KELLY ISLAND PRE-CONSTRUCTION MONITORING STUDY IN DELAWARE BAY

Prepared for

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FOREWORD

This document, *Kelly Island Pre-Construction Monitoring Study in Delaware Bay*, was prepared by Versar, Inc., for Mr. John Brady, Environmental Resources Branch, U.S. Army Corps of Engineers, Philadelphia District, under Contract No. DACW61-95-D0011, Delivery Order No. 0015 The report provides and ecological characterization of near and offshore habitats around Kelly Island in Delaware Bay, Kent County, Delaware. Dr. Robert Diaz and Ms. Janet Nestlerode, R. J. Diaz and Daughters, conducted the sediment profile imagery. Dr. Gary F. Smith conducted the hydroacoustic survey.

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1.0 INTRODUCTION

1.1 JUSTIFICATION

The U.S. Army Corps of Engineers (USACE), Philadelphia District, proposes to use dredged material from the main navigational channel deepening project to reconstruct Kelly Island, located at the mouth of the Mahon River in Kent County, Delaware. Kelly Island has been subjected to severe shoreline erosion over many years to the extent that a significant amount of saltmarsh wetlands have been lost and commercial harbor facilities, originally occupying the protected lower Mahon River, have had to relocate farther upstream. The beneficial use of dredged material for restoring eroded beaches or creating productive saltmarsh habitat is increasingly being used as an alternative to traditional methods of dredged material disposal such as confined disposal facilities (CDF). If the deepening is implemented, dredged material from Liston, Cross Ledge, and/or Miah Maull navigation ranges (the Philadelphia to the Sea Deepening Project) would be used to reconstruct the shoreline of Kelly Island, and restore saltmarsh wetland habitat.

The restoration project would entail the installation of a 5,000-foot dike along the Delaware Bay shoreline of Kelly Island. The dike would be constructed with a Geotextile tube core overlain and supporting approximately 1.7 million cubic yards of sand. After the dike is constructed, dredged material of approximately 200,000 cubic yards of silt and 500,000 cubic yards of sand would be placed behind the dike to create a 60-acre saltmarsh wetland. During construction, dredged material would be pumped behind the dike and de-watered through a weir discharging into Delaware Bay at the northern end of the project.

It is expected that the reconstruction of Kelly Island would accrue a number of ecological benefits. On the bayshore side, a reconstructed sand beach would provide important nesting habitat for horseshoe crabs and diamondback terrapins. At present, most of this shoreline consists of eroding saltmarsh. Although there are areas of sand beach, for the most part these are broken up by hummocks of eroding saltmarsh as well. Behind the dike, saltmarsh restoration would provide habitat for shore nesting birds, and through several tidal cuts linking to the Mahon River, nursery habitat for fish and shellfish species. Further, stabilizing the Kelly Island shoreline may benefit the nearshore oyster beds by reducing sediment accumulation derived from erosion processes.

Should the Kelly Island reconstruction project proceed, a means to evaluate the ecological effects of the project is necessary. To that end, the purpose of this study is to provide a baseline ecological characterization of Kelly Island habitats prior to construction activities through the implementation of a multi-aspect monitoring program. Environmental data collected from this baseline monitoring program will be used to:

- identify sensitive habitats and natural resources present at Kelly Island prior to construction activities,

- evaluate the ecological benefits of the project by comparing to post-reconstruction monitoring data,
- provide a means to guide future wetland restoration projects planned for the Delaware River main channel deepening.

1.2 PROJECT SITE DESCRIPTION

Kelly Island is located on the western shore of Delaware Bay in Kent County, Delaware. It is bounded by Delaware Bay to the east, Simons River to the north, and Mahon River to the south and west. The Mahon River is an important port for local commercial and recreational fishermen. The reconstruction project would principally affect the lower eastern shore of the island, facing the Delaware Bay. Most of the sampling and monitoring activity for the project fell within the area bounded by the Kelly Island shoreline to the west, Mahon River mouth to the south, Simons River mouth to the north, and approximately 1.5-miles offshore toward the Delaware River main channel. Additional sampling for juvenile horseshoe crab data comparisons was undertaken along western shore Delaware Bay, Kitts Hummock and Broadkill beach. Shoreline erosion is occurring at an estimated rate of 20 feet per year, mostly from the loss of salt marsh. Depths in the Delaware Bay waters adjacent to Kelly Island are shallow and average approximately 9 feet out to the main channel, 5 miles to the east. The beach and access road to the south of the entrance of Port Mahon is severely eroded. Construction to stabilize the shoreline has occurred in the past as evidenced by the rock, sheet bulkheads, and construction rubble placed along the shoreline. The road leading to the state dock and ramp facilities is frequently washed out by storm events, and over time, the road has been moved farther back into the salt marsh.

1.3 OVERVIEW OF MAJOR STUDY ELEMENTS

This report summarizes the results of the first year monitoring of the environmental conditions in various habitats surrounding the Kelly Island restoration site. Seasonal sampling was conducted in 2001 to characterize spring, summer, fall, and winter conditions at the project site. Elements of the pre-construction survey included:

- Continuous water quality monitoring of oyster beds from May to November 2001,
- An estimation of sediment accumulation rates on oyster beds using sediment traps,
- Summer monitoring of oyster spat settlement,
- Seasonal oyster bed dredge surveys,
- Seasonal finfish and macro-invertebrate survey using otter trawl and beach seine,
- Spring horseshoe crab spawning survey,
- Summer juvenile horseshoe crab survey,
- Sediment profiling with a benthic camera before and after a major storm event,
- A fall benthic infaunal survey, and
- A hydroacoustic survey of oyster bed size.

2.0 METHODS

2.1 CHARACTERIZATION OF OYSTER BEDS

A number of Delaware Bay oyster beds near Kelly Island were monitored as part of the pre-construction study. Overall, six seedbeds and eight lease beds were investigated by a variety of monitoring activities (Table 2-1 and Figure 2-1). The seedbeds near Kelly Island are located further north or upbay relative to the lease beds. Seedbeds examined included Beck's Rock, Delaware Lower Middle, Drum Bed, Martin's Rock, Ridge Bed, and Silver Bed. Lease Beds (LB) included in the study were LB01, LB02, LB05, LB08, LB09, LB10, LB16, and LB102. Monitoring activities used to characterize the oyster beds included water quality monitoring, evaluation of the rate of oyster spat settlement, and a dredge survey to examine the population characteristics of the bed (Table 2-2). Not all of the monitoring activities were conducted at every oyster bed.

