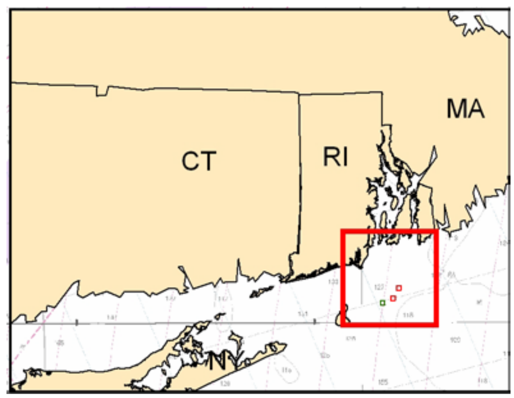
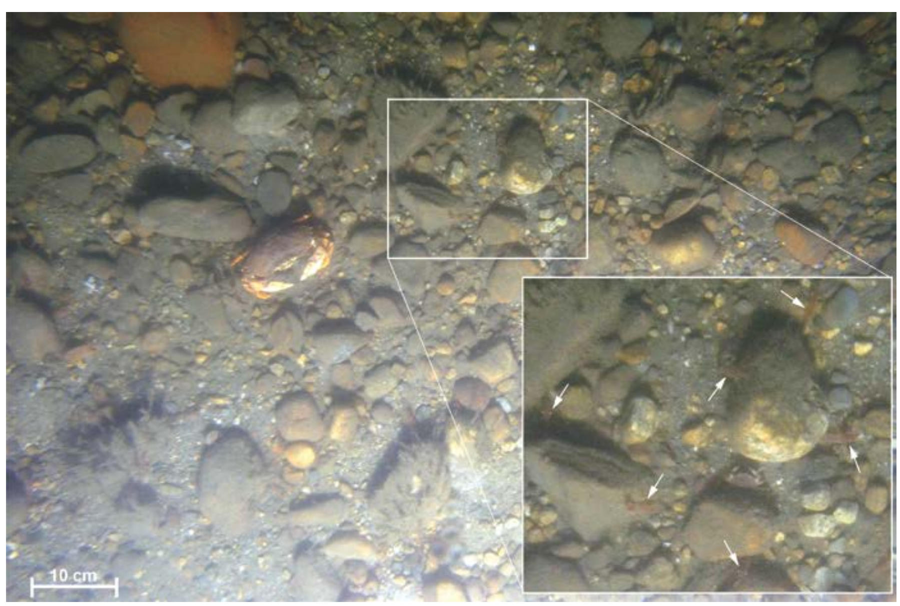
Monitoring Survey at the Rhode Island Sound Disposal Site
October 2009

Disposal Area Monitoring System DAMOS





DAMOS

DISPOSAL AREA MONITORING SYSTEM

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13. ABSTRACT

A monitoring survey was conducted in October 2009 at the Rhode Island Sound Disposal Site (RISDS) as part of the Disposal Area Monitoring System (DAMOS) Program. The 2009 field effort consisted of obtaining both sediment-profile images (SPI) and plan-view underwater camera (PUC) images at stations located throughout the disposal site and at three nearby reference areas. This survey was conducted more than four years after the disposal of a relatively large volume of sediment from the Providence River and Harbor Maintenance Dredging Project (PRHMDP). The PRHMDP and related projects disposed dredged material at RISDS every month from April 2003 to January 2005. The previous DAMOS monitoring survey of July 2005 found that the benthic community was recovering relatively rapidly over the disposal site, with Stage 2 and 3 infauna present throughout the region. Based on these earlier monitoring results, it was predicted that the October 2009 survey would continue to find evidence of relatively advanced succession (Stages 2 and 3) at RISDS. The 2009 survey found that the berm created on the western side of the disposal site was characterized by a variety of benthic habitat types ranging from silt-clay to small rocks (pebbles and cobbles). The 2009 survey also found that the dredged material across most of the site continued to consist of relatively soft, sulfidic mud that had undergone considerable consolidation since its original placement five years ago. The exception to this was a relatively small area within the site where sandy, organic-poor dredged material was placed in late 2008 and early 2009. This newer dredged material was characterized by relatively deep aRPD depths and an advanced successional status. The 2009 survey showed that while there continued to be ample evidence of advanced succession at the stations sampled within the disposal site, deposit-feeding Stage 3 organisms continued to be present at lower apparent densities within the site compared to nearby reference areas located on the ambient seafloor Possible explanations include grain size differences, continued consolidation of the Providence River dredged material, elevated levels of organic matter and sulfides in this material, and a lack of nearby populations of Stage 3 organisms for recruitment. The 2009 results run somewhat counter to the expected predictions about disposal site biological conditions gradually converging with those on the ambient seafloor over a period of several years following cessation of disposal activities. Although the 2009 survey found that RISDS has continued to experience a relatively healthy degree of benthic recolonization over the past several years, the low relative densities of deposit-feeding Stage 3 organisms is inconsistent with expectations. As a precautionary measure, it was recommended that additional monitoring be conducted in the near future following the recommendations in the DAMOS Tiered Monitoring Protocol.

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EXECUTIVE SUMMARY

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The previous DAMOS monitoring survey of July 2005 found that the benthic community was recovering relatively rapidly over the disposal site, with Stage 2 and 3 infauna present throughout the region. Because the July 2005 survey was conducted only six months following the cessation of disposal activities (relatively early in the recolonization process), the results showing lower densities of Stage 2 and 3 fauna at the disposal site as compared to the reference areas were expected and well within the normal range of observed recolonization patterns seen at other DAMOS disposal sites (Germano et al. 1994).

Based on these earlier monitoring results, it was predicted that the October 2009 survey would continue to find evidence of relatively advanced succession (Stages 2 and 3) at RISDS. The 2009 survey found that the berm created on the western side of the disposal site was characterized by a variety of benthic habitat types ranging from silt/clay to small rocks (pebbles and cobbles). Many of the rocks were found to be covered with encrusting epifauna, and small crustaceans were visible in a high percentage of the PUC images. Overall, the hard bottom conditions on the berm were providing habitat for a variety of epifauna, including hydroids, bryozoans, shrimp, crabs, and sea stars. Although they were not observed in the images collected during the 2009 survey, it is possible that juvenile lobsters might also be attracted to these hard bottom conditions.

The 2009 survey also found that the dredged material across most of the site continued to consist of relatively soft, sulfidic mud that had undergone considerable consolidation since its original placement five years ago. The exception to this was a relatively small area within the site where sandy, organic-poor dredged material was placed in late 2008 and early 2009. This newer dredged material was characterized by relatively high apparent redox potential discontinuity (aRPD) values and an advanced successional status.

The 2009 survey showed that while there continued to be ample evidence of advanced succession at the stations sampled within the disposal site, deposit-feeding Stage 3 organisms continued to be present at lower apparent densities within the site compared to nearby reference areas located on the ambient seafloor Possible explanations include grain size differences, continued consolidation of the Providence River dredged material, elevated levels of organic matter and sulfides in this material, and a lack of nearby populations of Stage 3 organisms for recruitment. As benthic recovery at the site has proceeded at a slower rate than expected, additional benthic monitoring is recommended following the DAMOS Tiered Monitoring Protocol (Germano et al. 1994).

1.0 INTRODUCTION

A monitoring survey was conducted at the Rhode Island Sound Disposal Site in October 2009 as part of the U.S. Army Corps of Engineers (USACE) New England District Disposal Area Monitoring System (DAMOS) Program. DAMOS is a comprehensive monitoring and management program designed and conducted to address environmental concerns surrounding the placement of dredged material at aquatic disposal sites throughout the New England region. An introduction to the DAMOS Program and the Rhode Island Sound Disposal Site, including brief descriptions of previous dredged material disposal and site monitoring activities, is provided below.

1.1 Overview of the DAMOS Program

The DAMOS Program features a tiered management protocol designed to ensure that any potential adverse environmental impacts associated with dredged material disposal activities are promptly identified and addressed (Germano et al. 1994). For over 30 years, the DAMOS Program has collected and evaluated disposal site data throughout New England. Based on these data, patterns of physical, chemical, and biological responses of seafloor environments to dredged material disposal activity have been documented (Fredette and French 2004).

DAMOS monitoring surveys are designed to test hypotheses related to expected physical and ecological response patterns following placement of dredged material on the seafloor at established disposal sites. The resulting information is used to guide the management of disposal activities at each site.

Two primary goals of DAMOS monitoring surveys are to document the physical location and stability of dredged material placed on the seafloor and to evaluate the biological recovery of the benthic community following placement of the dredged material. Sequential bathymetric measurements are used extensively in the DAMOS Program to characterize the height and spread of discrete dredged material deposits or mounds created at disposal sites and to track mound stability over time. In addition, sediment-profile imaging (SPI) surveys are performed routinely to evaluate the environmental impact of dredged material placement and monitor changes in seafloor (benthic) habitat conditions over time. Following completion of the periodic monitoring activities at each disposal site, the collected data are evaluated to determine the next step in the disposal site management process. The conditions found after a defined period of disposal activity are compared with the long-term data set at a specific site (Germano et al. 1994). Additional types of data collection activities conducted under DAMOS utilize side-scan sonar, plan-view underwater camera (PUC) photography, sediment coring, and grab sampling as deemed appropriate to achieve specific survey objectives.

1.2 Introduction to the Rhode Island Sound Disposal Site

The Rhode Island Sound Disposal Site (RISDS), originally labeled as Site 69b, was one of three sites (Site 69b, Site 69a, and Site 18) initially considered as an open-water disposal alternative in Rhode Island Sound for the Providence River and Harbor Maintenance Dredging Project (PRHMDP; USACE 2001) (Figure 1-1). In December 2004, Site 69b was officially designated the Rhode Island Sound Disposal Site (RISDS), an open-water disposal site for dredged material from Rhode Island and other surrounding harbors in Massachusetts and Connecticut (40 CFR Part 228).

RISDS is located approximately 21 km (11 nmi) south of the entrance to Narragansett Bay and 16.7 km (9 nmi) south of Point Judith, Rhode Island, within the separation zone for the Narragansett Bay shipping lanes. The site is defined as an 1800 x 1800 m (5900 x 5900 ft) area on the seafloor centered at 41°13.850' N, 71°22.817' W (NAD 83) (Figure 1-1). Prior to any dredged material disposal, the bottom topography at RISDS consisted of a broad topographic depression, with water depths ranging from 34 to 39 m (111 to 128 ft, Figure 1-2).

1.3 Dredged Material Disposal Activity

Prior to 2003, major dredging activity in Rhode Island waters had not occurred in almost 30 years, leading to significant shoaling of the Providence River shipping channel and consequent hazardous navigation conditions. The objective of the PRHMDP was to restore the depth and width of the Federal Navigation Channel, a 27-kilometer-long channel that runs from Providence Harbor south along the Providence River to deeper waters near Prudence Island (USACE 2001). A total of 2.9 million cubic meters (3.8 million cubic yards) () of maintenance dredged material was dredged from the six reaches of the Federal Navigation Channel, and an additional 1.5 million cubic meters (2.0 million cubic yards) of native parent material was dredged to create several Confined Aquatic Disposal (CAD) cells within the Providence River (ENSR 2008). Details regarding the characterization of the dredged material and the various disposal alternatives that were employed are provided in a previous DAMOS synthesis report (ENSR 2008).

An estimated 4 million cubic meters (5 million cy) of dredged material was placed at RISDS between April 2003 and January 2005 (Figure 1-3). Careful management of

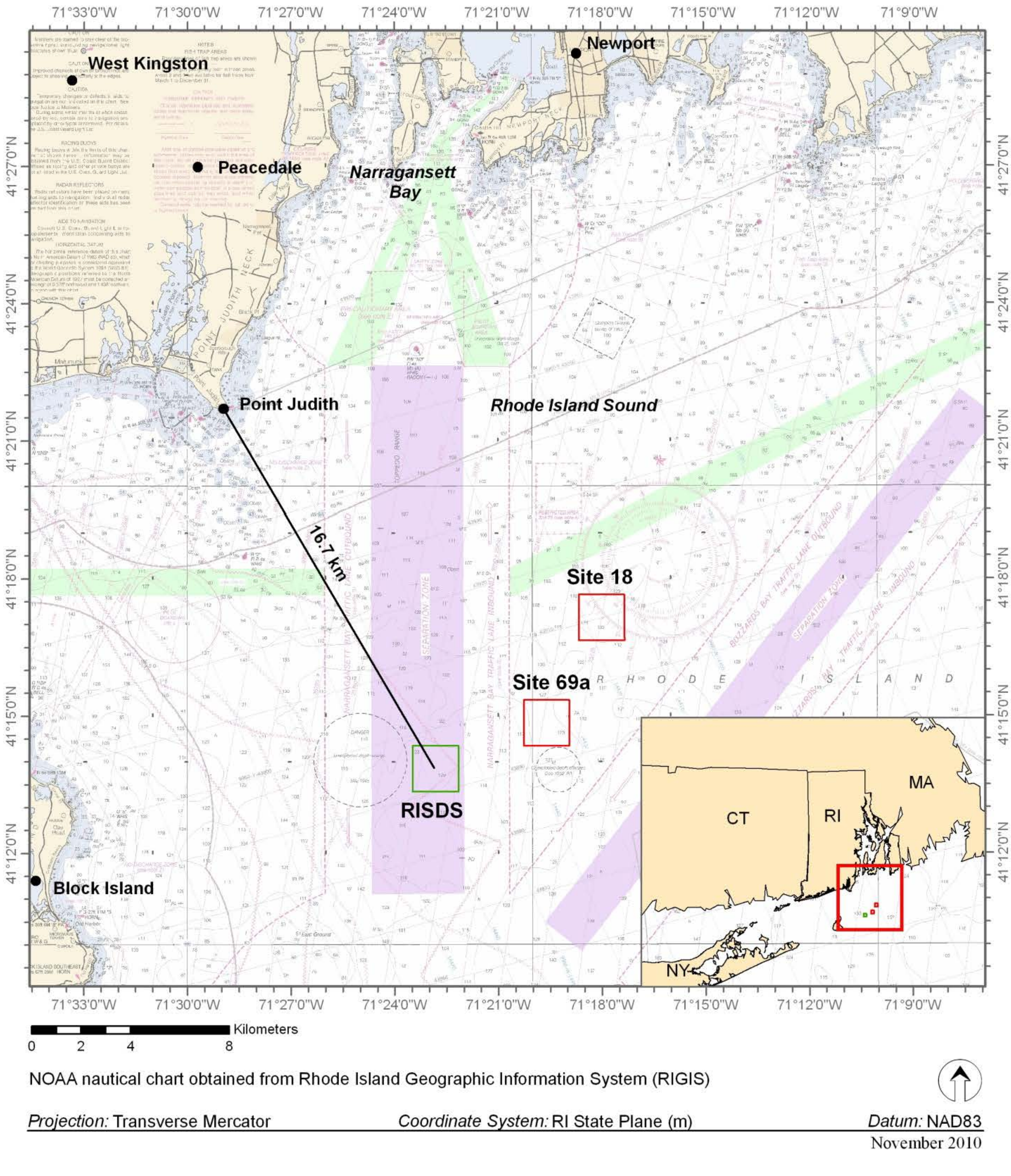


Figure 1-1. RISDS with open-water disposal site alternatives in Rhode Island Sound

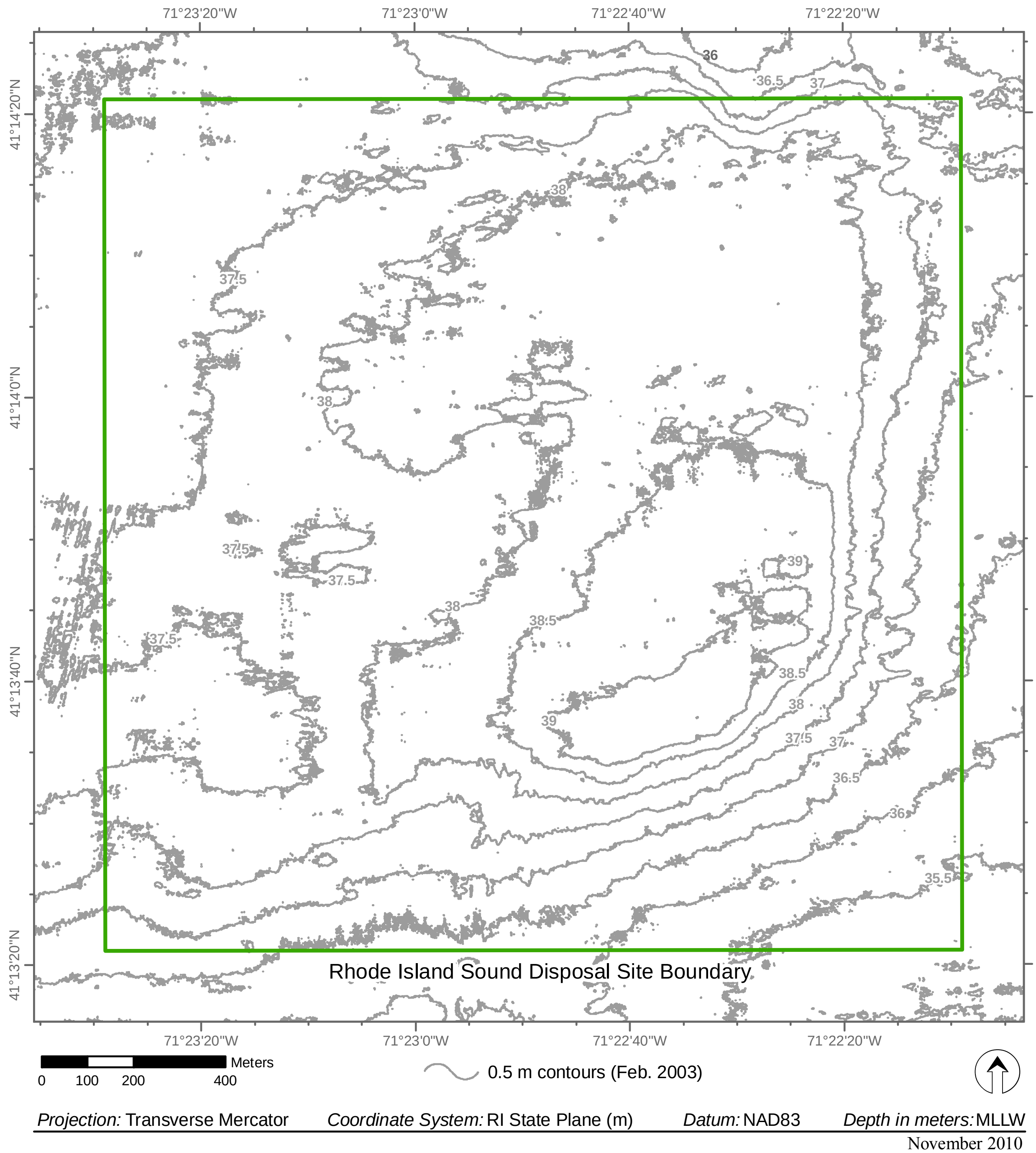


Figure 1-2. Bathymetric contour map of RISDS in February 2003, prior to any dredged material placement

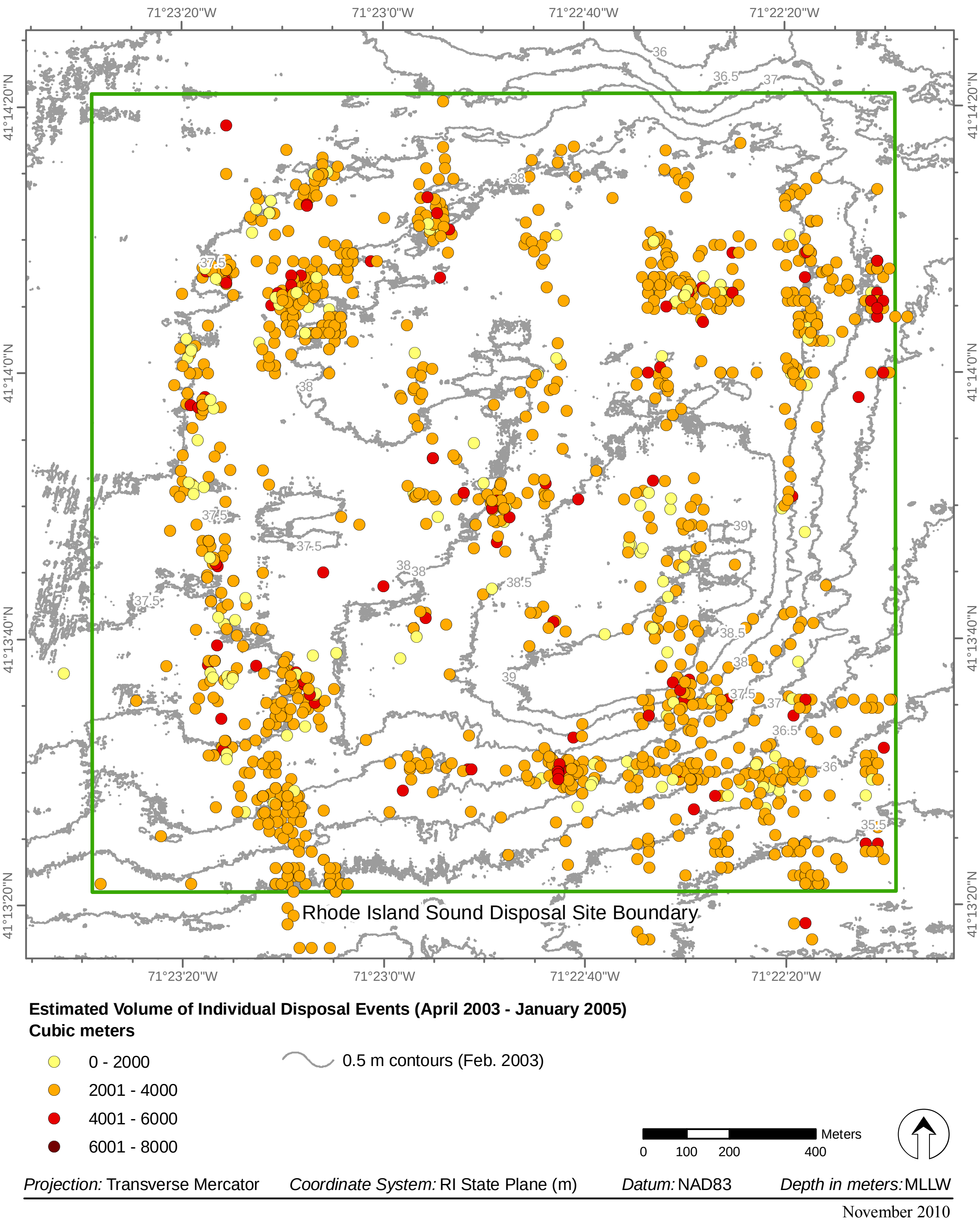


Figure 1-3. RISDS with reported dredged material disposal locations and estimated volumes for the period April 2003 to January 2005

the placement of glacial sediments removed to create CAD cells in the upper Providence channel resulted in the creation of a continuous ridge or berm of sediment along the western boundary of the disposal site (Figures 1-3 and 1-4) (SAIC 2004). This berm was created to enhance the capacity of the natural bottom depression located in the southeastern quadrant of the disposal site and limit the lateral spread of disposed unconsolidated sediment. Additional material, including maintenance material from the channel, was directed to a series of disposal points across the site to create a relatively even deposit (Figures 1-3 and 1-4). In the time that has passed since the previous DAMOS monitoring survey was conducted in July 2005, a relatively minor amount of dredged material (approximately 23,000 m^3, 30,000 cy) was placed in a small subsection of RISDS in late 2008 and early 2009 (Figure 1-5; Appendix A).

1.4 RISDS Monitoring Events

RISDS was monitored multiple times throughout the Providence River and Harbor Maintenance Dredging Project (2003 to 2005) to document the changes in seafloor topography and surficial sediment composition (Table 1-1). Surveys were conducted in February, July, September, and October 2003; February, May, and September 2004; and July 2005. Surveys consisted of multibeam or single-beam bathymetry, side-scan sonar, sediment-profile imaging, and/or underwater video. The February 2003 multibeam bathymetric survey served as a baseline survey to closely examine the seafloor topography in the area encompassing RISDS prior to placement of dredged material (Figure 1-2). Subsequent sequential bathymetric surveys performed in July and September 2003; February, May, and September 2004; and July 2005 documented changes in seafloor topography and tracked the development of the berm along the western site boundary. Additional imaging surveys (side-scan sonar, SPI, and underwater video) were performed in September and October 2003 to further examine the distribution of sediment and determine the sediment composition of areas where disposal trails and deposits were observed. Two studies were conducted in 2004 to track and assess potential toxicity of the suspended sediment plume during dredged material disposal at RISDS (SAIC 2005a, 2005b). A study also was conducted to investigate whether the dredged material disposal resulted in any significant changes in lobster abundance at RISDS (Table 1-1 and Valente et al. 2007).

The most recent previous monitoring survey was conducted in July 2005 and involved both plan-view underwater camera (PUC) and SPI photography, as well as the collection of grab samples. The latter were used to determine the actual taxonomic composition of infaunal communities inhabiting surface sediments both within the disposal site and at several nearby reference areas (ENSR 2007). The objective of the July 2005 survey was to assess the status of benthic recolonization over the surface of the extensive

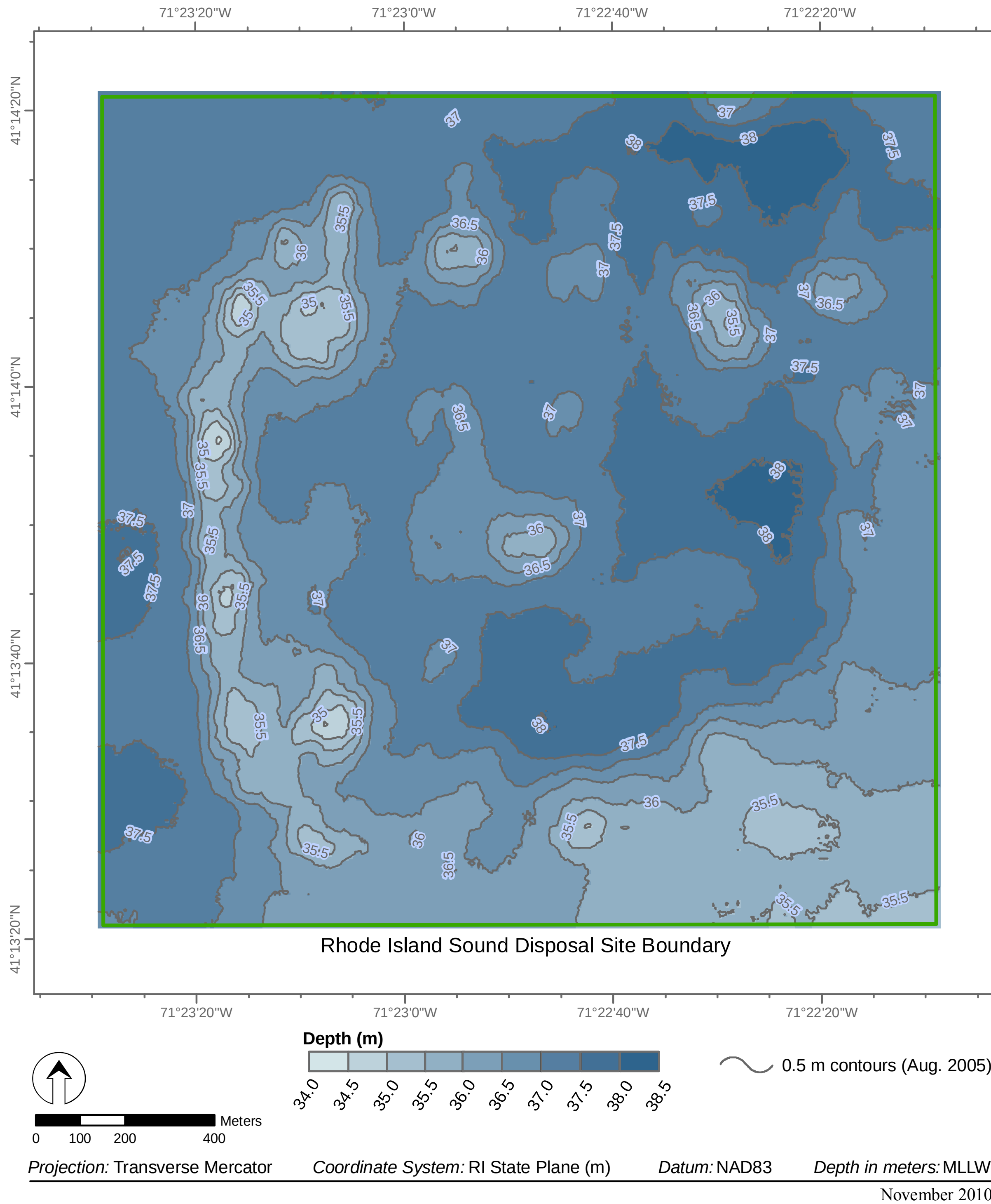


Figure 1-4. Bathymetric contour map of RISDS, August 2005 from SAIC unpublished DAMOS survey

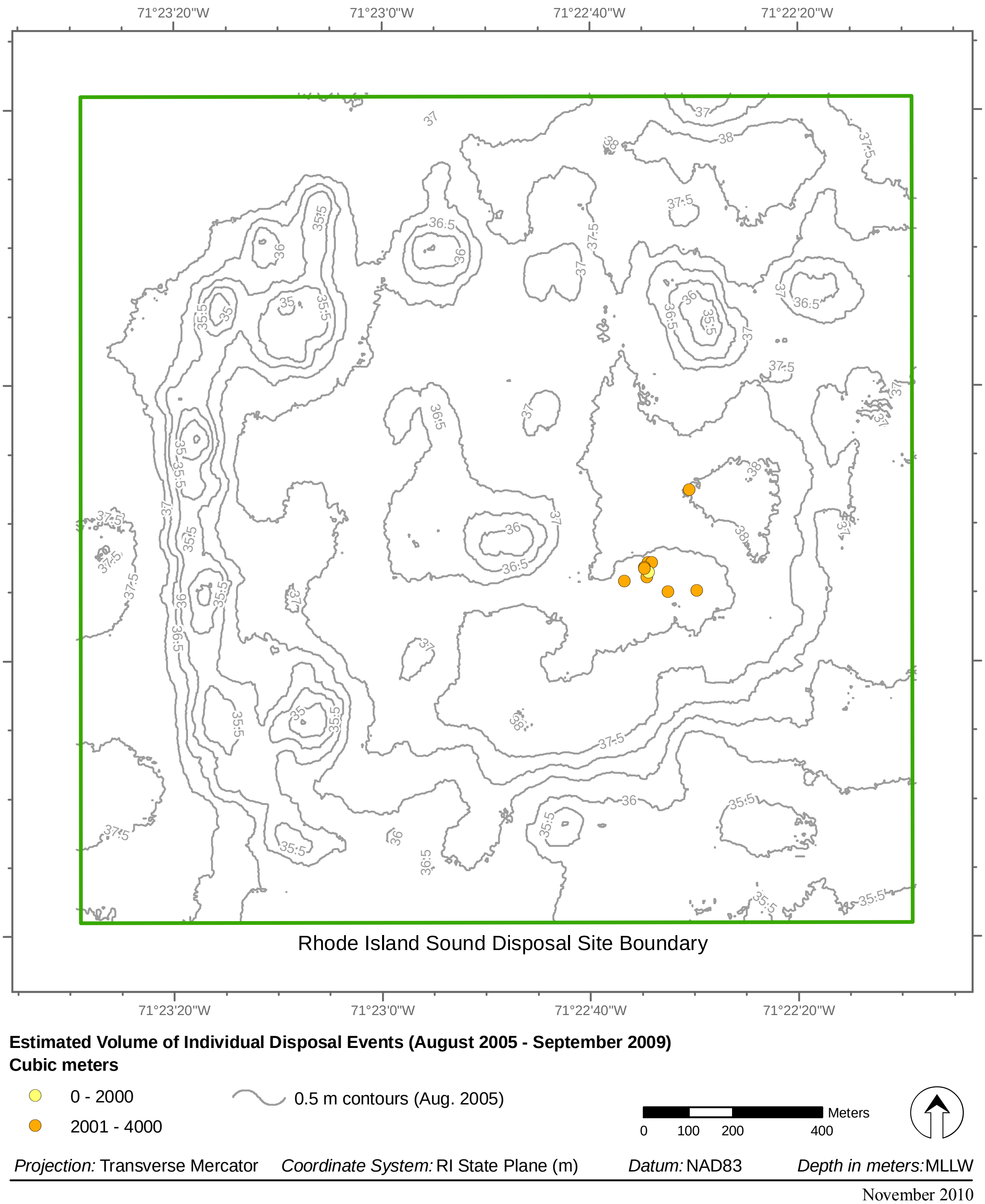


Figure 1-5. RISDS with reported dredged material disposal locations and estimated volumes for the period August 2005 to September 2009

Table 1-1.

Overview of Survey Activities in Rhode Island Sound since 1997

Date	Purpose of Survey	Bathymetry Area	SPI Stations	Additional Studies	Reference
June 1997	Evaluation of potential disposal sites		Site 69a - 18, Site 69b - 18		SAIC 1997[a]
Nov 1999	Characterize benthic resources and sediment at potential dredged material disposal sites		Site 69a - 28, Site 69b - 35		SAIC 2000[b]
Sept 2001	Rhode Island regional long-term dredged material disposal site evaluation		Site 16 - 5 (3 Ref), Site 18 - 9 (9 Ref), Site 69a - 6 (9 Ref), Site 69b - 9 (9 Ref)		Battelle 2002
Feb 2003	Baseline bathymetry survey in support of PRHMDP	Multibeam 4000 x 3800 m			SAIC 2004
July 2003	First postdisposal monitoring survey	Single-beam 1900 x 1900 m			SAIC 2004
Sept 2003	Second postdisposal monitoring survey	Single-beam 1900 x 1900 m		Side-scan sonar 2900 x 2900 m	SAIC 2004
Oct 2003	Assessment of surface sediment composition within RISDS and surrounding Area W[c]		RISDS - 11 Area W - 23	Towed video 8 transects	SAIC 2004
Apr 2004 Sept 2004	Track and assess suspended sediment plume			ADCP, OBS, drogues Water analysis	SAIC 2005a SAIC 2005b
Feb 2004 May 2004 Sept 2004 Aug 2005	Postdisposal monitoring in support of PRHMDP	Single-beam 1900 x 1900 m			Unpublished DAMOS data, ENSR 2008
July 2005	Assess benthic recolonization status		RISDS - 30, Ref Areas - 15	Infauna Analysis	ENSR 2007
Aug 2005 Sept 2005 Nov 2005	Assess postdisposal lobster abundance			Lobster trapping	Valente et al. 2007

Notes: a - Dimensions of site 69b and 69a were different from current configuration
b - Dimensions of site 69b and 69a were consistent with current boundaries
c - Area W was 2900 x 2900 m, with RISDS included in the southeast quadrant.

dredged material deposit created within the site boundaries from continuous disposal activities between April 2003 and January 2005. Prior to the survey, it was predicted that the benthic community within RISDS would be in an intermediate stage of recolonization (Stage 2; Rhoads and Germano 1982, 1986; see section 2.2.4 below). Specifically, the community was expected to consist of small, tubicolous polychaetes and ampeliscid amphipods or equivalent fauna.

