APPENDIX F

SEDIMENT PROFILE REPORT

SEDIMENT PROFILE CAMERA RECONNAISSANCE OF BENTHIC HABITATS IN DELAWARE BAY, SEPTEMBER 2000.

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INTRODUCTION

The Philadelphia District of the Army Corps of Engineers is planning to deepen the navigation channel in Delaware Bay. Much of the environmental concern over the dredging operation involves settling of fine sediments resuspended by the dredging on oyster bed adjacent to the navigation channel. The study area , consisting of that reach of the Delaware River and Bay encompassing the oyster seed beds, is located in Delaware Bay between River Miles 15 and 50 in Reaches D and E, in Kent County, Delaware and Salem, Cumberland, and Cape May Counties, New Jersey. Excessive sedimentation on existing oyster beds during dredging operations could smother live oysters or impede oyster spat settlement rates during the spawning season. To provide a baseline sedimentation profile around navigational ranges slated for dredging a pre-dredge survey was conducted in the fall of 2000. This baseline survey included a characterization of the sedimentation levels at nine oyster beds currently being monitored for biological condition by the USACE and along east/west transects in four navigational ranges where most of the Delaware Bay dredging will take place. The sediment profiling will be conducted during dredging and after the dredging is completed to determine the extent of sedimentation that may have been caused by the deepening project.

This report contains results of the sediment profile camera survey conducted in September 2000.

MATERIALS AND METHODS

Field Methods

On 13 and 14 September 2000 a sediment profile camera survey of Delaware Bay was conducted. Sediment Profile Images (SPI) were successfully collected at 50 stations (Figure 1). Stations located in and around the four navigational ranges were arranged in transects perpendicular to the axis of the navigation channel (Figure 1). Navigational ranges included in this survey were Miah Maull Range (designated MM), Cross Ledge Range (designated C), Listion Range (designated L), and Arnold's Range (designated A). On each transect a station was located in the center of the channel, designated 0, with five stations extending east-west, E or W, at distances of approximately 200-300, 700-1000, 1200-1500, 2200-2400, and 4000-4200 ft from the channel center line. Thus, Station LE3 would be on a transect across the Listion Range 1200 to 1500 ft east of the channel. The only exception was transect A (Arnold’s Range) that had only four east-west transect stations. An additional nine stations were located in oyster grounds near the channel (Figure 1). They were:

Station	Oyster Bed Name
554D	Section 554 Lease Beds (New Jersey)
ARN18	Arnold's Bed (New Jersey)
BEN110	Bennies (New Jersey)
DLM	Delaware Lower Middle (Delaware)
DOB	Delaware Over the Bar (Delaware)
EGG63	Egg Island (New Jersey)
NAN10	Nantuxent (New Jersey)
NEW26	New Beds (New Jersey)
SJN28	Ship John (New Jersey)

At each station a Hulcher Model Minnie sediment profile camera was deployed three times from Versar's research boat, 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 sediment penetration.

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 described 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.

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.

The following is provided as a means of comparing Phi scale sizes corresponding to sediment descriptors used in the current analysis:

Phi Scale	Upper Limit Size (mm)	Grains per cm of image	SPI Sediment Descriptor	Size Class and 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 Sand with Silt
8 to 5	0.0039	>320	SI	Silt
6 to 5	0.0039	>320	SIFS	Silt with Fine Sand
>8	<0.0005	>2560	CL	Clay
			SH	Shell

Surface Features - These parameters included a wide variety of features. Each gives a bit of 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 burrows, infaunal feeding voids, and/or actual infauna visible are generally more biologically accommodated (Rhoads and Germano 1986, Diaz and Schaffner 1988, Valente et al. 1992, Nilsson and Rosenberg 2000). Surface features were visually evaluated from each image and compiled by type and frequency of occurrence.

RESULTS AND DISCUSSION

September 2000 Delaware Bay Image Data

Three replicate sediment profile film images were collected at 50 stations. A complete listing of sediment profile image (SPI) data can be found in Appendix A and a station summary in Tables 1 and 2.

Physical processes and sediments

Sediment grain size ranged from pebbles on the surface of medium-sand (L0) to medium-coarse sand (A0) to stiff clayey sediments (AW1) (Table 1, Appendix A). Both L0 and A0 were stations located in the center of the navigation channel. Softest sediments were silty-clays at Station AW4. The predominated sediment type throughout the study area was fine-sand (modal Phi 4 to 2) and occurred at 19 (38%) stations, with six of the fine-sand stations being very-fine-sand. Fine-medium-sand also occurred at three stations. Medium-sand occurred at six stations and medium-coarse-sand at one station. A total of 15 stations (30%) had a fine sediment component (silts or clays) with silty-clay most common being found at seven (14%) stations. Fine-sandy-silts and fine-sand-silt-clay occurred at six (12%) stations. Oyster shell, whole shell to coarse shell hash, was the only substrate observed at eight (16%) stations. Shell hash was a significant component of the sediments at 17 stations that were not classified as oyster or mussel shell beds.

The small-scale spatial variability in sediment type, as estimated between the three replicate images collected at each station, was minimal with only two stations expressing any variation in surface sediment type. At Station AE1 sediments ranged from medium-sand to medium-coarse-sand and at Station LE1 from fine-sand to oyster shell bed.