Table 2-1. Delaware Bay oyster beds near Kelly Island and tasks performed at them in the 2001 pre-construction period of the Delaware River Main Channel Deepening Project (NAD 83)

Beds	Latitude	Longitude	Water Quality Monitoring	Oyster Spat Study	Oyster Dredge Survey
Seed Beds					
Becks Rock	39° 12.890	75° 22.914	X		
Delaware Lower Middle	39° 13.981	75° 21.725	X	X	X
Drum Bed	39° 12.285	75° 22.303	X	X	X
Martins Rock	39° 12.835	75° 21.585		X	X
Ridge Bed	39° 12.572	75° 21.501		X	X
Silver Bed	39° 13.110	75° 22.923		X	X
Lease Beds					
Lease Bed 102	39° 11.171	75° 22.625	X	X	
Lease Bed 01	39° 10.465	75° 22.361		X	X
Lease Bed 02	39° 10.111	75° 21.940		X	X
Lease Bed 05	39° 10.209	75° 21.698		X	X
Lease Bed 08	39° 10.524	75° 20.866		X	X
Lease Bed 09	39° 10.552	75° 20.689			X
Lease Bed 10	39° 10.576	75° 20.441			X
Lease Bed 16	39° 9.977	75° 20.258			X

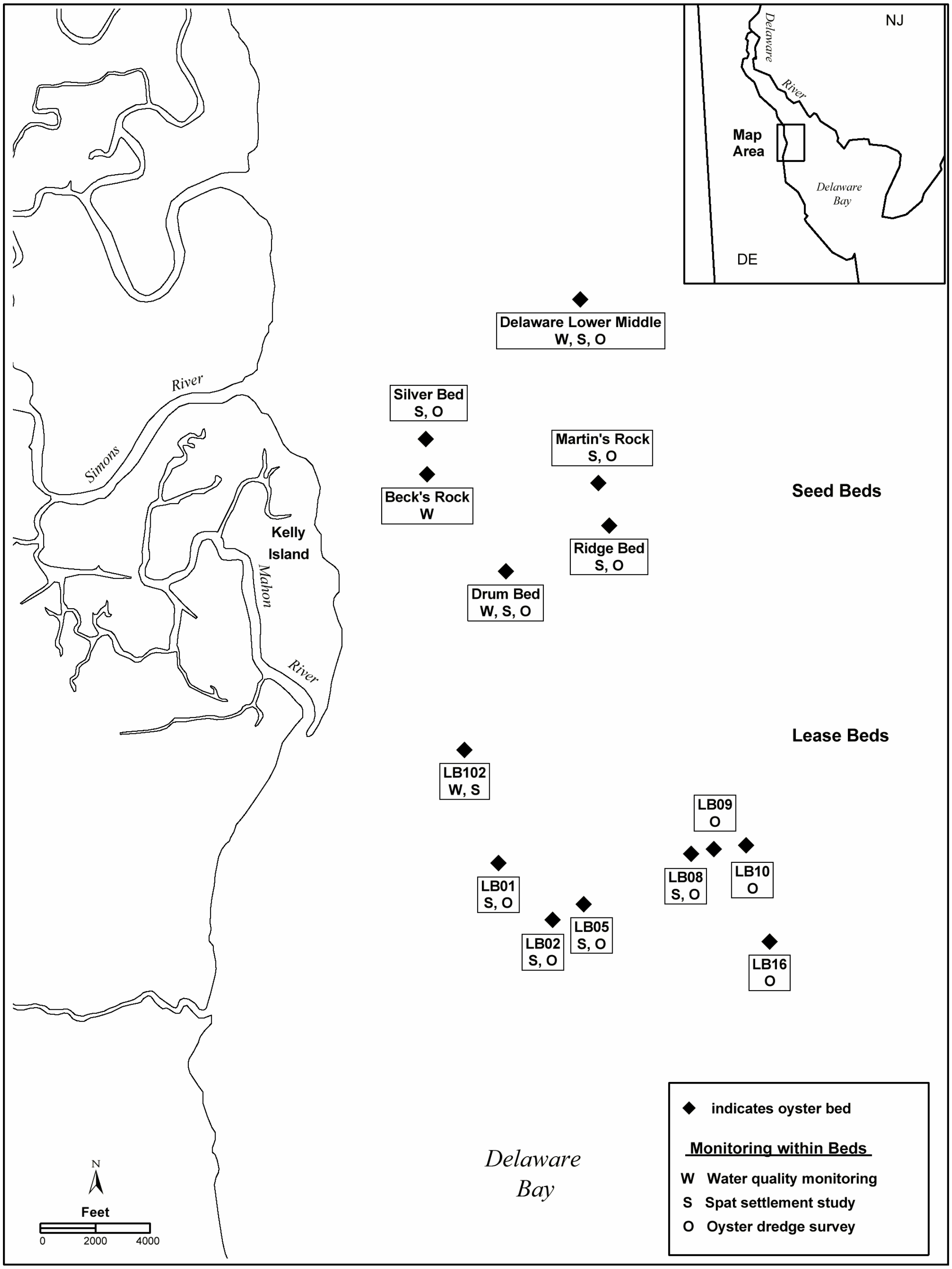

Figure 2-1. Oyster beds monitored during 2001 as part of the Kelly Island preconstruction characterization

Table 2-2. Schedule of monitoring tasks conducted at the Delaware Bay oyster beds near Kelly Island during 2001. Numbers represent event number the collection equipment was placed in the field.

Date	YSI	TSS	Sediment Trap	Oyster Spat	Oyster Dredging
01-May-01	Start				
31-May-01	1	X			
04-Jun-01			Start		
14-Jun-01	2	X	1		
27-Jun-01					Summer
28-Jun-01					
29-Jun-01					
03-Jul-01	3	X	2	Start	
17-Jul-01	4	X	3	1	
31-Jul-01	5	X	4	2	
15-Aug-01	6	X	5	3	
28-Aug-01	7	X	6	4	
19-Sep-01	8	X	7	5	
09-Oct-01					Fall
10-Oct-01					
11-Oct-01					
12-Oct-01	9	X	8	6	
02-Nov-01	10	X	9		
12-Dec-01	11	X			
15-Apr-02					Spring

2.1.1 Water Quality Monitoring

Water quality monitoring was conducted at four Delaware Bay oyster beds near Kelly Island from May through November 2001. Oyster beds monitored were Beck's Rock, Delaware Lower Middle, Drum Bed, and Lease Bed 102 (Table 2-1 and Figure 2-1). Water quality monitoring comprised continuous monitoring of physical/chemical parameters with water quality meters, analytical measures of total suspended solids, and estimation of sedimentation accumulation rates.

2.1.1.1 Continuous Monitoring with Water Quality Meters

Continuous data of physical/chemical parameters were collected by deploying data logging water quality meters (YSI 6600 Sondes). At 30-minute intervals, the meters recorded temperature, specific conductivity, salinity, dissolved oxygen, pH, turbidity, and chlorophyll. The meters were deployed over two to four weeks intervals for a total of eleven deployments

(Table 2-2). On each bed, the meters were moored such that the probes were positioned approximately 1-meter above the oyster bed substrate. As each meter was retrieved at the end of its logging cycle, a newly calibrated meter was deployed in its place. Retrieved meters were taken back to the laboratory for post-calibration, data download, maintenance/cleaning, and re-calibration. Post-calibration followed the normal sequence of calibration steps prior to cleaning. This enabled us to evaluate how effectively the probes were functioning toward the end of deployment. The sequence of calibration steps were as follows:

- Dissolved Oxygen – calibrated to 100% air saturation,
- Specific Conductivity – 58.6 mS/cm,
- pH – 7 and 10,
- Turbidity – 0 and 100 NTU,
- Chlorophyll – 0 and 75 to 85 (depending on temperature).

The temperature probe is factory set and cannot be calibrated. Salinity is derived from measures of specific conductivity and temperature and therefore does not need calibration.

