Composition, Seasonality, and Life History of Decapod Shrimps in Great Bay, New Jersey

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Abstract - Shrimp are critical to estuarine food webs because they are a resource to economically and ecologically important fish and crabs, but also consume primary production and prey on larval fish and small invertebrates. Yet, we know little of their natural history. This study determined shrimp community composition, seasonality, and life histories by sampling the water column and benthos with plankton nets and benthic traps, respectively, in Great Bay, a relatively unaltered estuary in southern New Jersey. We identified 6 native (*Crangon septemspinosa*, *Palaemon vulgaris*, *P. pugio*, *P. intermedius*, *Hippolyte pleuracanthus*, and *Gilvossius setimanus*) and 1 non-native (*P. macrodactylus*) shrimp species. These results suggest that the estuary is home to a relatively diverse group of shrimp species that differ in the spatial and temporal use of the estuary and the adjacent inner shelf.

Introduction

Estuarine ecosystems are typically dynamic, especially in temperate waters, and comprised of a diverse community of resident and transient species. These can include several abundant shrimp species which are vital to the system as prey (Able and Fahay 2010), predators during different life stages (Ashelby et al. 2013, Bass et al. 2001, Locke et al. 2005, Taylor 2005, Taylor and Danila 2005, Taylor and Peck 2004), processors of plant production (Welsh 1975), and commercially important bait (Townes 1938). Although shrimp are a critical link in the estuarine food web, relatively little work has been done to determine their species composition and examine their life histories in estuaries along the east coast of the US. Our lack of understanding has been compounded by the occurrence of non-native species documented in estuaries in the northeastern US including *Palaemon macrodactylus* M.J. Rathbun (Oriental Shrimp), *P. elegans* Rathke (Rockpool Prawn), and *P. adspersus* Rathke (Baltic Prawn) (González-Ortegón et al. 2015, Warkentine and Rachlin 2012).

Crangon septemspinosa Say (Sand Shrmip) and *Palaemonetes vulgaris* (Say) (= *Palaemon vulgaris*; De Grave and Ashelby 2013) (Marsh Grass Shrimp), however, have received some attention. Both species have been documented in the Mullica River–Great Bay estuary in New Jersey (Kennish et al. 2004). Sand Shrimp have also been documented preying on juvenile *Pseudopleuronectes americanus* (Walbaum) (Winter Flounder), as well as feeding on their eggs

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(Taylor and Danila 2005, Witting and Able 1995). Some shrimp species also play a role in detritus decomposition and nutrient cycling. For instance, *Palaemonetes pugio* Holthuis (= *Palaemon pugio*; De Grave and Ashelby 2013) (Daggerblade Grass Shrimp) accelerates the breakdown of detritus and makes detrital energy more readily available to several trophic levels (Welsh 1975). Prior research in the study area have only identified Marsh Grass Shrimp (Rountree and Able 1993, Wilson and Able 1995) or recognized 3 species: Marsh Grass Shrimp, Daggerblade Grass Shrimp, and *Palaemon intermedius* (Stimpson) (Able et al. 2018). *Palaemon intermedius* is now also recognized as *Palaemon mundusnovus* (De Grave and Ashelby 2013).

Despite the abundance and importance of shrimp in estuaries, there is relatively little known of their distribution and life history with the exception of Sand Shrimp (Haefner 1979, Modlin 1980, Price 1962).The objectives of this study were to determine the community composition and seasonality of the shrimp species in 2 polyhaline habitats, the water column and benthos, of Great Bay, a relatively undisturbed estuary in southern New Jersey. In addition, we explored the reproduction and recruitment patterns for the dominant species collected, Sand Shrimp and Marsh Grass Shrimp.

Field-Site Description

The Great Bay estuary is a shallow, polyhaline drowned river valley located near Tuckerton, in southern New Jersey (Fig. 1). It is one of the least impacted estuarine systems on the east coast of the United States (Kennish and O'Donnell 2002). Most of the estuary is located within the Jacques Cousteau National Estuarine Research Reserve (JCNERR) and is connected to the Atlantic Ocean at Little Egg Inlet (Kennish et al. 2004). The Rutgers University Marine Field Station (RUMFS) is strategically located at the mouth of the Great Bay estuary, where water column and benthic habitats can be easily accessed. Little Sheepshead Creek (LSHC) is located 2.5 km behind Little Egg Inlet where exchanges between the ocean and southern Barnegat Bay (Little Egg Harbor) and Great Bay estuaries occur during regular semidiurnal tides in water depths of 3–4 m (Able et al. 2017, Charlesworth 1968). Previous studies over several decades have indicated ichthyoplankton samples analyzed from LSHC represent resident and estuarine dependent assemblages (Able et al. 2011, Chant et al 2000, Neuman and Able 2003, Witting et al. 1999). The RUMFS boat basin (Fig. 1), with water depths of 1–2 m, has been naturalized since its creation in the 1930s (Able 2015) and is representative of much of the high-salinity portions of Great Bay based on extensive sampling of the fishes and crabs over several decades (Able et al. 2010, Jivoff and Able 2001). The intertidal perimeter is fringed with *Spartina alterniflora* Loisel (Saltmarsh Cordgrass), brown algae (*Ascophyllum nodosum* f. *scorpioides* Hauck, *Fucus vesiculosus* L. [Bladder Wrack]), and green algae (*Ulva lactuca* L. [Sea Lettuce]). The subtidal portion has a muddy, uncontaminated substrate in the vicinity of the docks where the sampling took place.

