PRE-CONSTRUCTION HORSESHOE CRAB MONITORING; EGG ISLAND, NEW JERSEY AND KELLY ISLAND, DELAWARE WETLAND RESTORATION AREAS

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1.0 INTRODUCTION

1.1 BACKGROUND

In 1992, Congress authorized the deepening of the Delaware River main shipping channel from Philadelphia Harbor to the mouth of the Delaware Bay. The U.S. Army Corps of Engineers, Philadelphia District, was directed to undertake construction of the project to deepen the channel by 5 feet to an overall controlling depth of 45 feet. In total, the project would span a distance of 102.5 miles. In order to complete the deepening of the channel in the Delaware Bay segment of the project, approximately 7.3 million cubic yards of primarily good quality sand would be removed by dredging. Beneficial use of this material is proposed through shoreline reconstruction, beach replenishment, and habitat enhancement.

At present, the USACE proposes using the dredged material from the Delaware Bay for shoreline restoration projects at Kelly Island, Delaware and Egg Island Point, New Jersey (Figure 1-1). Both sites are subject to severe shoreline erosion. Reconstruction would not only replace lost habitat but shore up the coastal margins to prevent future degradation. The project is expected to yield substantial ecological benefits by restoring beach habitat for horseshoe crab spawning.

The Delaware Bay shoreline provides spawning habitat to American horseshoe crabs, *Limulus polyphemus*, which are endemic to the Atlantic coast seaboard. From April to July, crabs that have migrated from the Atlantic continental shelf emerge along the bayshore to spawn near the high tide line of primarily sandy beaches. The peak of spawning activity usually occurs during May and June, and coincides with the highest spring tides associated with full and new moon events. At these times, female crabs, attended by several males, lay clusters of eggs up to 20-cm deep within the beach sands. The eggs develop over a minimum of two weeks and after about one month hatch into trilobite larvae, the ephemeral free-swimming stage of the horseshoe crab. Because of the intensity of spawning activity throughout the spawning period and the lengthy term of development, large numbers of eggs can become dislodged from their clusters by wave action and end up exposed on the beach surface. This abundance of eggs provides critical food resources for a number of species of migratory shorebirds during their brief springtime stopover period in Delaware Bay.

After hatching, juvenile horseshoe crabs make their way from the beach into the bay where they spend the remaining spring and summer developing. For the most part, the crabs occupy shallow water inshore habitats, where they undergo several molts before heading to deeper water at the end of the warm season. Not much is known of the ecology of juvenile horseshoe crabs, such as habitat preference or local movement patterns, as they are very small and difficult to sample.

At present, the Atlantic States Marine Fisheries Commission (1998) advises against implementing shoreline construction projects in the mid-Atlantic region between 15 April and 31

August, specifically to avoid adverse impacts to horseshoe crabs. However, ASMFC also provides that specific seasonal restriction dates should be based on site-specific information for any particular area. Given operational and scheduling constraints, the reconstruction projects for Egg Island and Kelly Island may be jeopardized if they are held to the restricted interval in its entirety.

An onsite evaluation of horseshoe crab spawning was deemed warranted to determine the current spawning intensity at the two restoration sites so that potential impacts of the reconstruction project could be evaluated if the project is allowed to proceed during the restricted period. These data were also needed to provide a measure of baseline conditions which would allow for comparisons of horseshoe crab spawning success after the restoration is completed. The enhancement of shoreline spawning habitat through the beneficial use of dredged material may offset any impact from construction during the window of restriction.

1.2 MONITORING OBJECTIVES

The objective of this study was to evaluate horseshoe crab use of Egg and Kelly Islands as spawning habitat, and similarly for adjacent nearshore areas, as nursery habitat for juvenile crabs. The study was conducted to provide baseline information of horseshoe crab use of the islands prior to reconstruction and to provide a means to compare post-construction conditions to gauge the effectiveness of the beneficial use of sediments. Furthermore, as the monitoring period spans the ASMFC window of constraint on construction, this study was designed to identify with greater precision the critical use of the two sites by horseshoe crabs. Finally, as other species of fishes and invertebrates inhabiting nearshore habitats might be affected by the reconstruction, baseline data on these species were collected off Egg and Kelly Islands in conjunction with the juvenile horseshoe crab surveys.

Figure 1-1. The Delaware Bay and the location of the two proposed reconstruction sites, Egg Island, New Jersey and Kelly Island, Delaware. The main shipping channel effectively serves as the state border between New Jersey and Delaware.

2.0 METHODS

During 2004, from late April to July, egg count surveys were conducted at spawning beaches on Egg Island and East Point, New Jersey and Kelly Island, Delaware. The methods used to sample horseshoe crab eggs differed somewhat between New Jersey and Delaware, and followed protocols developed independently by researchers in each state. Monitoring of horseshoe crab spawning by these researchers is ongoing and covers much of the Delaware Bay. By duplicating their respective sampling methods, we were able to compare our egg counts with other monitoring studies and place the spawning effort observed at Egg Island and Kelly Island into perspective with other parts of the Delaware Bay.

2.1 NEW JERSEY EGG COUNTS

Horseshoe crab eggs in New Jersey were sampled using methods developed by Drs. Mark Botton and Robert Loveland for the habitat evaluation of Jamaica Bay, New York during Spring 2004 (Jamaica Bay Ecosystem Research and Restoration Team, supported by ACOE and the National Park Service), and over a period of years in the Delaware Bay (primarily supported by New Jersey Sea Grant, New Jersey Department of Environmental Protection, and Public Service Electric & Gas Company).

On 20 April 2004, a site visit to Egg Island and East Point, New Jersey was conducted with Drs. Mark Botton and Robert Loveland. Under their oversight, 7 beach sampling plots were delineated and distributed accordingly: 3 on west Egg Island, 2 on east Egg Island (the impact beach) and 2 at East Point (control or reference beach; Figure 2-1, Table 2-1). Unlike the Cape May Peninsula, where there are many miles of contiguous spawning beaches, there are very few sandy areas in the Maurice River Cove area. East Point was chosen as a reference beach because it is one of the only good quality sandy beaches near Egg Island. The beach plots were located on the upper portion of the intertidal zone that would be flooded by only the highest spring tides. Although plot dimensions varied among beaches with respect to beach slope, all of the sample plots were comprised of 16 m^2. Steeper sloped beaches on west Egg Island and East Point had plots measuring 4 meters on each side (vertically and horizontally). The more gradual beach slopes of east Egg Island had plots measuring 2 meters at the head and toe (horizontally) of the beach and 8 meters on the sides (vertically). Beach plots on Egg Island were marked with a stake at the top of the beach slope; semi-permanent marks were not used at East Point because of frequent use by the public.

From late April to late July, beach plots were sampled for horseshoe crab eggs a total of 7 times at intervals of approximately 2 weeks (Table 2-2). At each beach, samples were collected in two ways to highlight different aspects of spawning. Core samples were taken to provide an overall density estimate of eggs for the beach. Pit samples were collected to evaluate dispersed eggs within the surface layer of beach sand, and freshly laid clusters of eggs deeper within the sand. Both of these sampling techniques were applied separately at upper and lower sections of

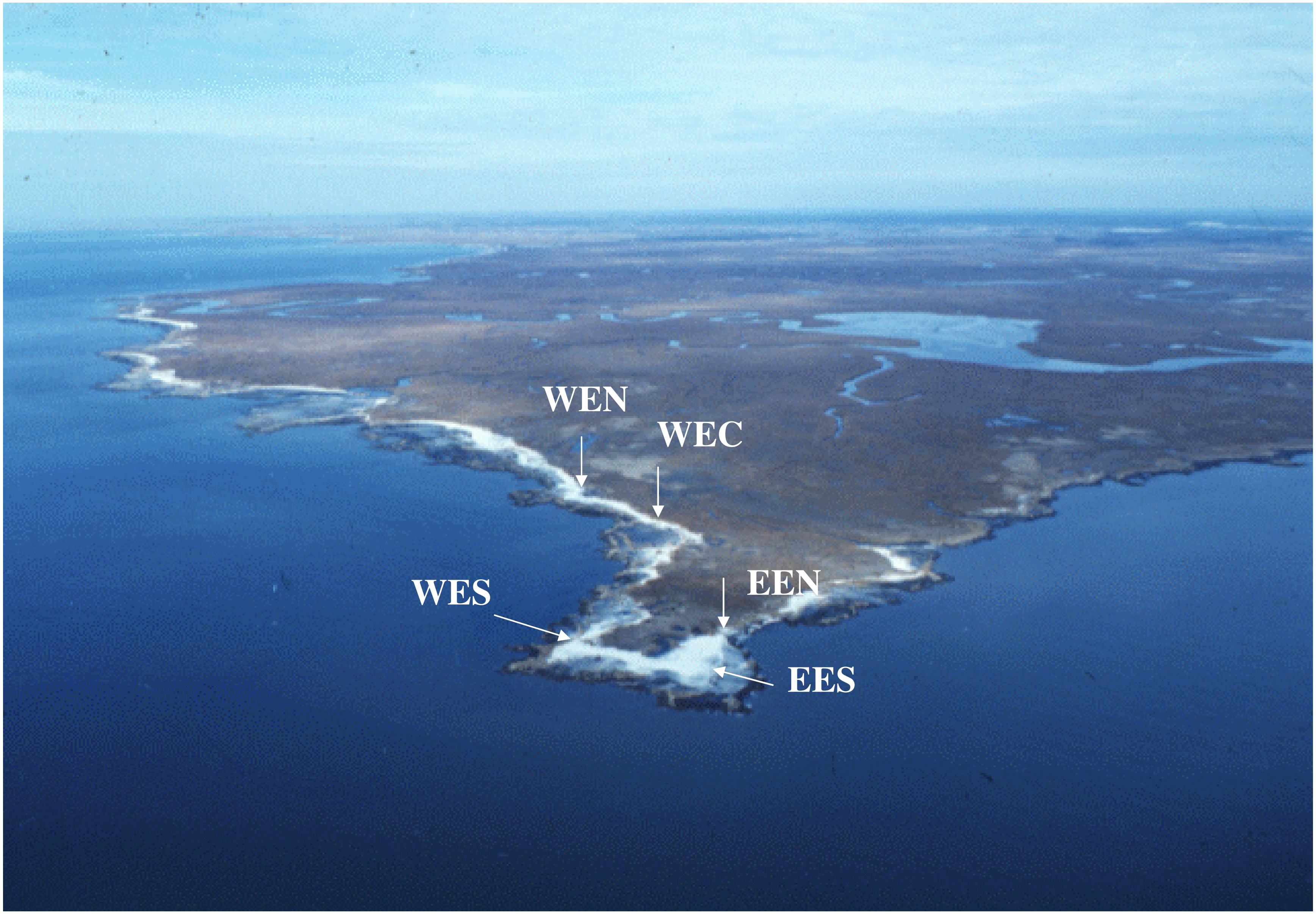


Figure 2-1. Horseshoe crab spawning beaches surveyed on Egg Island, NJ during 2004. East Point with 2 survey beaches is approximately 6 miles due east.

each beach. Within each section (upper or lower), five core samples and one pit sample were randomly located and sampled on each monitoring event. Figure 2-2 provides a conceptual illustration of New Jersey beach sampling. Randomization was achieved using the random number generating capability of Microsoft Excel spreadsheet software.

Table 2-1. Location coordinates (NAD83) of beaches on Egg Island and East Point, New Jersey and Kelly Island, Delaware surveyed for horseshoe crab eggs during 2004

Beach Designation	Code	North Latitude	West Longitude
New Jersey Study Beaches			
East Egg Island - North	EEN	39º 10.968'	75º 08.180'
East Egg Island - South	EES	39º 11.061'	75º 08.159'
West Egg Island - North	WEN	39º 11.385'	75º 08.706'
West Egg Island - Central	WEC	39º 11.280'	75º 08.520'
West Egg Island - South	WES	39º 10.978'	75º 08.220'
East Point - North	EPN	39º 11.850'	75º 01.692'
East Point - South	EPS	39º 11.835'	75º 01.692'
Delaware Study Beaches			
Kelly Island - Beach 1	KI01	39º 11.534'	75º 23.784'
Kelly Island - Beach 2	KI02	39º 11.918'	75º 23.815'
Kelly Island - Beach 3	KI03	39º 12.010'	75º 23.810'
Kelly Island - Beach 4	KI04	39º 12.060'	75º 23.807'

Table 2-2. Schedule of horseshoe crab egg sampling at Egg Island and East Point, New Jersey during 2004

Sampling Event	Date	Beaches Sampled
1	28 April	All samples collected
2	13 May	All samples collected
3	28 May	All samples except EEN; beach was overwashed by very high spring tide.
4	8 June	All samples collected
5	23 June	All samples collected
6	8 July	All samples collected
7	29 July	All samples collected

Arriving at a beach, a measured line, staked at the corners, was used to delineate the sample plot. Another line was fixed across the middle of the plot, perpendicular to the slope of the beach, to define upper and lower beach segments. Within each segment, wire marker flags were used to identify core and pit sample locations. Core samples were collected with 5.2 cm PVC pipes pushed into the beach sand to a depth of 20 cm. Each core sampled an area of

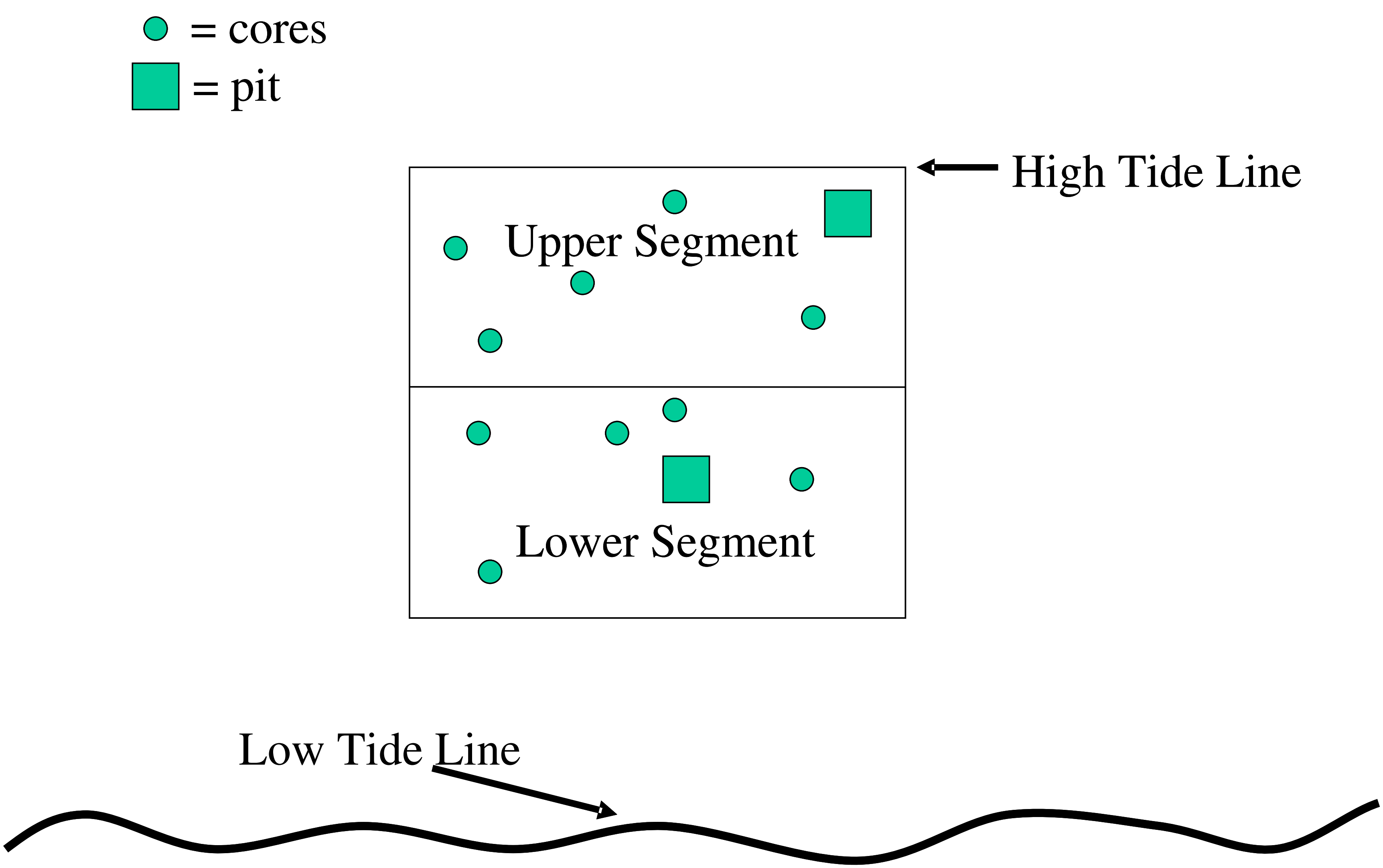


Figure 2-2. Schematic of horseshoe crab egg sampling methods at Egg Island and East Point, New Jersey. Core and pit samples were randomly located within upper and lower beach segments in the intertidal zone.

