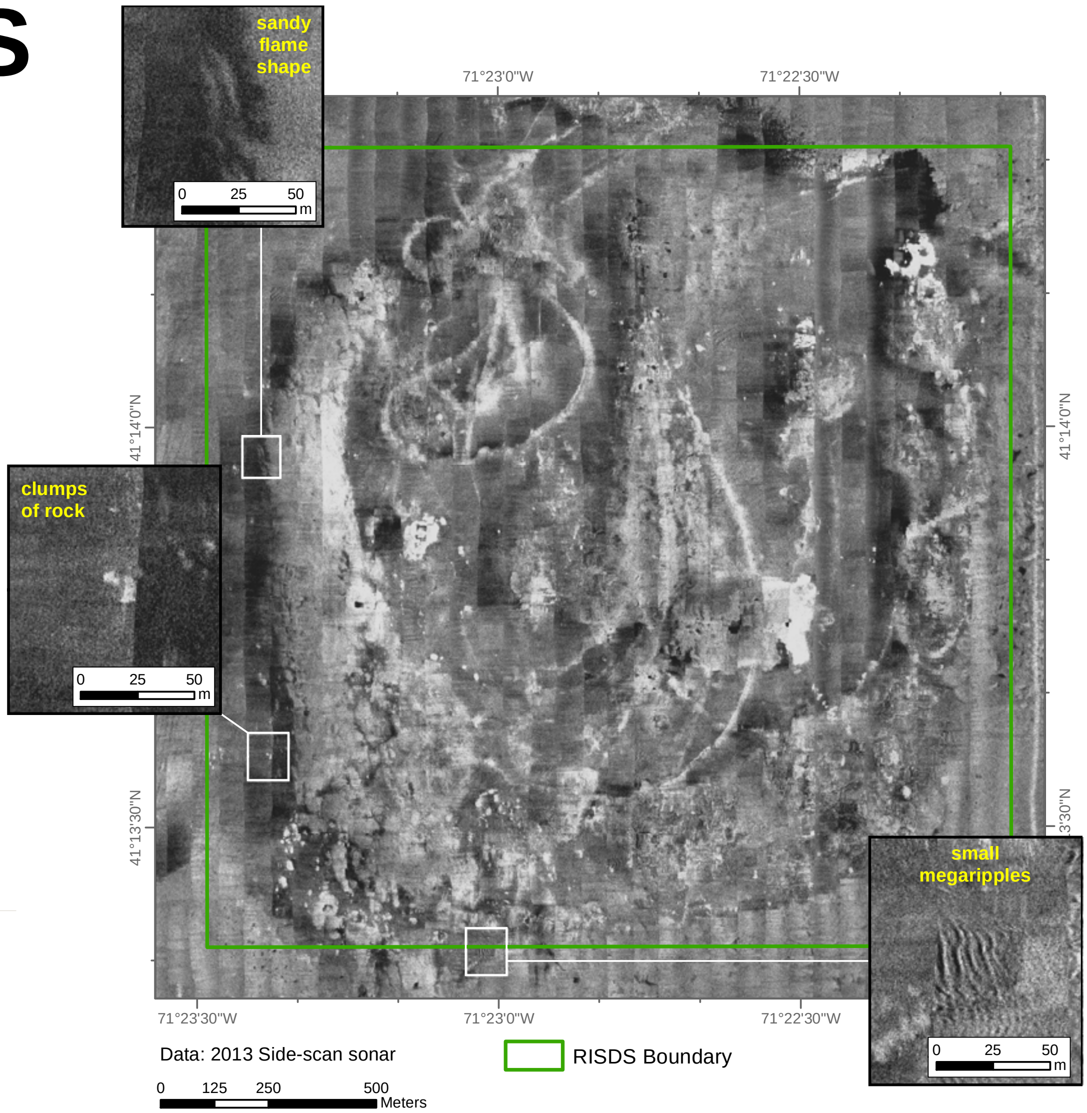
Monitoring Survey at the Rhode Island Sound Disposal Site
August 2013

Disposal Area Monitoring System DAMOS



D A M O S
DISPOSAL AREA MONITORING SYSTEM

Contribution 196
August 2015

US Army Corps
of Engineers®
New England District

This report should be cited as:

Carey, D. A.; Hickey, K.; Saffert, H.; Read, L. B. 2015. Monitoring Survey at the Rhode Island Sound Disposal Site August 2013. DAMOS Contribution No. 196. U.S. Army Corps of Engineers, New England District, Concord, MA, 105 pp.

<u>Note on units of this report</u>: As a scientific data summary, information and data are presented in the metric system. However, given the prevalence of English units in the dredging industry of the United States, conversions to English units are provided for general information in Section 1. A table of common conversions can be found in Appendix A.

REPORT DOCUMENTATION PAGE

form approved
OMB No. 0704-0188

1. AGENCY USE ONLY (LEAVE BLANK)

2. REPORT DATE
August 2015

3. REPORT TYPE AND DATES COVERED
FINAL Contribution, August 2013 Survey

4. TITLE AND SUBTITLE
Monitoring Survey at the Rhode Island Sound Disposal Site, August 2013

5. FUNDING NUMBERS
Contract No. W912WJ-12-D-0004

6. AUTHOR(S)
Drew A. Carey, Ken Hickey, Heather Saffert, Lorraine B. Read

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
DAMOSVision
215 Eustis Ave.
Newport, RI 02840

8. PERFORMING ORGANIZATION REPORT NUMBER
DV-2013-007

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers-New England District
696 Virginia Rd
Concord, MA 01742-2751

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Contribution No. 196

11. SUPPLEMENTARY NOTES
Available from DAMOS Program Manager, Evaluation Branch
USACE-NAE, 696 Virginia Rd, Concord, MA 01742-2751

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT
A monitoring survey was conducted in August 2013 at the Rhode Island Sound Disposal Site (RISDS) as part of the Disposal Area Monitoring System (DAMOS) Program. The 2013 monitoring effort involved a high-resolution acoustic survey to characterize seafloor topography and dredged material distribution, as well as a combined sediment-profile imaging (SPI)/plan-view imaging (PV) survey and benthic grab sampling to provide additional physical characterization and to assess benthic recolonization. The results of the 2013 survey were used to document changes at RISDS since the previous survey in 2009 and the subsequent placement of over 221,000 m3 of dredged material at the site.

The high-resolution acoustic survey consisted of multibeam bathymetric, acoustic backscatter and side-scan sonar data acquisition. The survey was conducted over a 2,000 × 2,000 m area that incorporated the full RISDS including the active disposal areas and past disposal target areas. The bathymetric data revealed that RISDS still contained a topographic depression in the center of the site surrounded by natural shallower areas to the south and east and a nearly continuous berm constructed of more consolidated dredged material deposits to the west. Recent dredged material placement at RISDS succeeded in extending the berm toward the northeast furthering the process of completely encircling the site.

Evidence of limited episodic sediment transport from the passage of large storms was observed around the margin of the berm. However, there were no significant changes in berm topography and no apparent reworking of the dredged material inside the berm, despite the passage of Hurricane Sandy in 2012, demonstrating the effectiveness of the disposal management strategy at this site.

SPI and PV images were collected from past disposal target areas within RISDS and three reference areas. Evidence of Stage 3 successional status was present in all replicate images from all survey stations. Low abundances of deep deposit-feeding infauna were evident throughout the disposal site. These findings suggest that the benthic community at the disposal site had recovered and was equivalent to reference area benthic communities except in abundance. Low abundance of deep deposit-feeding fauna may result in relatively shallow aRPDs. Similar to results from 2005 and 2009, the aRPD results were significantly lower at the disposal target areas than at reference areas. Statistical analysis revealed no significant difference in aRPD values between 2009 and 2013 at target areas B, C and D.

Reference area conditions were revealed by assessment of the regional seafloor topography and results suggest that reference area selection should be re-visited. Dredged material may have been placed at one station in REF-E, based on the finding of a distinctive layer of silty sand over fine sand with a very sharp interface (Figure 3-9, REF-E 2A). The presence of this deposit and the nature of sediment transport conditions at REF-NE (more mobile, hard sands than at disposal site) suggest that future surveys evaluate the reference areas with acoustic surveys and more detailed SPI/PV assessment to reassess the applicability of these areas as reference areas for RISDS.

14. SUBJECT TERMS DAMOS, dredged material, RISDS, Rhode Island Sound, acoustic, multibeam, SPI, PV, benthic, infauna

15. NUMBER OF TEXT PAGES: 105

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

MONITORING SURVEY AT THE RHODE ISLAND SOUND DISPOSAL SITE AUGUST 2013

CONTRIBUTION # 196

August 2015

Contract No. W912WJ-12-D-0004
Report No. DV-2013-007

Submitted to:
New England District
U.S. Army Corps of Engineers
696 Virginia Road
Concord, MA 01742-2751

Prepared by:
Drew A. Carey
Ken Hickey
Heather Saffert
Lorraine B. Read

Submitted by:
DAMOSVision
215 Eustis Avenue
Newport, RI 02840

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

EXECUTIVE SUMMARY

A monitoring survey was conducted in August 2013 at the Rhode Island Sound Disposal Site (RISDS) as part of the Disposal Area Monitoring System (DAMOS) Program. The 2013 monitoring effort involved a high-resolution acoustic survey to characterize seafloor topography and dredged material distribution, as well as a combined sediment-profile imaging (SPI)/plan-view imaging (PV) survey and benthic grab sampling to provide additional physical characterization and to assess benthic recolonization. The results of the 2013 survey were used to document changes at RISDS since the previous survey in 2009 and the subsequent placement of over 221,000 m^3 of dredged material at the site.

The high-resolution acoustic survey consisted of multibeam bathymetric, acoustic backscatter and side-scan sonar data acquisition. The survey was conducted over a 2,000 × 2,000 m area that incorporated the full RISDS including the active disposal areas and past disposal target areas. The bathymetric data revealed that RISDS still contained a topographic depression in the center of the site surrounded by natural shallower areas to the south and east and a nearly continuous berm constructed of more consolidated dredged material deposits to the west. Recent dredged material placement at RISDS succeeded in extending the berm toward the northeast furthering the process of completely encircling the site.

Evidence of limited episodic sediment transport from the passage of large storms was observed around the margin of the berm. However, there were no significant changes in berm topography and no apparent reworking of the dredged material inside the berm, despite the passage of Hurricane Sandy in 2012, demonstrating the effectiveness of the disposal management strategy at this site.

SPI and PV images were collected from past disposal target areas within RISDS and three reference areas. Evidence of Stage 3 successional status was present in all replicate images from all survey stations. Low abundances of deep deposit-feeding infauna were evident throughout the disposal site. These findings suggest that the benthic community at the disposal site had recovered and was equivalent to reference area benthic communities except in abundance. Low abundance of deep deposit-feeding fauna may result in relatively shallow aRPDs. Similar to results from 2005 and 2009, the aRPD results were significantly lower at the disposal target areas than at reference areas. Statistical analysis revealed no significant difference in aRPD values between 2009 and 2013 at target areas B, C and D.

Reference area conditions were revealed by assessment of the regional seafloor topography and results suggest that reference area selection should be re-visited. Dredged material may have been placed at one station in REF-E, based on the finding of a distinctive layer of silty sand over fine sand with a very sharp interface (Figure 3-9, REF-E 2A). The presence of this deposit and the nature of sediment transport conditions at REF-NE (more mobile, hard sands than at disposal site) suggest that future surveys evaluate the reference areas with acoustic surveys and more detailed SPI/PV assessment to reassess the applicability of these areas as reference areas for RISDS.

1.0 INTRODUCTION

A monitoring survey was conducted at the Rhode Island Sound Disposal Site (RISDS) in August 2013 as part of the U.S. Army Corps of Engineers (USACE) New England District (NAE) 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 RISDS, 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 are promptly identified and addressed (Germano et al. 1994). For over 35 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 fall into two general categories: confirmatory studies and focused studies. Confirmatory studies are designed to test hypotheses related to expected physical and ecological response patterns following placement of dredged material on the seafloor at established, active disposal sites. The data collected and evaluated during these studies provide answers to strategic management questions in determining the next step in the disposal site management process. Focused studies are periodically undertaken within the DAMOS Program to evaluate inactive or historical disposal sites and contribute to the development of dredged material placement and capping techniques. The resulting information is used to guide the management of disposal activities at each site. The 2013 RISDS survey was both a confirmatory study and a focused study. The survey featured confirmatory monitoring of areas that had recently received dredged material and additional focused data collection to support revision of the RISDS Site Management and Monitoring Plan (SMMP), a periodic requirement for U.S. Environmental Protection Agency (USEPA) designated offshore dredged material disposal sites.

Two primary goals of DAMOS confirmatory monitoring surveys are to document the physical location and stability of dredged material placed into the aquatic environment and to evaluate the biological recovery of the benthic community following placement of the dredged material. Several survey techniques are employed in order to characterize these responses to dredged material placement. Sequential acoustic monitoring surveys (including bathymetric, acoustic backscatter, and side-scan sonar measurements) are made to characterize the height and spread of discrete dredged material deposits or mounds created at open water sites as well as the accumulation/consolidation of dredged material into confined aquatic disposal (CAD) cells. Sediment-profile imaging (SPI) and plan-view underwater camera photography (referred to as plan-view [PV] imaging) surveys are performed to provide further physical characterization of the material and to support evaluation of seafloor (benthic) habitat conditions and recovery over time. Each type of data collection activity is conducted periodically at disposal sites and the conditions found after a defined period of disposal activity are compared with the long-term data set at a specific site to determine the next step in the disposal site management process (Germano et al. 1994). Focused DAMOS monitoring surveys may also feature additional types of data collection activities as deemed appropriate to achieve specific survey objectives, such as sub-bottom profiling, towed video, sediment coring, or grab sampling.

1.2 Introduction to the Rhode Island Sound Disposal Site

The Rhode Island Sound Disposal Site (RISDS) is located south of Narragansett Bay and approximately 16.7 km (10.4 mi) south of Point Judith, Rhode Island, within the separation zone for the Narragansett Bay shipping lanes. The site is defined as an 1800 × 1800 m (5900 × 5900 ft) area on the seafloor centered at 41°13.850' N, 71°22.817' W (NAD 83) (Figure 1-1). The RISDS was initially considered and surveyed in 1997 as an open-water disposal alternative in Rhode Island Sound for the Providence River and Harbor Maintenance Dredging Project (PRHMDP; USACE 2001). In December 2004, RISDS was officially designated as an open-water disposal site for dredged material from Rhode Island and other surrounding harbors in Massachusetts and Connecticut (40 CFR Part 228).

Prior to any dredged material disposal in 2003, 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). The RISDS topography became increasingly shallow in the southeast corner of the site, extending beyond the boundaries of RISDS to the south and east. This feature is considered part of a submerged glacial moraine formed of glacial drift and reworked coastal deposits (Figure 1-2, McMullen et al. 2011). Sediments at the site were observed to range from glacially-derived till to soft, silty sand (USEPA 2004).

1.3 Historical Dredged Material Disposal Activity

Prior to 2003, major dredging activity had not occurred in Rhode Island waters in almost 30 years. During that period, the Providence River shipping channel experienced significant infilling and shoaling. The PRHMDP was conducted to restore the depth and width of the 27-km (17-mile) long Providence River Federal Navigation Channel (USACE 2001a).

For the PRHDMP, a total of 4 million m^3 (5 million yd^3) of dredged material was placed at RISDS from April 2003 and January 2005 (Figure 1-3; Table 1-1). This total dredged material volume was composed primarily of two different types of material; (1) maintenance material for the navigation channel and (2) underlying native material that resulted from the creation of CAD cells beneath Providence River. The underlying native material was composed primarily of glacial sediments and was placed along the western boundary of the RISDS to create a continuous ridge or berm of sediment (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 to limit the lateral spread of disposed unconsolidated sediment. The maintenance material from the channel and additional material was directed to a series of disposal points across the site to create a relatively even deposit.

1.4 Previous RISDS Monitoring Events

Prior to the PRHMDP, several baseline studies were conducted as part of the site evaluation and characterization process for the Environmental Impact Study for designating RISDS (USEPA 2004) and for the PRHMDP EIS (USACE 2001a; Table 1-2 and 1-3).

A series of investigations were then conducted at RISDS throughout and immediately following the Providence River and Harbor Maintenance Dredging Project (PRHMDP, 2003 to 2005). Several studies were conducted to document changes in seafloor topography and surficial sediment composition (Valente et al. 2012a; Table 1-3). Two studies were conducted in 2004 to assess the extent of suspended sediment plumes originating from dredged material placement activities at RISDS (SAIC 2005a, 2005b). In 2005, an SPI survey was conducted to assess benthic recolonization status six months after completion of dredged material disposal activities. Also in 2005, three surveys were conducted to investigate whether the dredged material disposal resulted in any significant changes in lobster abundance at RISDS (Valente et al. 2007).

Bathymetric surveys that included RISDS were conducted as part of two National Ocean Service (NOS) surveys in 2008 and 2009 and processed by the United States

Geological Survey (McMullen et al. 2011, NOS 11996; Poppe et al. 2012, NOS 12009). An additional SPI survey was conducted in 2009 to assess benthic recolonization status.

While there have been numerous studies of RISDS (Tables 1-2 and 1-3), the previous studies of greatest relevance to the August 2013 survey were three bathymetric surveys, conducted pre-PRHMDP (2003), post-PRHMDP (2005) and later by NOS (2008-2009), and two post-PRHMDP benthic assessment surveys, conducted in 2005 and 2009. Each of these surveys is introduced briefly below.

The results of the pre-PRHMDP bathymetry survey are described above (Section 1.2; Figure 1-2). The 2005 post-PRHMDP survey confirmed the creation of a continuous ridge or berm of sediment along the western boundary of the disposal site (Figure 1-4; ENSR 2008). This berm enhanced the capacity of the topographic depression in the natural bottom and limited the potential for lateral spread of disposed unconsolidated sediment. The NOS 2008 and 2009 bathymetric survey results confirm that the relatively large-scale shallow area to the southeast and the western berm create a horseshoe-shaped feature surrounding central RISDS and open to the north (Figure 1-5).

The 2005 and 2009 benthic assessment surveys featured SPI and PV image analysis at five RISDS disposal target areas identified as areas A through E (Figure 1-6) and at three reference areas, REF-SW, REF-NE, and REF-E (Figure 1-7). Previous monitoring reports have referred to groups of disposal points at RISDS as disposal "mounds" similar to other DAMOS disposal sites. At RISDS, visible mounds of material were not formed at all groups of disposal points due to the management plan to create relatively evenly-deposited layers described below. For this report, the groups of disposal points, or as previously termed "mounds", are referred to here as disposal target areas.

Results of the 2005 RISDS survey indicated that in the six months after disposal activities had concluded, the biological community at RISDS recovered relatively rapidly, and that Stage 2 and 3 infauna were present throughout the site. 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.

The 2009 RISDS survey showed that there continued to be ample evidence of advanced succession at the stations sampled within the disposal site. The 2009 survey also found lower apparent densities of deposit-feeding Stage 3 organisms within the site compared to nearby reference areas located on the ambient seafloor (based on observations of shallower aRPDs and lack of abundance of feeding voids). This could potentially have been due to several factors including grain size differences, dredged material consolidation, elevated levels of organic matter and sulfides, and/or a lack of nearby populations of Stage 3 organisms for recruitment. Since benthic recovery at the site had proceeded at a somewhat slower rate than expected, additional benthic monitoring was recommended per the DAMOS Tiered Monitoring Protocol (Germano et al. 1994).

The 2009 survey also included assessment of the western berm and found a variety of benthic habitat types on the berm ranging from silt/clay to small rocks (pebbles and cobbles). Overall, the hard bottom conditions on the berm were found to provide habitat for a variety of epifauna, including hydroids, bryozoans, shrimp, crabs, and sea stars.

In 2008 and 2009, a small amount of maintenance dredged material from the National Marine Fisheries dock in Great Harbor, MA (approximately 23,000 m^3, [30,000 yd^3]) was placed near the center of the RISDS (Figure 1-8; Table 1-1).

1.5 Recent Dredged Material Disposal Activity

Since the 2009 survey, approximately 221,000 m^3 (289,000 yd^3) of dredged material has been placed at the site (Table 1-1). Most of this material (89%) was from improvement dredging at Quonset Point in 2012 (primarily fine sand) and was targeted to a single location near the midpoint of the northern site boundary (Figure 1-8). The remaining material came from a New Bedford Harbor CAD cell construction project (primarily glacial till and clay) and was placed at RISDS from May 2013 to February 2014. This dredged material was directed to another disposal location further west along the northern boundary (Figure 1-8).

1.6 2012 Survey Objectives

The 2013 survey was designed to address the following three objectives.

- To characterize the seafloor topography and surficial features of the full RISDS by completing a high-resolution acoustic survey. Based on the disposal history of the site, recently disposed material was expected to be found in the northwestern quadrant extending eastward from the western berm. Only minor consolidation is predicted in areas with disposal given the limited volumes disposed since 2005.

- To use SPI/PV imaging to further define the physical characteristics of surficial sediment and to assess the benthic recolonization status (recovery of the bottom-dwelling animals) of a representative portion of the site with past disposal activity. Since placement of dredged material was ongoing at the northern target area during and following the survey, SPI/PV assessment was not conducted in this active disposal area.

- Survey efforts focused on three disposal target areas B, C, and D as a representative subset of the conditions for the other target areas. Benthic conditions were expected to have improved, with more Stage 3 organisms and deeper RPDs. The disposal target areas were expected to be consistent with reference areas having similar physical characteristics. Based on the 2009 results, target areas B and D were expected to have silt/clay sediments, while target area C was expected to have mostly silty fine sand and a station or two that indicated silt and/or clay. A similar range of conditions with lower organic content was expected to occur at the reference areas.

- To obtain additional insight into the benthic community structure, sediment grab samples were collected to augment the SPI/PV imaging survey. It was predicted that coarse-grained areas would have less evidence of Stage 3 organisms and that other areas would have a benthic community consistent with those of the reference areas.

Table 1-1.

Estimated Volume of Dredged Material Placed at RISDS
from April 2003 to February 2014

Project	Disposal Dates	Volume (m^3)	Volume (yd^3)	Source
Providence River and Harbor Maintenance Dredging	04/2003 to 01/2005	4,062,000	5,312,000	Disposal logs (USACE)
National Marine Fisheries at Great Harbor, Woods Hole, MA - Maintenance Dredging	11/2008 to 01/2009	23,200	30,400	Valente et al. 2012a
Port of Davisville, Quonset Point, RI - Improvement Dredging	1/2012 to 01/2013	196,000	257,000	Disposal logs (USACE)
New Bedford Harbor CAD Cell Construction Material	05/2013 to 02/2014	24,500	32,100	Disposal logs (USACE)
Total		4,306,000	5,631,000	

USACE Reference: Data from Richard Loyd, USACE, April 2014.

Table 1-2.

Overview of DAMOS Survey Activities in Rhode Island Sound since 1997

Date	Purpose of Survey	Acoustic Surveys	SPI Stations	Additional Studies	Reference
June 1997	Evaluation of potential disposal sites		18		SAIC 1997[a]
Nov 1999	Characterize benthic resources and sediment at potential dredged material disposal sites		35		SAIC 2000[b]
Sept 2001	Rhode Island regional long-term dredged material disposal site evaluation		RISDS - 9 REF Areas - 9		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		11	Towed video 8 transects	SAIC 2004

Table 1-2. (continued)

Overview of DAMOS Survey Activities in Rhode Island Sound since 1997

Date	Purpose of Survey	Acoustic Surveys	SPI Stations	Additional Studies	Reference
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 (RISDS-A thru E BE[d]) Ref Areas - 15	Infauna Analysis	ENSR 2007
Aug 2005 Sept 2005 Nov 2005	Assess postdisposal lobster abundance			Lobster trapping	Valente et al. 2007
Oct 2009	Assess benthic recolonization status		RISDS – 30 (RISDS-A thru E BE[d]) Ref Areas - 15		ENSR 2007
Aug 2013	Assess full-site seafloor topography Assess benthic recolonization status	Multibeam 2000 x 2000 m Side-scan sonar 2000 x 2000 m	RISDS – 15 (RISDS-B, C and D) Ref Areas - 15	Infauna Analysis	Current Study

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.

d - BE refers to the berm area.

Table 1-3.

Overview of Additional Survey Activities in Rhode Island Sound since 1997

Date	Purpose of Survey	Additional Studies	Reference
1997	Shellfish Sampling and Site Characterization		USACE 1998
Fall 1999	Short-term current measurements	1-month current meter deployment	USACE 2001b
Fall 2001	Benthic/sediment characterization study	Benthic	USACE 2002c
2002 and Summer 2003	Quahog Survey		USACE 2003c
Spring 2002	Short-term current measurements	2-month current meter deployment	USACE 2003a
July 2003	Benthic/sediment characterization study	Benthic	USACE 2003b
Fall 2001; Winter and Spring 2002	Water Quality (T,S,TSS, DO, and contaminants)		USACE 2002a; USACE 2002b; USACE 2003a
Fall 2008	Surficial geology of the seafloor in central RI Sound and southeast of Point Judith, RI		McMullen et al. 2011
Spring 2009	Seafloor character and sedimentary processes of Block Island Sound, offshore RI		Poppe et al. 2012

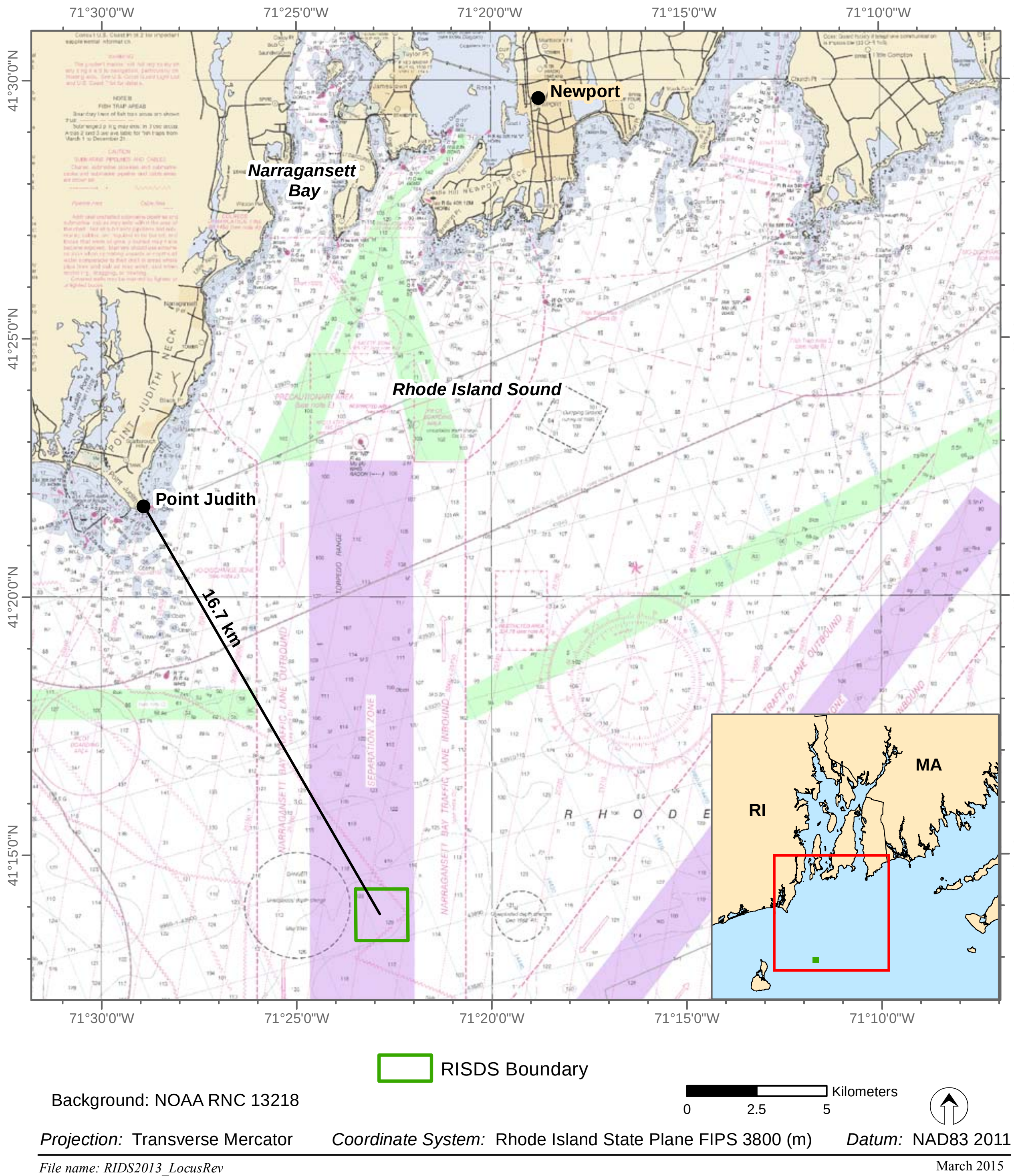


Figure 1-1. Location of the Rhode Island Sound Disposal Site (RISDS) within the vessel traffic separation zone on the approach to Narragansett Bay

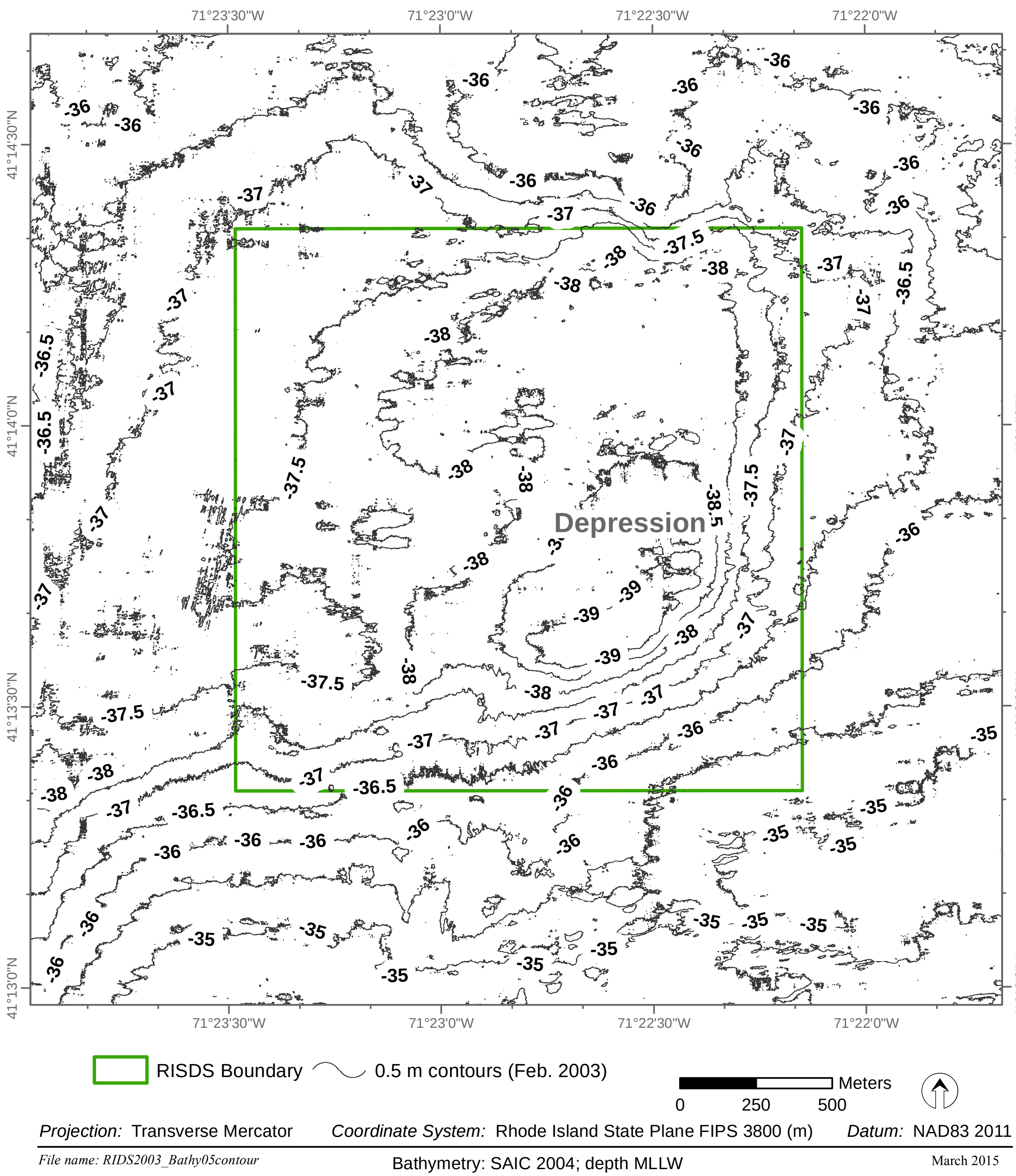


Figure 1-2. Bathymetric contour map of RISDS in February 2003, prior to any dredged material placement