Methods

Sampling techniques

We collected all shrimp species regularly (weekly to monthly) from 2 sites in the Great Bay estuary from January to December 2017 at Little Sheepshead Creek Bridge and the boat basin at RUMFS (Fig. 1, Table 1). Sampling of the water column at ~1.5 m depth at Little Sheepshead Creek Bridge took place during the night

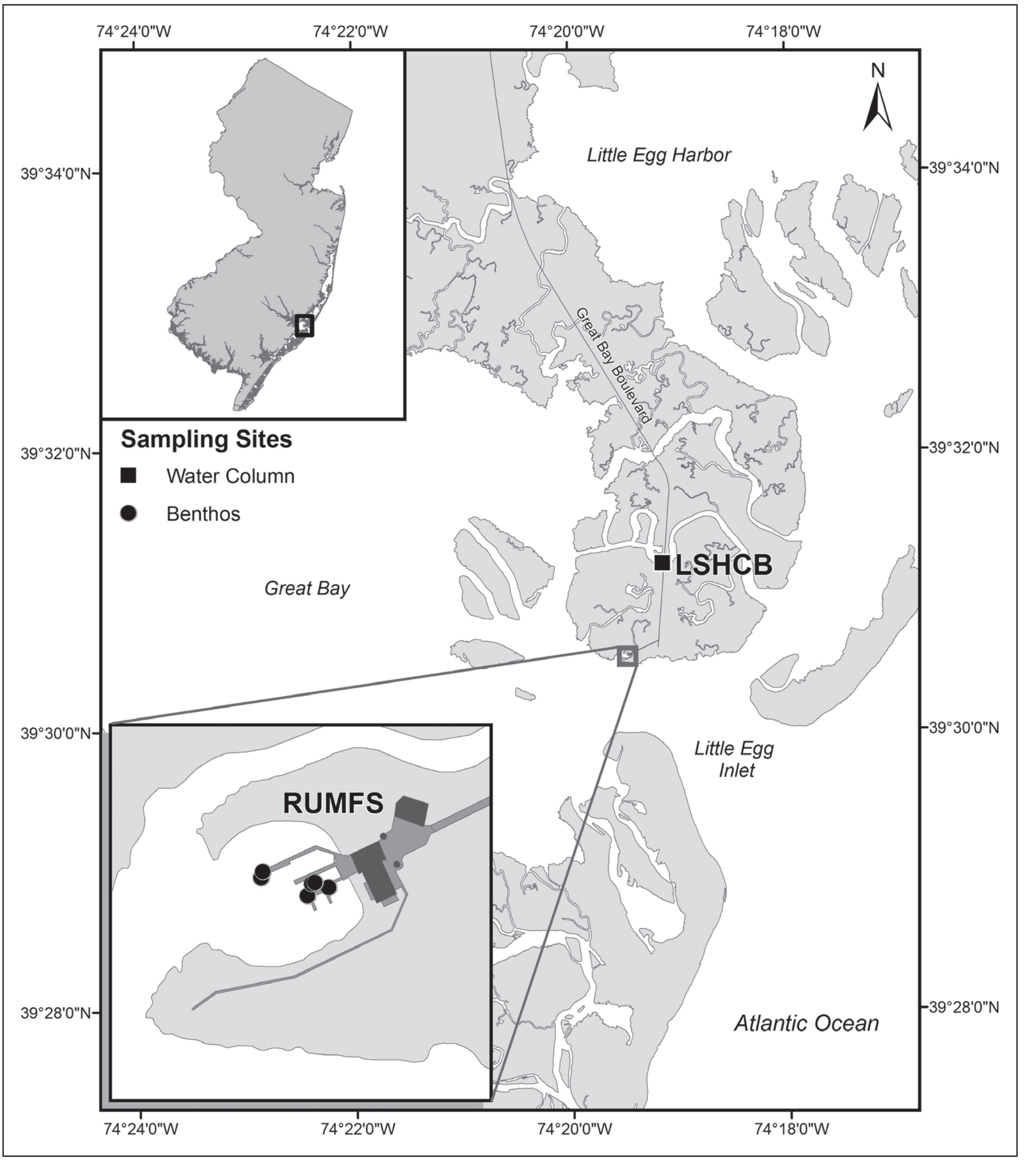

Figure 1. Map of shrimp sampling locations within the Great Bay estuary in southern New Jersey. Sampling of the water column occurred at Little Sheepshead Creek bridge (LSHCB), benthos was sampled in Rutgers University Marine Field Station (RUMFS) boat basin. Insets show sampling location in New Jersey and details of boat basin site. See Table 1 for additional details.

Table 1. Description of sampling location, habitat, and effort for juvenile and adult shrimp within the Great Bay estuary in southern New Jersey during January–December 2017. RUMFS = Rutgers University Marine Field Station. See Figure 1 for sampling locations.

Habitat	Location	Sampling gear	Sampling frequency	Sampling depth
Water column	Little Sheepshead Creek (between Great Bay and Little Egg Harbor estuaries)	Plankton net (diameter = 1 m, 1-mm mesh)	Once a month (3 tows) on night flood tide	1.5 m
Benthos	RUMFS boat basin	Wire-mesh trap (length x diameter = 45 cm x 35 cm; conical opening = 20 mm in diameter; 6-mm mesh)	Twice a week (6 traps)	1.0 m

Table 2. Shrimp species composition, raw abundance, and size ranges by gear, for monthly collections in Great Bay estuary during 2017.

			Number of individuals		Size range (mm)	
Family	Scientific name	Common name	Plankton	Benthos	Plankton	Benthos
Crangonidae	*Crangon septemspinosa*	Sand Shrimp	2343	57	2.1–40.1	27.9– 40.5
Palaemonidae	*Palaemon vulgaris*	Marsh Grass Shrimp	351	162	11.4–33.7	18.6–38.6
	Palaemon pugio	Daggerblade Grass Shrimp	8	42	6.2–31.5	28.6–41.0
	Palaemon mundusnovus	Brackish Grass Shrimp	6	3	14.0–27.5	29.4–33.1
	Palaemon macrodactylus	Oriental Shrimp	4	16	32.9–52.1	34.4–50.0
Hippolytidae	*Hippolyte pleuracanthus*	False Zostera Shrimp	39	-	5.3–15.5	-
Callianasidae	*Gilvossius setimanus*	Ghost Shrimp	1	-	22.0	-

flood tide. We deployed a 1 m-diameter (1 mm mesh) plankton net on the last week of each month from the bridge for 30 min. We used 2 General Oceanics flowmeters to measure water volume for calculating shrimp density during each tow: one attached in the mouth of the plankton net and the other suspended from the bridge as the control, to determine if net clogging occurred. After collection, all invertebrates were removed, preserved in 95% EtOH, and stored to be sorted for all shrimp at a later date. We fished unbaited wire-mesh traps (6 mm mesh) in the boat basin (average collecting depth = 1 m) twice a week, with a soak time varying from 3 to 4 days (Table 1). All shrimp were immediately removed and preserved in 95% EtOH to be identified and measured at a later date.