The pure sandy and shell sediments that occurred at 27 stations (54%) were indicative of high kinetic energy bottoms and tended to occur toward the mouth of the Delaware Bay, predominantly on the Miah Maull Range, Cross Ledge Range and Listion Range transects (Figure 2). Bedforms, also an indicator of higher energy bottoms, occurred at 27 stations (54%), seven of which had significant amounts of finer silts mixed in with the sand, for example AW2 and LW4 (Table 1). Coarse-sand-sized particles of detritus were mixed into the sediment at four stations (Table 2). This incorporation of detritus particles into the sediment points to deep suspension/resuspension events that can mix sediments to at least 4 cm.

At most stations sediments were homogeneous with depth from the sediment surface, but layered sediments occurred at ten stations (20%). Sandy sediments overlaid finer sediments at eight stations (16%) with thin layers of finer sediments over sandier sediments at two stations (Figure 3). Medium to fine-medium-sands overlaid silty-clay sediments at four stations, all of which were in the Arnold's Range, transect (AE1, AE2, AE4, and AW2). Fine to very-fine-sands overlaid fine-sand-silt-clay sediments at four stations, which were all on the lower three Bay transects (CLE4, CLW1, LW4, and MMW4) (Figure 3). The occurrence of sandy layers over finer sediments may be an indication that these stations are near transition points from finer to coarser sediment bottoms. The sand layers possibly being transported over finer sediments during storm events.

Very thin layers of silty sediments that ranged in thickness from 0.06 to 0.11 cm overlaid by sandier fine-sand-silt-clay sediments at Station CLW3 and MMW5. At both these stations the fine silty layers appeared to be recently deposited. This is possibly a result of a wind generated suspension/resuspension event because the silty sediments that overlaid the sandier sediments appeared to be well oxidized (Figure 4). Had the silty sediments come from deeper anaerobic sediments, such as those generated by a dredging operation, their color would have been grayer reflecting the reduced geochemical state of compounds adsorbed to the silt particles.

The relatively narrow range of sedimentary habitats within the stations sampled was reflected in the narrow range of average station prism penetration (0.0 to 13.1 cm). Prism penetration was related to sediment type with lowest penetration in coarser sediments and shell beds and highest penetration in fine sediments (Table 3). The average penetration at all stations was 3.0 cm (3.2 cm SD) with 50% of all stations falling between 0.6 and 4.2 cm.

The bed roughness or surface relief in areas that appeared to be dominated by both physical and biological processes was about the same magnitude (Table 1). Physically dominated bottoms tend to have coarser sediments with bedforms, small waves of sand formed by water movement, and sediment surfaces that lack evidence of biological activity. Biologically dominated bottoms tend to have mixed to finer sediments and surface sediments modified by biogenic activity (burrowing, feeding, and irrigating). The exception was shell beds, that were primarily whole shell and shell fragments. The range of surface relief was 0.4 to 2.5 cm over the entire study area (Table 1). For stations having predominantely sandy habitats the surface relief (bed roughness) was typically small sand ripples or bedforms about 2 cm high. For sites with finer sediments the surface relief was typically uneven surfaces (due to biogenic activity of benthic organisms) and were about 1.5 cm high.

Biogenic Activity

Average apparent color redox potential discontinuity (RPD) layer depth ranged from 0.1 to 3.6 cm over the study area (Table 1). Because of limited prism penetration the RPD layer depth was not observed at 28 stations. At the 22 stations with measured RPD depths, layered medium-sand over silty-clay sediments had the deepest apparent color RPD depths with shallowest RPD depths associated with clay sediments that exhibited signs of physical processes structuring surface sediments (Table 3). The shallowest average RPD layer depth was 0.1 cm at Station AW1 and the deepest RPD layer of 3.6 cm at Station AE4. Biogenic activity in the form of active infaunal burrows surrounded by a halo of oxic sediments convoluted and extended the maximum depth of the RPD layer. For example, the maximum extent of oxic sediments was 8.5 cm at Station AW2 replicate 1 (Figure 5).

Biological processes (shell building of oysters and mussels, clumps of fine sediment tubes, and feeding mounds) dominated the sediment surface at 19 stations (38%) (Tables 1 and 2). Physical processes dominated the other 31 stations (62%). Clean shell with little to no sediment trapped inside occurred at five stations (554D, EGG63, LE1, LE2, and MMW4). Five other stations (BEN, CLE3, LW5, NEW26, and SJN28) had thin layers of sediment covering the shells, which provided substrate for tube building organisms (Table 1, Figure 6). Blue mussels formed a shell bed, with no sediment drap, at Station MME1 (Figure 7).

The distribution of subsurface biogenic features (burrow structures, infaunal organisms, water filled voids) coorelated to sediment type. Most of these features occurred at fine sediment stations, and tended to mirror patterns seen for surface biogenic features. Burrows were seen at five (10%) stations with the number of burrows per image highest in finer silty-clay sediments (Figure 5). Water filled voids, both oxic and anaerobic, occurred at seven (14%) stations with a pattern of occurrence similar to burrows (Table 1). Both voids and burrows are biogenic structures indicative of infaunal activities and tend to be most common in sediments with significant amounts of fine sediments, usually >25% silt-clay content (Rhoads 1974). The number of water filled voids was about equally split between oxic 40% (apparently filled with oxidized sediment indicating current or recent infaunal activity) and anaerobic 60% (apparently relic voids from previous infaunal activity). Infaunal organisims were more abundant in silty sediments than in sandy sediment types (Table 2). Infauna organisms were observed at five (10%) stations, all of which had finer sediments.

