Appendix A: SPI Methodology

5.1 SPI Camera Methods

SPI photographic images were collected at 48 locations at the DWS. Two sets of three replicate images were collected during three separate sampling events in July, September, and October 2002[1]. Images were collected using a Benthos model 3731 sediment-profile camera (Benthos, Inc., North Falmouth, MA). Color slide film (Ektachrome ASA 100) was used for all photographs and developed on-site to verify successful image acquisition. The sediment-profile camera consists of a wedge-shaped prism with a Plexiglas face plate and a back mirror mounted at a 45° angle. Light was provided by an internal strobe. The mirror reflects the image of the profile of the sediment-water interface up to a 35 mm camera that is mounted horizontally on top of the prism. The camera can obtain images of up to 20 cm of the upper sediment column in profile.

The camera prism is mounted on an assembly that can be moved up and down within a stainless steel frame by allowing tension or slack on the winch wire. As the camera is lowered, tension on the winch wire keeps the prism in the up position. Once the camera frame touches the bottom, slack on the winch wire allows the prism to vertically intersect the seafloor. The rate of fall of the prism (6 cm/second) is controlled by an adjustable passive hydraulic piston, which minimizes the disturbance of the sediment-water interface.

A trigger is tripped on impact with the bottom, activating a 13 second time-delay on the shutter release; this gives the prism a chance to obtain maximum penetration before a photograph is taken. When the camera is raised from the bottom, a wiper blade automatically cleans off any sediment adhering to the prism faceplate, the film is advanced, and the strobes are recharged. The camera can then be lowered to collect another replicate image.

When the camera is brought to the surface, optical prism penetration is measured from a penetration indicator, which measures the distance the prism falls relative to the camera base. Due to the predominately sandy conditions anticipated at the DWS, two weight racks, each capable of holding 125 lb. of lead (in 25 lb. increments), were loaded to increase penetration. The 250 lbs of lead weights were used for each sampling event, which permitted good penetration at most locations. If penetration is too great, adjustable stops, which control the distance the prism can descend, can be lowered, and "mud" doors can be attached to each side of the frame to increase the bearing surface of the entire unit. The mud doors were not needed for the MCR surveys due to the consolidated nature of the seafloor at the two disposal sites

SPI Image Analysis

Analysis of the SPI images was conducted using the REMOTS® (Remote Ecological Monitoring Of The Seafloor) system. REMOTS® is a formal and standardized technique for SPI image acquisition, image analysis, and interpretation developed by SAIC scientists (Rhoads and Germano, 1982 and 1986; SAIC, 1986a). Physical and biological parameters were measured directly from the SPI transparencies using a video digitizer and computer image analysis system. The image analysis system can discriminate up to 256 different tonal scales, so subtle features can be accurately digitized and measured. All REMOTS® computer image analysis measurements

[1] *One roll of film collected during the September survey proved unusable due to camera malfunction. The 'missed' locations were re-sampled during the month of October. The SPI images obtained during September and October surveys are being used collectively for comparison with the images acquired during the July survey.*

were performed on the slide transparencies to avoid changes in image density that can accompany the printing of a positive image on photographic paper.

The image analysis software allows the measurement and storage of data from up to 21 different variables for each image. All data were edited and verified by a senior-level scientist before final data synthesis, statistical analyses, and interpretation. The specific REMOTS® parameters for the MCR survey included: sediment grain size (major mode and range), optical prism penetration depth, surface boundary roughness, mud clasts, gas voids, apparent Redox Potential Discontinuity (RPD) depth, infaunal successional stage, and calculation of the organism-sediment index (OSI). SPI imaging can also be utilized for determining dredged material thickness at disposal sites. However, since the DWS has not been previously used for dredged material disposal, this metric is not relevant at this time.

Sediment Grain-Size

The sediment grain-size major mode and range, in phi (Φ) units, were visually determined from the SPI images by overlaying a grain-size comparator at the same scale. This comparator was prepared by photographing a series of Udden-Wentworth size classes (equal to or less than coarse silt up to granule and larger sizes) through the SPI optical system. Seven grain-size classes are on this comparator: ≥ 4 phi (silt/clay), 4 to 3 phi (very fine sand), 3 to 2 phi (fine sand), 2 to 1 phi (medium sand), 1 to 0 phi (coarse sand), 0 to -1 phi (very coarse sand), and < -1 phi (gravels). The lower limit of optical resolution is about 62 μm, allowing recognition of grain sizes equal to or greater than coarse silt. The accuracy of this method has been documented by comparing SPI estimates with grain-size statistics determined from laboratory sieve analyses (SAIC, 1986b).