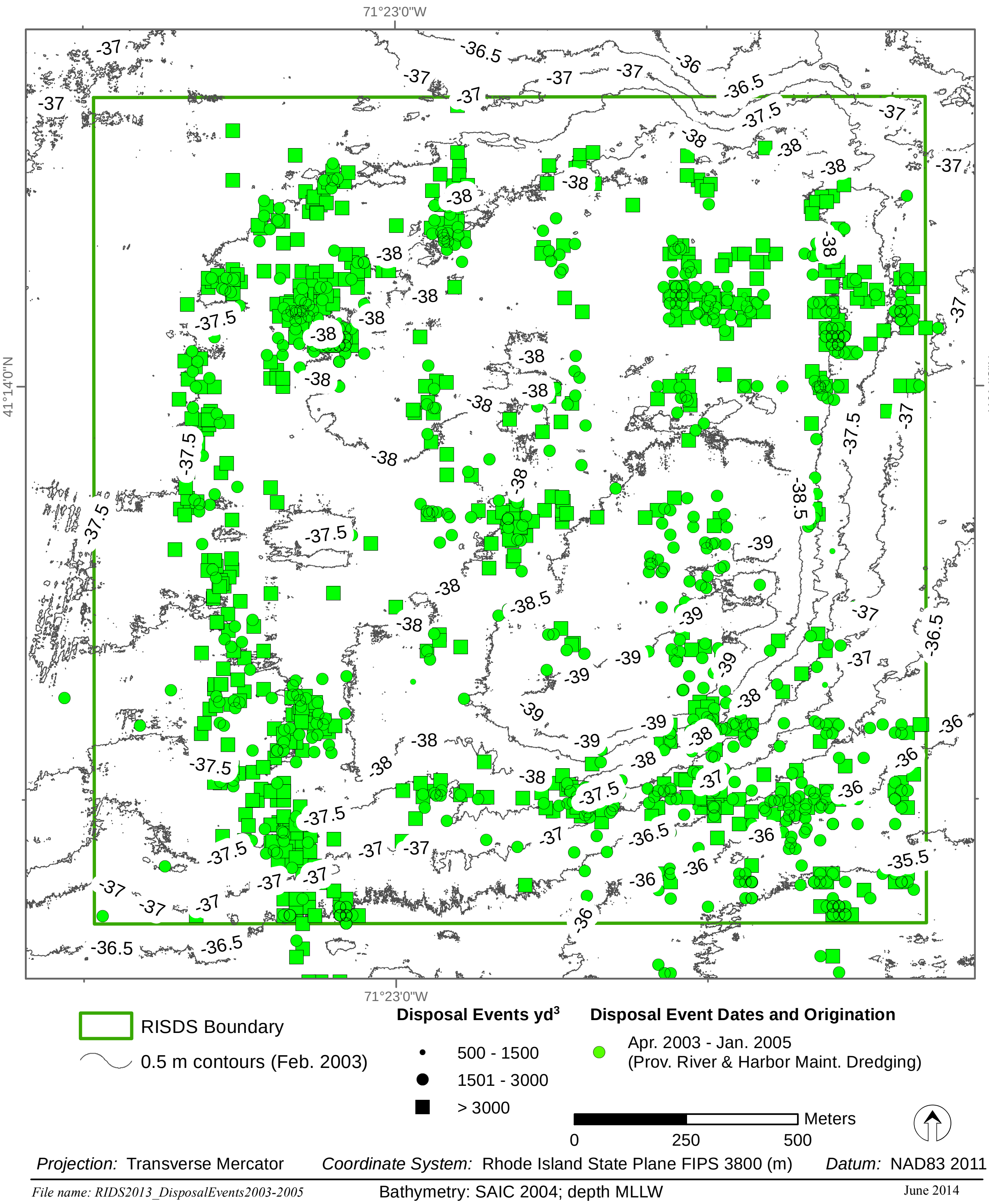


Figure 1-3. Location of reported disposal events at RISDS: 2003-2005

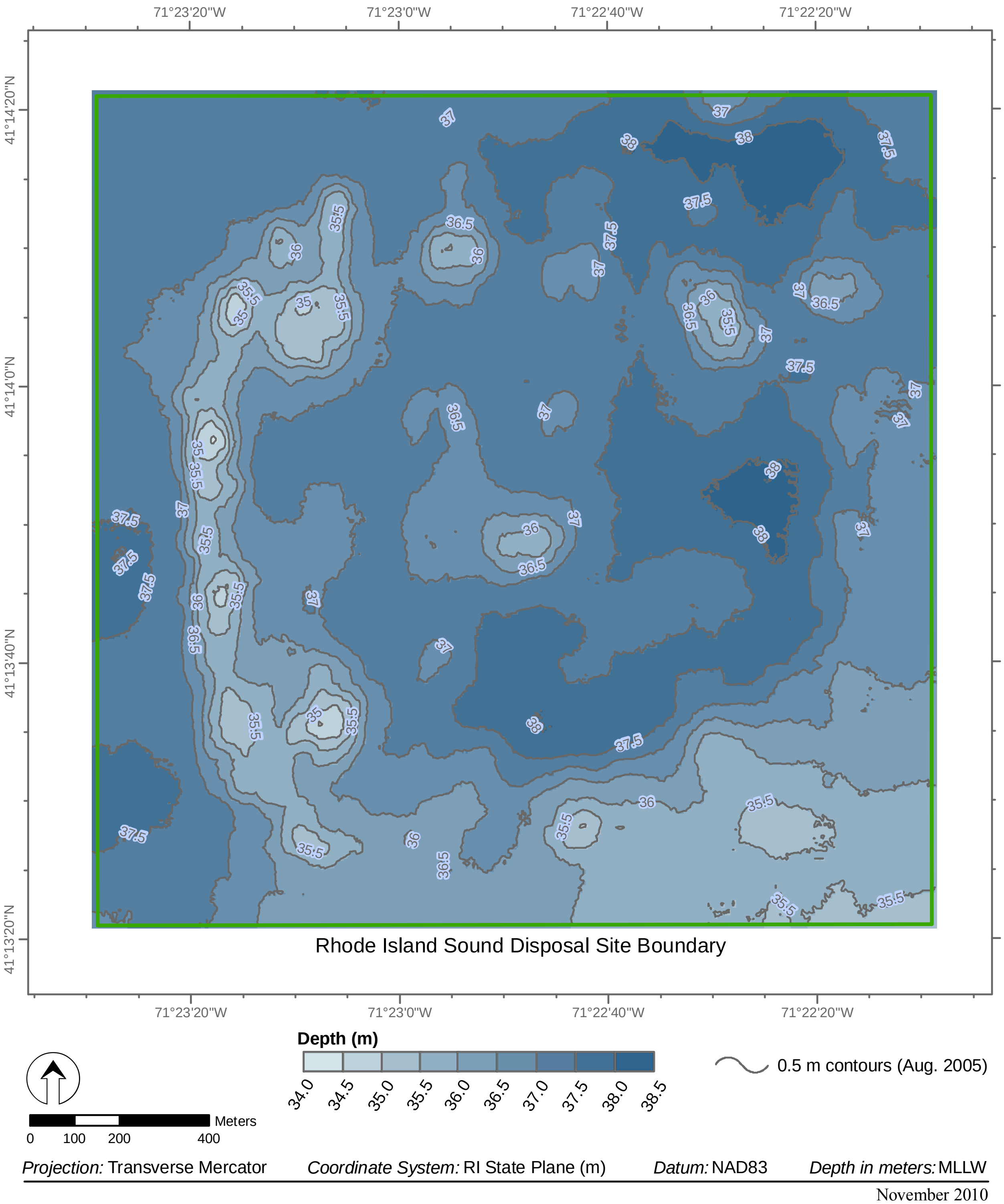


Figure 1-4. Bathymetric contour map of RISDS, August 2005 from SAIC unpublished DAMOS survey

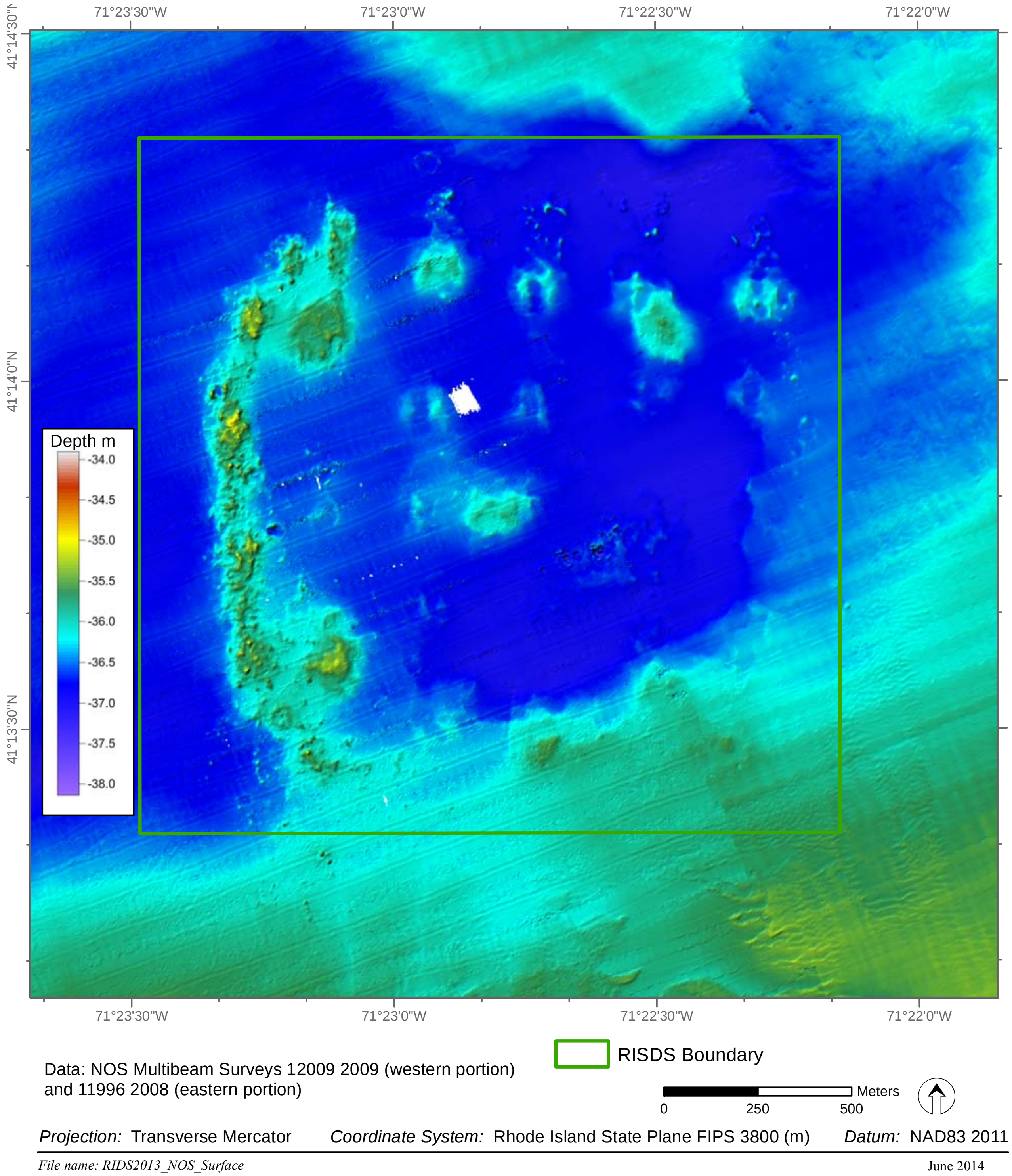


Figure 1-5. Bathymetric depth data over acoustic relief model of RISDS, 2008 and 2009 from National Ocean Service surveys

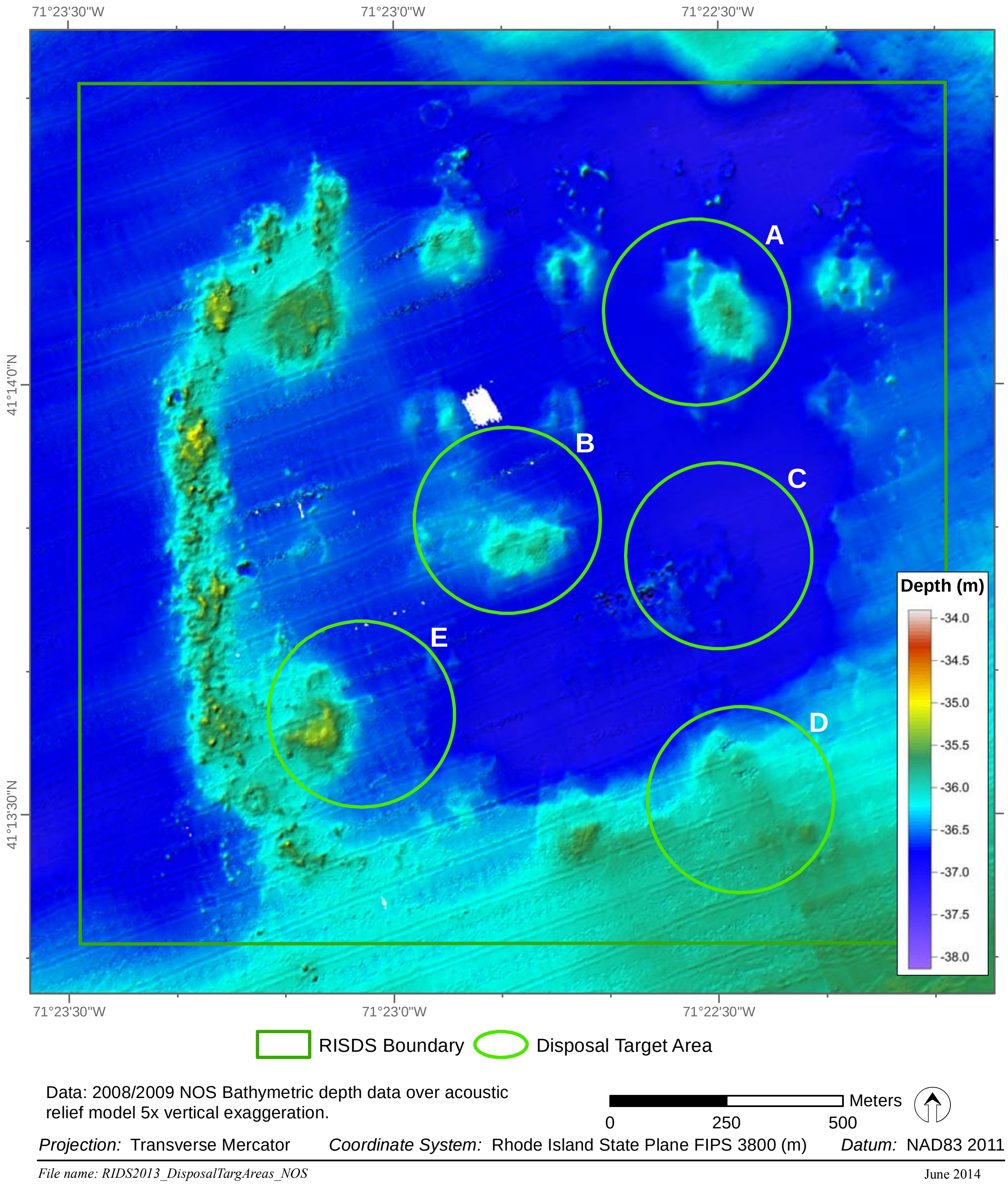


Figure 1-6. RISDS with disposal target areas indicated

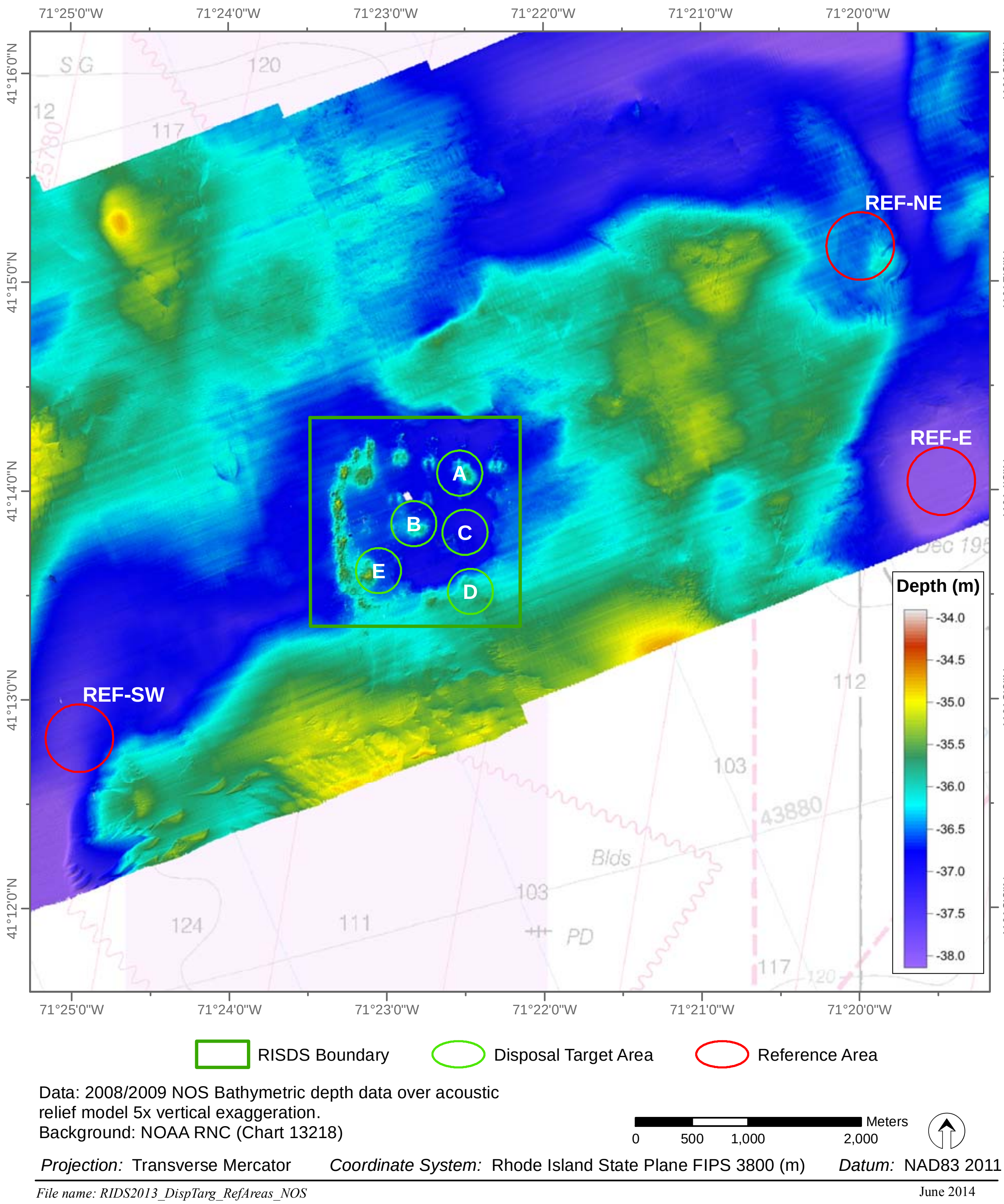


Figure 1-7. RISDS and reference areas with disposal target areas indicated

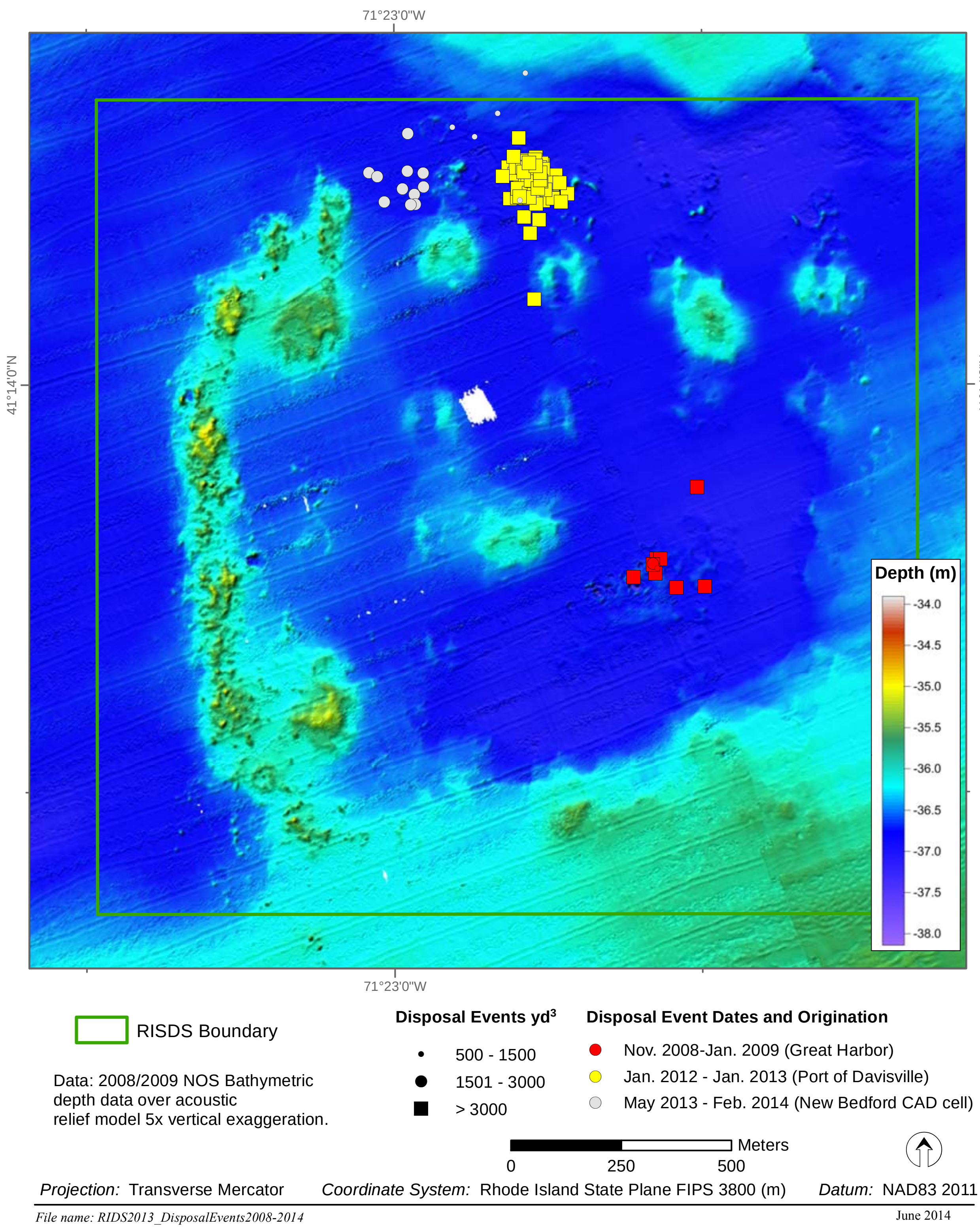


Figure 1-8. Location of reported disposal events at RISDS: 2008-2014

2.0 METHODS

The August 2013 survey at RISDS was conducted by a team of investigators from DAMOSVision (CR Environmental and Germano & Associates) and Battelle aboard the 55-foot R/V *Jamie Hanna*. The sediment-profile/plan-view (SPI/PV) imaging survey was conducted on 25 August, the acoustic survey was conducted on 27 August, and the benthic grab survey was conducted on 28 August 2013.

2.1 Navigation and On-Board Data Acquisition

Navigation for the survey was accomplished using a Hemisphere VS-110 12-channel Differential Global Positioning System (DGPS) and Digital Compass system capable of receiving satellite-based differential corrections (SBAS) and U.S. Coast Guard (USCG) Beacon corrections. Trimble DGPS systems were available as necessary as backups. Both systems are capable of sub-meter horizontal position accuracy. The DGPS system was interfaced to a laptop computer running HYPACK MAX® hydrographic survey software. HYPACK MAX® continually recorded vessel position and DGPS satellite quality and provided a steering display for the vessel captain to accurately maintain the position of the vessel along pre-established survey transects and targets.

Vessel heading measurements were provided by a dual-antenna Hemisphere VS-110 Crescent Digital compass accurate to within 0.05° up to 20 times per second. The pulse-per-second (PPS) signals from the DGPS system was hardware interfaced to HYPACK using a translation circuit and provided microsecond level accuracy of data stream time-tagging from each sensor.

2.2 Acoustic Survey

The acoustic survey in this study included bathymetric, backscatter, and side-scan sonar data collection and processing. The bathymetric data provided measurements of water depth that, when processed, were used to map the seafloor topography. The processed data were also compared with previous surveys to track changes in the size and location of seafloor features. This technique is the primary tool of the DAMOS Program for mapping the distribution of dredged material at disposal sites. Backscatter and side-scan sonar data provided images that supported characterization of surficial topography, sediment texture, and roughness. Backscatter data can be processed into a seamless image with corrections for topography while side-scan sonar data retains a higher resolution image without correction for topography. The comparison of synoptic acoustic data types has the greatest utility for assessment of dredged material placement.

2.2.1 Acoustic Survey Planning

The acoustic survey featured coverage of the entire RISDS. DAMOSVision hydrographers coordinated with USACE NAE scientists and reviewed alternative survey areas. A 2000 × 2000 m acoustic survey was selected to provide greater than 100-percent coverage of the 1800 × 1800 m RISDS seafloor. The acoustic survey design featured a series of survey lines spaced 60 m apart and cross-tie lines spaced 500 m apart (Figure 2-1). Hydrographers obtained site coordinates, imported them to ArcView GIS software, and created maps to guide survey activities. The proposed survey area encompassing the entire site was then reviewed and approved by NAE scientists.

2.2.2 Acoustic Data Collection

The 2013 multibeam bathymetric survey of RISDS was conducted on 27 August 2013. The survey was initiated on 26 August, but was suspended due to adverse weather conditions. Although the weather had improved on 27 August, conditions were still somewhat unfavorable and the resulting high seas adversely affected acoustic data collection. Bathymetric, acoustic backscatter, and side-scan sonar data were collected using a Reson 8101 Multibeam Echo Sounder (MBES). This 240-kHz system forms 101 1.5° beams distributed equiangularly across a 150° swath. The MBES transducer was mounted amidships to the port rail of the survey vessel using a high strength adjustable boom, and offsets between the primary DGPS antenna and the sonar were precisely measured and entered into HYPACK. The transducer depth below the water surface (draft) was checked and recorded at the beginning and end of data acquisition, and confirmed using the bar check method.

The MBES topside processor was equipped with components necessary to export depth solutions, backscatter, and side-scan sonar signals to the HYPACK MAX® acquisition computer via Ethernet communications. HYPACK MAX® also received and recorded navigation data from the DGPS, motion data from a serially interfaced TSS DMS 3-05 motion reference unit (MRU), and heading data from the Hemisphere compass system. Several patch tests were conducted during the surveys to allow computation of angular offsets between the MBES system components. The system was calibrated for local water mass speed of sound by performing conductivity-temperature-depth (CTD) casts at frequent intervals throughout the survey day with a Seabird SBE-19 Seacat CTD profiler. Additional confirmations of proper calibration, including static draft, were obtained using the "bar check" method, in which a metal plate was lowered beneath the MBES transducer to a known depth (e.g., 5.0 m) below the water surface. "Bar-check" calibrations were accurate to within 0.05 m in tests conducted at the beginning and end of the survey day.

2.2.3 Bathymetric Data Processing

Bathymetric data were processed using HYPACK HYSWEEP® software. Processing components are described below and included

- Adjustment of data for tide fluctuations
- Correction of ray bending associated with refraction in the water column
- Removal of spurious points associated with water column interference or system errors
- Development of a grid surface representing depth solutions
- Statistical estimation of sounding solution uncertainty
- Generation of data visualization products

NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) provided a Tide Zoning Model (TZM) calculated specifically for this survey area. The model applied a time correction of -6 minutes and a range correction of 0.87 to the six-minute Mean Lower Low Water (MLLW) data series acquired at NOAA's Newport Tide Station (#8452660). Bathymetric data processed using the TZM displayed elevated uncertainty along cross-tie lines which was minimized by applying a -12 minute offset.

Correction of sounding depth and position (range and azimuth) associated with refraction due to water column stratification was conducted using a series of six sound-velocity profiles acquired by the survey team. The water column was strongly stratified during the survey (Figure 2-2). Stratification resulted in data artifacts associated with refraction that remained in the bathymetric surface model at a relatively fine scale (generally less than 5 to 10 cm) relative to the survey depth. Bathymetric data were filtered to accept only beams falling within an angular limit of 45° to minimize refraction artifacts. Spurious sounding solutions were flagged or rejected based on the careful examination of data on a sweep-specific basis.

The 240 kHz Reson 8101 MBES system has a published nadir beam width of 1.5° (across track) and 1.5° along track. Assuming an average depth of 36.9 m and a maximum beam angle of 45°, the average diameter of the beam footprint was calculated at approximately 1.9 × 1.4 m (2.6 m^2). Because of adverse sea conditions (heave >1 m, pitch >8°, roll >9°), data were reduced to a cell (grid) size of 5.0 × 5.0 m, acknowledging the system's fine range resolution while accommodating beam position uncertainty. This data reduction was accomplished by calculating and exporting the average elevation for each cell in accordance with USACE recommendations (USACE 2002).

Within-cell standard deviations (1-sigma) ranged from 0 to 0.28 m (average 0.033 m). Ninety-five percent of the cell-specific standard deviation values were less than 0.06 m. The average Root Mean Squared uncertainty at the 95th percentile confidence interval (1.96 - sigma) was 0.087 m. Ninety-five percent of these uncertainty values were less than 0.18 m. Uncertainty estimates greater than approximately 0.10 m were associated with refraction of outer portions of the swath, with steep slopes relative to the cell diameter and in isolated areas where severe vessel motion was experienced. It is noteworthy that the most stringent National Ocean Service (NOS) standard for this project depth (Special Order 1A) would call for a 95th percentile confidence interval (95% CI) of 0.38 m at the maximum site depth (38.1 m) and 0.37 m at the mean site depth (36.9 m). Performance Standards for an NOS Order 1A survey at the mean and maximum depths would be 0.69 m and 0.70 m, respectively.

Nadir data from the mainstay and cross-tie transects were compared to further refine the uncertainty assessment. Differences between co-located points occupied on perpendicular transects were tabulated and statistically analyzed to assess and report data quality relative to promulgated USACE performance standards (note that USACE Standards were developed for a maximum depth of 24 m). The average difference between cross-tie intersections was -0.004 m (SD 0.05 m), indicating minimal tide bias. The 95th percentile accuracy estimate for cross-tie comparisons was calculated per USACE (2002) as 0.09 m, further demonstrating data compliance with the promulgated USACE performance standard of 0.61 m in depths greater than 12.2 m.

Reduced data were exported in ASCII text format with fields for Easting, Northing, and MLLW elevation (meters). All data were projected to the Rhode Island State Plane, NAD83 (metric). A variety of data visualizations were generated using a combination of IVS3D Fledermaus (V.7), ESRI ArcMap (V.10.1), and Golden Software Surfer (V. 11.6). Visualizations and data products included:

- ASCII databases of all processed soundings including MLLW depths and elevations
- Contours of seabed elevation (10-cm, 25-cm, 50-cm, and 1.0-m intervals) in SHP format suitable for plotting using GIS and CAD software
- 3-dimensional surface maps of the seabed created using 5× vertical exaggeration and artificial illumination to highlight fine-scale features not visible on contour layers (delivered in grid and TIF formats), and
- An acoustic relief map of the survey area created using 5× vertical exaggeration, delivered in georeferenced TIF format.

2.2.4 Backscatter Data Processing

MBES backscatter data were processed using HYPACK®'s implementation of GeoCoder software developed by NOAA's Center for Coastal and Ocean Mapping Joint Hydrographic Center (CCOM/JHC). GeoCoder was used to create a mosaic best suited for substratum characterization through the use of innovative beam-angle correction algorithms.

2.2.5 Side-Scan Sonar Data Processing

The side-scan sonar data were processed using both Chesapeake Technology, Inc. SonarWiz software and HYPACK®'s implementation of GeoCoder software. SonarWiz allows Empirical Gain Normalization (EGN), EGN removes the angular dependencies of the sonar backscatter so the final output image is closer to filtered backscatter and less dependent on slope. Seamless mosaics of unfiltered side-scan sonar data was developed and exported in grayscale TIF format. Individual georeferenced TIF images of each sonar file and georeferenced mosaics with resolutions of 0.2 m/pixel were generated.

2.2.6 Acoustic Data Analysis

The processed bathymetric grids were converted to rasters, and bathymetric contour lines and acoustic relief models were generated and displayed using GIS. GIS was also used to calculate depth difference grids between a 2008-2009 NOS bathymetric survey and the 2013 bathymetric dataset. The depth difference grids were calculated by subtracting the 2008-2009 survey depth estimates from the 2013 survey depth estimates at each point throughout the grid. The resulting depth differences were contoured and displayed using GIS.

Backscatter and side-scan sonar mosaics and filtered backscatter grids were combined with acoustic relief models in GIS to facilitate visualization of relationships between acoustic datasets (images and color-coded grids are rendered with sufficient transparency to allow three-dimensional acoustic relief model to be visible underneath).

2.3 Sediment-Profile and Plan-View Imaging Survey

Sediment-profile imaging (SPI) and plan-view (PV) imaging are monitoring techniques used to provide data on the physical characteristics of the seafloor and the status of the benthic biological community.

2.3.1 SPI and PV Survey Planning

For the RISDS survey, a total of 30 SPI/PV stations were surveyed; 15 stations within RISDS focused on three disposal target areas (B, C, and D; Figure 2-3) and five stations in each of three reference areas (NEREF, EREF and SWREF; Figure 2-4). Five stations were randomly located within each of the 150 m-radius circular sampling target areas and at the reference areas. SPI/PV station locations are provided in Table 2-1 and actual SPI/PV station replicate locations are provided in Appendix B.

2.3.2 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. In the 2013 survey at RISDS, high-resolution SPI images were acquired using a Nikon® D7000 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 2-5).

The camera remained on the seafloor for approximately 20 seconds to ensure that a successful image had been obtained. Details of the camera settings for each digital image are available in the associated parameters file embedded in each electronic image file. For this survey, the ISO-equivalent was set at 640, shutter speed was 1/250, f-stop was f9, and storage was in compressed raw Nikon Electronic Format (NEF) files (approximately 20 MB each). Electronic files were converted to high-resolution JPEG (8-bit) format files (3264 × 4928 pixels) using Nikon Capture® NX2 software (Version 2.2.7).

Test exposures of the Kodak® Color Separation Guide (Publication No. Q-13) were made on deck at the beginning and end of the 2013 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 the requisite number of replicates had been obtained. 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 names immediately after downloading as a further quality assurance step.

2.3.3 Plan-View Imaging

An Ocean Imaging® Model DSC16000 plan-view underwater camera (PV) system with two Ocean Imaging® Model 400-37 Deep Sea Scaling lasers mounted to the DSC16000 was attached to the sediment-profile camera frame and used to collect plan-view photographs of the seafloor surface; both SPI and PV images were collected during each "drop" of the system. The PV system consisted of a Nikon D-7000 encased in an aluminum housing, a 24 VDC autonomous power pack, a 500 W strobe, and a bounce trigger. A weight was attached to the bounce trigger with a stainless steel cable so that the weight hung below the camera frame; the scaling lasers projected two red dots that are separated by a constant distance (26 cm) regardless of the field-of-view of the PV system, which can be varied by increasing or decreasing the length of the trigger wire. 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 PV camera (Figure 2-5). Details of the camera settings for each digital image are available in the associated parameters file embedded in each electronic image file; for this survey, the ISO-equivalent was set at 400. The additional camera settings used were as follows: shutter speed 1/20, f10, white balance set to flash, color mode set to Adobe RGB, sharpening set to none, noise reduction off, and storage in compressed raw NEF files (approximately 20 MB each). Electronic files were converted to high-resolution JPEG (8-bit) format files (3264 × 4928 pixels) using Nikon Capture® NX2 software.

Prior to field operations, the internal clock in the digital PV system was synchronized with the GPS navigation system and the SPI camera. Each PV image acquired was assigned a time stamp in the digital file and redundant notations in the field and navigation logs. Throughout the survey, PV images were downloaded at the same time as the SPI images after collection and evaluated for successful image acquisition and image clarity.