The July 2005 survey found that the infaunal community within RISDS was recovering relatively rapidly, and the initial predictions of this community being in at least a Stage 2 recolonization phase proved correct. The SPI and PUC images showed evidence of Stage 3 infauna present both within the disposal site and at the reference areas, although, as anticipated, their densities were much lower within the disposal site.

The benthic grab samples collected in the July 2005 survey revealed the presence of dense populations of filter-feeding invertebrates and suggested that Stage 2 organisms dominated the surface sediments. At the reference stations sampled in Rhode Island Sound, an even greater diversity of filter-feeding organisms was present, and included dense populations of amphipods, bivalves, and polychaetes. The benthic grabs did not capture any head-down deposit-feeding Stage 3 organisms at the disposal site; however, large, surface-deposit-feeding polychaetes were found in the benthic samples.

Results of the 2005 RISDS survey indicated that in the six months since disposal activities at RISDS had concluded, the biological community at RISDS was recovering relatively rapidly, and Stage 2 and 3 infauna were present throughout the region. Based on those results, recovery was expected to continue to the point where the benthic community within RISDS would eventually become comparable to that found in the surrounding ambient sediments.

1.5 Survey Objectives

The objective of the 2009 survey was to continue assessing the benthic recolonization status of surface sediments within RISDS following placement of sediment from the PRHMDP. The survey utilized a sampling design that was similar to the one used in the 2005 survey, with both plan-view and sediment-profile images being collected within the disposal site and at three nearby reference areas. Emphasis was again directed toward monitoring the basin area in the east-southeast quadrant of the site, with less emphasis on the berm feature located along the western boundary (ENSR 2007). The 2005 survey included benthic grab sampling for infaunal community analysis, which is used only occasionally in the DAMOS Program to provide comparison with SPI results. Because SPI sampling alone is the standard technique employed for routine monitoring of benthic recolonization at DAMOS disposal sites, grab samples for infaunal community analysis were not collected in 2009. Given the limited additional disposal of dredged material at RISDS since the 2005 survey, additional bathymetry was not collected as part of this investigation.

Based on observed patterns of physical, chemical, and biological responses of seafloor environments to dredged material disposal activity, it was expected that the benthic community over most of the basin area of RISDS, where there had been no dredged material disposal since the previous survey of 2005, would be in an advanced phase of recolonization (Stage 3). In particular, it was expected that the community would consist of large-bodied, long-lived species living at depth within the sediment column, with perhaps some mixtures of Stages 1 and 2 continuing to occur at the sediment surface in a typical patchwork of benthic conditions. In the subsection of the disposal site that had received dredged material in late 2008 and early 2009, it was expected that earlier successional stages (Stages 1 and 2) would be dominant.

2.0 METHODS

Working from the 42-ft *F/V Shanna Rose*, a team of investigators from CR Environmental and Germano and Associates conducted the survey on 4–5 October, 2009. The survey consisted of collecting sediment-profile images and sediment plan-view images both within the disposal site and at three nearby reference areas. An overview of the methods used to collect the survey data is provided below. A more detailed description of methodology and the related terminology can be found in ENSR (2004).

2.1 Navigation and On-Board Data Acquisition

A Differential Global Positioning System (DGPS) was used to accurately measure and record vessel and sampling locations during the SPI survey. The DGPS system calculates geographic position by monitoring signals from a network of U.S. Government satellites. Real-time corrections are applied to position solutions using ultrahigh frequency (UHF) signals transmitted from nearby U.S. Coast Guard base stations. These "differential" corrections are required to correct atmospherically induced interferences to the satellite signals in order to achieve submeter horizontal accuracy. The DGPS system used for this survey was a Trimble Ag GPS132. The DGPS outputs digital position, time, and satellite quality data once a second to the HYPACK® hydrographic acquisition software. HYPACK® was used for navigation by providing a visual representation of the location of the vessel in reference to the target SPI sampling location.

2.2 Sediment-Profile and Plan-View Imaging

2.2.1 Sediment-Profile Imaging

Sediment-profile imaging (SPI) is a monitoring technique used to provide data on the physical characteristics of the seafloor as well as the status of the benthic biological community. The technique involves deploying an underwater camera system to photograph a cross section of the sediment-water interface. Acquisition of high-resolution sediment-profile images was accomplished using a Nikon® D200 digital single-lens reflex camera mounted inside an Ocean Imaging Model 3731 pressure housing system. The pressure housing sat atop a wedge-shaped prism with a front faceplate and a back mirror. The mirror was mounted at a 45° angle to reflect the profile of the sediment-water interface. As the prism penetrated the seafloor, a trigger activated a time-delay circuit that fired an internal strobe to obtain a cross-sectional image of the upper 15–20 cm of the sediment column (Figure 2-1). The camera remained on the seafloor for approximately 20 seconds to ensure that a successful image had been obtained.

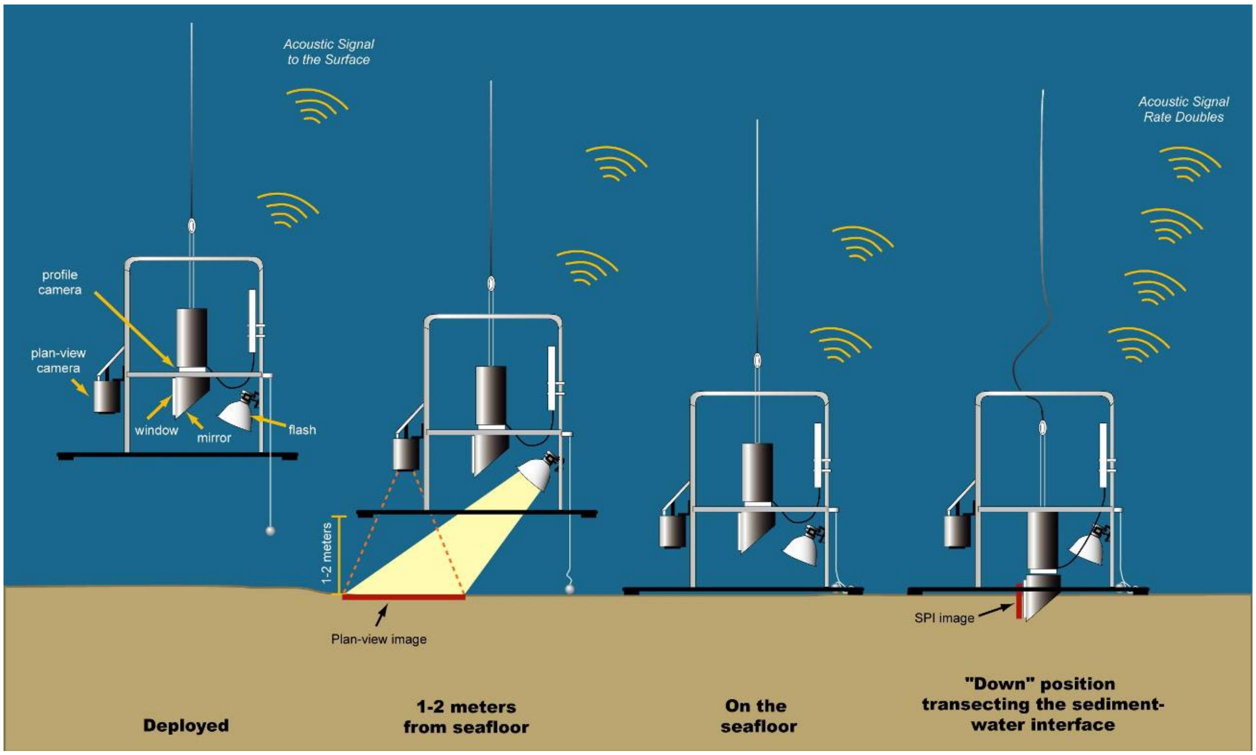


Figure 2-1. Operation of the combined Ocean Imaging Model 3731 sediment-profile and Model DSC-6000 plan-view cameras

Test exposures of the Kodak® Color Separation Guide (Publication No. Q-13) were made on deck at the beginning and end of each survey to verify that all internal electronic systems were working to design specifications and to provide a color standard against which final images could be checked for proper color balance. After deployment of the camera at each station, the frame counter was checked to ensure that at least three replicate images had been obtained. In general, under the DAMOS monitoring protocol, three replicates are obtained at each station in order to generate a mean value for the various measured parameters described below. In addition, a prism penetration depth indicator on the camera frame was checked to verify that the optical prism had actually penetrated the bottom to a sufficient depth. If images were missed or the penetration depth was insufficient, the camera frame stop collars were adjusted and/or weights were added or removed, and additional replicate images were taken. Changes in prism weight amounts, the presence or absence of mud doors, and frame stop collar positions were recorded for each replicate image.

Each image was assigned a unique time stamp in the digital file attributes by the camera's data logger and cross-checked with the time stamp in the navigational system's computer data file. In addition, the field crew kept redundant written sample logs. Images were downloaded periodically to verify successful sample acquisition and/or to assess what type of sediment/depositional layer was present at a particular station. Digital image files were renamed with the appropriate station name immediately after downloading as a further quality assurance step.

Computer-aided analysis of the resulting images provided a set of standard measurements that enabled comparison between different locations and different surveys. The DAMOS Program has successfully used this technique for over 20 years to map the distribution of disposed dredged material and to monitor benthic recolonization at disposal sites. For a detailed discussion of SPI methodology, see ENSR (2004).

2.2.2 Plan-View Imaging

Plan-view images of the surface sediments were also collected at each station, using a second camera mounted on the sediment-profile camera frame. An Ocean Imaging Systems Model DSC6000 plan-view underwater camera (PUC) system was attached to the Model 3731 camera frame and used to collect downward-looking (i.e., horizontal or "plan-view") photographs of the seafloor surface (Figure 2-1). The PUC system consisted of a Nikon® D-90 camera encased in a titanium housing, a 24-VDC autonomous power pack, a 500W strobe, and a bounce trigger along with two Ocean Imaging Model 400-37 Deep Sea Scaling lasers. As the camera apparatus was lowered to the seafloor, the weight attached to the bounce trigger contacted the seafloor prior to the camera frame hitting the bottom and triggered the camera. The length of the stainless steel trigger cable was adjusted for changing conditions in water clarity within the site; the scaling lasers projected two red dots that are separated by a constant distance (26 cm) regardless of the length of the trigger cable. The field of view for the plan-view images ranged from approximately 0.6 m^2 to 3.1 m^2, depending on the length of the trigger wire. All PUC images were collected as 12-megapixel raw Nikon Exchange Format (*.nef) files and converted to compressed (*.jpeg [Joint Photographic Experts Group]) files after the survey.

2.2.3 SPI and PUC Data Collection

The field team collected SPI and PUC images at 30 stations within RISDS (Figure 2-2) and at 15 reference stations (Figure 2-3). Within RISDS, five stations were spaced at roughly equal distances apart along the berm feature near the western site boundary (stations denoted with a BE prefix in the station name; Figure 2-2). The remaining 25 stations were divided equally into five groups (denoted by the prefix A, B, C, D or E in the station name; Figure 2-2). Within each of these five groups, each of the five stations was randomly located within a circular area having a radius of 150 m (Figure 2-2). The circular sampling areas were places where prior disposal activity was concentrated (compare Figures 1-3 and 2-2) and had resulted in the creation of distinct mounds (Figure 1-4). The coordinates of the center point of each circle (mound) depicted in Figure 2-2, and the target coordinates of each SPI target station sampled during 2009 survey, are provided in Table 2-1.

As part of the 2009 survey, three reference areas were surveyed—east of the disposal site (REF-E), southwest of the disposal site (REF-SW), and northeast of the disposal site (REF-NE)—to provide a basis of comparison between RISDS sediment conditions and the ambient sediment conditions in Rhode Island Sound. The northeast reference area was located in the northwest corner of Site 69a, one of the alternative sites considered in the designation of RISDS for the PRHMDP. Five reference stations were selected randomly within a 300-m radius of the centers of each of the three reference areas (Table 2-1, Figure 2-3). At REF-E, only one replicate could be analyzed from Station 5, this station was rejected and replaced with a new random station, Station 6 (Table 2-1, Figure 2-3).

At each station, the vessel was positioned at the target coordinates, and the frame was deployed within a defined station tolerance of 10 m. The SPI and plan-view cameras were deployed simultaneously. At least three replicate SPI images were collected at each of the 45 stations. High-quality PUC images were more difficult to obtain due to changing water conditions; therefore, the collection of at least one quality replicate PUC image was considered adequate for further analysis. In many cases more than three replicates are collected at stations, only three are selected for analysis.

Table 2-1.

Center Coordinates of SPI/PUC Disposal Site Station Groups (Figure 2-2), Reference Areas (Figure 2-3) and Coordinates of Each Station Collected During the October 2009 Survey

Station Group	Latitude (N)	Longitude (W)
Disposal Site:		
RISDS-A	41° 14.083'	71° 22.533'
RISDS-B	41° 13.842'	71° 22.825'
RISDS-C	41° 13.800'	71° 22.500'
RISDS-D	41° 13.517'	71° 22.467'
RISDS-E	41° 13.617'	71° 23.050'
BE-01	41° 13.454'	71° 23.175'
BE-02	41° 13.694'	71° 23.263'
BE-03	41° 13.879'	71° 23.313'
BE-04	41° 14.114'	71° 23.272'
BE-05	41° 14.240'	71° 23.114'
Reference Areas:		
REF-NE	41° 15.168'	71° 19.987'
REF-SW	41° 12.816'	71° 24.950'
REF-E	41° 14.041'	71° 19.475'

Notes: Coordinate System NAD83: Coordinates for A, B, C, D and E as well as reference areas are for center points of 200-meter-radius circles that define the target sampling area.

Table 2-1., (continued)

Center Coordinates of SPI/PUC Disposal Site Station Groups (Figure 2-2), Reference Areas (Figure 2-3) and Coordinates of Each Station Collected During the October 2009 Survey

Station	Replicate	Latitude (N)	Longitude (W)	Station	Replicate	Latitude (N)	Longitude (W)
RISDS Locations				**RISD Locations**			
BE-01	A	41° 13.456'	71° 23.171'	RISDS-C-1	A	41° 13.807'	71° 22.631'
BE-02	A	41° 13.688'	71° 23.270'	RISDS-C-2	A	41° 13.870'	71° 22.566'
BE-03	A	41° 13.872'	71° 23.317'	RISDS-C-3	A	41° 13.850'	71° 22.454'
BE-04	A	41° 14.108'	71° 23.284'	RISDS-C-4	A	41° 13.803'	71° 22.379'
BE-05	A	41° 14.238'	71° 23.108'	RISDS-C-5	A	41° 13.741'	71° 22.559'
RISDS-A-1	A	41° 14.088'	71° 22.471'	RISDS-D-1	A	41° 13.496'	71° 22.564'
RISDS-A-2	A	41° 14.142'	71° 22.585'	RISDS-D-2	A	41° 13.567'	71° 22.565'
RISDS-A-3	A	41° 14.032'	71° 22.559'	RISDS-D-3	A	41° 13.569'	71° 22.442'
RISDS-A-4	A	41° 14.076'	71° 22.634'	RISDS-D-4	A	41° 13.496'	71° 22.408'
RISDS-A-5	A	41° 14.128'	71° 22.637'	RISDS-D-5	A	41° 13.436'	71° 22.422'
RISDS-B-1	A	41° 13.844'	71° 22.901'	RISDS-E-1	A	41° 13.662'	71° 23.154'
RISDS-B-2	A	41° 13.907'	71° 22.895'	RISDS-E-2	A	41° 13.655'	71° 23.005'
RISDS-B-3	A	41° 13.897'	71° 22.795'	RISDS-E-3	A	41° 13.600'	71° 22.981'
RISDS-B-4	A	41° 13.827'	71° 22.752'	RISDS-E-4	A	41° 13.546'	71° 23.108'
RISDS-B-5	A	41° 13.742'	71° 22.849'	RISDS-E-5	A	41° 13.540'	71° 23.014'
				Reference:			
				Ref-NE-1	A	41° 15.155'	71° 20.013'
				Ref-NE-2	A	41° 15.242'	71° 20.058'
				Ref-NE-3	A	41° 15.192'	71° 20.159'
				Ref-NE-4	A	41° 15.086'	71° 20.115'
				Ref-NE-5	A	41° 15.060'	71° 19.984'
				Ref-SW-1	A	41° 12.924'	71° 24.995'
				Ref-SW-2	A	41° 12.798'	71° 24.902'
				Ref-SW-3	A	41° 12.848'	71° 25.099'
				Ref-SW-4	A	41° 12.710'	71° 25.006'
				Ref-SW-5	A	41° 12.737'	71° 24.855'
				Ref-E-1	A	41° 13.996'	71° 19.512'
				Ref-E-2	A	41° 13.960'	71° 19.616'
				Ref-E-3	A	41° 14.084'	71° 19.574'
				Ref-E-4	A	41° 14.060'	71° 19.354'
				Ref-E-5	A	41° 13.957'	71° 19.243'
				Ref-E-6	A	41° 13.984'	71° 19.351'

Notes: Coordinate System NAD83

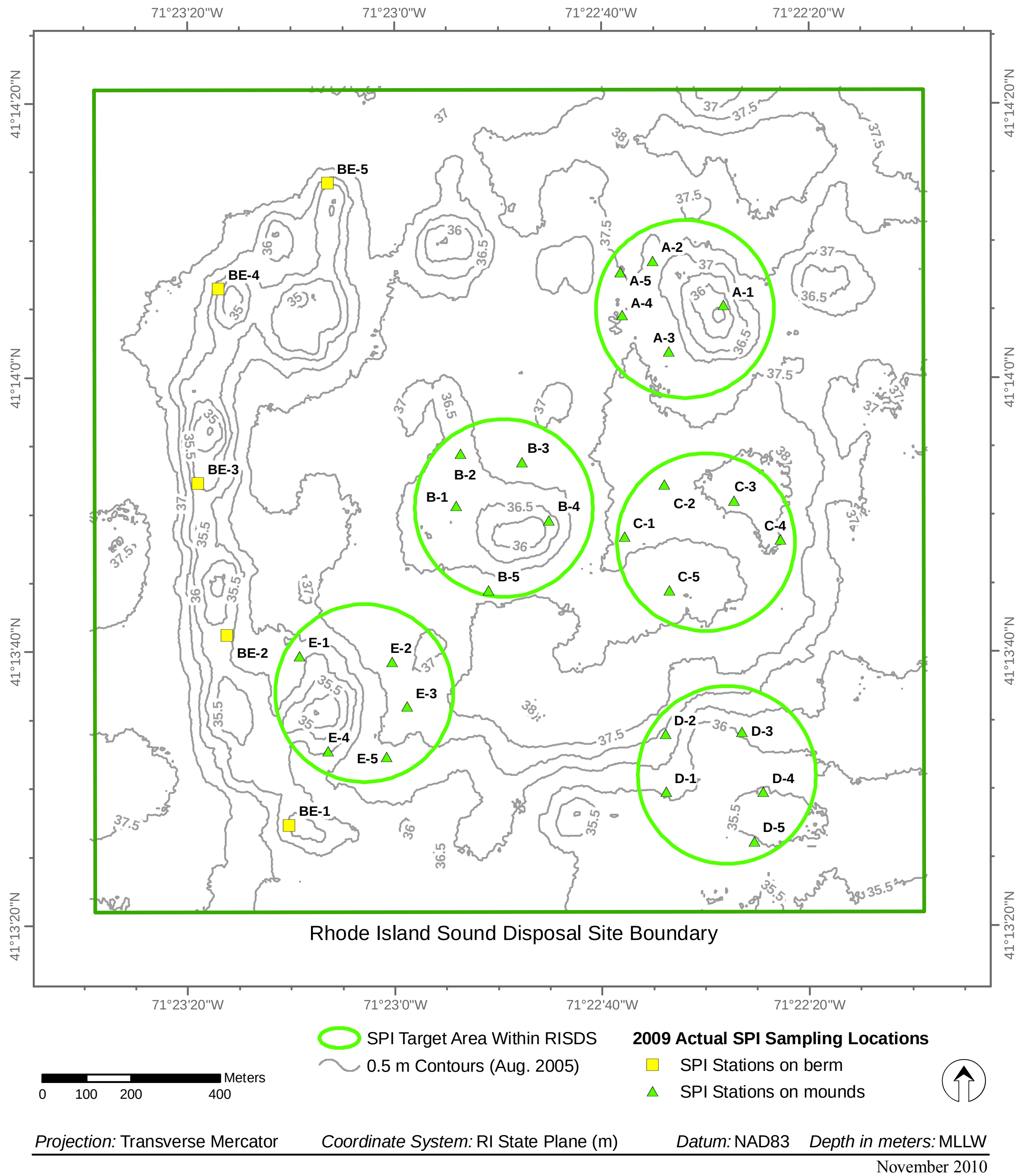


Figure 2-2. Station locations for collection of SPI and PUC images at RISDS in October 2009

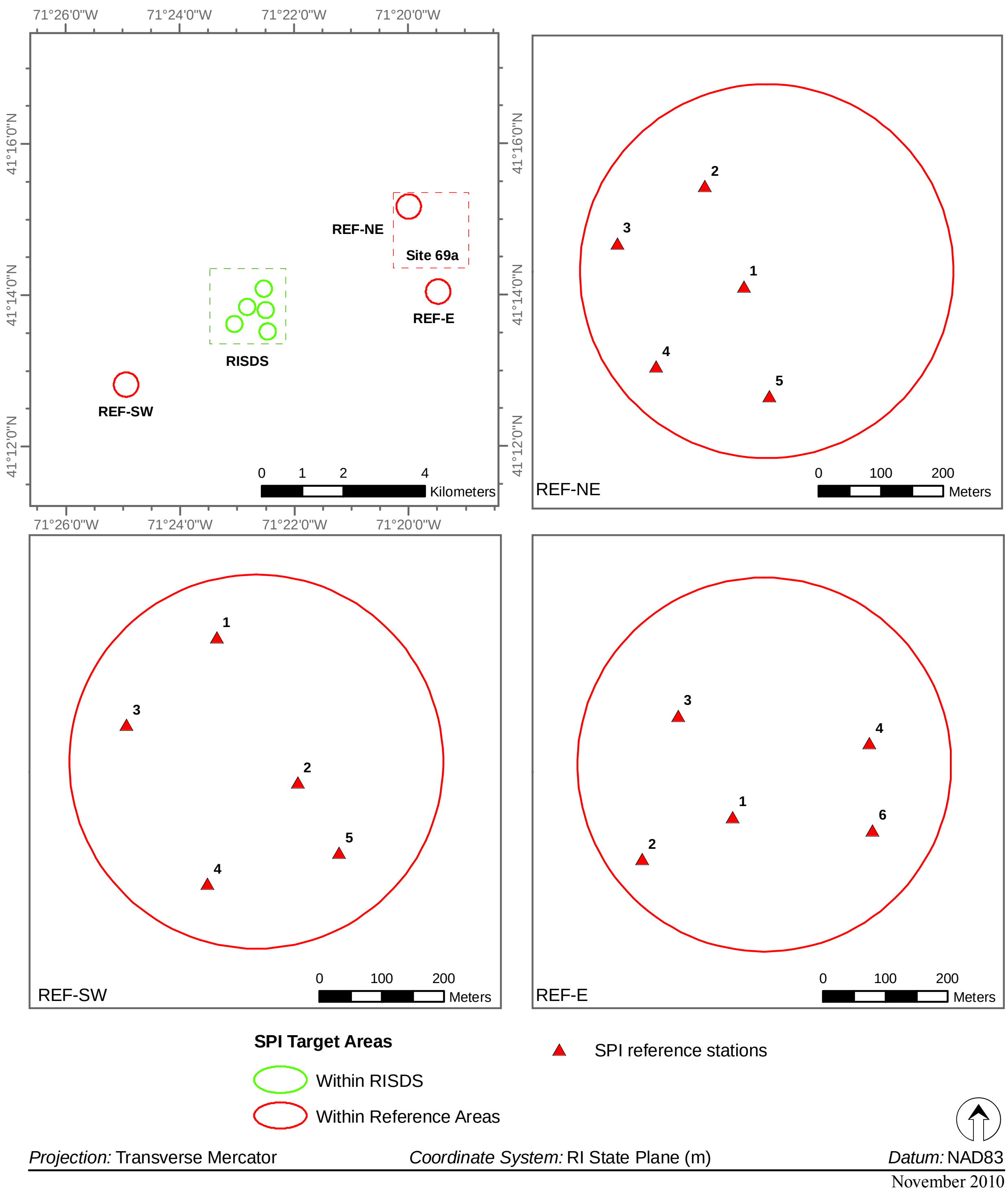


Figure 2-3. Target station locations for collection of SPI and PUC images at the three RISDS reference areas in October 2009

2.2.4 SPI and PUC Data Analysis

2.2.4.1 SPI Data Analysis

Computer-aided analysis of three replicate SPI images from each station was performed to provide measurement of the following standard set of parameters:

Sediment Type—The sediment grain size major mode and range were estimated visually from the images using a grain-size comparator at a similar scale. Results were reported using the phi scale. Conversion to other grain-size scales is provided in Appendix B. The presence and thickness of disposed dredged material were also assessed by inspection of the images.

Penetration Depth—The depth to which the camera penetrated into the seafloor was measured to provide an indication of the sediment density or bearing capacity. The penetration depth can range from a minimum of 0 cm (i.e., no penetration on hard substrata) to a maximum of 20 cm (full penetration on very soft substrata).

Surface Boundary Roughness—Surface boundary roughness is a measure of the vertical relief of features at the sediment-water interface in the sediment-profile image. Surface boundary roughness was determined by measuring the vertical distance between the highest and lowest points of the sediment-water interface. The surface boundary roughness (sediment surface relief) measured over the width of sediment-profile images typically ranges from 0 to 4 cm, and may be related to physical structures (e.g., ripples, rip-up structures, mud clasts) or biogenic features (e.g., burrow openings, fecal mounds, foraging depressions). Biogenic roughness typically changes seasonally and is related to the interaction of bottom turbulence and bioturbation.

Apparent Redox Potential Discontinuity (aRPD) Depth— The aRPD is defined as the boundary or horizon that separates the positive electrochemical potential (Eh) region of the sediment column from the underlying negative Eh region. Accurately measuring the location of the Eh=0 boundary requires the use of microelectrodes. In SPI images, the aRPD depth is determined by assessing color and optical reflectance boundaries within the sediment column and is therefore described as the "apparent" aRPD (aRPD).

The aRPD provides a measure of the integrated history of the balance between near-surface oxygen conditions and biological reworking of sediments. Sediment particles exposed to oxygenated waters oxidize and lighten in color to brown or light grey. As the particles are moved downwards by biological activity or buried, they are exposed to reduced oxygen concentrations in subsurface pore waters and their oxic coating slowly reduces, changing color to dark grey or black. When biological activity is high, the aRPD depth increases; when it is low or absent, the aRPD depth decreases.

Infaunal Successional Stage - Infaunal successional stage is a measure of the biological community inhabiting the seafloor. Current theory holds that organism-sediment interactions in fine-grained sediments follow a predictable sequence of development after a major disturbance (such as dredged material disposal), and this sequence has been divided subjectively into three stages (Rhoads and Germano 1982, 1986). Successional stage was assigned by assessing which types of species or organism-related activities were apparent in the images.

Additional components of the SPI analysis included calculation of means and ranges for the parameters listed above and mapping of mean values of replicates from each station.

2.2.4.2 PUC Image Data Analysis

Computer-aided analysis of each PUC image was performed to provide additional information about large-scale sedimentary features, density and patch size of surface fauna, density of infaunal burrowers, and occurrences and density of epifaunal foraging patterns on the seafloor of the disposal site and reference areas.

2.2.5 Statistical Analysis of the Survey Results

The objective of both the 2005 and 2009 SPI surveys at RISDS was to assess the benthic recolonization status of the sediment at the disposal site relative to reference conditions. Statistical analyses were undertaken to examine the degree of comparability between disposal site station groups A–E (mounds where disposal activity was concentrated) and reference areas for the following SPI variables: 1) aRPD depth, 2) successional stage, and 3) number of subsurface feeding voids counted in each image. These three variables were compared because they are known to be key indicators of infaunal activity within muddy seafloor environments like Rhode Island Sound. The first step in the statistical analysis was to prepare a series of basic boxplots to provide a visual assessment of differences among stations and years. The second step, described in detail below, consisted of testing for significant differences between the reference and disposal mound stations in 2009, as well as for differences between the October 2009 results and those from the previous survey of July 2005.

Traditionally, the objective of this study would be addressed using point null hypotheses of the form “There is no difference in benthic conditions between the reference area and the disposal mound.” However, in this instance, an approach using bioequivalence or interval testing was considered to be more informative than the point null hypothesis test of "no difference" (Germano 1999). One reason is that there is always some small difference, and the statistical significance of this difference may or may not be ecologically meaningful. Without an associated power analysis, the results of traditional point null hypothesis testing often provide an inadequate ecological assessment.

In this application of bioequivalence (interval) testing the null hypothesis is chosen as one that presumes the difference is great, i.e., an inequivalence hypothesis (e.g., McBride 1999). This is recognized as a "proof of safety" approach because rejection of this inequivalence null hypothesis requires sufficient proof that the difference is actually small. The null and alternative hypotheses to be tested were:

H_0: $d \leq -\delta$ or $d \geq \delta$ (presumes the difference is great)

H_A: $-\delta < d < \delta$ (requires proof that the difference is small)

where d is the difference between a reference mean and a site mean. If the null hypothesis is rejected, then it can be concluded that the two means are equivalent to one another within $\pm\delta$ units. The size of δ should be determined from historical data and/or best professional judgment to identify a maximum difference that is within background variability/noise and is therefore not ecologically meaningful. Previously established δ values of 1 for aRPD, and 0.5 for successional stage rank on the 0–3 scale were used.

The test of this interval hypothesis can be broken down into two one-sided tests (TOST) (McBride 1999 after Schuirmann 1987) which are based on the normal distribution, or on Student's *t*-distribution when sample sizes are small and variances must be estimated from the data (the typical case in the majority of environmental monitoring projects). The statistics used to test the interval hypotheses shown here are based on such statistical foundations as the Central Limit Theorem (CLT) and basic statistical properties of random variables. A simplification of the CLT says that the mean of any random variable is normally distributed. Linear combinations of normal random variables are also normal so a linear function of means is also normally distributed. When a linear function of means is divided by its standard error the ratio follows a *t*-distribution with degrees of freedom associated with the variance estimate. Hence, the *t*-distribution can be used to construct a confidence interval around any linear function of means.

In this sampling design, there were eight distinct areas, three of which were categorized as reference locations and five of which were disposal locations. (The five stations on the berm feature representing a variable substratum with a higher prevalence of rocky, harder bottom conditions were excluded from this analysis.)

The three reference areas collectively represented ambient conditions, but if there were mean differences among these three areas then, pooling them into a single reference group would have increased the variance beyond true background variability. The effect of keeping the three reference areas separate had no effect on the grand reference mean (when n was equal among these areas) but it maintained the variance as a true background variance for each individual population with a constant mean.

The difference equation, $\hat{d}$, for the comparison of interest was a linear contrast defined as the mean of the 3 reference means minus the mean of the 5 mound means, or

$$\tfrac{1}{3}\left(\text{Mean}_{ERef} + \text{Mean}_{NERef} + \text{Mean}_{SWRef}\right) - \tfrac{1}{5}\left(\text{Mean}_A + \text{Mean}_B + \text{Mean}_C + \text{Mean}_D + \text{Mean}_E\right) \quad \text{[Eq.1]}$$

and the standard error of each difference was calculated from the fact that the variance of a sum is the sum of the variances for independent variables, or

$$se(\hat{d}) = \sqrt{\sum_j \left(S_j^2 c_j^2 / n_j\right)} \quad \text{[Eq.2]}$$

Where:

$se(\hat{d})$ standard error of the difference

$\hat{d}$ observed difference in means between the reference and the mound

c_j coefficients for the j means in the difference equation, $\hat{d}$ [Eq. 1] (i.e., for equation 1 shown above, the coefficients were 1/3 for each of the 3 reference areas, and -1/5 for each of the 5 disposal mounds [station groups A–E]).

S_j^2 variance for the jth area. If we can assume equal variances, a single pooled residual variance estimate can be substituted for each group, equal to the mean square error from an ANOVA.

n_j number of replicates for the jth area (5 for each of the reference areas; and 5 for each of the disposal mounds).

The inequivalence null hypothesis was rejected (and equivalence was concluded) if the confidence interval on the difference of means, $\hat{d}$, was fully contained within the interval [–δ, +δ].

Thus the decision rule was to reject H_0 if

$$D_L = \hat{d} - t_{\alpha,\upsilon} se(\hat{d}) > -\delta \quad \text{and} \quad D_U = \hat{d} + t_{\alpha,\upsilon} se(\hat{d}) < \delta \qquad \text{[Eq. 3]}$$

where:

$t_{\alpha,\upsilon}$ upper 100α percentile of a Student's *t*-distribution with υ degrees of freedom

υ degrees of freedom for the standard error. If a pooled residual variance estimate was used, it was the residual degrees of freedom from an ANOVA on all groups (total number of samples minus the number of groups); if separate variance estimates were used, degrees of freedom were calculated based on the Brown and Forsythe estimation (Zar 1996, p. 189).

Validity of the normality and equal variance assumptions was tested using Shapiro-Wilk's test for normality on the area residuals ($\alpha=0.05$) and Levene's test for equality of variances among the four areas ($\alpha = 0.05$). If normality was not rejected but equality of variances was, then the variance for the difference equation was based on separate variances for each group. If systematic deviations from normality were identified, then the data were transformed to approximate normality, if possible. Otherwise, a nonparametric bootstrapped interval was used.

3.0 RESULTS

Detailed image analysis results are provided in Appendices B (SPI) and C (PUC). The following sections summarize the results for the reference area and disposal site stations, and the statistical analyses comparing reference area and disposal mound stations.

3.1 Rhode Island Sound Reference Areas

3.1.1 Sediment-Profile Imaging Results

3.1.1.1 Physical Sediment Characteristics

Previous investigations of the ambient sediments in and around Rhode Island Sound were performed as part of the site designation investigations (Battelle 2002, 2003; EPA/USACE 2004). Results of these investigations showed the seafloor to be primarily silty sand with patches of gravel. The grain size major mode at all three reference areas surveyed in 2009 was similar to that found in previous investigations: very fine to fine sands with varying degrees of silt (Table 3-1, Figure 3-1). As in the previous survey of July 2005, the sediments with the highest silt component were located in the REF-E area, those with the lowest silt and highest sand fraction were located in the REF-NE area, and those from the REF-SW area were intermediate in silt content (Figure 3-2). There was no evidence of dredged material at any of the stations sampled in the reference areas, as well as no evidence of low dissolved oxygen or sedimentary methane (Appendix C).

Mean prism penetration among stations at the three reference areas ranged from 6.6 to 18.6 cm (Table 3-1). The number of weights and camera penetration settings were adjusted by only a small amount during sampling at the reference areas, so the variation in prism penetration among the stations was a reasonably accurate indication of the relative bearing strength of the sediment and directly proportional to the gradient in silt content among the three areas. As in the previous SPI survey of July 2005, the deepest prism penetration again occurred in the REF-E area (mean penetration value = 15.5 cm), while the lowest penetration occurred in the REF-NE area (mean penetration value = 10.4 cm). An intermediate mean prism penetration value of 11.0 cm was calculated for the five stations within the REF-SW area (Table 3-1). Mean small-scale boundary roughness ranged from 0.8 to 2.0 cm at the reference stations (Table 3-1), and this roughness was attributed to both physical (e.g., current-induced ripples) and biological (e.g., biogenic feeding pits or mounds) seafloor processes (Figure 3-3).