Subsurface biogenic structures and activities were highest at stations where biological processes dominated surface features. The stations with the highest degree of biogenic infaunal activity were LW2, MMW5, and DOB. At stations AW2, AW4, and LW1 the surfaces appeared to be physically dominated but significant infaunal activity was observed.

SUMMARY

Based on the 50 Delaware Bay stations sampled with sediment profile imaging in September 2000 the following general observations were noted:

- Sediments were predominantly compact sands, being composed of fine to medium sands. Silty-clays were the second most predominant sediment type. Within station variation in sediment characteristics was minor with little variation in grain-size. Coarsest sediments, pebbles and coarse-sand, occurred in the center of the navigation channel.

- Oyster shell in the form of fine to coarse shell hash was a significant component of sediments at most stations. Whole oyster shell, in high concentrations representing oyster beds, occurred at ten stations. Blue mussels occurred at one station in lower Delaware Bay.

- Thin layers of sediment were drapped over oyster shell at five of ten stations with oyster shell. This fine sediment provided substrate for tube building organisms. At the other five stations there was little to no sediment deposited over the shells.

- Sediment layering occurred at ten stations. Layers were primarily coarser over finer sediments at eight of ten stations, and likely represent a lens of coarser sediments transported over finer during storm events. Stations with a sandy layer over a silt-clay layer may be located near a sediment transition area of Delaware Bay. At two stations thin (<1 mm) layers of fines overlaid coarser sediments. It appeared that the fine silty layers were likely due to a recent suspension/resuspension event.

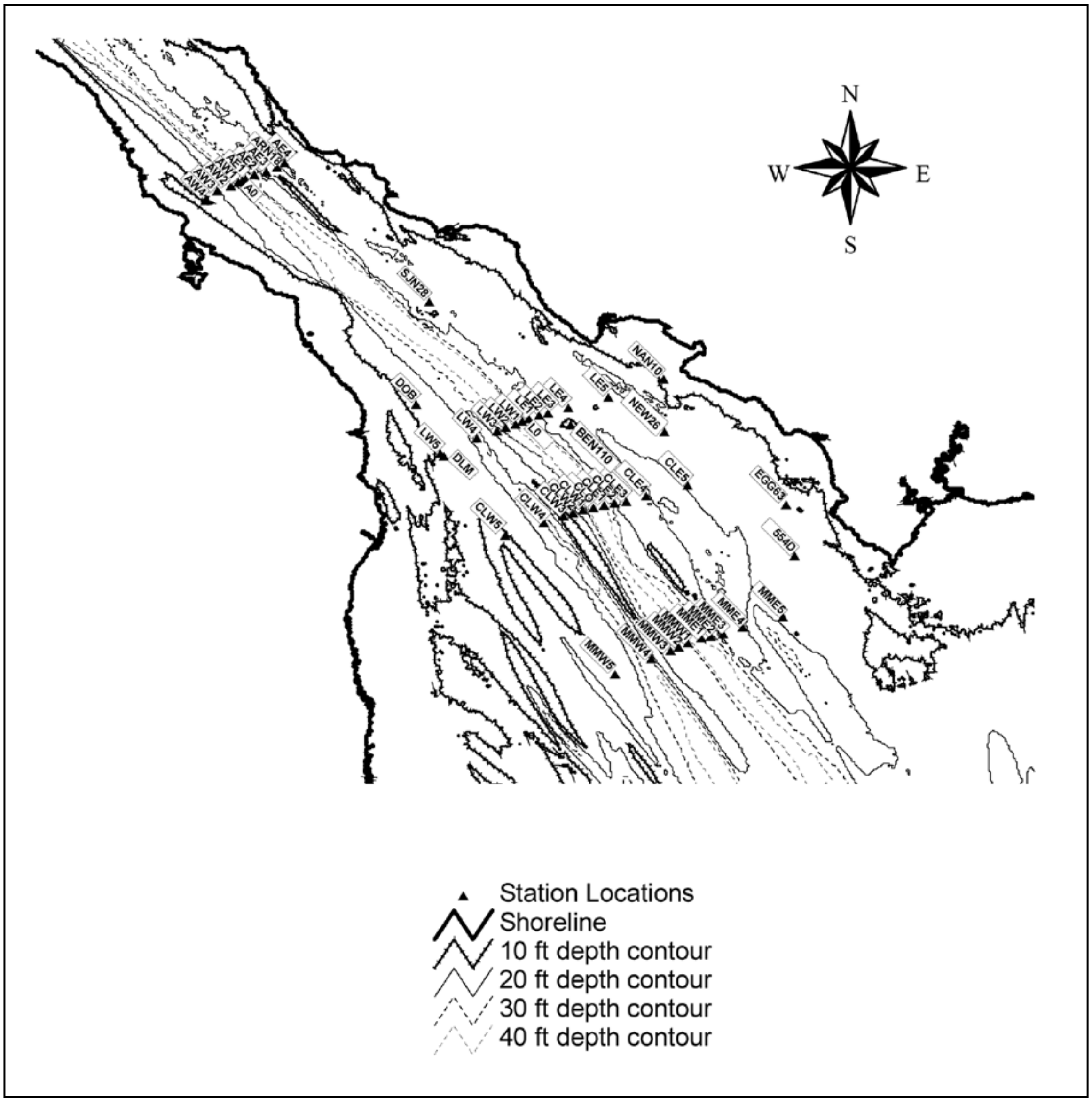


Figure 1. Location of transect and oyster bed station in Delaware Bay.