For both sampling programs, we sorted samples in shallow pans, identified shrimp to the lowest possible taxon, and counted and measured specimens (to the nearest 0.1 mm total length [TL= tip of rostrum to end of telson]) under a dissecting microscope. We utilized keys developed by Weiss (1995), Williams (1984), and Warkentine and Rachlin (2012) to identify shrimp to the species level. We note that it has been proposed that the taxonomy of some species of *Palaemon* have been changed to *Palaemonetes* in recent years and also, that *P. mundusnovus* has replaced *P. intermedius* (De Grave and Ashelby 2013). Gravid shrimp were counted and measured, based on the visual presence of eggs on the abdomen of each female.

Environmental variables

We measured water temperature and salinity for both sampling programs using a YSI multiparameter meter (Professional Plus) at the time and water depth where samples were collected. We averaged the readings monthly for each sampling location.

Data analysis

We standardized species-specific abundance of shrimp from each plankton net sampling event to density (catch per 1000 m^3). We calculated shrimp abundance for the wire mesh traps from the benthos by dividing the number of individuals per species by the number of days fished and multiplying by 7 for a final catch per unit effort (CPUE) of individuals per week.

To minimize skew in abundance, we plotted the proportion of individuals of each species relative to the total number of individuals per month. Length data for dominant species was sorted into size classes and treated to reflect the abundance of species per month; we log-transformed shrimp density or CPUE for each sampling gear.

Results

Environmental variables

Monthly variation in mean water temperature was pronounced in the plankton and benthos during 2017 (Fig. 2). Highest temperatures (mean ± SD) in both habitats were recorded in July and August (23.9 ± 1.7 ºC) and lowest in December and January (3.7 ± 3.3 ºC). Most extreme temperature changes in both habitats occurred from April through June and October through December. Salinity, which varied little over the sampling period, was also similar in the 2 habitats, with an average of 29.7 ppt in the water column and 29.1 ppt in the benthos (Fig. 2).

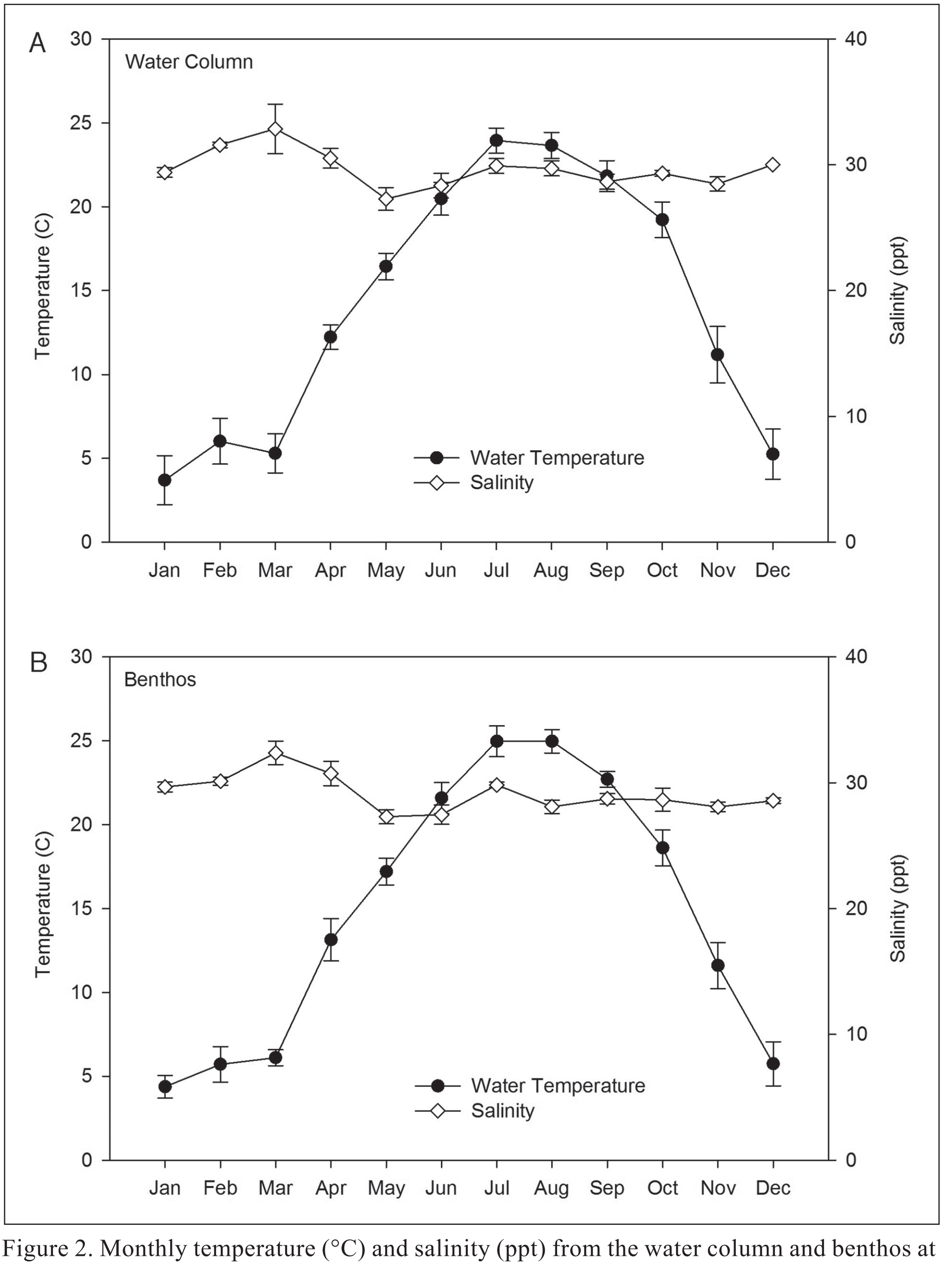

Figure 2. Monthly temperature (°C) and salinity (ppt) from the water column and benthos at the sampling sites during 2017. Error bars are 1 standard deviation of the mean. See Figure 1 for sampling locations.