Downloaded data were screened following protocols developed by the National Estuary Program which were comparable to those used by Delaware's Department of Natural Resources and Environmental Control (DNREC). At the outset, data were screened for obvious reporting errors due to probe malfunction, probe fouling, or power loss to the meter. Further, data were rejected if measurements were outside of the ranges of the listed specifications of the meter:

- Temperature – -5 to 45ºC,
- Specific Conductivity – 0 to 100-mS/cm,
- Salinity – 0 to 70-ppt,
- Dissolved Oxygen – 0 to 50-mg/L,
- pH – 0 to 14,
- Turbidity – 0 to 1000-NTU,
- Chlorophyll – 0 to 400-µg/L.

Lastly, data were flagged if consecutive measures (30-minute intervals) of a parameter varied too greatly. In these cases, if the error was obviously a result of probe malfunction, the data were eliminated from the data set. In order to determine appropriate cutoff ranges for each parameter, the raw data were graphed and visually examined to identify patterns of naturally occurring variation. In general use, the cutoff criteria were as follows:

- Temperature – change greater than 1.1ºC,
- Salinity – change greater than 5-ppt,
- Dissolved oxygen – change greater than 1.2-mg/L,
- Turbidity – change greater than 100-NTU.

The beginning and ending of each data set were also visually identified taking into account the time of field deployment and retrieval. A few lines of data were eliminated at the beginning of deployment data set to allow for the meters to fully equilibrate to ambient conditions. The water quality meters recorded approximately 40,000 lines of data over the seven months of monitoring.

2.1.1.2 Total Suspended Solids

Total suspended solids (TSS) were measured in the lower water column at the four oyster beds 11 times during the monitoring period (Table 2-2). Whole water samples were collected one meter above the oyster bed using a submersible pump. The water samples were collected in pre-labeled sample containers, stored at 4ºC, and shipped to the analytical laboratory (Blue Marsh Laboratories, Inc.). Laboratory methods for the analysis of TSS followed U.S. EPA Method 160.2. By this method, a measured volume of sample water is passed through a pre-weighed filter-pad with a nominal pore size of 0.7-µm. Following this, the filter-pad is rinsed of salts with double de-ionized water, and dried at 104ºC to a constant weight. TSS is calculated as the difference in weights between the dried filter-pad and it's pre-weight over the volume of water filtered.

2.1.1.3 Sedimentation Accumulation Rates

Sedimentation accumulation rates were measured in the lower water column at the four oyster beds over nine intervals during the monitoring period (Table 2-2). Rates were calculated from the amount of sediment that was deposited over time in sediment traps. Sediment traps were constructed by attaching two collection cups to the upper section of a commercial crab-pot. The tubular cups were secured to the crab-pot wire mesh with plastic cable-ties in an upright position within the hinged top-opening door. Collection cups were straight-sided PVC cylinders of 50-cm in length and a collection area of 45.4-cm^2. Sediment traps of similar design (i.e., with aspect ratios >5) have been successfully used to measure vertical particle flux in the Chesapeake Bay and Puget Sound (Norton and Barnard 1992, Boynton et al. 1993). When deployed, the openings to the collection cups were 70-cm above the oyster bed substrate. Each crab-pot was moored with a 50-lb weight and a buoy marked a line extending to the surface. At retrieval, the entire crab-pot was hoisted aboard. The replicate collection cups were removed and capped for laboratory processing. New collection cups were installed and the crab-pot was then redeployed overboard.

Sediments within the collection cups were processed in the laboratory by first washing them through a 1-mm sieve to remove amphipods and other sediment colonizing organisms. Samples were then placed in pre-weighed stainless steel vessels and oven-dried at 60°C for 14-21 days. The vessels were then re-weighed on a top-loading balance and the weight of the sediment determined in grams.

Sediment accumulation rates were calculated from sediment trap data. The accumulation rate (g/ cm^2/yr) is the measured flux of particulate matter into the traps and is composed of net sedimentation plus resuspension. These two processes cannot be estimated separately from sediment trap data; consequently, the results reported overestimate net sedimentation. Sedimentation rate calculations were as follows:

Mass Accumulation (g/ cm^2/yr) = [(P/A)/D] x Y

P = Amount of material collected (dry grams)
A = Collection area of sediment trap cup (cm^2)
D = Number of days trap was deployed
Y = Number of days in a year

2.1.2 Spat Settlement Rates

Spat settlement was investigated at five seedbeds and five lease beds in the Delaware Bay near Kelly Island during 2001 (Table 2-1; Figure 2-1). The seedbeds included Delaware Lower Middle, Drum Bed, Martin's Rock, Ridge Bed, and Silver Bed. The lease beds (LB) included LB-01, LB-02, LB-05, LB-08, and LB-102. At each bed, a weighted crab pot was deployed fitted with four spat settlement trays. Spat settlement trays comprised 1-ft^2 sheet of coated wire hardware cloth folded in half and wire-tied at the margins. Each tray held six clean oyster shells placed in alternating positions, and when affixed to a crab pot, was vertical in the water column and immediately above the oyster bed bottom. In total, 24 oyster shells were presented for spat settlement at each bed during each deployment.

Spat settlement trays were deployed seven times during the 2001 monitoring period (Table 2-2). Deployment dates were 3 July, 17 July, 31 July, 15 August, 28 August, 19 September, and 12 October. Soak time, or time deployed at an oyster bed ranged from 13 to 23 days. The last set, deployed 12 October, was retrieved 2 November.

After a crab pot was retrieved, the spat settlement trays were removed and labeled for the oyster bed and deployment dates. The crab pot was refitted with new trays and then redeployed. In the laboratory, the oyster shells were inspected under a dissecting microscope. Spat settlement rate was calculated by counting the number of oyster spat that settled onto a measured area of natural oyster shell for a specific period of time.

2.1.3 Oyster Dredge Survey

Oyster dredge surveys were conducted at 12 of the oyster beds near Kelly Island (Table 2-1; Figure 2-2). Five seedbeds were dredged and included Delaware Lower Middle, Drum Bed, Martin's Rock, Ridge Bed, and Silver Bed. Because Ridge Bed and Silver Bed were much larger than the other beds, three portions of these beds were dredged, designated East, West, Center. In total, 9 locations were dredged within the seedbeds. Seven lease beds (LB) were dredged and included LB-01, LB-02, LB-05, LB-08, LB-09, LB-10, and LB-16. Because LB-02 and LB-05 were proportionally larger than the other lease beds, two portions of these beds were dredged. In total, 9 locations were dredged within the lease beds.