21.2 cm^2 or 0.00212 m^2. The core contents were emptied into a 1-liter sample bottle and treated with a 10% formalin fixative. Sample bottles were labeled for beach, segment (upper or lower), date, and time. A total of 70 core samples were collected for each sampling event. Pit samples consisted of an area of 35 X 35 cm demarked by measured sticks to form a frame. Each pit sampled an area of 1,225 cm^2 or 0.1225 m^2. Surface samples to evaluate dispersed eggs were collected by excavating material within the frame to a depth of 5 cm. This material placed on a 1 mm mesh screen and sieved in the field to separate eggs from beach sand sediment. Material remaining on the sieve was contained in a labeled sample bottle and fixed as before. Sub-surface samples to evaluate recent spawning by the presence of egg clusters was conducted by excavating the material from 5 to 20 cm and processing it by hand to separate egg clusters. Egg clusters comprising the sample were either placed in a sample bottle entirely (when few) or sub-sampled (when many) by weighing the total number of eggs and a portion to be returned to the lab. Samples were weighed in the field using an Ohaus Scout II electronic balance. The number of eggs in a sub-sample of known weight was extrapolated to the total weight of the egg cluster to estimate the total number of eggs contained within the cluster.

2.2 DELAWARE EGG COUNTS

Delaware horseshoe crab egg counts followed survey protocols that have been implemented by Dr. Richard Weber of the Delaware National Estuarine Research Reserve (DNERR) since 1997 (Weber and Ostroff, 1997). From that year to present, prominent horseshoe crab spawning beaches have been sampled each spring. During 2004, six beaches were sampled by DNERR; Port Mahon, Pickering, Kitts Hummock, North Bowers, Mispillion Inlet, and Slaughter (Weber 2004).

From late April to late July, Kelly Island beaches were sampled 7 times at intervals of approximately 2 weeks (Table 2-3). Four beach monitoring stations were established along the eastern shore of the island, fronting the Delaware Bay (Figure 2-3; Table 2-1). Each station was marked with a stake at the top of the beach slope (i.e., the high tide line during a spring tide). From that point to the low tide waterline, in a line perpendicular to the beach slope, a transect was defined along which samples were collected. In this way, the entire intertidal zone of a beach was sampled. The four beaches of Kelly Island were very similar in width, and the transect line distance over which samples were collected at each beach was approximately 6 meters.

To sample a beach, 25 equally-spaced cores were collected along the transect line (Figure 2-4). Sample cores (constructed from galvanized steel fence-post) had an internal diameter of 5.7 cm and sampled to a depth of 20 cm. Each core sampled an area of 25.5 cm^2 (or 0.00255 m^2), such that the total area represented by 25 cores was 637.5 cm^2 (or 0.06375 m^2). After each core was extracted, it was divided into two fractions: 0 to 5 cm and 5 to 20 cm. These two fractions represent the surface layer where most shorebirds feed on eggs and the subsurface layer where most eggs are laid. Surface and subsurface fractions were composited among the 25 cores

Figure 2-3. Horseshoe crab spawning beaches surveyed on Kelly Island, Delaware during 2004

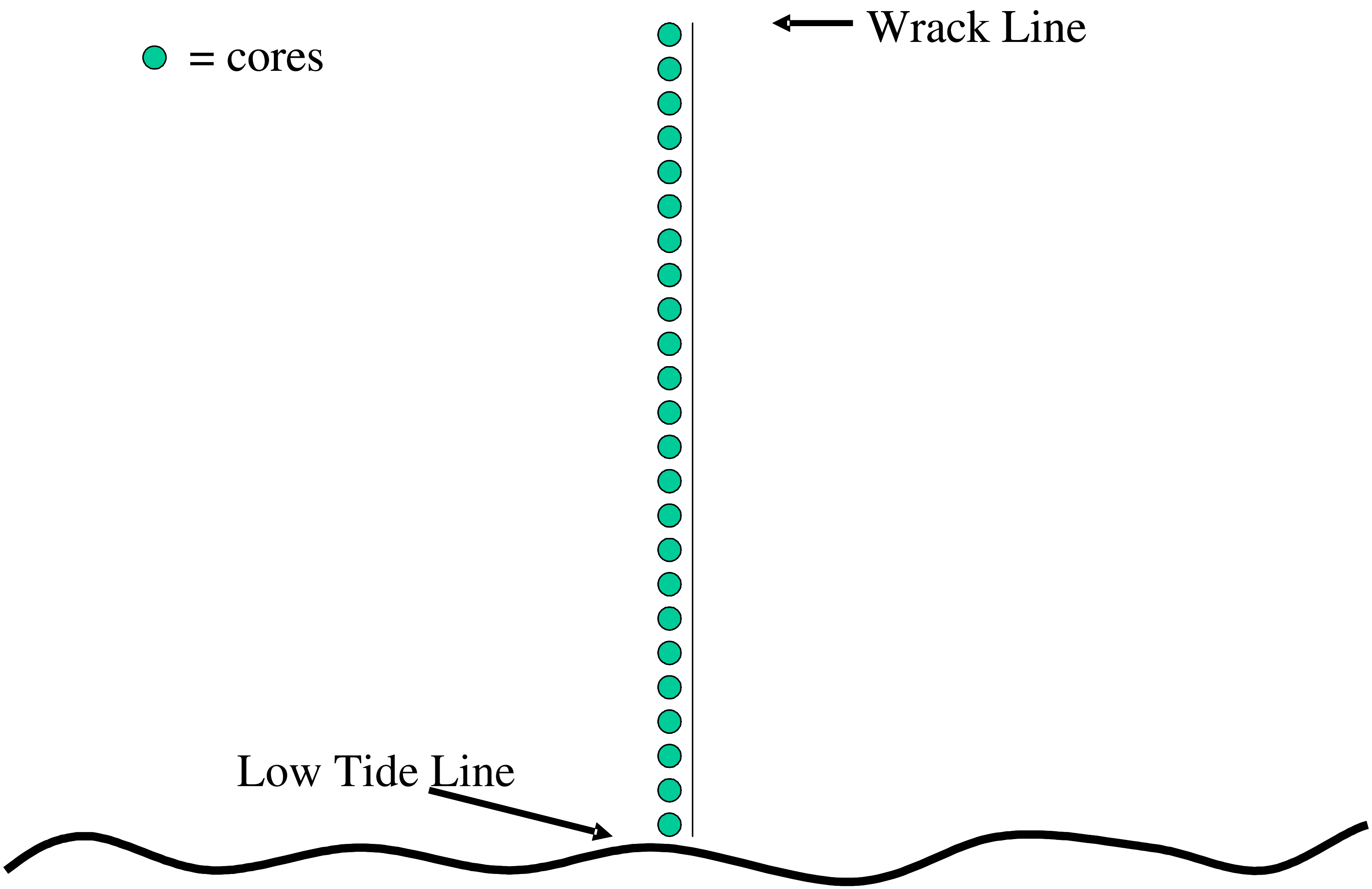


Figure 2-4. Schematic of horseshoe crab egg sampling methods on Kelly Island, Delaware. Twenty-five core samples were collected along a transect spanning the intertidal zone.

into two buckets. Composite surface and subsurface samples were sieved in the field with a 1 mm mesh screen to separate eggs and beach sand sediment. Eggs and material retained on the sieve were contained in a sample bottle labeled for time, date, location, and surface or subsurface layer, and treated with a 10% formalin fixative. A total of 8 samples (4 each, surface and subsurface) were collected on each survey date.

Table 2-3. Schedule of horseshoe crab egg sampling at Kelly Island, Delaware during 2004

Sampling Event	Date	Beaches Sampled
1	29 April	All samples collected
2	14 May	All samples collected
3	26 May	All samples collected
4	9 June	All samples collected
5	21 June	All samples collected
6	7 July	All samples collected
7	28 July	All samples collected

2.3 LABORATORY SAMPLE PROCESSING OF HORSESHOE CRAB EGGS

Horseshoe crab egg samples collected from Delaware Bay beaches in New Jersey and Delaware were processed in a benthic laboratory. Sample material was washed on a 1 mm seive to remove the formalin fixative. The material was transferred to sorting trays and inspected under a magnifying lamp. All viable horseshoe crab eggs were counted (blue-green in color) and totalled for the sample.

2.4 JUVENILE HORSESHOE CRAB SURVEY

We conducted juvenile horseshoe crab surveys in the Delaware Bay in nearshore habitats adjacent to spawning beaches. Beaches surveyed in New Jersey and Delaware included the principal study beaches, West Egg Island, East Egg Island and Kelly Island, as well as reference beaches, East Point, Port Mahon, Kitts Hummock and North Bowers Beach (Figures 2-5a, 2-5b, and 2-5c; Table 2-4). The surveys were conducted monthly from July to October during 2004 (Table 2-5). Two types of gear were used to collect juvenile crabs, a suction-dredge assembly and a modified fish trawl (see below for specific descriptions of gear).

A survey area was delineated adjacent to each spawning beach. The survey areas were divided into 3 transect corridors, positioned parallel to shore and approximately 0.2 nautical miles in breadth. In order of proximity to shore, the corridors were defined as nearshore, midshore, and offshore habitats. Along the center of each corridor, 4 station targets were positioned at equal distances of approximately 0.2 NM apart. In total, 12 stations were defined for each beach. When sampling, the station targets were visually tracked using a differential global positioning system (DGPS) during the deployment of gear. In this way, sample tows could be conducted within habitat corridors. In each of the four months of the survey period, 84 station targets were surveyed using both suction-dredge and trawl methods (7 beaches x 3 transects x 4 stations).

Table 2-4. Target locations (NAD83) for suction-dredge and trawl surveys of juvenile horseshoe crabs in the Delaware Bay during 2004

Beach	Habitat	Latitude	Longitude
East Egg Island, NJ			
EEI01	Nearshore	N39 11.478’	W75 7.363’
EEI02		N39 11.305’	W75 7.529’
EEI03		N39 11.110’	W75 7.729’
EEI04		N39 10.920’	W75 7.918’
EEI05	Midshore	N39 11.408’	W75 7.141’
EEI06		N39 11.223’	W75 7.313’
EEI07		N39 11.020’	W75 7.507’
EEI08		N39 10.847’	W75 7.663’
EEI09	Offshore	N39 11.287’	W75 6.914’
EEI10		N39 11.136’	W75 7.063’
EEI11		N39 10.942’	W75 7.274’
EEI12		N39 10.743’	W75 7.413’
West Egg Island, NJ			
WEI01	Nearshore	N39 11.296’	W75 9.055’
WEI02		N39 11.158’	W75 8.833’
WEI03		N39 11.050’	W75 8.616’
WEI04		N39 10.886’	W75 8.362’
WEI05	Midshore	N39 11.184’	W75 9.205’
WEI06		N39 11.050’	W75 8.950’
WEI07		N39 10.899’	W75 8.722’
WEI08		N39 10.747’	W75 8.456’
WEI09	Offshore	N39 11.045’	W75 9.394’
WEI10		N39 10.873’	W75 9.105’
WEI11		N39 10.730’	W75 8.839’
WEI12		N39 10.553’	W75 8.534’

Table 2-4. (Continued)			
Beach	**Habitat**	**Latitude**	**Longitude**
East Point, NJ			
EPT01	Nearshore	N39 12.238’	W75 1.620’
EPT02		N39 12.004’	W75 1.676’
EPT03		N39 11.810’	W75 1.742’
EPT04		N39 11.663’	W75 1.765’
EPT05	Midshore	N39 12.233’	W75 1.870’
EPT06		N39 12.035’	W75 1.898’
EPT07		N39 11.832’	W75 1.925’
EPT08		N39 11.663’	W75 1.959’
EPT09	Offshore	N39 12.311’	W75 2.125’
EPT10		N39 12.095’	W75 2.136’
EPT11		N39 11.875’	W75 2.147’
EPT12		N39 11.629’	W75 2.209’
Kelly Island, DE			
KI01	Nearshore	N39 12.181’	W75 23.513’
KI02		N39 11.914’	W75 23.496’
KI03		N39 11.650’	W75 23.513’
KI04		N39 11.417’	W75 23.530’
KI05	Midshore	N39 12.164’	W75 23.285’
KI06		N39 11.888’	W75 23.297’
KI07		N39 11.637’	W75 23.319’
KI08		N39 11.365’	W75 23.319’
KI09	Offshore	N39 12.151’	W75 23.047’
KI10		N39 11.870’	W75 23.074’
KI11		N39 11.603’	W75 23.086’
KI12		N39 11.378’	W75 23.096’
Port Mahon, DE			
PM01	Nearshore	N39 10.929’	W75 24.057’
PM02		N39 10.739’	W75 24.184’
PM03		N39 10.570’	W75 24.289’
PM04		N39 10.372’	W75 24.418’
PM05	Midshore	N39 10.877’	W75 23.807’
PM06		N39 10.687’	W75 23.957’
PM07		N39 10.480’	W75 24.101’
PM08		N39 10.272’	W75 24.240’

Table 2-4. (Continued)			
Beach	**Habitat**	**Latitude**	**Longitude**
Port Mahon, DE			
PM09	Offshore	N39 10.817’	W75 23.585’
PM10		N39 10.618’	W75 23.746’
PM11		N39 10.393’	W75 23.879’
PM12		N39 10.177’	W75 24.045’
Kitts Hummock, DE			
KH01	Nearshore	N39 5.755’	W75 23.774’
KH02		N39 5.517’	W75 23.763’
KH03		N39 5.249’	W75 23.769’
KH04		N39 5.011’	W75 23.741’
KH05	Midshore	N39 5.785’	W75 23.347’
KH06		N39 5.548’	W75 23.364’
KH07		N39 5.280’	W75 23.392’
KH08		N39 5.011’	W75 23.370’
KH09	Offshore	N39 5.837’	W75 22.964’
KH10		N39 5.573’	W75 22.959’
KH11		N39 5.284’	W75 22.948’
KH12		N39 4.968’	W75 22.915’
Bowers Beach, DE			
BB01	Nearshore	N39 4.453’	W75 23.780’
BB02		N39 4.215’	W75 23.686’
BB03		N39 4.012’	W75 23.597’
BB04		N39 3.843’	W75 23.541’
BB05	Midshore	N39 4.514’	W75 23.320’
BB06		N39 4.302’	W75 23.281’
BB07		N39 4.099’	W75 23.226’
BB08		N39 3.921’	W75 23.198’
BB09	Offshore	N39 4.570’	W75 22.926’
BB10		N39 4.341’	W75 22.859’
BB11		N39 4.146’	W75 22.815’
BB12		N39 3.969’	W75 22.754’

Table 2-5. Schedule of juvenile horseshoe crab surveys in the Delaware Bay during 2004. Spawning beaches included East Egg Island (EEI), West Egg Island (WEI), and East Point (EPT) in New Jersey, and Kelly Island (KI), Port Mahon (PM), Kitts Hummock (KH), and Bowers Beach (BB) in Delaware.