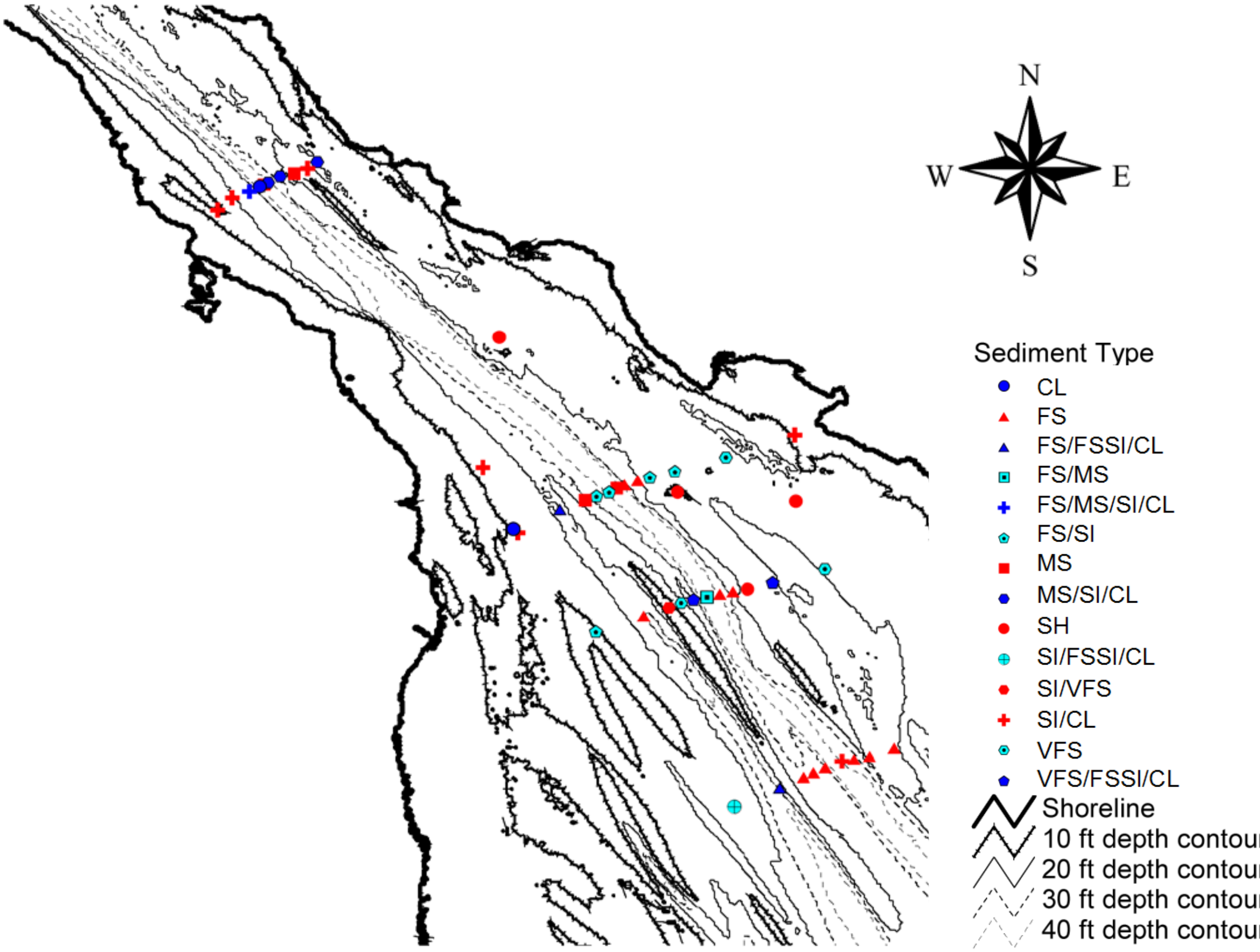


Figure 2. Distribution of sediment types at Delaware Bay stations as determined from SPI, September 2000. Sediment codes: CL = clay; FS = fine sand; FSSI = fine sand with silt; MS = medium sand; SI = silt; SH = shell; VFS = very fine sand.