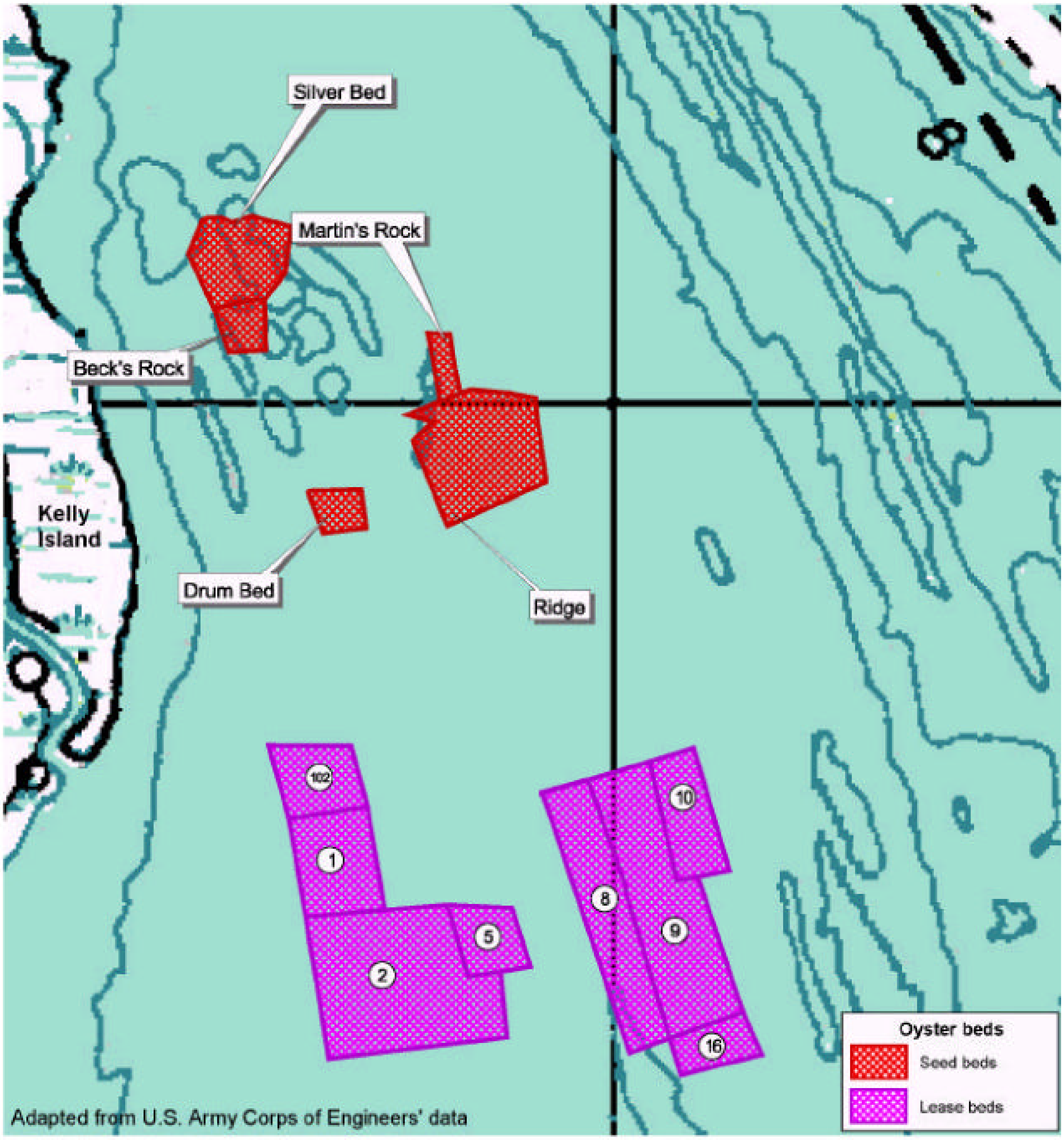

Figure 2-2. Delaware Bay seed and lease oyster beds off Kelly Island surveyed by dredging during 2001. Seed bed Delaware Lower Middle is not represented

Initially, oyster dredging was to be conducted seasonally over the monitoring period, or once during spring, summer, and fall. In the end, we managed to sample during early summer and fall (Table 2-2). We intended to complete the third dredge sampling within the monitoring period, however, the State of Delaware opened the seedbeds to a limited season for commercial oyster dredging. Given that we intended to collect baseline data to characterize the oyster beds, we felt that it was prudent to complete the last survey after the commercial harvest. To that end, we intend to finish the sampling in April 2002, which in effect fulfills the originally proposed sampling scheme.

Oyster dredging was conducted off of the Delaware research vessel, *Ringgold Brothers*, using the same crew and gear as used in their annual survey of oyster beds. Oysters were collected with a standard oyster dredge with a 54-inch tooth-bar width and a capacity of 7 bushels. Three dredge hauls were collected at each sampling location and processed as individual replicates. During operation, the dredge was towed at a speed of approximately 2 knots for in most cases 1-minute or less (depending on recovery, dredge time was occasionally longer in some of the less productive lease beds). Location data was recorded at the start and end of each dredge tow with a GPS.

For each dredge haul, we recorded the total number of bushels of material collected, and retained one bushel for oyster bed characterization. In characterizing the bushel samples, we counted the total number of live oysters present as well as categorizing them into spat (roughly less than 2-cm), small size (from 2 to 7-cm), and market size (7-cm or greater). In addition, we measured to the nearest millimeter up to 100 randomly selected oysters in each bushel. To assess recent mortality of oysters, we counted the number of "boxes" or articulated shells present in the bushel sample. In addition, we measured to the nearest millimeter up to 100 randomly selected boxes. To assess predation due to the oyster drill, we counted the number of boxes with oyster drill holes. Additionally we counted the number of oyster drills collected in the bushel sample. Ancillary species collected by the dredge were identified and recorded.

2.2 CHARACTERIZATION OF FISHERIES

Kelly Island fisheries were characterized principally by employing a seasonal trawl and seine survey. Additionally, horseshoe crabs were identified as a fisheries species that mandated special concern, and two methods were employed to characterize their occurrence at Kelly Island at distinct stages of their life history: an adult spawning survey was conducted during the spring and a nearshore juvenile survey was conducted in late summer.

2.2.1 Seasonal Trawling and Seining

Trawling and seining surveys were conducted seasonally during 2001 (Table 2-3). Trawling was conducted in three areas adjacent to Kelly Island in Delaware Bay (South, Central, and North), reference areas north and south, and within the Mahon River (Figure 2-3). Similarly, seining was conducted at three locations along Kelly Island (South, Central, and North) and the north and south reference locations (Figure 2-3). Trawling was conducted with a 16-ft otter