Species composition

We caught 7 shrimp species from 4 families (Palaemonidae, Crangonidae, Hippolytidae, Callianasidae) while sampling with the plankton net in the water column (n = 2752 individuals) and traps on the benthos (n = 280 individuals) (Table 2). The dominant species in the water column was *C. septemspinosa* (85.1% of all individuals). The dominant species from the benthos was *P. vulgaris* (57.9%) followed by *C. septemspinosa* (20.9%). All 5 species collected in the benthos were also found in the water column. The 2 species that were only found among the plankton were *Hippolyte pleuracanthus* (n = 39) and *Gilvossius setimanus* (n = 1). Other species were represented by fewer individuals, including *P. pugio* and *P. mundosnovus* (Table 2). One non-native species was collected in both the water column and benthos: *Palaemon macrodactylus* (n = 4 and 16, respectively).

Total shrimp abundance varied by month in the different habitats (Fig. 3). The majority of shrimp specimens collected in the water column occurred during the summer months of May through July. In the benthos, most shrimp were collected

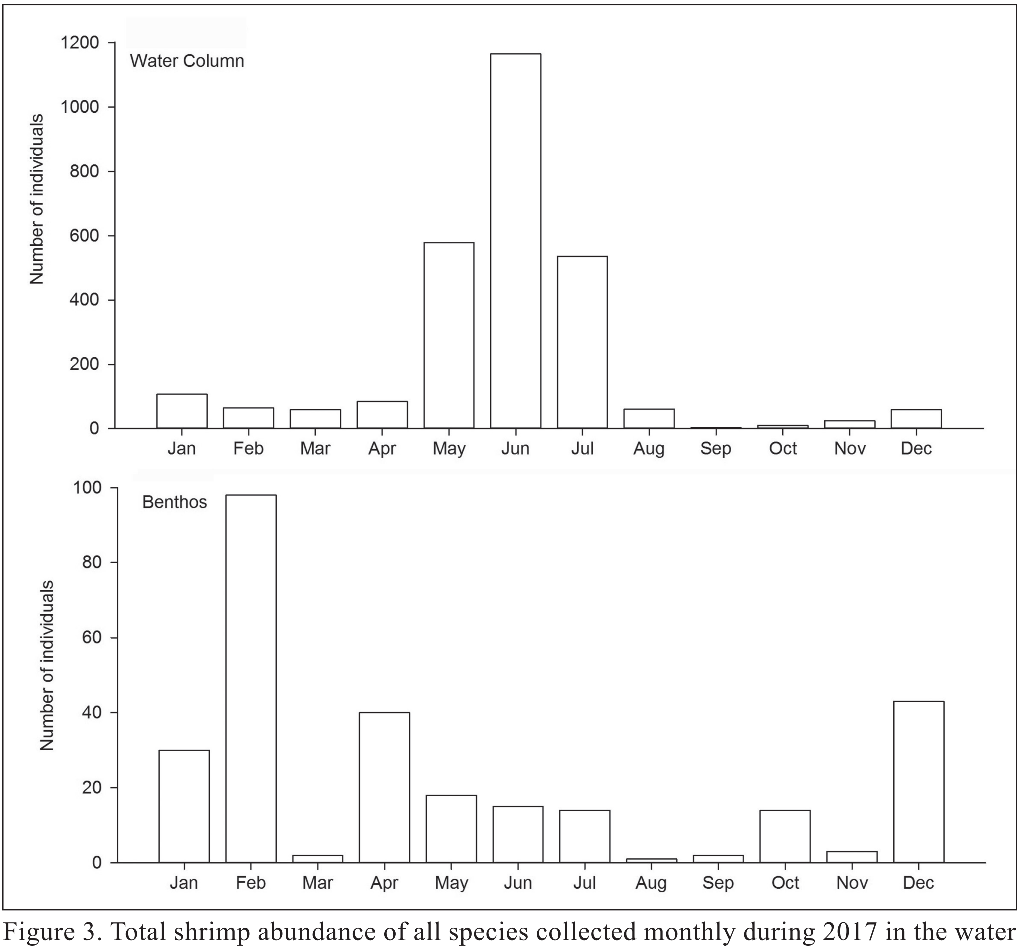

Figure 3. Total shrimp abundance of all species collected monthly during 2017 in the water column (top) of Little Sheepshead Creek and in the benthos (bottom) of RUMFS boat basin. Note the difference in y-axis scales.

in February, with relatively high numbers collected during December–January and April–July. The size composition of shrimp varied between the 2 habitats as sampled with different gears (Fig. 4). Most shrimp caught in the water column with the plankton net were <30 mm TL (average = 17 mm). Shrimp collected on the benthos with wire-mesh traps averaged 33 mm; there were relatively few individuals less than 24 mm and none less than 17 mm.

There was pronounced seasonality in the dominant shrimp species between the 2 different habitats (Fig. 5). In the water column, *C. septemspinosa* dominated the collections from January through September followed by *H. pleuracanthus* from September through November, and *P. vulgaris* were abundant from November through January. On the benthos, *P. vulgaris* dominated from March through October while *P. macrodactylus and P. mundusnovus* were the only shrimp collected in November. Also on the benthos, *P. pugio* was collected from December through February, and *C. septemspinosa* was caught during January and February.

