Distribution of Juvenile Horseshoe Crabs in Subtidal Habitats of Delaware Bay Using a Suction-Dredge Sampling Device

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Abstract Surveys of horseshoe crab juvenile distribution and abundance typically do not include shallow subtidal areas primarily because of the logistical difficulties with sampling in this habitat. A suction-dredge was constructed consisting of a "T"-shaped sampling head; an 8-hp trash pump, a 15.2-m-long non-collapsible hose-pipe; and a gunwale-mounted catch-basin to survey newly hatched juvenile horseshoe crabs in shallow subtidal habitats of lower Delaware Bay. Suction-dredge data were compared to catches taken in 4.9-m-small trawl collections at a series of 84 shallow water stations in 4 separate sampling events conducted in the summer and fall of 2004. Suction-dredge sampling for standard tow lengths of 15.2 m produced orders of magnitude higher catches compared to the trawls which were towed for an average of 109 m. The dredge was capable of sampling many stations in a single day and did not damage juveniles excessively. There was evidence for gradual bayward migrations of juvenile horseshoe crabs, as higher densities were found close to the spawning beaches in July, but progressively higher densities were found in offshore transects in August. Few juveniles were collected in September and October. This study demonstrated that juvenile horseshoe crabs were abundant in shallow subtidal areas of Delaware Bay, and that suction-dredge sampling could provide a valuable tool to monitor horseshoe crab populations.

1 Introduction

There is limited information on population dynamics and abundance of horseshoe crabs (*Limulus polyphemus*), as traditional population and harvest data have historically not been collected for this species (Walls et al. 2002). Some offshore trawling studies have been conducted (Botton and Ropes 1987, Hata and Berkson 2003), as well as spawning surveys and egg-count surveys (Smith et al. 2002, ASMFC 1998). However, juvenile horseshoe crabs may be missed in

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these studies, due to the unique habitats they occupy. After emerging from egg clusters buried in the sand, juvenile horseshoe crabs occupy the intertidal zone and shallow subtidal areas where they undergo several molts before migrating to deeper waters (Rudloe 1981, Shuster 1982). Surveying the abundance of newly hatched, epibenthic horseshoe crabs in shallow water habitats of estuaries presents a unique challenge because traditional sampling devices such as small trawls are not very effective at collecting 5–40 mm prosoma width juvenile horseshoe crabs. Quadrat sampling in mud flats at low tide can only be conducted in very shallow water and only a small area can be effectively sampled. The distribution of juvenile horseshoe crabs in shallow water habitat and their seasonal use of these areas are not well known due to the difficulty with current sampling methods. In this chapter, we describe a suction-dredge sampler to survey for juvenile horseshoe crabs in shallow water habitats of Delaware Bay, and report on their distribution and abundance at selected beaches during summer and early fall of 2004.

2 Methods

A suction-dredge sampling device was constructed and tested in shallow nearshore habitats in lower Delaware Bay (Fig. 1). The dredge itself consisted of a "T"-shaped intake pipe assembly powered by an 8 hp centrifugal trash pump. The head-pipe was constructed from a 1 m length, 8 cm diameter PVC pipe, perforated with 20 intake holes of 2.5 cm diameter. The intake holes were arranged symmetrically in two rows on the wall of the pipe that contacted bottom substrate. The head-pipe was closed at each end by threaded caps, which could be removed in the field to facilitate cleaning. The head-pipe was joined at the center with a PVC pipe of the same dimension to form the "T". To provide rigidity and strength, the entire assembly was attached to a delta-wing-shaped piece of 2-cm-thick plywood. The plywood base also allowed us to add weight (approximately 22 kg) to the head-pipe end of the dredge to keep it in close contact with the bottom. We used a non-collapsible hose-pipe, 15.2 m in length and 7.62 cm in diameter to connect the suction head to the centrifugal pump. A similar length of hose-pipe ran from the outlet of the pump around the bow of the sampling vessel and back to a catch-basin attached to the port gunwale of the research vessel. The catch-basin was constructed of plywood and measured 1.8 m in length, 0.6 m in height, and 0.5 m in depth. The bottom of the basin was fitted with hardware cloth of 0.4 cm mesh.

At higher boat speeds (4–5 knots) the delta wing kept the suction head on the surface, and with the pump running, allowed for flushing between fixed sampling stations. In operation, a target station was approached using the vessel's global positioning system (GPS) while moving with the tide. The sampling vessel was then slowed to about 2 knots which allowed the dredge to sink to the bottom. When the suction head contacted the bottom, the outlet hose was

Fig. 1 Detail of the underside of the suction-dredge head and plywood delta wing

monitored for sediment discharge. As soon as the discharge turned sufficiently muddy, the outlet hose was directed into the catch-basin while a 15.2 m tag-line was deployed over the starboard side to standardize distance towed. At the end of the tow, the outlet hose was removed from the catch-basin; boat speed was increased to raise the dredge from the bottom. When the discharge became clear the dredge was ready for the next sampling station. All sampling was conducted during daylight hours.