Prism Penetration Depth

The prism penetration depth is determined by measuring both the largest and smallest linear distance between the sediment-water interface and the bottom of the film frame. Observations regarding the nature and condition of the sediment-water interface are also recorded. Comparative penetration depths from stations of similar grain-size give an indication of relative sediment water content and shear strength.

Surface Boundary Roughness

Surface boundary roughness was determined by measuring the vertical distance (parallel to the film border) between the highest and lowest points of the sediment-water interface. In addition, the origin (physical or biogenic) of this small-scale topographic relief is sometimes evident and can be recorded. In sandy sediments, boundary roughness can be a measure of sand-wave height. On silt-clay bottoms, boundary roughness values often reflect biogenic features such as fecal mounds or surface burrows. These features are abundant only in areas where boundary shear stresses are low enough that such delicate features are preserved. Disposed dredged material often introduces high surface relief on an otherwise “smooth” bottom. Other surface features are noted when evident, including shell fragments/lag deposits, mud-clay clasts, and wood debris.

Mud Clasts

When fine-grained, cohesive sediments are disturbed, either by physical bottom scour or faunal activity (e.g., decapod foraging), intact clumps of sediment are often scattered about the seafloor. Following dredged material disposal of finer grained material, relict sediment clumps also may be present on the seafloor. These mud or clay clasts can be seen at the sediment-water interface in SPI images and their abundance, distribution, oxidation state, and appearance of mud clasts may be used to make inferences about the recent pattern of seafloor disturbance. However, the seafloor and the dredged material that has or will be placed at the MCR disposal sites are dominated by larger grain sizes (i.e. sand), thereby making the evaluation of mud clasts inconsequential.

Benthic Habitat Classification

Based on extensive past sediment-profile imaging surveys (Diaz 1995; SAIC 1997a and b), five basic benthic habitat types have been identified: AM = *Ampelisca* mat, SH = shell bed, SA = hard sand bottom, HR = hard rock/gravel bottom and UN = unconsolidated soft bottom. Several sub-habitat types exist within these major categories. During image analysis, each sediment profile images is assigned one of the habitat categories listed in Table A.1.

Apparent Redox Potential Discontinuity (RPD) Depth

The depth of the apparent RPD, which is the change from oxidized to reduced sediment, will be measured using SPI photography and REMOTS® image analysis. The upper surface of aerobic fine-grained sediments has a higher light reflectance value than underlying hypoxic or anoxic sediments. This is readily apparent in SPI images and is due to oxidized surface sediment that contains minerals in an oxidized state (typically an olive brown color), while the reduced sediments below this oxygenated layer are generally green, gray, blue, or black. The boundary between the colored ferric hydroxide surface sediment and underlying sediment is called the apparent redox potential discontinuity (RPD). The apparent RPD is a sensitive indicator of infaunal succession, sediment bioturbation activity, and sediment oxygen demand. The depth of the apparent RPD has proven to be a useful parameter for mapping gradients of enrichment on the seafloor (Rhoads and Germano, 1982; Lyle, 1983).

The actual RPD is the boundary that separates the positive Eh region (presence of free oxygen) of the sediment column from the underlying negative Eh region (absence of free oxygen). The exact location of the Eh boundary (where Eh = 0) can only be determined with microelectrodes. Therefore, the reflectance boundary observed in the SPI images is termed the apparent RPD. In general, the depth of the actual RPD will be shallower than the depth of the apparent RPD, because organisms cause bioturbation of ferric hydroxide-coated particles downward below the Eh = 0 horizon. As a result, the apparent RPD depth provides an estimate of the degree of biogenic sediment mixing. This variable is important in evaluating the effect of colonizing benthos on disposed materials. Bioturbation vertically transports buried reduced compounds to the sediment surface and exposes them to an oxidizing water column (Aller 1982). Bioturbation also affects sediment transport by changing the physical properties of sediments and their mechanical behavior (Rhoads and Boyer, 1982).