The ability of the PV system to collect usable images was dependent on the clarity of the water column. Water conditions at RISDS allowed use of a 1-m trigger wire, resulting in an area of bottom visualization approximately 1 × 0.7 m in size.

2.3.4 SPI and PV Data Collection

The SPI/PV survey was conducted at RISDS on 25 August 2013 aboard the R/V *Jamie Hanna.* At each station, the vessel was positioned at the target coordinates and the camera was deployed within a defined station tolerance of 10 m. At least three replicate photographs were obtained from each station (90 SPI/90 PV total) for full analysis of benthic conditions and infaunal successional status. Three of the replicates with the best quality images from each station were chosen for analysis (Appendix C)

The DGPS described above was interfaced to HYPACK® software via laptop serial ports to provide a method to locate and record target sampling locations. Throughout the survey, the HYPACK® data acquisition system received DGPS data. The incoming data stream was digitally integrated and stored on the PC's hard drive. Actual SPI/PV sampling locations were recorded as target files using this system.

2.3.5 SPI and PV Data Analysis

Computer-aided analysis of the resulting images provided a set of standard measurements to allow comparisons between different locations and different surveys. The DAMOS Program has successfully used this technique for over 30 years to map the distribution of disposed dredged material and to monitor benthic recolonization at disposal sites (Germano et al. 2011).

Following completion of data collection, the digital images were analyzed using Adobe Photoshop® CS 5 Version 12.1. Images were first adjusted in Adobe Photoshop® to expand the available pixels to their maximum light and dark threshold range. Linear and areal measurements were recorded as number of pixels and converted to scientific units using the Kodak® Color Separation Guide for measurement calibration. Detailed results of all SPI and PV image analyses are presented in Appendix C.

2.3.5.1 SPI Data Analysis

Analysis of each SPI image 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 D. 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 bioturbational activities.

Apparent Redox Potential Discontinuity (aRPD) Depth–The aRPD depth provides a measure of the integrated time 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 gray. As the particles are buried or moved down by biological activity, they are exposed to reduced oxygen concentrations in subsurface pore waters and their oxic coating slowly reduces, changing color to dark gray or black. When biological activity is high, the aRPD depth increases; when it is low or absent, the aRPD depth decreases. The aRPD depth was measured by assessing color and reflectance boundaries within the images.

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 means of replicate values from each station. Station means were calculated from three replicates from each station and used in statistical analysis.

2.3.5.2 PV Data Analysis

The PV images provided a much larger field-of-view than the SPI images and provided valuable information about the landscape ecology and sediment topography in the area where the pinpoint "optical core" of the sediment profile was taken. Unusual surface sediment layers, textures, or structures detected in any of the sediment-profile images can be interpreted in light of the larger context of surface sediment features; i.e., is a surface layer or topographic feature a regularly occurring feature and typical of the bottom in this general vicinity or just an isolated anomaly? The scale information provided by the underwater lasers allows for accurate density counts (number per square meter) of attached epifaunal colonies, sediment burrow openings, or larger macrofauna or fish which may have been missed in the sediment-profile cross section. Information on sediment transport dynamics and bedform wavelength were also available from PV image analysis. Analysts calculated the image size and field-of-view and noted sediment type; recorded the presence of bedforms, burrows, tubes, tracks, trails, epifauna, mud clasts, and debris; and included descriptive comments (Appendix C).

2.3.6 Statistical Methods

The objectives of the 2005, 2009, and 2013 SPI surveys at RISDS were 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 B–D (target areas where disposal activity was concentrated) and reference areas for the following SPI variables: 1) aRPD depth, and 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 target area stations in 2013, as well as for differences between the August 2013 results and those from the previous survey of October 2009.

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 target areas." 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 for the 2013 Survey, there were six distinct areas, three of which were categorized as reference locations and three were disposal locations.

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 three reference means minus the mean of the three target area means, or

$$\tfrac{1}{3}\,(\text{Mean}_{\text{REF-E}} + \text{Mean}_{\text{REF-NE}} + \text{Mean}_{\text{REF-SW}}) - \tfrac{1}{3}\,(\text{Mean}_{\text{RISDS-B}} + \text{Mean}_{\text{RISDS-C}} + \text{Mean}_{\text{RISDS-D}})$$

[Eq.1]

Because of a coarser substrate at REF-NE, and indeterminate images at two of the five stations at this location, a second difference equation comparing reference to disposal target areas was also tested which excluded REF-NE from the reference group, i.e.,

$$\tfrac{1}{2}\,(\text{Mean}_{\text{REF-E}} + \text{Mean}_{\text{REF-SW}}) - \tfrac{1}{3}\,(\text{Mean}_{\text{RISDS-B}} + \text{Mean}_{\text{RISDS-C}} + \text{Mean}_{\text{RISDS-D}})$$ [Eq.2]

The standard errors of the difference equations were calculated from the fact that the variance of a sum is the sum of the variances for independent variables, or

$$se(\hat{d}) = \sqrt{\sum_j \left(S_j^2 c_j^2 / n_j\right)}$$ [Eq.3]

Where:

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

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

c_j coefficients for the *j* means in the difference equation, $\hat{d}$ (i.e., for [Eq.1] shown above, the coefficients were 1/3 for each of the three reference locations, and -1/3 for each of the three disposal target areas; for [Eq.2], the coefficients were 1/2 for both reference locations and -1/3 for the each of the three disposal target areas).

S_j^2 variance for the *j*th 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 *j*th area (up to five for each location, the actual number determined by the number of determinate results obtained).

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 Welch-Satterthwaite estimation (Satterthwaite 1946).

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 six 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 a nonparametric bootstrapped interval were used (Appendix E).

2.4 Benthic Grab Collection and Analysis

Benthic biology grab samples were collected at ten stations on 28 August 2013. Six samples were collected at stations located within RISDS, with three each in areas B and C, and four samples were collected in reference areas (two each in REF-SW and REF-NE; Figure 2-6). Grab sediment samples were analyzed for benthic infaunal community and for grain size. The ten sediment grab sampling stations were co-located with SPI stations sampled on 25 August 2013 (Table 2-1). All stations were sampled as planned except for station C-01, which was moved to SPI station C-04 based upon results from the SPI survey that indicated the substrate at C-01 was predominantly cobble. To remain consistent with the naming of the sediment grab sampling stations, the station was re-named C-04.

Sediment grab samples were collected using a 0.04-m^2 Ted Young-modified Van Veen grab sampler. At each station, the vessel was positioned at the target coordinates and grab samples were collected within a defined station tolerance of 30 m. The samples were checked for penetration depth (10 cm was the maximum and 6 cm was the minimum acceptable penetration depth), depth of the apparent redox potential discontinuity (aRPD) layer, sediment texture, odor, and observed biota.

Two grab samples were collected at each station. One grab sample was processed for grain size analyses, and the other grab sample was processed for infaunal community analysis. For grain size grab samples, the overlying water was first removed with a siphon. Next, the entire contents of the grab sample were homogenized until a consistent color and texture was achieved. An aliquot of sediment was then placed into a 125-ml clear glass jar. The grain size samples were stored on ice and shipped priority overnight to Katahdin Analytical Services (Scarborough, ME) for analysis.

The sediment grab samples for benthic community analysis were washed into clean 10 liter plastic buckets and sieved through a 0.5 mm mesh screen. The material retained on the sieve was then placed in an appropriate sample container (1 liter or 500 ml) and preserved with 10% formalin and half a tablespoon of borax to buffer the solution. The samples were hand-delivered to NAE (Concord, MA) on 30 August 2013 for sorting and analysis. NAE followed standard operating procedures for benthic community analysis of sediment grab samples (Appendix F).

Table 2-1.

RISDS 2013 Survey Target SPI/PV and Sediment Grab Station Locations

Target Station Locations			Target Reference Station Locations		
Station	Latitude (N)	Longitude (W)	Station	Latitude (N)	Longitude (W)
RISDS-B-01	41° 13.836'	71° 0.381'	REF-E-01	41° 13.976'	71° 0.325'
RISDS-B-02	41° 13.906'	71° 0.382'	REF-E-02	41° 13.984'	71° 0.327'
RISDS-B-03	41° 13.914'	71° 0.379'	REF-E-03	41° 14.119'	71° 0.326'
RISDS-B-04	41° 13.804'	71° 0.380'	REF-E-04	41° 14.042'	71° 0.324'
RISDS-B-05	41° 13.764'	71° 0.380'	REF-E-05	41° 14.023'	71° 0.322'
RISDS-C-01	41° 13.783'	71° 0.376'	REF-NE-01	41° 15.229'	71° 0.332'
RISDS-C-02	41° 13.888'	71° 0.376'	REF-NE-02	41° 15.274'	71° 0.334'
RISDS-C-03	41° 13.844'	71° 0.373'	REF-NE-03	41° 15.243'	71° 0.336'
RISDS-C-04	41° 13.794'	71° 0.374'	REF-NE-04	41° 15.051'	71° 0.334'
RISDS-C-05	41° 13.748'	71° 0.376'	REF-NE-05	41° 15.087'	71° 0.332'
RISDS-D-01	41° 13.486'	71° 0.376'	REF-SW-01	41° 12.880'	71° 0.416'
RISDS-D-02	41° 13.584'	71° 0.375'	REF-SW-02	41° 12.835'	71° 0.415'
RISDS-D-03	41° 13.594'	71° 0.374'	REF-SW-03	41° 12.849'	71° 0.417'
RISDS-D-04	41° 13.476'	71° 0.374'	REF-SW-04	41° 12.691'	71° 0.417'
RISDS-D-05	41° 13.456'	71° 0.375'	REF-SW-05	41° 12.771'	71° 0.414'

Target Benthic Grab Station Locations		
Station	Latitude (N)	Longitude (W)
RISDS-B-01	41° 13.836'	71° 0.381'
RISDS-B-02	41° 13.906'	71° 0.382'
RISDS-B-03	41° 13.914'	71° 0.379'
RISDS-C-01	41° 13.783'	71° 0.376'
RISDS-C-02	41° 13.888'	71° 0.376'
RISDS-C-03	41° 13.844'	71° 0.373'
REF-NE-01	41° 15.229'	71° 0.332'
REF-NE-02	41° 15.274'	71° 0.334'
REF-SW-01	41° 12.880'	71° 0.416'
REF-SW-02	41° 12.835'	71° 0.415'

Note: Coordinate system NAD83

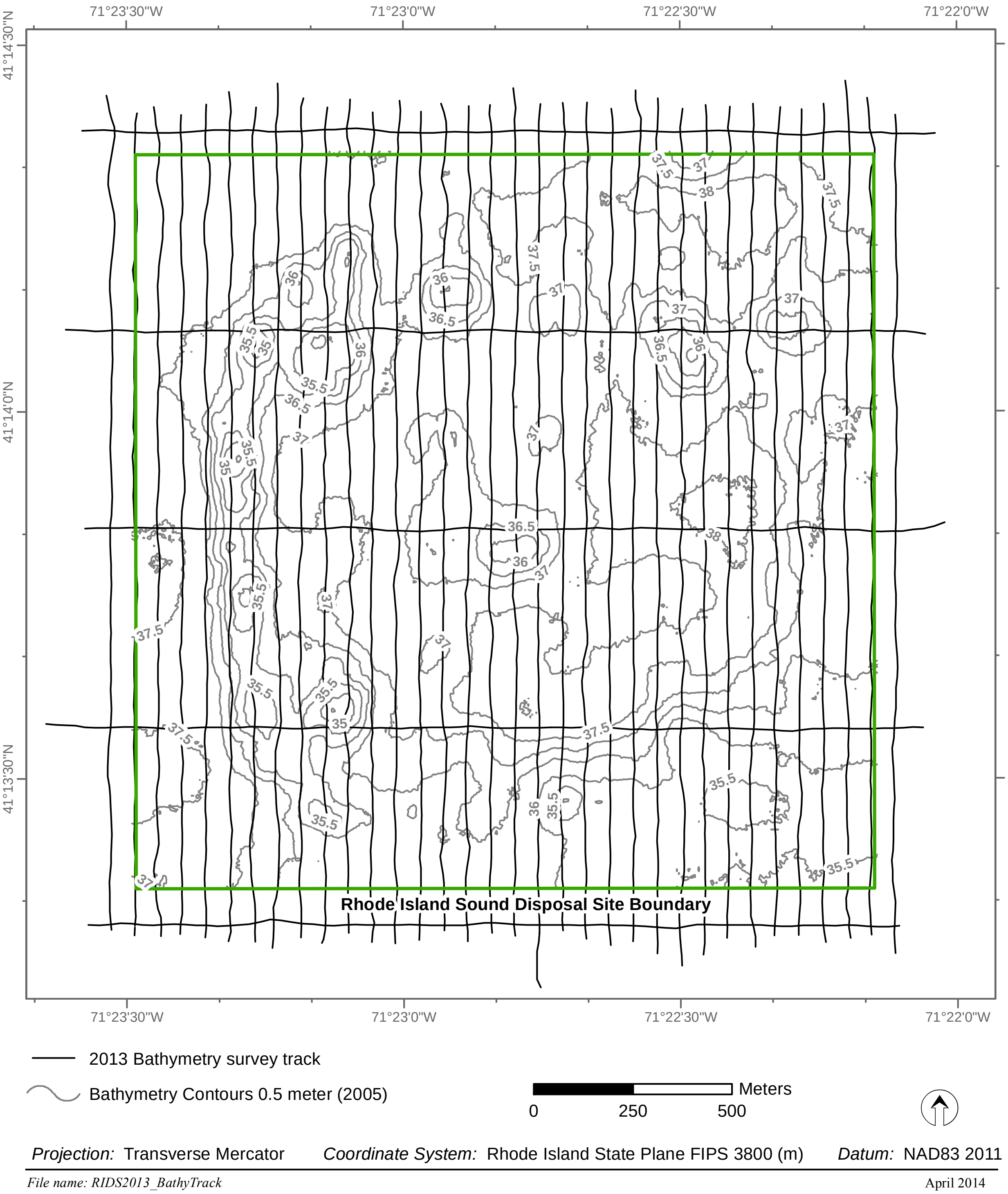


Figure 2-1. RISDS bathymetric survey area and tracklines

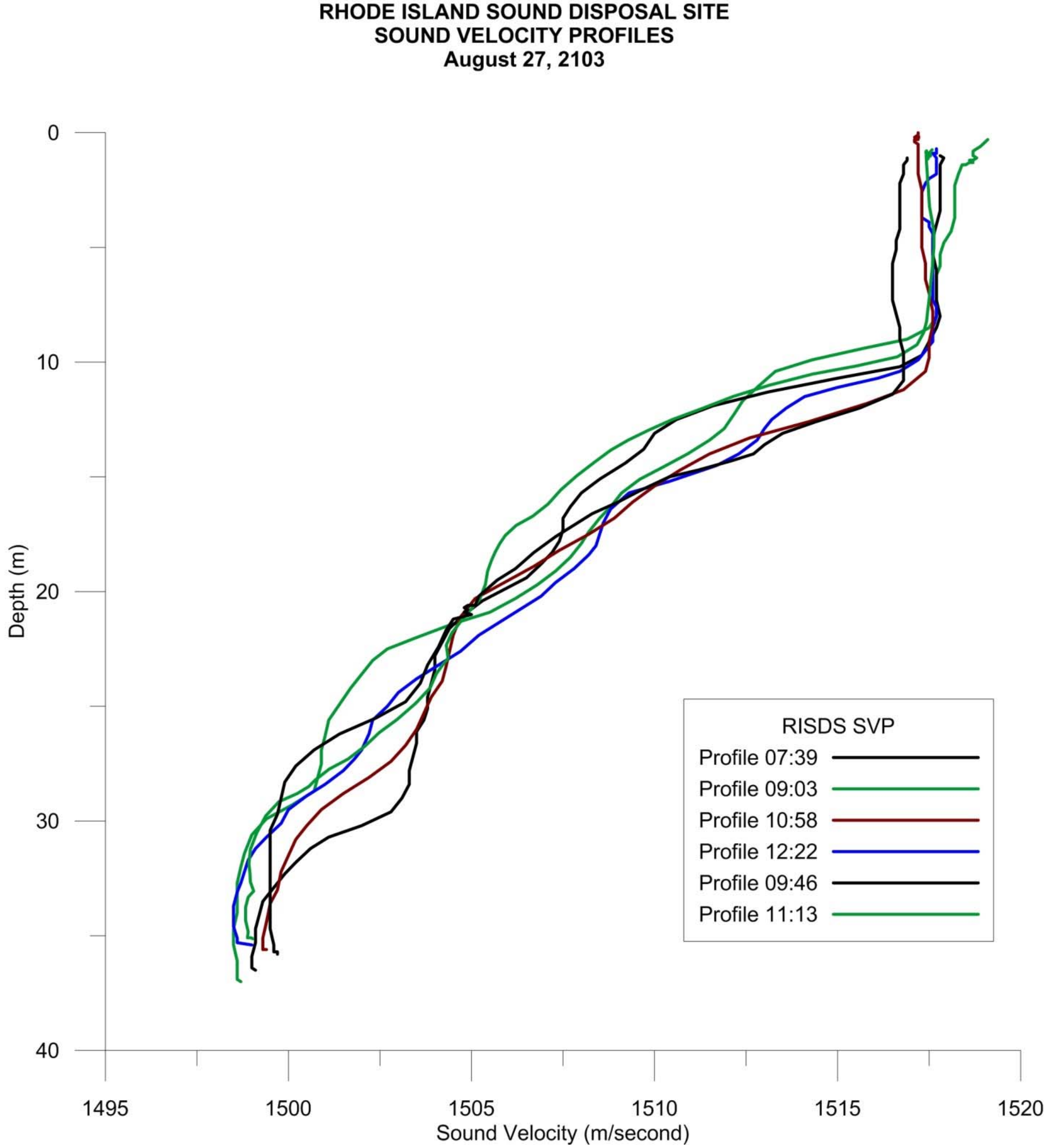


Figure 2-2. Sound-velocity profiles from 27 August 2013 at RISDS

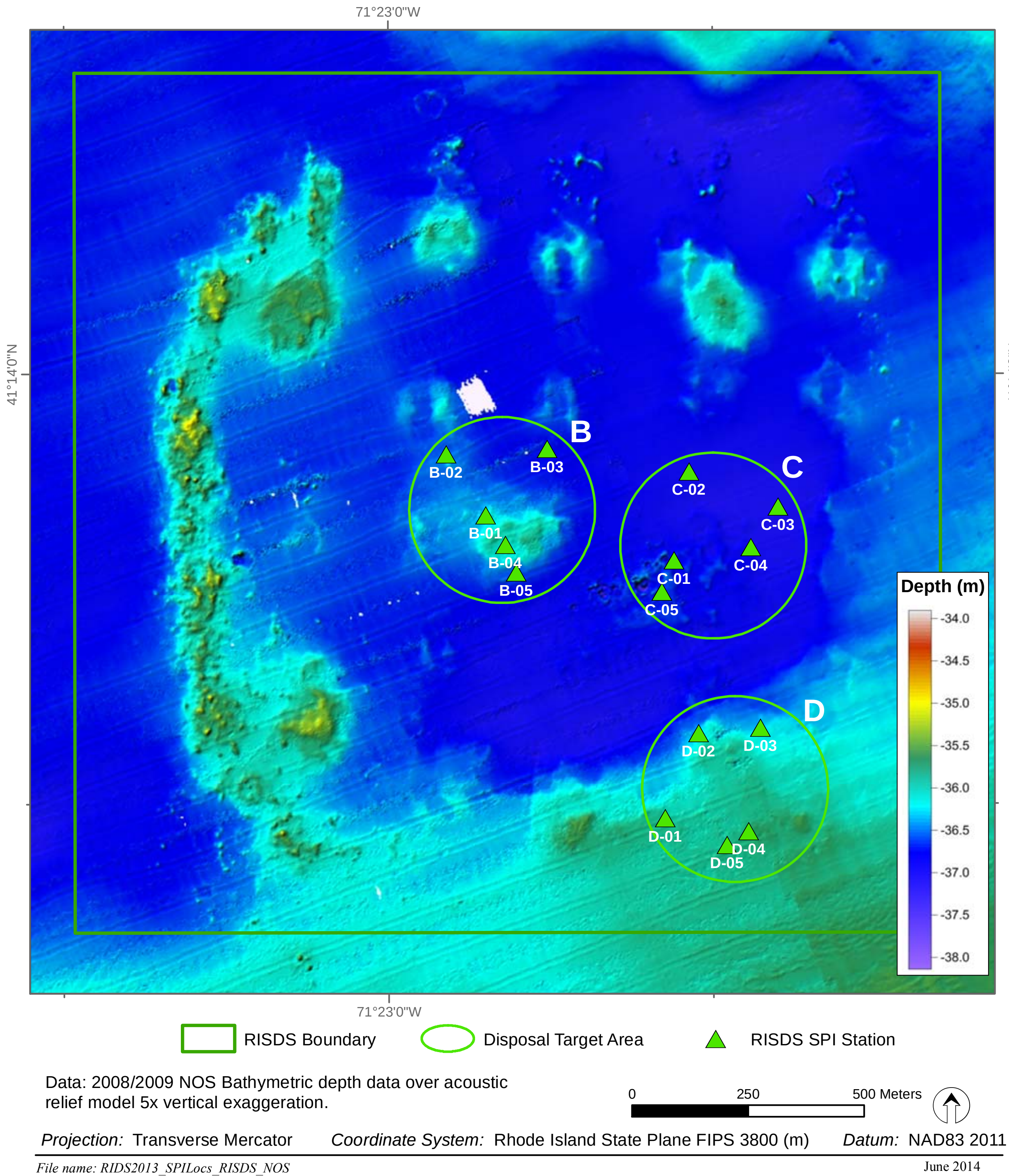


Figure 2-3. RISDS with target SPI/PV stations indicated

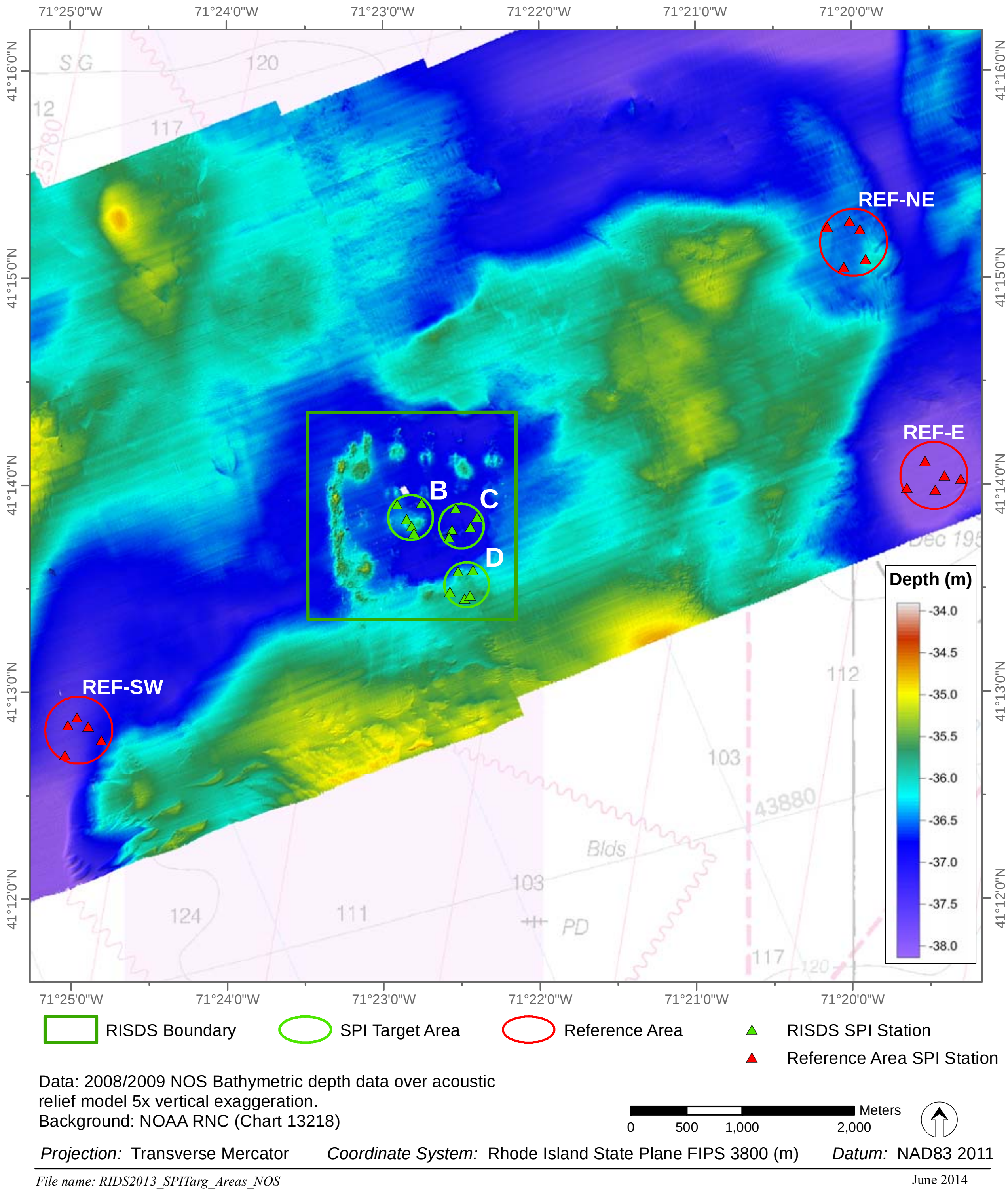


Figure 2-4. RISDS and reference areas with target SPI/PV stations indicated

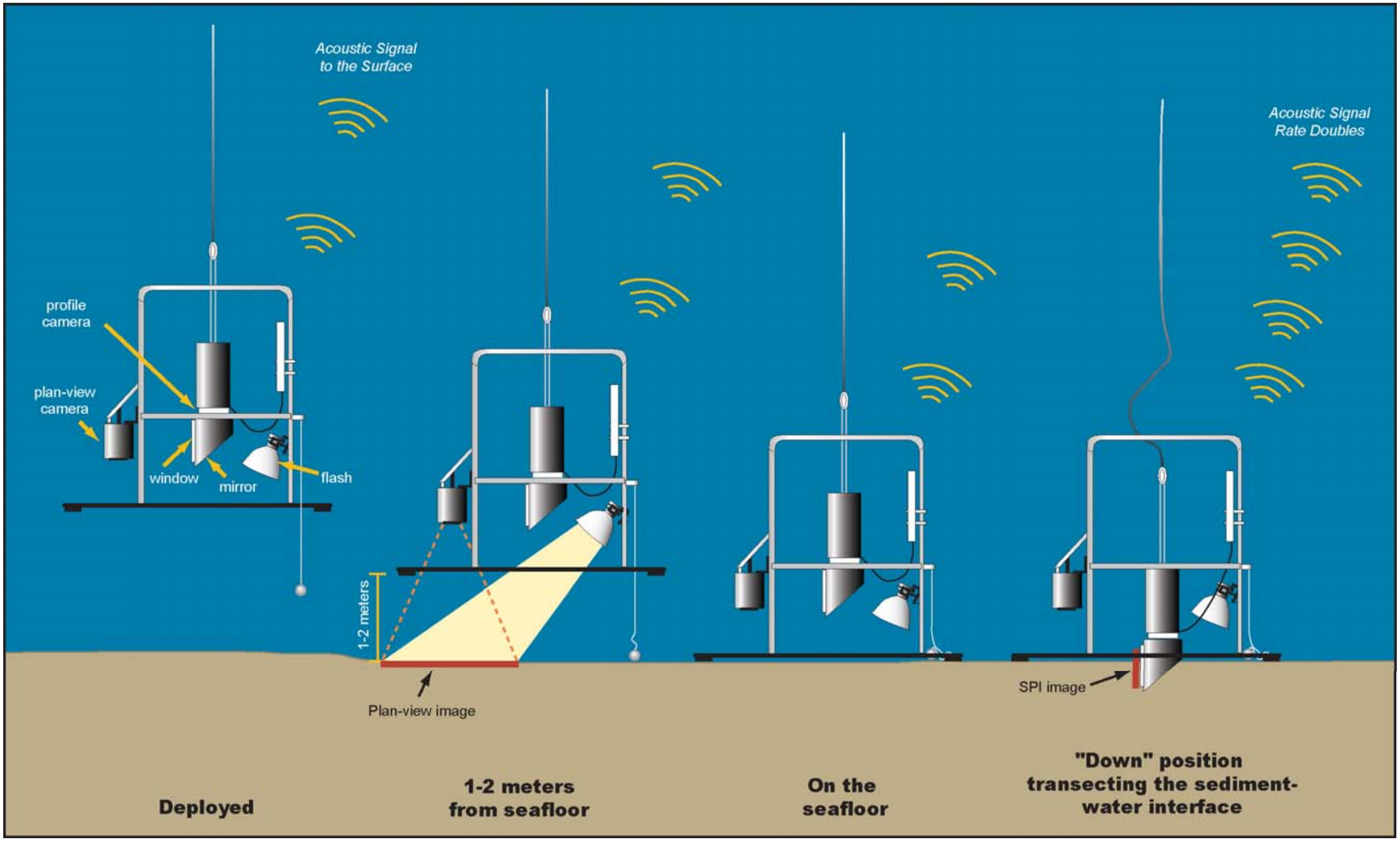


Figure 2-5. Schematic diagram of the SPI/PV camera deployment

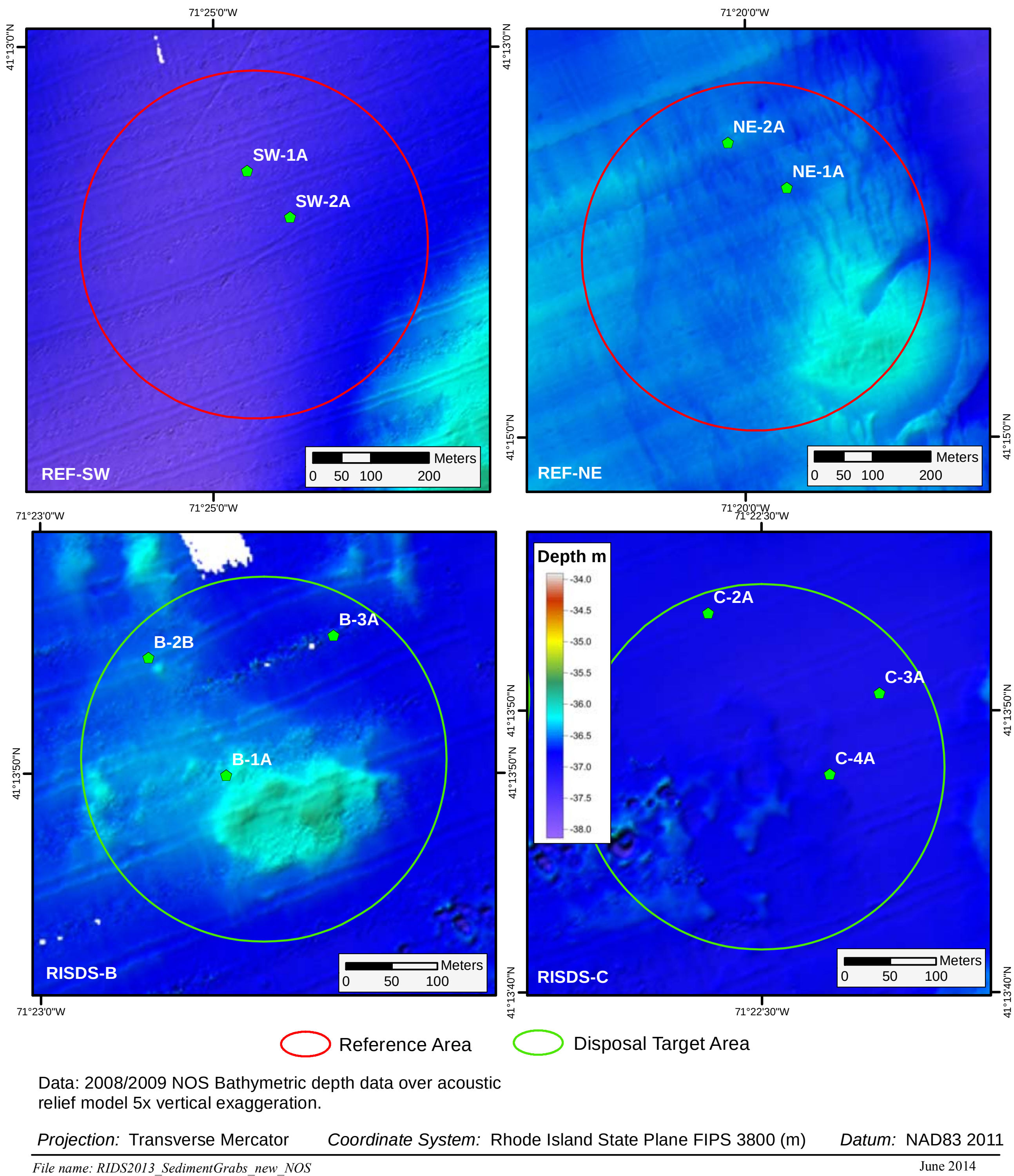


Figure 2-6. RISDS and reference areas with grab sample stations indicated

3.0 RESULTS

3.1 Acoustic Survey

3.1.1 Existing Bathymetry

The bathymetry of RISDS as surveyed in 2013 revealed a topographic depression in the center of the site surrounded by a shallower area to the south and east and a nearly continuous berm to the west (Figure 3-1). The berm, created through careful placement of dredged material, curved toward to the northeast and was extended by several small mounds near the northern margin of the site. The large central depression had a small mound nearly in its center. The southern end of the berm connected with the natural shallower feature along the southern margin of the site. The survey also identified a shallowing trend to the northeast beginning at the margin of the site (Figures 3-1 and 1-5). The overall site bathymetry, with water depths ranging from approximately 34 m over the berm to 38 m in the depression, was shallower than baseline conditions in 2003 which ranged from 35 to 39 m (USEPA 2004).

Multibeam bathymetric data rendered as an acoustic relief model (color scale with hillshading) provided a more detailed representation of the site topography (Figure 3-2). The central portion of the site was relatively smooth ranging in depth from 36.5 to 38 m. The berm was very distinctive with a rough surface texture of small, rounded hummocks (ca. 10-35 m across). Patterns consistent with placement of dredged material were visible as raised isolated mounds or as small circular features (pits with raised rims 35 m in diameter). The surface of the shallower area inside RISDS was covered with circular patterns consistent with dredged material placement.