Life history of dominant species

The 2 dominant shrimp species (*C. septemspinosa, P. vulgaris)* have different patterns of reproduction and habitat use. *C. septemspinosa* was rare in collections from September through November (Fig. 6). Adult female *C. septemspinosa* were identified as those individuals >16 mm based on the minimum size with eggs on the abdomen in this study. These adults were captured in both habitats: in the water

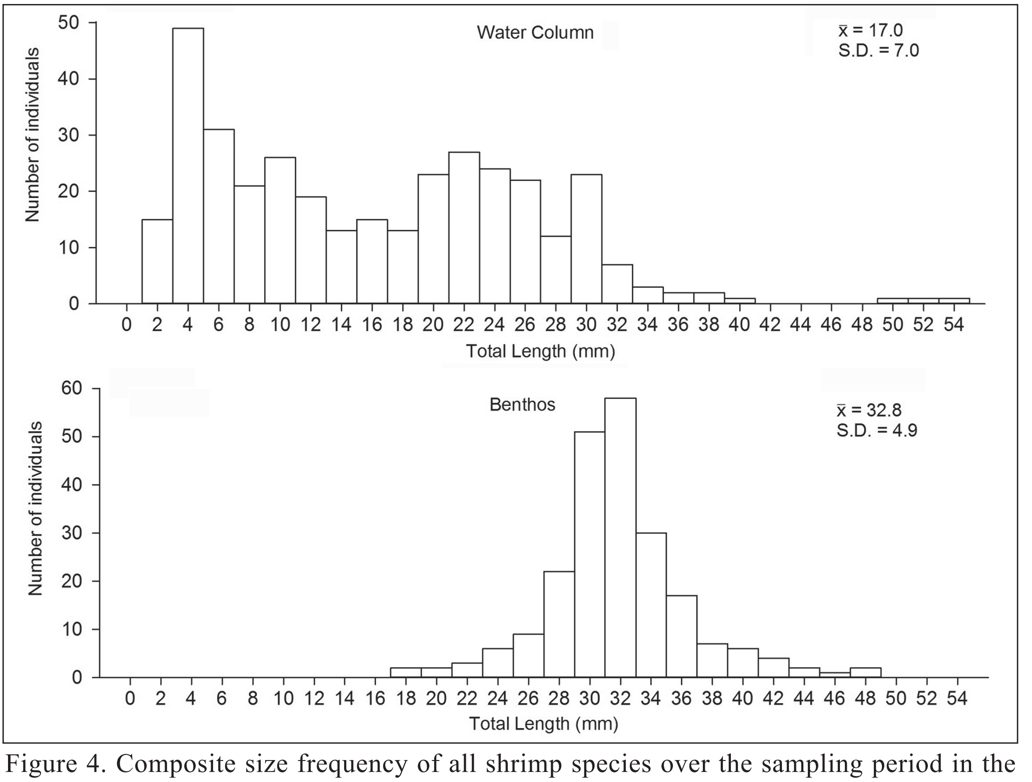

Figure 4. Composite size frequency of all shrimp species over the sampling period in the water column (top) and benthos (bottom).

column from November through April and on the benthos during January and February. A few gravid females of *C. septemspinosa* were present in both February (n = 8), March (n = 1), and again in June (n = 3), which is perhaps indicative of 2 spawning seasons per year. The average length of gravid females collected in February was 36.9 mm, whereas those collected in June averaged 16.9 mm. *Crangon septemspinosa* recruitment began in February, but small (<10 mm) individuals occurred consistently in the water column through August. Juveniles (<16 mm) were present in the estuary in every month, but most occurred in February.

Palaemon vulgaris was rare in collections in August and September but present the rest of the year. Adult (>20 mm) *P. vulgaris* dominated from January through July and again from October through December in the benthos and water column (Fig. 7). Gravid females (>27 mm TL) were present in April through July

