0.718$), whereas the habitat main effect was significant ($P = 141.5$; $P < 0.001$) for large crabs. Weak but significant temporal variation in large crab abundance was not confounded by any interactions ($F = 2.837$; $P = 0.025$). No other interaction effects were significant within this fully factorial 3-way model.

The location by habitat interaction effect for large crabs reflected the greater difference in abundance between marsh edge and subtidal habitats at Fort Point than at Marsh Point; although, large crabs were more abundant in marsh edge than in adjacent subtidal habitat at both locations. High densities of large crabs occurred within marsh-edge at both Fort Point and Marsh Point (grand mean ± 1 SE $= 16.07 \pm 1.24\ m^2$ and $7.27 \pm 2.00\ m^2$, respectively) relative to adjacent subtidal habitat (grand mean ± 1 SE $= 0.16 \pm 0.09\ m^2$ and $1.74 \pm 0.47\ m^2$, respectively).

Crab Size Distributions

Size distributions of similar form occurred among the four subtidal unvegetated sites, with single modes represented by post-settlement crabs (<6 mm CW), and with few large crabs (Fig. 3). Relatively more small crabs occurred at lower subtidal unvegetated sites (i.e., Marsh Point–marsh subtidal and Furr Dock–developed subtidal), than at subtidal unvegetated sites farther upestuary (i.e., Fort Point–marsh subtidal and East Beach–developed subtidal), where overall abundances of crabs were also lower (KS $D = 0.328$; $P < 0.001$ vs. 0.0125 critical value). Furthermore, large crabs were relatively more abundant at structured-habitat sites (i.e., Marsh Point–marsh subtidal, Fort Point–marsh subtidal and Fort Bayou–submerged vegetated) than at subtidal unvegetated sites (i.e., Furr Dock–developed subtidal, Marsh Point–marsh subtidal, Fort Point–marsh subtidal, and East Beach–developed subtidal) (KS $D = 0.337$; $P < 0.001$ vs. 0.0125 critical value).

Appreciable numbers of large crabs (CW ≥6 mm) occurred at structured-habitat sites; however, size distributions varied among these sites. For example, crab size-distributions were very different between the marsh-edge sites at Fort Point and Marsh Point (KS $D = 0.466$; $P < 0.001$ vs. 0.0125 critical value); whereas, distributions were similar between the Marsh Point–marsh-edge and Fort Bayou–submerged vegetated sites (KS $D = 0.115$; $P > 0.1$). Crabs were much less abundant and represented a wider range of sizes at

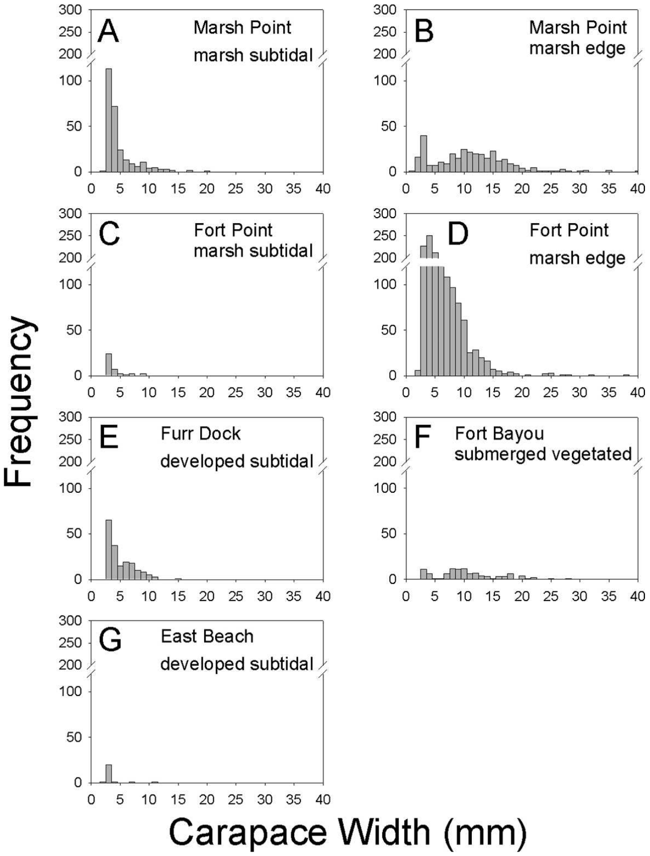

Figure 3. Size-distributions of *C. sapidus* sampled at the seven sites pooled across the study period; lefthand panels depict subtidal unvegetated sites (i.e., sites 3, 6, 1, and 4), and righthand panels depict structured habitat sites (i.e., sites 2, 5, and 7).

the Marsh Point–marsh-edge site than at the Fort Point–marsh-edge site. Crabs from the former site reached 35-mm CW; whereas crabs from the latter site only reached 25-mm CW. Crabs <12-mm CW were much more abundant at the Fort Point–marsh-edge site than at the Marsh Point–marsh-edge site. The size distribution of the Fort Bayou–submerged vegetated site was distinctive in not containing many early postsettlement crabs. Although the forms of the size distributions were similar between the Marsh Point–marsh edge site and the Fort Bayou–submerged vegetated site, abundances were much lower at the latter site.