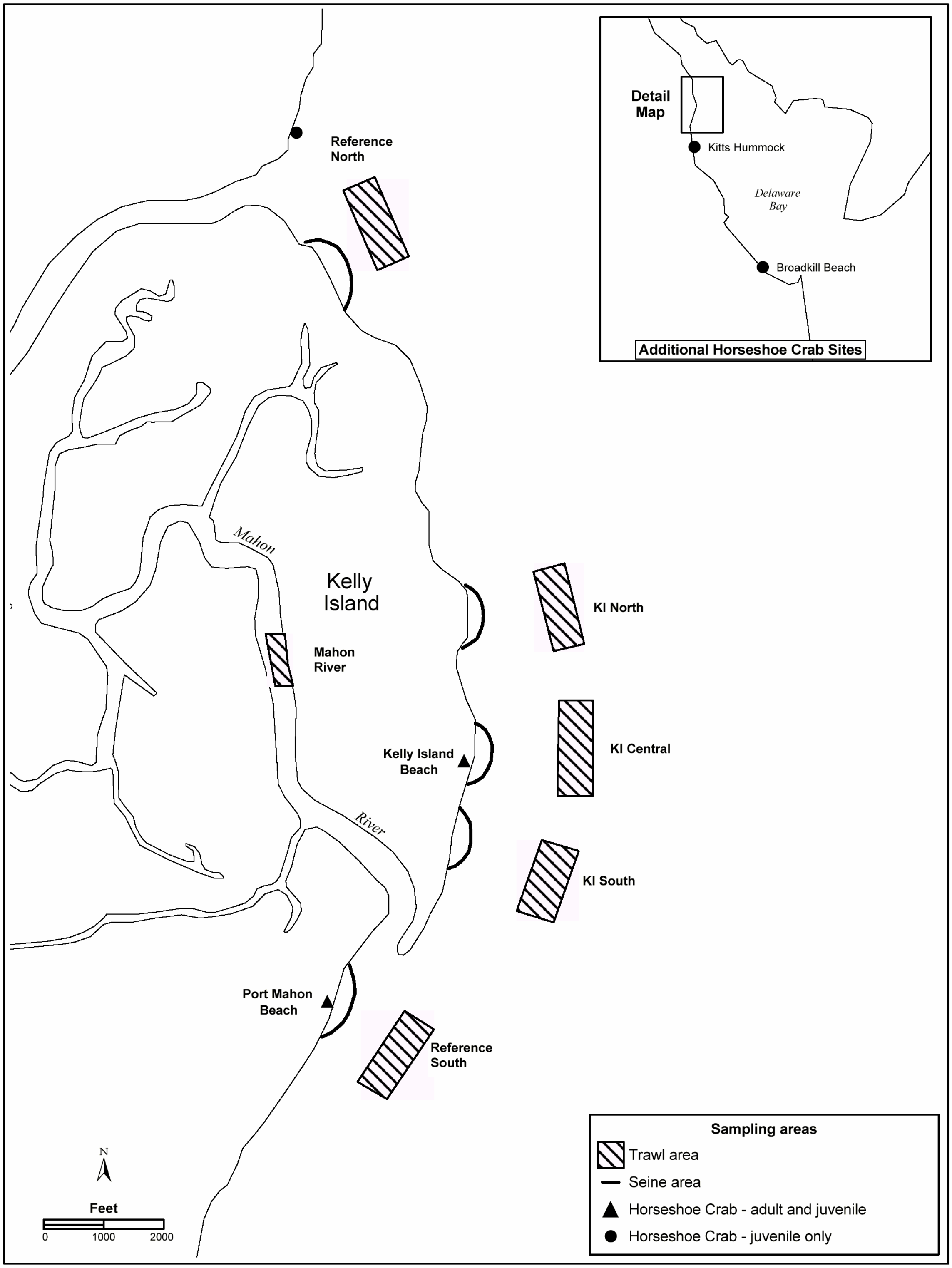

Figure 2-3. Location of sampling areas for the characterization of fisheries at Kelly during 2001

trawl with ¼"-mesh cod-end liner towed for 5-minutes parallel to the shoreline in shallow water habitat. Three replicate trawls were completed at each station. Seining was conducted with a 100-foot beach seine with 6-ft depth and ¼"-mesh. Three replicate seine-hauls were completed at each station. Fish species collected from trawling and seining were identified, counted, and measured in millimeters for total length of 25 specimens. Horseshoe crabs were identified by sex, counted, and measured in millimeters for carapace width and total length. Blue crabs were identified by sex, counted, and measured in millimeters for carapace width. Diamondback terrapins were identified by sex, counted, and measured in millimeters carapace width and length.

Table 2-3. Schedule of fisheries monitoring at Kelly Island during 2001

Date	Trawling	Seining	Spawning Horseshoe Crab	Juvenile Horseshoe Crab
22-May			New Moon	
30-May	Spring			
31-May				
4-Jun				
5-Jun		Spring	Full Moon	
23-Jul	Summer			
24-Jul				
25-Jul		Summer		
19-Sep				Late Summer
20-Sep				
2-Oct		Fall		
3-Oct				
16-Oct	Fall			
23-Oct				
24-Oct				
19-Dec		Winter		
20-Dec	Winter			
21-Dec				

2.2.2 Adult Horseshoe Crab Spawning Survey

Adult horseshoe crabs were surveyed on Kelly Island and Port Mahon beaches during the spring spawning of 2001 (Table 2-2; Figure 2-3). Spawning adult horseshoe crabs were surveyed by methods instituted by the Delaware National Estuarine Research Reserve (DNERR). Horseshoe crabs were counted along two transects each (South and North) for Port Mahon and Kelly Island beaches. Transects were 50-m in length and followed the "crab-line" or the upper limit of the beach where crabs were laying most intensively. Only crabs within 1-m of the "crab-line" were counted. Along the transect area border, crabs with more than half of their bodies within the area were included in the count. Male and female crabs were counted separately. Logistically, two surveyors using mechanical count recorders worked in tandem along each transect, one counting males and the other females. Transect surveys were started 20-minutes after the evening high tide. Start and end times were recorded as well as qualitative assessments of wave height and cloud cover. Port Mahon was surveyed on the new moon of 22 May and full moon of 5 June. Kelly Island was surveyed only on 5 June; thunderstorms precluded working on the earlier date.

2.2.3 Late Summer Juvenile Horseshoe Crab Survey

A juvenile horseshoe crab survey was conducted along Delaware Bay shoreline during September 2001 (Table 2-2; Figure 2-3). The survey was designed to characterize juvenile crab use of subtidal habitats adjacent to known spawning beaches. Beaches surveyed included Kelly Island, Kitts Hummock, Broadkill, and in addition adjacent reference areas located 0.5-miles north and south of Kelly Island. The south reference beach was near the Port Mahon spawning beach. Two transects were surveyed at each beach. Each transect constituted twin replicate tows (8 total) of a biological dredge at distances from the mean high tide line of 50, 100, 200, and 300-ft. The dredge was towed for a distance of 30-ft as measured by an incremental tag line. The biological dredge was constructed with a rectangular framed mouth of 10 x 18-in fitted with ¼-in mesh nylon bag. In operation, the heavy flat bar of the frame scraped along the bottom and dislodged epibenthic fauna into the collection bag. Following a tow, bottom material collected by the dredge was washed, sieved, and sorted; all juvenile horseshoe crabs were counted and measured for carapace width.

2.3 CHARACTERIZATION OF SEDIMENTS

Bottom sediments offshore of Kelly Island were characterized in two ways. Sediment profile imagery was used to characterize the physical structure and quality of sediments, as well as gauge recent sedimentation patterns. A benthic survey was conducted to characterize invertebrate communities inhabiting the bottom sediments.

2.3.1 Sediment Profile Imagery

Two sediment profile camera surveys were conducted off Kelly Island, Delaware Bay during 2001. On 6 July, Sediment Profile Images (SPI) were successfully collected at 50 stations (Figure 2-4). The same stations were resampled 24 October after several storm events. At four stations during the October sampling rough seas caused the profile camera to pullout of the sediment before any images could be obtained. Stations were arranged in five transects oriented east-west, they were; Reference North (RN), Kelly Island North (KN), Kelly Island Middle (KM), Kelly Island South (KS), and Reference South (RS).