Table 3-1.

Summary of SPI Results for RISDS Reference Stations, October 2009

Station	Grain Size Major Mode (phi)	Mean Prism Penetration Depth (cm)	Mean Boundary Roughness (cm)	Mean aRPD Depth (cm)	Mean # of Subsurface Feeding Voids	Successional Stages Present (no. of replicates)
REF-E 1	>4	18.6	1.4	3.2	2	2 on 3 (1), 1 on 3 (2)
REF-E 2	>4	15.6	1.1	2.7	2	1 on 3 (3)
REF-E 3	>4	15.2	1.2	2.3	2	1 on 3 (3)
REF-E 4	>4	15.1	1.0	2.9	1	1 on 3 (3)
REF-E 6	>4 to 3	13.1	1.4	5.2	1	1 on 3 (1), 3 (2)
REF-NE 1	3 to 2	12.5	0.9	5.5	2	1 on 3 (3)
REF-NE 2	4 to 3	9.7	1.1	6.5	3	1 on 3 (3)
REF-NE 3	4 to 3	10.6	1.4	5.9	2	1 on 3 (3)
REF-NE 4	4 to 3	9.0	1.7	8.3	3	1 on 3 (3)
REF-NE 5	3 to 2	10.3	1.4	9.3	4	1 on 3 (3)
REF-SW 1	>4 to 3	11.2	2.0	6.2	6	1 on 3 (3)
REF-SW 2	>4 to 3	13.3	1.1	7.0	4	2 on 3 (1), 1 on 3 (2)
REF-SW 3	>4 to 3	11.0	1.8	4.8	5	2 on 3 (2), 1 on 3 (1)
REF-SW 4	>4 to 3	12.9	1.9	5.6	4	2 on 3 (3)
REF-SW 5	4 to 3	6.6	0.8	5.5	0	2->3 (1), 2 on 3 (2)
Mean	NA	12.3	1.3	5.4	3	NA
Minimum	NA	6.6	0.8	2.3	0	NA
Maximum	NA	18.6	2.0	9.3	6	NA

NA = Not Applicable

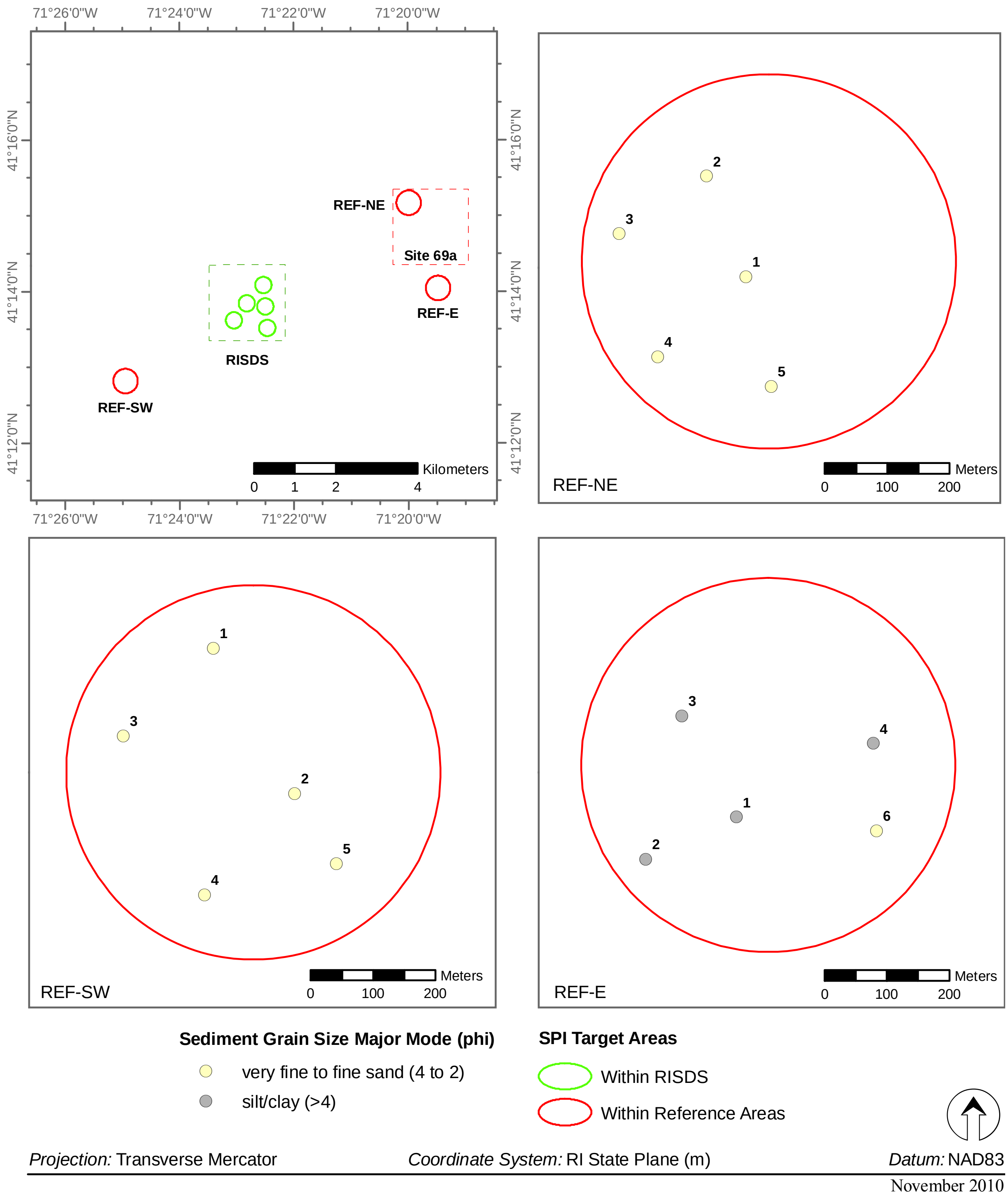


Figure 3-1. Sediment grain size major mode at the RISDS reference stations, October 2009

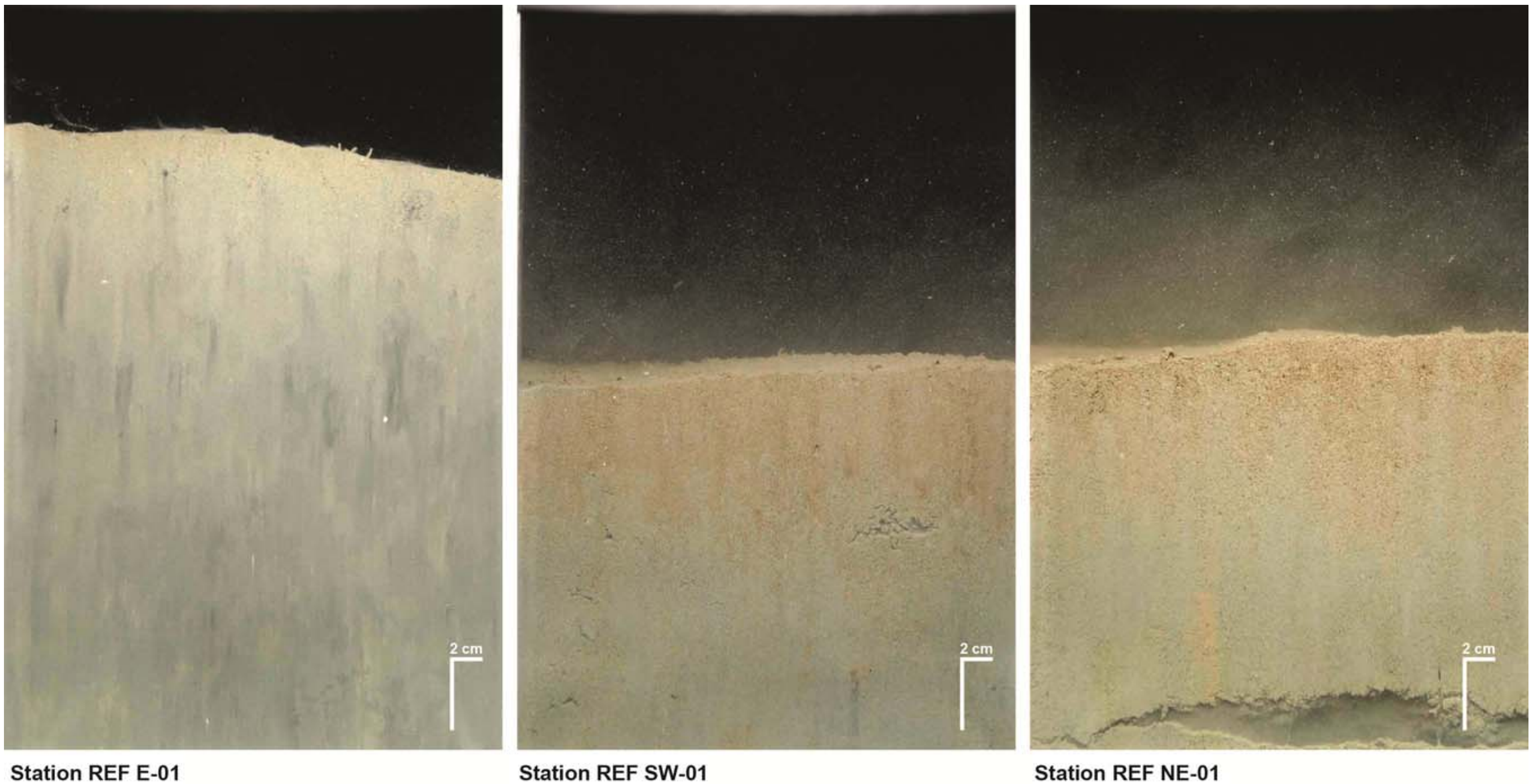


Figure 3-2. SPI images illustrating the varying percentage of silt in the surface sediments at each of the three reference areas. Arranged from left to right in order of highest to lowest silt content: Station REF-E-01, Station REF-SW-01, and Station REF-NE-01.

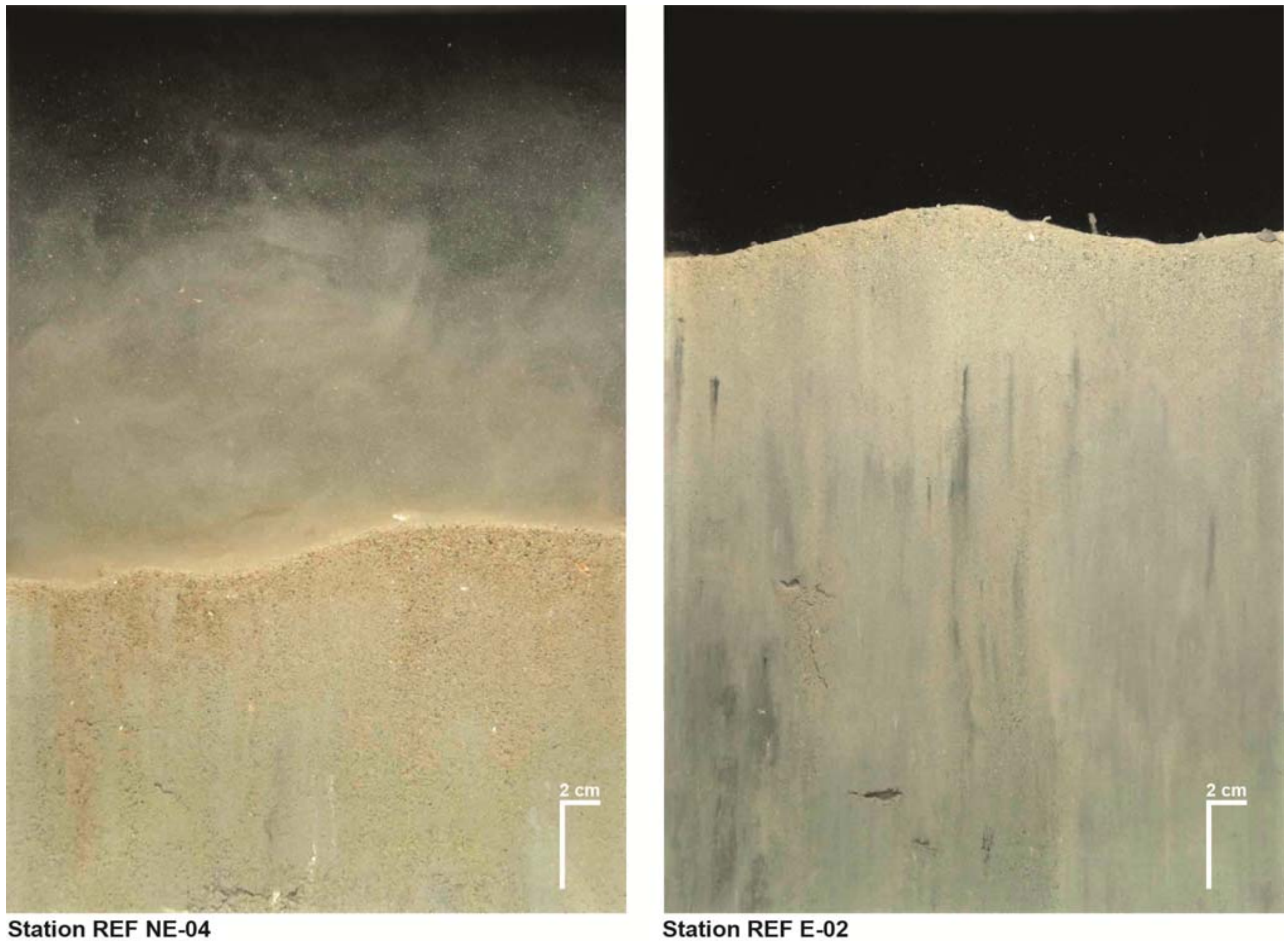


Figure 3-3. SPI images illustrating two different types of small-scale surface roughness. In the left image, a sand ripple has been transected (roughness is due to physical processes), while the small mound in the right image is due to the feeding activities of infauna (biological processes).

3.1.1.2 Biological Conditions

The mean aRPD depth among stations at the reference areas ranged from 2.3 to 9.3 cm, with an overall reference area mean of 5.4 cm (Table 3-1). The highest aRPD values were observed at the REF-NE and REF-SW areas (Figure 3-4). Overall, the aRPD depths at all three of the reference areas were relatively deep and consistent with values measured outside the disposal site in past surveys (Battelle 2003).

All fifteen of the replicate images from the reference areas showed evidence of Stage 3 taxa (Table 3-1; Figure 3-5). In addition to the presence of large subsurface burrows, feeding voids, and/or large-bodied infauna (Figure 3-6), there were also dense assemblages of tubicolous surface fauna, including both polychaetes and amphipods (Figure 3-7). The mean number of subsurface feeding voids at the reference area stations ranged from 0 to 6, with an overall mean of 3 voids per image per station (Table 3-1). There was no indication of any severe disturbance to the reference area benthic communities from trawling or other anthropogenic impacts.

3.1.2 Plan-view Image Results

The widespread presence of Stage 3 infauna detected in the sediment-profile images was further supported in the corresponding plan-view images from the reference areas. All of the plan-view images from the reference areas showed burrow openings at the sediment surface (Appendix D; Figure 3-8). Other evidence of infaunal activity, visible in many of the images, included tubes, pits, and fecal mounds (Figure 3-9). There also was abundant evidence of epifauna in the form of tracks, pits, and the organisms themselves, particularly sea stars (Figure 3-10).

3.2 Rhode Island Sound Disposal Site

3.2.1 Sediment-Profile Images

3.2.1.1 Physical Sediment Characteristics

Surface sediments at all of the stations sampled within RISDS consisted of dredged material, the bulk of which was placed at the site from April 2003 to January 2005 (see Figure 1-3). At the majority of stations, this dredged material was composed of soft mud having a grain size major mode of >4 phi (Table 3-2; Figure 3-11). Visually, the dredged material at many stations consisted of deposited layers of primarily reduced silt/clay, with lighter colored clay inclusions mixed within the sediment (Figure 3-12). The layer of dredged material was thicker than the camera prism penetration depth at all

Table 3-2.

Summary of SPI Results for RISDS Stations, October 2009

Station	Grain Size Major Mode (phi)	Mean Prism Penetration Depth (cm)	Mean Boundary Roughness (cm)	Mean aRPD Depth (cm)	Mean Dredged Material Thickness (cm)	Mean # of Subsurface Feeding Voids	Successional Stages Present (no. of replicates)
A-1	>4	14.8	1.6	0.7	>14.8	1	1 on 3 (3)
A-2	>4	14.0	1.4	1.3	>14.0	1	1 on 3 (3)
A-3	>4	17.9	1.1	1.9	>17.9	1	1 on 3 (3)
A-4	>4	15.2	1.2	1.8	>15.2	1	1 on 3 (3)
A-5	>4	14.6	0.8	1.6	>14.6	2	1 on 3 (3)
B-1	>4	14.2	0.9	1.3	>14.2	0	2 -> 3 (3)
B-2	>4	11.3	0.8	1.1	>11.3	1	1 -> 2 (1), 1 (1), 1 on 3 (1)
B-3	>4	13.7	0.8	1.4	>13.7	2	1 on 3 (3)
B-4	>4	11.4	1.4	0.6	>11.4	1	2 -> 3 (1), 1 (1), 1 on 3 (1)
B-5	>4	16.5	0.6	1.8	>16.5	2	1 on 3 (3)
BE 01	<-1	1.0	1.3	IND	>1.0	IND	IND
BE 02	>4	10.4	1.6	1.3	>10.4	1	1 on 3 (2), 2 (1)
BE 03	<-1	1.0	1.9	IND	>1.0	IND	IND
BE 04	>4	6.3	1.2	0.9	>6.3	1	2 -> 3 (1), 2 (1)
BE 05	<-1	3.7	3.4	3.0	>3.7	IND	IND
C-1	3 to 2	10.3	0.8	2.9	>10.3	0	2 -> 3 (2), 1 on 3 (1)
C-2	3 to 2/>4	15.0	0.8	1.8	>15.0	2	1 on 3 (3)
C-3	3 to 2/>4	9.9	1.5	1.8	>9.9	1	2 -> 3 (1), 1 on 3 (2)
C-4	>4	14.3	1.2	1.6	>14.3	0	1 on 3 (3)
C-5	3 to 2	6.8	3.1	5.4	>6.8	1	1 on 3 (1), 3 (2)

Continued

Table 3-2., continued

Summary of SPI Results for RISDS Stations, October 2009

Station	Grain Size Major Mode (phi)	Mean Prism Penetration Depth (cm)	Mean Boundary Roughness (cm)	Mean aRPD Depth (cm)	Mean Dredged Material Thickness (cm)	Mean # of Subsurface Feeding Voids	Successional Stages Present (no. of replicates)
D-1	>4	11.8	1.0	1.5	>11.8	1	1 on 3 (3)
D-2	>4	13.8	0.7	1.1	>13.8	1	1 ->2 (1), 1 on 3 (2)
D-3	>4	15.0	1.1	0.9	>15.0	0	1 ->2 (1), 1 on 3 (2)
D-4	>4	14.7	1.1	0.8	>14.7	0	2->3 (1), 1 on 3 (2)
D-5	>4	16.2	0.7	1.1	>16.2	1	1 (2), 1 on 3 (1)
E-1	>4	12.6	0.7	1.2	>12.6	1	1 on 3 (2), 1 (1)
E-2	>4	15.2	0.6	2.3	>15.2	1	1 on 3 (3)
E-3	>4	13.3	0.6	0.7	>13.3	1	2->3 (1), 1 on 3 (2)
E-4	>4	14.0	1.4	0.9	>14.0	1	2->3 (1), 1 on 3 (2)
E-5	>4	16.6	1.2	1.2	>16.6	0	2 (1), 1 on 3 (2)
Mean	NA	12.2	1.2	1.6	>14.3	1	NA
Minimum	NA	1.0	0.6	0.6	>11.8	0	NA
Maximum	NA	17.9	3.4	5.4	>16.6	2	NA

NA = Not Applicable
IND = indeterminate

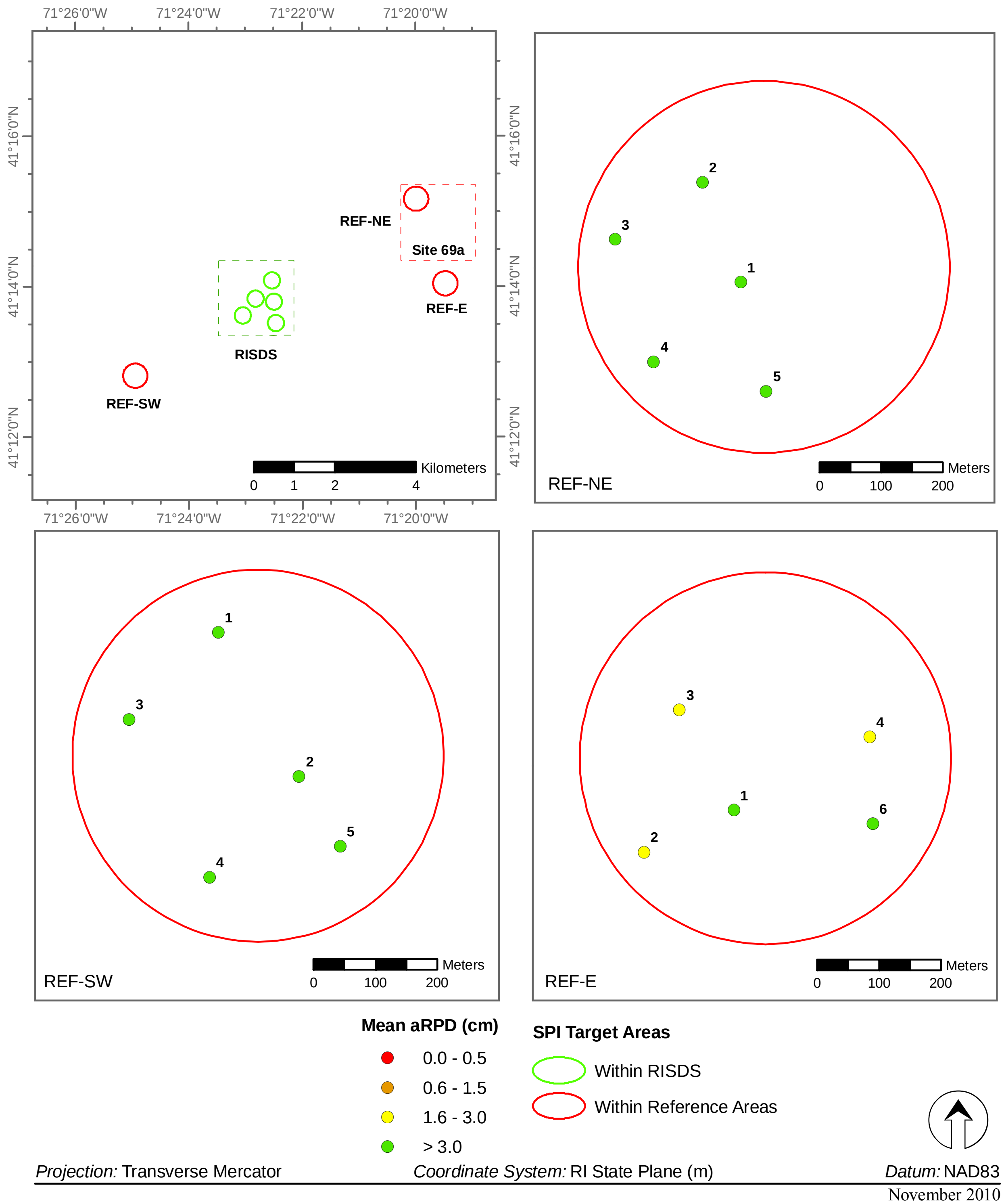


Figure 3-4. The distribution of means of replicate aRPD depths (cm) from the RISDS reference area stations, October 2009

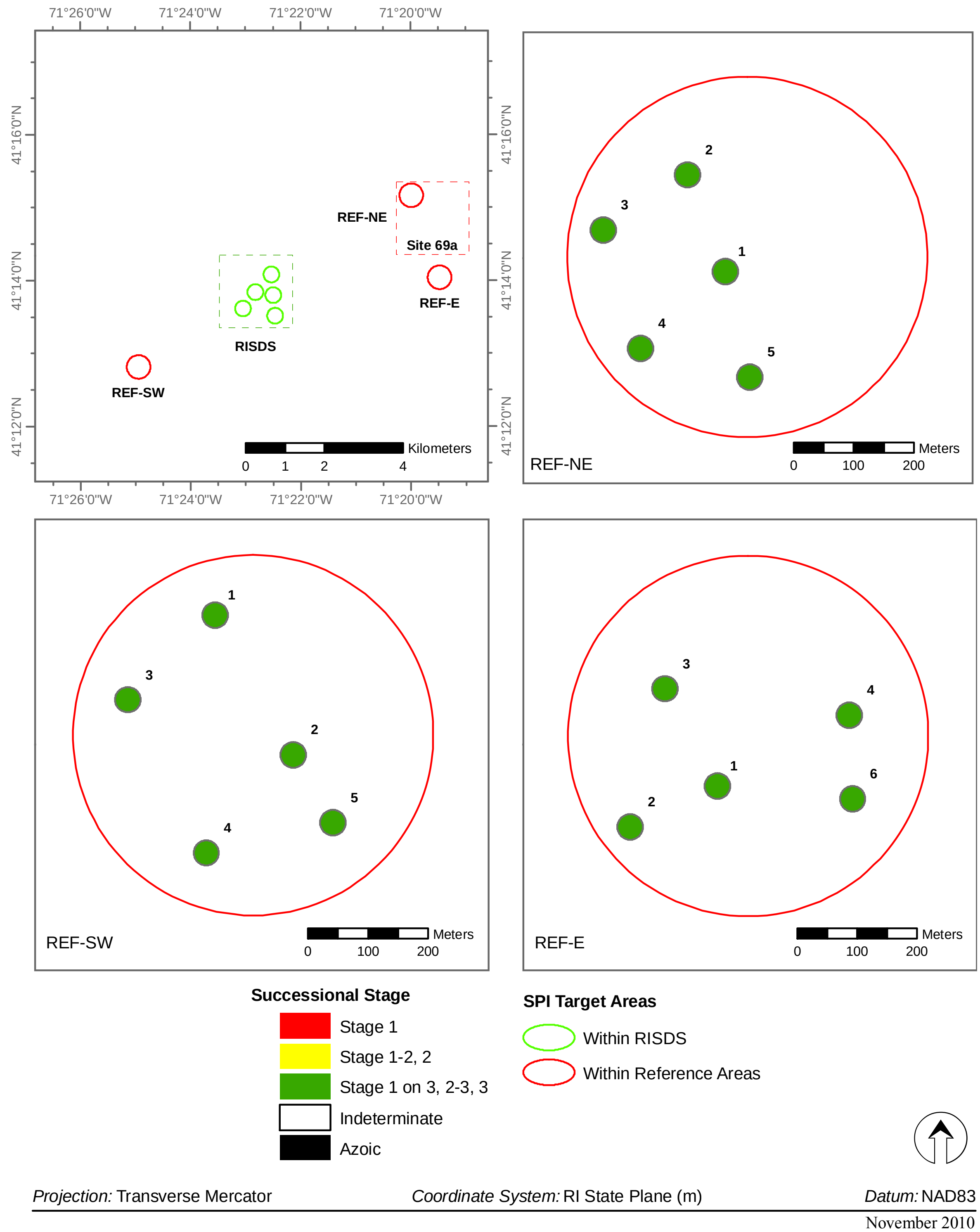


Figure 3-5. The distribution of infaunal successional stages at the RISDS reference areas, October 2009

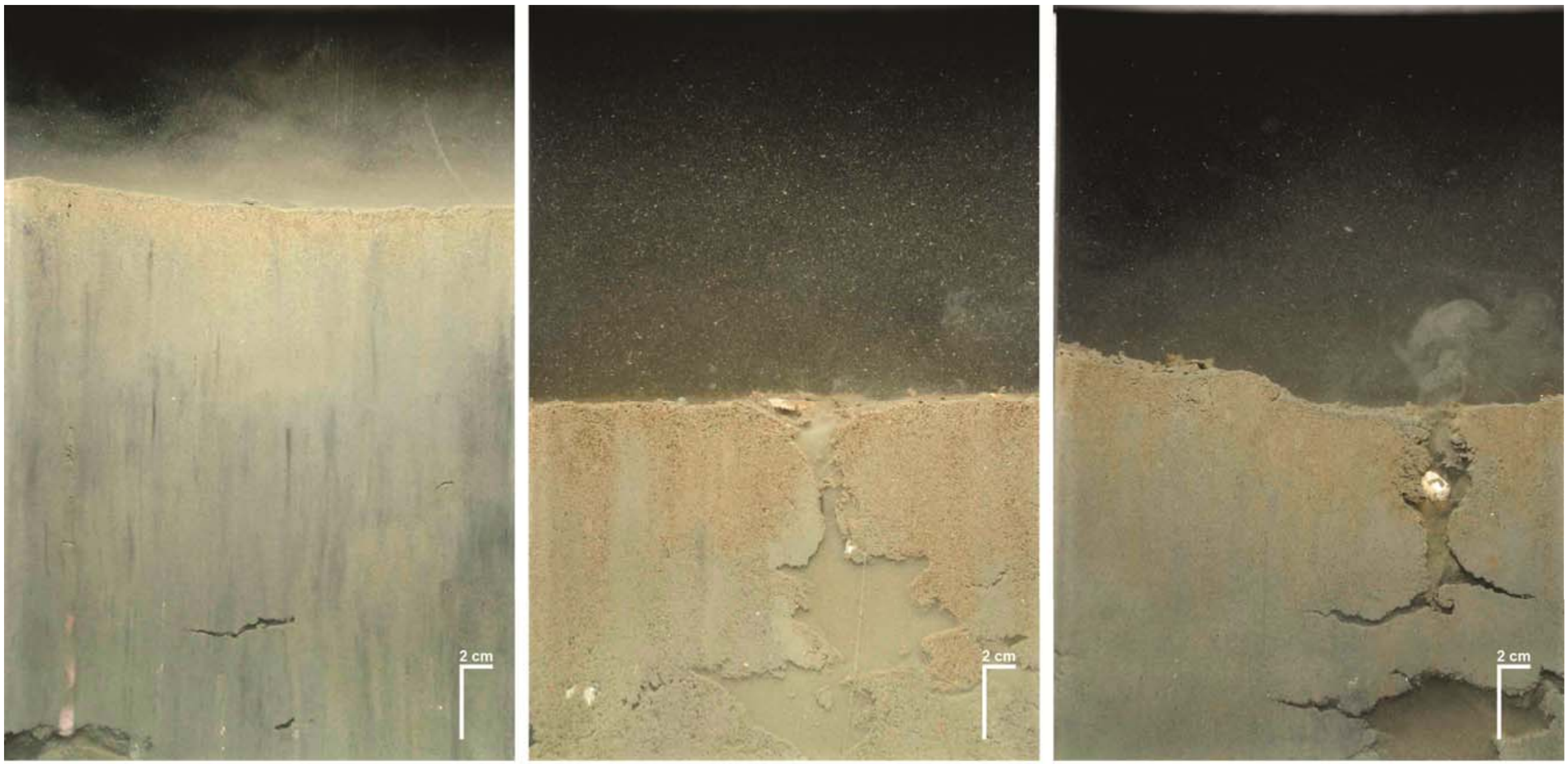


Figure 3-6. Reference area SPI images showing evidence of Stage 3 infauna: subsurface feeding voids and a large-bodied organism (left); a large subsurface burrow with an opening at the sediment surface (center and right)