Survey Period	Date	Gear	Beaches Sampled
July/August	20-Jul	Dredge	KI/PM
	21-Jul	Dredge	BB/KH
	22-Jul	Dredge	EEI/WEI/EPT
	27-Jul	Trawl	BB/KH
	28-Jul	Trawl	PM/KI
	2-Aug	Trawl	EEI/WEI
	3-Aug	Trawl	EPT
August/September	23-Aug	Dredge	BB/KH
	24-Aug	Dredge	KI/PM
	25-Aug	Dredge	EEI/WEI/EPT
	30-Aug	Trawl	BB/KH
	1-Sep	Trawl	PM/KI
	2-Sep	Trawl	EEI/WEI/EPT
September/October	30-Sep	Dredge	BB/KH/KI
	4-Oct	Dredge	EEI/WEI/EPT/PM
	6-Oct	Trawl	EEI/EPT
	7-Oct	Trawl	WEI/KI/PM
	8-Oct	Trawl	BB/KH
October/November	27-Oct	Dredge	KI
	28-Oct	Dredge	BB/KH/PM/EEI
	29-Oct	Dredge	WEI/EPT
	4-Nov	Trawl	KI/PM
	9-Nov	Trawl	BB/KH
	10-Nov	Trawl	EEI/WEI/EPT

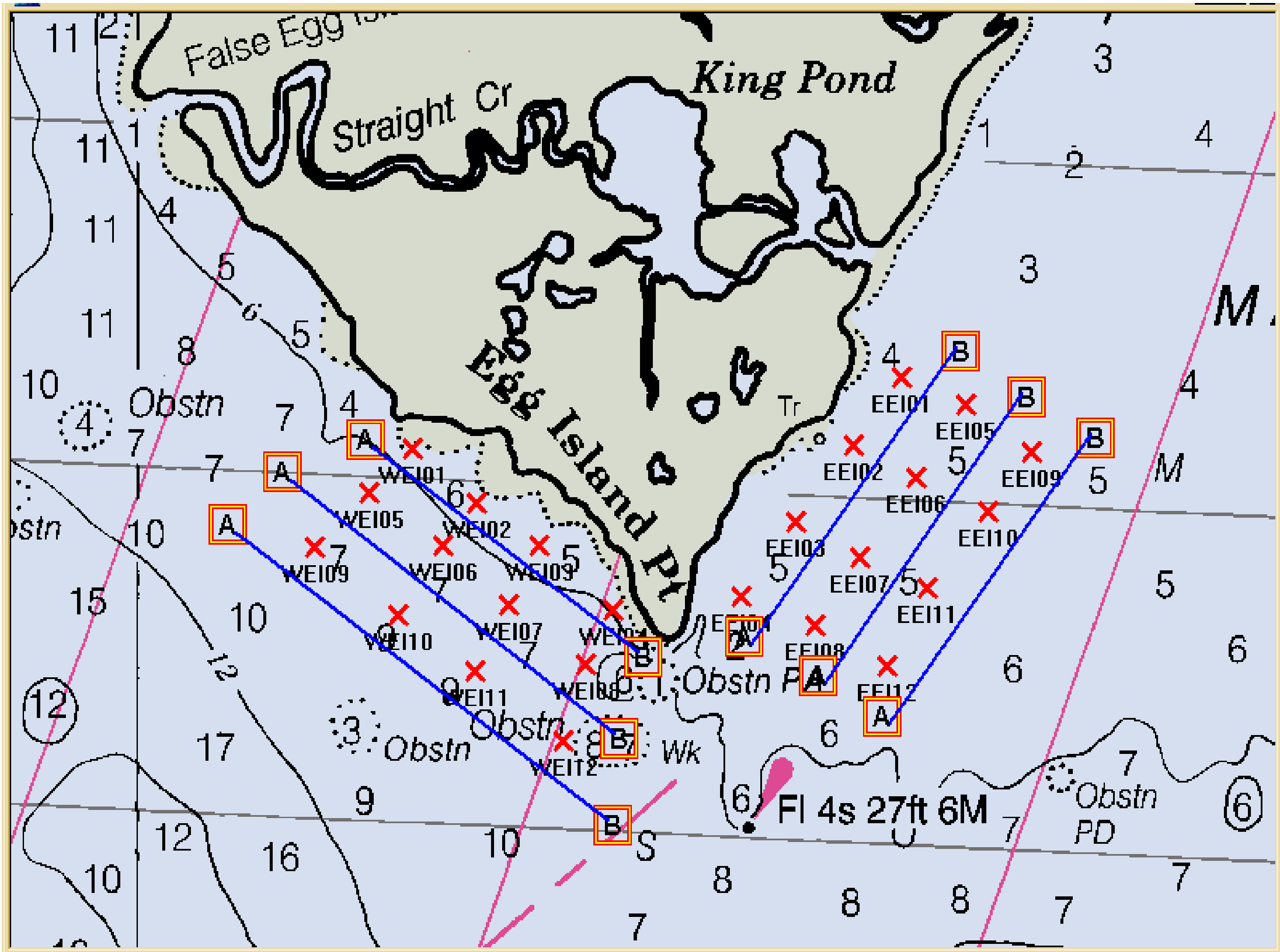


Figure 2-5a. Juvenile horseshoe crab survey locations off Egg Island, New Jersey including West Egg Island (WEI-01 to -12) and East Egg Island (EEI-01 to –12). Surveys were conducted using suction-dredge and trawl methods, monthly from July to October, 2004.

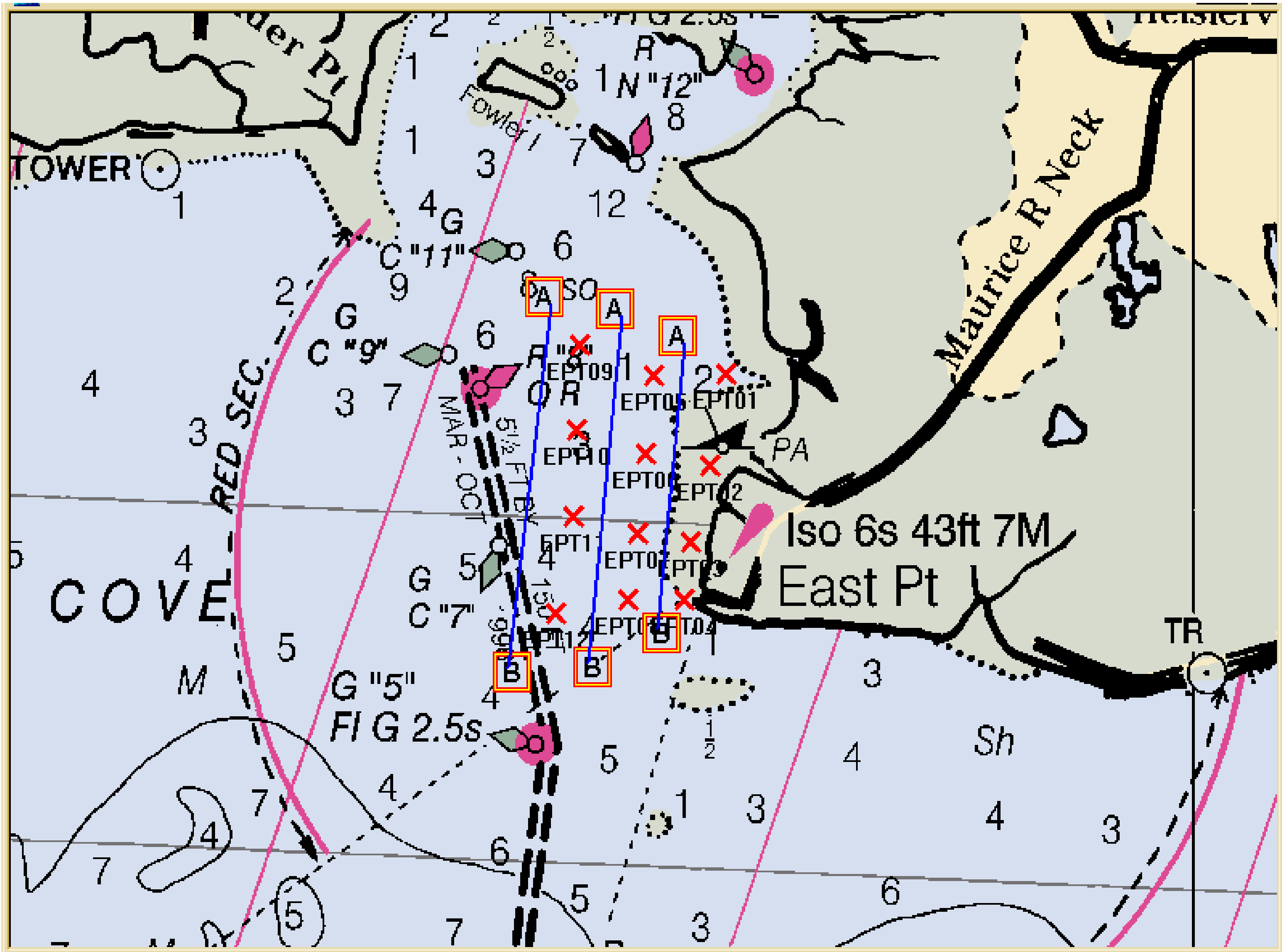


Figure 2-5b. Juvenile horseshoe crab survey locations off East Point (EP-01 to -12), New Jersey. Surveys were conducted using suction-dredge and trawl methods, monthly from July to October, 2004.

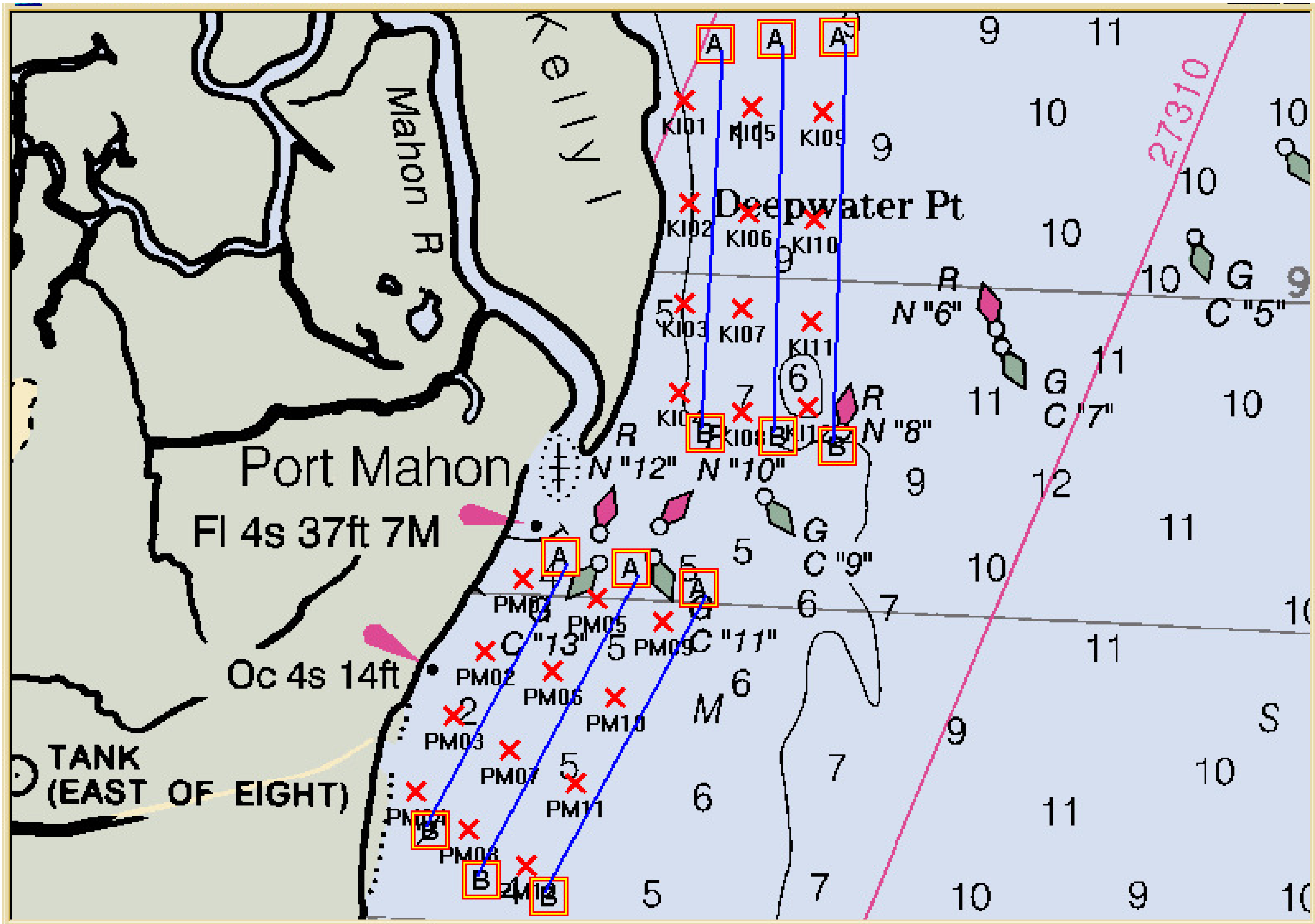


Figure 2-5c. Juvenile horseshoe crab survey locations off Kelly Island (KI-01 to -12) and Port Mahon (PM-01 to –12), Delaware. Surveys were conducted using suction-dredge and trawl methods, monthly from July to October, 2004.

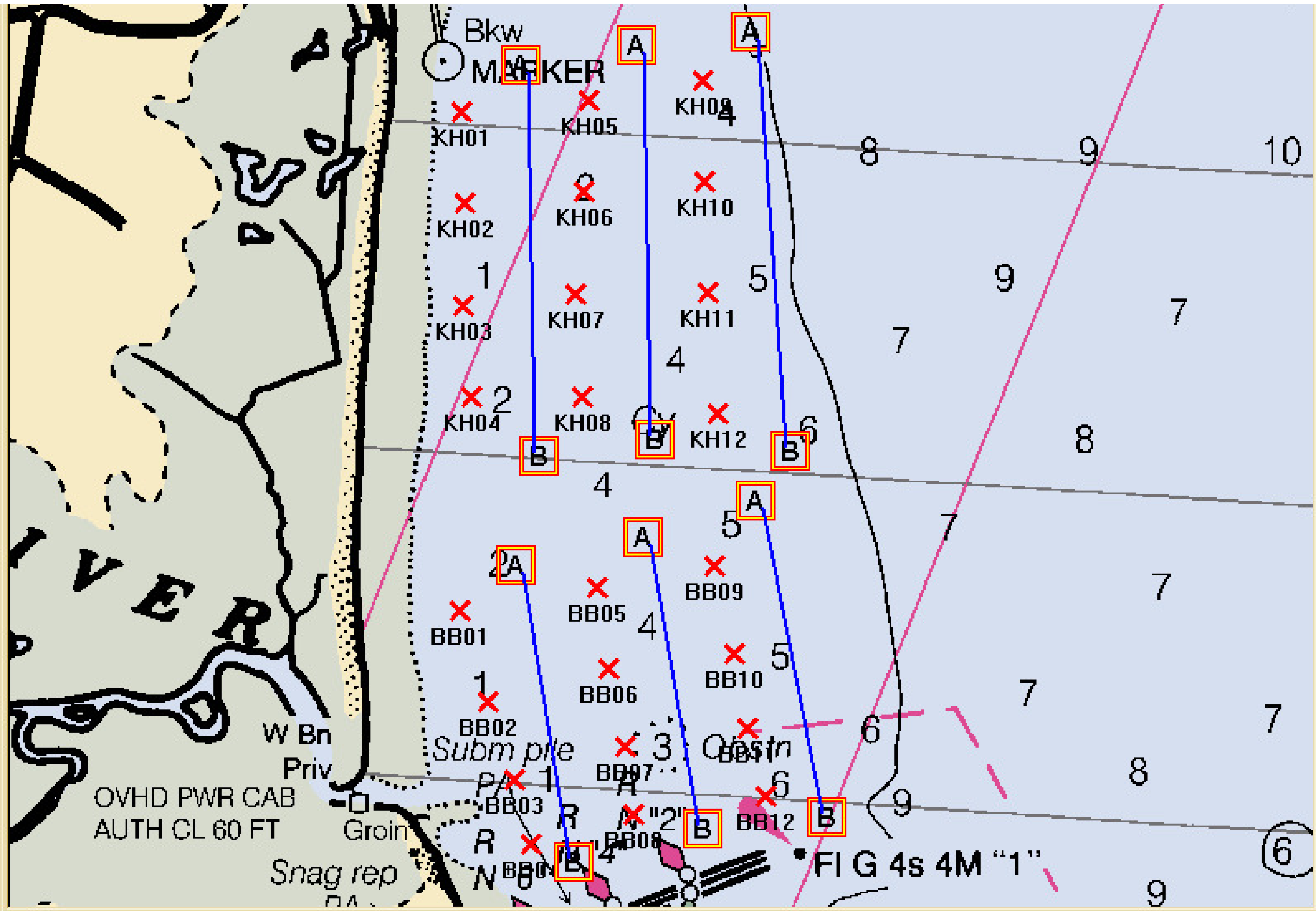


Figure 2-5d. Juvenile horseshoe crab survey locations off Bowers Beach (BB-01 to –12) and Kitts Hummock (KH-01 to -12), Delaware. Surveys were conducted using suction-dredge and trawl methods, monthly from July to October, 2004.