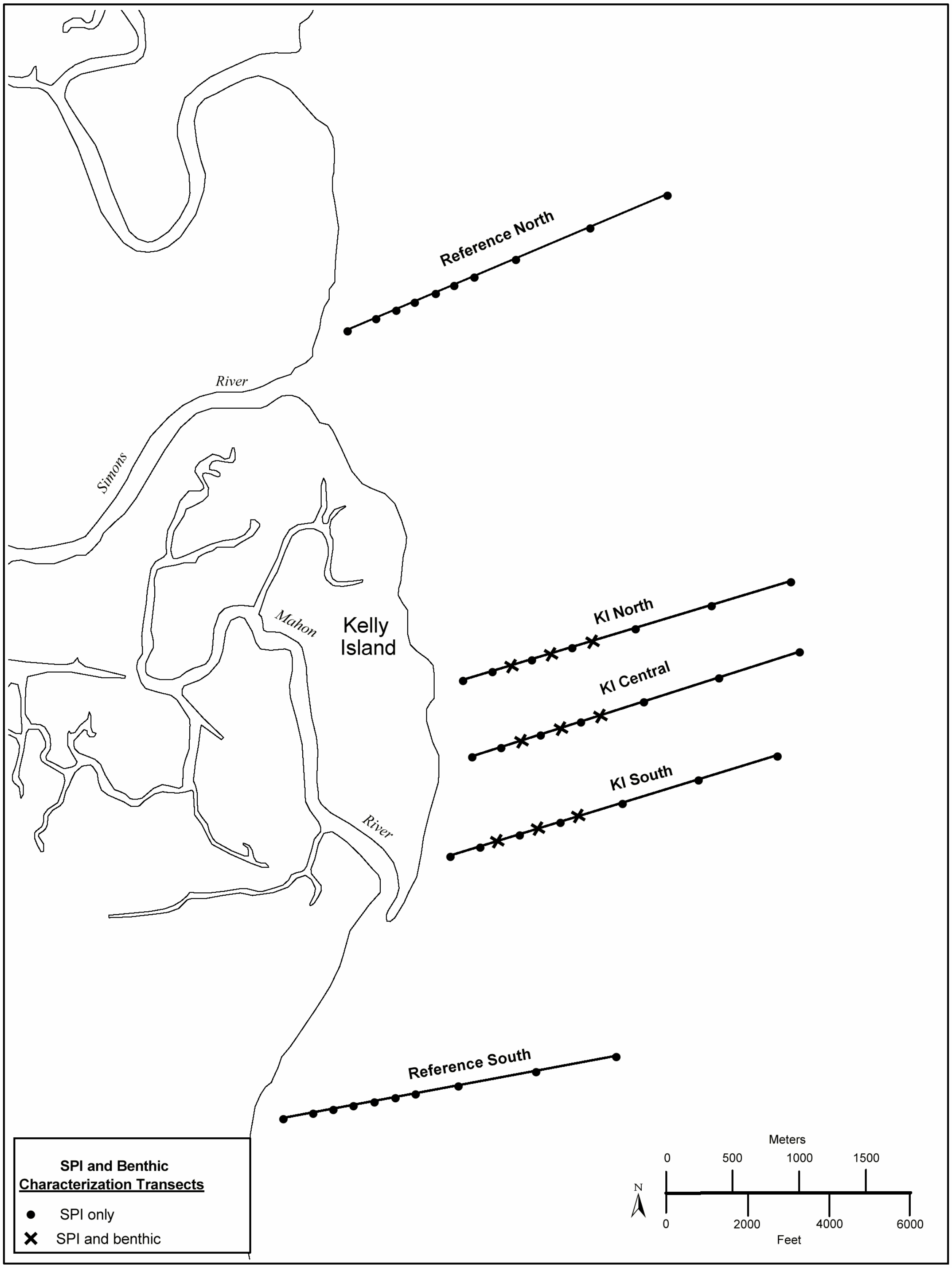

Figure 2-4. Transects monitored for Sediment Profile Imagery (SPI) and benthic assessment to characterize bottom sediments off Kelly Island during 2001

At each station a Hulcher Model Minnie sediment profile camera was deployed one to two times from the R/V Polgar. The profile camera was set to take two pictures, using Fujichrome 100P slide film, on each deployment at 2 and 12 seconds after bottom contact. Seventy-five pounds of lead were added to the camera frame to improve penetration.

2.3.1.1 Image Analysis

Both the 2- and 12-second sediment profile images were analyzed visually by projecting the images and recording all features seen into a preformatted standardized spreadsheet file. The 12-second image was then digitized using a Nikon LS-2000 scanner and analyzed using the Adobe PhotoShop and NTIS Image programs. Steps in the computer analysis of each image were standardized and followed the basic procedures in Viles and Diaz (1991). Data from each image were sequentially saved to a spread sheet file for later analysis. Details of how these data were obtained can be found in Diaz and Schaffner (1988) and Rhoads and Germano (1986). A summary of major parameters measured follows:

Prism Penetration - This parameter provided a geotechnical estimate of sediment compaction with the profile camera prism acting as a dead weight penetrometer. The further the prism entered into the sediment the softer the sediments, and likely the higher the water content. Penetration was measured as the distance the sediment moved up the 23-cm length of the faceplate. The weight on the camera frame was kept constant at 75 lbs. so prism penetration provided a means for assessing the relative compaction between stations and sampling dates.

Surface Relief - Surface relief or boundary roughness was measured as the difference between the maximum and minimum distance the prism penetrated. This parameter also estimated small-scale bed roughness, on the order of the prism faceplate width (15 cm). The origin of roughness can often be determined from visual analysis of the images.

Apparent Color Redox Potential Discontinuity (RPD) Layer - This parameter has been determined to be an important estimator of benthic habitat quality (Rhoads and Germano 1986, Diaz and Schaffner 1988, Nilsson and Rosenberg 2000), providing an estimate of the depth to which sediments appear to be oxidized. The term apparent is used in describing this parameter because no actual measurement was made of the redox potential. It is assumed that given the complexities of iron and sulfate reduction-oxidation chemistry the reddish-brown sediment color tones (Diaz and Schaffner 1988) indicate sediments are oxic, or at least are not intensely reducing. This is in accordance with the classical concept of RPD layer depth, which associates it with sediment color (Fenchel 1969, Vismann 1991). The apparent color RPD has been very useful in assessing the quality of a habitat for epifauna and infauna from both physical and biological points of view. Rhoads and Germano (1986), Revelas et al. (1987), Day et al. (1988), Diaz and Schaffner (1988), Valente et al. (1992), Bonsdorff et al. (1996), and Nilsson and Rosenberg (2000) all found the depth of the

RPD layer from sediment profile images to be directly correlated to the quality of the benthic habitat.

Sediment Grain Size - Grain size is an important parameter for determining the nature of the physical forces acting on a habitat and is a major factor in determining benthic community structure (Rhoads 1974). The sediment type descriptors used for image analysis follow the Wentworth classification as described in Folk (1974) and represent the major modal class for each image. Grain size was determined by comparison of collected images with a set of standard images for which mean grain size had been determined in the laboratory. Table 2-4 provides a means of comparing Phi scale sizes corresponding to sediment descriptors used in the current analysis.

Table 2-4 Comparison of Phi scales to various sediment characteristics used in the SPI analysis

Phi Class & Scale	Upper Limit Size (mm)	Grains per cm of image	SPI Descriptor	Sediment Size Subclass
-2 to –6	64.0	<1	PB	Pebble
-1 to –2	4.0	2.5	GR	Gravel
1 to –1	2.0	5	CS	Coarse-sand
2 to 1	0.5	20	MS	Medium-sand
4 to 2	0.25	40	FS	Fine-sand
4 to 3	0.12	80	VFS	Very-fine-sand
5 to 4	0.06	160	FSSI	Fine-sandy-silt
8 to 5	0.0039	>320	SI	Silt
6 to 5	0.0039	>320	SIFS	Silty-fine-sand
8 to 6	<0.0039	>320	SICL	Silty-clay
>8 to 7	<0.0039	>320	CLSI	Clayey-silt
>8	<0.0005	>2560	CL	Clay

Surface Features - These parameters included a wide variety of features. Each contributed information on the type of habitat and its quality for supporting benthic species. The presence of certain surface features is indicative of the overall nature of a habitat. For example, bedforms are always associated with physically dominated habitats, whereas the presence of worm tubes or feeding pits would be indicative of a more biologically accommodated habitat (Rhoads and Germano 1986, Diaz and Schaffner 1988). Surface features were visually evaluated from each image and compiled by type and frequency of occurrence.