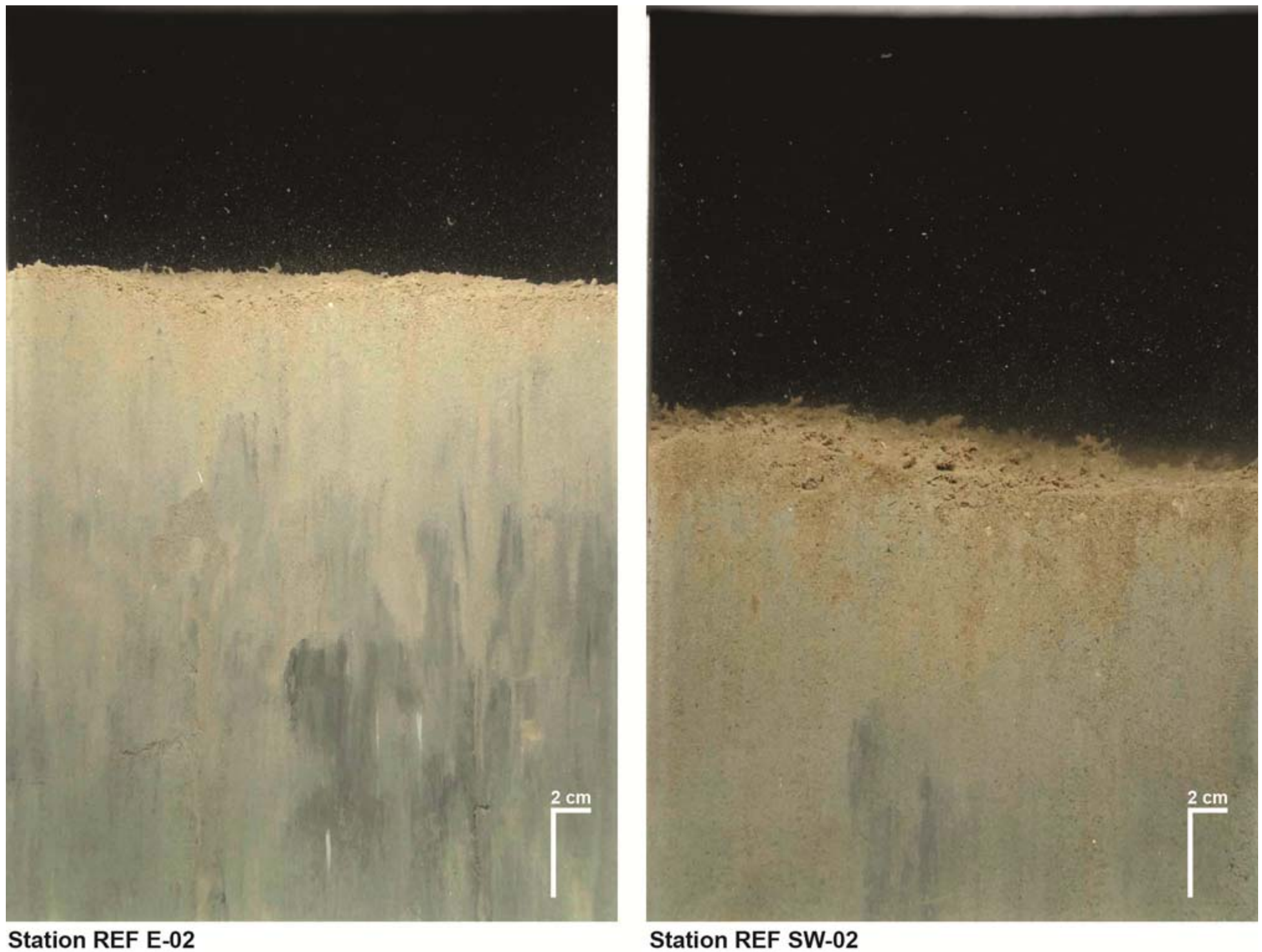
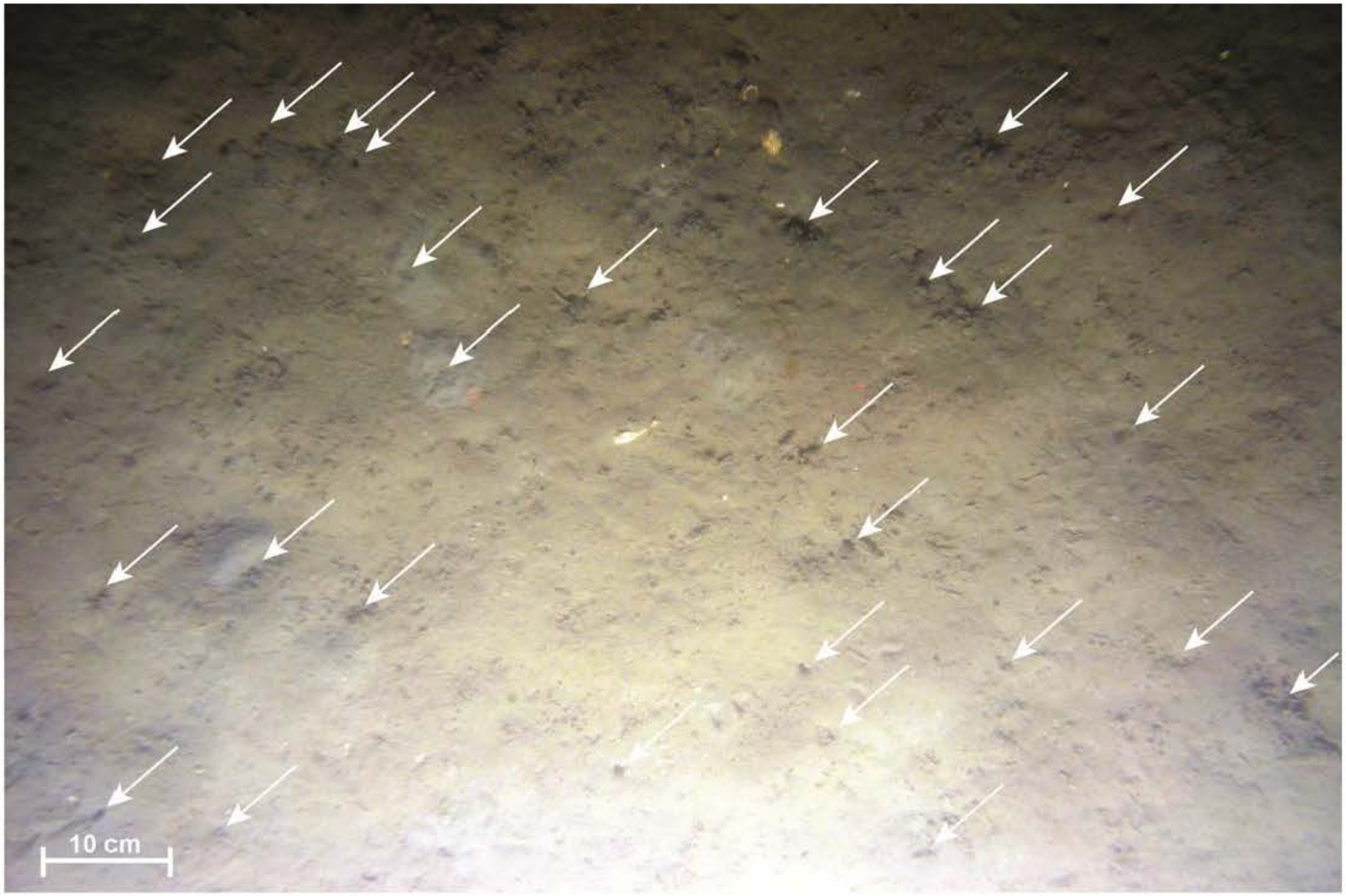
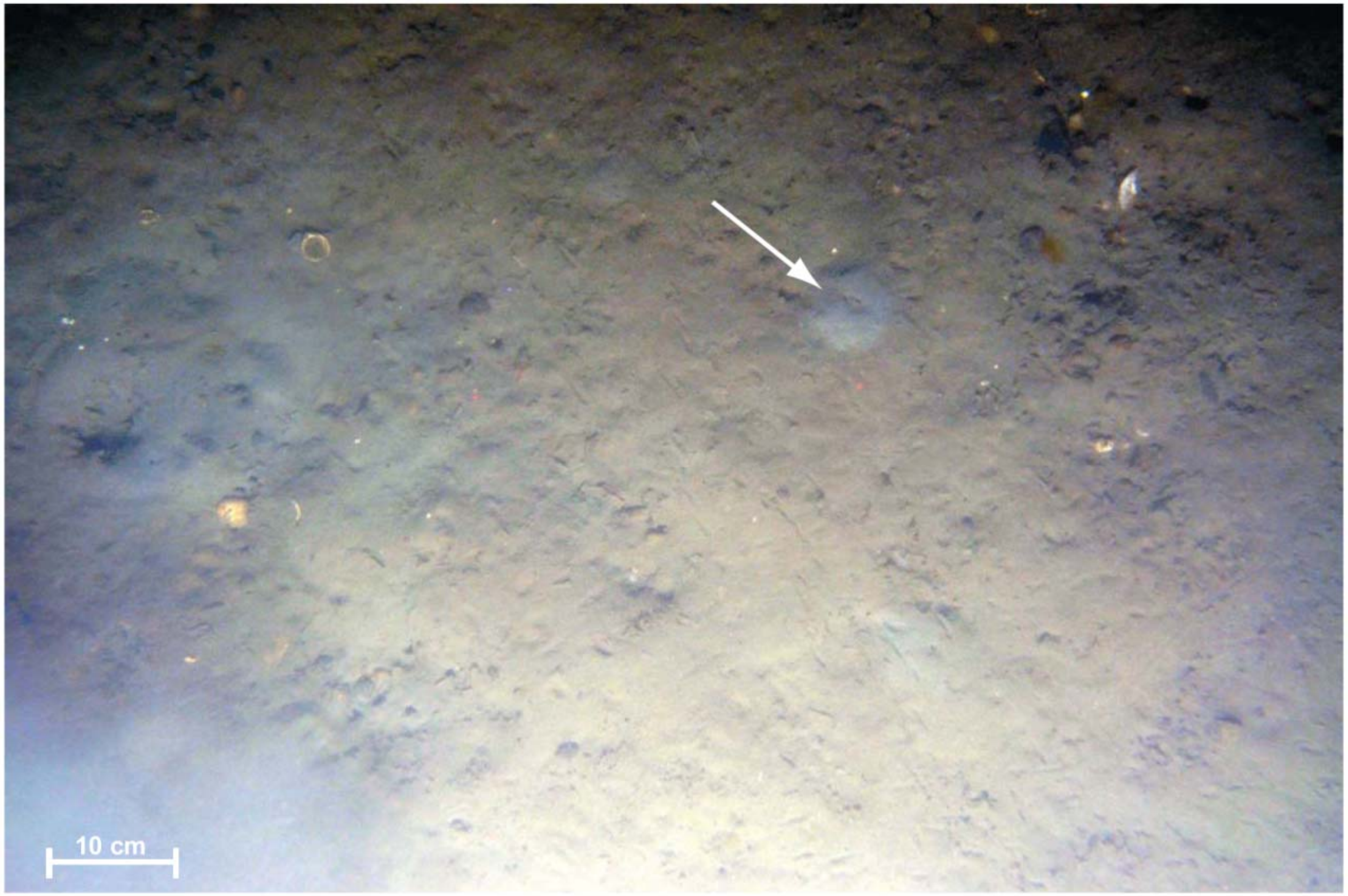


Figure 3-7. Reference area SPI images showing dense assemblages of tubicolous polychaetes (left image) and amphipods (right image) at the sediment surface



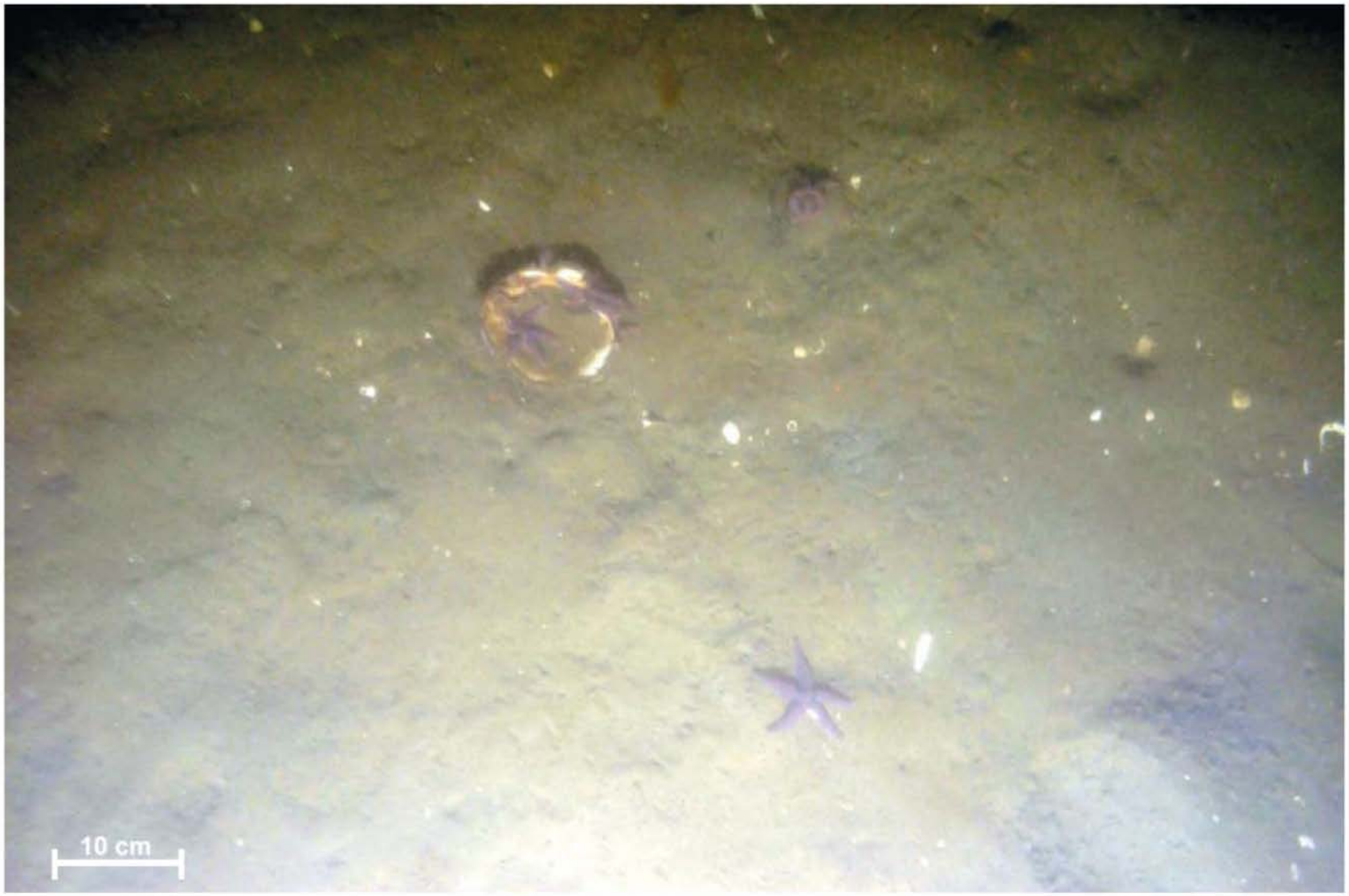
Station REF NE-02

Figure 3-8. Plan-view image showing numerous small holes (burrow openings) at the sediment surface



Station REF NE-04

Figure 3-9. Plan-view image showing a fecal mound (arrow)



Station REF SW-05

Figure 3-10. Several sea stars are visible in this plan-view image.

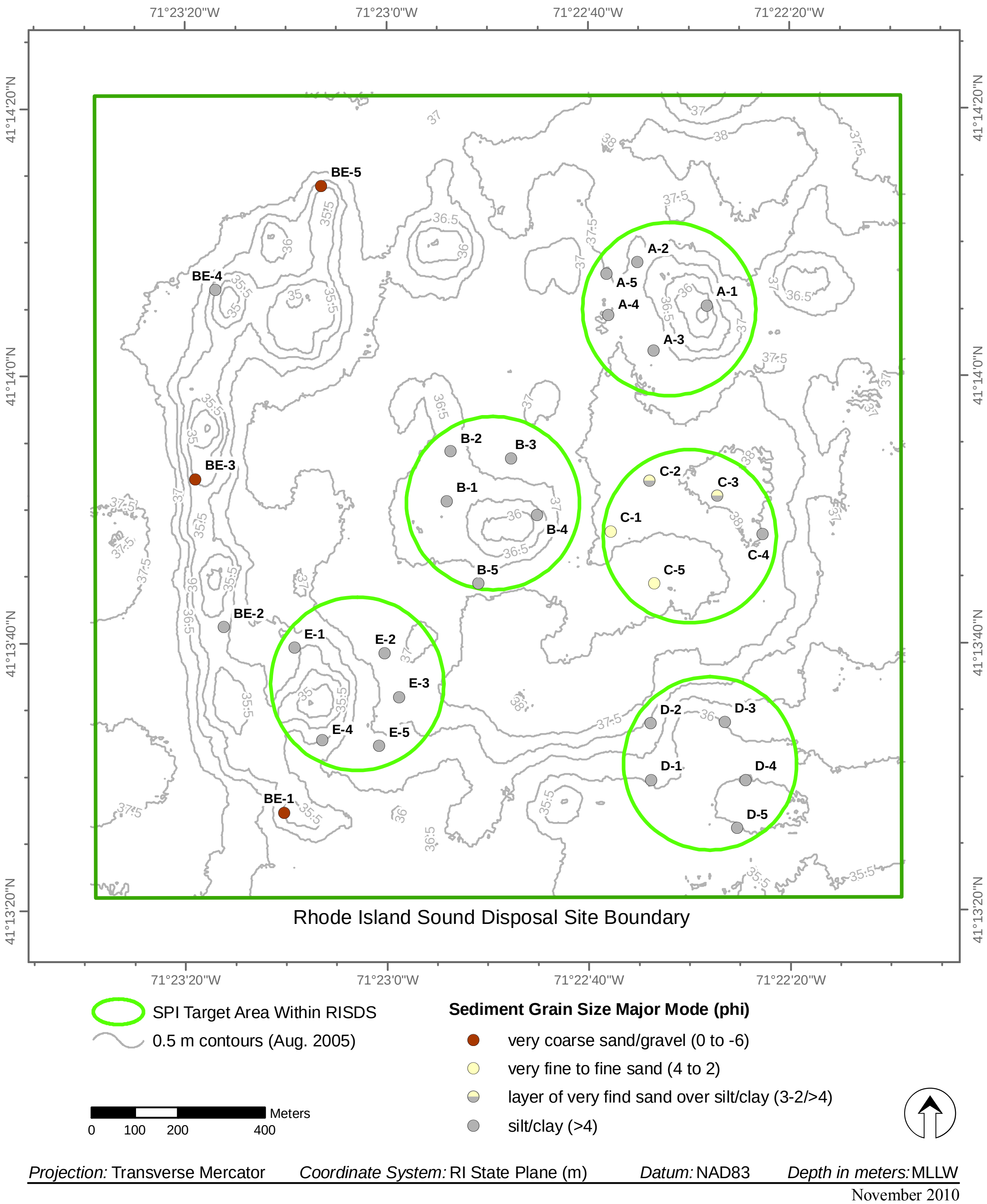


Figure 3-11. Sediment grain size major mode at the stations sampled within RISDS, October 2009

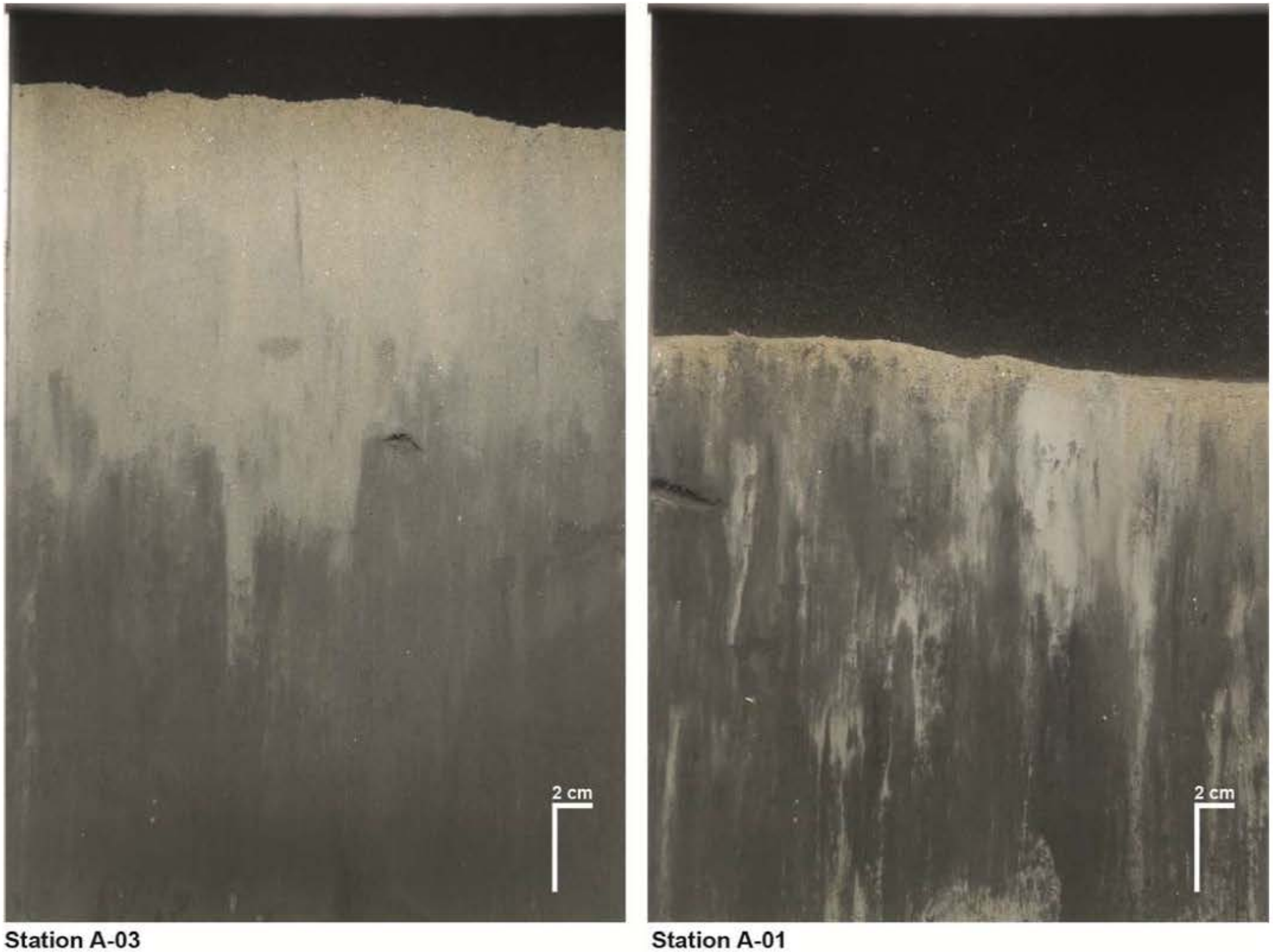


Figure 3-12. SPI images showing the soft muddy dredged material observed at many of the RISDS stations

stations sampled within the disposal site (Table 3-2). Even though this material was very reduced (black in color below the surface oxidized layer), there was no evidence of low dissolved oxygen in the overlying water or subsurface methane generation at any of the locations sampled (Appendix C).

In the previous survey of July 2005, the newly deposited dredged material had high water content and low bearing strength. As a result, the SPI camera had to be outfitted with mud doors for sampling this extremely soft mud at many of the stations within the disposal site. In the October 2009 survey, mud doors were not required, indicating that significant dewatering and consolidation of the material had occurred in the intervening four years.

At four of the five stations within sampling area C, the dredged material consisted of silty fine sand. In a few images, the sand was visible as a discrete surface deposit overlying reduced, muddy dredged material at depth (Figures 3-11 and 3-13). In July 2005, the dredged material in this area was found to consist of soft reduced mud. The new surface depositional layers of sand most likely are due to the approximately 23,000 cubic meters of dredged material disposed in and around area C (see Figure 1-5) since the 2005 survey.

Small rocks and cobble were observed in at least one of the three replicate images at each of the five "BE" stations located atop the western berm feature. At stations BE-02 and BE-04, there was small-scale spatial variability in the distribution of the small rocks and cobble: two of the three replicate images at each of these stations had a grain size major mode of >4 phi while the third replicate showed small rocks and cobble (Figure 3-14). Stations BE-02 and BE-04 were therefore mapped as having a grain size major mode of >4 in Figure 3-11. At the other three BE stations, rocks were observed more consistently in the replicate images; these stations are shown as having cobble bottom in Figure 3-11. Rocky material similarly was observed at the top of the berm in the July 2005 survey.

Mean camera prism penetration depth varied across the site, ranging from 1.0 cm at berm stations BE-01 and BE-03 to 17.9 cm at station A-3 (Table 3-2). Low penetration at several of the BE stations was due to the presence of small rocks, while intermediate penetration values at the stations in area C were due to the presence of fine sand. At all of the other disposal area stations, penetration was relatively deep due to the widespread presence of soft muddy dredged material (Table 3-2).

Mean small-scale boundary roughness ranged from 0.6 to 3.4 cm, with an overall site mean of 1.2 cm (Table 3-2). As in the previous survey of July 2005, the origin of this small-scale topography was split approximately equally between physical and

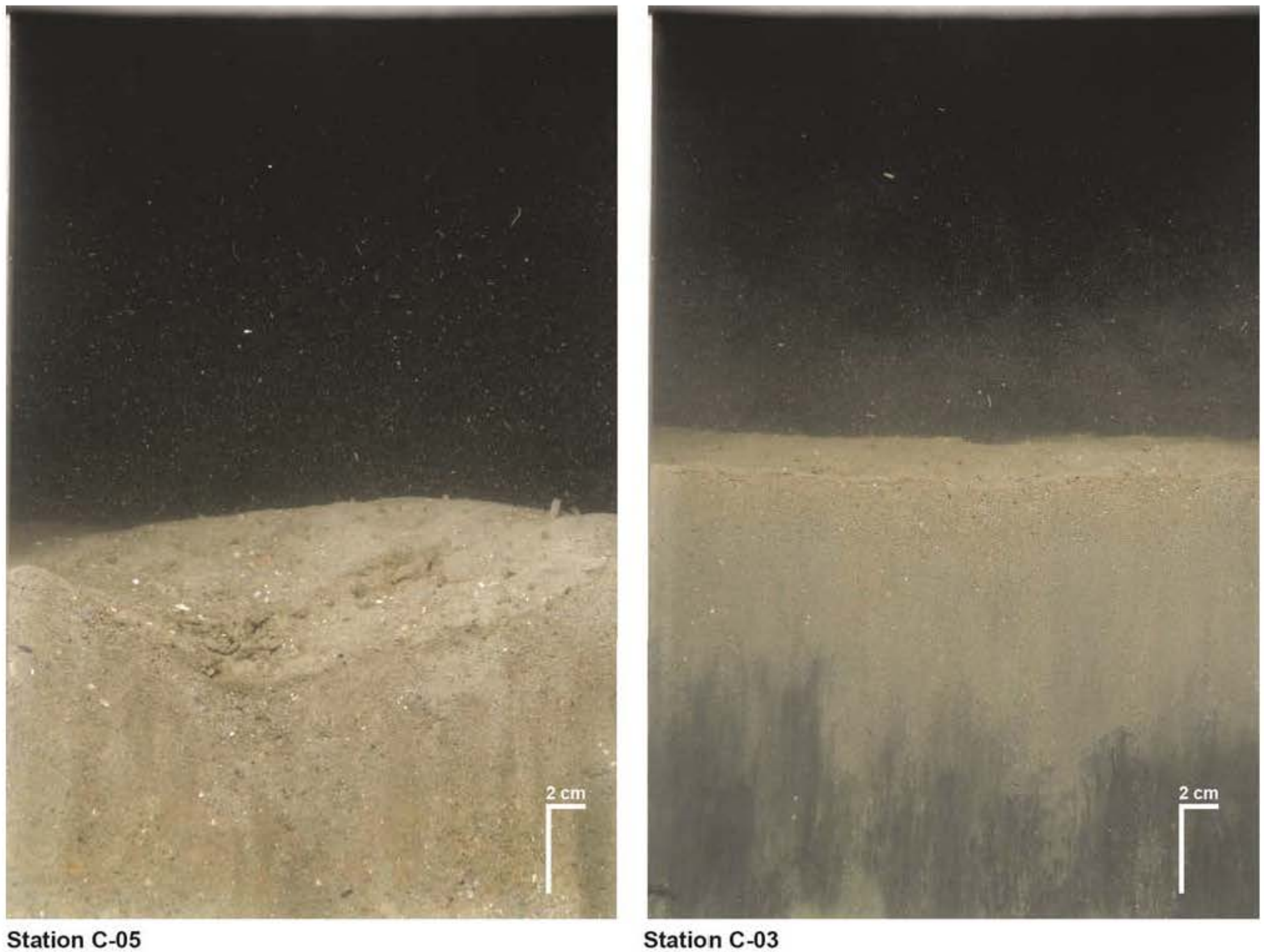


Figure 3-13. SPI images showing silty fine sand (left) and sand-over-mud stratigraphy (right)

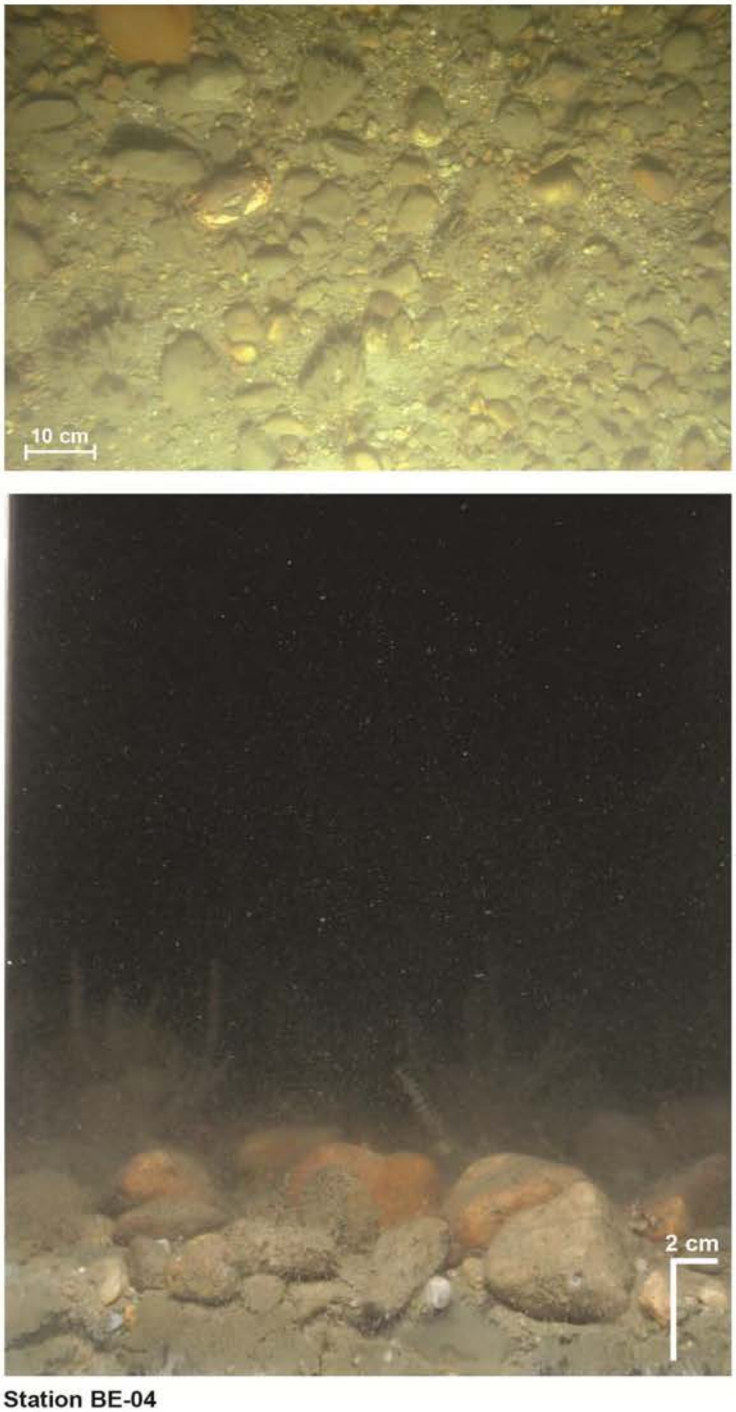


Figure 3-14. SPI and corresponding plan-view image showing mixed gravel (pebbles and small cobbles) at station BE-04. A crab foraging among the hydroid-covered rocks is also visible in the plan-view image.

biological processes among the station replicates (Appendix C). Physical roughness elements were caused by small-scale bedforms/ripples due to bottom currents, while biological roughness elements were due to feeding pits, burrow openings, or fecal mounds from infaunal bioturbation (Figure 3-15).

3.2.1.2 Biological Conditions and Benthic Recolonization

The mean aRPD values at the stations within RISDS ranged from 0.6 to 5.4 cm, with an overall site mean of 1.6 cm (Table 3-2, Figure 3-16). The mean aRPD value at 80% of the stations was between 0.6 and 2 cm; only four stations (Stations C-1, C-5, E-2 and BE-05) had mean aRPD values exceeding 2 cm. These results are similar to those of the July 2005 survey, when relatively shallow mean aRPD depths likewise were measured at 80% of the disposal site stations.

With the exception of Stations BE-01, BE-03, and BE-05, where shallow prism penetration prevented an accurate assessment of infaunal successional status, at least one replicate image at all the stations sampled showed evidence of Stage 3 infauna present (Table 3-2, Figure 3-17). At a majority of stations (60%), all three of the replicate images showed evidence of Stage 3 organisms. This evidence typically consisted of subsurface feeding voids, burrows, and large-bodied infaunal organisms (Figure 3-18). At many stations, small tubes constructed by opportunistic Stage 1 organisms were also visible at the sediment surface, resulting in a Stage 1 on 3 successional designation (Figure 3-19). The mean number of subsurface feeding voids observed in the SPI images at each station ranged from 0 to 2, with an overall mean of 1 void/image for the disposal area stations as a whole (Table 3-2).

3.2.2 Plan-View Images

The plan-view images confirmed that the sediment surface over much of the disposal site consisted of soft mud, with the exception of several of the berm stations, where small rocks (pebbles and small cobbles) were observed (e.g., Figure 3-14). Unlike the July 2005 survey, when small ripples were visible at some stations, there was an overall absence of such current-induced bedforms in the October 2009 survey (Appendix D).

At many of the disposal site stations, the plan-view images showed evidence of biological activity in the form of burrow openings and feeding pits (Figure 3-20), extensive crab and/or shrimp tracks (Figure 3-21), and the crabs themselves (Figure 3-22). Burrow openings and pits were observed in 75% of the replicate plan-view images at the disposal site, while crab tracks were observed in 82%. Epifaunal organisms,

Station D-04

Figure 3-15. An example of biogenic surface roughness at the disposal site. The mound at the sediment surface consists of sediment excavated from the underlying burrow.