2.4.1 Suction-dredge Sampling

The suction-dredge we used to collect juvenile horseshoe crabs was designed and tested prior to initiating field surveys. The dredge itself constituted a “T” shaped intake pipe assembly powered by an 8 hp centrifugal pump. The head-pipe was constructed from a 1 meter length, 8 cm diameter PVC pipe, perforated with 20 intake holes of 2.5 cm diameter (Figure 2-6). The intake holes were arranged symmetrically in two rows on the wall of the pipe that would face the 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 braced against a delta-wing shaped piece of 2” plywood. The plywood base also allowed us to add weight (approximately 50 lbs) to the head-pipe end of the dredge. We used a non-collapsible hose-pipe, 15.2 m (50 ft) long and 7.62 cm (3”) in diameter, to connect the dredge to the centrifugal pump. A similar length of hose-pipe ran from the outlet of the pump to a catch-basin attached to the gunwhale of the research vessel (Figure 2-7). The catch-basin was constructed of plywood and measured 1.8 m (6’) by 0.6 m (2’) by 0.5 m (1.5’). The bottom of the basin was fitted with hardware cloth of 0.4 cm (1/4”) mesh.

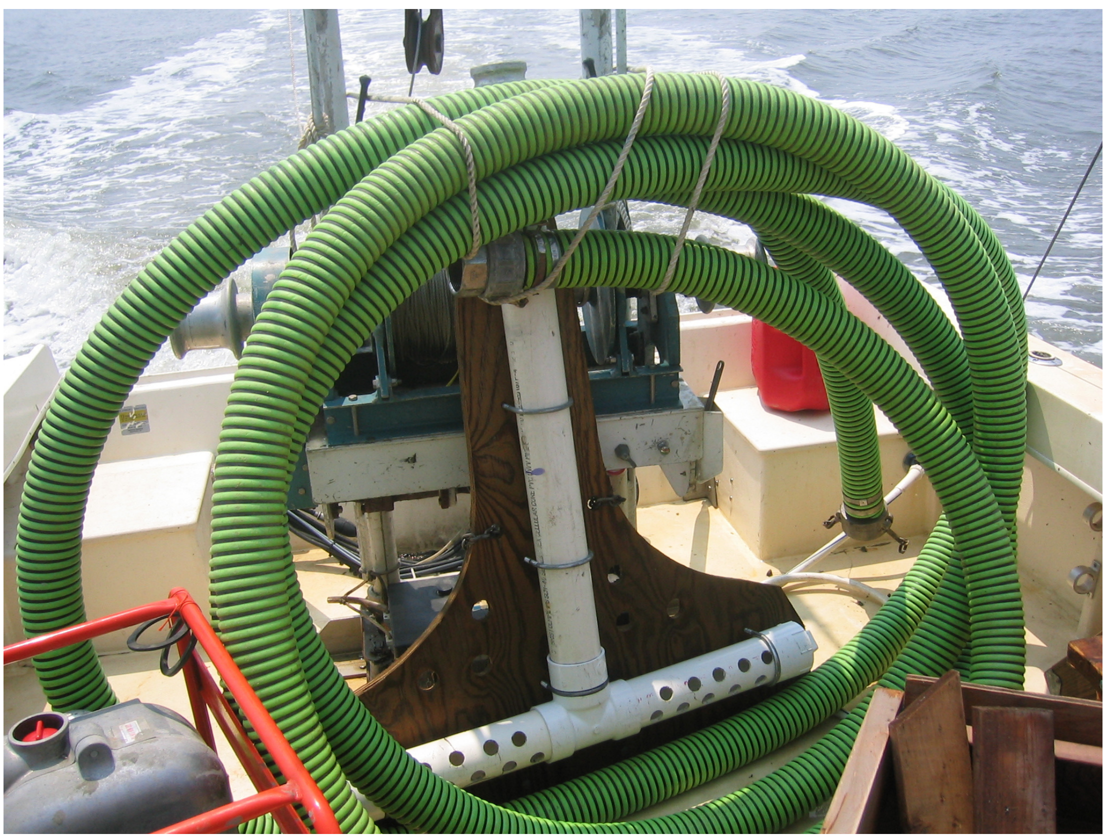


Figure 2-6. Suction-dredge and intake hose used in the juvenile horseshoe crab survey

Figure 2-7. Catch-basin used to retain juvenile horseshoe crabs collected by the suction-dredge

In operation, a target station was approached while moving with the tide; when in position, the dredge was allowed to sink to the bottom. The centrifugal pump was started, and the outlet hose was monitored for sediment suspended in the discharge. As soon as the discharge was gauged acceptable, the outlet hose was directed into the catch-basin, while a 50 meter tag-line was deployed over the 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, the discharge was monitored for clarity, and lastly the centrifugal pump was switched off. In this way, the suction dredge was kept from fouling.

Juvenile horseshoe crabs collected by the suction-dredge were sorted by hand from material within the catch-basin. Each crab was inspected for viability (many shell casts closely resembling live crabs were also collected). Most crabs passed through the dredge and pump apparatus without suffering physical damage. Up to 30 crabs were measured for prosomal width (i.e., helmet width), and any additional crabs were counted. Following sample processing, all live crabs were released overboard.

2.5 TRAWL SAMPLING

Trawl sampling was conducted using a 16-foot semi-balloon otter trawl with 1.5-inch stretch mesh in the wings and body, and 0.5-inch stretch mesh liner in the cod end. This is the same equipment used by the Delaware Division of Fish and Wildlife in their surveys for juvenile horseshoe crabs. Two-minute tows were conducted at each station. Up to 30 live horseshoe crabs, juvenile and adult, were measured for prosomal width, and released overboard. Fish collected as by-catch were identified, counted, and up to 30 were measured for total length (mm). Blue crabs collected as by-catch were measured for carapace width for up to 30 crabs, additional crabs were counted.

2.6 BOTTOM SEDIMENT SAMPLING

At the 84 stations surveyed for juvenile horseshoe crabs, samples of bottom sediment were collected during August. Sediment samples were collected using a petite-ponar benthic grab-sampler. For each station, material representing surface sediment was placed in a container labeled for station location, date, and time. Sediment samples were kept in a cooler on wet ice until they could be transferred to an analytical laboratory where they were stored in a freezer. Sediment samples were analyzed for grain size, percent silt-clay content, and total organic carbon (TOC) using ASTM Method D422-63.

2.7 WATER QUALITY MEASURES

The water quality parameters, salinity (ppt) and temperature (ºC), were measured during the juvenile horseshoe crab surveys for each month of sampling. Most times, surface and bottom measures of the parameters were recorded midway through suction-dredge sampling at each of the seven nearshore survey areas. Water quality was not measured at West Egg Island during the August/September survey period. Bottom water quality was not measured during the October/ November survey period. Salinity and temperature were measured with a pre-calibrated YSI water quality monitoring probe.

3.0 RESULTS

3.1 HORSESHOE CRAB SPAWNING AT EGG ISLAND AND EAST POINT, NEW JERSEY

3.1.1 Core-sampling

The onset of spawning by horseshoe crabs along the New Jersey shore of Delaware Bay was characteristically abrupt. Horseshoe crab eggs were not observed at any of the seven beaches surveyed during the first sampling event (28 April), but by the second event (13 May), eggs were present at all but one beach (Table 3-1). More than likely, the initial spawning occurred around the time of the full moon on 4 May during the previous week. Substantial spawning likely also occurred around the new moon on 18 May, ten days prior to the third sampling event. Highest counts of eggs at most beaches were observed during the third sampling event (28 May; Table 3-1). Thereafter from June into July, regular spawning occurred along east Egg Island and East Point. The peak of spawning for this region of Delaware Bay occurred during mid to late May during 2004.

East Egg Island afforded better spawning habitat than most beaches including reference beaches along East Point. The east Egg Island north station produced the highest total number of eggs during the survey period (totaling about 13,000 eggs per core between the upper and lower beach strata). Unfortunately, on 28 May when peak spawning was in progress, this beach was over washed by a very high tide and could not be sampled. At that time, adult crabs were visible in the shallow water that had inundated the beach. The horseshoe crab total egg production at the East Egg Island south station was comparable to the East Point reference beaches ranging from 5,000 to 7,000 eggs per core. With the exception of sampling event 3, collections on the west Egg Island beaches produced dramatically fewer eggs relative to east Egg Island and the East Point reference beach. West Egg Island has experienced severe erosion, as there are numerous clumps of marsh peat in front of the spawning beaches about 50-feet from the shoreline. These clumps could be limiting the access of spawning adults on this side of the island. In contrast, the east Egg Island north and south stations were much closer to the shoreline where spawning adults had direct access to the beach face.

Although high numbers of eggs were counted in late June and July, the eggs were in various states of development representing the cumulative spawning effort from previous weeks. Horseshoe crabs seemed to prefer to spawn on the lower portions of the beach habitats. In most instances, higher counts were recorded from the lower segments among the study beaches. This area represents the portion of the beach closest to the high water mark of normal high tides, but is over-washed by spring high tides.

Table 3-1. Mean counts of horseshoe crab eggs collected by core sampling at spawning beaches on Egg Island and East Point, New Jersey during 2004. Means and standard deviations are calculated among five samples collected at upper and lower beach segments. Each core sampled 21.2 cm^2; to convert to m^2 multiply counts by 471.7.

			West Egg Island						East Egg Island				East Point Reference			
		Beach	WEN		WEC		WES		EEN		EES		EPN		EPS	
Date	Event	Segment	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
28-Apr	1	Upper	0	-	0	-	0	-	0	-	0	-	0	-	0	-
		Lower	0	-	0	-	0	-	0	-	0	-	0	-	0	-
13-May	2	Upper	0	-	0	-	0	-	2095	878	4	6	16	20	270	343
		Lower	5	9	<1	1	0	-	2294	1029	357	675	239	421	486	969
28-May	3	Upper	28	42	0	-	<1	1	NS		1	1	227	314	1481	1543
		Lower	1114	1407	9	16	3	2	NS		1634	2304	2080	2310	1996	1999
08-Jun	4	Upper	1	1	0	-	3	5	1703	561	1	1	216	261	93	172
		Lower	3	3	3	5	2	5	747	466	192	196	360	334	478	559
23-Jun	5	Upper	0	-	0	-	1	1	1400	1009	1	1	246	504	195	426
		Lower	12	22	0	-	<1	1	1559	194	31	39	908	570	2047	1392
08-Jul	6	Upper	0	-	0	-	<1	<1	1305	506	289	598	<1	<1	<1	1
		Lower	0	-	0	-	<1	1	1194	679	2473	2351	468	834	92	200
29-Jul	7	Upper	0	-	0	-	0	-	760	715	104	230	827	633	11	24
		Lower	0	-	6	11	<1	<1	611	293	0	-	609	829	51	58
		Sum	1163		18		8		13669		5085		6196		7198	

3.1.2 Pit-sampling

The pit sampling methodology employed on the New Jersey beaches was designed to estimate two components of horseshoe crab spawning, 1) the number of dispersed eggs in surface layer beach sands (0 to 5 cm) resulting from biogenic disturbances or wave action, and 2) the number of eggs comprising fresh egg clutches in subsurface sediments (5 to 20 cm) as an indicator of recent spawning. These data are not directly comparable to egg densities derived from core sampling. All eggs were counted from core samples regardless of maturation stage, whereas lower pit samples selected recently deposited eggs (i.e., egg clutches). Data on the timing and intensity of egg laying derived from the pit samples were comparable to patterns observed in the core sampling (Tables 3-2 and 3-3). For example, spawning occurred principally during May and June, tapering off to lower levels but continuing through July. Dramatically higher egg counts were recorded from pit samples taken from east Egg Island and East Point relative to pit sampling on west Egg Island. As observed in the core collections, the only significant concentrations of eggs observed on west Egg Island occurred on 28 May (event 3) for both surface and lower pit samples.

Egg counts for surface layer pit samples (0-5 cm) were generally highest at the northern station on eastern Egg Island (EEN). An upper beach segment mean count on 13 May of 14,304 eggs was the highest recorded among all beaches. The 28 May count was not available for this beach due to high tide over wash as stated above. Counts from June through July appeared to taper off progressively. Egg counts among the subsurface layer pit samples (5-20 cm) reflected the same patterns observed for the surface layer pit samples. However, the highest count of 38,783 eggs was recorded on 13 May from the southern reference station at East Point Beach (EPS). The two stations on west Egg Island (WEC and WES) produced no egg clutches in the subsurface pit sampling throughout the monitoring period.

Table 3-2. Summary of 2004 horseshoe crab egg count at Egg Island and East Point Beach, New Jersey using the surface pit sampling technique. Each pit sampled 1,225 cm^2; to convert to m^2 multiply counts by 8.2.

			Egg Island					East Point Reference	
			West			East			
Date	**Event**		**WEN**	**WEC**	**WES**	**EEN**	**EES**	**EPN**	**EPS**
28-Apr	1	Upper Beach	0	0	0	0	0	0	0
		Lower Beach	0	0	0	0	0	0	0
13-May	2	Upper Beach	0	0	61	14304	11	112	0
		Lower Beach	0	0	2	2629	18	86	160
28-May	3	Upper Beach	222	0	0	NS	0	67	58
		Lower Beach	497	6	0	NS	0	178	486
08-Jun	4	Upper Beach	2	3	0	2691	0	75	12
		Lower Beach	15	100	297	3231	87	596	30
23-Jun	5	Upper Beach	0	0	6	18	0	189	25
		Lower Beach	0	0	0	884	90	473	64
08-Jul	6	Upper Beach	0	0	0	240	26	0	5
		Lower Beach	8	0	0	408	726	0	0
29-Jul	7	Upper Beach	0	0	0	0	0	43	1
		Lower Beach	0	0	0	24	1	0	1
		Sum	744	109	366	24429	959	1819	842

Table 3-3. Summary of 2004 horseshoe crab egg count at Egg Island and East Point Beach, New Jersey using the lower pit (egg clutch) sampling technique. Each pit sampled 1,225 cm^2; to convert to m^2 multiply counts by 8.2.

			Egg Island					East Point Reference	
			West			East			
Date	**Event**		**WEN**	**WEC**	**WES**	**EEN**	**EES**	**EPN**	**EPS**
28-Apr	1	Upper Beach	0	0	0	0	0	0	0
		Lower Beach	0	0	0	0	0	0	0
13-May	2	Upper Beach	0	0	0	6891	1823	0	0
		Lower Beach	0	0	0	8069	3782	0	38783
28-May	3	Upper Beach	2656	0	0	NS	0	0	4642
		Lower Beach	24528	0	0	NS	0	995	36264
08-Jun	4	Upper Beach	0	0	0	3687	0	0	0
		Lower Beach	0	0	0	0	114	2639	0
23-Jun	5	Upper Beach	0	0	0	2958	0	0	0
		Lower Beach	0	0	0	14852	1731	4853	10588
08-Jul	6	Upper Beach	0	0	0	1866	0	0	0
		Lower Beach	0	0	0	0	596	0	0
29-Jul	7	Upper Beach	0	0	0	0	0	0	0
		Lower Beach	0	0	0	30	0	0	0
		Sum	27184	0	0	38353	8046	8487	90277

3.2 HORSESHOE CRAB SPAWNING AT KELLY ISLAND

3.2.1 Kelly Island Core-Sampling

Similar to the New Jersey beaches on Egg Island and East Point, spawning on the Delaware shore of the Delaware Bay commenced abruptly. During the first sampling event on 29 April, no horseshoe crab eggs were observed among the four beaches sampled along Kelly Island (Table 3-4). Approximately two weeks later on 14 May, spawning was apparent and most likely coincided with the full moon on 4 May. During the third round of sampling on 26 May, egg counts were highest for the monitoring period with an average of almost 10,000 in the subsurface cores. The average counts during successive samplings for the most part declined throughout, however, a secondary peak was observed from 21 June at nearly 3,000 eggs in the subsurface cores.

In general, horseshoe crab eggs were more concentrated in the deeper beach sand substrate, however, in May during peak spawning, eggs were much more evenly distributed throughout. Given that the surface layer sample (0-5 cm) has a volume three times less than the subsurface sample (5-20 cm), the egg counts during May reflect a more homogeneous distribution of eggs throughout the cores. From June and thereafter, eggs were more concentrated in the subsurface layers. This probably reflects the attenuation of the breeding effort and perhaps depletion of surface eggs by foraging shorebirds. The sum of the average egg counts on Kelley Island totaled 21,400 among the four stations monitored during the program.