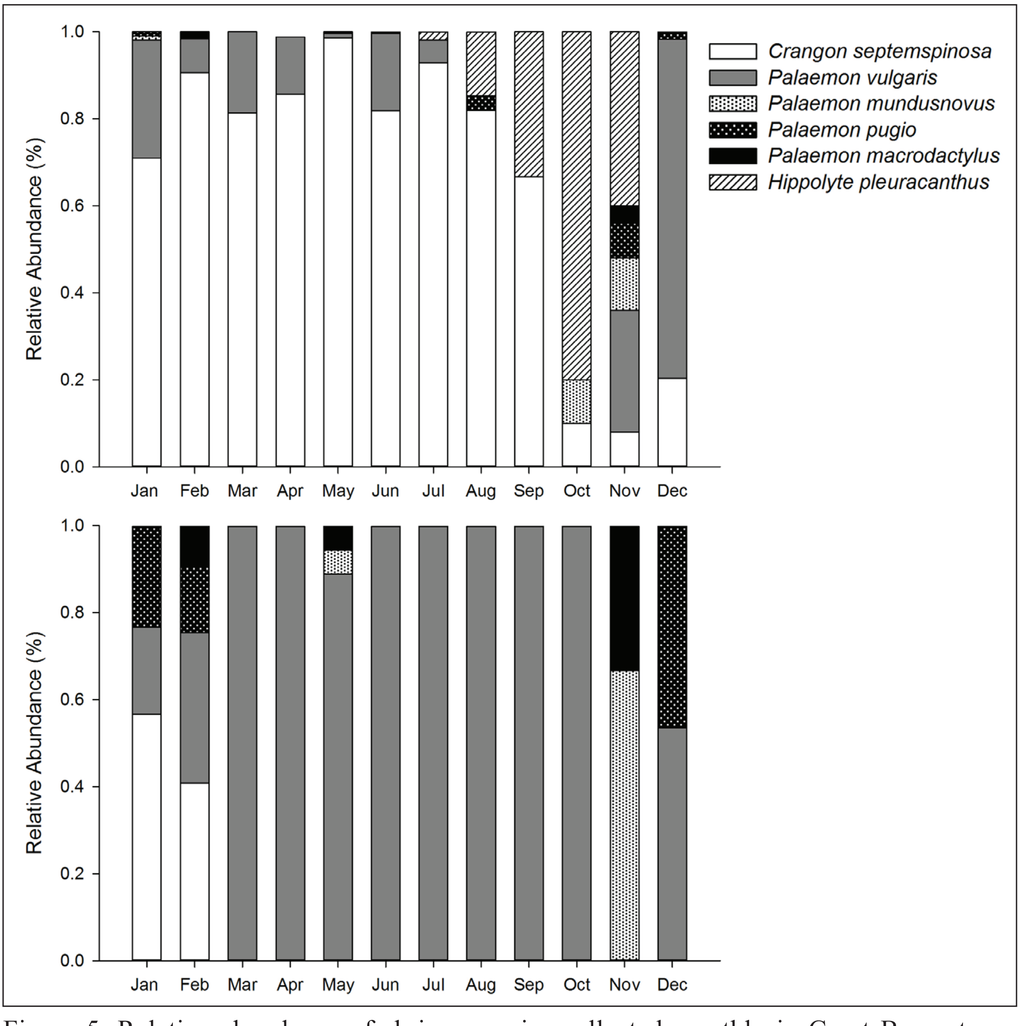

Figure 5. Relative abundance of shrimp species collected monthly in Great Bay estuary in 2017 from plankton nets in the water column (top) and wire-mesh traps on the benthos (bottom).

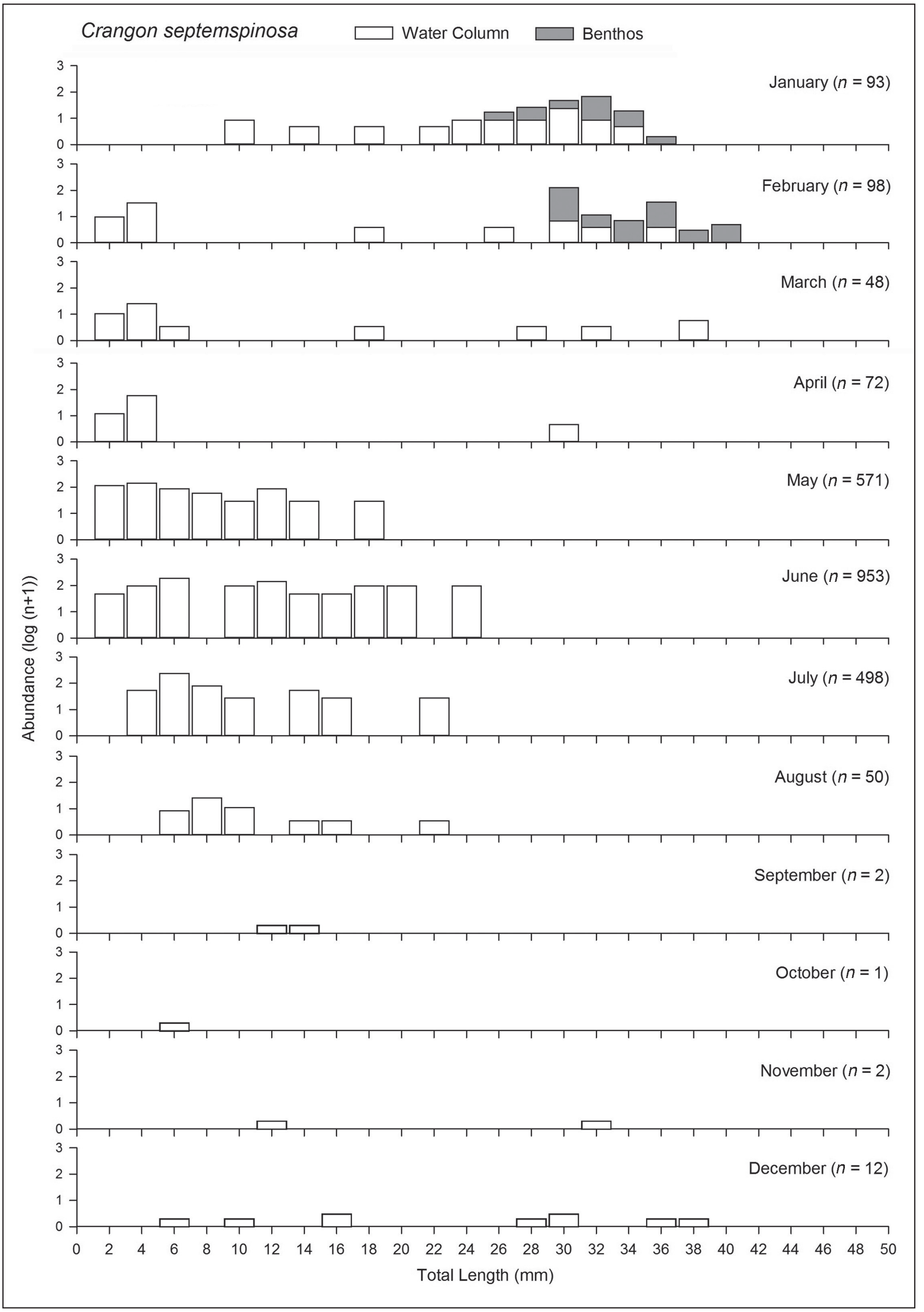

Figure 6. *Crangon septemspinosa* length frequency from monthly sampling during 2017 in the water column (plankton net) and benthos (wire-mesh traps).