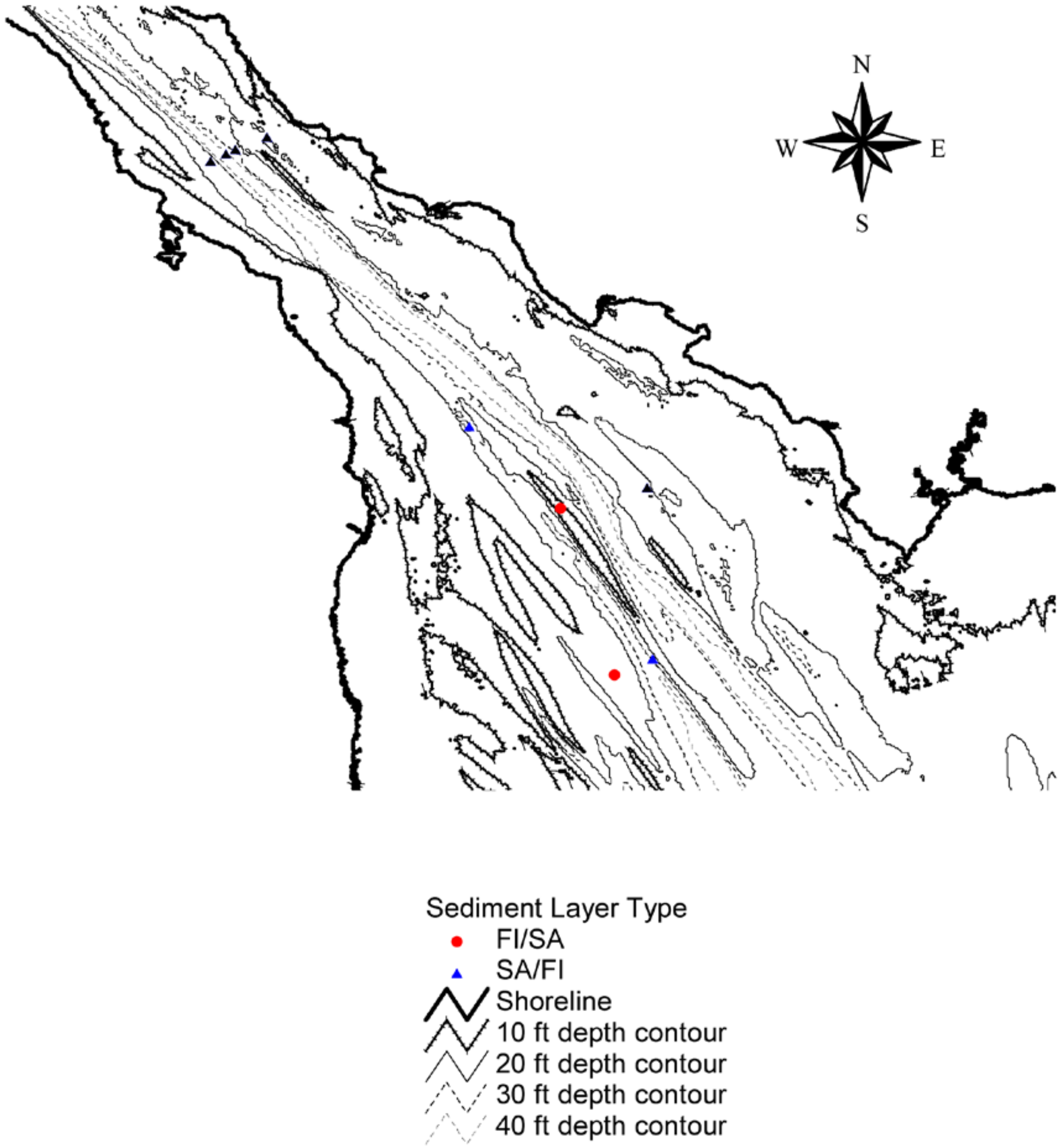


Figure 3. Distribution of layered sediments at Delaware Bay stations as determined from SPI, September 2000. FI/SA = fine sediment overlaid by sand; SA/FI = sand overlaid by fine sediments.

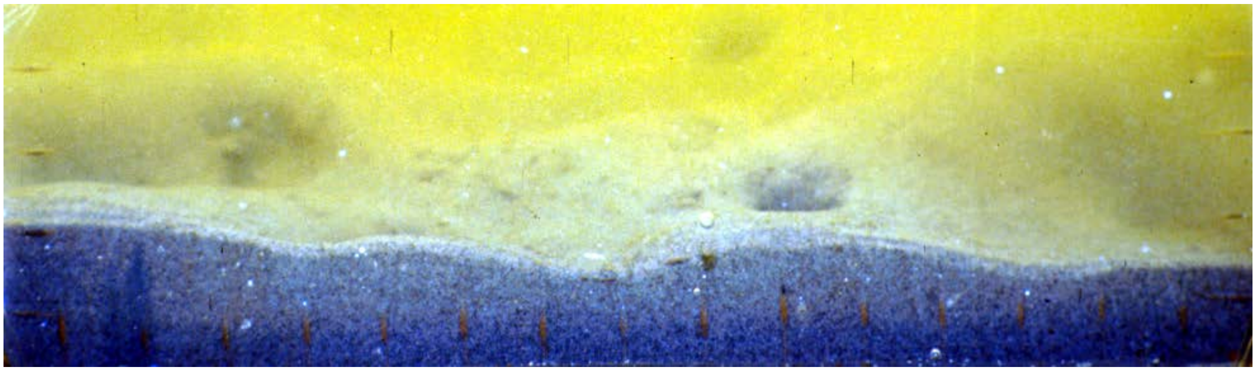


Figure 4. Delaware Bay, September 2000, SPI image from Station CLW3, replicate 1, showing a 1.5 cm layer of very-fine-sand under a thin layer of silty sediment about 0.06 cm thick. The RPD layer depth was deeper than the prism penetratrion. Scale marks along the edge of the image are 1 cm.