Table 3-4. Summary of 2004 average horseshoe crab egg counts at four stations sampled on Kelly Island using the DNERR composite core sampling technique. Upper Core: 1 to 5 cm; Lower Core: 5 to 20 cm. Each composite core sampled 637.5 cm^2; to convert to m^2 multiply counts by 15.7.

Date	Event		Kelly Island	
			Mean	SD
29-Apr	1	Upper Core	0.0	-
		Lower Core	0.0	-
14-May	2	Upper Core	1239.3	2465.8
		Lower Core	1942.5	1612.2
26-May	3	Upper Core	3057.3	3298.1
		Lower Core	9914.5	5692.6
09-Jun	4	Upper Core	24.8	25.4
		Lower Core	1411.5	1948.0
21-Jun	5	Upper Core	29.0	28.6
		Lower Core	2978.5	3381.5
07-Jul	6	Upper Core	1.3	1.0
		Lower Core	786.8	852.4
28-Jul	7	Upper Core	4.5	8.3
		Lower Core	9.8	17.5
		Sum	21399.5	

3.2.2 Delaware National Estuarine Research Reserve Core Sampling

During 2004, Dr. Richard Weber from the DNERR conducted core sampling at six noted horseshoe crab spawning beaches along the Delaware shore of the Delaware Bay. These included (in order of proximity to Kelly Island) Port Mahon, Pickering, Kitts Hummock, North Bowers, Mispillion Inlet, and Slaughter beaches (Table 3-5). Egg counts from the DNERR survey provide additional perspective on the timing and relative magnitude of regional horseshoe crab spawning. Because of the similarity of survey methods, the DNERR data are directly comparable to the Kelly Island counts. Disregarding the first and last sampling events of our survey (few to no eggs were collected during these events, which were expected to be low, so as to bracket the spawning season), the DNERR survey schedule closely matched ours and included five sampling events through the peak season of spawning.

Horseshoe crab spawning at Kelly Island was comparable to the lesser beaches among the five surveyed. Total egg counts, summed across all events, at Kelly Island (21,400) were very similar to those at Bowers Beach (23,176) and Slaughter Beach (20,937) during 2004. All three of these beaches had total counts that were 3 to 4 times less than at Port Mahon (93,086), Pickering (95,823), and Kitts Hummock (56,644), and more than 10 times less than Mispillion Inlet (299,615).

Of interesting note is the disparity between Kelly Island and Port Mahon, which are very close and separated only by the Mahon River entrance. This may be due in part to differences in beach morphology. The beach at Port Mahon has a gradual slope from the wrack line down through the intertidal zone, whereas spawning beach habitat on Kelly Island is separated from this lower zone by masses of decaying salt marsh that are slowly eroding along the island's shore. To spawn at Kelly Island, crabs must wait until the high tide crests the salt marsh berm before they can access the preferred upper beach habitat. Successful reconstruction of Kelly Island's shore should enhance the future spawning of horseshoe crabs.

Table 3-5. Summary of 2004 average horseshoe crab egg counts at the DNERR sampled beaches in Delaware using the multiple core sampling technique

Date	Event		Port Mahon	Pickering Beach	Kitts Hummock	Bowers Beach	Mispillion Inlet	Slaughter Beach
11-May	1	Upper Core	1,253.0	1,328.6	1,165.5	186.5	16,313.0	305.0
		Lower Core	10,408.0	16,483.0	12,179.3	3,772.0	53,775.0	4,843.0
24-May	2	Upper Core	4,842.5	9,968.5	2,627.5	1,101.0	28,281.5	1,180.5
		Lower Core	57,378.0	48,901.5	24,391.5	15,776.0	74,301.0	8,411.0
07-Jun	3	Upper Core	683.5	461.5	226.5	79.0	10,350.5	243.0
		Lower Core	4,596.5	10,041.5	12,050.0	890.1	75,257.5	3,979.5
21-Jun	4	Upper Core	594.8	167.0	198.3	23.5	2,792.0	78.0
		Lower Core	12,036.5	8,157.0	3,670.7	715.1	28,956.5	1,625.5
07-Jul	5	Upper Core	93.5	20.0	2.5	0.5	1,086.0	15.0
		Lower Core	1,199.7	294.5	133.0	633.1	8,502.5	256.5
		Sum	93,086.1	95,823.1	56,644.7	23,176.8	299,615.5	20,937.0

3.3 JUVENILE HORSESHOE CRAB SAMPLING

Juvenile horseshoe crabs were most abundant during July at spawning beaches in Delaware and New Jersey (Figures 3-1 through 3-7). Although the highest count for a single tow of 302 crabs was recorded from West Egg Island (Figure 3-5), crabs were typically more abundant along the Delaware beaches (Figures 3-1 through 3-4). Among the Delaware beaches, suction dredging at Kelly Island produced the lowest number of juveniles (Figure 3-1) potentially reflecting the poor egg recruitment seen in the spawning survey. Most of the crabs

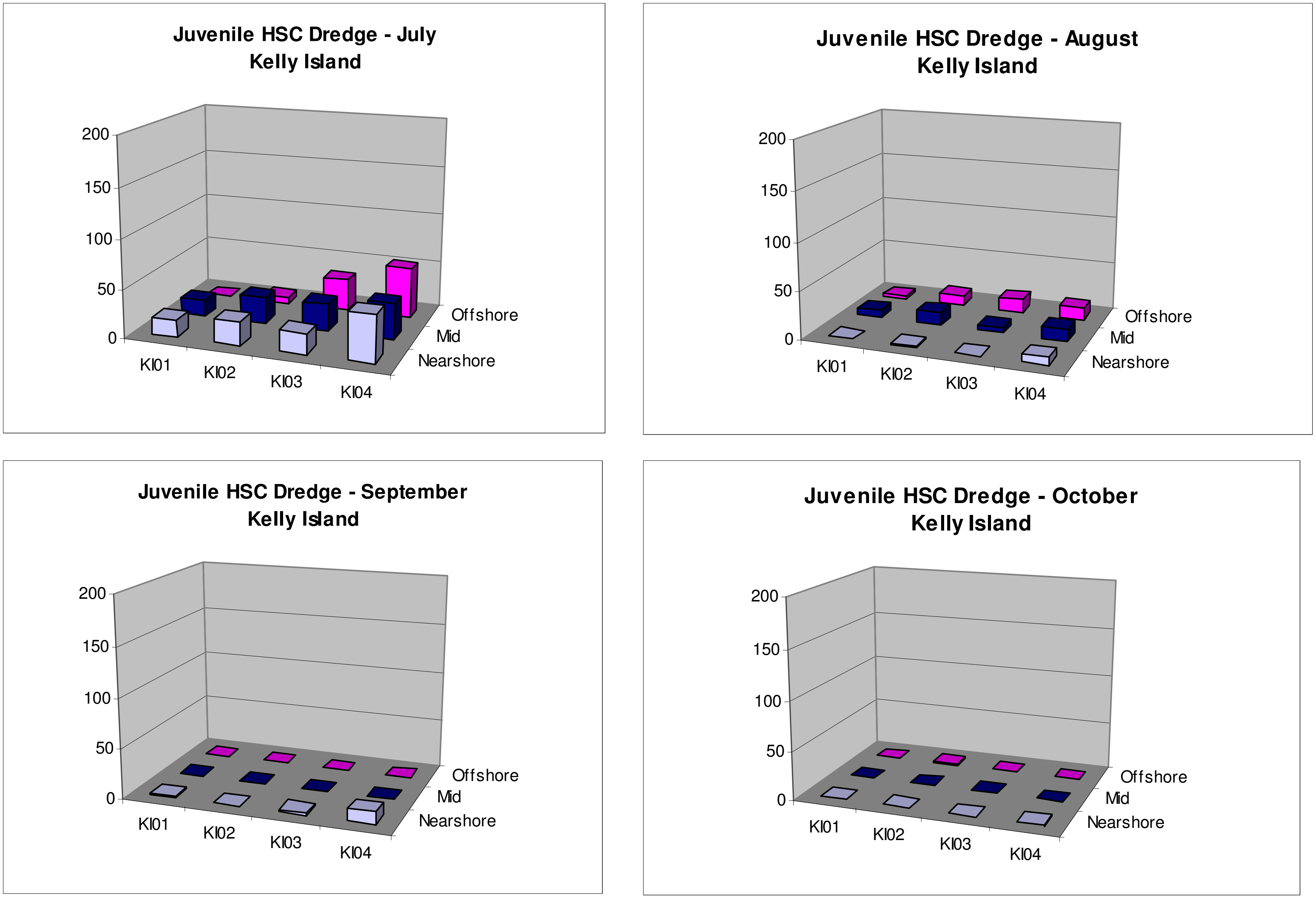


Figure 3-1. Number of juvenile horseshoe crabs collected per 50-foot tow with a suction-dredge off Kelly Island during July, August, September, and October 2004

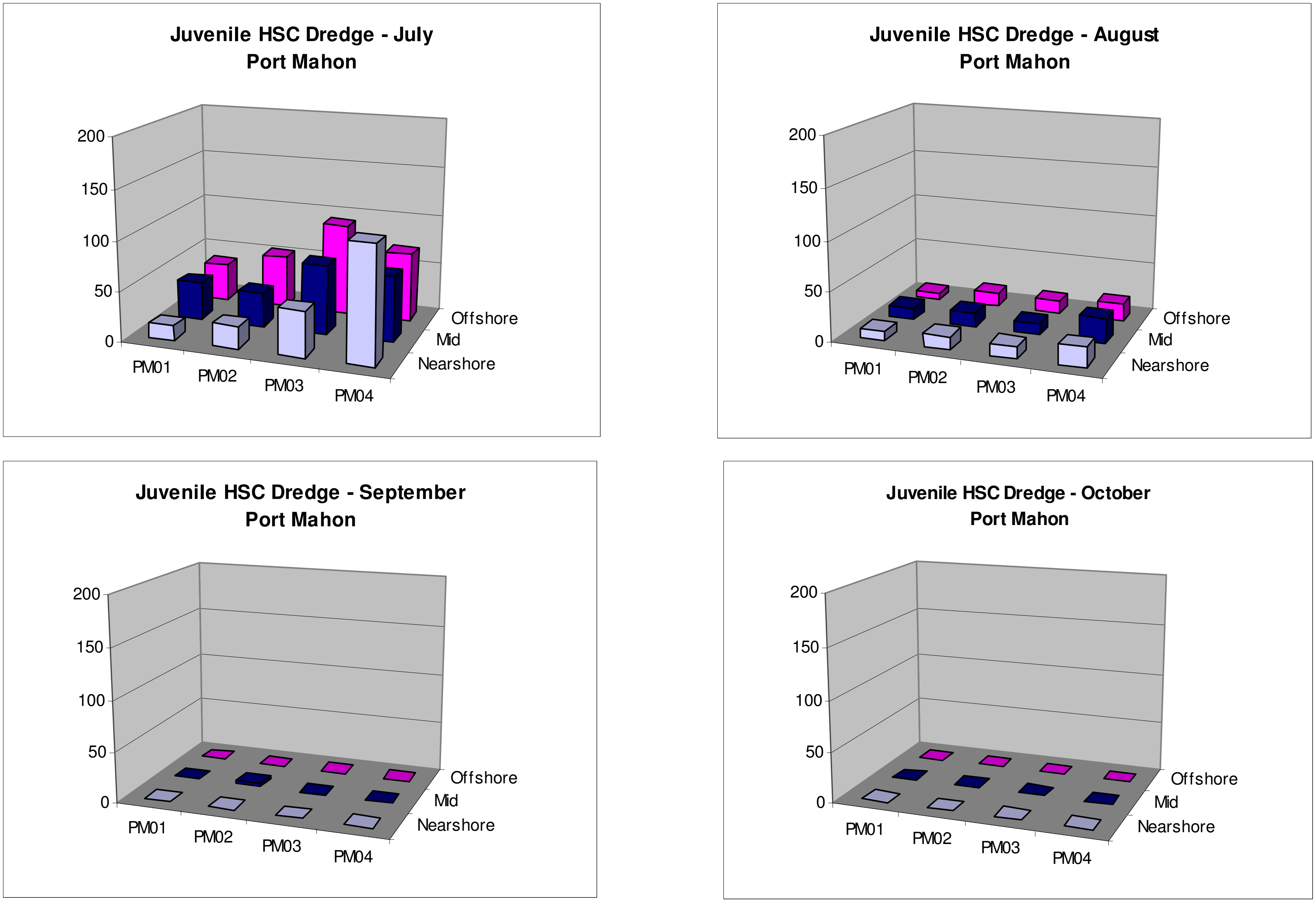


Figure 3-2. Number of juvenile horseshoe crabs collected per 50-foot tow with a suction-dredge off Port Mahon July, August, September, and October 2004

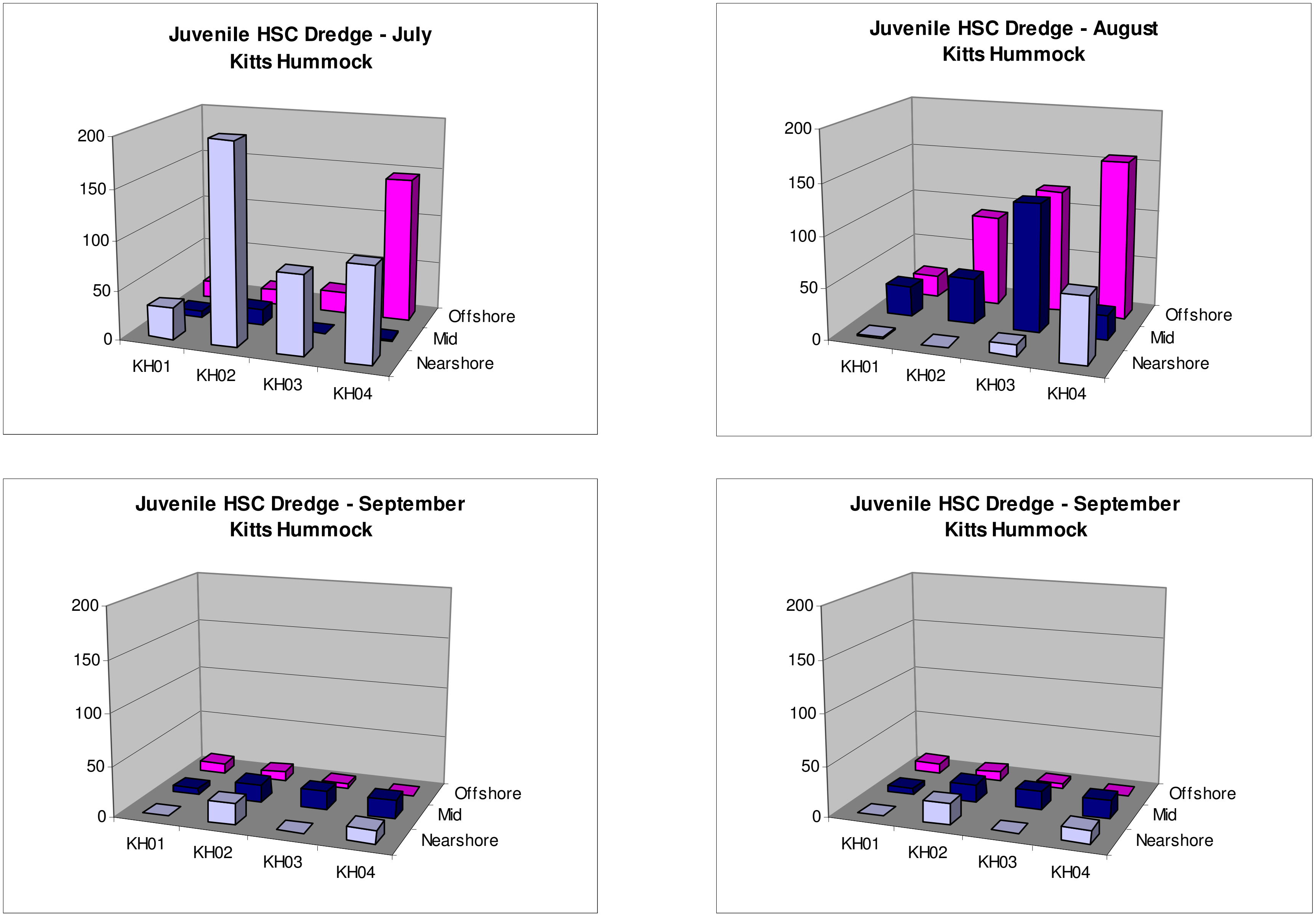


Figure 3-3. Number of juvenile horseshoe crabs collected per 50-foot tow with a suction-dredge off Kitts Hummock July, August, September, and October 2004