Juvenile horseshoe crabs collected by the suction-dredge were sorted from material within the catch-basin and each crab was inspected for viability (many shell casts closely resembling live crabs were also collected). Up to 30 crabs were measured using calipers for prosoma width and all crabs were counted.

Within 2 or 3 days after finishing the suction-dredge survey, trawl sampling was conducted using a 5.2-m semi-balloon otter trawl with 3.2-cm stretch mesh in the wings and body, and 1.3-cm stretch mesh liner in the cod end. Trawl sampling was done primarily to characterize fish, blue crab, and adult horseshoe crab populations at our study sites but also collected 5–40 mm prosoma width juveniles. This is the same equipment used by the Delaware Division of

Fish and Wildlife in their annual Delaware Bay trawl surveys. Two-minute tows were conducted at each station. Beginning and ending coordinates were recorded to measure distance towed; tow length averaged 109 m among 336 trawls conducted during the study. Counts and prosomal widths of all 5–40-mm horseshoe crabs taken by the small trawl were recorded.

We conducted juvenile horseshoe crab surveys in Delaware Bay in nearshore habitats ranging in depths from 1 to 4 m adjacent to seven spawning beaches with the suction-dredge and the small trawl. Beaches surveyed in New Jersey included West Egg Island, East Egg Island, and East Point while the Delaware beaches included Kelly Island, Port Mahon, Kitts Hummock, and North Bowers Beach (Fig. 2). The surveys were conducted monthly from July to October 2004. Each survey area was divided into three transect corridors, positioned parallel to shore and approximately 0.2 nautical miles (0.4 km) in breadth. In order of proximity to shore, the corridors were defined as nearshore, mid-shore, and offshore habitats. Along each transect corridor, four station targets were positioned at equal distances of approximately 0.2 nautical miles (0.4 km) apart. In total, 12 stations were positioned at each beach. In each sampling event, 84 stations were surveyed using both suction-dredge and trawl methods (7 beaches × 3 transects × 4 stations).

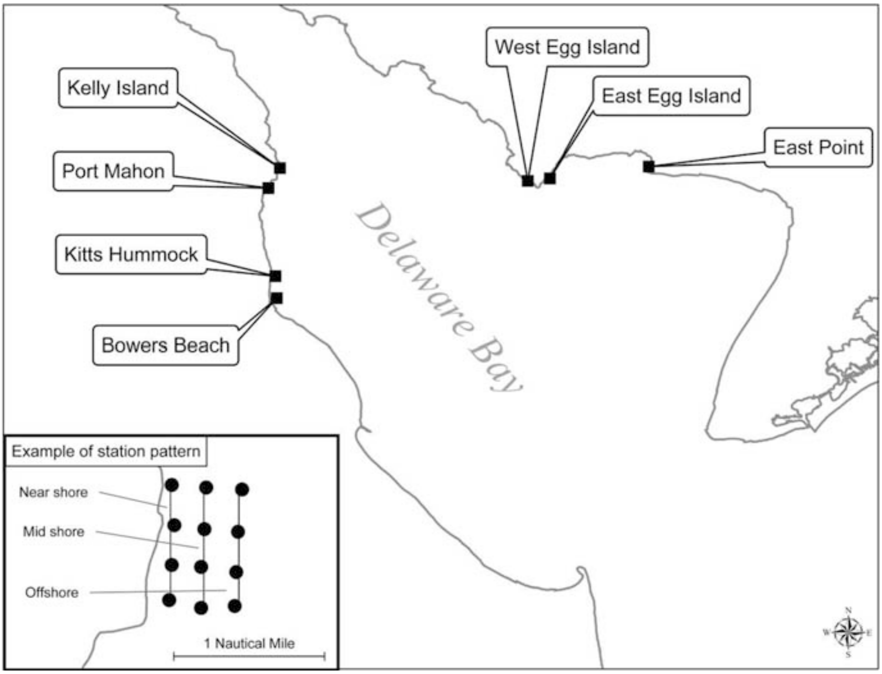

Fig. 2 Locations of the seven horseshoe crab spawning beaches surveyed for juveniles in the summer and fall of 2004 in Delaware Bay

Suction-dredge and trawl catches of juvenile horseshoe crabs were expressed in numbers per 100 m^2 of bottom sampled and compared to evaluate each gear's relative efficiency. Spatial and temporal movement patterns of juvenile horseshoe crabs were evaluated by combining the data from all seven beaches and calculating the average numbers of juvenile crabs taken by standard suction-dredge tow by transect and sampling month.