Subsurface Features - These parameters included a wide variety of features and revealed a great deal about physical and biological processes influencing the bottom. For example, habitats with grain-size layers or homogeneous color layers are generally dominated by physical processes while habitats with burrows, infaunal feeding voids, and/or actual infauna visible are generally dominated by biological processes (Rhoads and Germano 1986, Diaz and Schaffner 1988, Valente et al. 1992, Nilsson and

Rosenberg 2000). Sediment layering, caused either by grain-size or sediment color differences, were noted and layer thickness measured. Subsurface features were visually evaluated from each image and compiled by type and frequency of occurrence.

2.3.2 Benthic Assessment

Benthic sampling was conducted off Kelly Island on 4 October 2001. Benthic samples were collected at nine locations that coincided with sediment profile imagery sites (Figure 2-4). Sampling locations were 2000, 3000, and 4000 feet along the three transects, KI South, KI Central, and KI North, that radiated in an easterly direction from Kelly Island and toward the main channel. At each location, four replicate benthic samples were collected with a Young grab-sampler, which samples an area of 440-cm^2 to a depth of 10-cm. A total of 36 benthic samples were collected and processed individually. Each sample was sieved in the field on a 500-µm mesh screen, transferred to a pre-labeled sample container, and preserved with 10% buffered formalin stained with “Rose Bengal”. At each sampling location, a fifth sediment grab was taken and a surface subsample was collected for grain-size and organic content analysis.

In the laboratory, benthic macroinvertebrates were sorted from the sample material under dissecting microscope, identified, and enumerated. Each organism was sorted and identified to the lowest taxon practicable depending on the maturity or physical condition of the specimen. To calculate biomass, organisms were combined at higher taxonomic levels and processed for ash-free dry weight (AFDW). AFDW was measured by drying the organisms to a constant weight at 60ºC and then ashing them in a muffle furnace at 500ºC for four hours. Sediment subsamples were analyzed for grain-size by the standard method ASTM D2487, excepting that the hydrometer portion of the test was not included. The minimum grain size category, or silt, was defined as that passing through U.S. Standard Sieve No. 200 at 63-µm. Total organic carbon (TOC) of sediments was measured by loss on ignition.

2.4 HYDROACOUSTIC SURVEY

An Acoustic Seabed Classification Survey (ASCS) was conducted in Delaware Bay adjacent to Kelly Island in July and August 2001.

2.4.1 Survey Area

The survey grid was located between 39.16297 and 39.23674 degrees N and 75.34837 and 75.38928 degrees W (decimal degrees). Boundaries were provided by the U.S. Army Corps of Engineers, Philadelphia District (Figure 2-5). The ASCS survey was conducted over four days between July 21-28, 2001. Sixteen principal transects were spaced 200 m apart over the entire extent of the survey. In the northwest corner of the survey, where oyster seedbeds are located, transect spacing was decreased to 100 m. All transects were oriented north - south. Individual bottom interrogations (pings) were spaced between 6 - 9 m apart, depending on vessel speed over ground. A total of 26.66 km^2 of bottom was surveyed.

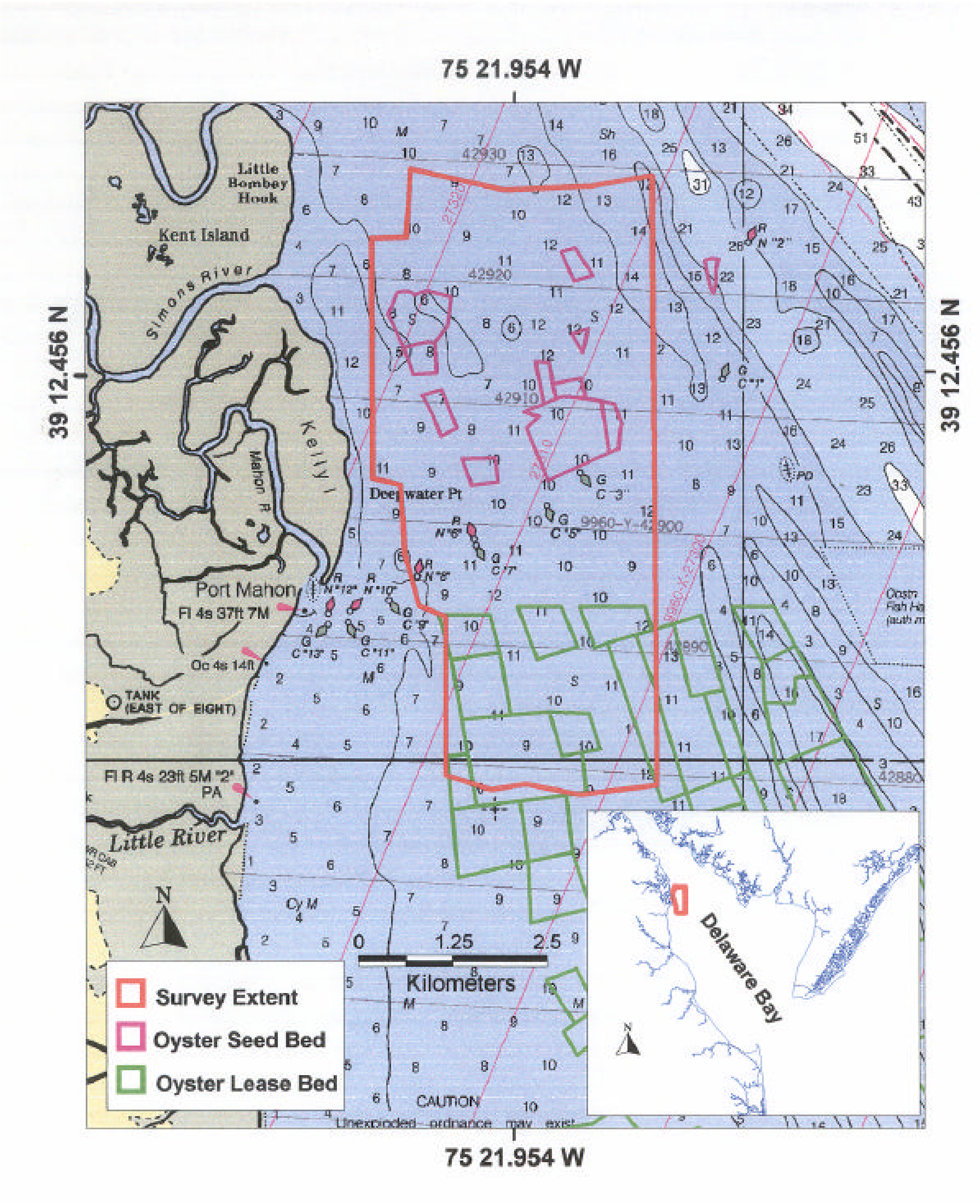

Figure 2-5. Location of the Acoustic Seabed Classification System (ASCS) survey off of Kelly Island in Delaware Bay.