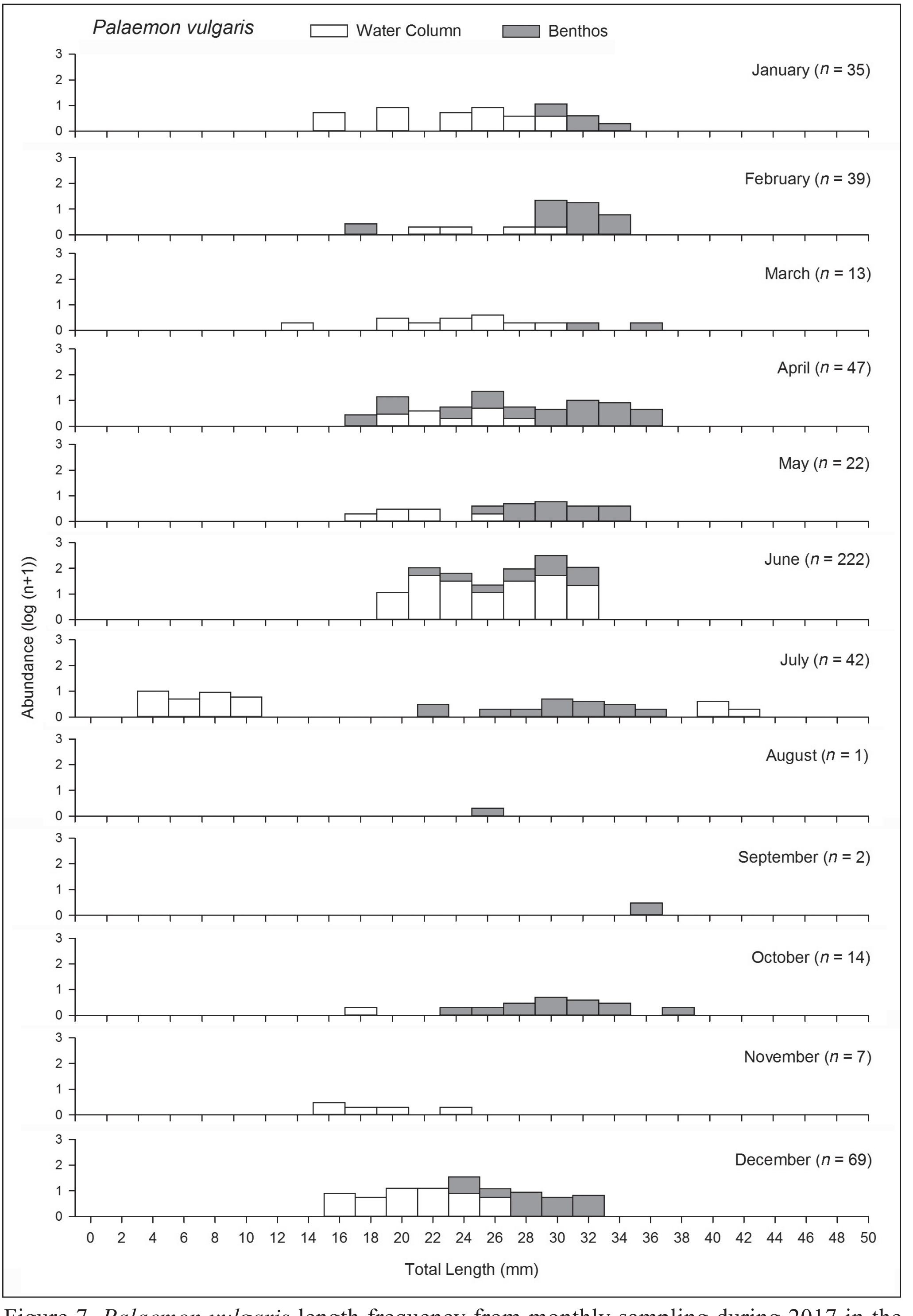

Figure 7. *Palaemon vulgaris* length frequency from monthly sampling during 2017 in the plankton (plankton net) and benthos (wire-mesh traps).

(*n* = 29), indicative of a single, spring–early summer spawning period. Females collected in May and July had an average length of 32.2 mm and 32.7 mm, respectively, and those collected in June had an average length of 30.6 mm. Recruitment began in July with the smallest individuals (5.6–9.6 mm) present in the water column at that time.

Discussion

Limitations of the study

Sampling with different gears in different habitats on different schedules is likely to introduce some biases in size and species composition of shrimp caught and could perhaps influence the interpretation of life histories. This has been shown for the fauna in the study estuary in comparisons across several gears (Able 1999, Able et al. 2005b). A striking example is in the difference in size of shrimp between the 2 sampling gears in this study. Much of this difference is likely an influence of mesh size, with larger individuals only represented in the traps, which had larger mesh relative to the mesh of the plankton net. Mesh size differences may also explain the absence of the smaller species, *H. pleuracanthus,* in the trap collections over the benthos although this species apparently prefers submerged aquatic vegetation (Sogard and Able 1991, Wilson and Able 1996), a habitat not sampled in this study. This gear-based mesh difference also likely accounts for the absence of early life-history stages of shrimp from the trap (6-mm mesh) collections because they are well represented in the plankton net (1-mm mesh) samples. On the other hand, the use of more than a single type of gear also increased our ability to capture the spatial and temporal patterns of multiple species of a variety of sizes.

Another bias is the general inability of these 2 gears to sample burrowing species of shrimp. Several burrowing species not collected in this study are known to occur in this estuary (e.g., *Squilla empusa* Say, *Upogebia* spp.). We only captured a single individual of *Gilvossius setimanus* (DeKay), in the plankton net. These differences are due, in part, to the fact that the traps while fishing on the benthos are a passive gear and require the shrimp to select/enter them, an unlikely event for these burrowing forms.

An additional source of bias in estimating abundance is due to the possibility of predation by fishes also captured in the traps. Common fish (*Fundulus heteroclitus* (L.) [Mummichog], *Centropristis striata* (L.) [Black Sea Bass]) have been observed attempting to ingest shrimp based on an evaluation of trap selectivity from a camera mounted in the trap (Able et al. 2005a, b). Also, our sampling approach may not be completely representative of the entire estuary because both sampling sites were in close proximity at similar polyhaline salinities. Thus, our findings may not include the entire shrimp fauna of the estuary.

This study was also limited by the single year of sampling. Recruitment of many species in estuaries is known to be annually variable (Able 2005, Able and Fahay 2010), and our study would not discern that interannual varation. Diel differences in behavior may also influence our understanding of species composition and life history because some shrimp are known to make diel vertical migrations (Clark et al.

2003) and thus influence their availability to the plankton net. Since the traps were sampling over several days, diel migration should not influence availability to this gear. Despite these disadvantages, our approach offers several advantages including year-round sampling across all seasons, the use of multiple gears to lessen biases based on a single gear, and the advantage of night sampling to reduce gear avoidance, as is indicated by the overlapping sizes for larger individuals (Figs. 6, 7).