3 Results

The operation of the suction-dredged proved to be very effective. Close inspection of the suction-dredge catches of juvenile horseshoe crab revealed that very few specimens were damaged by the pump. Minimal clogging of the T sampler occurred except in bottom habitats where excessive filamentous bryozoans existed (generally in the higher salinity New Jersey beaches sampled).

On all four sampling events, the suction-dredge collected an order of magnitude more 5–40 mm juvenile horseshoe crabs relative to the small trawl (Table 1). Markedly higher densities were estimated from the suction-dredge which was towed for only 15.2 m relative to the small trawls that were towed an average of 109 m.

Densities of juvenile horseshoe crabs were highest in the nearshore transect in July relative to the mid-shore and offshore transects (Table 2). During August, fewer crabs were taken nearshore relative to the mid-shore and offshore transects. Suction-dredge sampling during September and October found few juveniles in any of the three transects, suggesting that the majority of juveniles had migrated out to deeper waters by September.

The juvenile horseshoe crab data from the suction-dredge collection were examined for prosoma width frequencies by sampling event for the combined catches taken in New Jersey and Delaware. Three potential cohorts were observed in the data, particularly during the months of July, September, and October (Fig. 3). In July, three peaks of 7-, 10-, and 15-mm-wide horseshoe crabs existed. This pattern was not observed in the August survey, but in the September and October survey three distinct prosomal widths existed in the size data at 13.5, 17, and 24 mm. The peak spawning migration in the Delaware Bay area generally occurs during the evening new and full moon tides in May and June (Shuster 1982, Shuster and Botton 1985). During May and June 2004, two new (May 19 and June 17) and two full moons (May 4 and June 3) occurred. These data suggest that three major spawning events occurred during these four moon phases. Separate size analyses for the New Jersey and Delaware data indicated that the tri-modal size frequencies were mostly a function of the Delaware collections.

Table 1 Average densities (SD) of horseshoe crab juveniles per 100 m^2 of bottom sampled among 12 stations ($n = 12$) sampled in the shallow nearshore habitats adjacent to seven spawning beaches sampled in Delaware Bay in 2004

	July		August		September		October	
	Dredge	Trawl	Dredge	Trawl	Dredge	Trawl	Dredge	Trawl
New Jersey Beaches								
West Egg Island	303.5 (795.7)	3.7 (4.1)	54.2 (47.0)	0.6 (1.0)	7.0 (13.8)	0.1 (0.1)	7.7 (13.6)	0.1 (0.3)
East Egg Island	73.6 (71.4)	6.4 (7.9)	58.8 (41.8)	0.9 (1.6)	7.7 (13.0)	0.02 (0.05)	5.4 (8.4)	0.1 (0.1)
East Point	10.1 (19.6)	0.3 (0.7)	4.6 (7.4)	0.2 (0.4)	0.8 (2.7)	0.02 (0.07)	2.3 (8.1)	0 .0 (0.0)
Delaware Beaches								
Kelly Island	240.0 (141.8)	6.4 (5.4)	68.9 (49.7)	0.2 (0.4)	12.4 (31.8)	0.0 (0.0)	1.6 (3.6)	0.0 (0.0)
Port Mahon	514.1 (273.7)	20.8 (12.6)	133.2 (44.5)	0.6 (0.5)	2.3 (8.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Kitts Hummock	493.2 (612.4)	5.4 (4.0)	538.1 (499)	2.4 (3.3)	90.6 (71.4)	0.1 (0.1)	65.0 (55.8)	0.5 (0.5)
Bowers Beach	329.0 (434.9)	5.5 (3.8)	581.4 (577)	9.7 (15.3)	125.4 (97.9)	0.0 (0.0)	154.1 (130.3)	0.2 (0.3)

Table 2 Mean numbers (SD) of horseshoe crab juveniles taken in 15.2 m tows with the suction-dredge sampler among all seven study beaches by transect and sampling event

Event	Nearshore (*n* = 28)	Mid-shore (*n* = 28)	Offshore (*n* = 28)
July	45.5 (69.4)	15.9 (19.7)	29.1 (40.1)
August	7.6 (12.8)	24.8 (35.1)	34.0 (53.6)
September	3.0 (5.4)	4.0 (6.9)	4.4 (8.9)
October	2.9 (4.8)	3.5 (6.3)	4.6 (11.7)