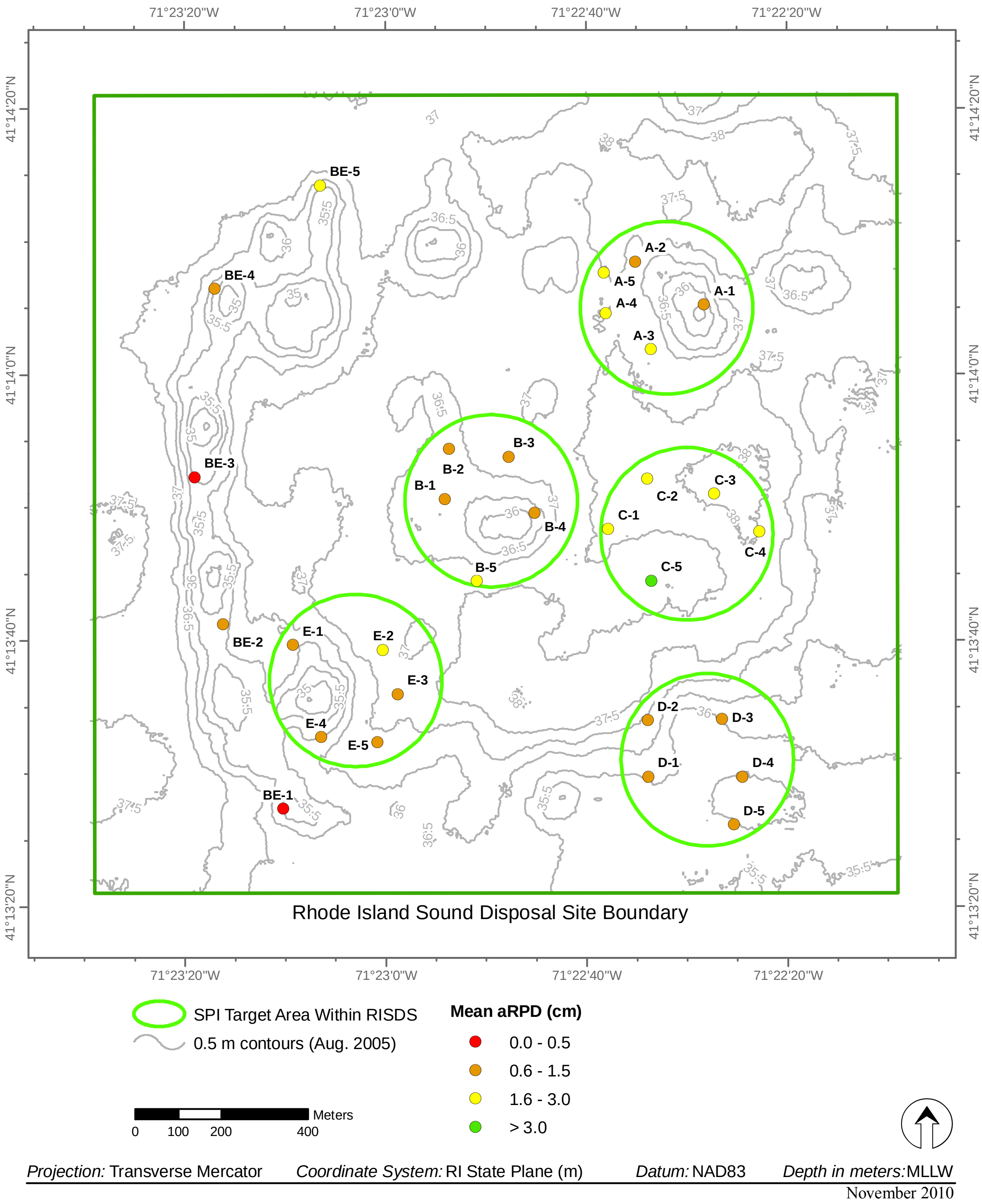


Figure 3-16. The distribution of means of replicate aRPD depths (cm) from RISDS disposal stations, October 2009

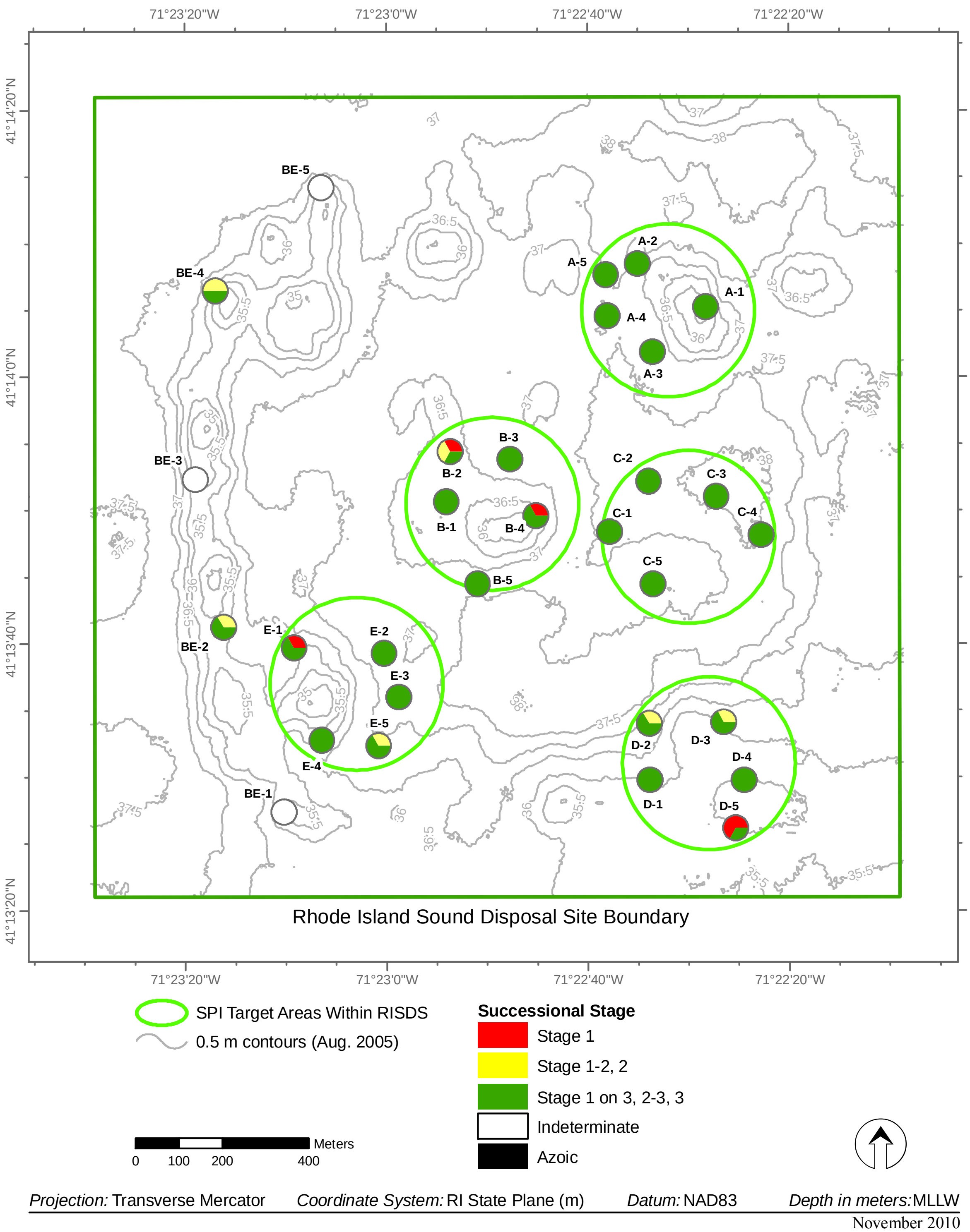


Figure 3-17. The distribution of infaunal successional stages at RISDS, October 2009

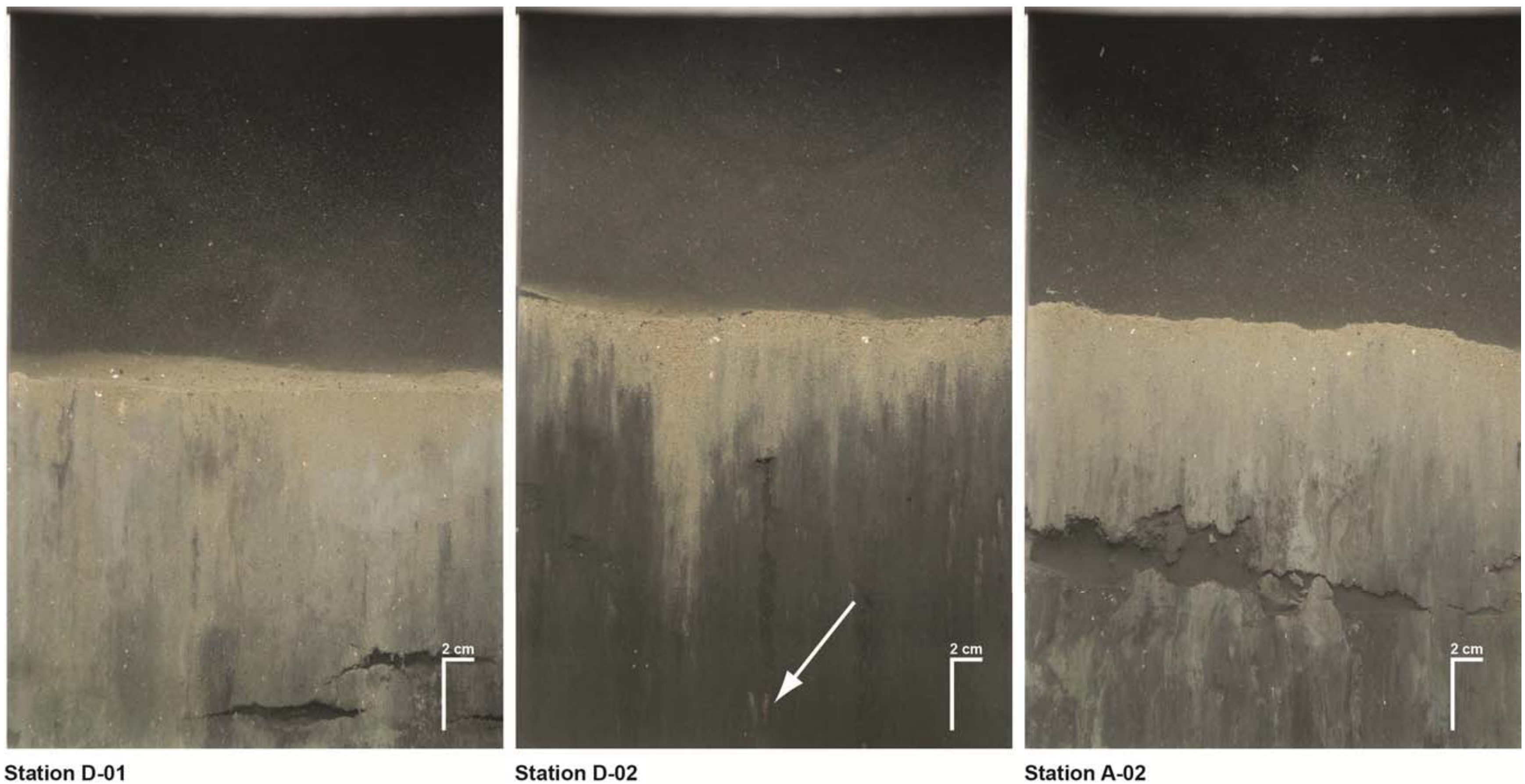
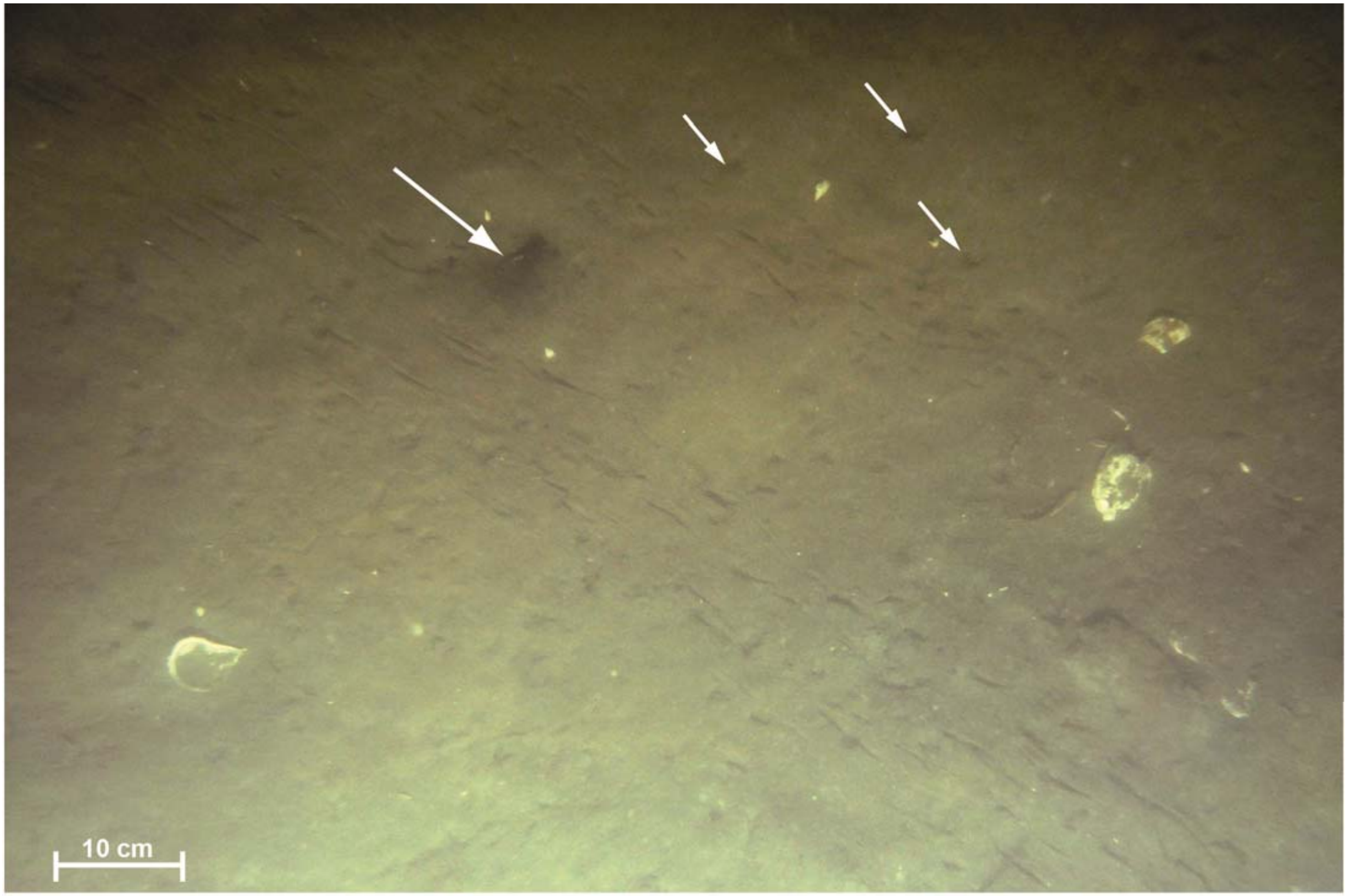


Figure 3-18. Sediment features in SPI images illustrate the presence of Stage 3 infauna within the surface layers of dredged material at RISDS: a cluster of subsurface feeding voids (left image), subsurface void and worm-like organism (arrow in center image), and large horizontal burrow at depth (right image).

Station B-03

Figure 3-19. Small tubes of Stage 1 organisms at the sediment surface and a subsurface feeding void (far right) resulted in a Stage 1 on 3 successional designation for this image.



Station A-01

Figure 3-20. Plan-view image showing one large burrow (large arrow) and several smaller burrow openings and pits at the sediment surface

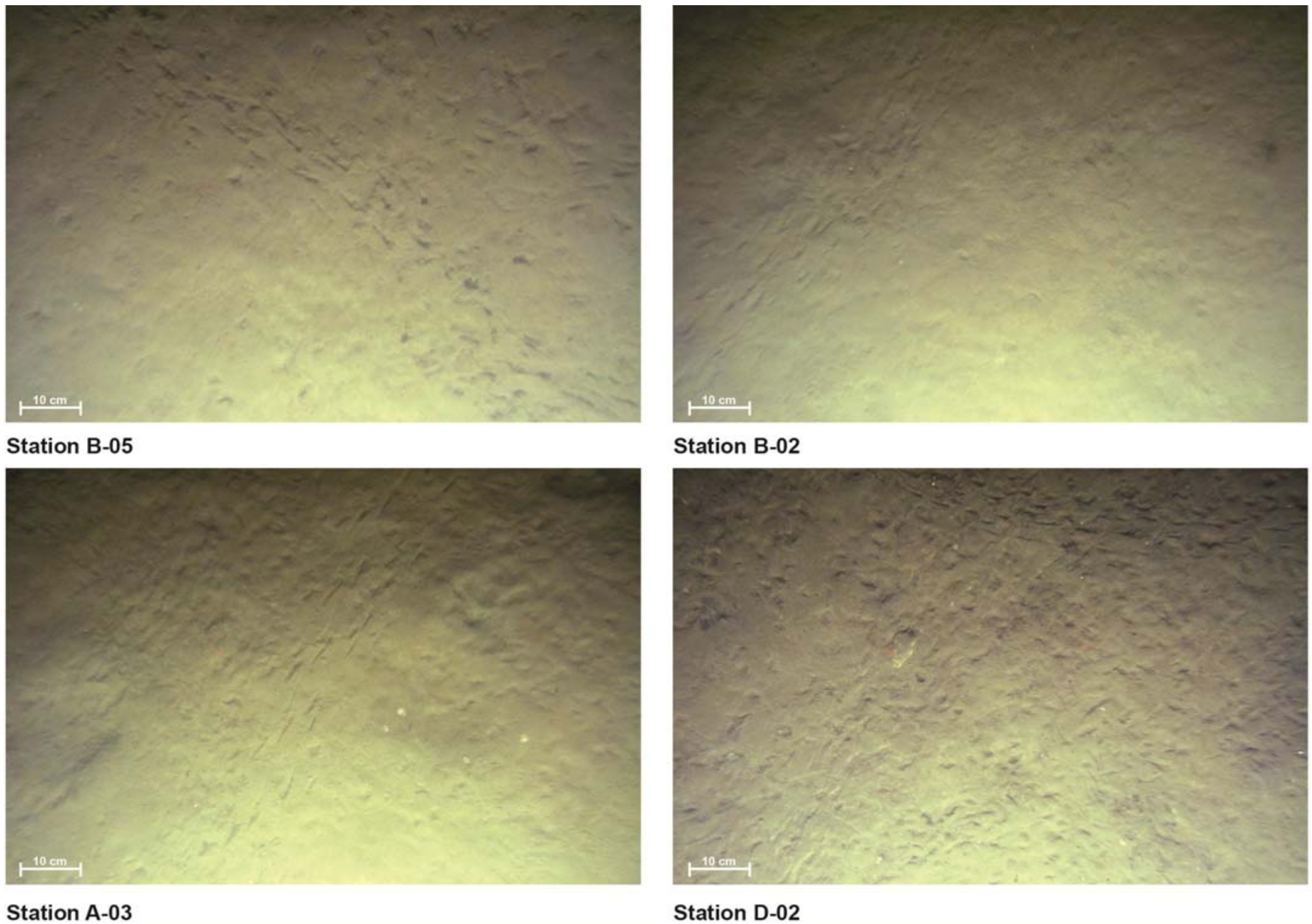


Figure 3-21. Panel of four plan-view images showing extensive crab tracks across the sediment surface

Station C-04

Figure 3-22. A crab is visible in the upper part of this plan-view image.

consisting mostly of individual crabs and an occasional sea star, were visible in 22% of the replicate plan-view images.

The berm formed on the western side of the disposal site represents a unique feature, comprised of a variety of sediment types ranging from silt/clay to small rocks. The small-scale heterogeneity in substrate types and the overall elevation of the berm above the surrounding seafloor were attractive to mobile epifauna at the time of the survey. Specifically, both crabs and small shrimp were observed frequently among the small rocks and cobbles at several of the berm stations (Figure 3-23). Overall, 10 of the 15 replicate plan-view images (67%) collected at the berm stations had either direct or indirect evidence of epifaunal activity. The direct evidence included visible organisms such as hydroids or bryozoans, shrimp, crabs, and sea stars, while the indirect evidence included tracks and burrows (Appendix D).

3.3 Statistical Comparisons

3.3.1 Mean aRPD Depths

In both 2005 and 2009, the mean aRPD values were more variable among the reference areas than among the five disposal mounds (station groups A–E, green circles in Figure 2-2) within the disposal site (Table 3-3 and Figure 3-24). In both years, the mean aRPD values also were consistently deeper at the reference areas compared to the five RISDS disposal mounds (Figure 3-24).

A test was performed to determine whether the difference observed in 2009 in mean aRPD values between the three reference areas and the five mounds was statistically significant. The three 2009 reference areas were each distinct in their distribution of aRPD values (Table 3-3 and Figure 3-24). Results for the normality test indicated that the area residuals (i.e., each observation minus the area mean) were not normally distributed (Shapiro-Wilk's test p-value < 0.01). There were 3 extreme residuals that resulted in the non-normality (1 each from REF-E, REF-NE, and RISDS-C). These values did not appear to be in error, so excluding them from the analysis was unjustified. Due to the non-normal distribution of these data, a nonparametric confidence interval was constructed on the difference between the reference mean and the disposal site mean using a bootstrap-*t* interval (Lunneborg 2000, Manly 1997; see methods in Appendix E).

The confidence region for the difference between the 2009 reference versus disposal mound means was not contained within the interval $[-\delta, +\delta]$ (Table 3-4). The conclusion was that the reference and mound areas had significantly different aRPD values in the 2009 survey, with a difference in means of approximately 3.8 cm.

Table 3-3.

Summary of Station Means by Sampling Location

		Mean aRPD (cm)		Successional Stage Rank		No. of Feeding Voids	
Area	N	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Reference Locations							
2005							
E	5	3.11	0.67	3	0	2.3	1.4
NE	5	3.06	0.52	3	0	0.3	0.4
SW	5	3.88	0.73	3	0	1.3	0.9
Mean		3.35		3.0		1.3	
2009							
E	5	3.26	1.14	3	0	1.7	0.4
NE	5	7.09	1.62	3	0	2.9	1.0
SW	5	5.80	0.83	3	0	3.9	2.3
Mean		5.39		3.0		2.8	
Disposal Mound Station Groups							
2005							
A	5	1.46	0.32	3	0	1.3	0.3
B	5	1.52	0.71	3	0	1.3	0.6
C	5	1.39	0.15	3	0	1.5	0.5
D	5	1.61	0.45	2.9	0.2	1.7	0.7
E	5	1.62	0.41	3	0	1.5	1.1
Mean		1.52		3.0		1.5	
2009							
A	5	1.44	0.47	3	0	1.2	0.4
B	5	1.26	0.43	2.9	0.2	1.2	0.9
C	5	2.73	1.60	3	0	0.9	0.8
D	5	1.07	0.25	3	0	0.9	0.6
E	5	1.25	0.61	3	0	0.8	0.4
Mean		1.55		3.0		1.0	

Table 3-4.

Summary Statistics and Results of Bootstrap-*t* Confidence Bounds for aRPD Values

Difference Equation	Observed Difference ($\hat{d}$)	SE($\hat{d}$)	df for SE($\hat{d}$)	95% Lower Confidence Bound	95% Upper Confidence Bound
2009 Data (mean reference) – (mean disposal mounds)	3.8	0.32	32	3.2	4.4
Disposal Data 2009Mean – 2005Mean	0.03	0.17	40	-0.34	0.29

A second test was performed to determine whether there was any significant difference in the aRPD depths of disposal area station groups A–E (mounds) between the 2005 and 2009 surveys. As a whole, the disposal area stations were fairly similar between the two years, with a slightly higher mean and more variability in the 2009 survey (Table 3-3 and Figure 3-24). The residuals for this group of data failed the normality test (Shapiro-Wilks p-value < 0.001), primarily due to a single influential data point (station C-5 in 2009). Consequently, a nonparametric confidence interval was constructed using the bootstrap-*t* interval.

The confidence region for the difference between 2009 and 2005 for disposal site stations was fully contained within the interval [$-\delta$, $+\delta$] (Table 3-4), leading to the conclusion that there was no significant change in aRPD values in the four years that had passed between the two different surveys.

3.3.2 Successional Stage Ranks

Similar to the aRPD analysis, two statistical analyses were performed for successional stage rank. One test examined the difference between the reference areas and disposal site mounds in 2009. In 2009, all but one station indicated successional stage at Stage 3 or equivalent (Table 3-3 and Figure 3-25). The mean successional stage rank among reference areas was 3; the mean among all disposal areas was also 3 with the

Station BE-04

Figure 3-23. A crab and numerous small pink shrimp are visible among the pebbles and small cobbles in this plan-view image from berm station BE-04.

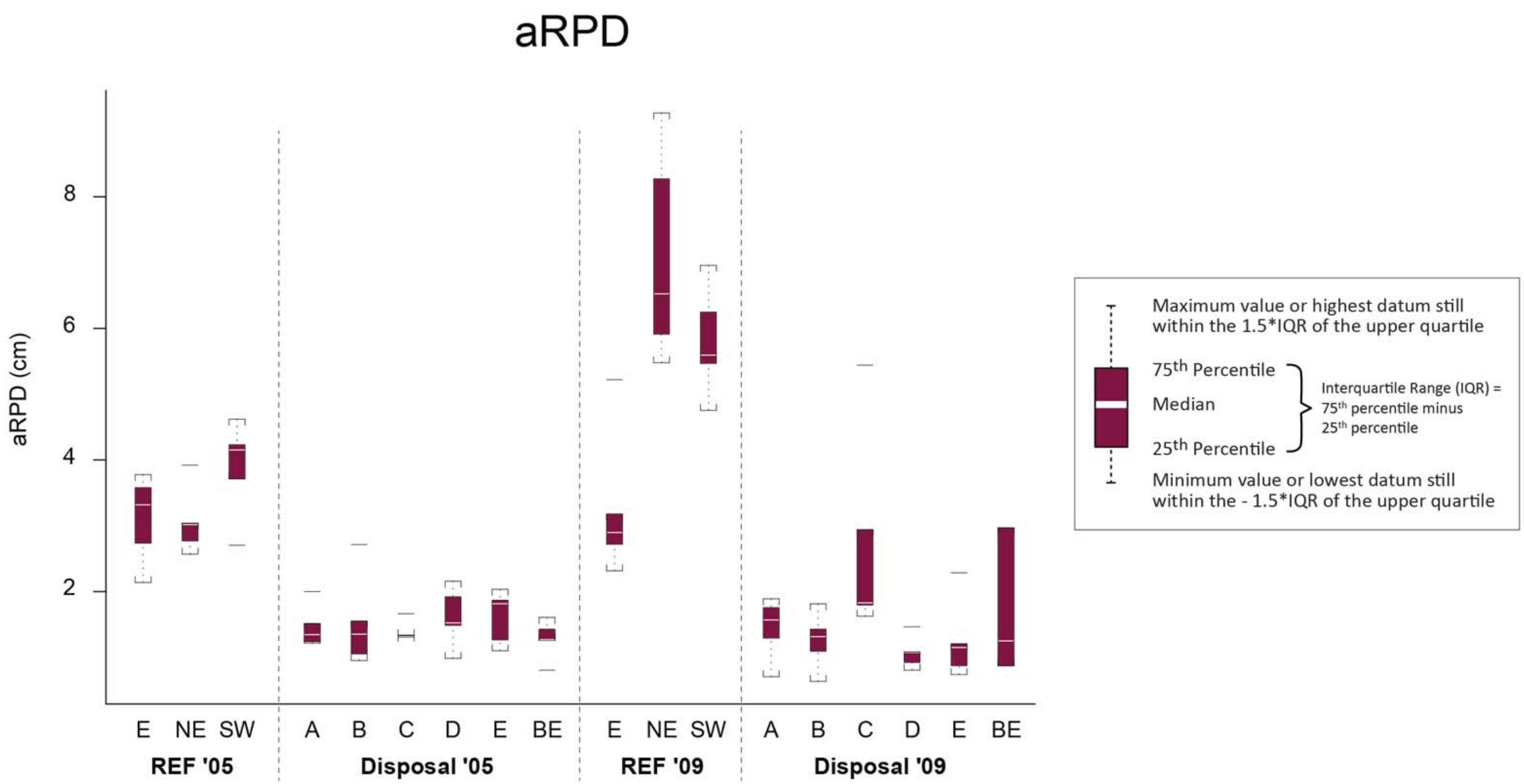


Figure 3-24. Boxplots showing the distribution of mean aRPD depths measured at the disposal site and reference area stations in the 2005 and 2009 surveys

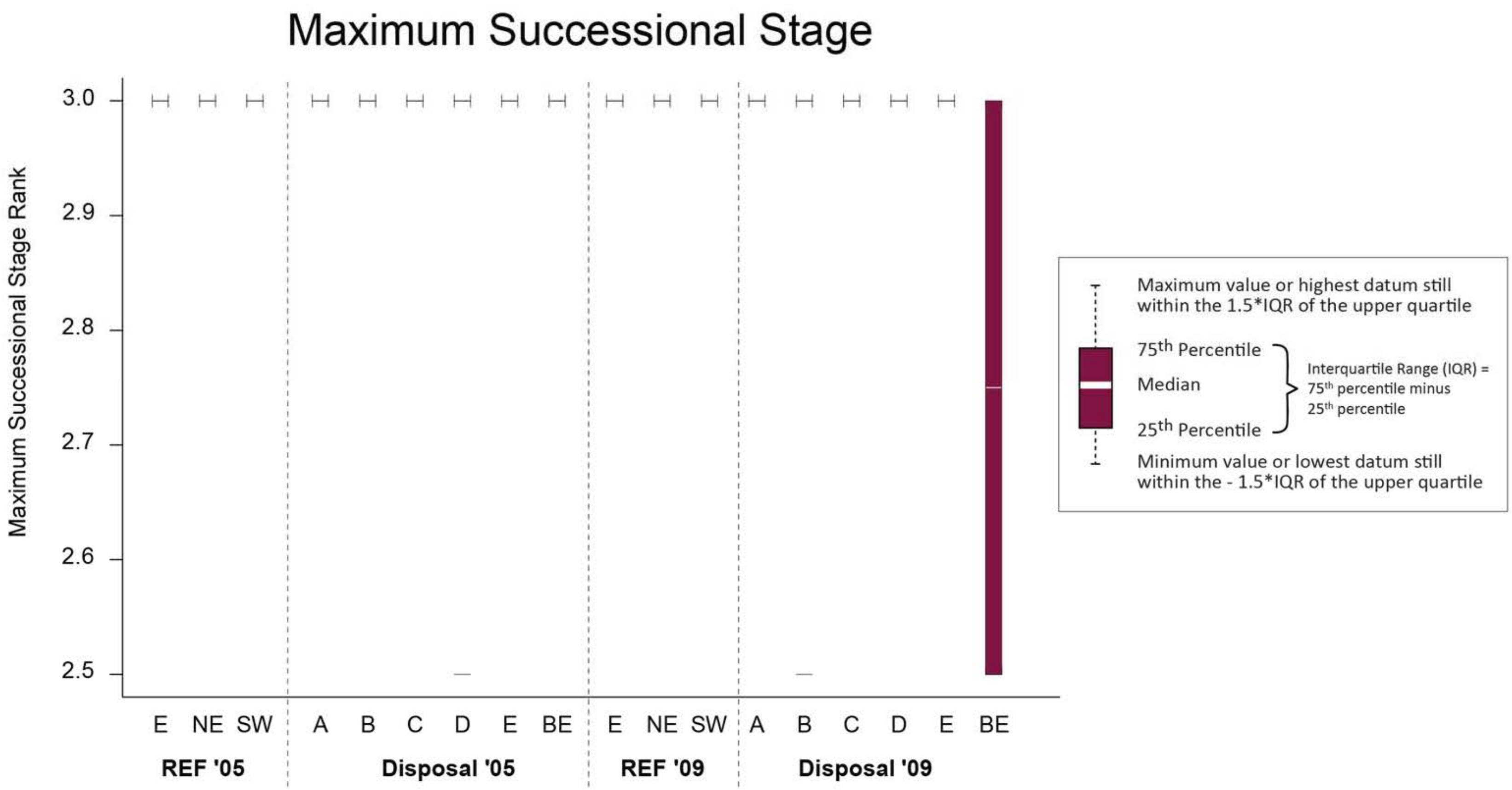


Figure 3-25. Boxplots showing the distribution of successional stage rank values at the disposal site and reference area stations in the 2005 and 2009 surveys

exception of mound B which had a mean rank of 2.9 (one station had a rank of 2.5 for a Stage 2–3 observation). No statistics were needed to conclude that there were no significant differences in successional stage rank between the disposal site and reference area stations in 2009.

It was also of interest to examine whether there was any significant change in successional stage rank at the disposal area mound stations between the 2005 and 2009 surveys. Only two stations indicated mean successional stage rank less than Stage 3 or equivalent: station D-1 in 2005 and station B-2 in 2009. The mean successional stage rank among the disposal area mound stations was identical for the two years at 2.98. No statistics were needed for this variable to conclude that there were no significant differences between years.

3.3.3 Number of Feeding Voids

The number of feeding voids counted in each image provides some indication of the relative density of Stage 3 organisms. In 2009, the three reference areas were each distinct in their distribution of number of feeding voids, with mean values ranging from 1.7 to 3.9 (Table 3-3 and Figure 3-26). In contrast, the disposal area mound stations had consistently lower values, ranging from 0.8 to 1.2 (Table 3-3). Results for the normality test indicated that the area residuals (i.e., each observation minus the area mean) were not normally distributed (Shapiro-Wilk's test p-value 0.0004), so a bootstrapping approach was utilized.

The results of the statistical test are presented in Table 3-5. The approach used two one-sided tests for the inequivalence hypothesis and used the one-sided upper and lower 95% confidence bounds (i.e., 5% error above the upper bound and 5% below the lower bound). As an interval, these bounds comprised 90% confidence within the interval, and 10% outside of the interval. The statistical analysis showed that the mean number of feeding voids was significantly less at the disposal area mound stations compared to the reference areas in 2009 (Table 3-5). The difference was 1.9 on average, with the 90% confidence interval between 1.3 and 2.8.

The mean number of feeding voids for the disposal area mound stations was slightly higher in 2005 (1.5) compared to 2009 (1.0) (Table 3-3 and Figure 3-26). The residuals for this group of data passed the normality test (Shapiro-Wilks p-value = 0.15). Consequently, it was possible to use a parametric confidence interval, but for the sake of comparison, both normal theory and the bootstrap-*t* interval approaches were used. Very similar results were obtained with these two approaches (Table 3-5).

The comparisons of feeding voids at the disposal site stations between 2009 and 2005 averaged -0.5, and neither the normal theory nor the bootstrap-*t* approach for the 90% confidence interval contained 0 (Table 3-5). Based on these results, we concluded that there was a small but significant decrease in the number of feeding voids counted in the SPI images between the 2005 and 2009 surveys.

Table 3-5.

Summary Statistics and Results of Bootstrap-*t* Confidence Bounds for Mean Number of Feeding Voids

Difference Equation	Observed Difference ($\hat{d}$)	SE($\hat{d}$)	df for SE($\hat{d}$)	95% Lower Confidence Bound	95% Upper Confidence Bound
2009 Data (mean reference) – (mean disposal mounds)	1.9	0.36	32	1.3	2.8
Disposal Data					
2009 Mean – 2005 Mean					
Normal theory	-0.5	0.19	40	-0.79	-0.14
Bootstrap-*t*	-0.5	0.17	40	-0.77	-0.19

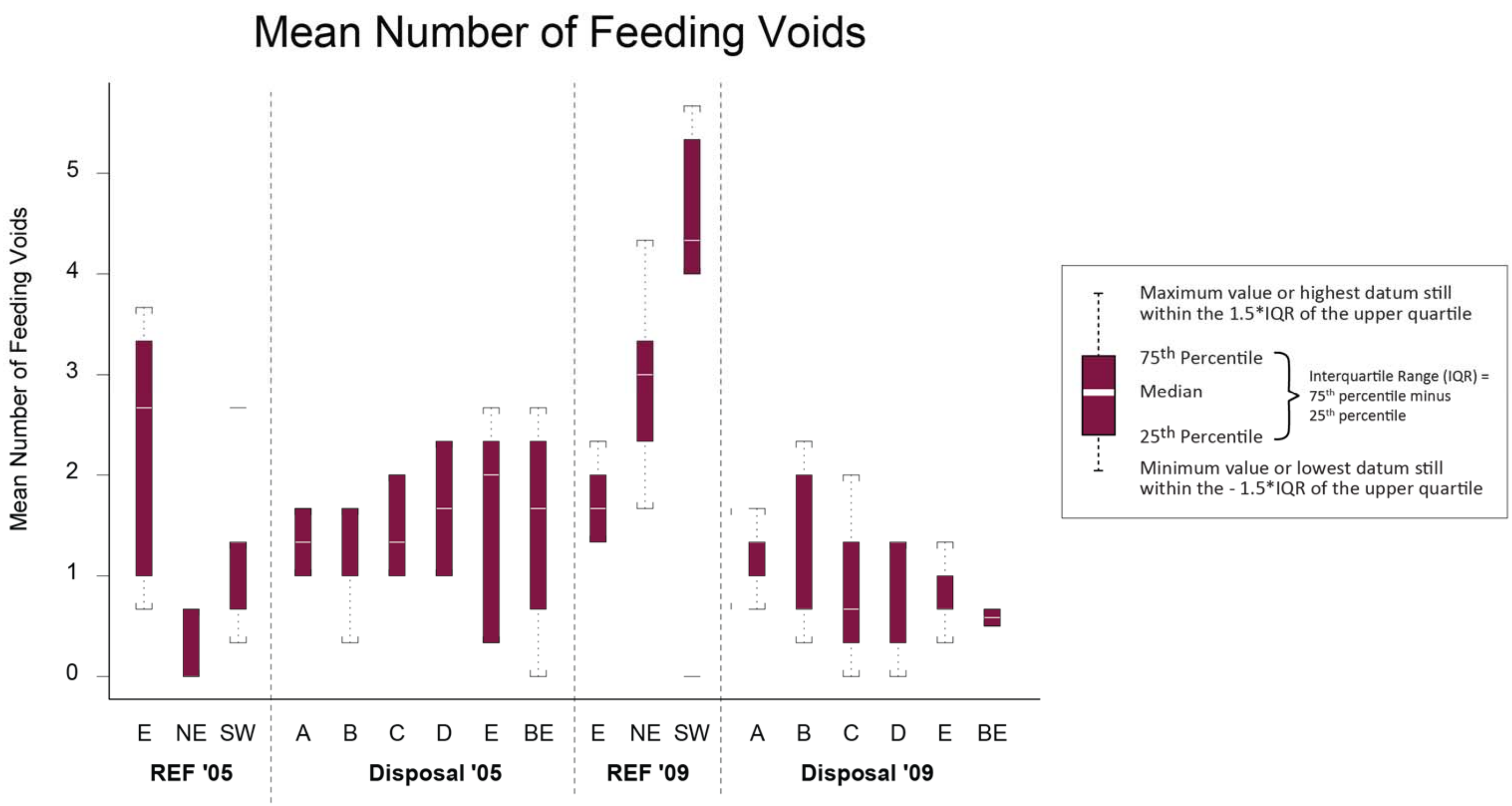


Figure 3-26. Boxplots showing the distribution of the mean number of feeding voids counted at the disposal site and reference area stations in the 2005 and 2009 surveys

4.0 DISCUSSION

The objective of the 2009 survey was to further assess the benthic recolonization status of the dredged material previously placed at RISDS. As described in Section 1.3, approximately 4 million m^3 (5 million cy) of material was disposed at the site between 2003 and early 2005 as part of the Providence River and Harbor Maintenance Dredging Project (PRHMDP). Placement of material was targeted over much of RISDS, forming a berm along the western boundary and a series of low mounds over the central basin and western portions of the site (Figure 1-4). The previous survey at the site was performed in October 2005, less than one year following cessation of PRHMDP disposal activity. The infaunal community inhabiting the sediment surface was found to be recovering relatively rapidly, with Stage 2 and 3 infauna present throughout the disposal site (ENSR 2007). Specifically, the sediment-profile and plan-view images collected in 2005 showed evidence of Stage 3 infauna present at both the reference areas and the disposal site. However, as expected, their apparent densities (as estimated from the images) were much lower at the disposal site, because it was relatively early in the recolonization process following the cessation of disposal activities six months prior to the survey.