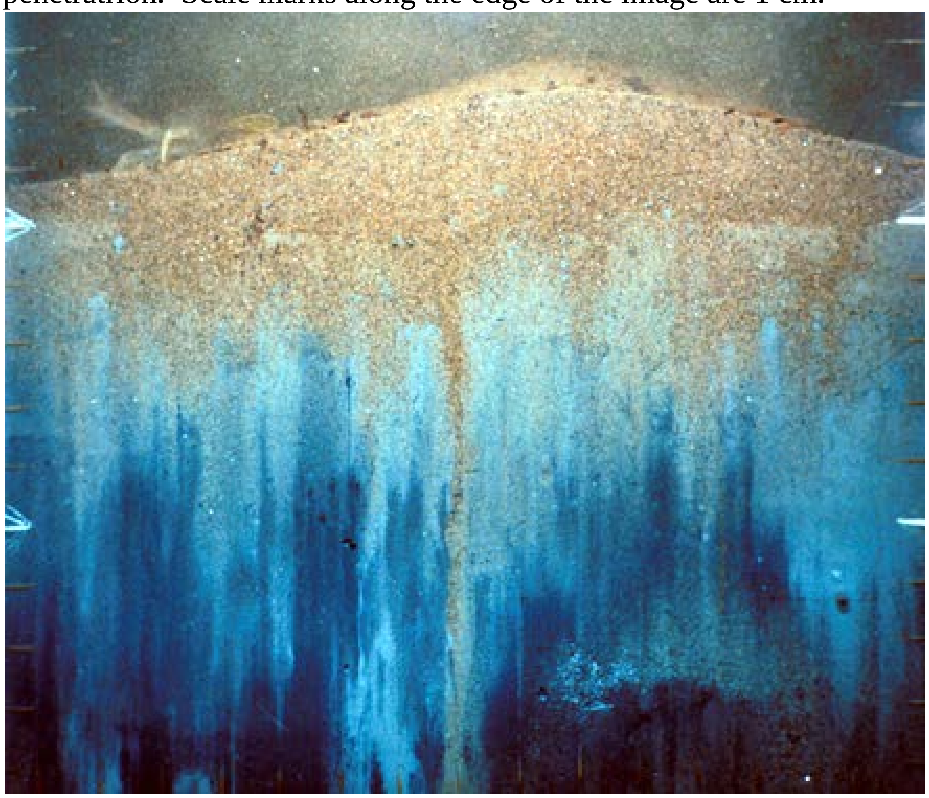
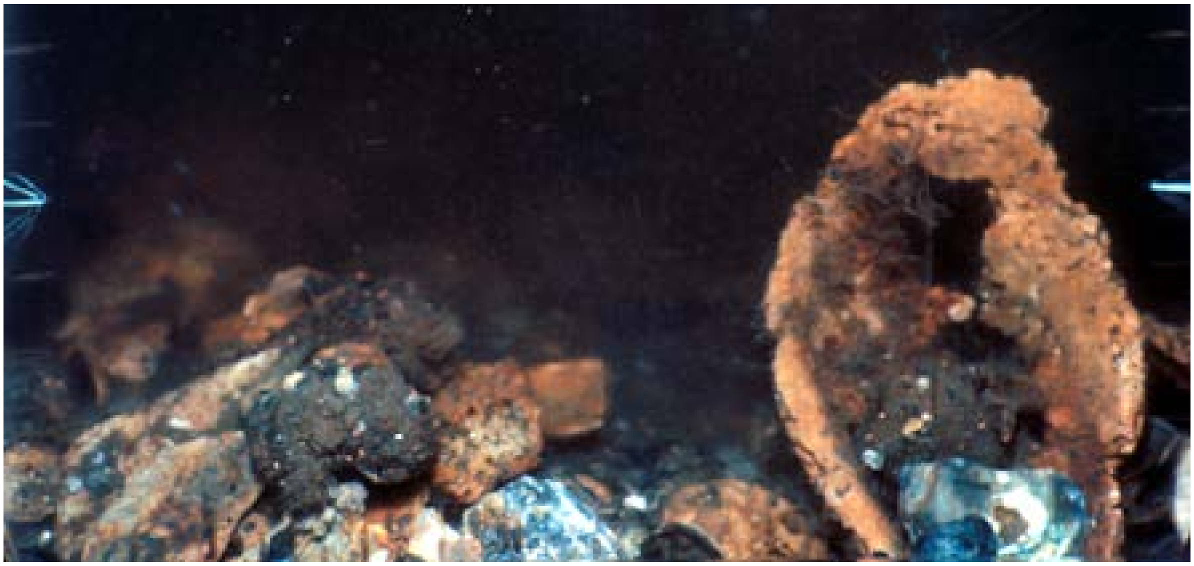


Figure 5. Delaware Bay, September 2000, SPI image from Station AW2, replicate 1, showing a 3.6 cm fine-medium-sand layer over silty-clay, the crest of a 1.7 cm high bedform is in the center of the image, the RPD layer is 2.5 cm thick and extends to 8.5 cm deep around an active infaunal burrow. Oxidized sediment are brown/reddish tones. A small blue crab is on the sediment surface to the left. Scale marks along the edge of the image are 1 cm.