Table A.0.1. Benthic Habitat Categories Assigned to REMOTS® Sediment-Profile Images

Habitat AM: *Ampelisca* Mat Uniformly fine-grained (i.e., silty) sediments having well-formed amphipod (*Ampelisca* spp.) tube mats at the sediment-water interface. Other species of benthic infauna may also create mats similar to those of *Ampelisca*.
Habitat SH: Shell Bed A layer of dead shells and shell fragments at the sediment surface overlying sediment ranging from hard sand to silts. Epifauna (e.g., bryozoans, tube-building polychaetes) commonly found attached to or living among the shells. Two distinct shell bed habitats: **SH.SI: Shell Bed over silty sediment** - shell layer overlying sediments ranging from fine sands to silts to silt-clay. **SH.SA: Shell Bed over sandy sediment** - shell layer overlying sediments ranging from fine to coarse sand.
Habitat SA: Hard Sand Bottom Homogeneous hard sandy sediments do not appear to be bioturbated, bed forms common, successional stage mostly indeterminate because of low prism penetration. **SA.F: Fine sand** - uniform very fine sand (4 to 3 phi) or fine sand sediments (3 to 2 phi). **SA.M: Medium sand** - uniform medium sand sediments (grain size: 2 to 1 phi). **SA.G: Medium sand with gravel** – predominately medium to coarse sand with a minor gravel fraction.
Habitat HR: Hard Rock/Gravel Bottom Hard bottom consisting of pebbles, cobbles and/or boulders, resulting in no or minimal penetration of the REMOTS® camera prism. Some images showed pebbles overlying silty-sediments. The hard rock surfaces typically were covered with epifauna (e.g., bryozoans, sponges, tunicates).
Habitat UN: Unconsolidated Soft Bottom Fine-grained sediments ranging from very fine sand to silt-clay, with a complete range of successional stages (I, II and III). Biogenic features may be common (e.g., amphipod and polychaete tubes at the sediment surface, small surface pits and mounds, large borrow openings, and feeding voids at depth). Several sub-categories: **UN.SS: Fine Sand/Silty** - very fine sand mixed with silt (grain size range from 4 to 2 phi), with little or no shell hash. **UN.SI: Silty** - homogeneous soft silty sediments (grain size range from >4 to 3 phi), with little or no shell hash. Generally deep prism penetration. **UN.SF: Very Soft Mud** - very soft muddy sediments (>4 phi) of high apparent water content and deep prism penetration.

Another important characteristic of the apparent RPD is the contrast in reflectance values at this boundary. This contrast is related to the interactions among the degree of organic-loading in the sediment, bioturbation, and bottom-water dissolved oxygen levels. High inputs of labile organic material increase sediment oxygen demand, stimulate sulfate reduction rate, and result in sulfitic products. This results in more highly reduced (lower-reflectance) sediments at depth and higher RPD contrasts. In a region where generally low RPD contrasts exist, images with high RPD contrasts indicate localized sites of relatively high inputs of organic-rich material, such as dredged material.

Infaunal Successional Stage

The mapping of infaunal successional stages from SPI images is based on the theory that organism-sediment interactions follow a predictable sequence after a major seafloor perturbation. This theory states that primary succession results in "the predictable appearance of macrobenthic invertebrates belonging to specific functional types following a benthic disturbance and these invertebrates interact with sediments in specific ways. Moreover, functional types are the biological units of interest, and by definition do not demand a sequential appearance of particular invertebrate species or genera" (Rhoads and Boyer, 1982).

Benthic disturbance can result from natural processes, such as seafloor erosion, changes in seafloor chemistry, and predator foraging, as well as from human activities like dredged material disposal, bottom trawling, pollution from industrial discharge, and excessive organic loading. Evaluation of successional stages involves deducing dynamics from structure, a technique pioneered by R. G. Johnson (1972) for marine soft-bottom habitats. The application of this approach to benthic monitoring requires *in situ* measurements of salient structural features of organism-sediment relationships as imaged through REMOTS® technology.

Infaunal succession following a major seafloor disturbance initially involves pioneering populations (Primary or Stage I succession) of very small organisms that live at or near the sediment/water interface (Pearson and Rosenberg 1978; Rhoads and Germano 1986). In the absence of further disturbance, infaunal deposit feeders eventually replace these early successional assemblages. The start of this "infaunalization" process is designated as Stage II. Large, deep-burrowing infauna (Stage III taxa) represents a high order successional stage typically found in areas of low disturbance.