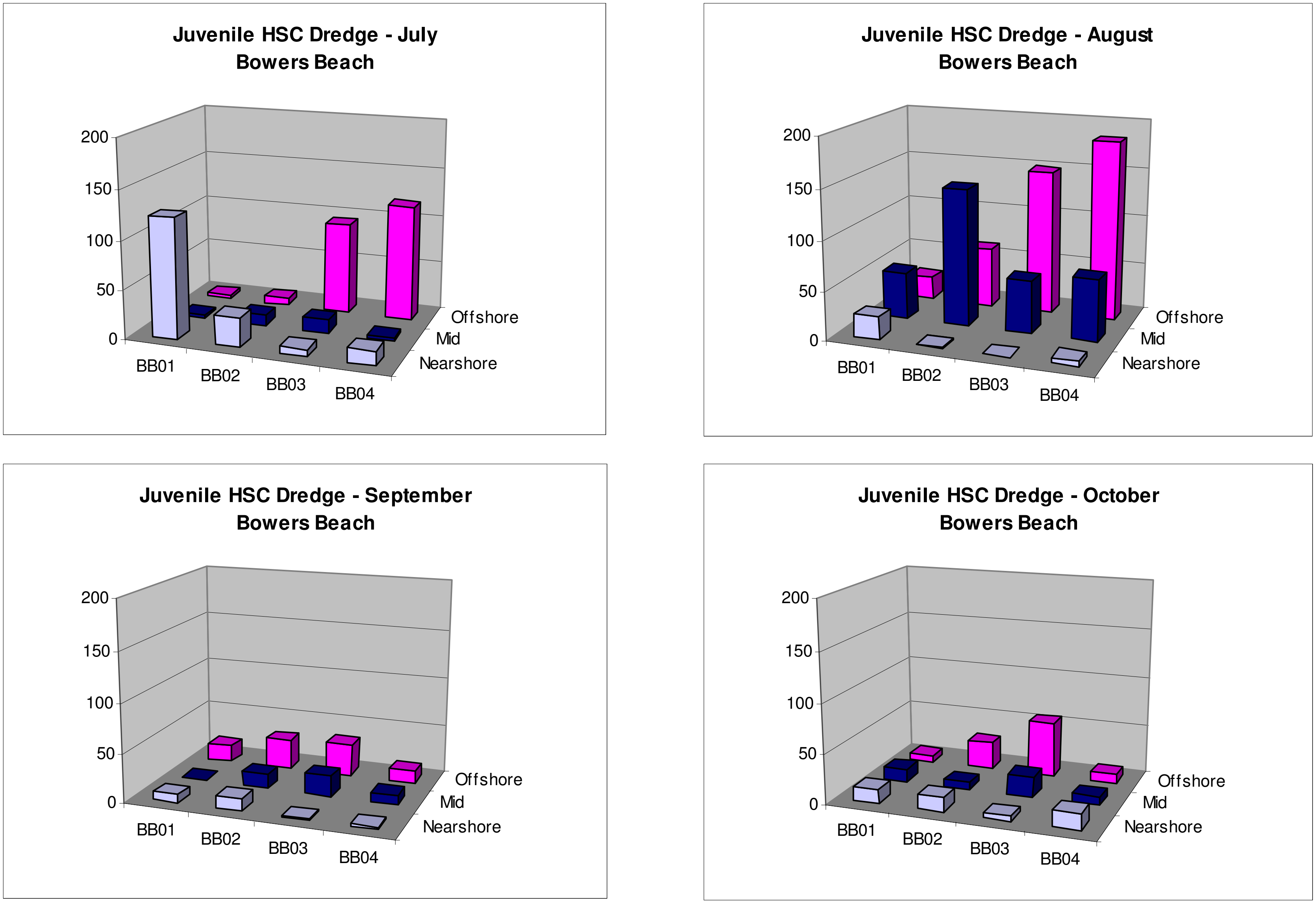


Figure 3-4. Number of juvenile horseshoe crabs collected per 50-foot tow with a suction-dredge off Bowers Beach July, August, September, and October 2004

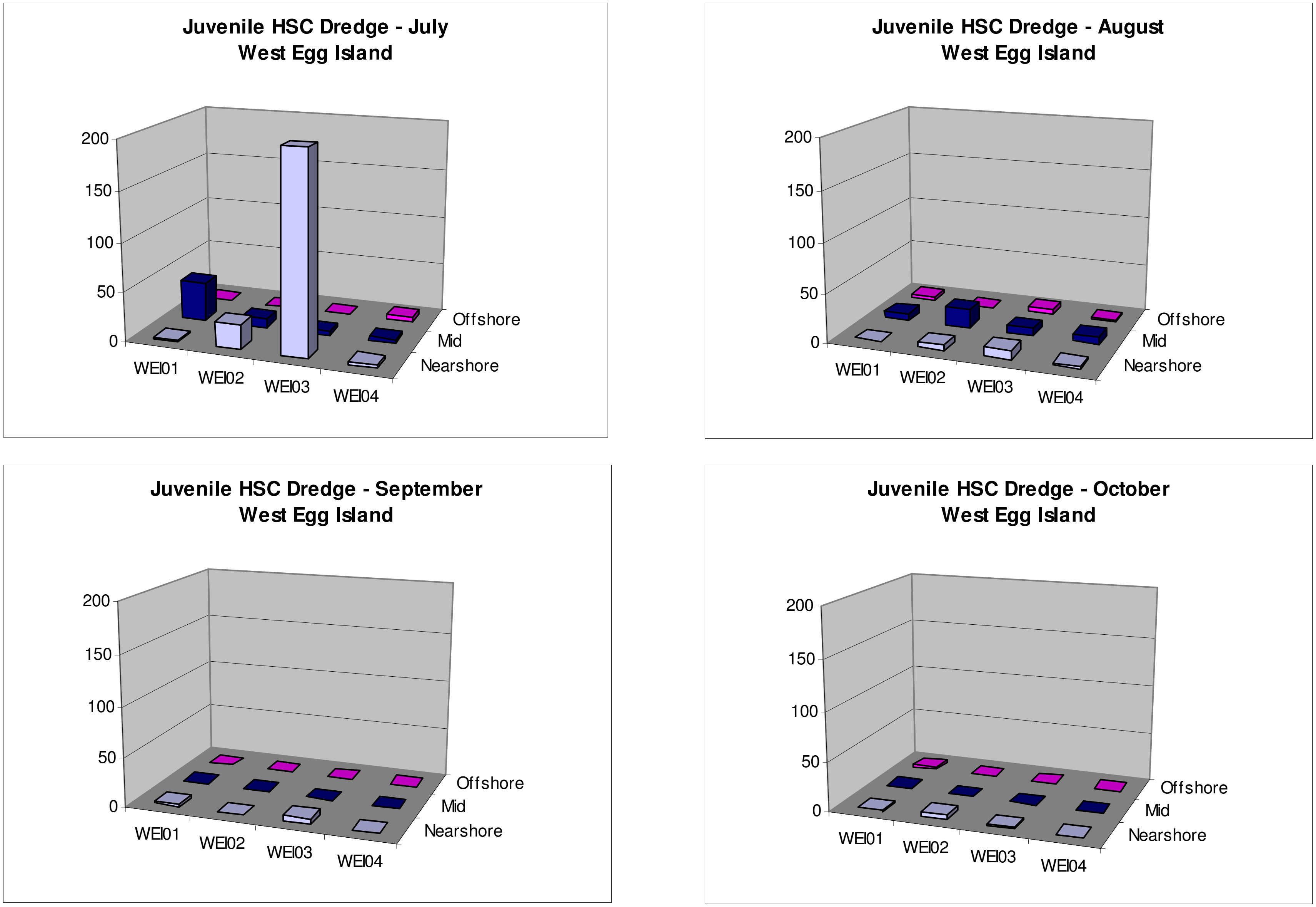


Figure 3-5. Number of juvenile horseshoe crabs collected per 50-foot tow with a suction-dredge off West Egg Island July, August, September, and October 2004

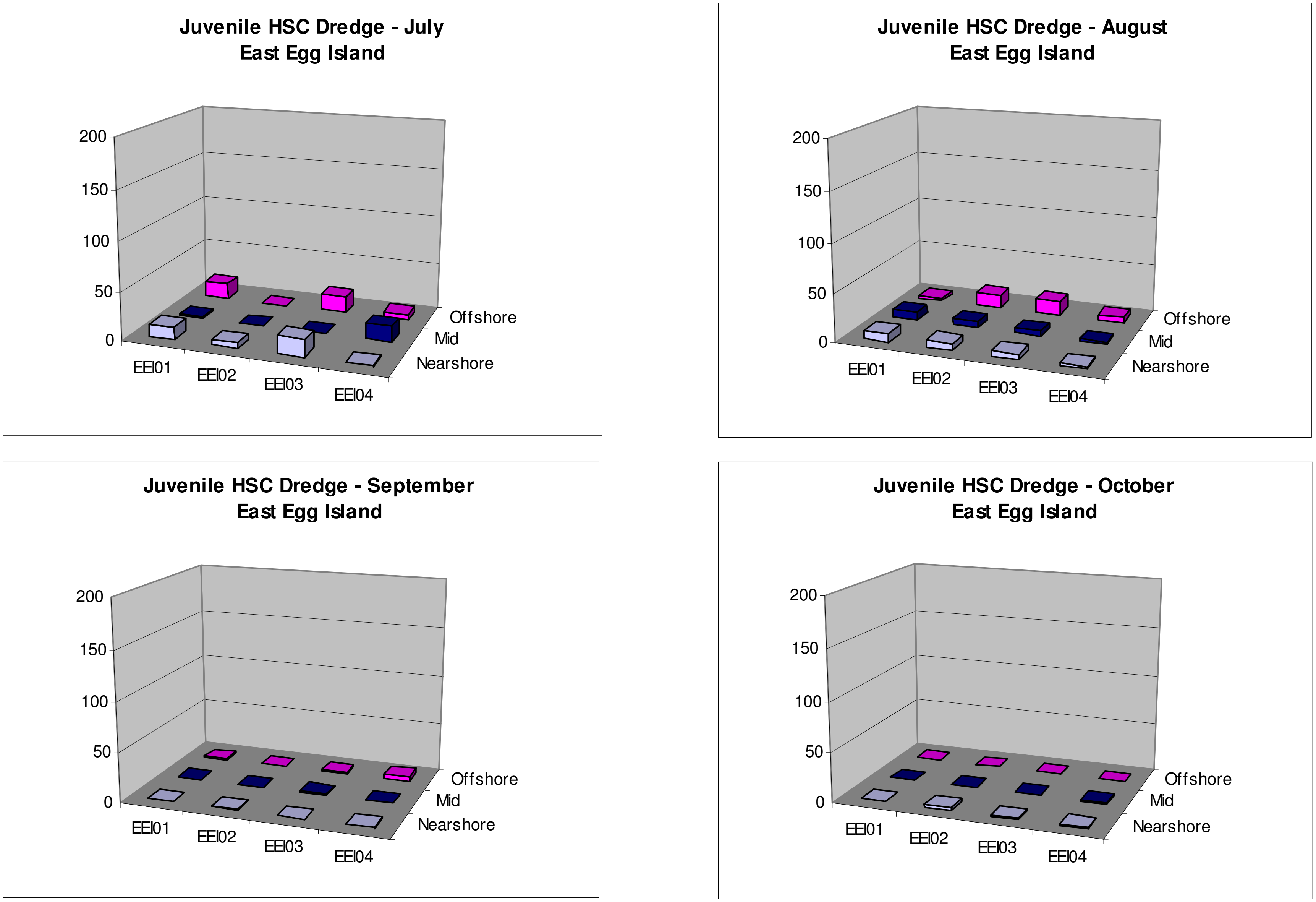


Figure 3-6. Number of juvenile horseshoe crabs collected per 50-foot tow with a suction-dredge off East Egg Island July, August, September, and October 2004

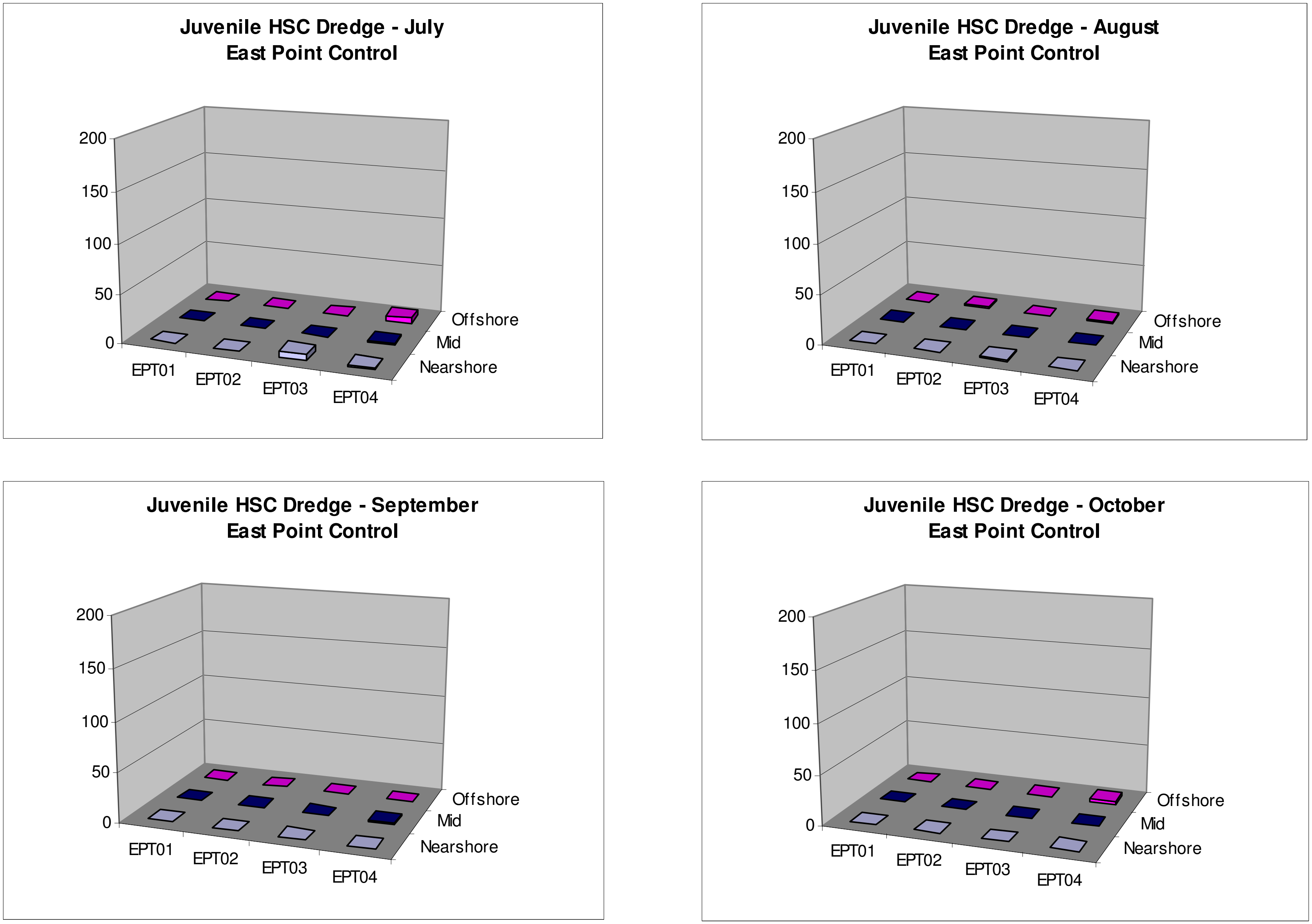


Figure 3-7. Number of juvenile horseshoe crabs collected per 50-foot tow with a suction-dredge off East Point Reference July, August, September, and October 2004

along this beach were concentrated at the southern end of the nearshore, mid, and offshore transects in July. The same pattern was also apparent at Port Mahon (Figure 3-2), although about twice as many crabs were collected. Suction dredging at the two southern Delaware beaches, Bowers Beach and Kitts Hummock, showed a disparity among sampling transects in July (Figure 3-3 and 3-4). More crabs were collected from the nearshore and offshore transects than in the mid-distance transect. The highest count for the Delaware side of the bay occurred at the Kitts Hummock nearshore transect in July at 207 crabs (Figure 3-3). During August, juvenile crabs were more abundant farther down the bay and along the Delaware shore. More than half of the counts at Bowers Beach and Kitts Hummock exceeded 40 crabs per sample, whereas counts at all other beaches ranged 25 or fewer. Assuming that natural mortality and predation were minimal, the juvenile crabs also appeared to be moving farther from shore. Counts from the mid-distance and offshore samples at the two southern beaches were consistently greater and ranged to 184 at Bowers Beach and 157 at Kitts Hummock.