A

B

Figure 6. Delaware Bay, September 2000, SPI images from: A) Station EEG63, replicate 2, showing an oyster bed with clean shell, no sediment covering the shell. Thin hydroid stolens are attached to the shell on the right. B) Station SJN28, replicate 1, showing an oyster bed with some shell drapped with a thin layer of sediment, likely from wind susspension/resspension events. A group of small tunicates can be seen in the center of the image. Scale marks along the edge of the image are 1 cm.

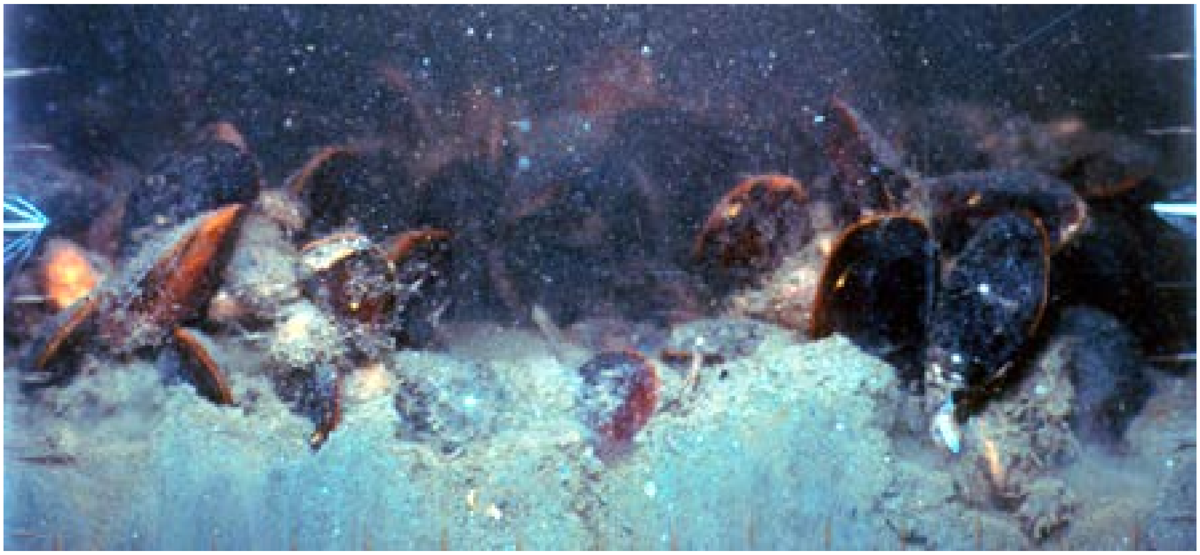


Figure 7. Delaware Bay, September 2000, SPI images from Station MME1, replicate 1, showing a blue mussel bed on a silty-clay sediment, the RPD layer is 0.1 cm thick. Scale marks along the edge of the image are 1 cm.

Table 2. Summary of categorical SPI data from Delaware Bay, September 2000.

Station	Bed-forms	Black Detritus Grains	Shell Hash	Shell Bed	Oyster	Mussel	Algae	Hydroids	Snail	Sponge	Worm Tubes	In-fauna	Bur-rows	Oxic Voids	An-aerobic Voids
Arnold's Range															
AE4	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AE3	+	-	+	-	+	-	-	+	-	-	-	-	-	-	-
AE2	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
AE1	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
A0	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
AW1	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
AW2	+	-	-	-	-	-	-	+	-	-	-	+	+	-	-
AW3	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
AW4	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-
Cross Ledge Range															
CLE5	+	-	+	-	+	-	-	-	-	-	+	-	-	-	-
CLE4	+	-	+	-	+	-	-	-	-	-	+	-	-	-	-
CLE3	-	-	+	+	+	-	+	-	-	+	-	-	-	-	-
CLE2	+	-	+	-	-	-	+	+	-	-	-	-	-	-	-
CLE1	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CL0	+	-	+	-	+	-	-	+	-	-	-	-	-	-	-
CLW1	+	-	+	-	+	-	-	-	-	-	-	-	-	-	-
CLW2	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-
CLW3	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CLW4	+	-	+	-	+	-	-	-	-	-	-	-	-	-	-
CLW5	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Listion Range															
LE5	+	-	+	-	+	-	-	+	-	-	-	-	-	-	-
LE4	-	-	-	-	-	-	-	+	-	+	+	-	-	-	-
LE3	-	-	-	-	+	-	-	+	-	-	+	-	-	-	+
LE2	-	-	+	+	+	-	-	+	-	-	-	-	-	-	-
LE1	+	-	+	+	+	-	-	+	-	-	-	-	-	-	-
L0	+	-	-	-	+	-	-	+	-	-	-	-	-	-	-
LW1	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
LW2	-	-	-	-	-	-	-	-	-	-	-	+	+	+	-
LW3	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LW4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
LW5	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-

Table 2. Continued.