The benthic community analysis that was also part of the July 2005 survey further supported the conclusion that total infaunal density and species richness were much lower at the disposal site compared to the reference areas. In particular, the number of subsurface deposit feeders (i.e., Stage 3 organisms) was on average much lower, while the number of surface-dwelling suspension feeders (i.e., Stage 1 organisms) was much higher, at the disposal site compared to the reference areas. This is consistent with the conclusion that the disposal site, despite having Stages 2 and 3 organisms present, was still in an intermediate stage of recolonization at the time of the July 2005 survey.

In the more than four years between the July 2005 survey and the October 2009 survey reported here, a limited amount of additional dredged material was disposed at the site (approximately 23,000 m^3 [30,000 cy]), with placement focused over a relatively small area of mound C (see Figure 1-5). Hence, there was no appreciable disposal-related physical disturbance across the majority of RISDS between the 2005 and 2009 surveys. Based on the results of the 2005 survey and the disposal record since that time, it was predicted that the October 2009 survey would continue to find evidence of relatively advanced succession (i.e., Stages 2 and 3) in those areas of RISDS that had not been subject to recent disposal activities, while the area of recent disposal activity was expected to be in the early to intermediate stages of succession. The 2009 findings are discussed below in relation to this prediction and in relation to general physical groupings of the stations along the berm and those over the mounds in the basin area to the east of the berm.

Berm

The berm area apparent in Figure 1-4 was created from material dredged in construction of the Confined Aquatic Disposal (CAD) cells as part of the PRHMDP. As the CAD cells were constructed beneath the navigational channel, construction entailed removal of native material consisting primarily of glacial till, a mixture of rock, gravel, sand, and fines. Directed placement of the approximately 1.5 million m^3 of this more consolidated, low water content material was used to create the berm along the western boundary of RISDS to enhance the capacity of the natural bottom depression located in the southwestern quadrant of the disposal site and limit the lateral spread of less consolidated maintenance material dredged as part of the PRHMDP.

Five stations were spaced along the length of the berm in the 2005 monitoring survey. Aside from one station that had gravel or hard bottom characteristics in two of the three replicates, the sediment profile and plan view imagery at the berm stations was similar to that of the remainder of the site in 2005, i.e. fine-grained sediments at an intermediate stage of benthic recovery. These five stations were reoccupied in 2009 (Figure 2-2); all five had at least one replicate with coarse-grained material, and three of the five stations had gravel or hard bottom as the dominant sediment type. This coarsening of the surficial sediments was not unexpected; the small-scale ripples on the sediment surface and the orientation of the "stick" amphipods (family *Podoceridae*) apparent in the 2005 plan view images indicated that bottom currents were capable of initiating bedload transport of fine-grained material during high energy events (ENSR 2007). This intermittent bedload transport likely led to the armoring of the berm area with its higher elevation relative to the rest of the site and the availability of ample coarse material within the berm sediment.

The hard bottom conditions at the majority of the berm stations limited the ability of the SPI camera to penetrate the bottom and provide the standardized measurements of biological conditions. However, the SPI and plan-view imagery revealed a healthy, hard-bottom community; much of the visible rock was covered with hydroids and bryozoans, and small crustaceans (shrimp and crabs) were visible in a high percentage of the plan-view images. Although they were not seen in any of the plan-view images, it is reasonable to assume that juvenile lobsters might also be attracted to the hard-bottom conditions of the armored berm surface.

Basin Area

Approximately 2.0 million m^3 (2.6 million cy) of maintenance material was dredged as part of the PRHMDP and disposed at RISDS between 2003 and early 2005.

The material generally consisted of fine sediment with high water content and was placed in the basin area of RISDS to the east of the constructed berm (Figure 1-3). Although placement was spread over much of the basin area, it was generally focused around target locations that resulted in the formation of a series of somewhat distinct, low mounds (Figure 1-4). Five of these mounds were selected as discrete areas for imaging and benthic collection as part of the 2005 survey (circular areas over mounds A, B, C, D, E each with a diameter of 300 m, Figure 2-2). These areas were again surveyed in 2009. The dredged material disposal that took place at RISDS between the 2005 and 2009 surveys was within the bounds of mound C (see Figure 1-5). The volume of this placement (approximately 23,000 m^3[30,000 cy]) was sufficient to be apparent in the SPI results from mound C stations but was not expected to affect the surrounding basin area. Hence, the results for the mound C stations are discussed separately below.

The previous DAMOS monitoring survey of July 2005 found the biological community at RISDS to be recovering relatively rapidly, with Stage 2 and 3 infauna present throughout the region meeting, and in some cases exceeding, initial predictions regarding the process of infaunal recolonization (ENSR 2007). Although Stage 3 infauna were present at both the reference areas and the disposal site in 2005, their densities were much lower at the disposal site, as evidenced by lower overall aRPD values measured with SPI (indicating lower overall bioturbation due to lower densities of burrowing and conveyor-belt species) and fewer burrow openings counted in the plan-view images. The 2005 infaunal analysis further supported these observations, showing much lower densities of subsurface deposit-feeding Stage 3 organisms at the disposal site compared to the reference areas.

In the 2009 images for basin area mounds A, B, D, and E, there was again abundant evidence that Stage 3 organisms continued to be present in the topmost 20 cm of the dredged material deposits. However, the results also suggest that these organisms continued to be present at lower densities compared to ambient conditions, as evidenced by lower average aRPD depths and significantly fewer subsurface feeding voids at the disposal site basin area stations versus the reference areas in 2009. It is notable that mound C had the highest average aRPD value among the 2009 disposal site stations (Table 3-3 and Figure 3-24); this is attributed to the lower apparent levels of organic matter and sulfides in the recent sandy dredged material placed at this mound (Battelle 2008) compared to the highly sulfidic mud comprising the other mounds from the PRHMDP. While the sandy dredged material at mound C had only been in place for roughly 10 months, evidence of Stage 3 organisms was found in all of the replicate SPI images over this mound (Figure 3-17). However, the apparent density of these Stage 3 organisms, as reflected in the mean number of feeding voids, was not appreciably different at mound C compared to the other mounds (Table 3-3 and Figure 3-26).

For the basin area stations over mounds A, B, D, and E, there was no significant deepening of aRPD depths between the 2005 and 2009 surveys. Such deepening would be expected if burrowing and/or conveyor-belt species had been increasingly populating the surface sediments of these stations. The 2009 results, therefore, run somewhat counter to the expected predictions about disposal site biological conditions gradually converging with those of the ambient seafloor over a period of several years following cessation of disposal activities (Germano et al. 1994). Such expectations are based in large part on previous findings from a large body of DAMOS monitoring results in New England as well as results from other disposal site monitoring programs (Newell et al. 1998, Bolam and Rees 2003). A high degree of convergence in biological conditions between disposal sites and nearby reference areas is expected to be particularly rapid (i.e., within a 1- to 3-year time-frame) in situations where nontoxic dredged sediments are placed in a seafloor environment that consists of similar sediments (e.g., same relative grain size range and organic carbon content).

In the more open coastal waters of Rhode Island Sound, much of the ambient seafloor consists of organic-poor, silty, fine to very fine sand, like that observed at two of the three RISDS reference areas (see Figure 3-2). The July 2005 survey of these reference areas showed that this sediment supported a species-rich, dense infaunal community, with high species diversity typical of undisturbed shallow-water habitats in New England. Although species diversity was high, the community was dominated by suspension-feeding and interface-feeding taxa, principally amphipods but also including cumaceans, owenid and spionid polychaetes, and shallow-dwelling bivalves belonging to the genus *Nucula*. Most notable in terms of the present discussion was the finding that head-down (conveyor-belt) species were present only at very low densities in these ambient sediments, accounting for 1% or less of the collected fauna. However, it also should be noted that larger head-down species may be underrepresented in sample counts due to inefficiencies of small grab samplers in capturing deeper burrowing organisms.

The 2005 results therefore provide a possible explanation for the most recent observation of continued low relative densities of Stage 3 organisms within the basin area of RISDS: such low densities are in fact characteristic of the surrounding seafloor. Although the organic-rich, soft, muddy dredged material placed at the site appears *capable* of supporting a more dense population of Stage 3 organisms, higher densities have not yet been observed, perhaps due to the limited numbers of adults and/or larvae available for recruitment from the surrounding area. Another factor that may have acted to inhibit Stage 3 colonization was the high apparent inventories of organic matter and associated reduced end-products (e.g., sulfides and ammonia) in the dredged material. Additional time may be needed for microbial processes to fully metabolize this excess organic matter such that levels begin to approximate those found on the ambient seafloor of Rhode Island Sound. In this regard, it is notable that the recently-disposed, organic-poor fine sand comprising mound C exhibited both relatively deep aRPDs and advanced recolonization at the time of the October 2009 survey just 10 months following placement of the material.

Some inhibition of Stage 3 colonization might also be due to the initial geotechnical properties of the sediment; it is likely that this sediment has undergone some degree of dewatering and self-weight consolidation since being placed at the RISDS. As noted in the DAMOS Tiered Monitoring Protocol (Germano et al. 1994):

> "Another physical factor [that can cause anomalous benthic recruitment patterns] is the mass or geotechnical properties of disposed sediments. Sediments which have very high water content (non-Newtonian muds) may not provide settling larvae with adequate support to keep them at or near the sediment-water interface until adequate consolidation has occurred."

From a wider ecological perspective, the 2009 results suggest that the surface of the RISDS deposit continues to support dense populations of primarily surface-dwelling, suspension feeders (i.e., SPI Stages 1 and 2), comparable to those on the ambient seafloor. This indicates that RISDS has continued to experience a relatively healthy degree of benthic recolonization. It is also notable that intensive monitoring prior to and following disposal from the PRHMDP demonstrated a lack of any significant impact on lobster populations in and around RISDS (Valente et al. 2007). It is possible, perhaps likely, that low relative densities of large-bodied, head-down, subsurface deposit feeders (i.e., "conveyor-belt" species) might be an ongoing feature of the basin area RISDS deposit for some years to come, with contributing factors of grain size differences, elevated levels of organic matter and sulfides, lack of nearby populations for recruitment, and the consolidation of the RISDS deposit. Future monitoring surveys that include some organic carbon analysis and traditional infaunal sampling and analysis in addition to the SPI surveys will serve to test this prediction.

5.0 CONCLUSIONS

The 2009 survey provided a follow up assessment of the benthic recolonization status within RISDS following placement of sediment from the Providence River and Harbor Maintenance Dredging Project. The previous survey of July 2005 had found that the benthic community was recovering relatively rapidly, with Stage 2 and 3 infauna present throughout the region, although as expected their densities (as estimated from the images and confirmed by infaunal analyses) were much lower, in comparison to reference, at the disposal site because it was still relatively early in the recolonization process.

Based on these earlier results, it was predicted that the October 2009 survey would continue to find evidence of relatively advanced succession (i.e., Stages 2 and 3) at RISDS. Mound C was the only area of the disposal site that had received dredged material within the previous 10 months, and it was characterized by both an advanced successional status and a higher mean aRPD depth than the other mounds. These results were attributed to lower overall levels of organic matter in the new, sandy dredged material at mound C compared to the older surrounding material (Battelle 2008). At the time of the survey, the mean number of subsurface feeding voids at the mound C stations was lower than that found at the three nearby reference areas, but with continued recolonization it is expected that the number of feeding voids will increase in the future at the mound C stations.

Both the SPI and PUC images collected in 2009 suggested that there were patches of small rocks near the top of the berm that was created on the western side of the disposal site. These rocks were providing habitat for a variety of epifauna, including hydroids, bryozoans, shrimp, crabs, and sea stars. The 2009 survey also found that the original Providence River dredged material that was widespread across the majority of the site continued to consist of relatively soft, sulfidic mud, but that it had undergone considerable consolidation since its original placement five years previous. While there continued to be ample evidence of advanced succession in 2009, large-bodied Stage 3 organisms continued to be present at lower apparent densities within the disposal site boundaries compared to ambient conditions. This was evidenced by lower mean aRPD depths and significantly fewer subsurface feeding voids at the disposal site versus the reference areas in 2009. Furthermore, there was no significant increase in the aRPD depths at the disposal site in 2009 compared to 2005; such deepening would be expected if burrowing and/or conveyor-belt species had been increasingly populating the surface sediments of the disposal site.

The 2009 results, therefore, run somewhat counter to the expected predictions about disposal site biological conditions gradually converging with those on the ambient seafloor over a period of several years following cessation of disposal activities. One explanation for these results is the difference in sediment type between the disposal site, which had soft, organic-rich mud; and the surrounding area, which is characterized by large expanses of organic-poor, silty fine to very fine sand. Low natural populations of mud-dwelling Stage 3 organisms in the surrounding area could have resulted in lower-than-expected recruitment of these organisms onto the dredged material deposit via the usual mechanism of lateral adult migration. Dewatering (consolidation) of the dredged material within the first few years of its placement may have also acted to inhibit the survival of Stage 3 larvae.

Overall, the 2009 SPI/PUC survey shows that populations of Stage 3 organisms continued to be present at RISDS, but the low relative densities of these organisms are anomalous. Based on the findings of the 2009 RISDS survey, the following recommendations are proposed:

R1) Monitoring within the next several years is recommended, even if additional placement at the site has not occurred.

R2) SPI/plan-view stations should be kept in the same groupings with berm stations and the basin mound groupings. Given the similarities of mounds A, B, D, and E a subset could be monitored in the future. Mound C and potential areas receiving new material should also be included in monitoring.

R3) Monitoring should include multibeam bathymetry to assess stability of the disposal mounds. Backscatter should be included to provide insight on the extent of armoring/hard bottom areas.

R4) A subset of stations should be sampled for benthic community and organic carbon analyses.

6.0 REFERENCES

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APPENDIX A

DISPOSAL BARGE LOG SUMMARY FOR RISDS, NOVEMBER 2008 TO JANUARY 2009

APPENDIX A

Disposal Barge Log Summary for RISDS
November 2008 to January 2009

Project Name: GREAT HARBOR
Permittee: NMFS-NOAA
Permit Number: NAE2008023

Disposal Date	Volume (yd^3)	Volume (m^3)	Latitude (degrees)	Longitude (degrees)
11/12/2008	3462	2647	41.229400	-71.376867
11/18/2008	2965	2267	41.229667	-71.376333
11/19/2008	3268	2499	41.229650	-71.376333
11/20/2008	3425	2619	41.229767	-71.376133
11/21/2008	3353	2564	41.229200	-71.374933
11/24/2008	3154	2412	41.229183	-71.375700
11/28/2008	3154	2412	41.229467	-71.376267
11/29/2008	3400	2600	41.229767	-71.376233
12/13/2008	3277	2506	41.231233	-71.375133
1/6/2009	909	695	41.229570	-71.376220

APPENDIX B

GRAIN SIZE SCALE FOR SEDIMENTS

APPENDIX B

Grain Size Scale for Sediments

Phi (Φ) size	Size range (mm)	Size class (Wentworth class)
< -1	> 2	Gravel
0 to –1	1 to 2	Very coarse sand
1 to 0	0.5 to 1	Coarse sand
2 to 1	0.25 to 0.5	Medium sand
3 to 2	0.125 to 0.25	Fine sand
4 to 3	0.0625 to 0.125	Very fine sand
> 4	< 0.0625	Silt/clay

APPENDIX C

SPI RAW DATA

APPENDIX C – Part 1

SPI Raw Data

Station	REP	DATE	TIME	Stop Collar Setting (in)	# of Lead Weights per Carriage	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	Grain Size RANGE	Penetration Area (sq.cm)	Penetration Mean (cm)	Penetration Minimum (cm)	Penetration Maximum (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD Area (sq.cm)	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	METHANE
A-1	A	10/5/2009	10:09	12	1	14.5	>4	0	>4	>4 to 0	238.9	16.5	15.2	17.6	2.4	Physical	13.4	0.92	3	Reduced	No
A-1	B	10/5/2009	10:10	12	1	14.5	>4	1	>4	>4 to 1	192.7	13.3	12.5	13.8	1.3	Physical	7.7	0.53	0		No
A-1	C	10/5/2009	10:10	12	1	14.5	>4	2	>4	>4 to 2	210.3	14.5	14.2	15.2	1.0	Physical	9.6	0.66	0		No
A-2	A	10/5/2009	10:26	12	1	14.5	>4	2	>4	>4 to 2	180.3	12.4	11.5	13.1	1.6	Physical	15.6	1.08	0		No
A-2	B	10/5/2009	10:27	12	1	14.5	>4	2	>4	>4 to 2	215.3	14.8	13.7	15.6	1.9	Physical	28.9	1.99	0		No
A-2	C	10/5/2009	10:28	12	1	14.5	>4	2	>4	>4 to 2	213.3	14.7	14.3	15	0.7	Physical	11.6	0.80	0		No
A-3	A	10/5/2009	10:32	12	1	14.5	>4	2	>4	>4 to 2	248.8	17.2	16.9	17.4	0.5	Biogenic	24.9	1.72	0		No
A-3	B	10/5/2009	10:33	12	1	14.5	>4	1	>4	>4 to 1	248.9	17.2	18.9	20.7	1.8	Biogenic	23.6	1.63	0		No
A-3	C	10/5/2009	10:34	12	1	14.5	>4	2	>4	>4 to 2	280.3	19.3	18.7	19.8	1.1	Biogenic	33.7	2.32	0		No
A-4	A	10/5/2009	10:40	12	1	14.5	>4	2	>4	>4 to 2	223.5	15.4	14	16.3	2.3	Physical	19.3	1.33	0		No
A-4	C	10/5/2009	10:42	12	1	14.5	>4	2	>4	>4 to 2	198.4	13.7	13.4	14	0.6	Biogenic	29.4	2.03	0		No
A-4	D	10/5/2009	10:42	12	1	14.5	>4	2	>4	>4 to 2	239.1	16.5	16.2	16.8	0.6	Biogenic	27.7	1.91	1	Reduced	No
A-5	A	10/5/2009	10:47	12	1	14.5	>4	1	>4	>4 to 1	231.5	16.0	15.5	16.3	0.8	Biogenic	33.9	2.34	0		No
A-5	B	10/5/2009	10:48	12	1	14.5	>4	1	>4	>4 to 1	202.5	14.0	13.8	14.5	0.7	Biogenic	15.5	1.07	0		No
A-5	C	10/5/2009	10:49	12	1	14.5	>4	2	>4	>4 to 2	203.1	14.0	13.6	14.4	0.8	Biogenic	18.8	1.30	1	Reduced	No
B-1	A	10/5/2009	11:12	12	1	14.5	>4	2	>4	>4 to 2	227.5	15.7	15	16.1	1.1	Biogenic	20	1.38	0		No
B-1	C	10/5/2009	11:14	12	1	14.5	>4	2	>4	>4 to 2	202.5	14.0	13.6	14.6	1.0	Biogenic	17.4	1.20	0		No

APPENDIX C – Part 1 (CONTINUED)

SPI Raw Data

Station	REP	DATE	TIME	Stop Collar Setting (in)	# of Lead Weights per Carriage	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	Grain Size RANGE	Penetration Area (sq.cm)	Penetration Mean (cm)	Penetration Minimum (cm)	Penetration Maximum (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD Area (sq.cm)	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	METHANE
B-1	D	10/5/2009	11:14	12	1	14.5	>4	2	>4	>4 to 2	188.9	13.0	12.7	13.4	0.7	Physical	19.8	1.37	7	Reduced	No
B-2	B	10/5/2009	11:19	12	1	14.5	>4	2	>4	>4 to 2	133.5	9.2	8.9	9.6	0.7	Physical	14.9	1.03	0		No
B-2	C	10/5/2009	11:20	12	1	14.5	>4	2	>4	>4 to 2	180.7	12.5	12	12.8	0.8	Biogenic	14.3	0.99	0		No
B-2	D	10/5/2009	11:21	12	1	14.5	>4	2	>4	>4 to 2	177	12.2	11.7	12.6	0.9	Biogenic	18.4	1.27	3	Reduced	No
B-3	B	10/5/2009	11:24	12	1	14.5	>4	2	>4	>4 to 2	193.8	13.4	12.2	13.5	1.3	Biogenic	20	1.38	0		No
B-3	C	10/5/2009	11:25	12	1	14.5	>4	2	>4	>4 to 2	196.3	13.5	13.2	14	0.8	Biogenic	24	1.66	0		No
B-3	D	10/5/2009	11:26	12	1	14.5	>4	2	>4	>4 to 2	206.1	14.2	14.1	14.4	0.3	Biogenic	18.1	1.25	0		No
B-4	A	10/5/2009	11:30	12	1	14.5	>4	2	>4	>4 to 2	229.1	15.8	15.6	16	0.4	Biogenic	14.6	1.01	0		No
B-4	C	10/5/2009	11:32	12	1	14.5	>4	2	>4	>4 to 2	145.2	10.0	8.9	11.4	2.5	Physical	7.1	0.49	6	Reduced	No
B-4	D	10/5/2009	11:33	12	1	14.5	>4	0	>4	>4 to 0	120.7	8.3	7.7	9	1.3	Physical	5.9	0.41	0		No
B-5	A	10/5/2009	11:40	12	1	14.5	>4	2	>4	>4 to 2	285.6	19.7	19.3	20.2	0.9	Biogenic	41.4	2.86	0		No
B-5	B	10/5/2009	11:41	12	1	14.5	>4	2	>4	>4 to 2	192.9	13.3	13.2	13.5	0.3	Biogenic	21.6	1.49	0		No
B-5	C	10/5/2009	11:42	12	1	14.5	>4	2	>4	>4 to 2	238.6	16.5	16.1	16.7	0.6	Biogenic	15.8	1.09	1	Reduced	No
BE 01	B	10/5/2009	17:12	14	4	14.5	3 to 2	-4	>4	>4 to -4	20.7	1.4	1	2.1	1.1	Physical	IND	IND	0		No
BE 01	C	10/5/2009	17:13	14	4	14.5	-2 to -4	-6	>4	>4 to -6	23.4	1.6	0	2.7	2.7	Physical	IND	IND	0		No
BE 01	D	10/5/2009	17:14	14	4	14.5	-6 to -7	-8	>4	>4 to -8	0	0.0	0	0	0.0	Physical	IND	IND	0		No
BE 02	A	10/5/2009	15:24	12	1	14.5	3 to 2/>4	-2	>4	>4 to -2	138.9	9.6	8.4	11.1	2.7	Physical	27.2	1.88	0		No
BE 02	C	10/5/2009	15:27	12	1	14.5	>4	1	>4	>4 to 1	152.3	10.5	10.1	11	0.9	Biogenic	19.2	1.32	0		No

APPENDIX C – Part 1 (CONTINUED)

SPI Raw Data

Station	REP	DATE	TIME	Stop Collar Setting (in)	# of Lead Weights per Carriage	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	Grain Size RANGE	Penetration Area (sq.cm)	Penetration Mean (cm)	Penetration Minimum (cm)	Penetration Maximum (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD Area (sq.cm)	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	METHANE
BE 02	D	10/5/2009	15:28	12	1	14.5	>4	1	>4	>4 to 1	162.8	11.2	10.4	11.7	1.3	Physical	8	0.55	10	Reduced	No
BE 03	A	10/5/2009	17:01	14	4	14.5	-5 to -6	-6	>4	>4 to -6	0	0.0	0	0	0.0	Physical	IND	IND	IND		No
BE 03	B	10/5/2009	17:02	14	4	14.5	-5 to -6	-6	>4	>4 to -6	17.7	1.2	0	3	3.0	Physical	IND	IND	n		No
BE 03	C	10/5/2009	17:03	14	4	14.5	-3 to -4	-5	>4	>4 to -5	27.2	1.9	0.3	2.9	2.6	Physical	IND	IND	n		No
BE 04	B	10/5/2009	16:11	12	1	14.5	>4	-5	>4	>4 to -5	119.2	8.2	7.6	8.9	1.3	Physical	12.1	0.83	n		No
BE 04	F	10/5/2009	16:51	14	4	14.5	-4 to -5	-6	>4	>4 to -6	21.9	1.5	1	2.1	1.1	Physical	IND	IND	n		No
BE 04	G	10/5/2009	16:52	14	4	14.5	>4	-1	>4	>4 to -1	133.1	9.2	8.4	9.5	1.1	Physical	13.2	0.91	3	Reduced	No
BE 05	B	10/5/2009	16:35	14	4	14.5	-5 to -6	-6	>4	>4 to -6	36.2	2.5	0	5.3	5.3	Physical	IND	IND	IND		No
BE 05	C	10/5/2009	16:36	14	4	14.5	-4 to -5	-6	>4	>4 to -6	82.5	5.7	4.5	6.4	1.9	Physical	IND	IND	0		No
BE 05	D	10/5/2009	16:37	14	4	14.5	-4 to -5	-6	>4	>4 to -6	43	3.0	0.9	3.9	3.0	Physical	43	2.97	0		No
C-1	A	10/5/2009	14:30	12	1	14.5	>4/3 to 2	-1	>4	>4 to -1	183.5	12.7	12.4	12.9	0.5	Physical	47.8	3.30	0		No
C-1	B	10/5/2009	14:31	12	1	14.5	3 to 2	-1	>4	>4 to -1	136.5	9.4	9	9.8	0.8	Biogenic	38.1	2.63	0		No
C-1	C	10/5/2009	14:32	12	1	14.5	3 to 2	-2	>4	>4 to -2	128.1	8.8	8.2	9.4	1.2	Physical	42	2.90	0		No
C-2	A	10/5/2009	14:37	12	1	14.5	3- 2 / >4	0	>4	>4 to 0	247.4	17.1	17	17.4	0.4	Biogenic	33.5	2.31	0		No
C-2	B	10/5/2009	14:38	12	1	14.5	>4	2	>4	>4 to 2	175.2	12.1	11.5	12.8	1.3	Physical	23.2	1.60	0		No
C-2	C	10/5/2009	14:39	12	1	14.5	3- 2 / >4	0	>4	>4 to 0	229.8	15.8	15.6	16.2	0.6	Physical	22.8	1.57	0		No
C-3	A	10/5/2009	14:43	12	1	14.5	3- 2 / >4	-1	>4	>4 to -1	151.9	10.5	9.6	11.2	1.6	Physical	15.3	1.06	0		No
C-3	B	10/5/2009	14:44	12	1	14.5	3- 2 / >4	-2	>4	>4 to -2	126.3	8.7	7.7	9.9	2.2	Biogenic	35.3	2.44	0		No

SPI Raw Data

Station	REP	DATE	TIME	Stop Collar Setting (in)	# of Lead Weights per Carriage	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	Grain Size RANGE	Penetration Area (sq.cm)	Penetration Mean (cm)	Penetration Minimum (cm)	Penetration Maximum (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD Area (sq.cm)	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	METHANE
C-3	D	10/5/2009	14:46	12	1	14.5	3- 2 / >4	0	>4	>4 to 0	151.6	10.5	10.2	10.8	0.6	Physical	27.5	1.90	0		No
C-4	A	10/5/2009	14:49	12	1	14.5	>4	0	>4	>4 to 0	221.1	15.2	14.4	16.5	2.1	Physical	24.6	1.70	0		No
C-4	B	10/5/2009	14:49	12	1	14.5	>4	2	>4	>4 to 2	187.1	12.9	12.7	13.3	0.6	Biogenic	17.2	1.19	0		No
C-4	D	10/5/2009	14:51	12	1	14.5	>4	2	>4	>4 to 2	213.4	14.7	14.2	15.2	1.0	Biogenic	28.9	1.99	0		No
C-5	A	10/5/2009	14:56	12	1	14.5	3 to 2	-1	>4	>4 to -1	98.9	6.8	5.5	8.6	3.1	Physical	98.9	6.82	0		No
C-5	B	10/5/2009	14:57	12	1	14.5	3 to2	-1	>4	>4 to -1	118.8	8.2	6.1	9.8	3.7	Physical	58.9	4.06	0		No
C-5	C	10/5/2009	14:58	12	1	14.5	3 to 2	-4	>4	>4 to -4	79.3	5.5	4.4	6.9	2.5	Physical	IND	IND	0		No
D-1	A	10/5/2009	13:41	12	1	14.5	>4	-1	>4	>4 to -1	174.9	12.1	11.3	12.5	1.2	Biogenic	28.5	1.97	0		No
D-1	B	10/5/2009	13:41	12	1	14.5	>4	-1	>4	>4 to -1	152.3	10.5	10.4	10.8	0.4	Physical	17.8	1.23	0		No
D-1	C	10/5/2009	13:42	12	1	14.5	>4	-1	>4	>4 to -1	184.9	12.8	12.2	13.6	1.4	Physical	17.4	1.20	0		No
D-2	B	10/5/2009	13:48	12	1	14.5	>4	2	>4	>4 to 2	206.8	14.3	14.1	14.6	0.5	Biogenic	19.9	1.37	0		No
D-2	C	10/5/2009	13:49	12	1	14.5	>4	-1	>4	>4 to -1	184.1	12.7	12.5	13.3	0.8	Physical	18.3	1.26	0		No
D-2	D	10/5/2009	13:50	12	1	14.5	>4	1	>4	>4 to 1	208	14.3	14	14.7	0.7	Biogenic	8.5	0.59	0		No
D-3	B	10/5/2009	13:53	12	1	14.5	>4	1	>4	>4 to 1	176.2	12.2	11.8	12.8	1.0	Biogenic	11.6	0.80	0		No
D-3	C	10/5/2009	13:54	12	1	14.5	>4	0	>4	>4 to 0	258.3	17.8	17.1	18.7	1.6	Biogenic	14.1	0.97	0		No
D-3	D	10/5/2009	13:54	12	1	14.5	>4	1	>4	>4 to 1	220	15.2	14.8	15.5	0.7	Biogenic	14.5	1.00	0		No
D-4	A	10/5/2009	13:58	12	1	14.5	>4	2	>4	>4 to 2	204.1	14.1	13.9	14.5	0.6	Biogenic	21.2	1.46	>20	Reduced	No
D-4	B	10/5/2009	13:59	12	1	14.5	>4	2	>4	>4 to 2	281.1	19.4	18.7	19.9	1.2	Physical	5.7	0.39	0		No

APPENDIX C – Part 1 (CONTINUED)

SPI Raw Data

Station	REP	DATE	TIME	Stop Collar Setting (in)	# of Lead Weights per Carriage	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	Grain Size RANGE	Penetration Area (sq.cm)	Penetration Mean (cm)	Penetration Minimum (cm)	Penetration Maximum (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD Area (sq.cm)	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	METHANE
D-4	D	10/5/2009	14:00	12	1	14.5	>4	2	>4	>4 to 2	154.6	10.7	9.7	11.3	1.6	Physical	8.1	0.56	0		No
D-5	A	10/5/2009	14:04	12	1	14.5	>4	2	>4	>4 to 2	248.4	17.1	16.8	17.5	0.7	Biogenic	13	0.90	0		No
D-5	B	10/5/2009	14:05	12	1	14.5	>4	2	>4	>4 to 2	244.9	16.9	16.4	17.2	0.8	Biogenic	19.8	1.37	0		No
D-5	C	10/5/2009	14:06	12	1	14.4	>4	2	>4	>4 to 2	209.7	14.6	14.2	14.9	0.7	Biogenic	14.1	0.98	0		No
E-1	A	10/5/2009	15:30	12	1	14.5	>4	2	>4	>4 to 2	208.2	14.4	14	14.7	0.7	Biogenic	21.3	1.47	2	Oxidized	No
E-1	C	10/5/2009	15:32	12	1	14.5	>4	1	>4	>4 to 1	176	12.1	11.9	12.4	0.5	Biogenic	10.5	0.72	3		No
E-1	D	10/5/2009	15:33	12	1	14.5	>4	0	>4	>4 to 0	163.8	11.3	11	11.8	0.8	Biogenic	18.3	1.26	0		No
E-2	A	10/5/2009	15:36	12	1	14.5	>4	2	>4	>4 to 2	225.5	15.6	15.4	15.8	0.4	Biogenic	43	2.97	0		No
E-2	B	10/5/2009	15:37	12	1	14.5	>4	2	>4	>4 to 2	223.3	15.4	14.9	15.9	1.0	Biogenic	22.5	1.55	0		No
E-2	C	10/5/2009	15:38	12	1	14.5	>4	2	>4	>4 to 2	212.3	14.6	14.5	14.8	0.3	Biogenic	33.9	2.34	0		No
E-3	A	10/5/2009	15:42	12	1	14.5	>4	1	>4	>4 to 1	201.3	13.9	13.7	14.3	0.6	Biogenic	12.1	0.83	0		No
E-3	B	10/5/2009	15:43	12	1	14.5	>4	2	>4	>4 to 2	177.7	12.3	12	12.7	0.7	Biogenic	10.9	0.75	0		No
E-3	D	10/5/2009	15:45	12	1	14.5	>4	2	>4	>4 to 2	200.2	13.8	13.5	14.1	0.6	Physical	9.1	0.63	0		No
E-4	A	10/5/2009	15:51	12	1	14.5	>4	0	>4	>4 to 0	216.8	15.0	14.2	15.4	1.2	Physical	14.6	1.01	3	Reduced	No
E-4	B	10/5/2009	15:52	12	1	14.5	>4	-1	>4	>4 to -1	167.6	11.6	11	12.2	1.2	Physical	7.6	0.52	0		No
E-4	C	10/5/2009	15:53	12	1	14.5	>4	-1	>4	>4 to -1	223.8	15.4	14.1	15.8	1.7	Biogenic	15.7	1.08	0		No
E-5	A	10/5/2009	15:57	12	1	14.5	>4	1	>4	>4 to 1	275.4	19.0	18.6	19.3	0.7	Biogenic	15	1.03	0		No
E-5	C	10/5/2009	15:59	12	1	14.5	>4	1	>4	>4 to 1	230.3	15.9	14.9	17.2	2.3	Physical	16.2	1.12	0		No