3.1.2 Acoustic Backscatter and Side-Scan Sonar

Unfiltered backscatter imagery of the disposal site indicated extensive patterns of dredged material disposal throughout the site. Strong backscatter returns that indicate rougher or coarse grain sediment were evident along the berm, along the shallower area to the southeast, and along the eastern margin resulting in a horseshoe pattern (Figure 3-3). Strong backscatter was also apparent at several large nearly-circular disposal target areas in the central portion of the site and at numerous small circular locations. Weaker returns were found in the depression and to the north indicating finer-grained sediment typical of ambient conditions. There were extensive linear patterns (appearing as long white lines in Figure 3-3) consistent with release of material while barges were under transport within the site.

Filtered backscatter, which presents a quantitative assessment of surface characteristics independent of slope effects, showed that the strongest backscatter returns (-22 to -19 dB) occurred along the berm and at a large oval-shaped feature within the depression (Figure 3-4). The large oval-shaped feature within the depression was co-located with target area C (Figure 2-3). Outside of the northeastern corner of the site an area of very strong backscatter return (-21 to -17 dB) was coincident with the shallower area at the northern margin of the site.

Side-scan sonar results also provided a clear representation of disposal activity over large portions of the site. Side-scan results confirmed observations from the backscatter results, but with additional information and some distinct differences (Figure 3-5). The side-scan sonar results had a higher resolution and are more responsive to minor surface textural features and slope than the backscatter. The steeply-sloped edges of the berm deposits and shallow area to the northeast were apparent as dark features. Details of smaller features were more apparent in the side-scan sonar results including some sandy flame shapes (5 m wide) along the western border of the berm and clumps of rock and till on the berm (Figure 3-5). Small megaripples (6 m wavelength) oriented N-S were visible along the southern margin of the site, separate from, and perpendicular to, the large sand waves noted in the NOS bathymetry (Figure 1-5; USGS 2011). The deposit of coarser material at target area C had covered a portion of one of the curved barge disposal traces. There was evidence of episodic sediment transport patterns (ripples, flame structures) but little evidence that storm activity had modified the features formed by placement of dredged material (traces of barge deposition and circular forms).

3.1.3 Comparison with Previous Bathymetry

The multibeam data from the 2013 survey was compared with multibeam data from the National Ocean Service (NOS) collected in 2008 and 2009 (Figure 1-5). The NOS surveys featured two overlapping multibeam survey datasets that provided full coverage for the site. The first survey, NOS Survey H11996, was conducted between 7 September 2008 and 1 October 2008 and covered the eastern part of the site. The second survey, NOS H12009, was conducted 8-19 May 2009 covering the western side of the site. The estimated uncertainty is approximately 0.3 m (1 ft). Unfortunately, the time gap between the two NOS surveys corresponds to the period when Port of Davisville and Great Harbor material was placed at target area C (November 2008 – January 2009, Figure 1-8 and Table 1-1).

A subtraction of the bottom depths in the 2008/2009 surveys from the 2013 depths captured the apparent changes in bathymetry since the 2008/2009 surveys (Figure 3-6). The elevation differences were computed from mean values of the two NOS surveys which introduced two artifacts into the results. Firstly, the elevation gain from placement in 2008-2009 is under-calculated by utilizing 2009 data points in the mean elevations. Secondly, the tidal corrections for the survey lines in 2008 and 2009 introduced a southwest-northeast striping into both apparent elevation gains and losses (Figure 3-6).

Expansion of the northern berm area was readily apparent with increases of up to about 3.4 m and 2.0 m at two disposal target areas in the northern part of the site. These increases were co-located with Port of Davisville and New Bedford Harbor disposal records (Figure 1-4 and Table 1-1). The last five New Bedford Harbor disposal events shown in Figure 1-4 occurred after the 2013 survey. Some accumulation (<1 m) was apparent to the east of the northern target areas.

The limited areas with apparent loss of elevation corresponded to areas that received dredged material from the PRHMDP (Figures 1-3 and 3-6). These areas were localized around mounds with low relief and may represent some consolidation of dredged material. Small apparent depth differences around these mounds were also located in areas of greatest slope and could have been measurement artifacts. In general, the patterns of elevation loss were largely oriented towards the patterns of artifacts in the bathymetry data (2013 wave noise oriented N-S; 2008/2009 tidal differences oriented SW-NE) and were likely minimal. The elevation gains were more significant and appeared independent of the apparent artifacts. The elevation gains in the northern region were consistent with harder material from the New Bedford CAD forming the highest accumulation and fine sand from Davisville spreading widely around the accumulation to the east (Figures 3-6 and 3-4).

3.2 Sediment-Profile and Plan-View Imaging

The primary purpose of the SPI/PV survey at the RISDS was to characterize the physical features of the surface sediments and assess the status of benthic recolonization on the selected target disposal areas and compare results with conditions at the three reference areas. A station summary of some of the measured parameters from the profile images can be found in Tables 3-1 and 3-2, with a complete set of results in Appendix C.

3.2.1 Reference Area Stations

SPI and PV images were collected at 5 stations at each of the reference areas, REF-NE, REF-E, and REF-SW, which have been used to represent ambient sediment conditions of the region relative to RISDS (Figure 3-7). Recent bathymetric data collected by NOS provided characterization of the depth and large-scale sediment features at each site (Figure 3-7).

Physical Sediment Characteristics: Sediments at the reference areas were variable ranging from silty very fine sands and fine sands at REF-NE to sandy silt at REF-E (Table 3-1, Figure 3-8). Very fine sands covered finer-grained sediments at most of the stations at REF-E and REF-SW and at one station at REF-NE (Figure 3-9). At some REF-E stations, there was a 5-10 cm silty sand layer over fine sand with a distinctive interface (Figure 3-9, REF-E 2A). Grain size was most variable and coarsest at REF-NE and least variable and finest at REF-E. This pattern was consistent with the average water depths at the reference area stations: REF-NE was the shallowest with clear evidence of bedforms, REF-E the deepest, and REF-SW in between with one station (REF-SW 05) on the edge of a shallower area (Figure 3-8 and Table 3-3). Many more mud clasts (40) were identified at REF-E, than at REF-SW (4) and REF-NE (1); these represented artifacts from fine-grained material adhering to the camera and dropping to the sediment surface illustrating the preponderance of fine-grain sediment at REF-E (Appendix C).

The differences in sediment compaction at the reference areas were evident in the camera penetration depths and weights used. Ten weights were used at REF-NE, while only eight weights were needed at REF-E and REF-SW (Appendix C). Mean prism penetration at the reference stations ranged from 3.2 to 20.4 cm, with an overall reference area average of 11.8 cm (Figure 3-10 and Table 3-1). REF-NE had the shallowest penetration depths despite the additional weight, while REF-E had the deepest penetration depths indicating softer sediments (Figure 3-9).

Small scale boundary roughness values were fairly consistent across the reference areas ranging from 0.5 to 1.6 cm with a mean roughness of 0.9 cm (Figure 3-11). Most of these small-scale roughness elements were biogenic in origin (e.g., burrow openings, fecal mounds, foraging depressions, Appendix C). There was no evidence of low dissolved oxygen in the overlying water or signs of methane in the subsurface sediments at any of the reference area stations (Appendix C).

Most of the plan-view images revealed a rather silty, fine sandy surface with small to large burrow openings and some shell fragments (Figure 3-12, Appendix C). Poor visibility occurred at most stations at both REF-NE and REF-E.

Biological Conditions and Benthic Recolonization: Values for the mean aRPD depths at the reference stations ranged from 0.7 to 3.6 cm, with an overall reference area mean of 2.4 cm (Table 3-1; Figure 3-13). The deepest aRPD depths were at REF-E. Relict aRPDs, indicated by a lighter color layer under dark sediments, were visible at a few of the stations (Figure 3-9, REF-E 02-A).

Evidence of mature, deposit-feeding infaunal (Stage 3) assemblages was found at all the reference stations, with bioturbation depths extending to 18 cm (Figure 3-14, Appendix C). Feeding voids occurred most frequently at REF-E which had the deepest penetration depths and least frequently at REF-NE. There were also assemblages of Stage 2 tubicolous surface fauna, including both polychaetes and amphipods at all three reference areas (Figure 3-15, Table 3-1). Small Stage 1 tubes of opportunistic feeders were present at the sediment water interface at several stations (Figure 3-15, REF-SW 01-B). Small bivalves were present in surficial sediments at REF-NE and Ref-E (Figure 3-15, REF-NE 03-A).

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 C; Figure 3-12). There also was abundant evidence of epifauna in the form of tracks, pits, and organisms, including sea stars, the remains of a crab, a fish, and a skate. There was no indication of any severe disturbance to the reference area benthic communities from trawling or other anthropogenic impacts.

3.2.2 Disposal Site Stations

SPI and PV images were collected at all 15 RISDS stations at the three disposal target areas (B, C, and D; Figure 3-16).

Physical Sediment Characteristics: Surface sediments at the stations sampled with SPI within RISDS consisted generally of dredged material with fine sand in the top few centimeters (Table 3-2, Appendix C). Most of the dredged material had been placed at the site in April 2003 to January 2005 at all three disposal target areas, and a smaller volume was placed at disposal target area C during the winter of 2008 (see Figure 1-5). Sediment particle size varied from clay to gravels and cobble (Figure 3-17). Target area C had the greatest variation in grain size (cobble to clay clumps), while primarily fine-grained sediments characterized target area D (Figure 3-18). Target area B had a distinct fine sand layer over fine-grained sediment at several stations, including some areas with light colored clay inclusions (Figure 3-18). Layering of sand and fine-grained sediments was evident at some of the stations (Figure 3-18, RISDS C 04-D).

Similar to the reference area, camera prism penetration depths varied relative to sediment grain size and density, ranging from no penetration at target area C to 16.7 cm at target area D, with an overall disposal site mean of 11.1 cm (Table 3-1; Figure 3-19). However, only two weights were used at the disposal site compared to the eight and ten weights at the reference areas as dredged sediments were generally not as dense as ambient conditions. The camera stop setting was also lower (12) than used for the settings (14 or 16) at the reference areas. Therefore, penetration depths between the reference area and disposal site were not directly comparable. Boundary roughness values were very similar to the reference area with an overall mean of 0.8 cm and attributed to biogenic processes other than a few stations that had cobbles or small-scale sand ripples (Figure 3-20).

Although several stations had reduced sediments at depth, there were no locations sampled at the disposal site that showed any evidence of low oxygen in the overlying waters or methane formation from excess organic enrichment in the subsurface sediments.

Plan-view images confirmed the cobbles and gravel at Station C-1 (RISDS-PV C 01-C) and in one of the three replicates at Station C-5. All other stations were described as silt-clay and had evidence of burrows and tracks of epifaunal organisms.

Biological Conditions and Benthic Recolonization: Station mean values for the aRPD depth at the disposal site ranged from 0.9 to 2.5 cm, with an overall disposal site mean aRPD depth of 1.7 cm (Table 3-1, Figure 3-21). Relict aRPDs were visible in some images, indicating a former sediment water interface and mixing layer and layering of dredged material over time (Figure 3-18, RISDS C 04-D).

Similar to the reference stations, evidence of mature, Stage 3 deposit-feeding assemblages was found at every station sampled within the disposal site boundary, except at Stations C-01 and C-05 where penetration was limited to hard sediments (Figure 3-22). Every replicate at target area B was either Stage 1 on 3 or Stage 2 on 3. A few replicates with reduced, organic-rich, fine grained sediments and surface fine sands had only Stage 1 or 2 present (Figure 3-18, Replicate D-03-D). Burrows, polychaetes, small tubes, and small bivalves were observed at many of the stations. The maximum depth of feeding void structures, when present, ranged from 2.9 to 11.4 cm; evidence of burrowing and feeding activities often was seen at the limit of camera prism penetration (Figure 3-18), indicating that resident infauna were bioturbating to depths greater than what were able to be measured in the collected profile images.

The plan-view images showed the presence of cobbles at some stations (Figure 3-23, RISDS-PV C 01-C) and evidence of biological activity in the form of burrow openings, shell fragments, extensive crab and/or shrimp tracks, as well as the direct evidence of crabs, shrimp, barnacles, and fish (Figure 3-23). Epifauna was seen at all three target areas, and tracks and burrows were found at most of the stations.

3.2.3 Statistical Comparisons

Mean aRPD Depths: The three 2013 reference areas were fairly distinct in their distribution of aRPD values (Table 3-4); aRPD values at REF-E were 1 cm deeper than at the other two reference areas, and values at REF-NE were much more variable than the other areas with aRPD values ranging from 0.7 cm to 3.4 cm.

At the disposal target areas, the deepest mean aRPD was at C (2.1 cm) and shallowest occurred at D (1.2 cm). Disposal target area B had the greatest variability in aRPD (1.3 to 2.5 cm).

A test was performed to determine whether the difference observed in 2013 in mean aRPD values between the three reference areas (2.2 cm) and the three mounds (1.7 cm) was statistically significant. Using the data from these six locations, the results for the normality test indicated that the area residuals (i.e., each observation minus the area mean) were not significantly different from a normal distribution (Shapiro-Wilk's test p-value = 0.2). There was one extreme residual from REF-NE, which skewed the residuals but did not appear to be in error and did not significantly affect the normality results. Levene's test for equality of variances was rejected (p = 0.0015), due to the elevated variance in the REF-NE group of stations. The confidence interval for the difference equation was constructed using normal theory equations with separate variance estimates for the six groups and the appropriate Welch-Satterthwaite degrees of freedom.

The confidence region for the difference between the 2013 reference versus disposal target area means was not contained within the interval [$-\delta$, $+\delta$] (Table 3-5). The conclusion was that the three reference and three disposal target areas had significantly different aRPD values in the 2013 survey, with a difference in means of approximately 0.56 cm.

REF-NE had a coarser substrate than the disposal target areas (except for parts of disposal target area C), with well-sorted sand and consequently a limited penetration depth for the SPI survey, including two stations with indeterminate results. A second difference equation comparing the mean of reference excluding REF-NE to the mean of disposal mounds [Eq. 2] was estimated. Using the data from these five locations, the results for the normality test indicated that the area residuals (i.e., each observation minus the area mean) were not significantly different from a normal distribution (Shapiro-Wilk's test p-value = 0.97). Levene's test for equality of variances was not rejected (p = 0.23). The confidence interval for this second aRPD difference equation was constructed using a normal theory equation and pooled variance estimate.

The confidence region for the difference between the 2013 reference excluding REF-NE versus disposal target area means was not contained within the interval [-1, +1] (Table 3-5). The conclusion was that the two reference and three mound areas had significantly different aRPD values in the 2013 survey, with a difference in means of approximately 0.83 cm.

The 2013 survey data was also compared with results from surveys in 2005 (ENSR 2007) and 2009 (Valente 2012a). In all three years, the mean aRPD values were more variable among the reference areas than among the disposal target areas (station groups A–E) within the disposal site (Table 3-6 and Figure 3-24). In all three years, the mean aRPD values also were consistently deeper at the reference areas compared to the RISDS disposal target areas (Table 3-6 and Figure 3-24).

A final test of the aRPD depths was conducted to determine whether there was a significant difference in aRPD depths at the disposal area station groups B, C, and D (target areas) between the 2013 and 2009 surveys. The disposal target areas B and D had slightly higher means and medians in the 2013 survey (Table 3-6 and Figure 3-25), area C had a higher median in 2013 but the mean and variance from 2009 was much higher due to an extreme aRPD value of 5.4 cm at Station C-5. The residuals for this group of data failed the normality test (Shapiro-Wilks p-value <0.001), due to a single influential data point (Station C-5 in 2009). Consequently, a nonparametric confidence interval was constructed using the bootstrap-*t* interval (Lunneborg 2000, Manly 1997; see methods in Appendix F).

The confidence region for the difference between 2013 and 2009 for disposal target area stations (B, C, and D) was fully contained within the interval [-1, +1] (Table 3-5), leading to the conclusion that there was no significant change in aRPD values in the four years that had passed between 2009 and 2013. Previous results (Valente et al. 2012a) indicated that there was a slight increase in aRPD values (0.03 cm) at the disposal site stations from 2005 to 2009, but these values were statistically equivalent (within [-1, +1] cm).

<u>Successional Stage Ranks</u>: Similar to the aRPD analysis, two comparisons were conducted for successional stage rank. One comparison examined the difference between the reference areas and disposal target area mounds in 2013. In 2013, all stations indicated successional stage at Stage 3 or equivalent (Table 3-6). The mean successional stage rank among reference areas was 3; the mean among all disposal areas was also 3. No statistics were needed to conclude that there were no differences in maximum successional stage rank between the disposal site and reference area stations in 2013.

It was also of interest to examine whether there was any significant change in successional stage rank at the disposal target area stations between the 2009 and 2013 surveys. In all surveys at this disposal site, all but two stations indicated mean maximum successional stage rank of Stage 3; the exceptions were station D-1 in 2005, station B-2 in 2009, both of which indicated a maximum successional stage rank between Stage 2 and Stage 3 (rank of 2.5). The mean of the maximum successional stage rank among the disposal area B, C, and D stations was 3.0 in 2005, 3.0 in 2009 and 3.0 in 2013. No statistics were needed for this variable to conclude that there were no significant differences between years.

3.3 Benthic Grab Results

Ten sediment grab samples were collected and analyzed for grain size and benthic community structure (Figure 2-5). Three grab samples were collected at disposal target areas B and C, and two grab samples were collected from reference areas REF-NE and REF-SW. One replicate per sample was processed and analyzed for grain size and one replicate was processed and analyzed for benthic community structure. The grain size data for the ten sampling stations had a very wide range (e.g., 0.8 – 89.5% fines, Table 3-7). In general, the variation in grain size was a result of different proportions of fines and fine sand, but two stations had more than 9% gravel.

A combined total of 81 benthic taxa were reported from analysis of grab results from the ten sampling stations (Table 3-8, Appendix F). The number of species per station ranged from a low of 11 taxa per 0.04 m^2 to a high of 36 taxa per 0.04 m^2. Numbers of individuals ranged from a low of 111 individuals per 0.04 m^2 to a high of 2,966 individuals per 0.04 m^2. Most of the variation in abundance was the dominance of one species, *Nucula proxima* (Figure 3-26).

3.3.1 Reference Area Stations

<u>Physical Sediment Characteristics</u>: At REF-NE, the grain size was highly variable (Table 3-7). Station REF-NE-01A was sandy silt with 2% gravel, whereas Station REF-NE-02A was gravelly fine sand with less than 1% silt/clay. At REF-SW, both stations had well-sorted fine sand with silt (Table 3-7).

<u>Biological Conditions:</u> The four samples from REF-NE and REF-SW had a total of 58 species and 2,458 individuals with an average of 31 species and 622 individuals per station (Table 3-8). The diversity of species, as measured by Shannon's Diversity Index H′, at the stations ranged from 1.36 at REF-NE-02 to 2.75 at REF-NE-01. Pielou's J′, which is a measure of species evenness within a community derived from H′, ranged from 0.31 to 0.63, with an average of 0.46. The suspension feeding amphipod *Byblis*

serrata was the dominant species (70%) at REF-NE-02 (a station with very well-sorted fine sand), while at the other three reference stations the surface and subsurface deposit feeder *Nucula proxima* was the most abundant. These two species made up 57% of the total abundance followed by the coralline tubeworm *Dodecaceria concharum* at 5%; the other 55 species were less than 3% (Table 3-9). The lowest number of individuals was observed at Station REF-NE-01 (a station with well-sorted fine sand over silt and 2% gravel) where *Nucula proxima* was not abundant. This lack of a dominant resulted in the highest diversity of any of the reference area stations.

3.3.2 Disposal Site Stations

Physical Sediment Characteristics: RISDS-B included a mix of sandy silt and silty fine sand that contained some gravel (2-11 %). RISDS-C consisted of silt/clay with small amounts of fine sand and little to no gravel (Table 3-7).

Biological Conditions: The six samples from RISDS-B and RISDS-C had a total of 44 species and 9,866 individuals with an average of 18 species and 1,644 individuals per station (Table 3-8). Stations B-01B and B-02D had relatively lower abundances (111 and 601 per 0.04 m^2). The diversity of species at the stations, as measured by Shannon's Diversity Index H′, ranged from 0.27 at B-02D to 1.31 at B-01B. Pielou's J′, ranged from 0.06 to 0.30, with an average of 0.18, indicating low species evenness within the samples. *Nucula proxima* was the most abundant at all six stations (87% of total individuals, Figure 3-26). The next five species were between 1.1% and 2.4%, and the other 38 were all less than 0.6% of the total (Table 3-9).

3.3.3 Comparison to the Reference Areas

The diversity at the reference areas was higher than the disposal site as reflected in the number of species and the diversity indices; however, more than double the average number of organisms was found at the disposal site due to the predominance of *Nucula proxima* (Figure 3-27). Abundance of *N. proxima* was highly patchy throughout the survey area ranging from 62 to 2,782 individuals per sample at RISDS and from 8 to 433 individuals per sample at the reference area. The fewest *Nucula proxima* (8 individuals) were found at REF-NE-02D, which also had the smallest percentage of fines (0.8%) and a dominant suspension feeder, the amphiphod *Byblis serrata.*

The top four species found at the disposal site were also in the top ten for the reference area (Table 3-10). *Tharyx setiger* was the only species in the top ten at the disposal site that did not occur at the reference area, where as three species, *Cyclocardia borealis, Unciola spp.* and *Polyphysia crassa*, were in the top ten for the reference area but were not found at the disposal site.

Examination of the species according to their taxonomic class reflected the patterns of species dominance (Figure 3-27 A and Figure 3-28). Bivalvia (molluscs), the class *Nucula proxima* belongs to, were dominant at RISDS and REF-SW, followed by Malacostraca (crustaceans) and Polychaeta (annelid worms). Malacostraca were more abundant at the reference areas than RISDS but had a patchy distribution. Polychaeta had a relatively consistent abundance at the reference areas stations (average 118 per sample) relative to RISDS stations (average 122 per sample). The remaining classes had an average of less than six individuals per sample at the reference areas and less than seven at RISDS stations.

3.3.4 Comparison to 2005 and 2001

Comparison of the 2013 benthic data with 2005 results provides some indication of potential changes in benthic community composition and sediment characteristics over time. Since 2005, 23,000 m^3 of material has been placed at disposal target area RISDS-C.

The most striking difference was the reversal in relative abundance between reference areas and disposal site stations between 2013 and 2005 (Table 3-10, Figure 3-27). While diversity and evenness were lower in 2013, the majority of stations in the disposal site had over 1,000 individuals and none of the reference areas had over 1,000 individuals. In 2005, all of the reference area stations had over 1,400 individuals and none of the disposal site stations had more than 410. These differences were due to fluctuations primarily in the abundance of *Nucula sp.* as well as in the abundance of several amphipods (the second to sixth most abundant species at the reference areas in 2005) (Table 3-9, Figure 3-26). In 2005, these protobranch bivalves were identified as *Nucula annulata* and in 2013 as *Nucula proxima*. These species may be the same or very hard to distinguish but they appear to occupy the same ecological niche. In both 2005 and 2013, these bivalves had a very patchy distribution and occurred in very high abundances (though at only one station in 2005) consistent with previous studies on their ecology.

Table 3-1.

Summary of RISDS Reference Station Sediment-Profile Imaging Results, August 2013

Station	Grain Size Major Mode (phi)	Station Mean Penetration (cm)**	Station Mean Boundary Roughness (cm)	Station Mean aRPD Depth (cm)	Methane Present?	Station Maximum Void Depth (cm)	Highest Successional Stage Present
REF-E-01	4 to 3/>4	19.9	1.1	3.6	No	11.0	Stage 1 on 3
REF-E-02	4 to 3/>4	18.2	1.4	3.0	No	16.7	Stage 1 on 3
REF-E-03	>4	18.8	0.5	3.2	No	11.8	Stage 2 on 3
REF-E-04	4 to 3/>4	20.4	0.5	3.2	No	18.0	Stage 1 on 3
REF-E-05	4 to 3	12.9	0.8	2.1	No	14.4	Stage 2 on 3
REF-NE-01	4 to 3/>4	8.5	1.4	1.0	No	10.8	Stage 1 on 3
REF-NE-02	4 to 3	3.2	0.7	ind	No	-	Indeterminate
REF-NE-03	3 to 2	5.8	0.8	3.4	No	-	Stage 2 on 3
REF-NE-04	4 to 3	7.5	0.7	0.7	No	-	Stage 1 on 3
REF-NE-05	3 to 2	5.4	0.8	ind	No	-	Indeterminate
REF-SW-01	4 to 3/>4	14.1	1.6	1.7	No	12.7	Stage 1 on 3
REF-SW-02	4 to 3/>4	8.6	0.7	2.4	No	10.5	Stage 2 on 3
REF-SW-03	4 to 3/>4	14.9	1.0	2.4	No	14.4	Stage 1 on 3
REF-SW-04	4 to 3/>4	14.8	1.1	1.4	No	14.9	Stage 2 on 3
REF-SW-05	4 to 3	4.2	0.8	ind	No	-	Indeterminate
Min	NA	3.2	0.5	0.7	NA	10.5	NA
Max	NA	20.4	1.6	3.6	NA	18.0	NA
Mean*	NA	11.8	0.9	2.4	NA	13.5	NA

*Station means were calculated from three replicates, disposal site mean values were calculated as the mean of station means.
** Different camera weights and settings were used at the reference areas compared to the disposal site.

Table 3-2.

Summary of RISDS Disposal Target Area Sediment-Profile Imaging Results, August 2013

Station	Grain Size Major Mode (phi)	Station Mean Penetration (cm)**	Station Mean Boundary Roughness (cm)	Station Mean aRPD Depth (cm)	Methane Present?	Station Maximum Void Depth (cm)	Highest Successional Stage Present
B-01	>4	10.2	0.9	1.4	No	10.1	Stage 1 on 3
B-02	>4	11.1	0.9	1.9	No	6.1	Stage 1 on 3
B-03	4 to 3/>4	9.3	1.3	1.3	No	7.2	Stage 1 on 3
B-04	4 to 3/>4	10.1	0.5	1.4	No	9.6	Stage 2 on 3
B-05	4 to 3/>4	10.9	0.5	2.5	No	8.6	Stage 2 on 3
C-01	Indeterminate	0.0	Indeterminate	Indeterminate	Indeterminate	-	Indeterminate
C-02	>4	12.3	0.5	2.3	No	-	Stage 1 on 3
C-03	>4	15.9	0.7	2.2	No	8.3	Stage 2 on 3
C-04	>4	13.7	0.7	1.8	No	8.0	Stage 2 on 3
C-05	3 to 2	4.2	1.4	2.2	No	-	Indeterminate
D-01	>4	13.2	0.8	1.1	No	2.9	Stage 1 on 3
D-02	>4	12.1	1.3	0.9	No	11.4	Stage 1 on 3
D-03	>4	16.7	0.6	1.2	No	-	Stage 1 on 3
D-04	>4	12.4	1.0	1.4	No	7.5	Stage 1 on 3
D-05	>4	14.1	0.5	1.4	No	10.1	Stage 2 on 3
Min	NA	0.0	0.5	0.9	NA	2.9	NA
Max	NA	16.7	1.4	2.5	NA	11.4	NA
Mean*	NA	11.1	0.8	1.7	NA	8.2	NA

*Station means were calculated from three replicates, disposal site mean values were calculated as the mean of station means.

** Different camera weights and settings were used at the reference areas compared to the disposal site.

Table 3-3.

Summary of Station Water Depth Range by Sampling Location

		Water Depth	
Area	**N**	**Min (m)**	**Max (m)**
Reference areas			
REF-E	5	40.8	42.1
REF-NE	5	36.9	37.5
REF-SW	5	37.2	39.9
Disposal site target areas			
B	5	36.6	37.5
C	5	37.5	38.1
D	5	35.4	36.6

Table 3-4.

Summary of Station Mean aRPD by Sampling Location

		Mean aRPD Depth (cm)	
Area	**N**	**Mean**	**Standard Deviation**
Reference areas			
REF-E	5	3.04	0.56
REF-NE	3	1.69	1.50
REF-SW	4	1.99	0.51
Mean:		2.24	
Disposal site target areas			
B	5	1.70	0.52
C	4	2.14	0.25
D	5	1.21	0.21
Mean:		1.68	

Table 3-5.

Summary Statistics and Results of Parametric or 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	Method[1]
2013 Data						
(mean of REF-E, REF-SW, REF-NE) – (mean of B, C, D disposal mounds)	0.56	0.33	3.2	-0.19	1.3	Ns
(mean of REF-E and REF-SW) – (mean of B, C, D disposal mounds)	0.83	0.19	18	0.50	1.2	Np
Disposal Data (B, C, D)						
2013Mean – 2009Mean	0.01	0.24	23	-0.33	0.71	B

[1]Ns = Normal parametric confidence bounds, using separate variance estimates;
Np = Normal parametric confidence bounds, using pooled variance estimates;
B = bootstrap-*t* non-parametric confidence bounds.

Table 3-6.

Summary Statistics of SPI Variables by Sampling Location and Year

Location	Useable N[1]	Mean aRPD (cm) Mean	Mean aRPD (cm) Stdev	Maximum Successional Stage Rank Mean	Maximum Successional Stage Rank Stdev	No. of Feeding Voids Mean	No. of Feeding Voids Stdev
Reference Areas							
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	
2013							
E	5	3.04	0.56	3	0	1.5	0.3
NE	3	1.69	1.50	3	0	0.7	1.2
SW	4	1.99	0.50	3	0	0.8	0.4
		2.24		3		1.0	
Disposal Target Areas							
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	
2013							
B	5	1.70	0.54	3	0	1.0	0.4
C	4	2.14	0.25	3	0	0.4	0.6
D	5	1.21	0.21	3	0	1.2	1.1
Mean		1.68		3		0.9	

[1] Number of stations with determinate results.

Table 3-7.

RISDS 2013 Grab Sampling Results of Grain Size Analysis

	Grain Size					
Sample ID	**Fines (%)**	**Total Sand (%)**	**Fine Sand (%)**	**Medium Sand (%)**	**Coarse Sand (%)**	**Gravel (%)**
NE-01A	53	45	29.5	13.2	2.3	2
NE-02A	0.8	89.6	71.3	16	2.3	9.6
SW-01A	24.8	75.2	73.7	1.4	0.1	0
SW-02A	15.3	84.7	78.7	6	0	0
B-01A	74.2	24.2	17.3	5.6	1.3	1.6
B-02B	59.8	29.6	23.6	4.6	1.4	10.6
B-03A	32.2	61.7	44.1	14.1	3.5	6.1
C-02A	83.3	16.7	15.1	1	0.6	0
C-03A	89.5	10.5	8.2	1	1.3	0
C-04A	88.2	11.1	10.4	0.4	0.3	0.7

Table 3-8.

Summary of Benthic Biology Community Parameters for Reference Areas and RISDS Stations, August 2013

Sample	No. of Species	No. of Individuals (0.04m²)	Shannon's H'	Pielou's J'
Reference Stations				
REF-NE-01 B	35	429	2.75	0.63
REF-NE-02 D	24	654	1.36	0.31
REF-SW-01 B	29	582	1.78	0.41
REF-SW-02 C	36	821	2.15	0.49
Average	**31**	**622**	**2.01**	**0.46**
Minimum	**24**	**429**	**1.36**	**0.31**
Maximum	**36**	**821**	**2.75**	**0.63**
Total	**58**	**2486**		
RISDS Stations				
B-01B	12	111	1.31	0.30
B-02 D	11	601	0.87	0.20
B-03 B	12	2,220	0.27	0.06
C-02 B	23	2,966	0.38	0.09
C-03 B	28	2,009	0.84	0.19
C-04 B	21	1,959	1.04	0.24
Average	**18**	**1,644**	**0.79**	**0.18**
Minimum	**11**	**111**	**0.27**	**0.06**
Maximum	**28**	**2,966**	**1.31**	**0.30**
Total	**44**	**9,866**		
All Stations	**81**	**12,352**		

Table 3-9.

Relative Abundance of Top Ten Species by Year

2013 REF-NE and REF-SW		2005 REF-NE, REF-SW, and REF-E	
36.5%	*Nucula proxima**	21.3%	*Nucula annulata**
20.2%	*Byblis serrate*	17.3%	*Crassicorophium crassicorne*
5.0%	*Dodecaceria concharum*	11.3%	*Erichthonius fasciatus*
2.8%	*Nematoda spp.*	10.0%	*Ampelisca agassizi*
2.7%	*Cyclocardia borealis*	7.1%	*Unciola irrorata*
2.4%	*Pectinaria gouldii*	3.7%	*Leptocheirus pinguis*
2.2%	*Unciola spp.*	3.4%	*Euchone incolor*
2.1%	*Lucinoma filose*	1.9%	*Scalibregma inflatum*
2.0%	*Polyphysia crassa*	1.7%	*Scoletoma hebes*
1.9%	*Lumbrineris acicularum*	1.4%	*Ninoe nigripes*
2013 B and C		**2005 B, C, D, and E**	
87.4%	*Nucula proxima*	33.3%	*Euchone incolor*
2.4%	*Lucinoma filose*	16.3%	*Nucula annulata*
2.3%	*Pectinaria gouldii*	15.8%	*Nephtys incisa*
1.6%	*Dodecaceria concharum*	6.0%	*Phoronis architecta*
1.5%	*Tharyx setiger*	3.0%	*Chone infundibulqriformis*
1.1%	*Phylo ornatus*	2.5%	*Cossura longocirrata*
0.6%	*Arctica islandica*	2.3%	*Cerastoderma pinnulatum***
0.4%	*Parvicardium pinnulatum*	2.0%	*Nephtys spp.*
0.4%	*Astarte undata*	1.9%	*Edwardsia elegans*
0.3%	*Yoldia limatula*	1.8%	*Cerianthidae spp. indet.*

**Nucula proxima* and *Nucula annulata* are distinct but similar species that are likely the same species for comparative purposes

**Accepted name is *Parvicardium pinnulatum*

http://www.marinespecies.org/aphia.php?p=taxdetails&id=156756

Table 3-10.