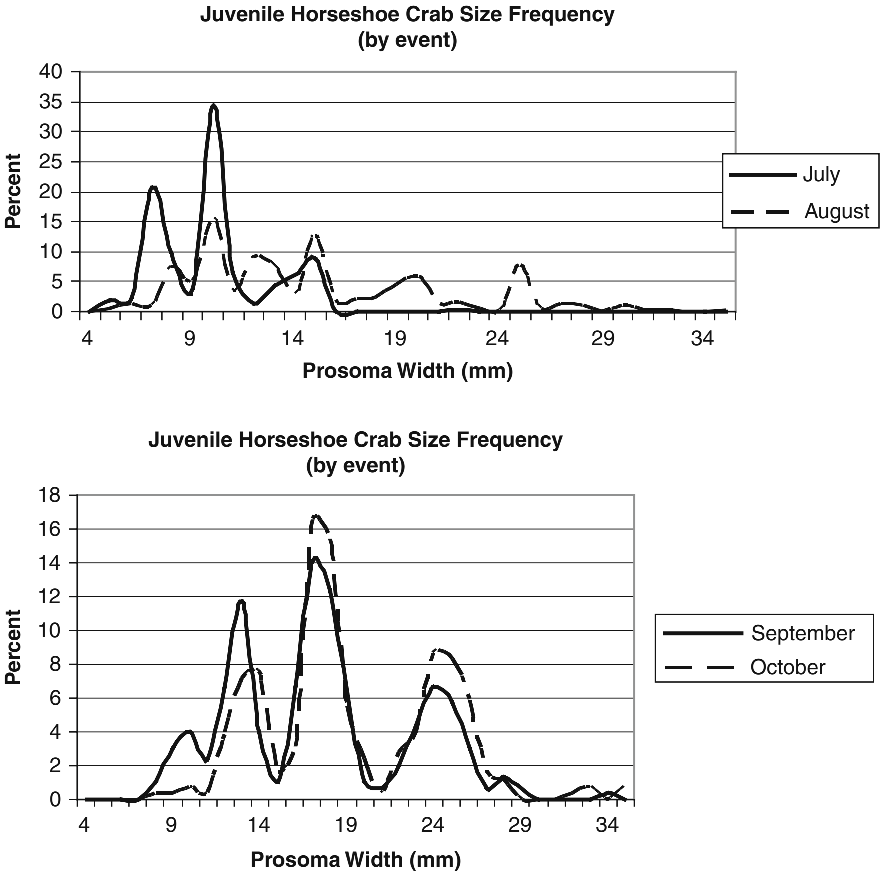

Fig. 3 Size frequency analysis of horseshoe crab prosomal widths for all suction-dredge collections (New Jersey and Delaware data combined) by sampling event

4 Discussion

The suction-dredge was much more effective at collecting juvenile horseshoe crabs relative to the small trawl. Although the total catches were much smaller in the trawl collections, the spatial trends among sampling beaches mirrored the dredge data suggesting that the small trawl was sensitive enough to characterize the relative abundances of juveniles among beach habitat. While the suction-dredge was clearly a more effective sampler, the gear efficiency is unknown but could be quantified by conducting a depletion experiment. By conducting multiple passes over the same sampling lane and monitoring the reduction in catch rate between passes, the dredge's catch efficiency could be calculated. The sampling efficiency could then be applied to survey data to estimate the total population size in a given area.

Subtidal densities of juvenile horseshoe crabs (per 100 m^2 of bottom) obtained through suction-dredge sampling were greater than those obtained in the small trawl and were also much greater than densities estimated in other studies for juvenile Asian horseshoe crabs – *Tachypleus tridentatus* in the Philippines and *Carcinoscorpius rotundicauda* in Singapore (Almendral and Schoppe 2005, Hong 2004). Almendral and Schoppe (2005) estimated 1.47 juvenile horseshoe crabs *(T. tridentatus)* per 100 m^2 in suitable substrata by walking the intertidal zone at Aventura Beach, Palawan, Philippines. Based on data for juvenile horseshoe crabs (*C. rotundicauda*) in Singapore generated by Hong (2004), densities of about 2.05 individuals per 100 m^2 were estimated. Juvenile densities found in our study often exceeded the 158.1/100 m^2 juvenile *L. polyphemus* found through quadrat sampling in intertidal areas by Carmichael et al. (2003) in Pleasant Bay, Cape Cod, Massachusetts.

Suction-dredge sampling of newly hatched horseshoe crabs may be a better indicator of annual spawning success than adult counts conducted during the spring spawning events and post-spawning surveys of egg masses deposited on the beach. Although the data are not presented in this chapter, our survey included quantitative sampling of egg masses on the subject beaches and there was a positive correlation between egg densities and densities of horseshoe crab juveniles sampled by the suction-dredge. Many external factors can alter the numbers of horseshoe crab juveniles that successfully hatch in a given year including storm events that can erode buried egg masses, desiccation, annual changes in the intensity of predation by shorebirds and gulls, and fertilization success. By the time the newly hatched horseshoe crabs reach 5–40 mm prosomal widths their chances of reaching adult stages is greatly increased and hence may be a better life stage to annually monitor for fisheries management needs. Monitoring juvenile abundance in shallow water habitats could also provide an index to future recruitment into the adult population.

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