Among the four Delaware beaches surveyed for horseshoe crab juveniles, the bulk of the population appeared to have moved out of the survey area into deeper water by September. During September and October, the abundance of juvenile horseshoe crabs markedly declined within all sampling transects. Although the highest counts were again recorded from Bowers Beach and Kitts Hummock, all but one ranged less than 40 crabs. As before, higher numbers of crabs were taken from the offshore habitat and farthest from the spawning beach.

In contrast, New Jersey had much lower counts during July and all other subsequent months (Figures 3-5 through 3-7) despite the fact that east Egg Island and East Point Beach produced high numbers of eggs in the spawning survey. Other than the high July count at the nearshore transect along West Egg Island, counts at all other stations ranged less than 40 crabs.

The juvenile horseshoe crab data from the suction dredge collection were examined for prosomal 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 (Figure 3-8). In July, three peaks of 7-mm, 10-mm, 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-mm, 17-mm, 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 and Botton, 1985; Shuster, 1982)[1]. 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 the tri-modal size frequencies were mostly a function of the Delaware collections.

[1] Shuster, C. N., Jr. and M. L. Botton. 1985. A contribution to the population of horseshoe crabs, Limulus polyphemus (L.), in Delaware Bay. Estuaries, 8: 63–372.

Shuster, C. N., Jr. 1982b. Xiphosurida. pp. 766–770. In: Encyclopedia of Science and Technology. McGraw-Hill.

Sediment samples were collected once at all 84 sampling stations for the juvenile horseshoe crab survey and analyzed for grain size, percent slit/clay, and total organic carbon (TOC, as percent carbon). These data were compared to the monthly suction dredge catches to evaluate whether juvenile horseshoe crabs were selecting specific bottom habitats. The regressions of crab catch versus percent silt/clay and TOC suggests they were not selecting muddier sites over sandier sites as none of the regressions were significant (Figure 3-9).

Table 3-6 presents water quality parameters, salinity and temperature, measured offshore of Delaware Bay spawning beaches in conjunction with juvenile horseshoe crab surveys. Salinity was high during the July/August survey ranging from 22 to 28 ppt throughout. For the remaining three survey events, salinity was more uniform and ranged from 10 to 20 ppt. Salinity usually increases with depth in estuarine environments owing to the difference in density between the mixing freshwater (lower) and saltwater (higher). The difference in salinity between surface and bottom measures was very slight given the shallowness of the nearshore habitats. Measures of temperature followed a seasonal pattern of decrease over the sampling period from late summer into fall. Average temperatures across the four survey events spanning July to November were 27, 25, 21, and 10 ºC.

3.4 TRAWL SURVEY

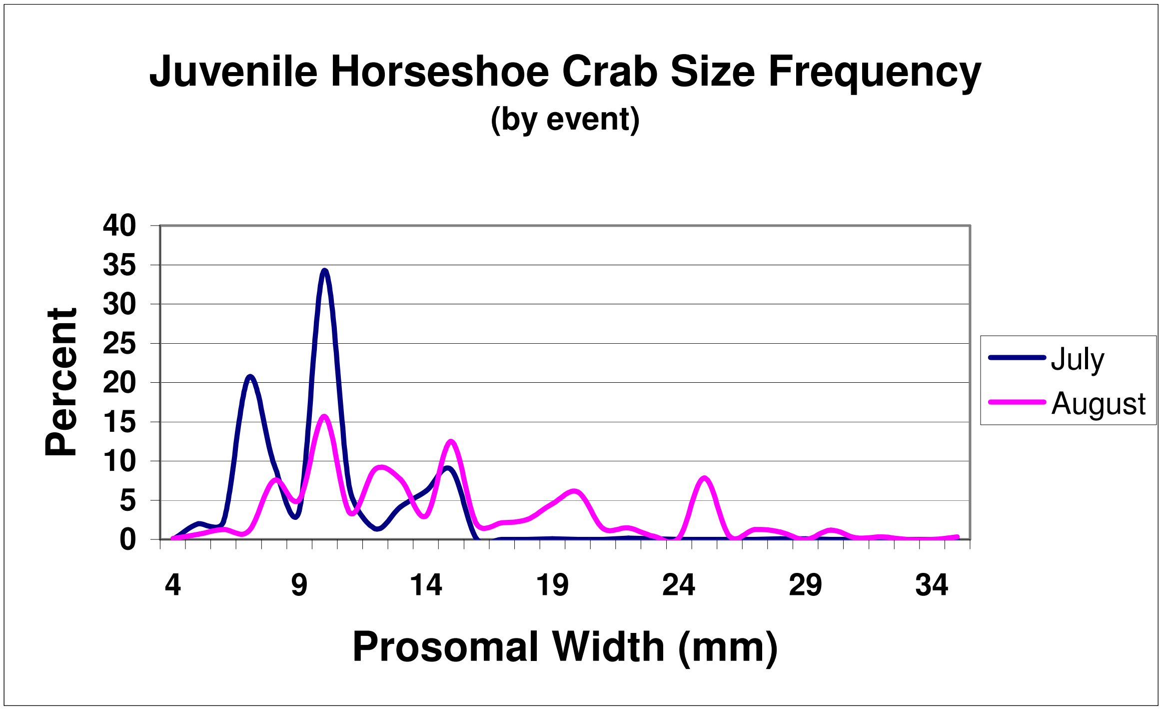
Data on fish and other invertebrates were collected to characterize the conditions prior to the planned Kelly Island and Egg Island restorations. These data will be used to assess effects of the project at a later time (i.e., post-construction). We determined that the trawls were less effective at catching juvenile horseshoe crabs. Suction-dredging for 50-foot tow lengths consistently collected more juveniles than the 2-minute trawls that typically covered about 500 feet of bottom. Therefore the timing and seasonal movements of horseshoe crab juveniles are primarily based on the suction dredging for this report. Below we provide a description of the general spatial and temporal patterns in fish and shellfish populations observed from the trawl data.

High numbers of adult and juvenile horseshoe crabs were collected off of the New Jersey and Delaware study beaches by the trawl survey during 2004 (Tables 3-7 and 3-8). Higher numbers of crabs were collected early in the survey during July and August as adult crabs are concluding annual spawning efforts and returning to the deeper water habitats. Average catches were highest in July/August along the Delaware shore off Port Mahon at 76.3; the three other beaches had similar catches at about 20 (Table 3-8). The highest mean catch among New Jersey beaches (24.8) was from East Egg Island also during the July/August survey (Table 3-7). During the August/September survey, a high mean catch of 25.7 was recorded from Bowers Beach (Table 3-8), a further indication that the crabs were migrating to the lower portions of the bay. The Bowers Beach survey location is the farthest down bay of all of the study beaches. By the September survey and beyond, horseshoe crabs were much reduced with all catches less than 2 per haul (Tables 3-7 and 3-8).

Table 3-6. Salinity (ppt) and temperature (ºC) measured while surveying for juvenile horseshoe crabs off Delaware Bay spawning beaches during 2004

Beach	Surface		Bottom	
	Salinity	**Temperature**	**Salinity**	**Temperature**
Event 1 - July/August				
East Egg Island	24.80	27.80	24.80	27.50
West Egg Island	24.40	27.30	24.90	26.70
East Point	21.20	26.90	22.10	26.90
Kelly Island	22.01	25.56	22.02	25.56
Port Mahon	22.57	25.45	22.71	25.49
Kitts Hummock	25.50	25.45	25.62	25.41
Bowers Beach	27.20	25.58	27.21	25.52
Event 2 - August/September				
East Egg Island	17.80	24.86	17.84	24.85
West Egg Island	NM	NM	NM	NM
East Point	17.81	25.62	17.81	25.50
Kelly Island	13.87	24.90	14.04	24.89
Port Mahon	14.20	26.12	14.20	26.07
Kitts Hummock	17.69	24.47	17.00	24.41
Bowers Beach	18.19	25.01	19.83	24.51
Event 3 - September/October				
East Egg Island	17.63	21.13	17.54	20.89
West Egg Island	14.83	19.62	16.71	19.80
East Point	10.94	20.81	11.11	21.14
Kelly Island	10.12	22.04	9.96	22.57
Port Mahon	15.75	21.46	16.49	20.94
Kitts Hummock	13.35	21.94	13.36	21.87
Bowers Beach	14.70	22.20	15.27	22.56
Event 4 - October/November				
East Egg Island	18.71	10.80	NM	NM
West Egg Island	19.28	10.72	NM	NM
East Point	16.85	9.52	NM	NM
Kelly Island	16.84	9.74	NM	NM
Port Mahon	15.13	9.12	NM	NM
Kitts Hummock	17.66	10.48	NM	NM
Bowers Beach	18.56	10.46	NM	NM

NM - not measured



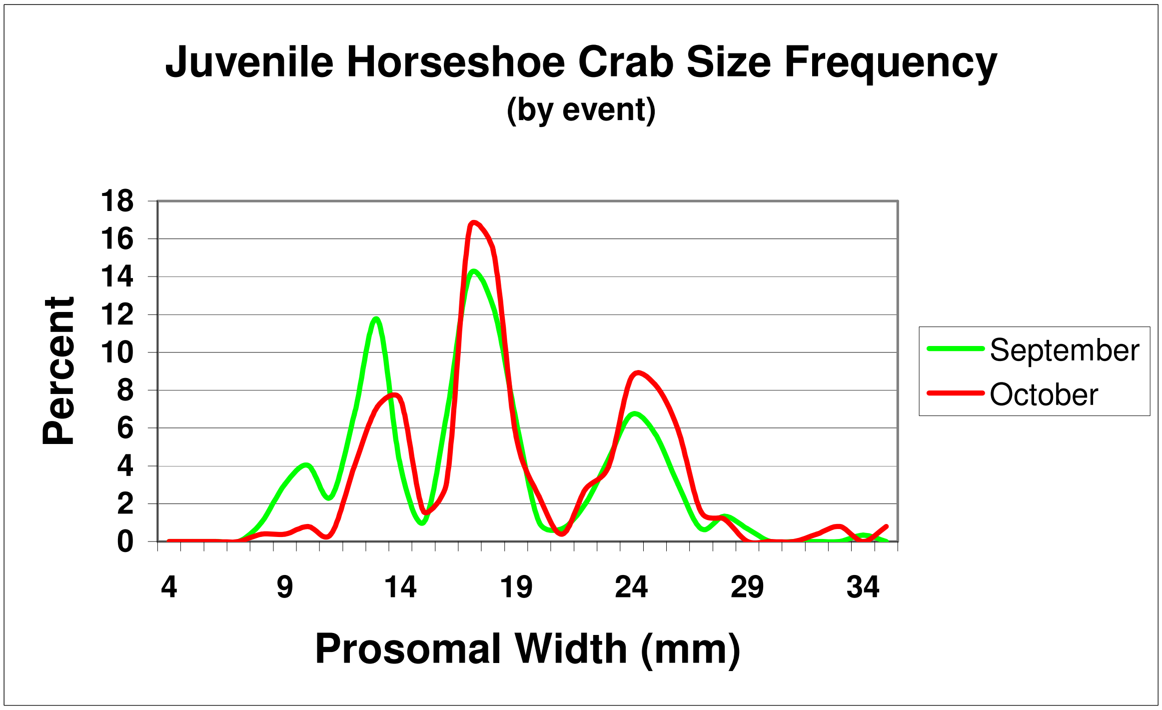


Figure 3-8. Size frequency analysis of horseshoe crab prosomal widths for all suction dredge collections (New Jersey and Delaware data combined) by sampling event

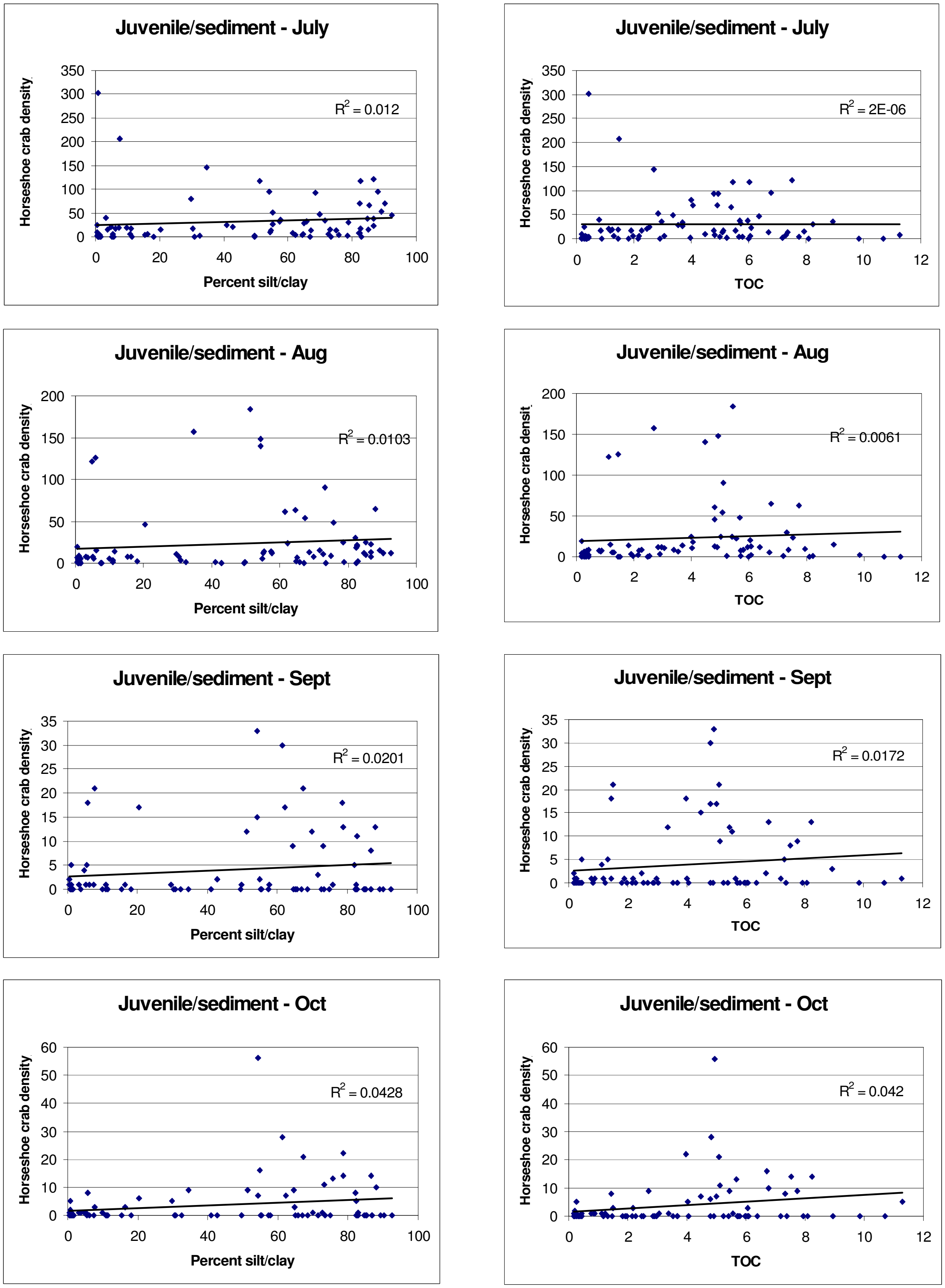


Figure 3-9. Regression of juvenile horseshoe crab catches in the suction-dredge versus TOC (as percent carbon) and silt/clay content

Table 3-7. Average catch of fish and other invertebrates collected from 12 trawls along New Jersey shore study beaches during 2004