Station	Bed-forms	Black Detritus Grains	Shell Hash	Shell Bed	Oyster	Mussel	Algae	Hydroids	Snail	Sponge	Worm Tubes	In-fauna	Bur-rows	Oxic Voids	An-aerobic Voids
Miah Maull Range															
MME5	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
MME4	+	-	+	-	-	-	-	+	-	-	-	-	-	-	-
MME3	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-
MME2	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-
MME1	-	-	+	+	-	+	-	-	-	-	-	-	-	-	-
MMW1	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-
MMW2	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-
MMW3	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-
MMW4	+	-	+	+	+	-	-	-	+	-	-	-	-	-	-
MMW5	-	-	-	-	-	-	-	-	-	-	+	+	+	+	-
Oyster Beds															
554D	-	-	+	+	+	-	-	+	+	+	-	-	-	-	-
ARN18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BEN110	-	-	+	+	+	-	+	-	-	+	-	-	-	-	-
DLM	-	-	-	-	-	-	-	+	-	-	+	-	-	-	+
DOB	-	-	-	-	+	-	-	-	-	-	-	+	+	+	+
EGG63	-	-	+	+	+	-	-	+	-	-	-	-	-	-	-
NAN10	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-
NEW26	-	-	+	+	+	-	-	+	-	+	-	-	-	-	-
SJN28	-	-	+	+	+	-	-	+	-	-	-	-	-	-	-

Table 3. Average prism penetration, surface relief, and RPD layer depth by sediment type for Delaware Bay stations. Average and SD are in cm. N is the number of stations with measured values for each parameter.

Predominant	Prism Penetration			Surface Relief			RPD Layer Depth		
Sediment Type	N	Ave.	SD	N	Ave.	SD	N	Ave.	SD
Shell	6	0.2	0.4	1	1.8	.	0	.	.
Medium-Sand	4	1.2	1.3	2	1.9	0.6	0	.	.
Fine-Medium-Sand	2	2.6	1.8	2	1.9	0.6	0	.	.
Fine-Sand	11	1.1	0.9	10	1.0	0.4	1	0.7	.
Very-Fine-Sand	3	1.4	0.7	3	1.2	0.7	1	1.3	.
Fine-Sandy-Silt	5	4.8	3.4	5	1.3	0.8	4	0.9	0.3
Silty-Clay	7	6.5	3.3	7	1.6	0.7	7	0.9	0.7
Clay	2	1.3	0.9	2	1.3	1.0	1	0.1	.
Layered Sediments:									
Medium-Sand/ Silty-Clay	3	5.1	1.6	3	1.5	0.2	3	2.8	1.2
Fine-Medium-Sand/ Silty-Clay	1	11.2	.	1	1.1	.	1	1.7	.
Fine-Sand/ Fine-Sand-Silt-Clay	2	4.5	4.5	2	1.3	0.4	1	0.8	.
Very-Fine-Sand/ Fine-Sand-Silt-Clay	2	2.9	0.7	2	1.5	0.6	2	1.8	0.1
Silt/ Very-Fine-Sand	1	1.3	.	1	1.3	.	0	.	.
Silt/Fine-Sand-Silt-Clay	1	8.5	.	1	1.3	.	1	1.6	.

LITERATURE CITED

Bonsdorff, E., R.J. Diaz, R. Rosenberg, A. Norkko and G.R. Cutter. 1996. Characterization of soft-bottom benthic habitats of the Åland Islands, northern Baltic Sea. Marine Ecology Progress Series 142:235-245.

Day, M.E., L.C. Schaffner, and R.J. Diaz. 1988. Long Island Sound sediment quality survey and analyses. Tetra Tec, Rpt. to NOAA, NOS, OMA, Rockville, MD. 113 pp.

Diaz, R.J. and L.C. Schaffner. 1988. Comparison of sediment landscapes in the Chesapeake Bay as seen by surface and profile imaging. p. 222-240. In: M. P. Lynch and E. C. Krome, eds. Understanding the estuary; Advances in Chesapeake Bay research. Chesapeake Res. Consort. Pub. 129, CBP/TRS 24/88.

Fenchel, T. 1969. The ecology of marine microbenthos. IV. Structure and function of the benthic ecosystem, its chemical and physical factors and microfauna communities with special reference to the ciliated Protozoa. Ophelia 6:1-182.

Folk, R.L. 1974. Petrology of sedimentary rocks. Austin, Texas, Hemphill's. 170 pp.

Nilsson, H. and R. Rosenberg. 2000.

Revelas, E.C., D.C. Rhoads, and J.D. Germano. 1987. San Francisco Bay sediment quality survey and analysis. NOAA Tech. Memor. NOS OMA 35. Rockville, MD. 127 pp.

Rhoads, D.C. 1974. Organism sediment relations on the muddy sea floor. Oceanography and Marine Biology Annual Review 12:263-300.

Rhoads, D.C. and J.D. Germano. 1982. Characterization of organism-sediment relations using sediment profile imaging: an efficient method of remote ecological monitoring of the seafloor (REMOTS system). Marine Ecology Progress Series 8:115-128.

Rhoads, D.C. and J.D. Germano. 1986. Interpreting long-term changes in benthic community structure: a new protocol. Hydrobiologia 142:291-308.

Valente, R.M., D.C. Rhoads, J.D. Germano and V.J. Cabelli. 1992. Mapping of benthic enrichment patterns in Narragansett Bay, Rhode Island. Estuaries 15:1-17.

Viles, C. and R.J. Diaz. 1991. Bencore, an image analysis system for measuring sediment profile camera slides. School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Pt. VA. 13 pp.

Vismann, B. 1991. Sulfide tolerance: Physiological mechanisms and ecological implications. Ophelia 34:1-27.