2.4.2 ASCS Data Collection – Analysis

A QTC View (Quester Tangent Corp.) ASCS system linked to a Furuno FCV-582 fathometer (200 kHz transducer) was used to collect benthic habitat data in the survey area. The QTC system digitized the first echo return and recorded 166 parameters describing each waveform (Collins and Lacroix 1997, Smith et al. 2001). Parameters were merged with real time GPS information (WGS84 datum) and logged on a shipboard PC. Initial data processing required the rejection of potentially corrupted records. Initial data cleaning included the removal of acoustic returns generated from fish suspended in the water column, turns made in the survey track, and other causes resulting in entraining air bubbles in the transducer path.

An additional source of corruption was the decreasing ability of the QTC system to accurately classify bottom in shallow water. This degradation usually occurs between 2.8 - 3.2 m of water depth, depending upon system settings and site conditions. The shallow conditions of the study site were very close to this threshold. An analysis of our data showed that best results were obtained when interrogations of less than 3.2 m were rejected. The shoreward limits of the survey, and gaps in survey transects are the result of these depth rejections.

Post-processing of acoustic data via Principal Component Analysis generated three indices of difference between each of the individual bottom interrogations (Q1, Q2, and Q3). Q-values were plotted in three-dimensional coordinate space. Values from the population data set that have similar acoustical properties occupy similar space.

Cluster analysis was then performed on Q-values, generating a user specified number of acoustic classes representing acoustically different bottoms. The clustering process can theoretically be carried out to split the population data set into a large number of classes. Observation of the decline in spatial variability from several statistical indices generated by the clustering software (Quester Tangent Corp.) provided information on how many acoustic classes might be appropriate. User discretion, experience, and post-survey validation techniques within the survey area are also important in identifying a realistic number of classes. The result of cluster analysis is a suite of discrete yet unknown bottom types that must be validated to assess habitat distinctiveness. This dataset was then used to create a preliminary GIS layer of colored points representing classed acoustic interrogations. This chart identified general spatial patterns in acoustic reflectivity and was used to direct validation efforts.

2.4.3 Video Validation

A tethered video sled with artificial lighting was used to validate bottom classes on August 1 and 10. Color video footage was GPS linked with GIS display via a VMS200 media mapping system. GPS linkage allowed real-time viewing and plotting of video transect location relative to acoustic interrogations on the digital ASCS chart. Initial site selection was based upon three principal factors relating to preliminary ASCS bottom classification information including:

- Obtaining replicate sled transects on acoustically similar, yet geographically separated ASCS classifications,

- Observing video over bottom regions where ASCS indicated transitions from one bottom type to another, and

- Observing ASCS anomalies or unusual patterns.

Because a high degree of spatial heterogeneity was observed in the acoustic and video data, a semi-quantitative approach was taken to assign video-derived bottom descriptions to the acoustic classes derived by the ASCS. Video footage was initially classified into categories based on dominant bottom that could be visually identified within the study site. GPS/video linkage facilitated the creation of a GIS chart of the scored video transects in relation to ASCS interrogations, and this chart provided the basis for a systematic validation of the ASCS bottom classes. In MapInfo GIS, the scored video transects were layered on top of the ASCS chart (Figure 2-6). A 60 m buffer polygon was formed around each video transect (the general area covered by each transect), and the number of acoustic interrogations from individual ASCS classes was recorded from within the buffer polygons. From video transects where the entire transect was judged to be of a visually similar habitat type, a frequency distribution of the total number of ASCS acoustic interrogations from each ASCS class was created. In the final step of the validation process, the most frequent acoustic class for each of the video bottom categories was assigned to the corresponding ASCS bottom type classes.

2.4.4 Data Representation

After completion of video and physical validation, a number of habitat classes was established which best reflected habitat variability within the population dataset. Once the acoustic classes were validated, the spatial dataset was imported into ArcView GIS to create an "interpolated" polygon representation of the bottom features. Polygons were created with the Spatial Analyst software using iterations of neighborhood statistics on a gridded version of the original ASCS chart.

2.4.5 Supplemental Data

Two additional sources of data relevant to this survey were obtained and converted to GIS format to be displayed in conjunction with ASCS data. These were catch per unit effort of oyster from dredge hauls conducted by Versar, Inc., and sediment profiles images taken by the Virginia Institute of Marine Sciences (VIMS) (Cutter and Diaz 1998). Versar data consisted of oyster shell and live oyster counts per minute of trawling for each oyster dredge haul, with latitude and longitude at the start and end of each haul. Images provided by VIMS were assessed as to general sediment character. We characterized individual video images from within or nearby to our survey site into one of six categories. Categories were sand, silt, oyster shell, worm tubes and sand, and unknown. To assess the success of the acoustic representation, the new polygon theme was then compared to these data sets as well as NOAA bathymetry and oyster seed area and lease polygons.

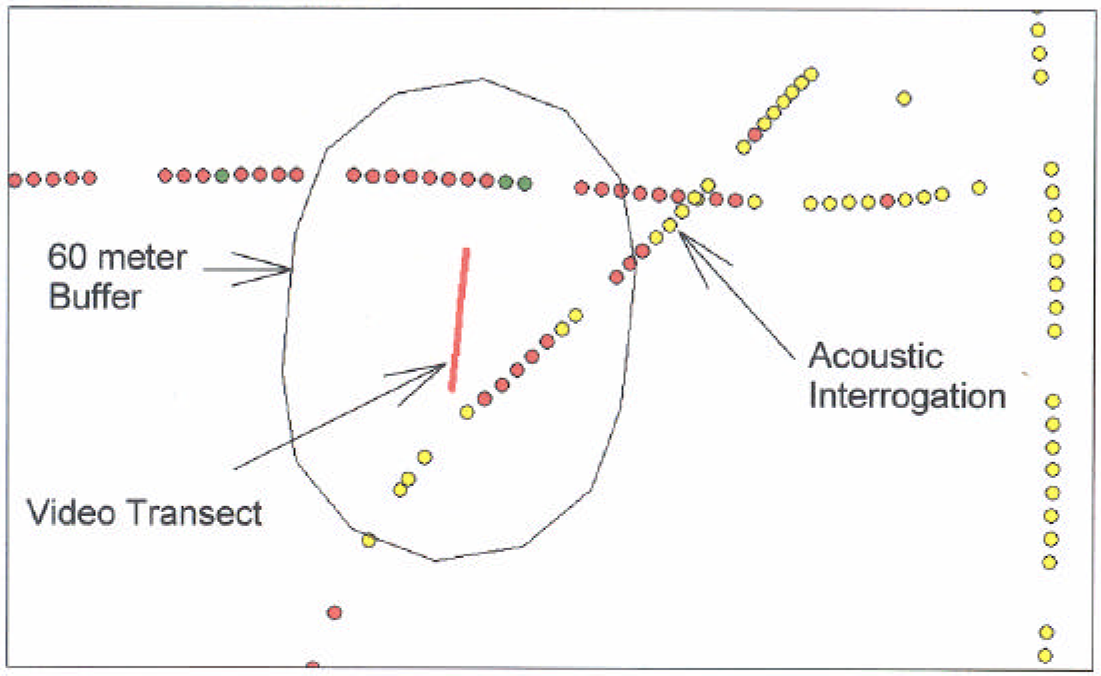

Figure 2-6. An example showing the video validation process of the Acoustic Seabed Classification System (ASCS) survey