Species composition

The shrimp fauna observed in this study is more diverse than in most previous efforts in this estuary. Sampling with block nets in marsh creeks, one of which was immediately adjacent to the benthos site, only identified 2 species (*C. septemspinosa*, *P. vulgaris*; Rountree and Able 1993). Another benthic study, which sampled with a throwtrap during the daytime in shallow macroalgae, eelgrass, and unvegetated marsh creek, found 3 abundant species: *P. vulgaris* in macroalgae and eelgrass, *H. pleuracanthus* most abundant in eelgrass but also occurring in macroalgae, and *C. septemspinosa* in most habitats sampled including both types of vegetation and unvegetated habitats (Sogard and Able 1991). The importance of vegetated habitats for shrimp was also experimentally indicated with artificial eelgrass during diel sampling with the same sampling gear (Sogard and Able 1994). In these observations, most colonization to the artificial eelgrass occurred at night for *H. pleuracanthus* and *P. vulgaris*, whereas colonization was approximately equal for *C. septemspinosa* during the day and night. *Palaemon vulgaris* has also been frequently collected on the marsh platform, including marsh pools and the vegetated marsh surface (Smith 1995), and in vegetated habitats and unvegetated portions of a marina in nearby Barnegat Bay (Wilson and Able 1996). More recently, Able et al. (2018) made daytime collections in creeks on peat reefs—calved-off portions of the marsh surface—near our water-column sampling area and found most of the same shrimp species, including *C. septemspinosa* and *Palaemon* spp., as we detected in this study. In adjacent Barnegat Bay, an additional burrowing species, *Upogebia affinis*, that we did not find in this study was collected in grab samples (G. Taghon, Rutgers University, New Brunswick, NJ, unpubl. data). Interestingly, none of the species collected in the estuary were found on the inner shelf except for *C. septemspinosa* (Viscido et al. 1997). Thus, all other species appear to be estuarine dependent, at least in southern New Jersey.

In recent years some southern species, including penaeid shrimps, have extended their range to the north into the study estuary (Able and Fahay 2010). While not collected in this study, some new species have occasionally been found in recent collections using plankton nets and otter trawls in this estuary, including *Farfantepenaeus aztecus* (Ives) (Brown Shrimp; Wilson and Able 1996) and *Litopenaeus setiferus* (L.) (White Shrimp; K.W. Able, pers. observ.). An apparently new species to the estuary, *P. macrodactylus*, was first detected in the northeastern United States in 2001 and was most likely transported in the ballast water of ships travelling from California or Europe (Warkentine and Rachlin 2010, 2012). The species is native to Japan, Korea, and China (Ashelby et al. 2013). Its presence in our study estuary may be indicative that the species is capable of reproducing there, allowing for more individuals to be transported around the region.

Life history of dominant species

The patterns of shrimp occurrence, abundance, and size in Great Bay provide some insights into the life histories and habitat use of some of the more abundant shrimp species. For *P. vulgaris*, it is clear that reproduction occurs during spring and early summer, with a higher frequency of gravid females and with small juvenile stages most abundant in July. However, it is not clear why the abundance of all stages was much lower during August and September. More frequent sampling might make this apparent contradiction easier to interpret.

Hippolyte pleuracanthus (Stimpson) (False Zostera Shrimp) is a small species; the length of gravid females = 12 –18 mm, and males are smaller (Williams 1984). It was collected only in the plankton net in May and July–November at low frequencies. All specimens collected, none gravid, were less than 16 mm, with the smallest being ~4 mm. This relatively low number of specimens could be attributed to the small size of the species and the larger mesh size of the traps as well as the preference of this species for submerged vegetation.

The abundance of *C. septemspinosa* in this study relative to that found in an adjacent study with a beam trawl on the inner continental shelf (Viscido et al. 1997) allowed us to gain unique insights into the life histories of this shrimp species. Capture in both the inner shelf and the estuary indicates there are linkages between these populations based on similar patterns of abundance but at different seasons, at least for the benthic stages. The virtual absence of this species in the estuary in the fall may be explained by their abundance on the inner shelf during that time (Viscido et al. 1997). One possibility is that they spend the winter on the inner shelf at more moderate temperatures relative to the estuary, a pattern observed elsewhere, e.g., in the Chesapeake Bay (Haefner 1976) and in Canadian waters (Corey 1981, Haefner 1979). The occurrence of this species in the estuary and the adjacent inner shelf may be facilitated by migrations within the water column. This hypothesis is supported by the occurrence of small and larger juveniles as well as adults in the water column, as collected by plankton net, during most months. Evidence for migration is noteworthy given that they are typically considered a benthic species (Haefner 1979). The linkage between Great Bay and the inner shelf, also referred to as the "offshore estuary" (McHugh 1967) or "surface entrainment volume" by some authors (Ray 1991, Ray and Hayden 1992), is consistent with that for many fish species (Able 2005, Able et al. 2011) and horseshoe crabs (Able et al. 2019).

The duration of the reproductive season of *C. septemspinosa* is not clear. There may be 2 peaks in spawning based on the occurrence of gravid females, but this suggestion is based on a small sample size. The pattern of occurrence of small (<10 mm TL) juveniles in the water column in all months suggests reproduction may occur nearly continuously, as reported for the species in lower Chesapeake Bay (Haefner 1976). However, it is clear that the peak in occurrence of small juveniles in our study is in the winter through early summer. In other Mid-Atlantic estuaries, the reported occurrence of gravid females varied from nearly year-round in Delaware Bay (Price 1962) to November through June in lower Chesapeake Bay (Haefner 1976) and spring and fall peaks in the Mystic River, CT (Modlin 1980). The potential differences reported may be correlated with the size of the gravid females, with larger ones with eggs in the spring and smaller ones in the other times of the year (Price 1962). Additionally, determining the number of spawning peaks in the year may be difficult because of the lack of deep-water benthic sampling where gravid females may occur (Haefner 1979).

In summary, it is clear that there are specific habitat-use patterns in the water column and on the benthos for the shrimp species in the Great Bay estuary. The patterns observed in this study may be representative of other small estuaries in the Mid-Atlantic Bight, including for species with linkages in their life history to the adjacent inner shelf, e.g., *C. septemspinosa*.

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