APPENDIX C – Part 1 (CONTINUED)

SPI Raw Data

Station	REP	DATE	TIME	Stop Collar Setting (in)	# of Lead Weights per Carriage	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	Grain Size RANGE	Penetration Area (sq.cm)	Penetration Mean (cm)	Penetration Minimum (cm)	Penetration Maximum (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD Area (sq.cm)	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	METHANE
E-5	D	10/5/2009	15:59	12	1	14.5	>4	1	>4	>4 to 1	217.8	15.0	14.6	15.3	0.7	Biogenic	21.1	1.46	0		No
REF E 1	A	10/4/2009	10:19	15	5	14.5	>4	2	>4	>4 to 2	255.7	17.6	16.6	18.3	1.7	Biogenic	37.2	2.56	0		No
REF E 1	B	10/4/2009	10:19	15	5	14.5	>4	1	>4	>4 to 1	274.7	18.9	18.5	19.4	0.9	Biogenic	47.1	3.25	6	Reduced	No
REF E 1	C	10/4/2009	10:20	15	5	14.5	>4	1	>4	>4 to 1	277.7	19.2	18.1	19.6	1.5	Biogenic	53.9	3.72	4	Reduced	No
REF E 2	A	10/4/2009	10:34	14	4	14.5	>4	2	>4	>4 to 2	216.2	14.9	14.5	15.5	1.0	Biogenic	39.8	2.74	0		No
REF E 2	C	10/4/2009	10:35	14	4	14.5	>4	1	>4	>4 to 1	236.7	16.3	15.6	16.9	1.3	Biogenic	44.4	3.06	1	Reduced	No
REF E 2	D	10/4/2009	10:36	14	4	14.5	>4	2	>4	>4 to 2	227.3	15.7	15.3	16.2	0.9	Biogenic	34.1	2.35	0		No
REF E 3	B	10/4/2009	10:43	14	4	14.5	>4	1	>4	>4 to 1	192.1	13.2	12.3	13.8	1.5	Biogenic	31.3	2.16	0		No
REF E 3	C	10/4/2009	10:43	14	4	14.5	>4	2	>4	>4 to 2	237.7	16.4	15.8	16.8	1.0	Biogenic	34.3	2.37	0		No
REF E 3	D	10/4/2009	10:44	14	4	14.5	>4	1	>4	>4 to 1	233.1	16.1	15.8	16.8	1.0	Biogenic	35.1	2.42	5	Reduced	No
REF E 4	B	10/4/2009	10:50	14	4	14.5	>4	0	>4	>4 to 0	201.8	13.9	13.4	14.7	1.3	Biogenic	59.8	4.13	0		No
REF E 4	F	10/4/2009	11:21	14	4	14.5	>4	2	>4	>4 to 2	238.9	16.5	16.1	17	0.9	Biogenic	38.1	2.63	1	Reduced	No
REF E 4	H	10/4/2009	11:22	14	4	14.5	>4	1	>4	>4 to 1	218.3	15.1	14.7	15.5	0.8	Biogenic	28.1	1.94	5		No
REF E 5	B	10/4/2009	10:56	14	4	14.5	>4 to 3	1	>4	>4 to 1	160.9	11.1	10.4	11.3	0.9	Biogenic	61.8	4.26	0		No
REF E 6	A	10/4/2009	10:59	14	4	14.5	>4	2	>4	>4 to 2	185.4	12.8	11.9	14.5	2.6	Physical	67.1	4.63	0		No
REF E 6	B	10/4/2009	11:00	14	4	14.5	>4 to 3	-1	>4	>4 to -1	197	13.6	13.1	14.2	1.1	Biogenic	80.7	5.56	0		No
REF E 6	C	10/4/2009	11:01	14	4	14.5	>4 to 3	0	>4	>4 to 0	185.5	12.8	12.6	13	0.4	Biogenic	79.3	5.47	0		No
REF NE 1	A	10/4/2009	8:43	16.5	5	14.5	4 to 3	1	>4	>4 to 1	155.9	10.8	10.4	11.2	0.8	Physical	85.2	5.88	0		No

SPI Raw Data

Station	REP	DATE	TIME	Stop Collar Setting (in)	# of Lead Weights per Carriage	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	Grain Size RANGE	Penetration Area (sq.cm)	Penetration Mean (cm)	Penetration Minimum (cm)	Penetration Maximum (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD Area (sq.cm)	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	METHANE
REF NE 1	B	10/4/2009	8:44	16.5	5	14.5	3 to 2	-1	>4	>4 to -1	169.7	11.7	11	12.1	1.1	Biogenic	94.2	6.50	5	Oxidized	No
REF NE 1	D	10/4/2009	8:45	16.5	5	14.5	3 to 2/>4	-1	>4	>4 to -1	219.1	15.1	14.7	15.5	0.8	Physical	58.9	4.06	0		No
REF NE 2	A	10/4/2009	9:22	16.5	5	14.5	3 to 2	0	>4	>4 to 0	168.6	11.6	11.1	12.2	1.1	Physical	80.7	5.56	0		No
REF NE 2	C	10/4/2009	9:23	16.5	5	14.5	4 to 3	0	>4	>4 to 0	150.8	10.4	9.7	10.7	1.0	Biogenic	104.1	7.18	0		No
REF NE 2	D	10/4/2009	9:24	16.5	5	14.5	4 to 3	1	>4	>4 to 1	103.5	7.1	6.6	7.8	1.2	Physical	99.1	6.83	0		No
REF NE 3	B	10/4/2009	9:41	16.5	5	14.5	4 to 3	1	>4	>4 to 1	140.8	9.7	8	10.3	2.3	Physical	84.3	5.81	0		No
REF NE 3	C	10/4/2009	9:41	16.5	5	14.5	4 to 3	-1	>4	>4 to -1	161	11.1	10.8	11.8	1.0	Physical	83.2	5.74	0		No
REF NE 3	D	10/4/2009	9:42	16.5	5	14.5	4 to 3	-1	>4	>4 to -1	160.9	11.1	10.8	11.8	1.0	Physical	89.7	6.19	0		No
REF NE 4	A	10/4/2009	9:47	16.5	5	14.5	4 to 3	1	>4	>4 to 1	118.3	8.2	7.6	8.9	1.3	Physical	118.3	8.16	0		No
REF NE 4	B	10/4/2009	9:48	16.5	5	14.5	3 to 2	-1	>4	>4 to -1	125.2	8.6	7.7	9.3	1.6	Physical	94.1	6.49	0		No
REF NE 4	C	10/4/2009	9:49	16.5	5	14.5	4 to 3	0	>4	>4 to 0	147.4	10.2	9.4	11.7	2.3	Biogenic	147.4	10.17	0		No
REF NE 5	A	10/4/2009	9:54	16.5	5	14.5	3 to 2	-1	>4	>4 to -1	146.2	10.1	9.1	10.3	1.2	Biogenic	146.2	10.08	0		No
REF NE 5	B	10/4/2009	9:54	16.5	5	14.5	3 to 2	-1	>4	>4 to -1	149.6	10.3	10	10.9	0.9	Biogenic	118.4	8.17	0		No
REF NE 5	C	10/4/2009	9:55	16.5	5	14.5	4 to 3	0	>4	>4 to 0	152.6	10.5	8.9	11.1	2.2	Biogenic	138.7	9.56	0		No
REF SW 1	B	10/5/2009	8:24	14	4	14.5	>4 to 3	2	>4	>4 to 2	167.9	11.6	10.9	12.1	1.2	Biogenic	78.8	5.44	0		No
REF SW 1	C	10/5/2009	8:25	14	4	14.5	>4 to 3	2	>4	>4 to 2	157.7	10.9	10.4	11.2	0.8	Physical	88.1	6.08	0		No
REF SW 1	D	10/5/2009	8:26	14	4	14.5	>4 to 3	1	>4	>4 to 1	160	11.0	8.2	12.1	3.9	Biogenic	104.7	7.22	0		No
REF SW 2	A	10/5/2009	8:32	14	4	14.5	>4 to 3	2	>4	>4 to 2	156	10.8	10.1	11.6	1.5	Biogenic	98.1	6.77	0		No

APPENDIX C – Part 1 (CONTINUED)

SPI Raw Data

Station	REP	DATE	TIME	Stop Collar Setting (in)	# of Lead Weights per Carriage	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	Grain Size RANGE	Penetration Area (sq.cm)	Penetration Mean (cm)	Penetration Minimum (cm)	Penetration Maximum (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD Area (sq.cm)	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	METHANE
REF SW 2	B	10/5/2009	8:33	14	4	14.5	>4 to 3	1	>4	>4 to 1	206.9	14.3	14.1	14.7	0.6	Biogenic	89.3	6.16	0		No
REF SW 2	C	10/5/2009	8:33	14	4	14.5	>4	1	>4	>4 to 1	215.4	14.9	14.3	15.5	1.2	Biogenic	115.3	7.95	0		No
REF SW 3	A	10/5/2009	8:40	14	4	14.5	>4 to 3	2	>4	>4 to 2	152.7	10.5	9.8	11.6	1.8	Biogenic	53.5	3.69	0		No
REF SW 3	B	10/5/2009	8:40	14	4	14.5	>4 to 3	2	>4	>4 to 2	166	11.4	9.8	12	2.2	Physical	72.2	4.98	0		No
REF SW 3	D	10/5/2009	8:42	14	4	14.5	>4 to 3	2	>4	>4 to 2	160.2	11.0	10.2	11.6	1.4	Biogenic	81.1	5.59	0		No
REF SW 4	A	10/5/2009	8:46	14	4	14.5	>4 to 3	2	>4	>4 to 2	145.6	10.0	9.7	10.7	1.0	Physical	66.7	4.60	0		No
REF SW 4	B	10/5/2009	8:47	14	4	14.5	>4	2	>4	>4 to 2	238.1	16.4	14.4	17.4	3.0	Physical	102.3	7.05	0		No
REF SW 4	D	10/5/2009	8:49	14	4	14.5	>4 to 3	2	>4	>4 to 2	178.1	12.3	11.1	12.7	1.6	Physical	74.3	5.12	0		No
REF SW 5	A	10/5/2009	8:54	14	4	14.5	>4 to 3	1	>4	>4 to 1	121	8.3	8.2	8.6	0.4	Biogenic	73.9	5.09	0		No
REF SW 5	B	10/5/2009	8:54	14	4	14.5	4 to 3	1	>4	>4 to 1	71	4.9	4.4	5.3	0.9	Physical	71	4.90	0		No
REF SW 5	C	10/5/2009	8:55	14	4	14.5	4 to 3	1	>4	>4 to 1	93	6.4	5.7	6.9	1.2	Physical	93	6.41	0		No

APPENDIX C – Part 2

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
A-1	A	238.9	>	16.5	>	15.2	>	17.6	No	DM>pen; sandy surface grading to sulfidic silt/clay@depth; many small surf tubes+1 lrg tube (Maldanid?); partial void/burrow@depth@left	1	11.7	12	11.9	1 on 3
A-1	B	192.7	>	13.3	>	12.5	>	13.8	No	DM>pen; streaky-sulfidic silt/clay DM w/ thin aRPD; 1 clear feeding void@left+2 partial void; cryptic worm at far lower right	1	3.5	3.9	3.7	1 on 3
A-1	C	210.3	>	14.5	>	14.2	>	15.2	No	DM>pen; sulfidic silt/clay over cohesive grey clay@depth; deep feeding voids@lwr left	2	13.9	14.5	14.2	1 on 3
A-2	A	180.3	>	12.4	>	11.5	>	13.1	No	DM>pen; moderately sulfidic silt/clay DM; small surf tubes; large burrow/void complex	2	5.6	7.7	6.7	1 on 3
A-2	B	215.3	>	14.8	>	13.7	>	15.6	No	DM>pen; moderately sulfidic silt/clay; numerous small surf tubes, transected burrows at depth	0				1 on 3
A-2	C	213.3	>	14.7	>	14.3	>	15	No	DM>pen; moderately sulfidic silt/clay; dense surf tubes; 1 cryptic subsurface worm@left=Stg 3	0				1 on 3
A-3	A	248.8	>	17.2	>	16.9	>	17.4	No	DM>pen; moderately sulfidic silt/clay; 1 small subsurface void+1 or 2 cryptic subsurface worm-like org	1	12.5	13	12.8	1 on 3
A-3	B	248.9	>	17.2	>	18.9	>	20.7	No	DM>pen; sulfidic mud w/ strong aRPD contrast; small voids; subsurface worm@right	1	12.5	12.9	12.7	1 on 3
A-3	C	280.3	>	19.3	>	18.7	>	19.8	No	DM>pen; sulfidic mud w/ moderate to strong aRPD contrast; 1 subsurface void & transected burrow @ right; small surf tubes	1	7.9	8	8.0	1 on 3
A-4	A	223.5	>	15.4	>	14	>	16.3	No	Older/weathered DM ; moderately reduced mud w/ moderate aRPD contrast; surf tubes and 1 small subsurface void@lwr left	1	12.3	12.4	12.4	1 on 3

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
A-4	C	198.4	>	13.7	>	13.4	>	14	No	Older, weathered DM -low aRPD contrast; small surf tubes+1 subsurface void	1	4.9	6.2	5.6	1 on 3
A-4	D	239.1	>	16.5	>	16.2	>	16.8	No	DM>pen; appears to be older/weathered muddy DM with well developed aRPD; several subsurface voids	2	10.7	12.5	11.6	1 on 3
A-5	A	231.5	>	16.0	>	15.5	>	16.3	No	DM>pen; sulfidic mud w/ well developed aRPD; large subsurface void/burrow complex; surf tubes	2	4.1	8.4	6.3	1 on 3
A-5	B	202.5	>	14.0	>	13.8	>	14.5	No	DM>pen; moderately sulfidic mud w/ moderate aRPD contrast; 2 small voids@bottom of image; small surf tubes	2	13.6	13.9	13.8	1 on 3
A-5	C	203.1	>	14.0	>	13.6	>	14.4	No	DM>pen; moderately sulfidic mud w/ moderate aRPD contrast; old/weathered DM; 1 void+surf tubes; vertical oxy burrow	1	7.3	7.6	7.5	1 on 3
B-1	A	227.5	>	15.7	>	15	>	16.1	No	DM>pen; sulfidic mud w/ moderate to strong aRPD contrast; a few surf tubes, edge of burrow transected lower left edge of image	0				2 -> 3
B-1	C	202.5	>	14.0	>	13.6	>	14.6	No	DM>pen; sulfidic mud w/ strong aRPD contrast; partial voids at depth	0				2 -> 3
B-1	D	188.9	>	13.0	>	12.7	>	13.4	No	DM>pen; sulfidic mud w/ moderate-strong aRPD contrast; 1 subsurface void; wiper clasts	1	3.4	3.7	3.6	2 -> 3
B-2	B	133.5	>	9.2	>	8.9	>	9.6	No	DM>pen; sulfidic mud w/ moderate aRPD contrast; a few small/cryptic subsurface orgs	0				1 -> 2
B-2	C	180.7	>	12.5	>	12	>	12.8	No	DM>pen; moderately sulfidic mud w/ low to moderate aRPD contrast; surf tubes but little subsurface activity	0				1
B-2	D	177	>	12.2	>	11.7	>	12.6	No	DM>pen; moderately sulfidic mud; reduced mud clasts; surf tubes+2 subsurface voids	2	9.1	10.7	9.9	1 on 3

APPENDIX C – Part 2 (CONTINUED)

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
B-3	B	193.8	>	13.4	>	12.2	>	13.5	No	DM>pen; moderately sulfidic mud w/ weak/gradual aRPD contrast; numerous surf tubes+at least 2 subsurface voids	2	2.7	8.1	5.4	1 on 3
B-3	C	196.3	>	13.5	>	13.2	>	14	No	DM>pen; moderately sulfidic mud w/ moderate aRPD contrast; dense surf tubes; voids; worm@lwr left	1	3.8	4.3	4.1	1 on 3
B-3	D	206.1	>	14.2	>	14.1	>	14.4	No	DM>pen; moderately sulfidic mud w/ moderate aRPD contrast; surf tubes+several small voids+1 small subsurface worm-like org	3	3.9	7.8	5.9	1 on 3
B-4	A	229.1	>	15.8	>	15.6	>	16	No	DM>pen; moderately sulfidic mud w/moderate aRPD contrast; surf tubes+1 void	1	3	3.4	3.2	2 -> 3
B-4	C	145.2	>	10.0	>	8.9	>	11.4	No	DM>pen; sulfidic slightly sandy mud>pen; thin aRPD w/ strong contrast; a few surf tubes	0				1
B-4	D	120.7	>	8.3	>	7.7	>	9	No	DM>pen; sulfidic slightly sandy mud>pen; vertical burrow opening; surf tubes	1	7.5	8.3	7.9	1 on 3
B-5	A	285.6	>	19.7	>	19.3	>	20.2	No	DM>pen; soft mud w/ deep aRPD w/ weak contrast grading into sulfidic mud@depth; subsurface voids	2	12.8	13.8	13.3	1 on 3
B-5	B	192.9	>	13.3	>	13.2	>	13.5	No	DM>pen; older/weathered DM; sulfidic mud w/ well-developed aRPD; 2 small voids@depth	2	8.5	11.6	10.1	1 on 3
B-5	C	238.6	>	16.5	>	16.1	>	16.7	No	DM>pen; older/weathered DM; moderately sulfidic mud w/ weak aRPD contrast; 3 subsurface voids; surf tubes; wiper clast/smear@left	3	6.7	10.6	8.7	1 on 3
BE 01	B	20.7	>	1.4	>	1	>	2.1	No	DM>pen; poorly-sorted sandy DM w/ significant coarse sand+gravel (pebbles); firm sand=low pen	IND				Indeterminate

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
BE 01	C	23.4	>	1.6		0	>	2.7	No	DM>pen; firm, poorly sorted mix of fine sand, coarse sand, shell frags, and gravel; firm texture=low pen=indeterminate aRPD and succ stg	IND				Indeterminate
BE 01	D	0		0.0		0		0	No	DM>pen; firm, poorly sorted mix of sand and rocks; no pen due to rocks	IND				Indeterminate
BE 02	A	138.9	>	9.6	>	8.4	>	11.1	No	DM>pen; poorly sorted sand and gravel over homogenous reduced mud; large stg 3 worm@right; small void; burrow@left	1	7.6	7.7	7.7	1 on 3
BE 02	C	152.3	>	10.5	>	10.1	>	11	No	DM>pen; sandy silt grading into silt clay; reduced mud w/ moderate aRPD contrast; surf tubes; small void@far left	1	3.1	3.2	3.2	1 on 3
BE 02	D	162.8	>	11.2	>	10.4	>	11.7	No	DM>pen; moderately reduced mud w/ moderate aRPD contrast; numerous reduced wiper clasts, shallow sub-surface burrows	0				2
BE 03	A	0		0		0		0	No	No pen=hard bottom=rocks (cobbles), presumably dredged material	IND				Indeterminate
BE 03	B	17.7	>	1.2		0	>	3	No	Low pen=hard bottom=rounded rocks (cobbles) over mud; presumably DM	IND				Indeterminate
BE 03	C	27.2	>	1.9	>	0.3	>	2.9	No	Low pen=poorly sorted mix of gravel, sand and mud=DM; hydroids growing on rocks	IND				Indeterminate
BE 04	B	119.2	>	8.2	>	7.6	>	8.9	No	DM>pen=S/M=upper 1-2 cm is poorly sorted mix of sand+gravel over reduced/sulfidic mud@depth; small voids+vertical oxy burrow; moderate to strong aRPD contrast	1	1.8	1.9	1.9	2 -> 3

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
BE 04	F	21.9	>	1.5	>	1	>	2.1	No	DM>pen=low pen=poorly sorted mix of mud, sand and gravel (pebbles+cobbles); hydroids on rocks	IND				Indeterminate
BE 04	G	133.1	>	9.2	>	8.4	>	9.5	No	DM>pen=S/M=upper 2-3 cm is medium to coarse sand over reduced/sulfidic muddy DM @ depth; transected edge of shallow void	0				2
BE 05	B	36.2	>	2.5	>	0	>	5.3	No	DM>pen=low pen=rounded cobbles+boulders covered with hydroids over mud/sand mix	IND				Indeterminate
BE 05	C	82.5	>	5.7	>	4.5	>	6.4	No	DM>pen=low pen=layering=poorly sorted gravel over silt/clay; profile disturbed by rock dragdown=indeterminate succ stage	IND				Indeterminate
BE 05	D	43	>	3.0	>	0.9	>	3.9	No	DM>pen=low pen=surface layer of poorly sorted gravel (rounded cobbles) over poorly sorted mix of silt/clay and sand	IND				Indeterminate
C-1	A	183.5	>	12.7	>	12.4	>	12.9	No	Layered DM>pen; 3 cm surface layers of oxidized silt over muddy/silty fine reduced sand; aRPD=surface silt layer	0				2 -> 3
C-1	B	136.5	>	9.4	>	9	>	9.8	No	DM>pen; DM=muddy fine sand; subsurface worm @ center of image+surf tubes	0				1 on 3
C-1	C	128.1	>	8.8	>	8.2	>	9.4	No	DM>pen; muddy fine to medium sand w/ sulfidic patches@depth; floccy surface; shell hash	0				2 -> 3
C-2	A	247.4	>	17.1	>	17	>	17.4	No	DM>pen; fine sand over mud w/ moderate to strong aRPD contrast; numerous surf tubes; 2 partial voids/burrows	2	4.5	5.8	5.2	1 on 3
C-2	B	175.2	>	12.1	>	11.5	>	12.8	No	DM>pen; sandy silt w/ moderate aRPD contrast; a few surf tubes+2 subsurface voids	2	6.9	8.4	7.7	1 on 3

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
C-2	C	229.8	>	15.8	>	15.6	>	16.2	No	DM>pen; fine sand over mud w/ moderate aRPD contrast; a few surf tubes+1-2 prominent voids/burrows	2	4.4	5.3	4.9	1 on 3
C-3	A	151.9	>	10.5	>	9.6	>	11.2	No	DM>pen; S/M=upper 1 to 4 cm is fine oxidized sand over reduced mud; voids/burrows	2	1.9	2.6	2.3	2 -> 3
C-3	B	126.3	>	8.7	>	7.7	>	9.9	No	DM>pen; S/M=upper 4-5 cm is fine oxidized sand over reduced mud; burrow opening	1	5.6	6	5.8	1 on 3
C-3	D	151.6	>	10.5	>	10.2	>	10.8	No	DM>pen; S/M=upper 5-6 cm is fine oxidized sand over reduced mud; void lwr left; surf tubes; small worms in sand lyr	1	10.1	10.4	10.3	1 on 3
C-4	A	221.1	>	15.2	>	14.4	>	16.5	No	DM>pen; old/weathered DM; homogenous texture; moderate aRPD contrast; subsurface void/burrow	1	6	9.7	7.9	1 on 3
C-4	B	187.1	>	12.9	>	12.7	>	13.3	No	DM>pen; old/weathered DM; homogenous texture but small sand patches; numerous surf tubes; vertical oxy burrows@depth	0				1 on 3
C-4	D	213.4	>	14.7	>	14.2	>	15.2	No	DM>pen; old/weathered DM; soft homogenous mud w/ weak to moderate aRPD contrast; surf tubes; vertical oxy burrow@depth	0				1 on 3
C-5	A	98.9	>	6.8	>	5.5	>	8.6	No	DM>pen; muddy fine sand w/ muddy floc@surface; sand=DM; large surf tubes, oxidized to depth, transected subsurface tube	0				3
C-5	B	118.8	>	8.2	>	6.1	>	9.8	No	DM>pen; fine sand w/ shell hash over patch of reduced mud@depth; burrows and worm at depth	0				3
C-5	C	79.3	>	5.5	>	4.4	>	6.9	No	DM>pen; DM=muddy fine sand; some pebbles@sed surf; floccy mud+tubes@sed surface; subsurface voids & worms at depth	2	1.5	2.3	1.9	1 on 3

APPENDIX C – Part 2 (CONTINUED)

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
D-1	A	174.9	>	12.1	>	11.3	>	12.5	No	DM>pen; layer of sandy silt/clay on surface transitioning to all silt/clay; shell frags; surf tubes+ subsurface burrow & worms	1	6	6.7	6.4	1 on 3
D-1	B	152.3	>	10.5	>	10.4	>	10.8	No	DM>pen; sandy silt/clay w/ small shell hash; surf tubes+void/burrow complex in lwr right corner	3	7.8	9.6	8.7	1 on 3
D-1	C	184.9	>	12.8	>	12.2	>	13.6	No	DM>pen; sandy silt/clay w/ weak to moderate aRPD contrast; surf tubes+shell frags, Maldanid tube in background above SWI	0				1 on 3
D-2	B	206.8	>	14.3	>	14.1	>	14.6	No	DM>pen; sandy silt/clay w/ strong aRPD contrast; surf tubes+one partial void	1	7.3	7.8	7.6	1 on 3
D-2	C	184.1	>	12.7	>	12.5	>	13.3	No	DM>pen; sandy silt/clay at surface w/ strong aRPD contrast; surf tubes+several voids+subsurface worm@bottom of central void	3	4.4	7.1	5.8	1 on 3
D-2	D	208	>	14.3	>	14	>	14.7	No	DM>pen; sandy silt/clay at surface w/ strong aRPD contrast; surf tubes; Caprellid@swi	0				1 ->2
D-3	B	176.2	>	12.2	>	11.8	>	12.8	No	DM>pen; slightly sandy silt/clay @ surface w/ strong aRPD contrast; burrow/white organism in lwr right corner	0				1 on 3
D-3	C	258.3	>	17.8	>	17.1	>	18.7	No	DM>pen; multiple depositional horizons, burrow openings in PV image; grey clay patches; a few surf tubes but little subsurface activity in profile image	0				1 ->2
D-3	D	220	>	15.2	>	14.8	>	15.5	No	DM>pen; slightly sandy silt/clay @ surface w/ strong aRPD contrast; portions of worms against faceplate @ depth, burrow openings in plan view image	0				1 on 3

APPENDIX C – Part 2 (CONTINUED)

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
D-4	A	204.1	>	14.1	>	13.9	>	14.5	No	DM>pen; soft sulfidic mud w/ moderate to strong aRPD contrast; many small wiper clasts@swi; edge of burrow transected at depth, burrow openings in PV image	0				1 on 3
D-4	B	281.1	>	19.4	>	18.7	>	19.9	No	DM>pen; sandy silt/clay w/ very thin aRPD w/ strong contrast; fresh DM; grey clay streaks; some cryptic surf tubes and subsurface burrows	0				2->3
D-4	D	154.6	>	10.7	>	9.7	>	11.3	No	DM>pen; sandy silt/clay on surface w/ thin oxy surface veneer of sandy silt; prominent vertical burrow	1	3.7	9.8	6.8	1 on 3
D-5	A	248.4	>	17.1	>	16.8	>	17.5	No	DM>pen; soft sulfidic mud w/ thin aRPD w/ strong contrast; surf tubes+several subsurface voids; blowout of reduced sed@swi=artifact	4	2.2	10.1	6.2	1 on 3
D-5	B	244.9	>	16.9	>	16.4	>	17.2	No	DM>pen; soft sulfidic mud w/ strong aRPD contrast; small surf tubes multiple DM depositional horizons	0				1
D-5	C	209.7	>	14.6	>	14.2	>	14.9	No	DM>pen; soft sulfidic mud w/ weak aRPD contrast (grading into strongly sufidic@depth); a few surf tubes	0				1
E-1	A	208.2	>	14.4	>	14	>	14.7	No	DM>pen; soft sulfidic mud w/ strong aRPD contrast; surf tubes; fresh DM	0				1
E-1	C	176	>	12.1	>	11.9	>	12.4	No	DM>pen; soft sulfidic mud w/ strong aRPD contrast; relatively fresh DM; edge of burrow transected subsurface mid-left	0				1 on 3
E-1	D	163.8	>	11.3	>	11	>	11.8	No	DM>pen; sandy silt clay with some surface shell fragments w/ strong aRPD contrast	2	3.2	6.1	4.7	1 on 3
E-2	A	225.5	>	15.6	>	15.4	>	15.8	No	DM>pen; soft sulfidic mud w/ moderate to strong aRPD contrast; small surf tubes; 1 prominent void	1	7.4	8.9	8.2	1 on 3

APPENDIX C – Part 2 (CONTINUED)

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
E-2	B	223.3	>	15.4	>	14.9	>	15.9	No	DM>pen; soft sulfidic mud w/ moderate to strong aRPD contrast; 1 partial void/burrow; small surf tubes	1	7	7.5	7.3	1 on 3
E-2	C	212.3	>	14.6	>	14.5	>	14.8	No	DM>pen; soft sulfidic mud w/ weak aRPD contrast but black@depth; surf tubes+void/burrow in lwr right corner	1	12.3	12.9	12.6	1 on 3
E-3	A	201.3	>	13.9	>	13.7	>	14.3	No	DM>pen; soft sulfidic mud w/ moderate to strong aRPD contrast; partial feeding voids@left; surf tubes	0				2->3
E-3	B	177.7	>	12.3	>	12	>	12.7	No	DM>pen; sulfidic mud w/ grey clay streaks; subsurface void+worm-like org; small surf tubes	1	5.7	8.2	7.0	1 on 3
E-3	D	200.2	>	13.8	>	13.5	>	14.1	No	DM>pen; slightly sulfidic slightly sandy mud w/ weak to moderate aRPD contrast; several voids/burrows	3	6	11.9	9.0	1 on 3
E-4	A	216.8	>	15.0	>	14.2	>	15.4	No	DM>pen; sulfidic sandy mud>pen; upper 3-5 cm is sandy over black silt/clay; partial void; subsurface worm visible against faceplate	0				1 on 3
E-4	B	167.6	>	11.6	>	11	>	12.2	No	DM>pen; sulfidic mud>pen; upper 1-2 is oxy fine sand over black streaky silt/clay@depth; 1 small void+ portion of bivalve against faceplate in upper right quadrant of image	1	4.7	4.7	4.7	2->3
E-4	C	223.8	>	15.4	>	14.1	>	15.8	No	DM>pen; sandy silt/clay at the surface w/ moderate to strong aRPD contrast>pen; partial void; small surf tubes; shell frags	1	5.4	6	5.7	1 on 3
E-5	A	275.4	>	19.0	>	18.6	>	19.3	No	DM>pen; sulfidic soft mud>pen; weak aRPD contrast grading into very black mud@depth	0				2
E-5	C	230.3	>	15.9	>	14.9	>	17.2	No	DM>pen; moderately sulfidic soft mud>pen; surf tubes+feeding void; vertical oxy burrow	1	11.3	11.6	11.5	1 on 3

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
E-5	D	217.8	>	15.0	>	14.6	>	15.3	No	DM>pen; slightly sandy mud>pen; weak to moderately sulfidic; weak aRPD contrast; surf tubes, evidence of subsurface burrowing	0				1 on 3
REF E 1	A								No	Ambient sediment; soft mud w/ some fine sand; weak aRPD contrast; Ampelisca tubes at SWI wth a few small worms in subsurface seds.	0				2 on 3
REF E 1	B								No	Ambient sediment; soft mud w/ some very fine sand, especially in upper 8-10 cm; numerous voids+small worm-like orgs@depth; wiper clasts on sediment surface	5	7.9	17.3	12.6	1 on 3
REF E 1	C								No	Ambient soft sed; soft mud w/ some very fine sand, esp. in upper 5-7 cm; weak aRPD contrast; low sulfides; large Nephtys+several smaller worms; wiper clasts @ surface	1	9.1	9.2	9.2	1 on 3
REF E 2	A								No	Ambient soft mud w/ some very fine sand, esp upper layers; dense surf tubes; several voids/burrows+at least 1 subsurface worm visible	2	5.1	13.8	9.5	1 on 3
REF E 2	C								No	Ambient soft mud w/ significant fine sand in upper layers; surf tubes; weak aRPD contrast=low sulfides; several voids+1or2 subsurface worms	3	8.3	15.3	11.8	1 on 3
REF E 2	D								No	Ambient soft mud w/ no excess organic loading; surf tubes; low sulfides; dense surf tubes, burrow openings in plan view	0				1 on 3
REF E 3	B								No	Ambient soft mud w/ weak aRPD contrast; Maldanid tube; subsurface burrow/void; several subsurface polychaetes	1	12.2	13.7	13.0	1 on 3

APPENDIX C – Part 2 (CONTINUED)

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN	TOTAL DM MIN	TOTAL DM MAX	Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
REF E 3	C					No	Ambient soft mud w/ weak aRPD contrast; low sulfides; bio reworking of upper 1 cm;voids/burrows with visible susbsurface polychaete	2	12.1	12.6	12.4	1 on 3
REF E 3	D					No	Ambient soft mud w/ minor fine sand; weak aRPD contrast=low sulfides; large-bodied polychaete w/ void+several other voids	4	7.9	16.4	12.2	1 on 3
REF E 4	B					No	Ambient soft mud w/ fine sand in upper layer; void; 1 small subsurface worm; surf tubes	1	4.4	5.6	5.0	1 on 3
REF E 4	F					No	Ambient soft mud w/ some fine sand; weak aRPD contrast=low sulfides; deep void/burrow; 1 small subsurface worm	1	14.6	15.1	14.9	1 on 3
REF E 4	H					No	Ambient soft mud w/ some very fine sand; weak aRPD contrast=low sulfides; deep large voids/burrows+1 large worm +small orgs+surf tubes; wiper clasts	2	8.8	12.1	10.5	1 on 3
REF E 5	B					No	Ambient muddy fine sand/sandy mud; 1 large tube in farfield, bivalve shells against faceplate at depth	0				1 on 3
REF E 6	A					No	Ambient silt/clay with fine sand in upper layer; numerous surf tubes; several partial voids/burrows+at least 1 subsurface worm	3	8	12.6	10.3	1 on 3
REF E 6	B					No	Ambient silty, poorly-sorted fine to very fine sand; void in lwr left corner but mostly out of frame; low sulfide inventory in sed	0				3
REF E 6	C					No	Ambient silty fine to medium sand with low sulfide inventory; ; 1 feeding void w/ oxy burrow/tube above+below	1	5	5.3	5.2	3

APPENDIX C – Part 2 (CONTINUED)