Summary of Benthic Biology Community Parameters and Grain Size Descriptions for Reference and RISDS Stations, July 2005

Sample	No. of Species	No. of Individuals (0.04m²)	Shannon's H'	Pielou's J'	Grain Size Description
Reference Stations					
REF-E-01	68	2986	3.06	0.50	Sandy silt
REF-NE-03	57	1942	3.50	0.60	Medium sand w/some silt
REF-NE-05	67	1494	4.53	0.75	Fine sand
REF-SW-01	59	2628	3.39	0.58	Fine sand/silt
REF-SW-02	58	2697	3.26	0.56	Silty fine sand
Average	**62**	**2349**	**3.55**	**0.60**	
Minimum	**57**	**1494**	**3.06**	**0.50**	
Maximum	**68**	**2986**	**4.53**	**0.75**	
Total	**119**	**11,747**			
RISDS Stations					
B-01	24	237	3.03	0.66	Silty
B-04	28	278	3.23	0.67	Silty
C-02	17	249	1.78	0.44	Silty
C-03	29	85	4.12	0.85	Silty w/fine sand on surface
D-03	32	410	3.06	0.61	Silty
D-05	26	240	3.16	0.67	Silty
E-05	24	211	2.92	0.64	Silty
Average	**26**	**244**	**3.04**	**0.65**	
Minimum	**17**	**85**	**1.78**	**0.44**	
Maximum	**32**	**410**	**4.12**	**0.85**	
Total	**60**	**1,710**			
All Stations		**13,457**			

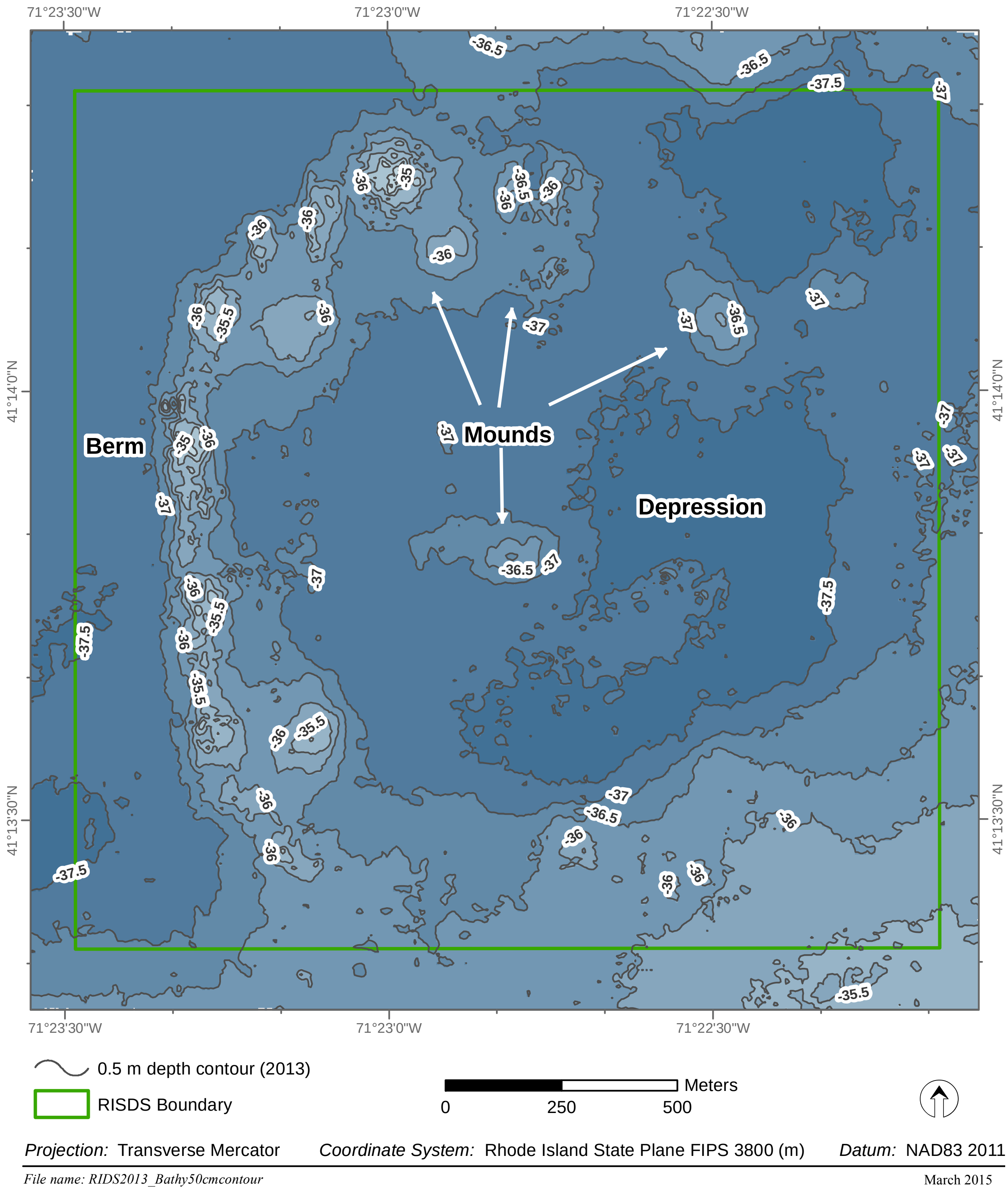


Figure 3-1. Bathymetric contour map of RISDS – August 2013

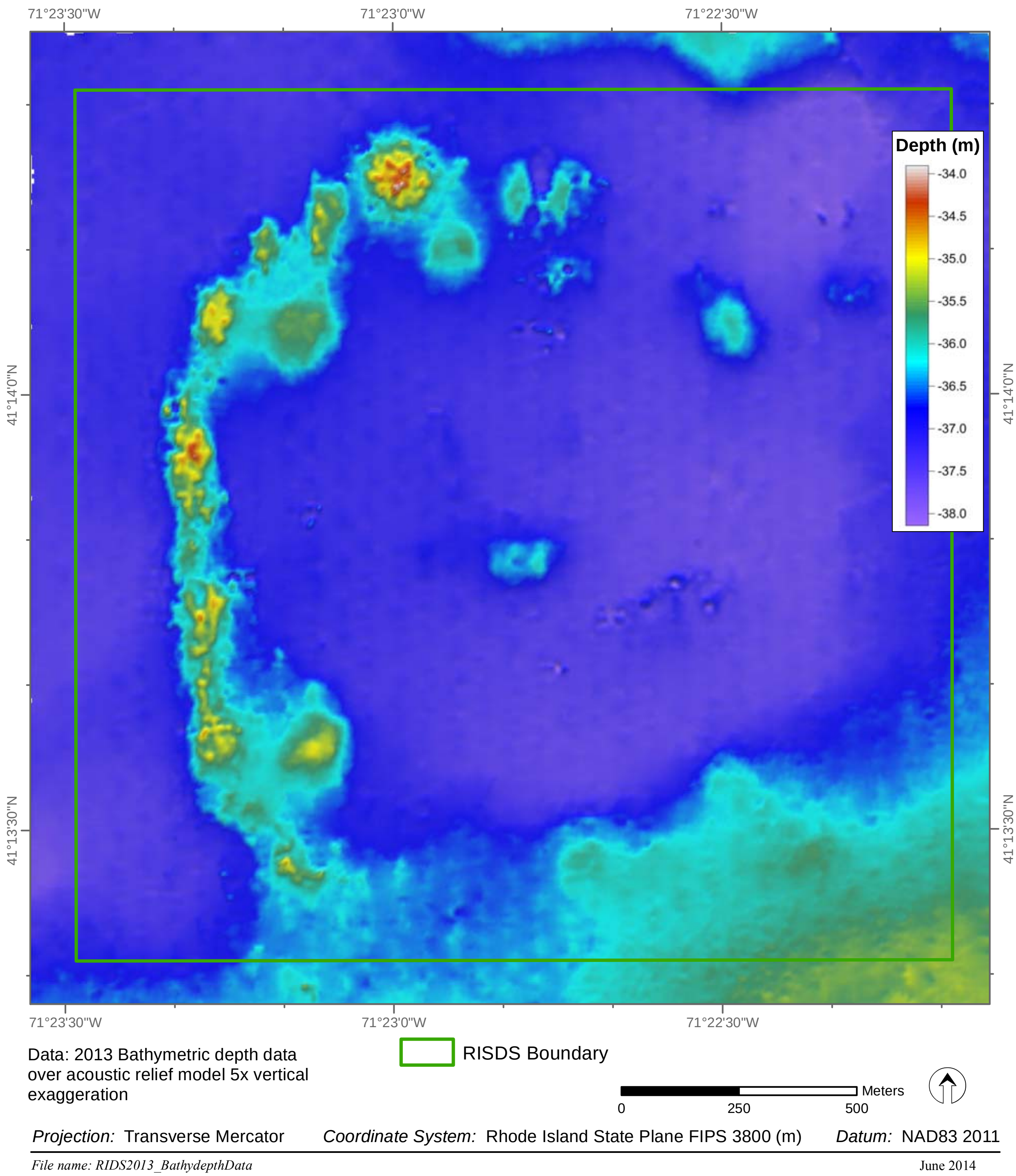


Figure 3-2. Bathymetric depth data over acoustic relief model of RISDS – August 2013

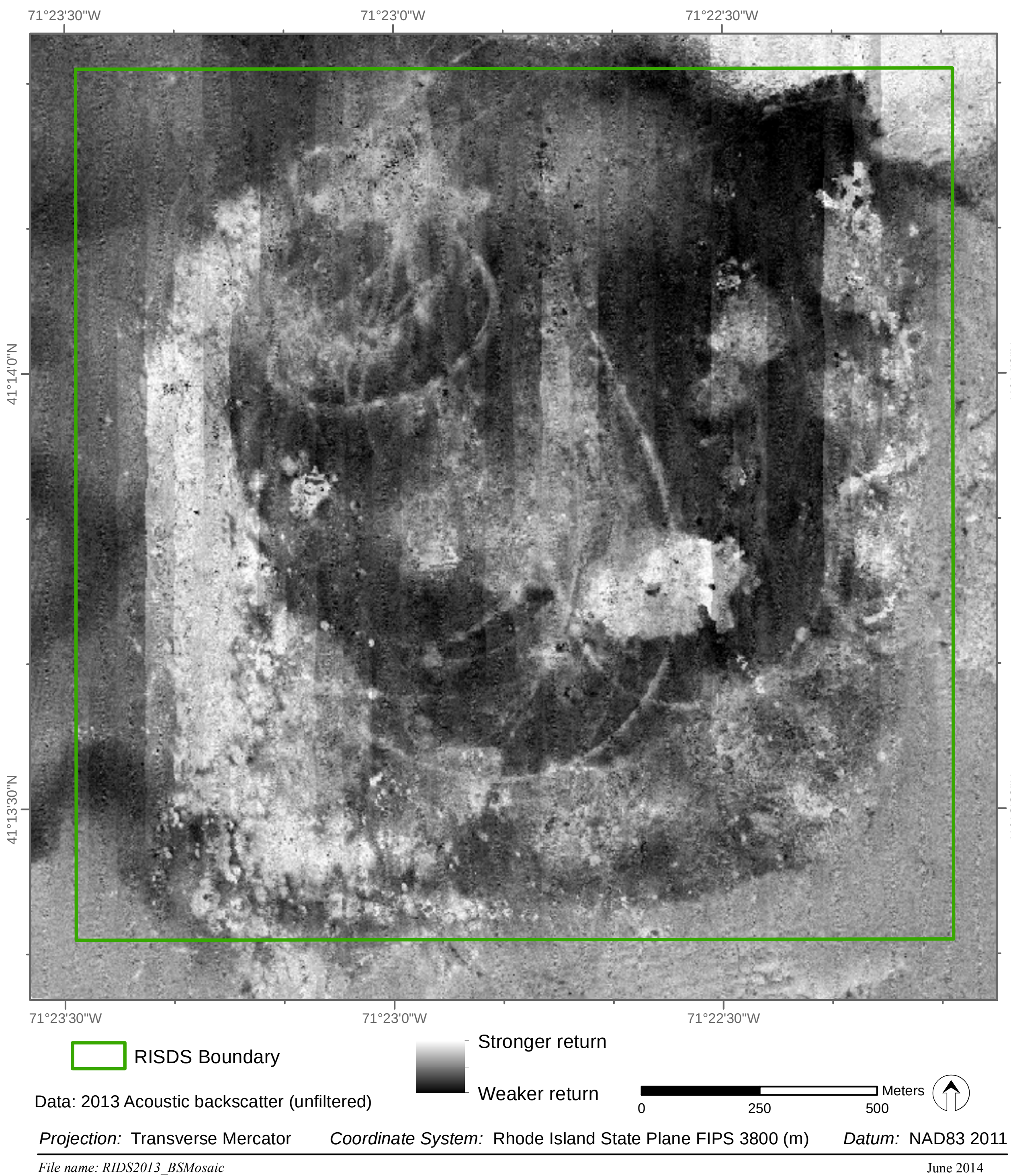


Figure 3-3. Mosaic of unfiltered backscatter data of RISDS – August 2013

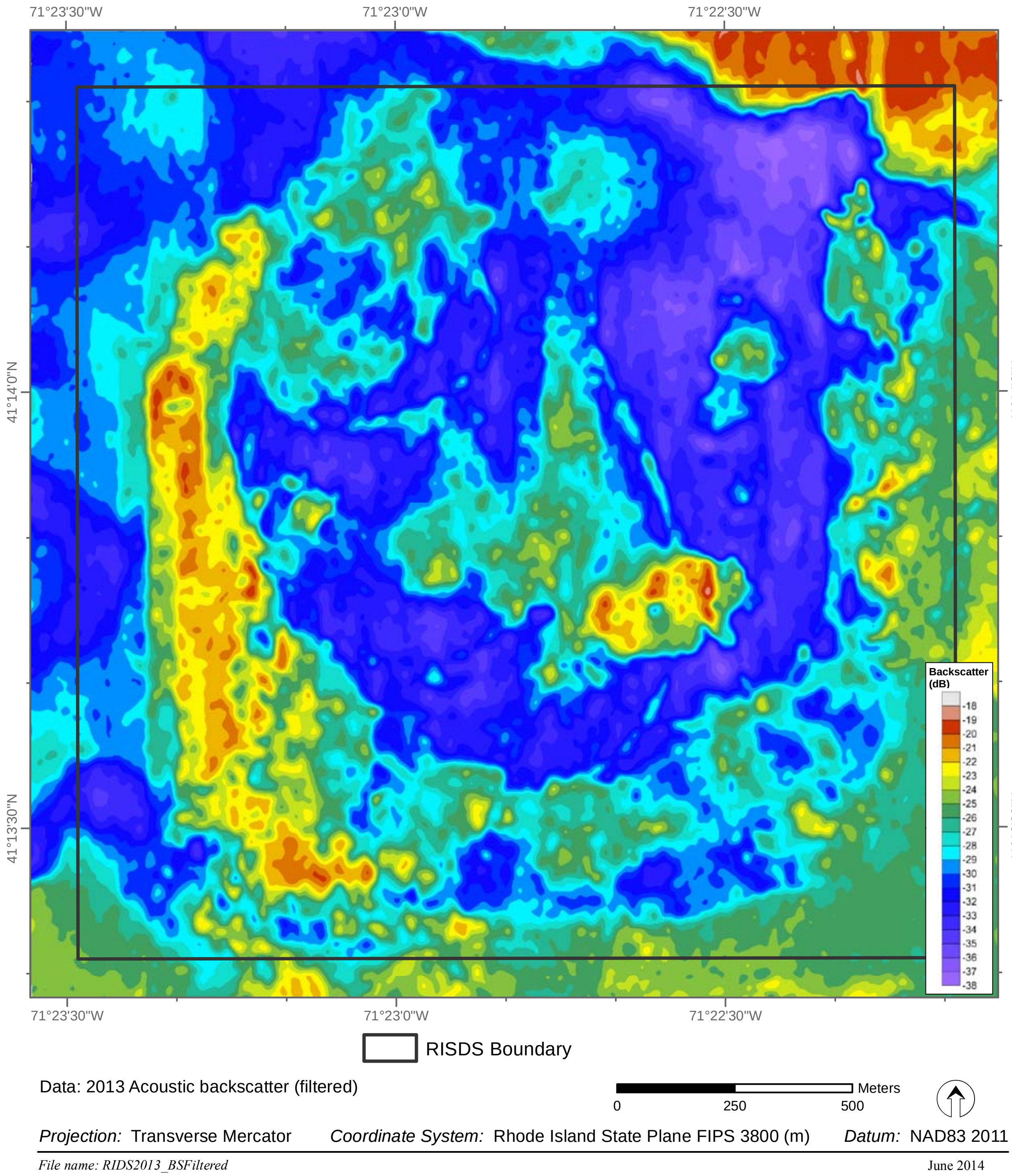


Figure 3-4. Filtered backscatter of RISDS – August 2013

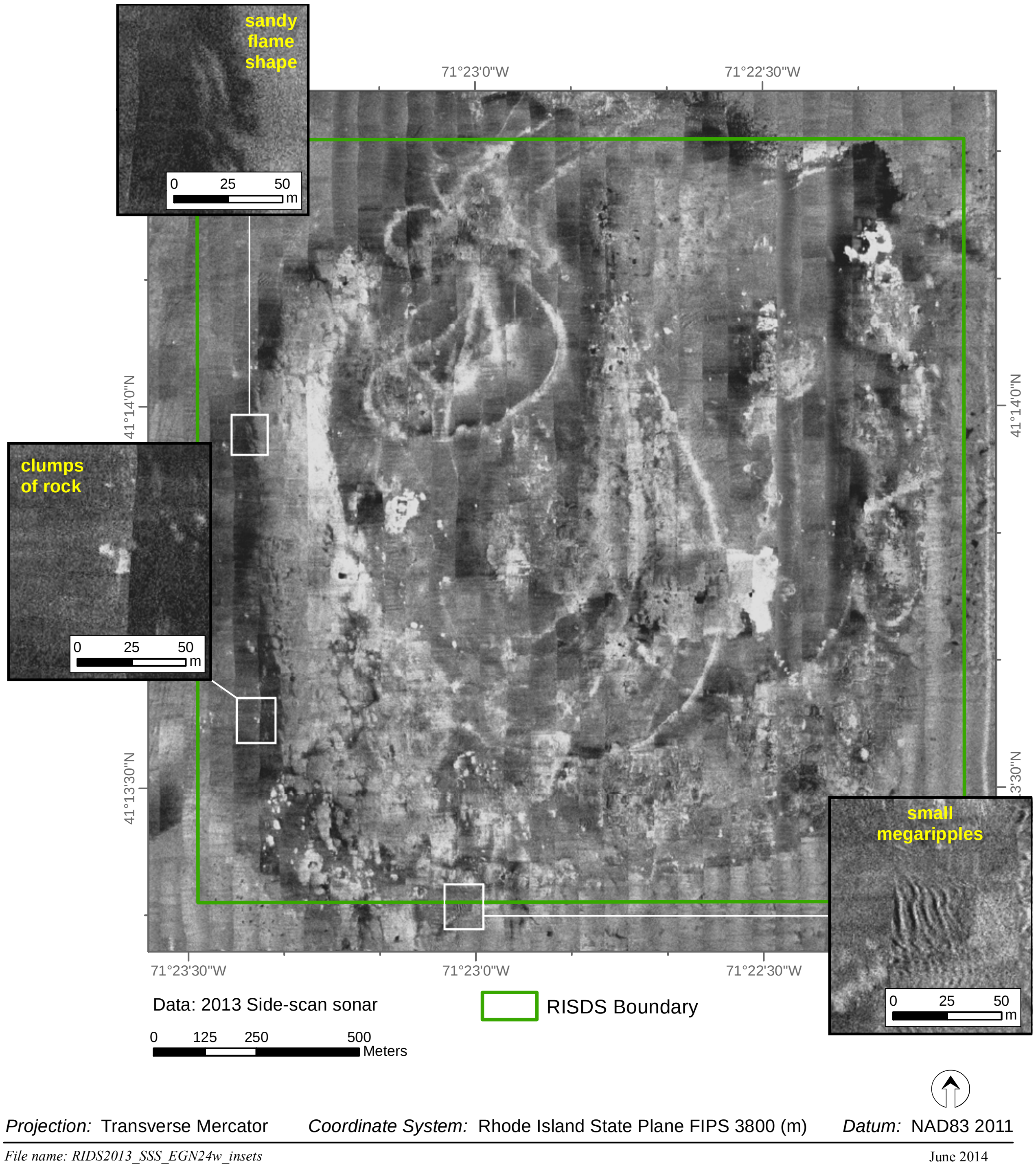
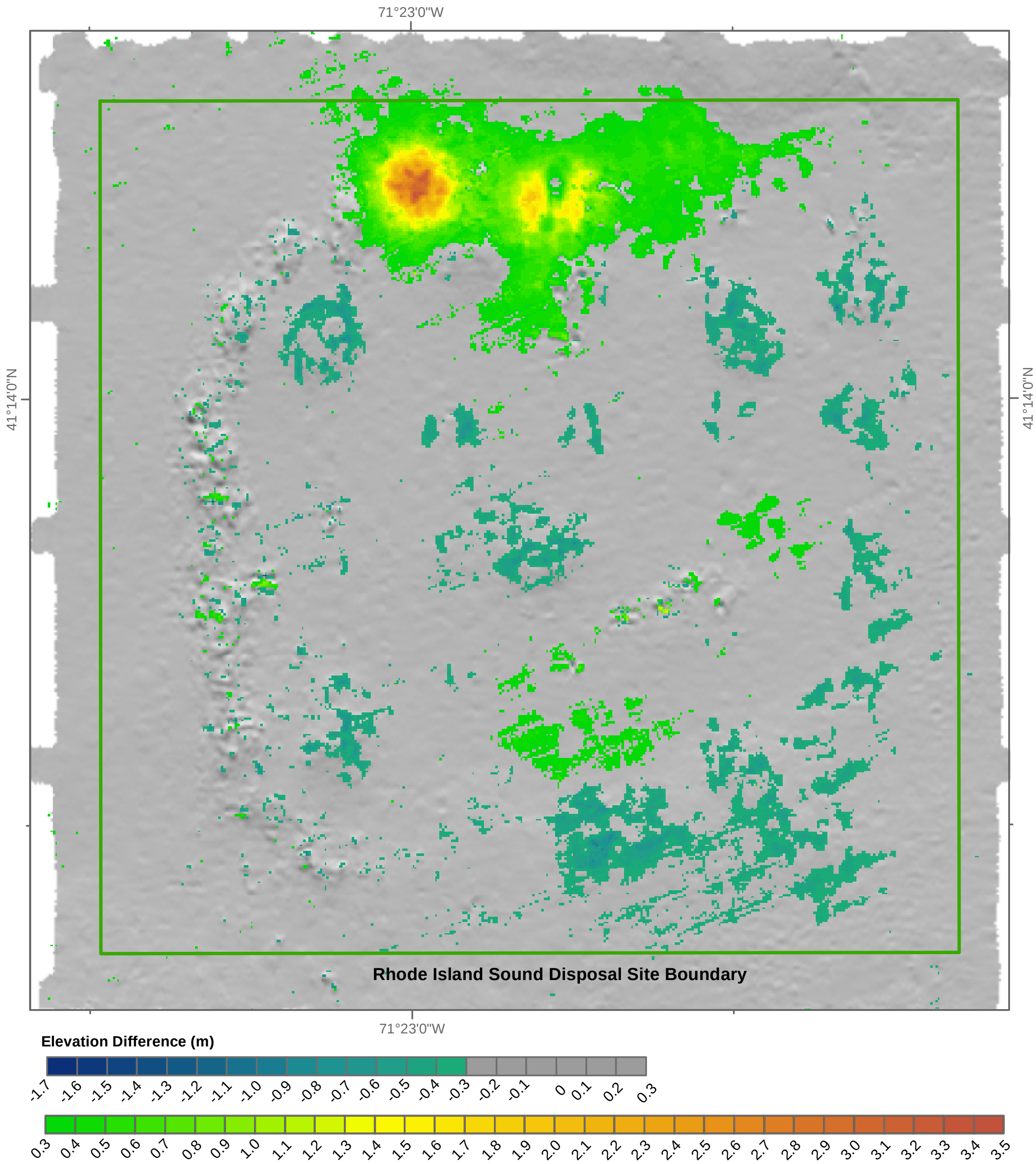


Figure 3-5. Side-scan mosaic of RISDS with feature close-ups – August 2013



Data: 2013 Acoustic Relief model 5x vertical exaggeration.
Depth Difference notes:
1. Positive values indicate elevation increase (depth decrease).
2. Changes within approximately +/- 0.3 m are considered statistically insignificant based on model uncertainties.
3. Depth difference based on 2013 survey and NOS hydrographic surveys H11996 (9/7/08-10/1/08) and H12009 (5/8/09-5/19/09).

Meters
0 250 500

Projection: Transverse Mercator *Coordinate System:* Rhode Island State Plane FIPS 3800 (m) *Datum:* NAD83 2011

File name: RIDS2013_DepthDifference_0315 March 2015

Figure 3-6. RISDS depth difference: 2013 vs. 2008 and 2009

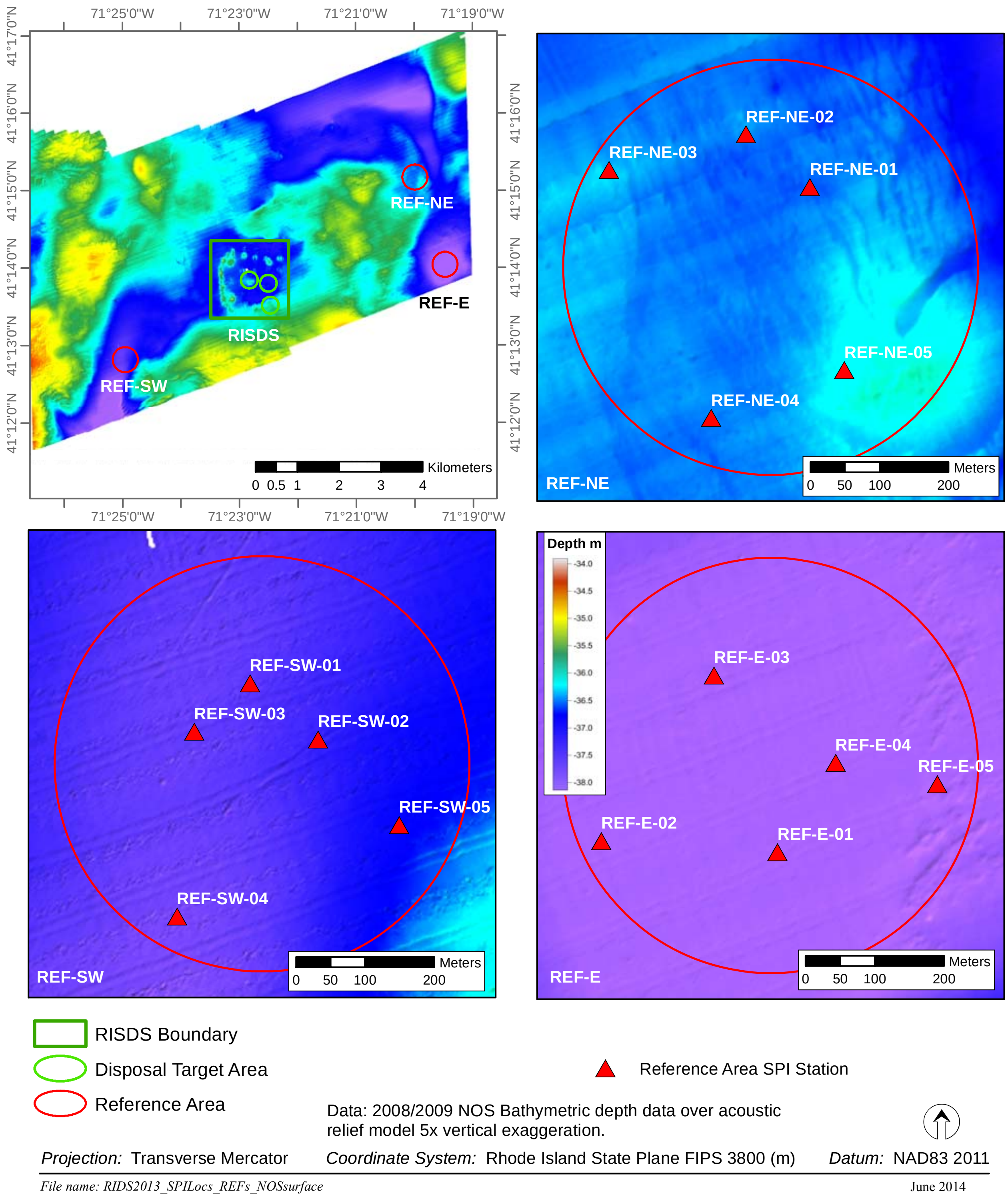


Figure 3-7. RISDS reference areas with SPI stations indicated

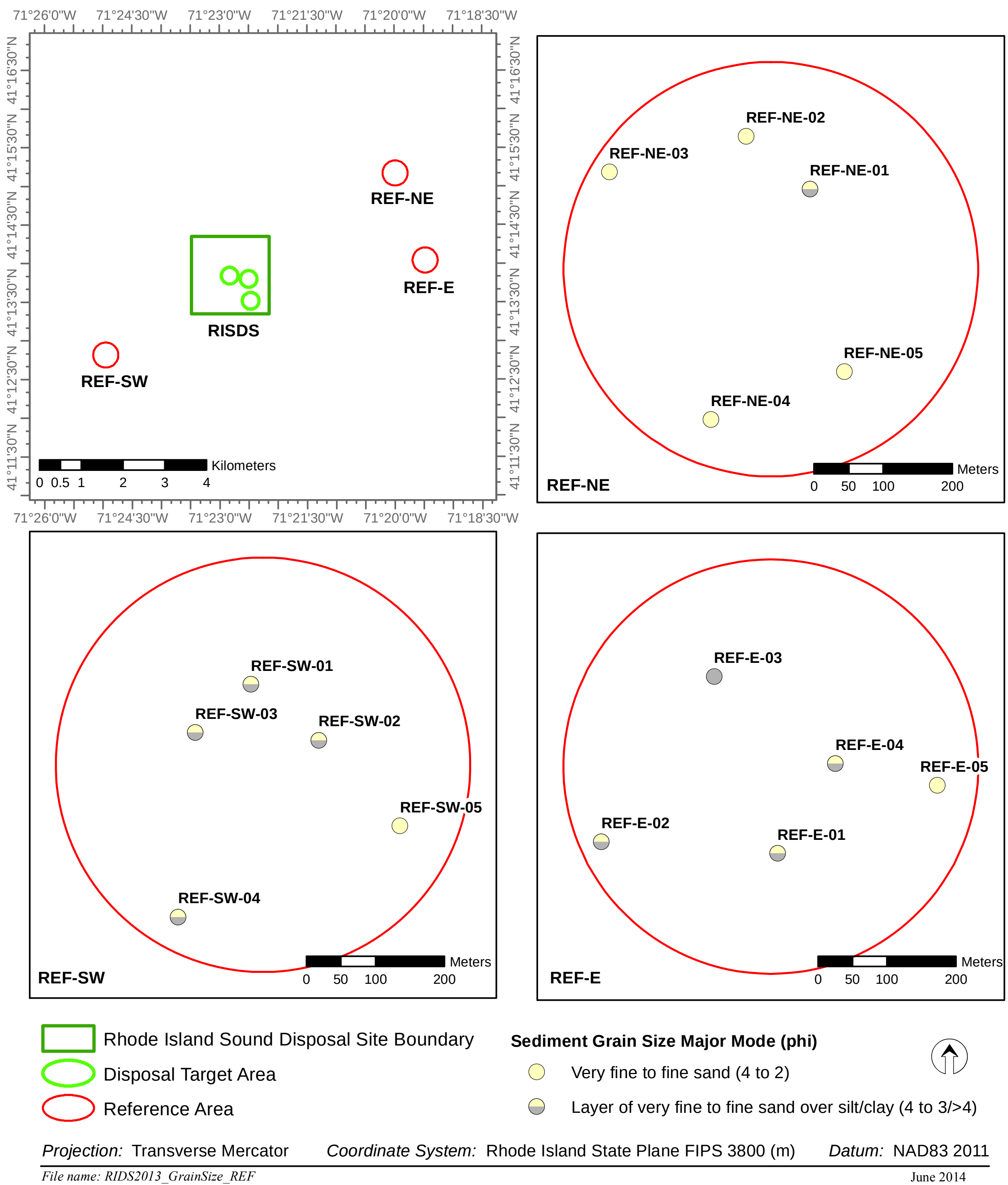


Figure 3-8. Sediment grain size major mode (phi units) at the RISDS reference areas

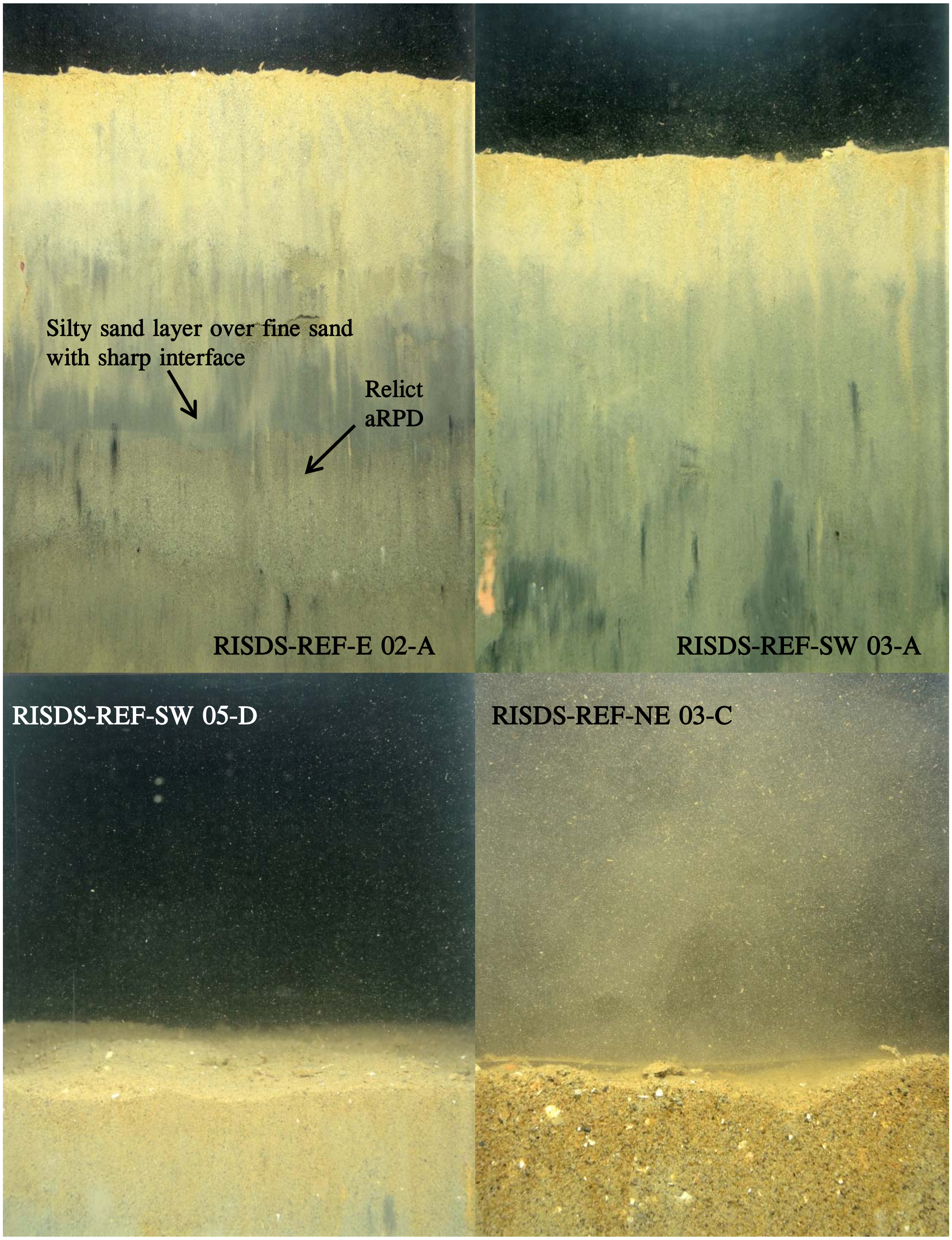


Figure 3-9. Sediment grain size and penetration variation at the RISDS reference areas