Pioneering assemblages (Stage I assemblages) usually consist of dense aggregations of near-surface living, tube-dwelling polychaetes (Figure A.1); alternately, opportunistic bivalves may colonize in dense aggregations after a disturbance (Rhoads and Germano 1982, Santos and Simon 1980a). These functional types are usually associated with a shallow redox boundary; and bioturbation depths are shallow, particularly in the earliest stages of colonization (Figure A.1).

Many deep-burrowing infauna feed at depth in a head-down orientation. This localized feeding activity results in distinctive excavations called feeding voids. Diagnostic features of these feeding structures include a generally semicircular shape with a flat bottom and arched roof, and a distinct granulometric change in the sediment particles overlying the floor of the structure. The relatively coarse-grained material represents particles rejected by head-down deposit-feeders, as this deep-dwelling infauna preferentially ingest the finer sediment particles. Other subsurface structures, including burrows or methane bubbles, do not exhibit these characteristics. The bioturbation

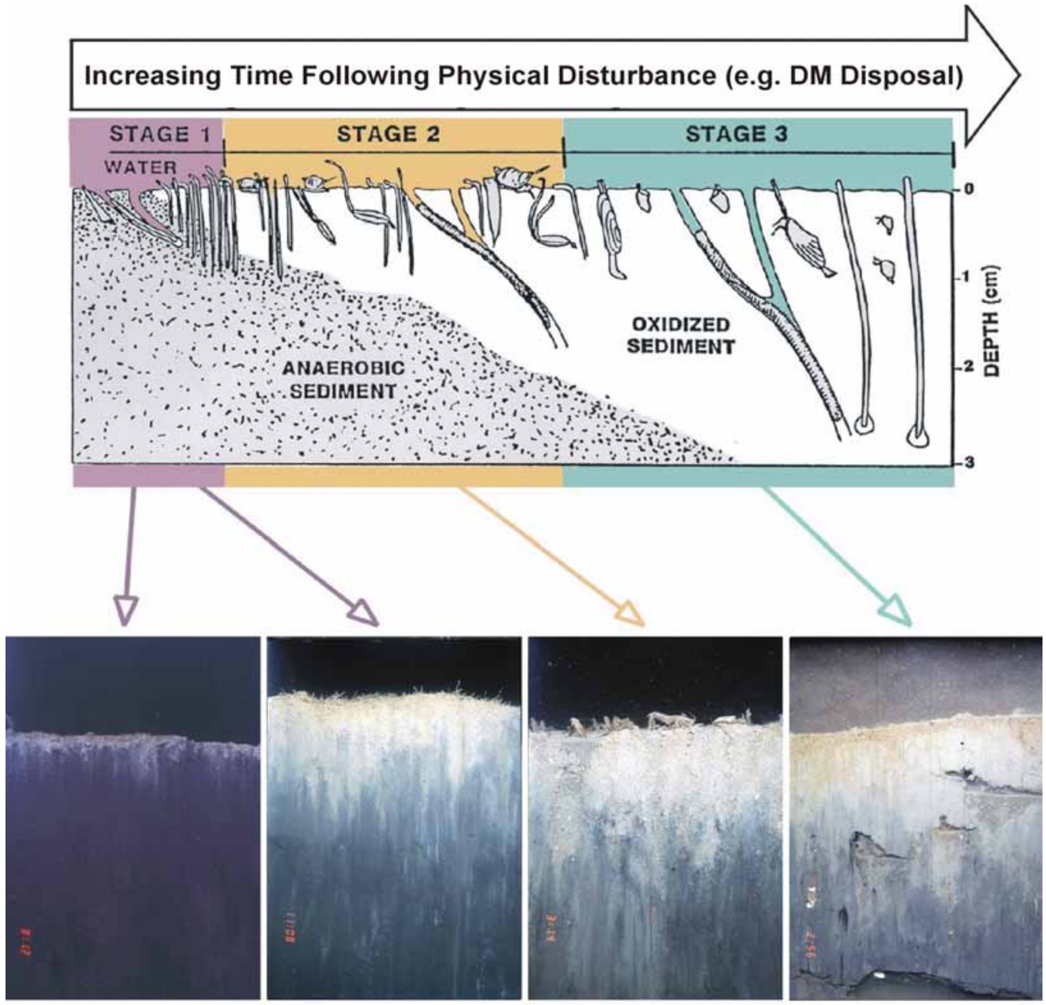

Figure A.0.1. Successional Assemblages and Relationship to SPI Imagery.