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN	TOTAL DM MIN	TOTAL DM MAX	Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
REF NE 1	A					No	Ambient muddy fine sand with surf tubes, voids/burrows; low sulfide inventory	3	7.6	10.3	9.0	1 on 3
REF NE 1	B					No	Ambient muddy fine sand grading to muddy fine sand@depth; large burrow@depth w/ subsurface polychaetes visible	1	10.4	11.9	11.2	1 on 3
REF NE 1	D					No	Ambient fine sand in upper 3-5 cm grading into silt/clay w/ minor fine sand@depth; several voids/burrows@depth; low sulfide inventory	3	2.8	13.1	8.0	1 on 3
REF NE 2	A					No	Ambient silty very fine to fine sand in upper 5-7 cm grading into sandy silt/clay@depth; low sulfide inventory; several small subsurface orgs+small cryptic voids/burrows; surf tubes	5	2.7	11.8	7.3	1 on 3
REF NE 2	C					No	Ambient muddy very fine sand; low sulfidesinventory; surf tubes+2 subsurface voids/burrows (1 w/ worm within)	2	8.8	10.4	9.6	1 on 3
REF NE 2	D					No	Ambient muddy very fine sand; low sulfide inventory; surf tubes; voids/burrows	2	5.4	5.8	5.6	1 on 3
REF NE 3	B					No	Ambient muddy very fine sand; low sulfide inventory; surf tubes; small/cryptic voids@depth	2	8.5	8.8	8.7	1 on 3
REF NE 3	C					No	Ambient muddy very fine sand; low sulfide inventory; surf tubes; shallow burrow+deeper burrow/org@left	2	2.3	8.5	5.4	1 on 3
REF NE 3	D					No	Ambient muddy very fine sand; low sulfide inventory; shell frags; shallow burrow@left; voids@lwr left; small subsurface orgs	1	10.4	10.8	10.6	1 on 3

APPENDIX C – Part 2 (CONTINUED)

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN	TOTAL DM MIN	TOTAL DM MAX	Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
REF NE 4	A					No	Ambient silty fine to very fine sand; surf tubes; voids/burrow complex@depth; low sulfide inventory	4	2.5	7.8	5.2	1 on 3
REF NE 4	B					No	Ambient silty, poorly-sorted fine sand; shell frags; ripple; low sulfide inventory with subsurface voids/burrows	3	3.2	8	5.6	1 on 3
REF NE 4	C					No	Ambient silty, poorly-sorted fine to very fine sand; surf tubes; large burrow/void; aRPD > penetration, well-mixed & aerated sediment column	3	4.4	7	5.7	1 on 3
REF NE 5	A					No	Ambient silty, poorly-sorted fine to very fine sand; surf tubes; large burrow complex; aRPD > penetration, well-mixed & aerated sediment column	3	5.4	9.8	7.6	1 on 3
REF NE 5	B					No	Ambient silty, poorly-sorted fine to medium sand; dense surf tubes; voids+burrows; shell frags	5	5.2	10.1	7.7	1 on 3
REF NE 5	C					No	Ambient silty, poorly-sorted fine to very fine sand; surf tubes; burrows/voids; u-shaped orange worm @depth	5	2.8	10	6.4	1 on 3
REF SW 1	B					No	Ambient silty fine to very fine sand with intense bio reworking of upper 5-6 cm=burrows+voids; surf tubes; Caprellids@swi	8	0.7	7.6	4.2	1 on 3
REF SW 1	C					No	Ambient silty fine to very fine sand; dense surf tubes; numerous voids/burrows; low sulfide inventory	7	2.3	10	6.2	1 on 3
REF SW 1	D					No	Ambient silty fine to very fine sand; dense surf tubes; numerous burrows, prominent void, worms visible against faceplate	2	2.2	5.8	4.0	1 on 3

APPENDIX C – Part 2 (CONTINUED)

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN	TOTAL DM MIN	TOTAL DM MAX	Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
REF SW 2	A					No	Ambient silty fine to very fine sand; dense surf tubes w/ Caprellids; shallow voids; low sulfide inventory, evidence of burrows to depth of penetration	2	0.5	1.1	0.8	2 on 3
REF SW 2	B					No	Ambient silty very fine sand; surf tubes; spionid tube in center background; numerous voids/burrows, especially in upper 5-8 cm	4	2.1	6.8	4.5	1 on 3
REF SW 2	C					No	Ambient very fine sandy silt, with a higher percentage of sand in the upper 7-8 cm; low sulfides; dense surf tubes; numerous small voids/burrows; 2 larger-bodied worms@depth	6	1.4	5.3	3.4	1 on 3
REF SW 3	A					No	Ambient silty fine sand/sandy silt/clay; large burrow opening; small voids; surf tubes	2	0.8	8.7	4.8	1 on 3
REF SW 3	B					No	Ambient silty very fine sand with intense bioturbation=numerous burrows/voids in upper layers; surf tubes; stg 3 taxa visible against faceplate at depth	8	0.7	6.1	3.4	2 on 3
REF SW 3	D					No	Ambient silty very fine sand with dense tubes+several shallow voids/burrows; Ampelisca tubes @ SWI; larger-bodied worm@depth	6	1.3	3.5	2.4	2 on 3
REF SW 4	A					No	Ambient silty very fine sand; low sulfides; dense tubes+numerous shallow voids/burrows; deeper voids; Ampelisca tubes	6	0.8	6.9	3.9	2 on 3
REF SW 4	B					No	Ambient silt/clay w/ minor very fine sand; surf tubes (some Ampelisca); burrows/voids; large-bodied worm@depth	3	1.3	6.3	3.8	2 on 3

APPENDIX C – Part 2 (CONTINUED)

SPI Raw Data

Station	REP	TOTAL DM AREA	TOTAL DM MEAN		TOTAL DM MIN		TOTAL DM MAX		Low DO?	COMMENT	Feeding Void #	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Mean Depth (cm)	Successional Stage
REF SW 4	D								No	Ambient silty very fine sand with dense surf tubes+numerous Caprellids; several voids/burrows; worm@depth	4	1	5.7	3.4	2 on 3
REF SW 5	A								No	Ambient silty very fine sand with surf tubes+dense Caprellids; evidence of burrows @ depth, burrow openings in plan view	0				2 on 3
REF SW 5	B								No	Ambient silty very fine to fine sand, dense Caprellids; aRPD > penetration depth, burrow openings in plan view	0				2 on 3
REF SW 5	C								No	Ambient silty very fine to fine sand, dense Caprellids; aRPD > penetration depth, a few burrow openings in plan view	0				2->3

APPENDIX D

PLAN-VIEW RAW DATA

APPENDIX D

Plan-view Raw Data

STATION	REP	Date	Time	Length of image (cm)	Height of image (cm)	Field of View imaged (m^2)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Mudclasts	Debris	COMMENT
A-1	A	10/5/2009	10:08	79	52.5	0.41	silt/clay	n	y	n	y	n	n	n	silty brown mud w/ numerous pits+tracks; a few shell frags
A-1	B	10/5/2009	10:09	93.2	61.9	0.58	silt/clay	n	y	n	y	n	n	n	silty brown mud w/ numerous pits+tracks; several white shell frags; 1-2 burrow openings
A-1	C	10/5/2009	10:10	81.7	54.2	0.44	silt/clay	n	y	n	y	n	n	n	silty brown mud w/ numerous pits+tracks; several shell frags; 1-2 burrow openings
A-2	A	10/5/2009	10:25	IND	IND	IND	silt/clay	n	n	n	y	n	n	n	fuzzy image=no lasers=indeterminate dimensions; looks like silt/clay w/ tracks
A-2	B	10/5/2009	10:26	IND	IND	IND	silt/clay	n	y	n	y	n	n	n	fuzzy image=no lasers=indeterminate dimensions; silt/clay w/ tracks & 2 burrow openings
A-2	C	10/5/2009	10:27	IND	IND	IND	silt/clay	n	y	n	y	n	n	n	4 prominent burrow openings, numerous tracks, mostly silt/clay
A-3	A	10/5/2009	10:31	82.5	54.6	0.45	silt/clay	n	y	n	y	n	n	n	silt/clay with pits, tracks and burrow openings
A-3	B	10/5/2009	10:32	82.8	54.8	0.45	silt/clay	n	n	n	y	n	n	n	silt/clay with pits and tracks
A-3	C	10/5/2009	10:33	84.7	56.1	0.48	silt/clay	n	y	n	y	n	n	n	silt/clay with prominent demersal fish feeding pits and multiple tracks
A-4	A	10/5/2009	10:39	90.5	60	0.54	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks and burrows
A-4	C	10/5/2009	10:41	86.6	57.4	0.50	silt/clay	n	y	n	y	n	n	n	silt/clay w/ burrows, pits, and tracks
A-4	D	10/5/2009	10:42	87.6	58.2	0.51	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks and burrows
A-5	A	10/5/2009	10:47	80.2	53.5	0.43	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks and burrows
A-5	B	10/5/2009	10:47	87.5	58	0.51	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks and burrows
A-5	D	10/5/2009	10:49	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	image is cloudy - seafloor obscured by turbidity - not analyzed
B-1	A	10/5/2009	11:11	82.2	54.4	0.45	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks and burrows; a few shell frags
B-1	B	10/5/2009	11:12	91.1	60.4	0.55	silt/clay	n	y	n	y	n	n	n	image is fuzzy; silt/clay w/ pits, tracks and burrows
B-1	D	10/5/2009	11:14	80.4	53.4	0.43	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, burrows+one deep gouge, small fish in top center of image
B-2	A	10/5/2009	11:17	85.2	56.5	0.48	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, with a few burrows

Plan-view Raw Data

STATION	REP	Date	Time	Length of image (cm)	Height of image (cm)	Field of View imaged (m^2)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Mudclasts	Debris	COMMENT
B-2	B	10/5/2009	11:18	86.3	57.2	0.49	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, with a few burrows
B-2	D	10/5/2009	11:20	78.3	51.9	0.41	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, with a few burrows
B-3	B	10/5/2009	11:23	85.2	56.3	0.48	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, with a few burrows
B-3	C	10/5/2009	11:24	83.4	54.2	0.45	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, with a few burrows
B-3	D	10/5/2009	11:25	86.8	57.7	0.50	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, with a few burrows
B-4	A	10/5/2009	11:29	90.3	59.8	0.54	silt/clay	n	y	n	y	y	n	n	silt/clay w/ pits, tracks, a few burrows; two small (juvenile=2 to 3 cm) crabs
B-4	B	10/5/2009	11:30	86.7	57.6	0.50	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, a few burrows; a few small shell frags
B-4	D	10/5/2009	11:32	78.9	52.4	0.41	silt/clay	n	y	n	y	y	n	n	silt/clay w/ pits, tracks, burrows, shell frags; 2 small crabs
B-5	A	10/5/2009	11:40	72.6	48.2	0.35	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, with a few burrows
B-5	B	10/5/2009	11:40	79.2	52.5	0.42	silt/clay	n	y	n	y	n	n	n	silt/clay w/ pits, tracks, several large burrows
B-5	C	10/5/2009	11:41	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	image is cloudy - seafloor obscured by turbidity - not analyzed
BE 01	B	10/5/2009	17:12	77.6	51.5	0.40	mixed gravel	n	n	n	n	n	n	n	mixed gravel (mostly pebbles+granules w/ a few small cobbles) interspersed with sand or silt
BE 01	C	10/5/2009	17:12	86.3	57.2	0.49	mixed gravel	n	n	n	n	y	n	n	mixed gravel (mostly pebbles+granules w/ a few small cobbles); several pink shrimp visible
BE 01	D	10/5/2009	17:13	91.7	60.6	0.56	mixed gravel	n	n	n	n	n	n	n	mixed gravel (pebbles+granules and small cobbles); shell frags
BE 02	A	10/5/2009	15:23	77.5	51.4	0.40	silty sand mixed with minor gravel	n	y	n	y	y	n	n	mostly silty mud w/ some pieces of gravel and shell frags; tracks+burrows, crab
BE 02	B	10/5/2009	15:24	80.4	53.2	0.43	mixed gravel w/ silty sand	n	n	n	n	n	n	n	mixed gravel, including rounded small cobbles; on top of silt or sand; somewhat fuzzy image
BE 02	C	10/5/2009	15:24	95.4	63.1	0.60	silty sand	n	y	n	n	n	n	n	silt/clay w/ tracks, small burrows; pits; several shell frags

Plan-view Raw Data

STATION	REP	Date	Time	Length of image (cm)	Height of image (cm)	Field of View imaged (m^2)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Mudclasts	Debris	COMMENT
BE 03	A	10/5/2009	17:00	60.9	40.4	0.25	mixed gravel+cobbles	n	n	n	n	y	n	n	mixed coarse sand and gravel (granules and pebbles) w/ some cobble; many rounded rocks; epifaunal growth on the cobbles; many pink shrimp
BE 03	B	10/5/2009	17:01	81.1	53.7	0.44	mixed gravel	n	n	n	n	y	n	n	mixed gravel w/ epifauna growth (hydroids)
BE 03	C	10/5/2009	17:02	IND	IND	IND	mixed gravel	n	n	n	n	IND	n	n	fuzzy image; no lasers; mixed gravel
BE 04	C	10/5/2009	16:11	94.9	63	0.60	mixed gravel	n	n	n	n	y	n	n	mixed gravel; rounded+semi-rounded granules, pebbles and cobbles; numerous small crabs (2-3 cm carapace length)
BE 04	D	10/5/2009	16:12	84.3	55.8	0.47	mixed gravel	n	n	n	n	y	n	n	mixed gravel=granules to pebbles; 1 asteroid; several small crabs
BE 04	F	10/5/2009	16:50	91.5	60.6	0.55	mixed gravel	n	n	n	n	y	n	n	mixed gravel=granules to pebbles and a few small cobbles; epifaunal growth on a few rocks; 1 large crab; numerous small pink shrimp
BE 05	A	10/5/2009	16:33	75	49.7	0.37	mixed gravel	n	n	n	n	y	n	n	mixed gravel; numerous small crabs and shrimp+1 large crab;
BE 05	B	10/5/2009	16:34	86.9	57.7	0.50	mixed gravel and sand	n	y	n	n	y	n	n	mixed gravel and sand; several small crabs and numerous small pink shrimp; burrow openings w/ excavated sediment; epifaunal growth on some of the rocks
BE 05	C	10/5/2009	16:35	88.5	58.7	0.52	mixed gravel	n	n	n	n	y	n	n	mixed gravel; a few small crabs
C-1	A	10/5/2009	14:29	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	image is cloudy - seafloor obscured by turbidity - not analyzed
C-1	B	10/5/2009	14:30	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	image is cloudy - seafloor obscured by turbidity - not analyzed
C-1	C	10/5/2009	14:30	91.7	54.3	0.50	silty sand	n	IND	IND	IND	y	IND	IND	image is cloudy - looks like silt/clay or silty sand; 1 small crab is visible
C-2	A	10/5/2009	14:36	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	image is cloudy - seafloor obscured by turbidity - not analyzed
C-2	B	10/5/2009	14:37	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	image is cloudy - seafloor obscured by turbidity - not analyzed

Plan-view Raw Data

STATION	REP	Date	Time	Length of image (cm)	Height of image (cm)	Field of View imaged (m²)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Mudclasts	Debris	COMMENT
C-2	E	10/5/2009	14:39	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	IND	image is cloudy - seafloor obscured by turbidity - not analyzed
C-3	A	10/5/2009	14:43	IND	IND	IND	silt/clay	n	IND	IND	IND	y	IND	IND	image is cloudy - looks like silt/clay; 1 small crab is visible; no lasers
C-3	B	10/5/2009	14:44	IND	IND	IND	sandy silt w/ some gravel	n	IND	IND	IND	IND	IND	IND	image is cloudy - looks like silt/clay w/ some gravel + shell frags; only 1 laser visible
C-3	C	10/5/2009	14:44	IND	IND	IND	silt/clay	n	IND	IND	IND	y	IND	IND	image is cloudy - looks like silt/clay; 1 small crab is visible; no lasers
C-4	B	10/5/2009	14:49	IND	IND	IND	silt/clay	IND	IND	IND	IND	IND	IND	IND	image is cloudy - seafloor obscured by turbidity - possibly silt/clay; not analyzed
C-4	C	10/5/2009	14:50	IND	IND	IND	silt/clay	n	n	n	y	y	n	n	image slightly cloudy; looks like silt/clay w/ tracks and pits; 1 crab visible; burrows??
C-4	D	10/5/2009	14:51	IND	IND	IND	silt/clay	n	y	n	y	n	n	n	image slightly cloudy; no lasers; silt/clay w/ numerous tracks+pits
C-5	A	10/5/2009	14:56	85.1	57.7	0.49	silty sand	n	n	n	y	n	n	n	image slightly cloudy; SPI shows silty sand; plan-view has tracks+pits; shell frags
C-5	C	10/5/2009	14:57	92.8	61.4	0.57	silty sand	n	n	n	y	n	n	n	image slightly cloudy; SPI shows silty sand; plan-view has scattered gravel+shells; some tracks
C-5	D	10/5/2009	14:58	82.8	54.9	0.45	silty sand	n	y	n	y	n	n	n	SPI shows silty sand; plan-view shows numerous tracks+a few burrow openings
D-1	A	10/5/2009	13:40	87.7	58	0.51	silt/clay	n	y	n	y	n	n	n	silt/clay w/ small burrows, pits, a few tracks, numerous small shell frags
D-1	C	10/5/2009	13:41	89.9	59.6	0.54	silt/clay	n	y	n	y	n	n	n	silt/clay w/ lots of shells and shell frags; a few small burrow openings; pits
D-1	D	10/5/2009	13:42	89.6	59.4	0.53	silt/clay	n	n	n	y	n	n	n	silt/clay w/ many pits, burrow openings and tracks; scattered shell frags
D-2	B	10/5/2009	13:47	93.3	61.8	0.58	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings, and numerous small tracks

APPENDIX D – (CONTINUED)

Plan-view Raw Data

STATION	REP	Date	Time	Length of image (cm)	Height of image (cm)	Field of View imaged (m^2)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Mudclasts	Debris	COMMENT
D-2	C	10/5/2009	13:48	88.6	58.6	0.52	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks, a few shell frags
D-2	D	10/5/2009	13:49	84.7	56.1	0.48	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks, a few shell frags
D-3	B	10/5/2009	13:52	85.8	56.8	0.49	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks, a few shell frags
D-3	C	10/5/2009	13:53	82.7	54.7	0.45	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks, a few shell frags
D-3	D	10/5/2009	13:54	83.9	55.5	0.47	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks
D-4	A	10/5/2009	13:57	81.3	53.9	0.44	silt/clay	y	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks; very slight/subtle bedforms
D-4	B	10/5/2009	13:58	86.2	57.4	0.49	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks; some shells
D-4	C	10/5/2009	13:59	88.6	58.7	0.52	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; 1 burrow opening has reduced sed halo; numerous tracks
D-5	A	10/5/2009	14:03	80.6	53.3	0.43	silt/clay	n	y	n	y	y	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks; 1 asteroid (appears to be Henricia)
D-5	B	10/5/2009	14:04	89.9	59.7	0.54	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks
D-5	D	10/5/2009	14:06	81.8	54.3	0.44	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, large burrow openings; numerous tracks
E-1	A	10/5/2009	15:29	76.1	50.6	0.39	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks
E-1	C	10/5/2009	15:30	67	44.5	0.30	silt/clay	n	y	n	y	n	n	n	silt/clay w/ many pits, some burrow openings; numerous tracks; scattered shell frags
E-1	D	10/5/2009	15:32	IND	IND	IND	silt/clay	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows silt/clay; numerous shells+shell frags visible in plan-view

APPENDIX D – (CONTINUED)

Plan-view Raw Data

STATION	REP	Date	Time	Length of image (cm)	Height of image (cm)	Field of View imaged (m^2)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Mudclasts	Debris	COMMENT
E-2	A	10/5/2009	15:36	90.6	60	0.54	silt/clay	n	y	n	y	n	n	n	slightly fuzzy image; silt/clay w/ pits, burrows, tracks
E-2	B	10/5/2009	15:36	86.7	57.5	0.50	silt/clay	n	y	n	y	n	n	n	slightly fuzzy image; silt/clay w/ pits, burrows, tracks
E-2	C	10/5/2009	15:37	87.3	58.5	0.51	silt/clay	n	y	n	y	n	n	n	slightly fuzzy image; silt/clay w/ pits, burrows, tracks
E-3	A	10/5/2009	15:42	80.4	53.3	0.43	silt/clay	n	y	n	y	n	n	n	slightly fuzzy image; silt/clay w/ pits, burrows, tracks
E-3	B	10/5/2009	15:43	85.7	56.7	0.49	silt/clay	n	y	n	y	n	n	n	slightly fuzzy image; silt/clay w/ pits, burrows, tracks; a few shells
E-3	C	10/5/2009	15:44	IND	IND	IND	silt/clay	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows silt/clay
E-4	A	10/5/2009	15:51	88.2	58.3	0.51	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; faint tracks; numerous shells+shell frags
E-4	B	10/5/2009	15:52	95.8	63.5	0.61	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; faint tracks; numerous shells+shell frags
E-4	D	10/5/2009	15:53	85.7	56.8	0.49	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks; numerous shells+shell frags
E-5	A	10/5/2009	15:56	89.1	58.9	0.52	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
E-5	B	10/5/2009	15:57	93.1	59	0.55	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
E-5	C	10/5/2009	15:58	IND	IND	IND	silt/clay	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows silt/clay
REF E 1	A	10/4/2009	10:18	94.5	62.7	0.59	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 1	B	10/4/2009	10:19	95.1	62.9	0.60	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 1	D	10/4/2009	10:20	87.1	57.7	0.50	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 2	A	10/4/2009	10:33	88.3	58.5	0.52	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 2	C	10/4/2009	10:34	92.3	61.2	0.56	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 2	D	10/4/2009	10:35	85.3	56.5	0.48	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 3	A	10/4/2009	10:41	91.8	60.6	0.56	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 3	C	10/4/2009	10:42	85.4	56.6	0.48	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 3	D	10/4/2009	10:43	IND	IND	IND	silt/clay	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows silt/clay
REF E 4	E	10/4/2009	11:19	86.9	57.5	0.50	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 4	F	10/4/2009	11:20	92.4	61.4	0.57	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks

Plan-view Raw Data

STATION	REP	Date	Time	Length of image (cm)	Height of image (cm)	Field of View imaged (m²)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Mudclasts	Debris	COMMENT
REF E 4	G	10/4/2009	11:21	85.3	56.7	0.48	silt/clay	n	y	n	y	n	n	n	silt/clay w/ numerous pits; some burrow openings; tracks
REF E 6	A	10/4/2009	10:58	IND	IND	IND	sandy silt/clay	IND	IND	IND	IND	IND	IND	IND	image is slightly fuzzy from turbidity; no lasers; SPI shows sandy silt/clay; pits, burrows, faint tracks
REF E 6	C	10/4/2009	11:00	91.6	60.7	0.56	sandy silt/clay	n	y	n	y	n	n	n	image is slightly fuzzy from turbidity; SPI shows sandy silt/clay; pits, burrows, faint tracks
REF E 6	D	10/4/2009	11:01	IND	IND	IND	sandy silt/clay	n	y	n	y	n	n	n	image is slightly fuzzy from turbidity; SPI shows sandy silt/clay; pits, burrows, faint tracks
REF NE 1	B	10/4/2009	8:43	IND	IND	IND	muddy fine sand	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows muddy fine sand; shell frags in plan-view
REF NE 1	C	10/4/2009	8:44	IND	IND	IND	muddy fine sand	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows muddy fine sand
REF NE 1	D	10/4/2009	8:44	IND	IND	IND	muddy fine sand	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows muddy fine sand; shell frags visible in plan-view
REF NE 2	A	10/4/2009	9:21	96.2	63.8	0.61	muddy fine sand	n	y	y	y	n	n	n	muddy fine sand w/ shells+shell frags; burrows, tracks, pits, tubes
REF NE 2	B	10/4/2009	9:22	91.7	60.4	0.55	muddy fine sand	n	y	y	y	n	n	n	muddy fine sand w/ shells+shell frags; burrows, tracks, pits, tubes
REF NE 2	C	10/4/2009	9:23	89.3	59.2	0.53	muddy fine sand	n	y	y	y	n	n	n	muddy fine sand w/ shells+shell frags; burrows, tracks, pits, tubes
REF NE 3	A	10/4/2009	9:39	92.6	61.3	0.57	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand w/ numerous shells and shell debris; several purple sea stars; burrows, pits, faint tracks
REF NE 3	B	10/4/2009	9:40	92.5	61	0.56	muddy fine sand	n	y	y	y	n	n	n	muddy fine sand; small scattered shells, pits, tubes, a few small burrows; faint tracks
REF NE 3	C	10/4/2009	9:41	93.8	62	0.58	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand; scattered shells+shell frags; pits, tubes, a few small burrows, faint tracks, hermit crab
REF NE 4	A	10/4/2009	9:46	87.3	57.7	0.50	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand; scattered shells (quahog shells)+shell frags; pits, tubes, a few small burrows, faint tracks; several purple sea stars

Plan-view Raw Data

STATION	REP	Date	Time	Length of image (cm)	Height of image (cm)	Field of View imaged (m^2)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Mudclasts	Debris	COMMENT
REF NE 4	B	10/4/2009	9:47	84.5	56	0.47	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand; scattered gravel; pits, tubes, tracks, a few burrow openings
REF NE 4	C	10/4/2009	9:48	89.6	59.4	0.53	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand; numerous burrows, tubes, tracks, pits, mounds; a few shells
REF NE 5	A	10/4/2009	9:53	89.6	59.5	0.53	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand; numerous burrows, tubes, tracks, pits, mounds; a few shells
REF NE 5	B	10/4/2009	9:54	80.3	53.2	0.43	muddy fine sand	n	y	y	y	n	n	n	muddy fine sand; numerous tubes and pits; a few burrows; tracks
REF NE 5	C	10/4/2009	9:54	81	53.8	0.44	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand; numerous tubes+pits; burrows; tracks; shells (including 1 large quahog shell); purple sea star
REF SW 1	C	10/5/2009	8:23	86.7	57.5	0.50	muddy fine sand	n	y	y	y	n	n	n	muddy fine sand; tubes, burrows, tracks, piece of shell; pits
REF SW 1	D	10/5/2009	8:24	94.4	62.6	0.59	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand or sandy mud; burrows, pits, tubes, faint tracks, sea star
REF SW 1	E	10/5/2009	8:25	99.1	65.7	0.65	muddy fine sand	n	y	y	y	n	n	n	muddy fine sand or sandy mud; burrows, pits, tubes, faint tracks
REF SW 2	A	10/5/2009	8:31	93.8	62.2	0.58	muddy fine sand	n	y	y	y	n	n	n	muddy fine sand or sandy mud; dense tubes, burrows, pits, faint tracks, shell frags; patch of reduced excavated sed
REF SW 2	B	10/5/2009	8:32	100.4	66.5	0.67	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand/sandy mud; tubes, tracks, pits, burrows, sea stars; patch of reduced excavated sed
REF SW 2	C	10/5/2009	8:33	88.3	58.5	0.52	muddy fine sand	n	y	y	y	y	n	n	muddy fine sand/sandy mud; tubes, tracks, pits, burrows, sea stars
REF SW 3	A	10/5/2009	8:39	IND	IND	IND	muddy fine sand	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows sandy mud/muddy fine sand w/ lots of bio activity
REF SW 3	C	10/5/2009	8:41	IND	IND	IND	muddy fine sand	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows sandy mud/muddy fine sand w/ lots of bio activity
REF SW 3	D	10/5/2009	8:41	IND	IND	IND	muddy fine sand	IND	IND	IND	IND	IND	IND	IND	image is fuzzy from turbidity; no lasers; SPI shows sandy mud/muddy fine sand w/ lots of bio activity

Plan-view Raw Data

STATION	REP	Date	Time	Length of image (cm)	Height of image (cm)	Field of View imaged (m²)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Mudclasts	Debris	COMMENT
REF SW 4	A	10/5/2009	8:45	87.4	57.8	0.51	sandy silt/clay	n	y	y	y	y	y	n	silt/clay w/ some fine sand; purple sea stars; pits, burrows, tubes, tracks; patches of reduced excavated sediment
REF SW 4	C	10/5/2009	8:47	98.6	65.4	0.64	sandy silt/clay	n	y	y	y	n	n	n	silt/clay w/ some fine sand; pits, burrows, faint tracks, tubes
REF SW 4	D	10/5/2009	8:47	97.4	64.6	0.63	sandy silt/clay	n	y	y	y	y	n	n	silt/clay w/ some fine sand; pits, burrows, faint tracks, tubes, sea star
REF SW 5	B	10/5/2009	8:54	88.8	58.9	0.52	muddy fine sand	n	y	y	n	y	n	n	muddy-silty very fine sand; shell frags; pits, burrows, 1 purple sea star
REF SW 5	C	10/5/2009	8:54	99.9	66.2	0.66	muddy fine sand	n	n	y	y	y	n	n	muddy-silty very fine sand; several purple sea stars; shells+shell frags; pits, faint tracks, tubes, burrows
REF SW 5	E	10/5/2009	8:55	92.7	61.5	0.57	muddy fine sand	n	y	y	y	y	n	n	muddy-silty very fine sand; sea stars; small shell frags, pits, burrows, faint tracks, tubes

APPENDIX E

NON-PARAMETRIC BOOTSTRAPPED CONFIDENCE LIMITS

APPENDIX E

Non-parametric Bootstrapped Confidence Limits

Bootstrapping is a statistical resampling procedure that uses the sample data to represent the entire population in order to construct confidence limits around population parameters. Bootstrapping assumes only that the sample data are representative of the underlying population, so random sampling is a prerequisite for appropriate application of this method.

Bootstrapping procedures entail resampling, with replacement, from the observed sample of size n. Each time the sample is resampled, a summary statistic (e.g., mean or standard deviation) of the bootstrapped sample is computed and stored. After repeating this procedure many times, a summary of the bootstrapped statistics is used to construct the confidence limit. For the bootstrap-*t* method (e.g., Manly 1997, pp. 56-59; or Lunneborg 2000, pp. 129-131), the bootstrapped statistic (T) is a pivotal statistic, which means that the distribution of T is the same for all values of the true mean (θ). The bootstrap-*t* is essentially the "Studentized" version (i.e., subtract the mean and divide by the standard error, as is done to obtain the Student *t*-distribution for the sample mean) of the statistic of interest. This approach is quite versatile, and can be applied to construct a confidence interval around any linear combination of means (Lunneborg 2000, p. 364).

For the purpose of constructing a confidence interval around the true value for the linear combination of means ($\theta = \mu_{Ref} - \mu_{Mound}$) the pivotal statistic T for the true difference is defined as

$$T = \frac{d - \theta}{SE(d)} \qquad \text{(Eq. A-1)}$$

We assume that this is adequately approximated by the bootstrap sampling distribution of T, denoted T*:

$$T^* = \frac{d^* - \hat{\theta}}{SE(d^*)} \qquad \text{(Eq. A-2)}$$

This distribution is comprised of the studentized statistic (T^*_B) computed from a large number (B) of randomly chosen bootstrapped samples y_1^*, y_2^*, … y_B^* from each of our eight group populations. Here, d^* is the linear combination of group means for the bootstrapped sample; $\hat{\theta}$ is the observed difference in sample means from the original samples; $SE(d^*)$ is the estimated standard error of the linear contrast.

The 5th and the 95th quantiles of the T^* distribution ($T^*_{0.05}$ and $T^*_{0.95}$, respectively) satisfy the equations:

$$\Pr[\frac{\theta - d}{SE(d)} > T^*_{0.05}] = 0.95 \quad \text{(Eq. A-3a)}$$

$$\Pr[\frac{\theta - d}{SE(d)} < T^*_{0.95}] = 0.95 \quad \text{(Eq. A-3b)}$$

Rearranging these equations yields 95% confidence in each of the following two inequalities:

$$\Pr[d + T^*_{0.05}\ SE(d) < \theta] = 0.95 \quad \text{(Eq. A-4a)}$$

$$\Pr[d + T^*_{0.95}\ SE(d) > \theta] = 0.95 \quad \text{(Eq. A-4b)}$$

Bootstrapping is used to estimate the values $T^*_{0.05}$, $T^*_{0.95}$ and $SE(d)$. The left side of equation A-4a represents the 95% lower confidence limit on the difference equation ($\mu_y - \mu_x$); the left side of equation A-4b is the 95% upper confidence limit on the difference equation. Based on the two one-sided testing (TOST) approach presented in McBride (1999), if the bounds computed by Equations A-4a and A-4b are fully contained within the interval [–δ , +δ], then we conclude equivalence within δ units.

The specific steps used to compute the 95% upper and 95% lower confidence limits on the difference between two means using the bootstrap-*t* method are described below.

1. Bootstrap (sample with replacement from the original sample of size n) B = 10,000 samples of size 5 from each of the eight populations (3 reference and 5 mounds) separately.
2. Compute the T^*_B statistic for each bootstrapped set of independent samples. T^*_i is the bootstrapped-*t* statistic computed from the i^{th} bootstrap sample, defined by the following equation

$$T^*_i = \frac{\sum_{j=1}^{8} c_j \bar{y}^*_{ji} - \sum_{j=1}^{8} c_j \bar{y}_j}{SE\left(\sum_{j=1}^{8} c_j \bar{y}^*_{ji})\right)} = \frac{\sum_{j=1}^{8} c_j \bar{y}^*_{ji} - \sum_{j=1}^{8} c_j \bar{y}_j}{\sqrt{\sum_{j=1}^{8} s^2_{y^*ji} c_j^2 / n_j}} \quad \text{(Eq. A-5)}$$

   where $\bar{y}^*_{ji}$, and $s^2_{y^*_{ji}}$ are the means and variances for the i^{th} bootstrapped sample from the j^{th} group (j=1 to 8); and $\bar{y}_j$ is the observed mean for the j^{th} group. Multiplying these group means by their respective coefficients c_j ($-1/3$, $-1/3$, $-1/3$, $1/5$, $1/5$, $1/5$, $1/5$, $1/5$) and summing the products yields the difference equation we wish to test (Equation 1). This step produces 10,000 values of the bootstrapped-*t* statistic which comprise the "bootstrap-*t* distribution".

3. Compute the standard deviation of the 10,000 bootstrapped linear combinations, $\sum_{j=1}^{8} c_j \bar{y}^*_{ji}$ and save it as SE(d). This is the bootstrap estimate of the true standard error.

4. Find $T^*_{0.05}$ and $T^*_{0.95}$, the 5th and 95th quantiles of the bootstrap-*t* distribution generated in Step 2. These values satisfy Equations A- 3a and A-3b.

5. Applying Equations A-4a and A-4b using the values $T^*_{0.05}$ and $T^*_{0.95}$ found in Step 4 gives the bootstrap-*t* estimate of the 95% lower and upper confidence limits on the difference equation, i.e.,

$$95\%\ \text{LCL} = \sum_{j=1}^{8} c_j \bar{y}_j + T^*_{0.05}\, SE(d) \qquad \text{(Eq. A-6a)}$$

$$95\%\ \text{UCL} = \sum_{j=1}^{8} c_j \bar{y}_j + T^*_{0.95}\, SE(d) \qquad \text{(Eq. A-6b)}$$

where ($\sum_{j=1}^{8} c_j \bar{y}_j$) is the linear combination expressing the difference between the mean of the three reference groups and the mean of the five disposal mounds based on the original sample observations, and *SE(d)* is the standard deviation of the bootstrapped differences computed in Step 3.

References

Lunneborg, Clifford E. 2000. Data Analysis by Resampling: Concepts and Applications. Duxbury. 556 pp. + Appendices.

Manly, Bryan F.J. 1997. Randomization, Bootstrap and Monte Carlo Methods in Biology. Second edition. Chapman & Hall, London. 340 pp. + Appendices