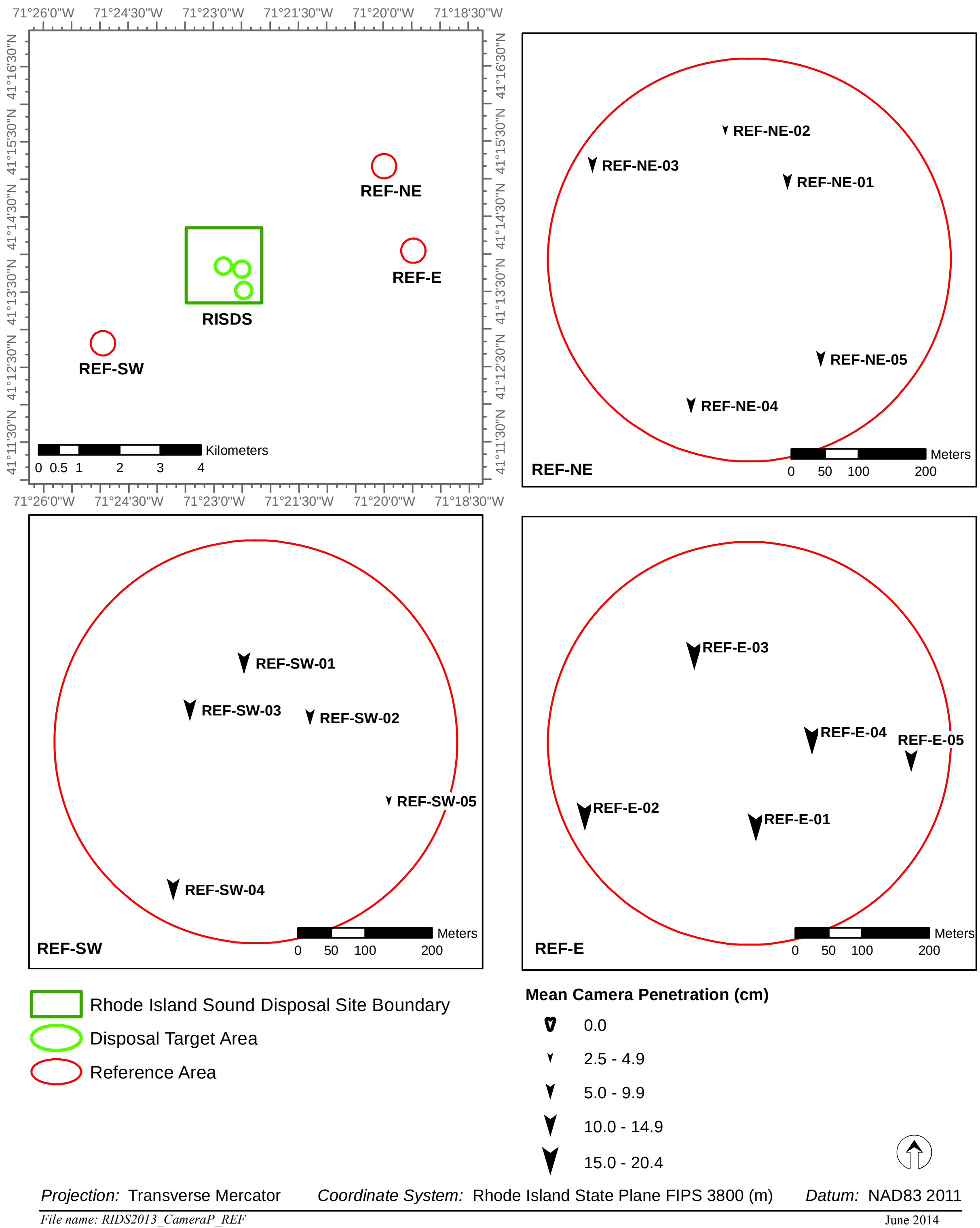


Figure 3-10. Mean station camera prism penetration depths (cm) at the RISDS reference areas

Figure 3-11. Mean station small-scale boundary roughness values (cm) at the RISDS reference areas

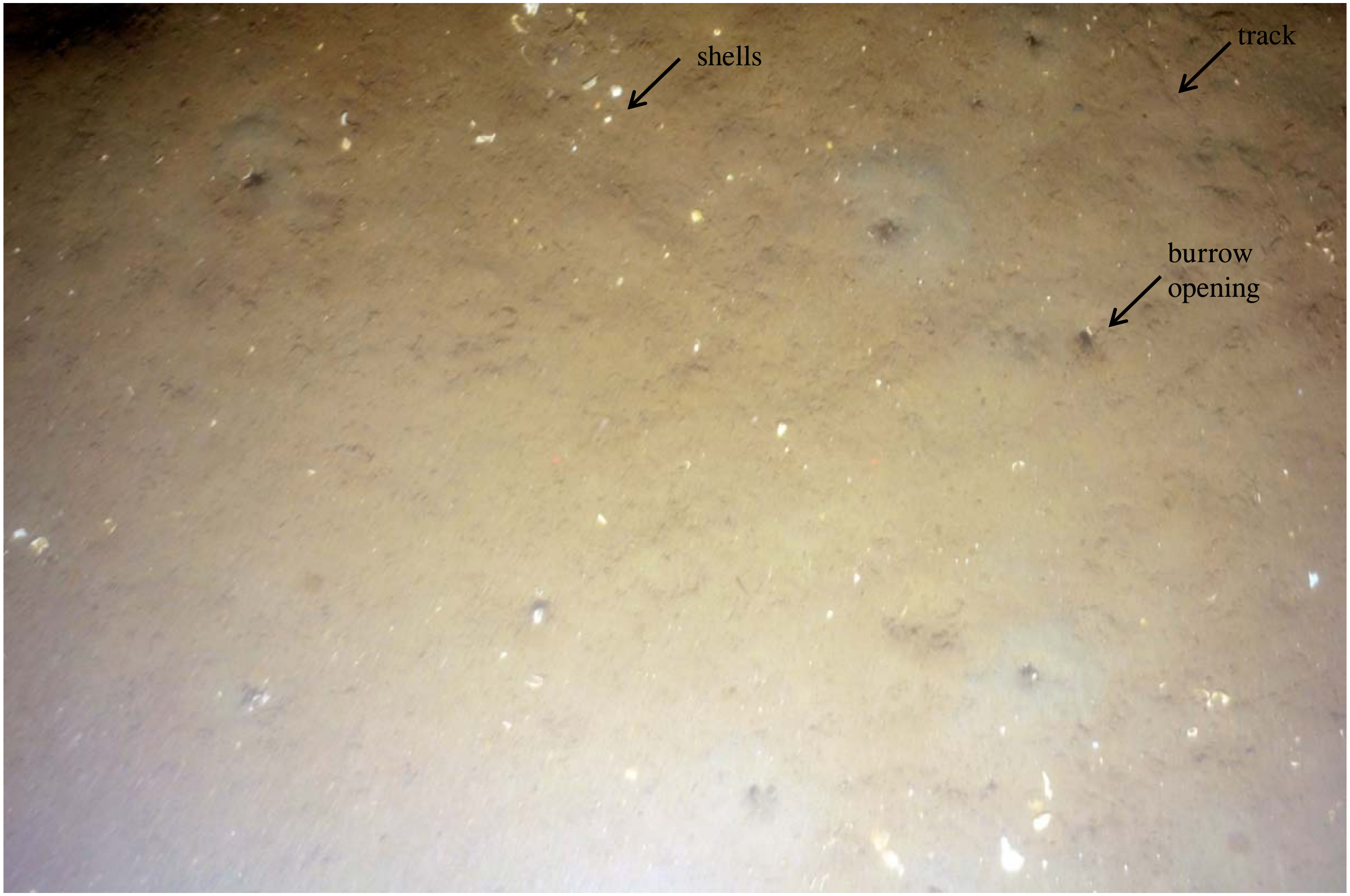


Figure 3-12. This plan-view image from REF-SW Station 5 shows tracks, multiple burrow openings and small shells scattered across the silty sediment surface. Scale: width of image = 110 cm.

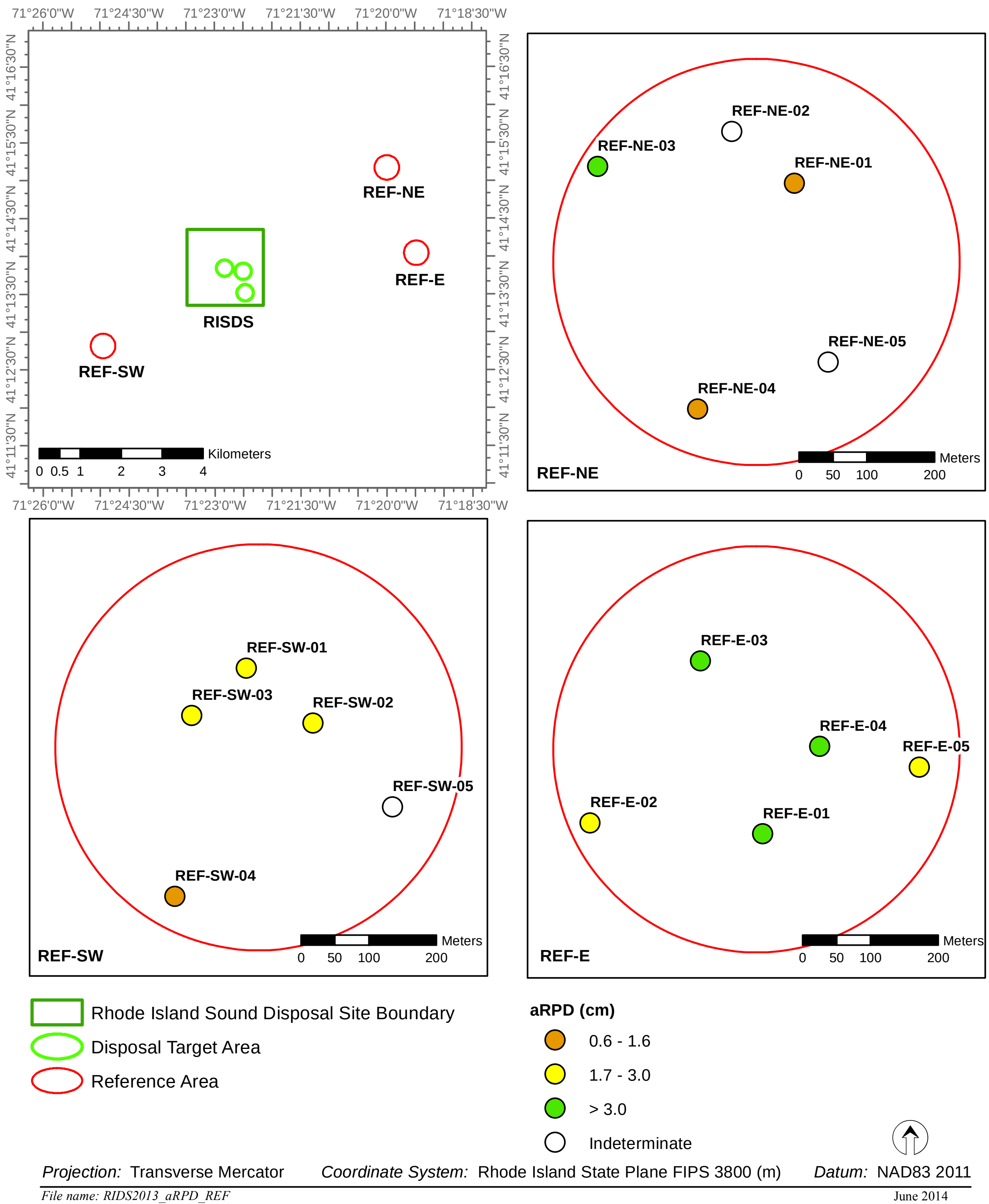


Figure 3-13. Mean station aRPD depth values (cm) at the RISDS reference areas

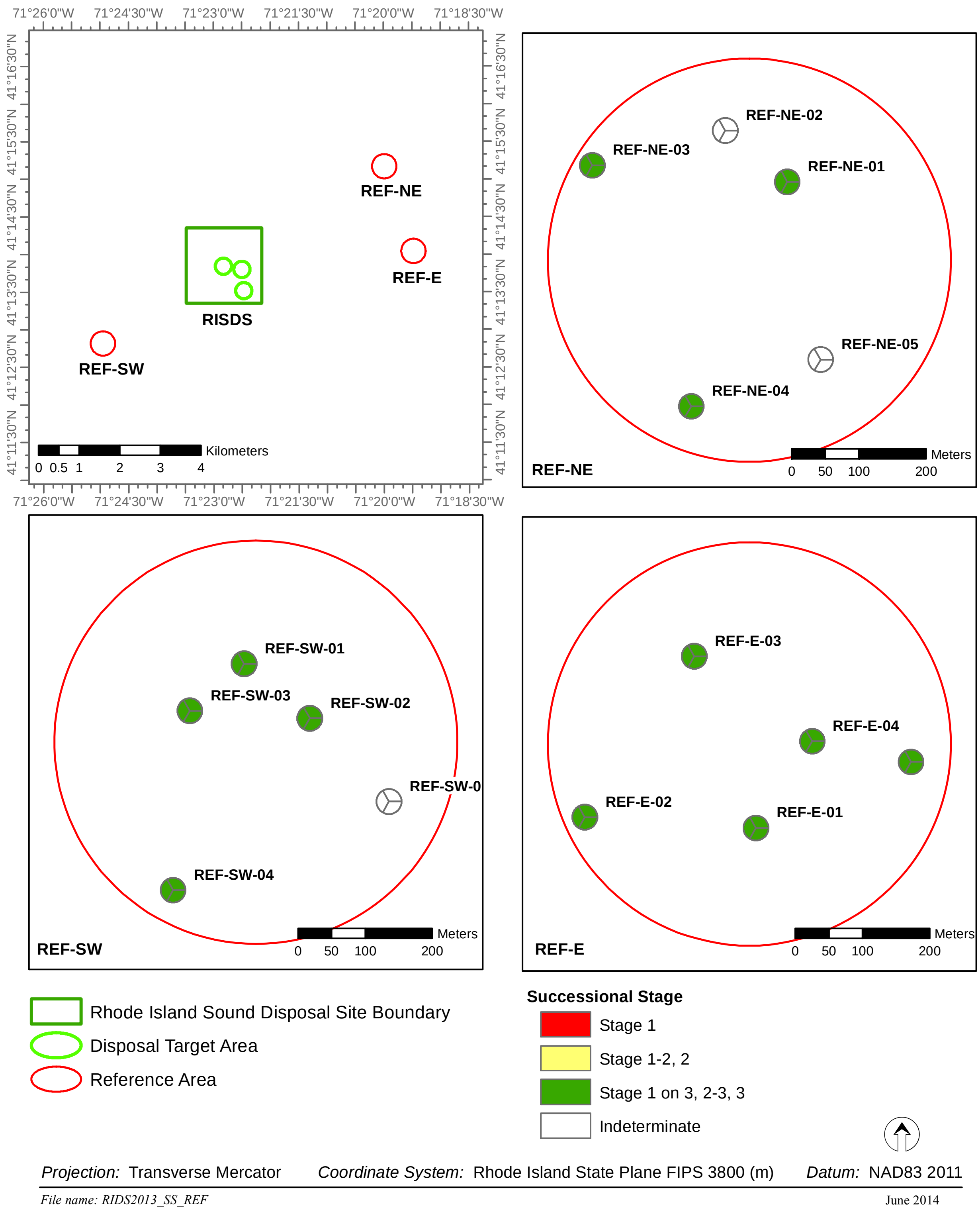


Figure 3-14. Infaunal successional stages found at the RISDS reference areas

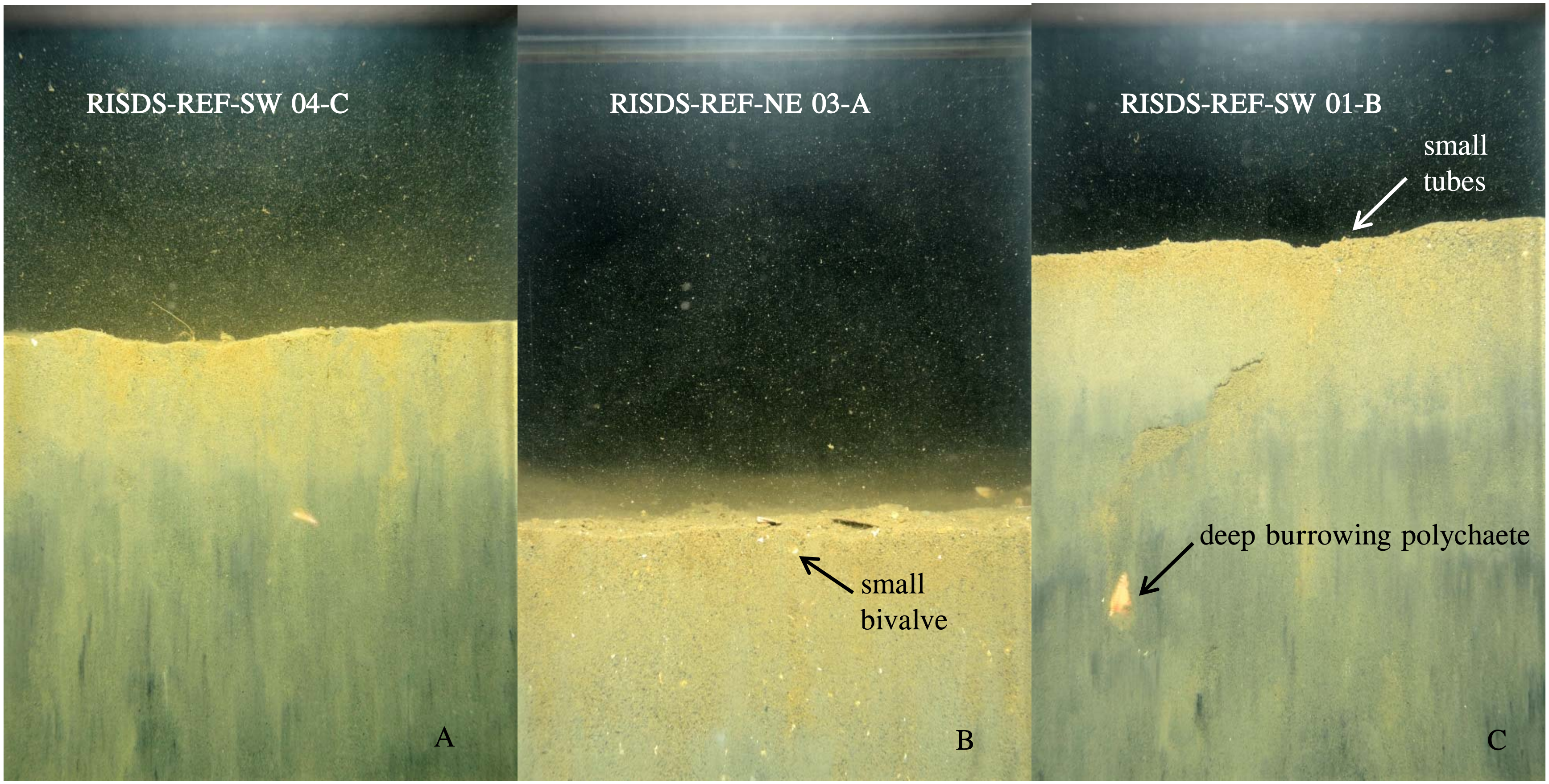


Figure 3-15. Infaunal successional stages found at the RISDS reference areas: A. Stage 1 on 3; B. Stage 2 on 3, small bivalves; C. Stage 1 on 3, small tubes and deep burrowing polychaete

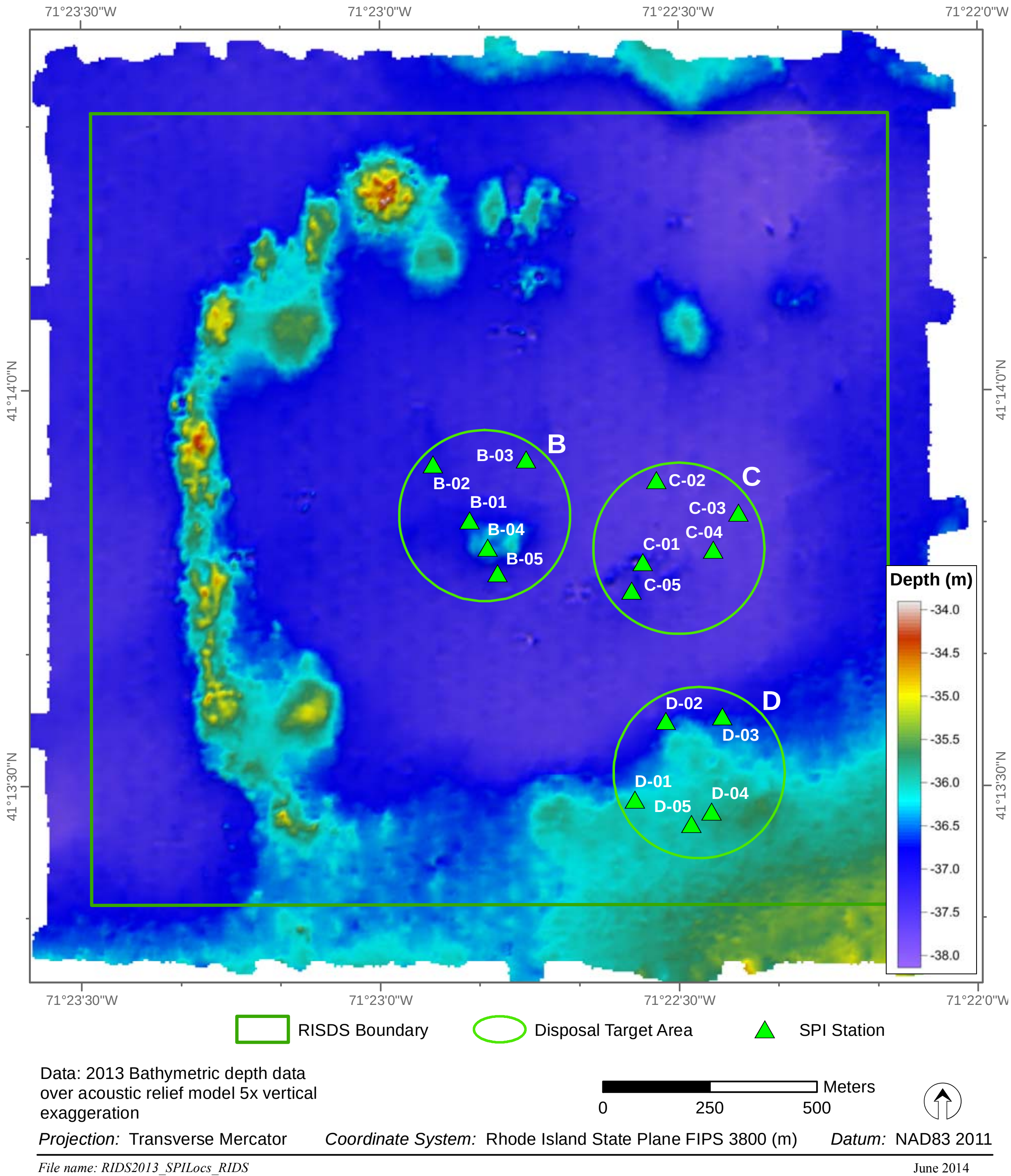


Figure 3-16. RISDS with disposal target areas B, C, D and SPI/PV stations indicated

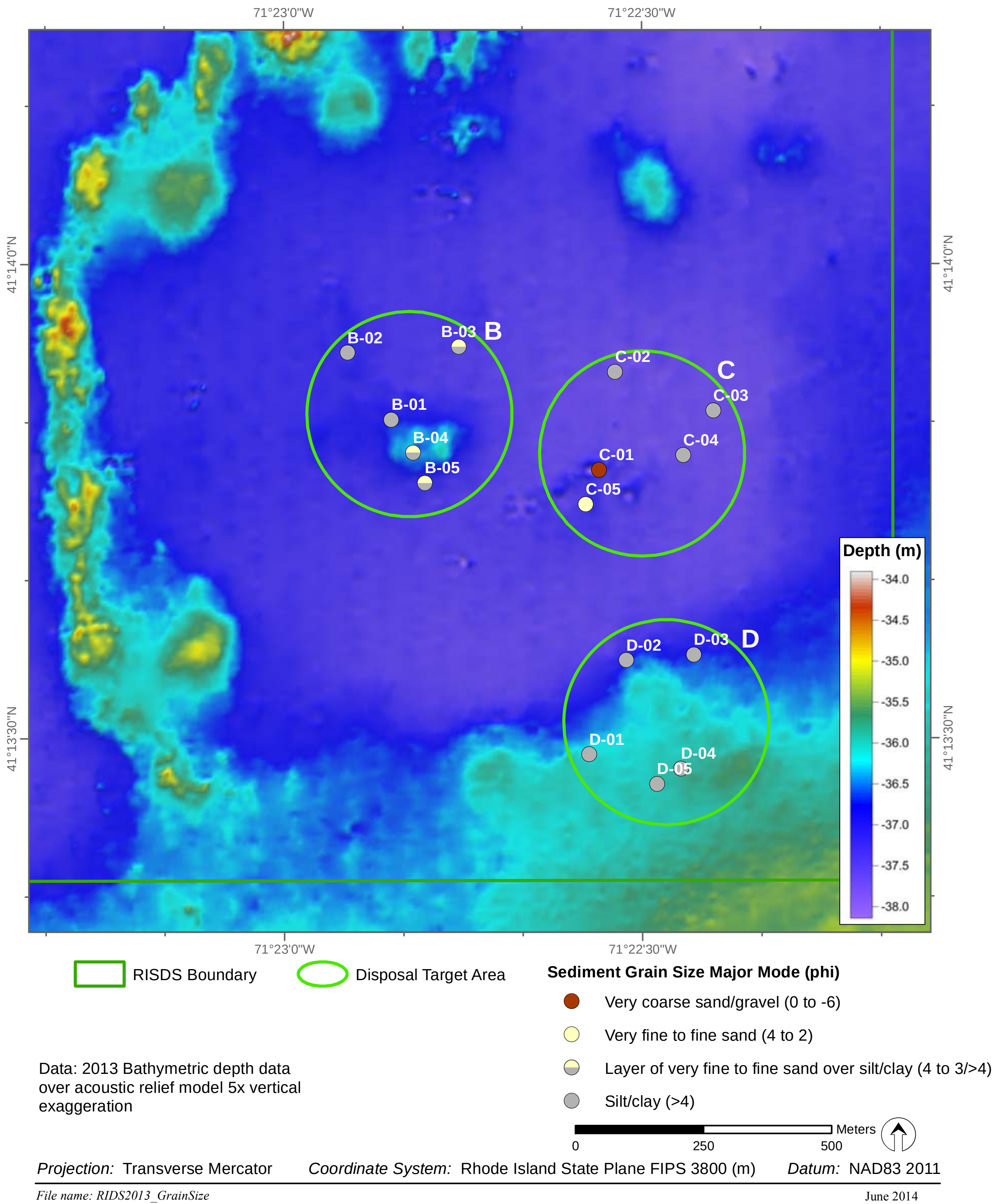


Figure 3-17. Sediment grain size major mode (phi units) at stations sampled within RISDS disposal target areas

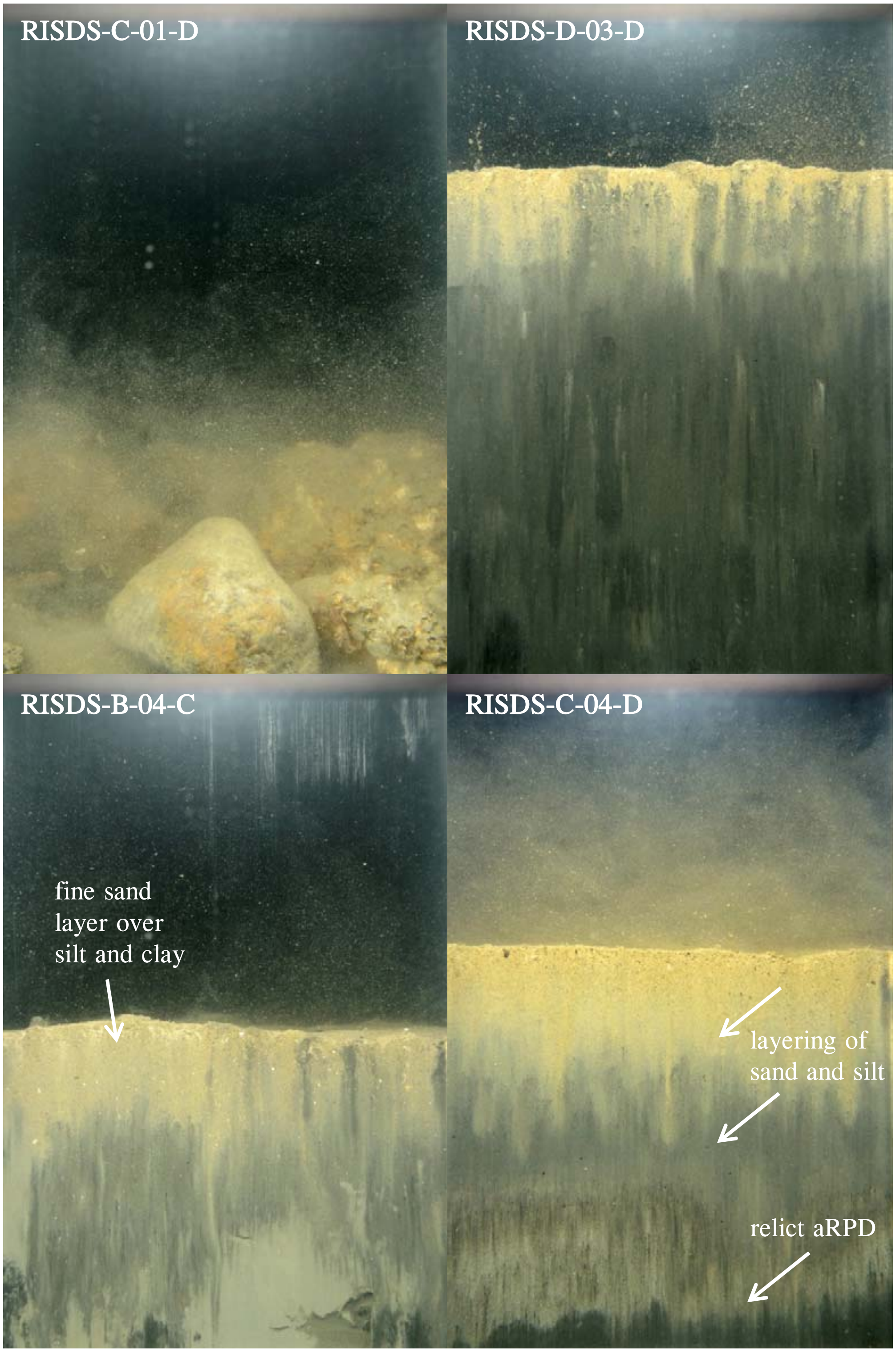


Figure 3-18. Sediment grain size and penetration variation at stations sampled within RISDS disposal target areas

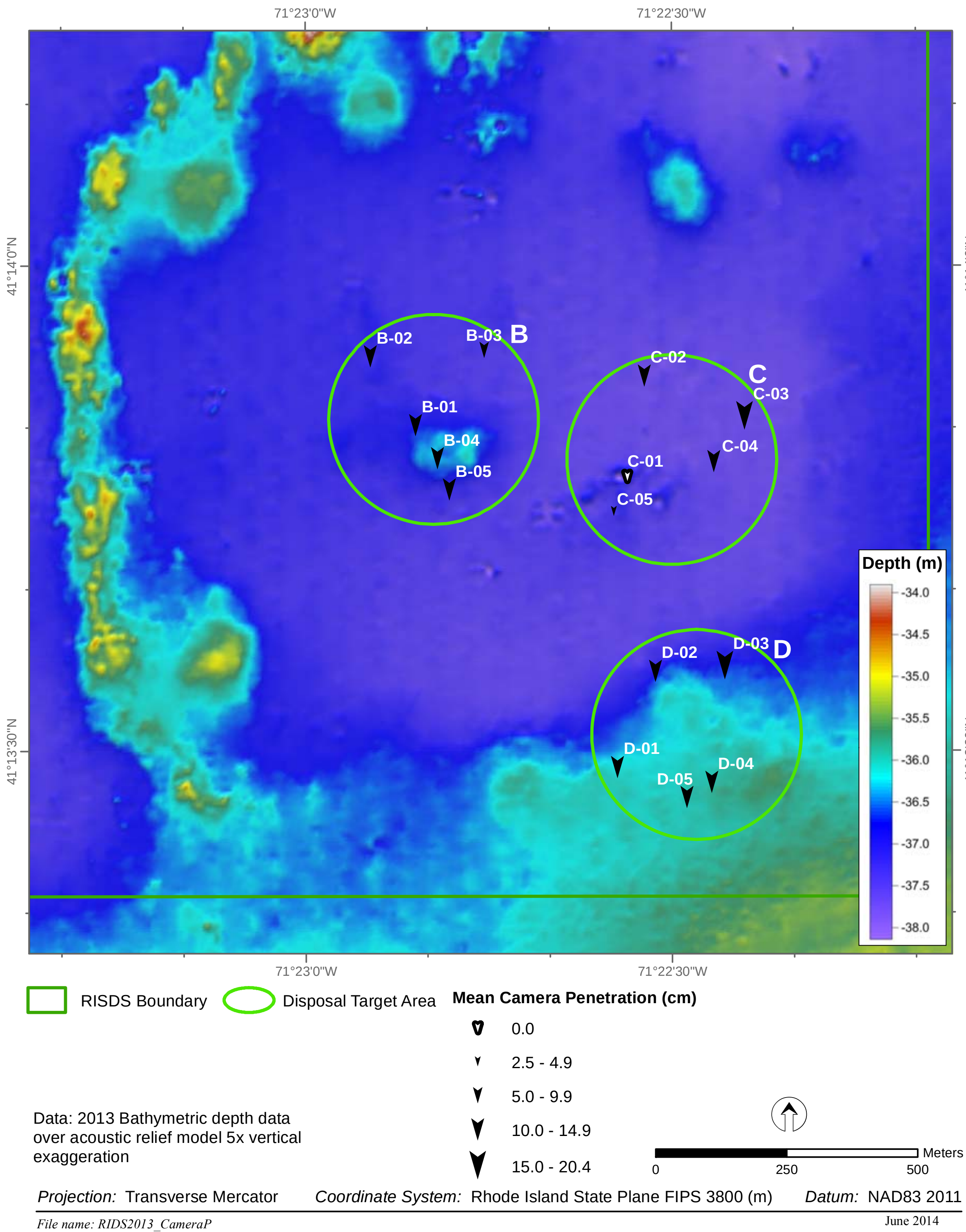


Figure 3-19. Mean station camera prism penetration depths (cm) at stations sampled within RISDS disposal target areas