The drawing at the top illustrates the development of infaunal successional stages over time following a physical disturbance or with distance from an organic loading source (from Rhoads and Germano 1986). The REMOTS® images below the drawing provide examples of the different successional stages.

Image A: Image A shows highly reduced sediment with a very shallow redox layer (contrast between light colored surface sediments and dark underlying sediments) and little evidence of infauna.

Image B: Numerous small polychaete tubes are visible at the sediment surface in image B (Stage I), and the redox depth is deeper than in image A.

Image C: A mixture of polychaete and amphipod tubes occurs at the sediment surface in image C (Stage II).

Image D: Image D shows numerous burrow openings and feeding pockets (voids) at depth within the sediment; these are evidence of deposit-feeding, Stage III infauna. Note the RPD is relatively deep in this image, as bioturbation by the Stage III organisms has resulted in increased sediment aeration and causing the redox horizon to be located several centimeters below the sediment-water interface.

activities of these deposit-feeders are responsible for aerating the sediment and causing the redox horizon to be located several centimeters below the sediment-water interface. The presence of Stage III feeding voids indicates the presence of Stage III organisms. The mapped distribution of deep infaunal assemblages may be useful in identifying undisturbed sites in both shallow and deep water environments.

In sandy, dynamic environments such as those found at the DWS, the climax communities may consist primarily of surface dwellers (e.g., *Amphiodia*) that reside in the upper cm of the sediment surface and have few if any naturally burrowing community members. These type communities are classified as Stage I communities by REMOTS® analysis reflective of an area influenced by physical factors (e.g., higher energy) and the presence of a sandy substrate, rather than a higher order successional stage that would typically be assigned a climax community (as described above) in a depositional environment dominated by a silt/clay substrate.

Organism-Sediment Index

The Organism-Sediment Index (OSI) provides a measure of general benthic habitat quality in shallow water environments based on dissolved oxygen conditions, depth of the apparent RPD, infaunal successional stage, and presence or absence of sedimentary methane. The OSI is a numerical index ranging from -10 to +11. The lowest value is given to bottom sediments with low or no dissolved oxygen in the overlying bottom water, no apparent macrofaunal life, and methane gas present in the sediment. The OSI for such a condition is –10 (highly disturbed or degraded benthic habitat quality). High OSI values are given to aerobic bottom sediments with a deep apparent RPD, mature macrofaunal community, and no methane gas (unstressed or undisturbed benthic habitat quality). The numerical values and ranges used in calculating the OSI are provided in Table A.2.

The OSI is calculated automatically by SAIC software after completion of all measurements from each REMOTS® photographic negative. The index has proven to be an excellent parameter for mapping disturbance gradients in an area and documenting ecosystem recovery after disturbance (Germano and Rhoads 1984, Revelas et al. 1987, Valente et al. 1992).

The OSI may be subject to seasonal changes because the mean apparent RPD depths vary as a result of temperature-controlled changes of bioturbation rates and sediment oxygen demand. Furthermore, the successional status of a station may change over the course of a season related to recruitment and mortality patterns or the disturbance history of the bottom. The sub-annual change in successional status is generally limited to Stage I (polychaete-dominated) and Stage II (amphipod-dominated) seres. Stage III seres tend to be maintained over periods of several years unless they are eliminated by increasing organic loading, extended periods of hypoxia, or burial by thick layers of dredged material. The recovery of Stage III seres following abatement of such events may take several years (Rhoads and Germano 1982). Stations that have low or moderate OSI values (< +6) are indicative of recently disturbed areas and tend to have greater temporal and spatial variation in benthic habitat quality than stations with higher OSI values (> +6).

Table A.0.2. Calculation of the Organism-Sediment Index.

Choose One Value:	Mean RPD Depth Classes	Index Value
	0.00 cm	0
	> 0 - 0.75 cm	1
	0.76 - 1.50 cm	2
	1.51 - 2.25 cm	3
	2.26 - 3.00 cm	4
	3.01 - 3.75 cm	5
	> 3.75 cm	6
Choose One Value:	Successional Stage	Index Value
	Azoic	- 4
	Stage I	1
	Stage I - II	2
	Stage II	3
	Stage II - III	4
	Stage III	5
	Stage I on III	5
	Stage II on III	5
Choose One or Both if Appropriate:	Chemical Parameters	Index Value
	Methane Present	- 2
	No/Low Dissolved Oxygen	- 4
SPI Organism-Sediment Index =		**Range: - 10 + 11**