DISCUSSION

Spatio-temporal variation in the early recruitment dynamics of blue crabs reflected temporal effects such as lunar periodicity, location effects such as position within the estuary, and habitat features. The blue crab recruitment paradigm highlights the importance of SAV habitat for blue crab settlement (Heck & Thoman 1984, Orth & van Montfrans 1987); and studies of blue crab recruitment conducted on the US Gulf coast confirm SAV to be an important habitat (Thomas et al. 1990, Williams et al. 1990, Rozas & Minello 1998). In Mississippi, seagrass (*Halodule*) beds located on the protected sides of barrier islands serve as important nursery habitat for early blue crabs. However, submerged SAV makes up a small portion of available substrate for settlement within Mississippi coastal waters; and the importance of alternative habitats for early blue crab recruitment is not well-known. Recently, Montane and Lipcius (unpublished) found that unvegetated habitats adjacent to vegetated habitat can harbor early blue crabs in lower Chesapeake Bay. Rakocinski et al. (2003) also noted that the extensive nature of subtidal unvegetated habitat makes it potentially important for early crab recruitment in Mississippi Sound.

We hypothesized that subtidal unvegetated habitat may provide a subsidiary source of early postsettlement crabs prior to their concentration within structured habitats (Rakocinski et al. 2003). However, the present study did not fully support the idea that subtidal unvegetated sites subsidize adjacent structural habitats. Abundances of postsettlement crabs within adjacent subtidal habitat varied greatly between two marsh locations. Furthermore, small crabs were very abundant within the marsh-edge at Fort Point, even though small crabs were scarce at the adjacent subtidal unvegetated site. Conversely, the subtidal unvegetated site at the Marsh Point location located further downestuary yielded greater abundances of small crabs than did the adjacent marsh-edge habitat. Apparently, adjacent subtidal unvegetated habitat is not a necessary source of early crabs, suggesting postsettlement crabs may move over fairly large distances to find suitable habitat. Other studies confirm that postsettlement crabs undertake movements over considerable distances (Mense & Wenner 1989, Pardieck et al. 1999).

This study and others imply that supply rates of early crabs of different stages can vary relative to spatial position within the estuarine landscape. For example, supply rates can vary with currents, winds, or other hydrologic factors (Morgan et al. 1996, Pardieck et al. 1999). In a previous study within Mississippi Sound, correlations between salinity and early crab abundance revealed episodic pulses of settling crabs in conjunction with wind-induced currents and tides (Rakocinski et al. 2003). In the present study, the two most seaward subtidal sites yielded markedly higher abundances of postsettlement crabs than two subtidal sites located further upestuary. Each set of sites included both marsh and developed shorelines. In contrast, Pardieck et al. (1999) found that densities of small crab instars increased with upriver distance due to strong onshore transport forces in the York River estuary of Chesapeake Bay.

Upestuary movement of early crabs is regarded as important for recruitment on the mid-Atlantic coast (Olmi 1994, 1995, Pardieck et al. 1999). One classic mid-Atlantic recruitment model involves upestuary transport of small crabs into low salinity SAV habitat, facilitated by tidal action. In the present study, small crabs were largely lacking within SAV habitat at the farthest upestuary site in Fort Bayou. However, large juvenile crabs were fairly common at this site. This implied regional difference in upestuary transport of small crabs possibly reflects corresponding differences in the influence of tidal periodicity and amplitudes between the US mid-Atlantic and Gulf coasts. Tides are semidiurnal and moderate in the mid Atlantic; whereas they are diurnal and relatively weak on the Gulf coast. The role of upestuary movements within the blue crab ontogenetic recruitment pattern needs to be studied on a larger scale before its importance can be fully assessed for the US Gulf coast.

Site-specific habitat features apparently mediated crab recruitment. For example, size distributions and abundances of crabs differed between the two marsh edge sites, possibly in relation to both hydroperiod and refuge availability. Although both sites provided habitat structure in the form of fringing *Spartina*, the Fort Point marsh edge site was submerged for greater periods and provided additional refuge for small crabs in the form of abundant shell hash. Accordingly, small crabs were also very abundant at this site; whereas the marsh edge at Marsh Point was occupied by much lower abundances of small crabs and a wider range of crab sizes.

Ongoing debate concerns whether the abundance of early crabs translates into the successful recruitment of harvestable blue crabs (van Montfrans et al. 1995). In this study, noticeable temporal variation in the abundance of small crabs corresponded with weaker temporal variation in the abundance of large crabs, implying some uncoupling between the supply of postsettlement crabs and subsequent abundances of early juvenile crabs. However, a closer inspection of temporal variation at specific sites where amplitudes were well-defined indicated coupling between abundances of small and large crabs. Heck and Coen (1995) proposed that supply rates of early crabs are considerably higher on the US Gulf coast than on the US East coast, but that higher mortality on the Gulf coast results in similar densities of adult crabs in both regions. Thus, the US Atlantic coast may be relatively recruitment limited compared with the US Gulf coast (van Montfrans et al. 1995). Nevertheless, identifying habitat use patterns is essential for understanding the recruitment dynamics of any commercial fishery species. This study allowed us to consider the relative importance of alternative nursery habitats for early stages of blue crabs across an inshore Gulf of Mexico landscape.

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