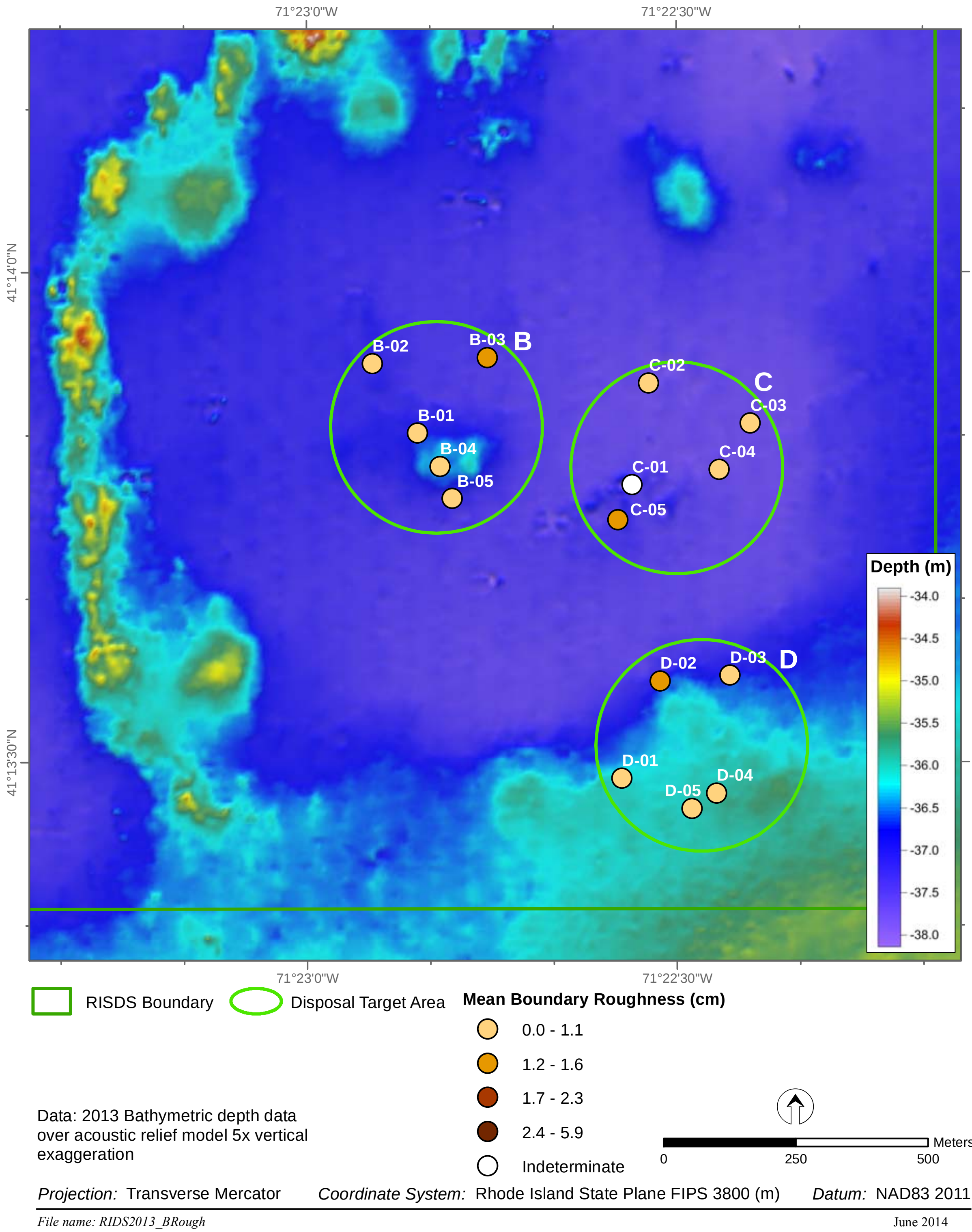


Figure 3-20. Mean station small-scale boundary roughness values (cm) at stations sampled within RISDS disposal target areas

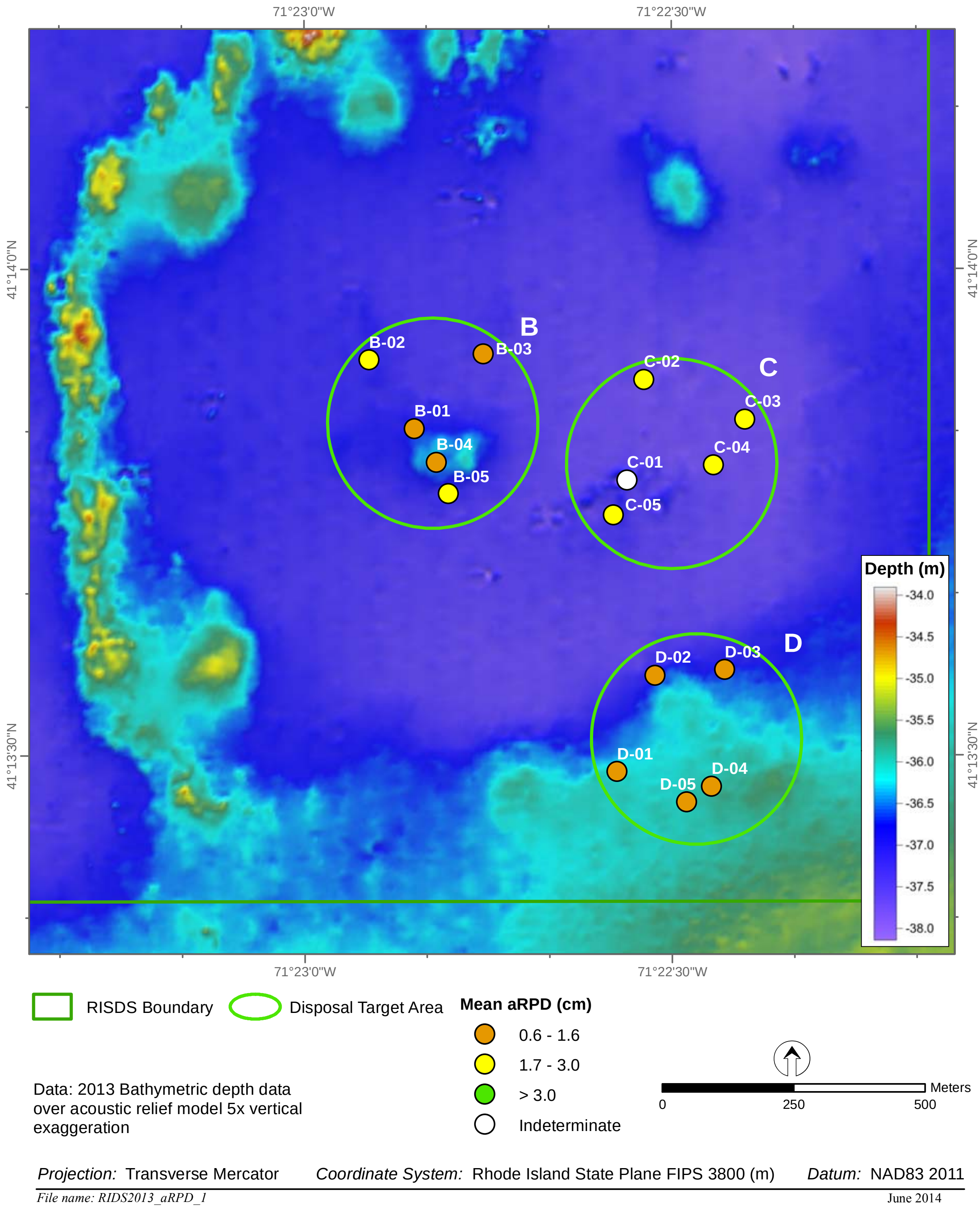


Figure 3-21. Mean station depth of the apparent RPD (cm) at stations sampled within RISDS disposal target areas

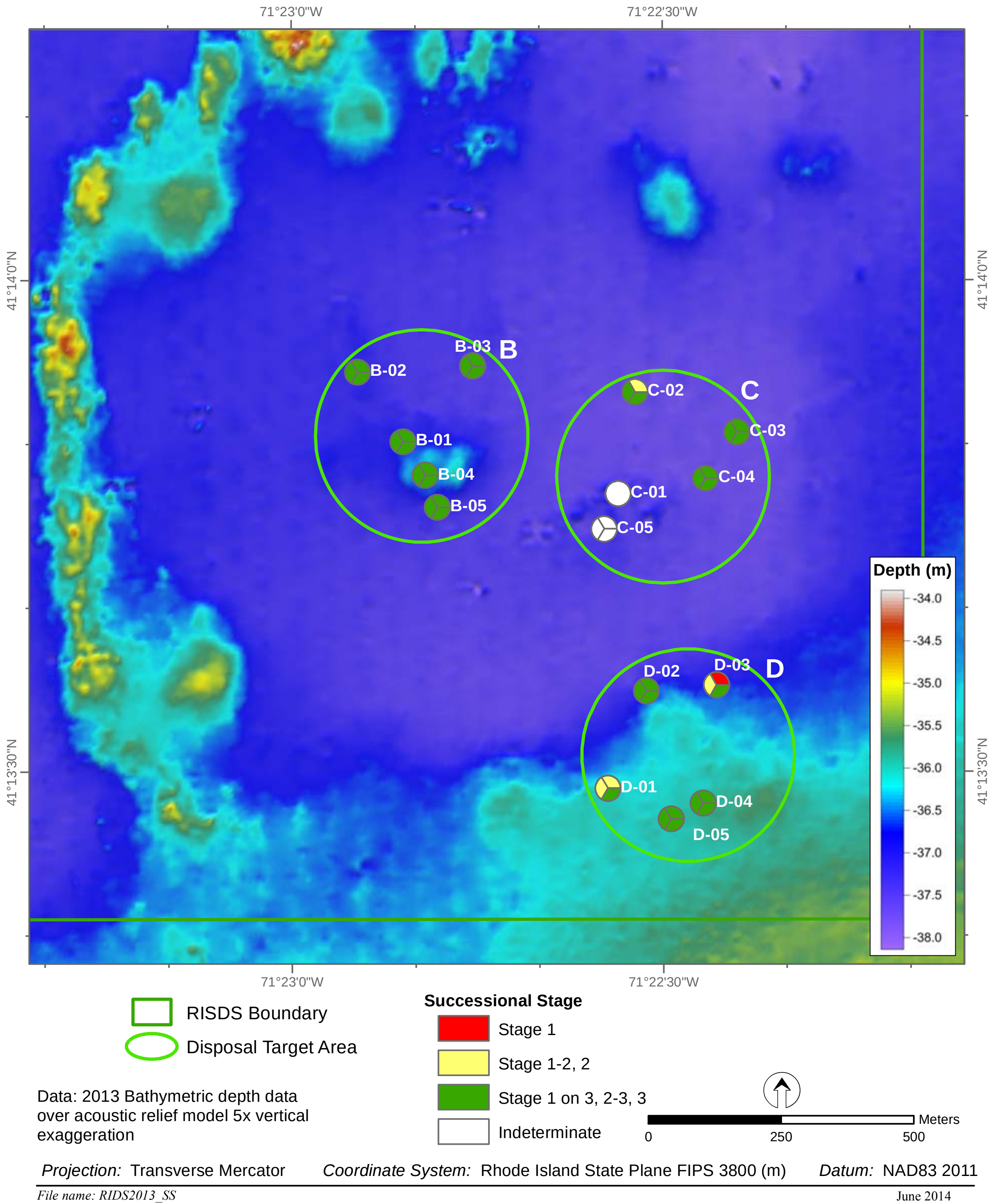


Figure 3-22. Infaunal successional at stations sampled within RISDS disposal target areas

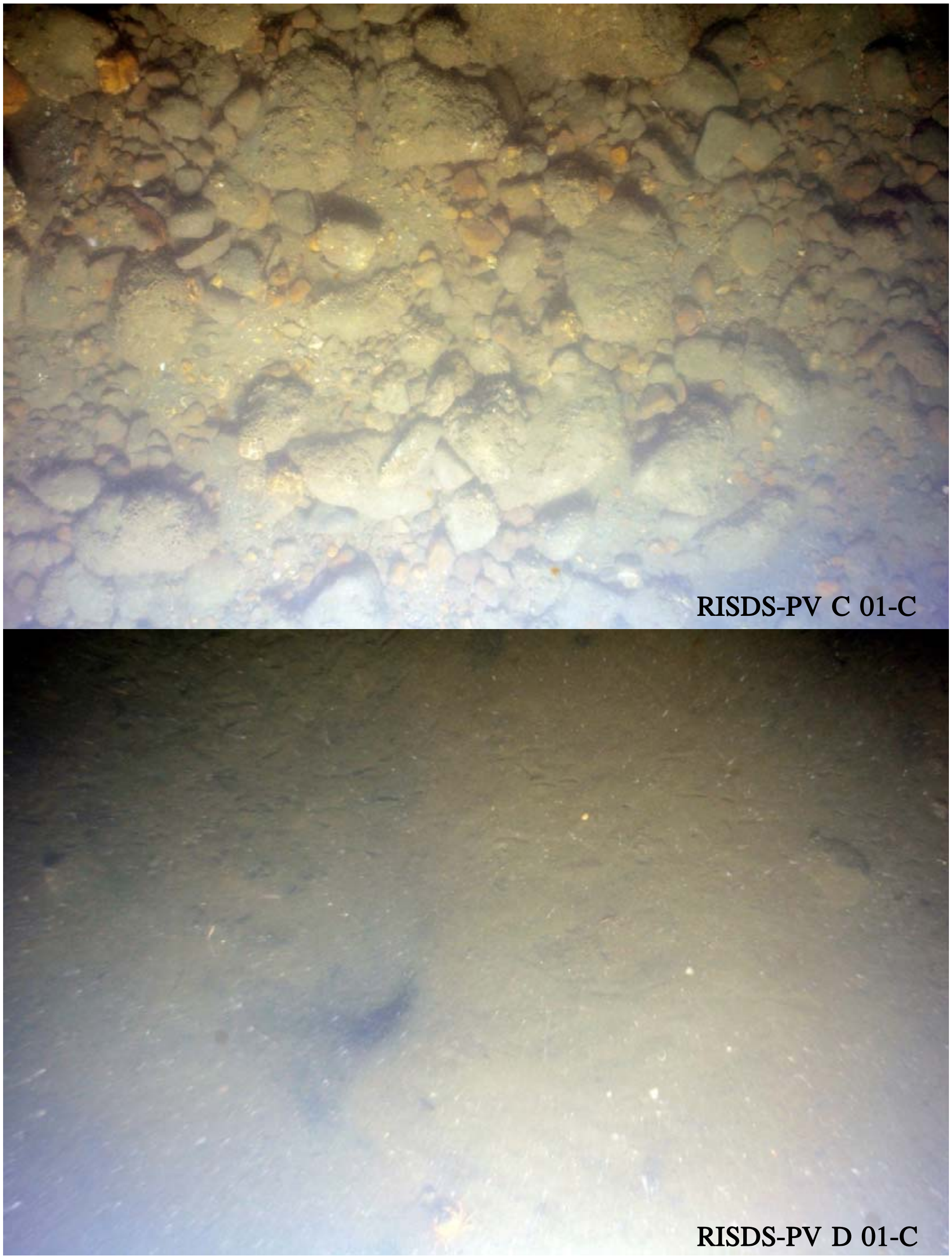


Figure 3-23. Plan-view images of sediment surface within the RISDS boundary. Top image is 110 cm across. Bottom image is indeterminate size as laser dots are not clear.

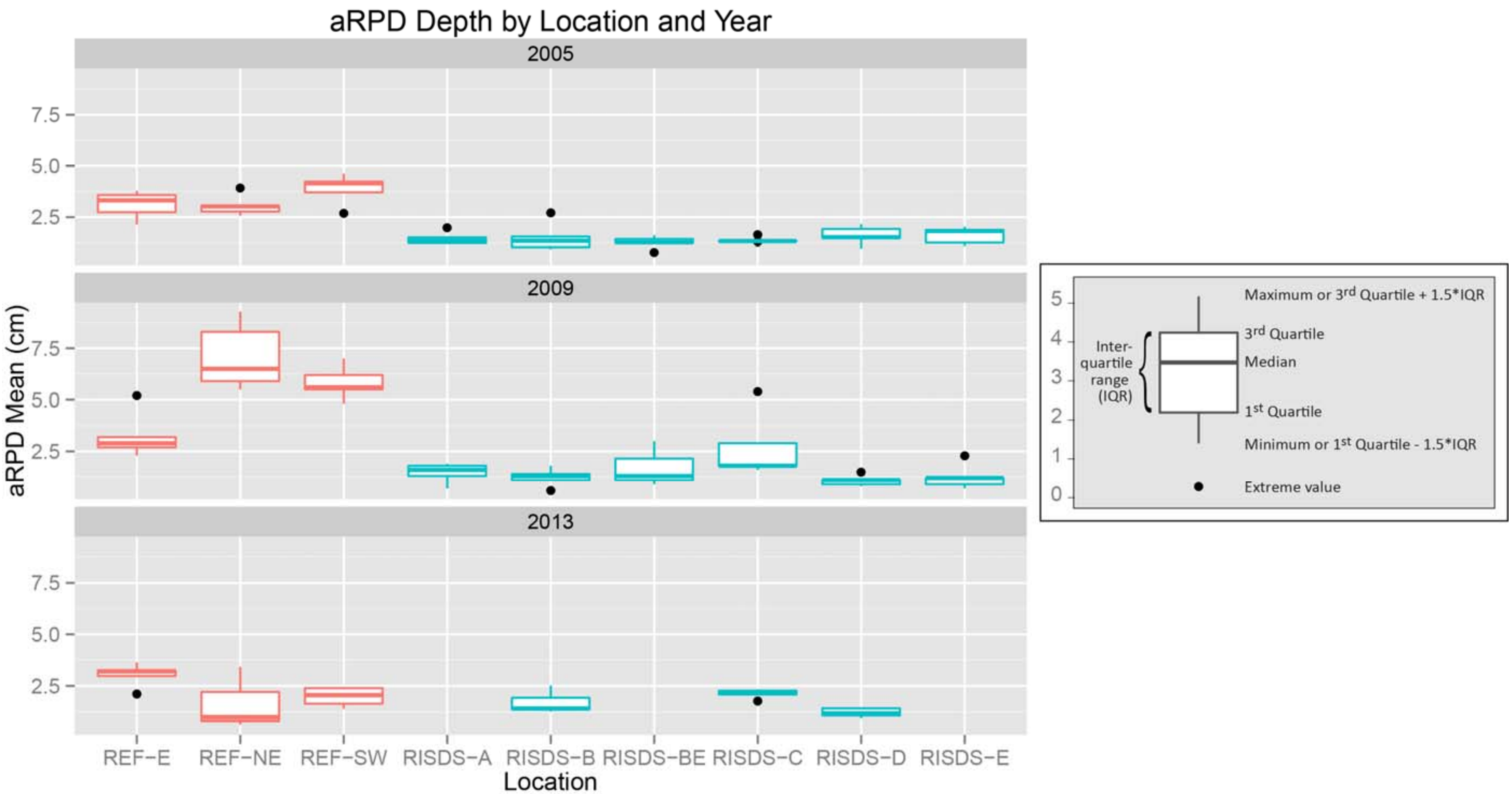


Figure 3-24. Boxplots showing the distribution of mean aRPD depths measured at the disposal site and reference area stations in the 2005, 2009 and 2013 surveys.

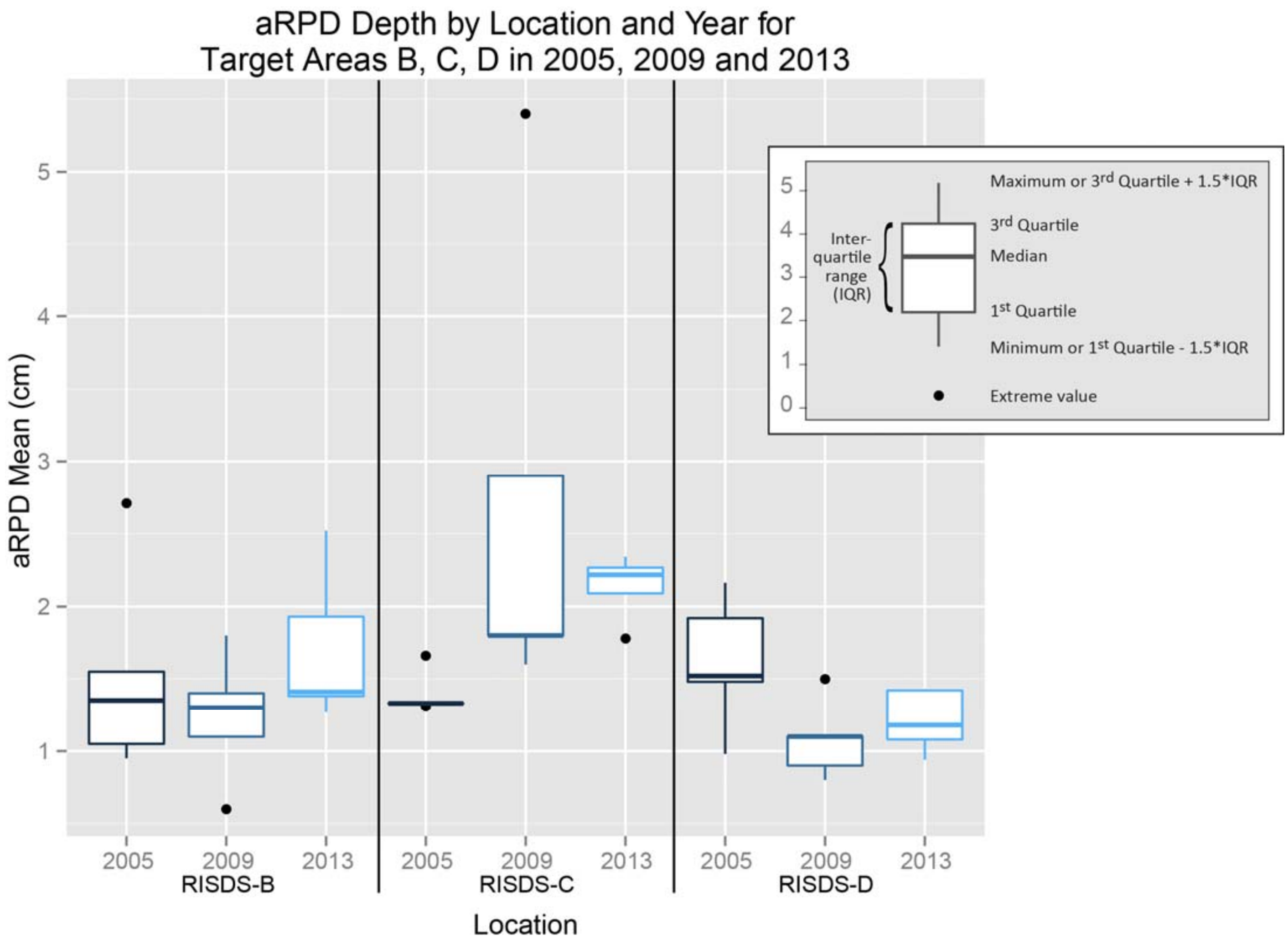


Figure 3-25. Boxplots showing the distribution of mean aRPD depths measured at disposal site target areas RISDS-B, RISDS-C, and RISDS-D in 2005, 2009 and 2013.

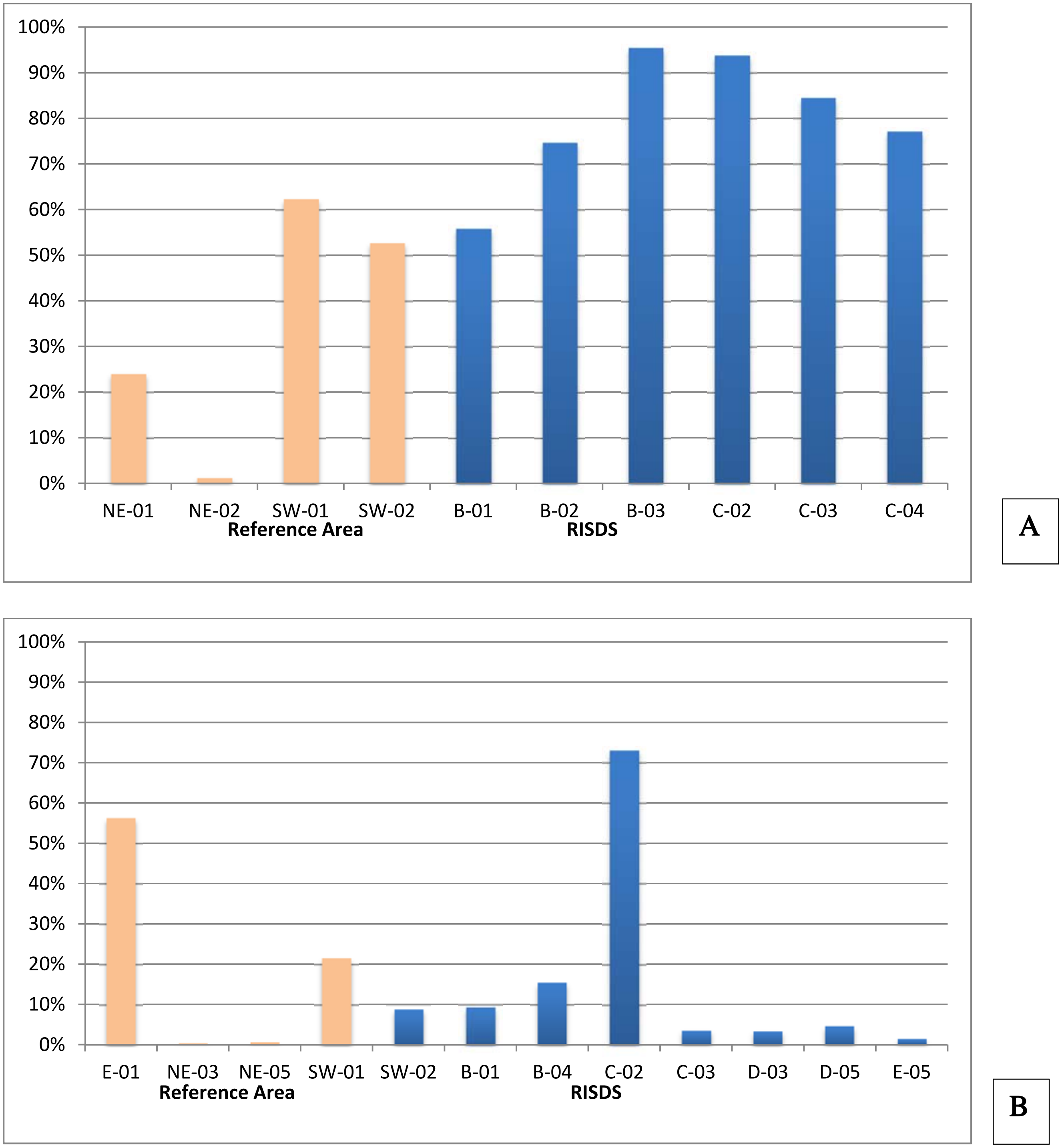


Figure 3-26. A. 2013 Relative Abundance of *Nucula proxima* in Grab Samples from Reference Areas and RISDS; B. 2005 Relative Abundance of *Nucula annulata** in Grab Samples from Reference Areas and RISDS

**This species has been determined to represent the same species as Nucula proxima*

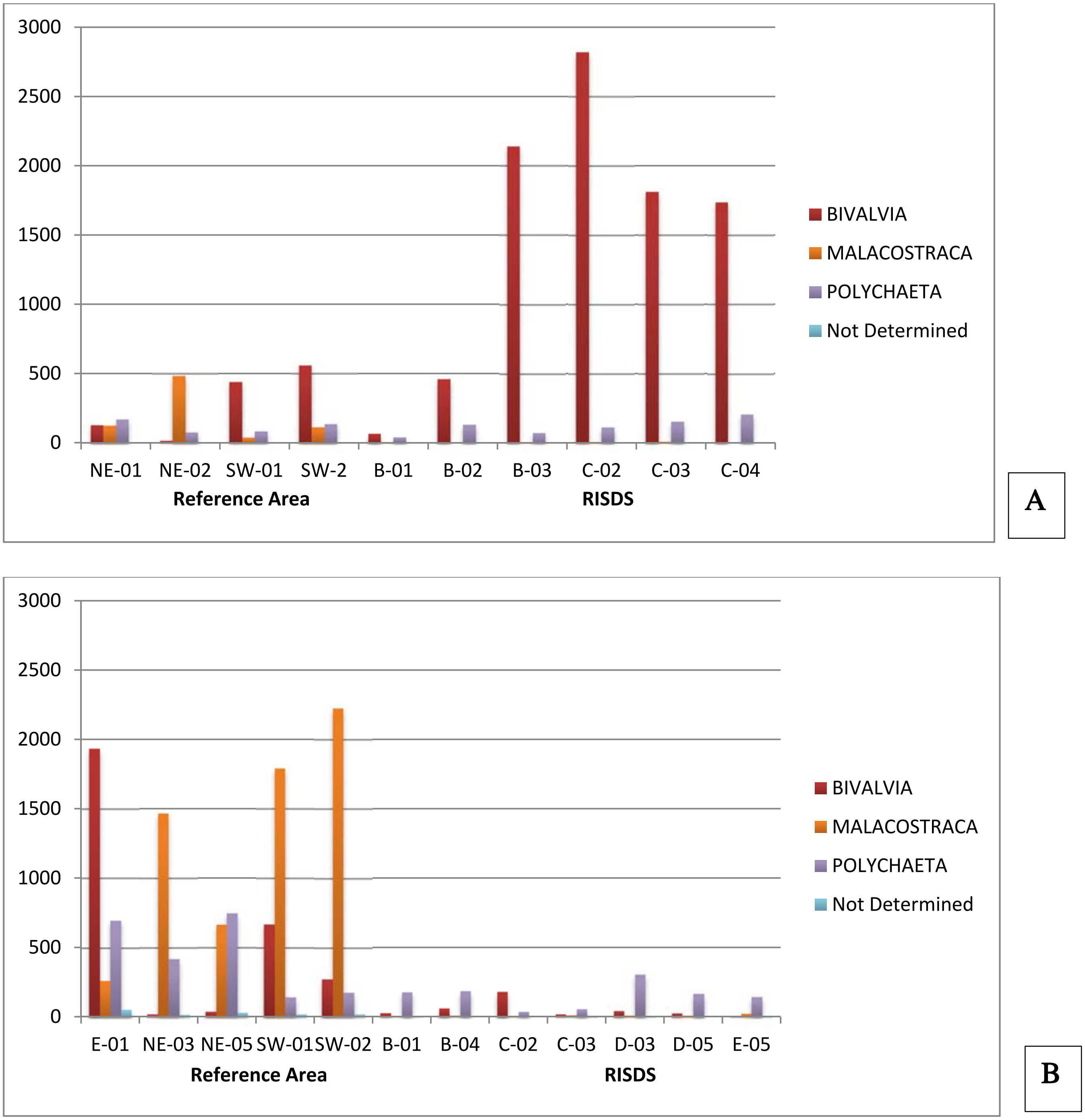


Figure 3-27. Number of individuals per sample in grab samples from reference areas and RISDS, A. 2013; B. 2005

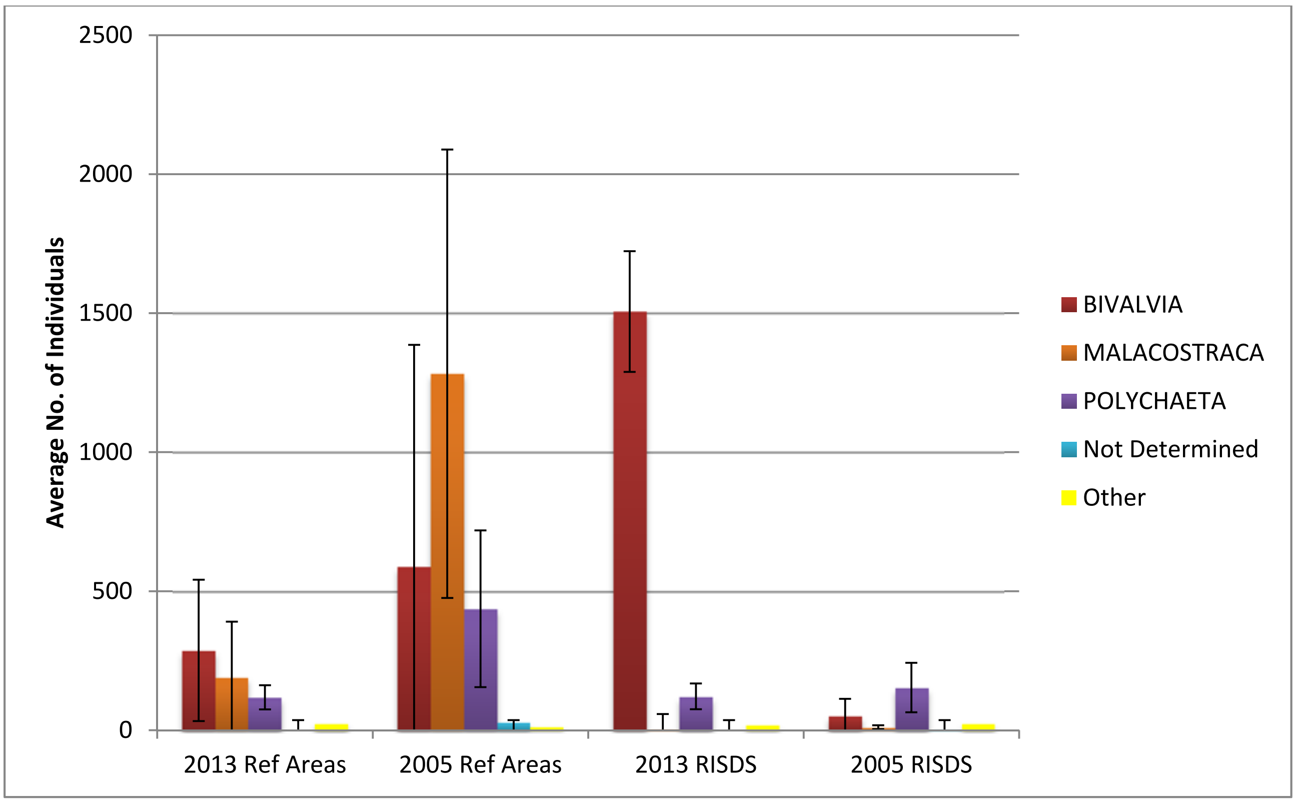


Figure 3-28. The average number of individuals per sample by class based on location and year, standard deviation indicated by bracketed lines.