Species	July/August			August/September			September/October			October/November		
	EEI	WEI	EPT	EEI	WEI	EPT	EEI	WEI	EPT	EEI	WEI	EPT
Alewife											0.17	0.08
American Eel						0.08					0.08	
Atlantic Croaker				0.08			1.08	7.42	2.83	3.67	6.92	7.25
Atlantic Menhaden										2.58		
Atlantic Silverside										0.50		0.08
Atlantic Stingray												
Bay Anchovy	13.83	3.50	3.00	8.08	2.92	6.08	43.50	26.08	115.92	7.67	22.00	6.25
Black Cheek Tonguefish						0.08						
Black Drum						0.08						
Black Sea Bass			0.33			0.17						
Blenny												
Blue Crab	3.17	1.42	2.67	11.17	2.17	5.42	0.83	1.33	2.50	0.58	1.42	18.50
Bluefish				0.17			0.08					
Butterfish		0.17		0.08								
Chain Pipefish												
Clearnose Skate												
Diamondback Terrapin						0.17						
Grass Shrimp							2.33					
Green Crab												
Gulf Kingfish	0.08											
Hermit Crab								0.08				
Hickory Shad											0.08	
Hogchoker	2.17	2.00	1.33	1.00	2.00	0.58	0.08	1.92		0.08	0.83	
Horseshoe Crab	24.83	10.75	1.58	3.33	2.25	0.67	0.08	0.42	0.08	0.17	0.42	
Lady Crab		0.08			0.17							
Little Skate										0.08	0.42	
Moon Snail												
Naked Goby												
Northern Kingfish	0.50	0.17	0.25	0.92	1.00	0.58						
Northern Pipefish	0.33	0.25	0.08	0.75		0.25				0.25	0.17	0.17
Northern Puffer				0.08	0.25		0.08					
Northern Stargazer	0.08			0.08	0.17	0.17						
Oyster Toadfish		0.33	1.67	0.08	0.17	1.83						0.17
Scup					0.42			0.25	0.17			
Silver Perch			0.17	0.08		0.92	1.08	0.75	1.17	0.42	0.17	0.08
Smallmouth Flounder											0.08	0.25
Smooth Dogfish												
Southern Kingfish												
Southern Sting Ray												
Spider Crab								0.08				
Spot					0.08				0.08			

Table 3-7. (Continued)

Species	July/August			August/September			September/October			October/November		
	EEI	**WEI**	**EPT**	**EEI**	**WEI**	**EPT**	**EEI**	**WEI**	**EPT**	**EEI**	**WEI**	**EPT**
Spotted Hake											0.17	0.25
Striped Bass									0.25			0.17
Striped Burrfish												
Striped Cusk Eel	0.33	0.33		0.17	0.50			0.08				
Striped Sea Robin	1.58	0.33	0.17		0.25							
Summer Flounder			0.08		0.17	0.08						
Tautog				0.08								
Unknown Alosid											0.25	0.33
Unknown Specimen	0.08											
Weakfish	51.50	11.58	15.00	7.25	22.17	7.42	3.42	1.42			0.08	
White Perch									0.08	0.17	0.75	0.67
White Shrimp												
Windowpane											0.08	
Winter Flounder												0.08
Winter Skate												
Total Species	***12***	***12***	***12***	***16***	***15***	***16***	***10***	***11***	***9***	***11***	***17***	***14***

EEI = East Egg Island
WEI = West Egg Island
EPT = East Point Beach

Table 3-8. Average catch of fish and other invertebrates collected by 12 trawls along Delaware shore study beaches during 2004

Species	July/August				August/September				September/October				October/November			
	PM	KI	KH	BB	PM	KI	KH	BB	PM	KI	KH	BB	PM	KI	KH	BB
Alewife													0.25	0.08	0.42	0.25
American Eel					0.08					0.08				0.08		
Atlantic Croaker									22.00	83.42	28.17	18.42	111.42	80.50	693.08	465.17
Atlantic Menhaden									0.08		0.08	0.08	0.08		0.08	0.17
Atlantic Silverside									0.08			1.08				
Atlantic Stingray			0.08													
Bay Anchovy	14.75	4.75	0.50	5.25	3.08	7.08	24.08	21.58	6.00	3.25	90.17	77.08	4.25	6.75	16.83	49.58
Black Cheek Tonguefish															0.08	0.25
Black Drum									0.33	0.17			0.08	0.67		
Black Sea Bass			0.33	0.08												
Blenny							0.08	0.17								
Blue Crab	1.50	2.17	1.83	2.33	88.83	17.33	17.33	22.50	6.08	4.00	1.25	0.67	12.42	11.83	3.00	5.58
Bluefish	0.08			0.17	0.17		0.08	0.08	0.08			0.17				
Butterfish											0.33	0.42				
Chain Pipefish			0.08													
Clearnose Skate																0.08
Diamondback Terrapin																
Grass Shrimp																
Green Crab			0.08													
Gulf Kingfish										0.08						
Hermit Crab																0.08
Hickory Shad																
Hog Choker	13.42	3.92	5.83	8.50	5.42	0.92	0.92	2.58	0.42	0.50	0.42	0.42	0.17	0.08	0.67	0.08
Horseshoe Crab	76.33	22.58	21.17	22.67	1.83	0.67	9.08	25.67			0.25				1.92	0.58
Lady Crab																
Little Skate																
Moon Snail																0.08
Naked Goby			0.33	0.50		0.25		0.17								
Northern Kingfish	0.08		0.08		0.08	1.50	0.58	0.75	0.08		0.17		0.08	0.08	0.08	0.33
Northern Pipefish	0.08	0.08	0.17	0.92	0.08	0.08	0.75	0.33	0.17		0.42	0.17	0.17		0.08	0.25
Northern Puffer																
Northern Stargazer							0.08							0.08		
Oyster Toadfish		0.92	1.75	1.75		0.08	0.92	0.67			0.08			0.08	0.08	0.08
Scup		0.33	0.83	0.42		0.08										
Silver Perch	0.08	0.17	1.08	1.17	0.50	0.17	3.58	0.25	1.00	0.92	0.17	0.50	0.17	0.25	0.25	0.17
Smallmouth Flounder									0.08							
Smooth Dogfish							0.08	0.08								
Southern Kingfish							0.08			0.25						
Southern Sting Ray							0.08									
Spider Crab																
Spot	0.25	0.17	0.17	0.75	0.33	1.17	0.92	0.50								

Table 3-8. (Continued)																
	July/August				**August/September**				**September/October**				**October/November**			
Species	**PM**	**KI**	**KH**	**BB**	**PM**	**KI**	**KH**	**BB**	**PM**	**KI**	**KH**	**BB**	**PM**	**KI**	**KH**	**BB**
Spotted Hake						0.08					0.25	0.25	0.08	0.25	0.08	0.17
Striped Bass									0.08	0.08	0.08	0.08	0.08	0.08	0.42	0.33
Striped Burfish			0.33				0.08	0.50								
Striped Cusk Eel	0.08	0.17	0.42		0.08	0.08	0.25	0.08		0.17				0.25	0.08	0.08
Striped Sea Robin	0.08	0.08	0.75	1.33	0.25	0.17	1.08	3.75								
Summer Flounder	0.08	0.17	0.50	0.33		0.08		0.08					0.08			
Tautog																
Unknown Alosid															0.33	
Unknown Specimen																
Weakfish	14.42	21.92	25.25	18.50	53.25	26.50	48.00	61.08	3.83	4.08	3.33	2.08	1.83	0.83	4.67	3.42
White Perch									0.33	1.50			0.92	1.50	4.83	2.42
White Shrimp																0.08
Windowpane																
Winter Flounder					0.08		0.33	0.50								
Winter Skate																0.08
Species Total	***13***	***13***	***20***	***15***	***14***	***16***	***20***	***19***	***15***	***13***	***14***	***13***	***15***	***16***	***18***	***22***

PM = Port Mahon
KI = Kelly Island
KH = Kitts Hummock
BB = Bowers Beach

In addition to horseshoe crabs, 53 species of fish and other invertebrates were collected during trawl surveys conducted off Delaware Bay study beaches during 2004 (Table 3-7 and 3-8). Species composition and abundance across the 4-month survey period from July to October followed a pattern consistent with seasonal changes. Species most commonly collected were Atlantic croaker, bay anchovy, blue crab, hogchoker, and weakfish. Overall, abundances of these species appeared to be consistent with seasonal migrations of juvenile and adult fish that use the bay as a spawning and nursery area.

The trawl surveys revealed a distinctive pattern of seasonal abundance for the Atlantic croaker. This species was all but absent from the seven study sites during the first two surveys in July and late August (Tables 3-7 and 3-8). During the last two surveys, spanning late summer into fall, Atlantic croakers were collected at all survey locations. Most were juvenile croakers (<150 mm) that had migrated into the estuary to feed after transitioning from larval stages. Numbers of croaker peaked along both New Jersey and Delaware shores during the October survey, but were much higher along the lower Delaware Bay at Bowers Beach and Kitts Hummock when croaker catches were 465.2 and 693.1 per tow, respectively (Table 3-8).

Bay anchovies, a major forage base for many species, were present throughout the entire sampling season in both New Jersey and Delaware sampling areas (Tables 3-7 and 3-8).

Because this species can form schools throughout the water column, bottom trawling generally does not provide a good quantitative method for estimating abundance. Nonetheless, the highest catches for this species were recorded during late summer (September/October Event), and most likely reflect juvenile recruitment following spawning that peaks in July.

Blue crabs were collected off all beaches during the trawl survey; however, they appeared to be most abundant during late August along the Delaware shore (Tables 3-7 and 3-8). From the August/September survey, catches ranged from 17.3 at Kelly Island and Kitts Hummock to 88.8 at Port Mahon (Table 3-8). Juvenile crabs in the 25 – 90 mm range made up a major part of the total catch. Adult crabs were also present, but in smaller numbers. Along the New Jersey study beaches, blue crabs were generally less abundant with catches usually ranging less than 10 per haul; although, a high catch of 18.5 was recorded at East Point during the October/November survey (Table 3-7).

Hogchokers were collected throughout the trawl survey period, but were most common along the Delaware shore during late July into August. Average catches for this species ranged as high as 13.4 at Port Mahon during the July/August survey (Table 3-7). From late August into fall, hogchoker catches dropped to generally less than 2 per sample.

Weakfish, which spawn in the spring, were more commonly collected during the earlier part of the survey period between July and early September. The higher catches during these times reflect juvenile recruitment when most young-of-the-year occupy shallow sub tidal habitats. The highest catch of 61.1 was recorded at Bowers Beach during the August/September survey (Table 3-7). With the onset of fall, weakfish are much less common in the shallow water habitats of the Delaware Bay. Weakfish average catches from September/October and thereafter ranged less than 5 throughout. Offshore movements of juvenile fish and/or predation in the fall likely contributed to the reduced catch rate as the sampling season progressed.

4.0 DISCUSSION

The principal objective of this study was to evaluate horseshoe crab spawning on Egg Island, New Jersey and Kelly Island, Delaware. The evaluation was based on comparing spawning intensity as measured by egg counts with other regional spawning beaches. The information from this study was necessary to provide a baseline measure of spawning prior to reconstruction, and to better define the spatial and temporal spawning characteristics along the affected beaches. A second objective was to evaluate juvenile horseshoe crab presence in nearshore habitats adjacent to the spawning beaches.

Horseshoe crab spawning at Delaware Bay beaches along the shores of Egg Island and Kelly Island followed an expected pattern during 2004. The onset of spawning in the spring was characteristically sudden and egg-laying by adult crabs was most intense during the months of May and June. Spawning of horseshoe crabs is usually synchronized with high (spring) tides associated with full or new moon phases. Survey methods for adult spawning crabs are usually scheduled around these times on the evening high tide. As our sampling schedule roughly followed 2-week intervals, we could not directly gauge the intensity of spawning, however on a number of occasions coupled adults were noted off spawning beaches, particularly at times near high tide.

Horseshoe crab spawning at Egg Island beaches was markedly different between the east and west sides of the Island. Egg counts along the west shore of Egg Island were the least productive among the New Jersey beaches. More than likely, this is in part due to the nature of the intertidal zone along this shore. In many parts, the intertidal zone leading up to the high beach is very broad and punctuated with clumps of decaying salt march. In effect, these might serve as obstacles to adult crabs trying to reach the higher beach to spawn. This observation is reinforced by sampling event 3 (28 May) on west Egg Island that produced high numbers of eggs. This event followed an extremely high tide that may have provided spawning adults access to this particular beach that was consistently unproductive at all other times. Spawning along the east side of Egg Island was much more prolific. Egg counts at the two beaches surveyed were comparable to those at East Point, the reference beach historically known for spawning. The east side of the island presents a more favorable habitat for spawning. The beaches have a more gradual slope and the high beach area preferred for egg-laying is much closer to the low tide mark. The spawning evaluation for Egg Island and the reference beach of East Point would benefit from a comparison with regional beaches surveyed using the same methods. At this time, comparative data are not available.

Horseshoe crab spawning at Kelly Island in Delaware was comparatively low during 2004. Egg counts from the island ranked among the lowest of 6 beaches sampled by DNERR, and several times lower than the proximal beach, Port Mahon. This last point is encouraging for the future of spawning on Kelly Island as it indicates that a fair number of crabs already spawn nearby. Spawning along the Delaware shore generally follows a consistent pattern with respect to location. For the past three years, a comparison among the 6 DNERR beaches by the total number of eggs collected has produced the same rankings. As described earlier, the intertidal zone at Kelly Island is interrupted in many places by a steep face of decaying salt marsh that might prevent horseshoe crabs from reaching optimal spawning beaches except during the highest tides that surmount the marsh.

Juvenile horseshoe crabs were successfully collected in nearshore habitats adjacent to New Jersey and Delaware spawning beaches. The suction-dredge provided a quantitative means by which to survey the youngest of crabs. The juvenile crabs were most abundant in the nearshore habitats during July and August. This is consistent with previous descriptions of juvenile habitat preference for intertidal flats near breeding beaches (Shuster 1982). Although it is suggested that they remain there for their first and second summers, juvenile crabs from our survey appeared to be moving farther from shore and to locations further down the bay by the end of summer. The impact of the reconstruction project on juvenile horseshoe crabs is not expected to be as great as that for the eggs. Shortly after hatching and reaching the bay, crab larvae molt into the juveniles capable of motility. In that regard, they at least have the ability to disperse into extensive intertidal habitat in the Delaware Bay. Given the success of the survey method employed for this study, it would be worthwhile to conduct a bay-wide survey for juvenile crabs following the spawning season to further elucidate patterns of dispersal and habitat preference.

Bottom sediment characterization of nearshore habitats did not correlate with the abundance of juvenile horseshoe crabs, suggesting that the juveniles were not selecting a specific sediment type. However, a limitation of this element of our study was point sampling for sediment in the vicinity of the track towed during suction-dredging which sampled crabs 25 feet to either side of the station. If the bottom habitat was more heterogeneous around the station point with respect to sediment type, this would obfuscate potential correlations. An alternative method would have been to take benthic grabs over a broader area. For example, a high count of 300 crabs was obtained in an individual tow. This reflects 6 crabs/m^2 assuming 100% efficiency of the gear. By replicate sampling within these high catch areas, crab density might be better correlated to bottom sediment type.

Trawl studies also highlighted several patterns of seasonal fish usage of inshore habitats in the vicinity of the reconstruction areas. Foremost, weakfish and Atlantic croaker (drum species) are abundant during early summer and late summer, respectively. Impacts from reconstruction may also occur for these species, but are less likely given their free-swimming abilities. Blue crabs were also frequently found in the nearshore habitats but are also capable of avoidance. The information from trawl studies will provide a comparative data set for surveys conducted post construction that will better assess the beneficial use of dredged materials for reconstruction.

The reconstruction of Egg and Kelly Island will likely span over a year, and therefore overlap with time of spawning for horseshoe crabs. Once the construction project is initiated, it must be carried on until completion so as to minimize the impact of uncontrollable factors such as weather and tide on its progress. By this circumstance, impacts to horseshoe crabs will be unavoidable for at least one spawning season. In broader scope however, the reconstruction of Egg and Kelly Islands stands to offer horseshoe crabs a much greater enhancement of spawning than would be lost by a single season by constructing suitable beaches. Continued monitoring after the restoration is completed will be needed to confirm that newly constructed beaches are in fact providing suitable spawning habitat. Based on results of the current study, gently sloping beaches with no physical barriers and high tide lines approximately 20 feet from the water edge appear optimal (i.e., similar to the slopes found at the eastern Egg Island sampling stations).