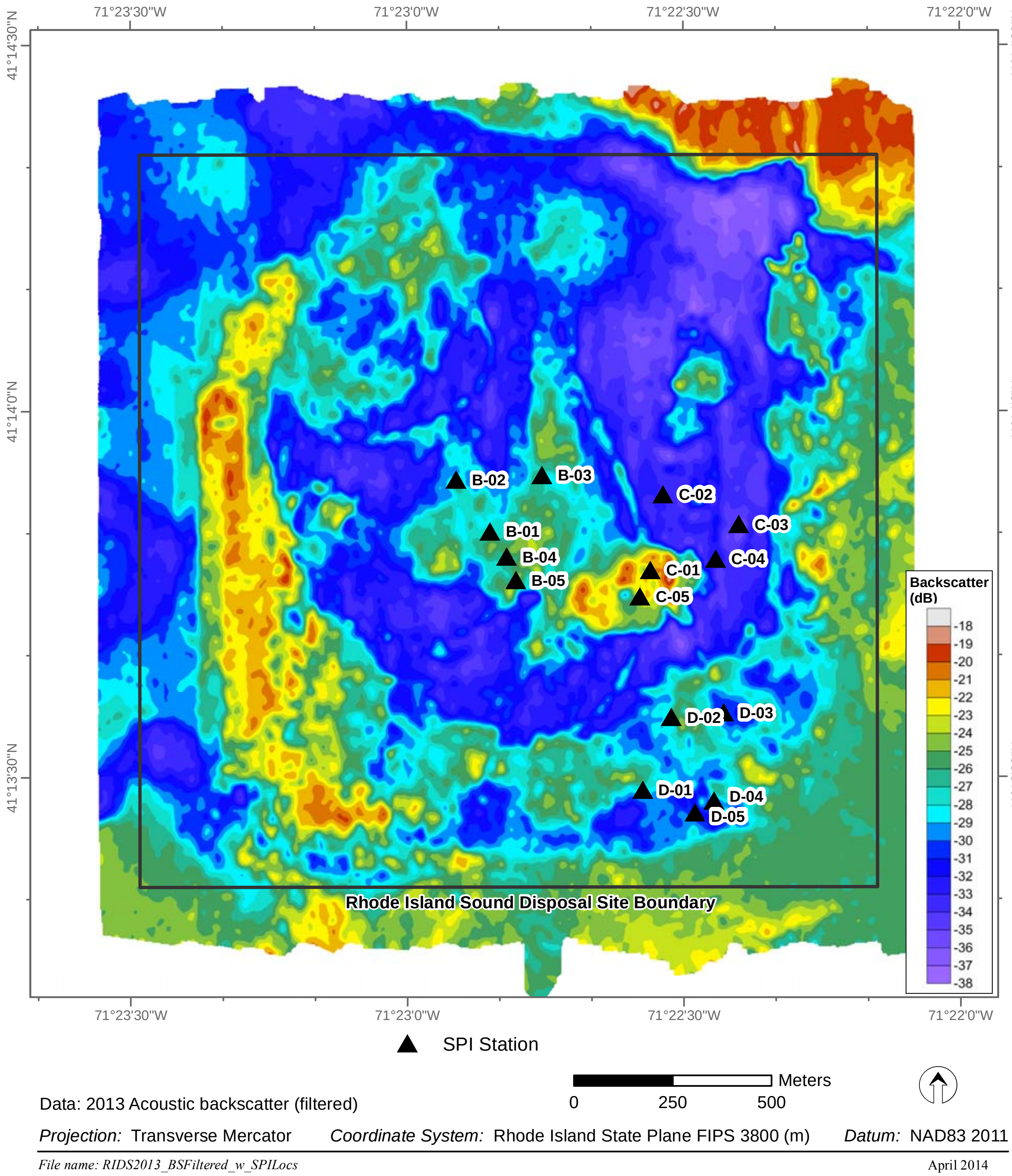


Figure 3-29. Filtered backscatter of RISDS with SPI stations indicated

4.0 DISCUSSION

The objectives of the August 2013 survey efforts at RISDS were to first characterize the seafloor topography and surficial features of the entire RISDS by completing a high resolution acoustic survey. Evidence of recently disposed material was expected to be found in the northern portion of the site and only minor consolidation was expected in other areas. A second objective was to characterize benthic recolonization status and further define the physical characteristics of surficial sediment by completing a SPI/PV imaging survey. Lastly, additional characterization of benthic community status was obtained through grab sediment sampling and analysis. The objective of this suite of analyses was to characterize the seafloor topography, the surficial features, and the benthic recolonization status at the RISDS.

4.1 Seafloor Topography

The high resolution acoustic survey revealed a topographic depression in the center of the site surrounded by a natural shallower feature to the south and east and a nearly continuous constructed berm to the west (Figure 3-1). The overall site bathymetry, with water depths ranging from approximately 34 m over the berm to 38 m in the depression, was shallower than baseline conditions in 2003 which ranged from 35 to 39 m (USEPA 2004). This observation suggests that the management plan of creating a berm to reduce potential for sediment transport and to place and retain dredged material relatively evenly across the site has been successful.

Recent dredged material placement was observed to have extended the berm toward the northeast (Figure 3-6). Depth difference analysis revealed an increase in elevation of approximately 0.3 – 1.0 m over an area of approximately 800 m × 300 m extending eastward from the northern end of the berm (shown in green in Figure 3-6). Within that elevated north-central area, a circular mound with a diameter of approximately 200 m and a maximum height of 3.4 m above the seafloor was formed since 2009. A second, smaller and less uniform mound with a maximum height 1.7 m above the seafloor had formed approximately 300 m east of the circular mound feature. The location of these two new features was consistent with the location of recent dredged material placement (Figure 4-1).

The relative shape of these two features was consistent with expectations based on the project-specific composition and dredged material volumes (Table 1-1). The Port of Davisville project (shown in yellow in Figure 4-1) was composed primarily of fine sand (196,000 m^3). This material spread on the seafloor and created a relatively flat deposit with a mottled surface (Figures 4-2 and 4-3). The New Bedford Harbor CAD project was composed primarily of glacial till and consolidated clay (24,500 m^3) that created a more defined mound with a harder surface (Figures 4-2 and 3-4). The Great Harbor material created a distinctive area of high backscatter with little relief (Figures 4-2 and 4-3).

Overall, recent dredged material distribution succeeded in extending the berm toward the northeast. This enhanced berm will serve to increase the containment capabilities for RISDS. Minor consolidation was observed at past disposal locations and was consistent with expectations (Figure 3-6).

Reference area conditions were revealed by assessment of the regional seafloor topography (Figure 3-7). A more complete understanding of the context of reference areas provides better comparison of reference area conditions to disposal site conditions. REF-NE is located on the edge of a shallower area with clear evidence of bedforms, REF-E is located in a basin slightly deeper than the disposal site, and REF-SW is located in a channel between shallower areas (Figure 3-8 and Table 3-3). These conditions are reflected in the grain size and results from each reference area: REF-E consistently has had fine-grained sediments while REF-NE and REF-SW have had silty very fine and fine sand (Table 3-1).

One station from REF-E had a distinctive layer of silty sand over fine sand with a very sharp interface; this is more indicative of placement of dredged material rather than sediment transport (Figure 3-9, REF-E 2A). The presence of this deposit and the nature of sediment transport conditions at REF-NE (more mobile, hard sands than at disposal site) suggest that future surveys should evaluate the reference areas with acoustic surveys and more detailed SPI/PV coverage to reassess the applicability of these areas as reference areas for RISDS.

Between 2009 and 2013 at least one significant coastal storm passed over RISDS: Hurricane Sandy (referred to unofficially as Superstorm Sandy because it was a Category 2 storm by the time it reached the Northeast) was the largest Atlantic hurricane on record (as measured by diameter, with winds spanning 1,100 miles (1,800 km). A significant wave height of 9.4 m (31 ft) was recorded at a Coastal Data Information Program (CDIP) wave buoy in outer Rhode Island Sound with one wave topping 14.3 m (47 ft) (Boothroyd et al. 2013; USACE 2013). Despite the passage of this intense storm, relatively little evidence of erosion or sediment transport is evident at RISDS. Small megaripples (6 m wavelength) that indicate an east-to-west flow (possibly due to deflection of waves around topographic highs) were observed at the southern boundary of the disposal site and around the margins of the berm, but ephemeral traces of dredged material placement (no topographic expression) that pre-dated the storm were clearly visible within the disposal site (Figure 4-4). SPI/PV images contained no evidence of surface erosion within the disposal site or at reference areas, but several reference area images had sand horizons over sandy silt which might indicate episodic sediment transport (Figure 3-9).

4.2 Distribution of Dredged Material

Ample evidence of dredged material was found throughout RISDS, and this is consistent with the site management plan and historic dredged material placement (e.g., Figure 1-3). Dredged material placement resulted in characteristic patterns on the seafloor including circular pits with raised rims, irregular hummocky topography as well as relatively smooth areas (Figure 4-2). The nature of the patterns is dependent on the material properties, the properties of the seafloor and water depth (Valente et al. 2012b). Recent dredged material placement from construction of the New Bedford Harbor CAD cell formed a small mound with a rough surface and distinct trails of dredged material (Figure 4-3). This project removed consolidated material that retained form after placement creating a rough topography. Dredged material placement from the Port of Davisville formed a flat mound with two lobes around a shallow depression, an extensive apron and one isolated crater (Figure 4-2). This project removed fine sand and silt from a navigational channel that spread upon contact with the seafloor and in the case of the crater had enough mass to deform the seafloor. Dredged material placement from Great Harbor, Massachusetts formed a distinctive area with high backscatter and little relief over an area with craters from previous placement activities (Figures 1-8, 3-29, 4-2 and 4-3). This project removed maintenance material with cobbles and sand that spread into a pancake-shaped deposit (Figure 4-3).

The continued extension of the berm to the northeast is consistent with the site management plan. By connecting the berm on the western margin of the site with the shallower area to the northeast, the open end of the ‘horseshoe’ can be closed and provide a basin for containment of future dredged material placement projects.

4.3 Benthic Recolonization and Community Composition

The primary purpose of the SPI/PV survey at the RISDS was to characterize the physical features of the surface sediments and assess the status of benthic recolonization on the selected target disposal areas and compare results with conditions at the three reference areas. SPI/PV images were collected at three disposal target areas B, C, and D as a representative subset of the conditions for the other target areas. Most of the dredged material had been placed at the site in April 2003 to January 2005 at all three disposal target areas, and a smaller volume was placed at disposal target area C during the winter of 2008 (see Figure 1-5). Since the survey conducted in October 2009, benthic conditions were expected to have improved, with more Stage 3 organisms and deeper RPDs. The disposal target areas were expected to be consistent with reference areas having similar physical characteristics. Based on the 2009 results, target areas B and D were expected to have silt/clay sediments, while target area C was expected to have mostly silty fine sand and a station or two that indicated silt and/or clay. A similar range of conditions was expected to occur at the reference areas.

There was evidence of Stage 3 organisms at every station (disposal site and reference areas) except at Stations C-01 and C-05 where penetration was limited to hard sediments (Figure 3-22). Observations of the presence of advanced successional stage activities were consistent with the results from 2005 and 2009 (ENSR 2007, Valente et al. 2012a). Further evidence of advanced successional status was visible in the corresponding plan-view images. All of the plan-view images showed burrow openings at the sediment surface or the presence of hard bottom (Appendix C). There also was abundant evidence of epifauna and no indication of any severe disturbance to the benthic communities from trawling or other anthropogenic impacts. Profile images from disposal target areas had evidence of sediment textures consistent with the dredged material (subsurface clay inclusions; Appendix C) but no methane or evidence of low dissolved oxygen.

Similar to results from 2005 and 2009, the aRPD results were significantly lower at the disposal target areas than at reference areas (Table 3-5). In all three years, the mean aRPD values were more variable among the reference areas than among the disposal target areas (station groups A–E) within the disposal site (Table 3-6 and Figure 3-24). In all three years, the mean aRPD values also were consistently deeper at the reference areas compared to the RISDS disposal target areas (Table 3-6 and Figure 3-24). Statistical analysis revealed no significant difference in aRPD values between 2009 and 2013 at target areas B, C and D (Table 3-5).

The primary purpose of the grab sampling survey was to characterize the bulk sediment grain size and composition of the infaunal benthic community at two disposal locations and compare results with composition of two of the reference areas (REF-NE and REF-SW).

Bulk grain size results were consistent with SPI major mode grain size estimates from the same stations, but due to the heterogeneity of the seafloor, sample location was critical (Tables 3-1 and 3-7). The reference areas were dominated by fine sand with the exception of NE-01A (fines) while the disposal site stations were more consistently fine-grained with the exception of B-03A (fine sand).

Benthic community results were strongly affected by the relative dominance of *Nucula,* a small surface and subsurface deposit-feeding bivalve (Figure 3-15). In 2005, *Nucula* and amphipods dominated the reference areas with very high abundances (Table 3-10). In 2013, *Nucula* dominated both the reference areas and disposal site stations, but with much higher abundances and greater dominance at most disposal site stations (Figures 3-26, 3-27). It is unclear what process or event(s) has led to a reversal in distribution of *Nucula*. The fewest *Nucula proxima* (8 individuals) were found at REF-NE-02D, which had the smallest percentage of fines (0.8%). This station was located in an area with active sand transport and conditions less suitable for a surface and subsurface deposit feeder. However B-01B also had relatively low abundance of *Nucula* (as well as low overall abundance) and a grain size distribution with 74% fines (Table 3-7).

There was decrease in the overall abundance in amphipods at the reference areas from 2005 to 2013 (Table 3-9). The most dominant species at the RISDS in 2005, the sabellid polychaete, *Euchone incolor*, a suspension feeder was barely present in 2013 with only three individuals at C-04. An overall shift from suspension/filters feeders to surface and subsurface deposit feeders and grazers appears to have occurred at RISDS from 2005 to 2013. Similar to 2005, the conveyor belt species *Clymenella torquata* occurred in low abundance (less than 1%) at only the reference areas. A few other head-down feeding worms identified at the reference areas in 2005 were not seen in 2013. *Capitella capitata*, a conveyor belt feeder not identified in 2005, was found in low abundance at all of the reference areas and C target area stations in 2013. *Phylo ornatus*, an Orbiniid polychaete that is likely to be a conveyor-belt feeder (e.g., same family as *Scoloplos sp*. Rice et al. 1986) was present at all stations and abundant at C target area stations (Appendix C). Cerianthids (burrowing anemones) were identified in 2005 at disposal sites and *Actinoe modesta* (burrowing anemone) was identified in 2013 at most stations and in SPI images. Burrowing anemones create large burrows that effectively bioturbate surface sediments but they are not conveyor-belt feeders. The presence and abundance of these specific species helps to explain a Stage 3 classification with limited development of aRPDs.

It seems clear, based on consistent results from 2005, 2009 and 2013 that the disposal site supports a healthy subsurface deposit-feeding community equivalent to Stage 3, but with less abundance and bioturbation activity than at the reference areas. Apart from a few outlier values, aRPD depths at disposal site stations have consistently been at or below 1.7 cm while mean reference area values have been at or above 2.2 (Figure 3-24 and Table 3-6). Although the disposal site aRPD values have consistently been lower than reference area values, the mean value of 1.7 does not by itself represent impaired conditions. Rather, the consistency between the 2005 and 2013 results suggest that both the ambient sediments and the deposits in the disposal site are dominated by dense populations of primarily near surface-dwelling, suspension and interface deposit feeders (i.e., *Nucula* sp., *Byblis* sp., *Euchone* sp.). The low relative densities of large-bodied, head-down, subsurface deposit feeders (i.e., "conveyor-belt" species) might be characteristic of the basin areas in this region. The differences in aRPD values (largely unaffected by suspension and surface deposit feeders) may reflect higher organic load and finer sediments within the disposal site. These results are somewhat complex, but are consistent with a healthy benthic community.

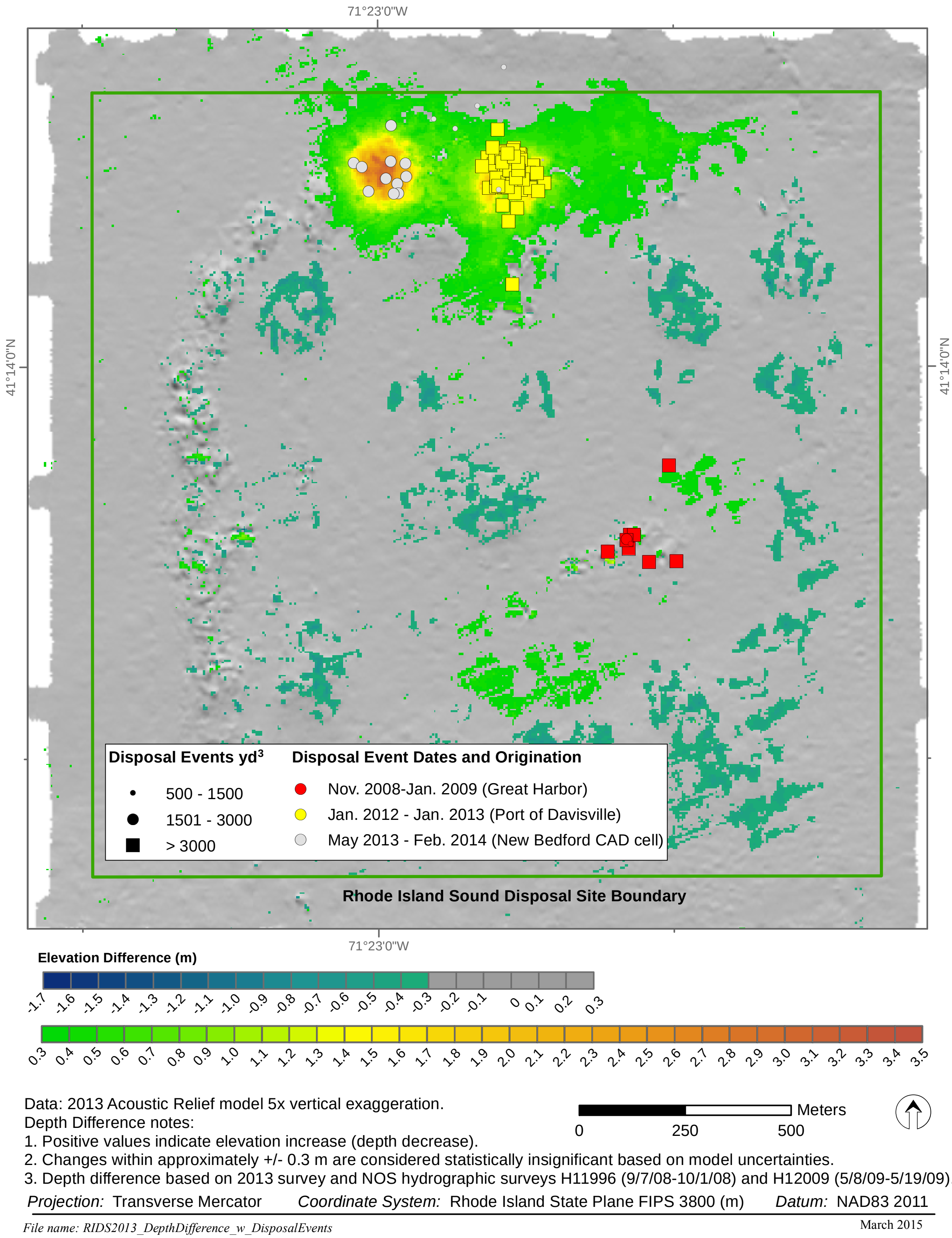


Figure 4-1. Depth difference map (2008/2009 and 2013) with disposal events by source

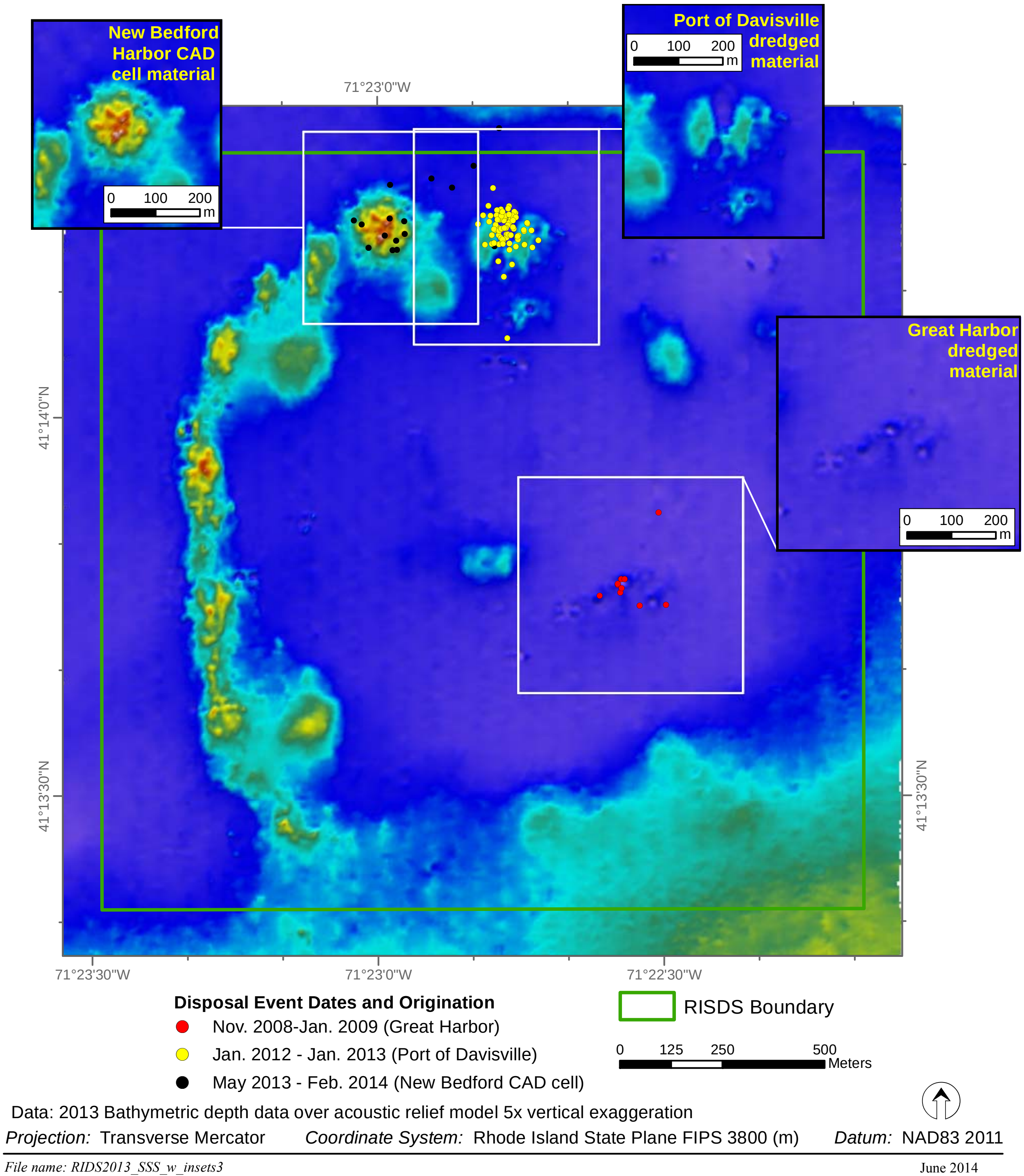


Figure 4-2. Bathymetric depth data with inset close-ups of dredged material by source

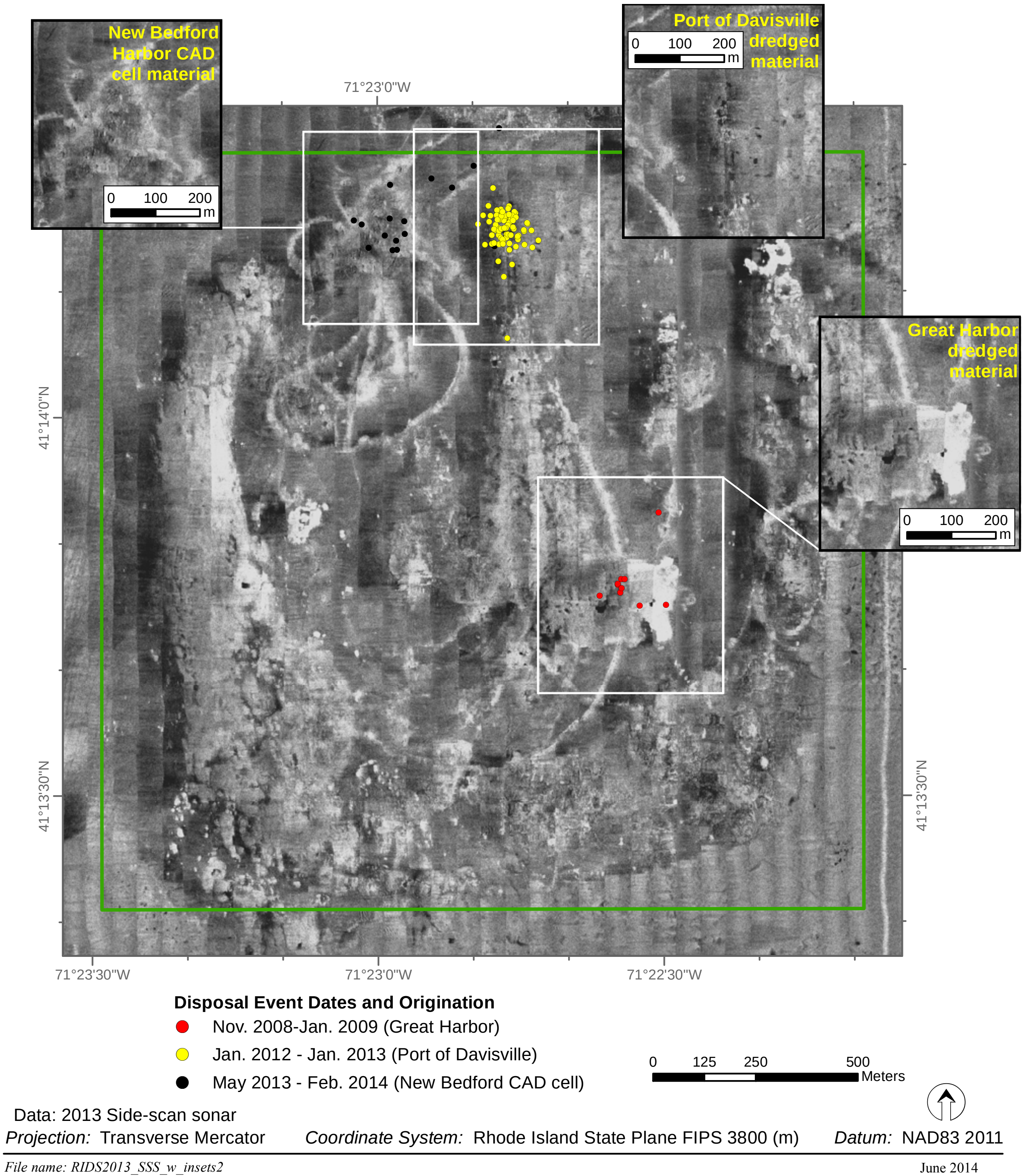


Figure 4-3. Side-scan sonar data with inset close-ups of dredged material by source

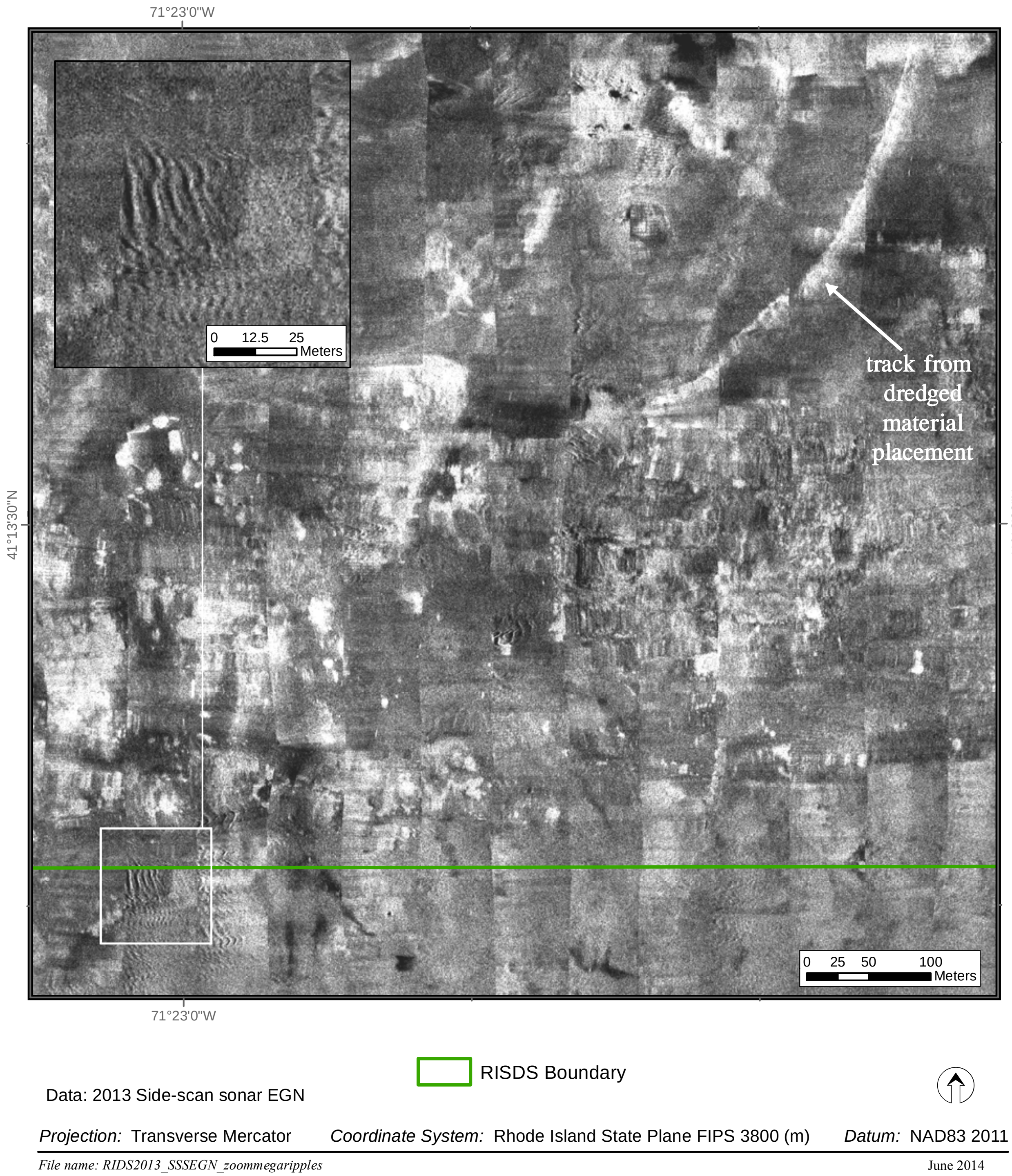


Figure 4-4. Side-scan sonar data with inset close-ups of megaripple and track from dredged material placement

5.0 CONCLUSIONS AND RECOMMENDATIONS

Overall, the 2013 survey showed that placement of dredged material continued to create a berm structure suitable for containment of large placement projects. The material placed at the site was stable and showed no evidence of displacement from Hurricane Sandy. Populations of Stage 3 organisms continued to be present at RISDS, but at low relative densities. Specific findings included:

- RISDS contained a topographic depression in the center of the site surrounded by a naturally shallower area to the south and east and a nearly continuous constructed berm to the west. Recent dredged material distribution succeeded in extending the berm toward the northeast furthering the process of completely encircling the site.
- Evidence of limited episodic sediment transport assumed caused by the passage of large storms was observed around the margin of the berm, but no apparent reworking of the dredged material inside the berm was observed despite the passage of Hurricane Sandy in 2012. The management plan of creating a berm to reduce potential for sediment transport and to place and retain dredged material relatively evenly across the site appears to have been successful.
- Reference area conditions were revealed by assessment of the regional seafloor topography, and results suggest that reference area selection should be re-visited. Dredged material may have been placed at one station in REF-E, based on the finding of a distinctive layer of silty sand over fine sand (Figure 3-9, REF-E 2A). The presence of this deposit and the nature of sediment transport conditions at REF-NE (more mobile, hard sands than at disposal site) suggest that future surveys evaluate the reference areas with acoustic surveys and more intense SPI/PV assessment.
- Distinctive features associated with dredged material placement were observed at locations that have recently received placement as well as historical locations throughout the site. The distribution of dredged material based on bathymetric changes and acoustic features was consistent with reported placement locations.
- Benthic recolonization was assessed at three disposal placement areas and compared to three reference areas. There was evidence of Stage 3 organisms at every station (disposal site and reference areas) except where penetration was limited to hard sediments. The results of the presence of advanced successional stage activities were consistent with the results from 2005 and 2009 surveys (ENSR 2007, Valente et al. 2012a).
- It was predicted (based on 2009 results) that the October 2013 survey would continue to find evidence of relatively advanced succession (i.e., Stages 2 and 3) at

RISDS. While there continued to be ample evidence of advanced succession in 2013, large-bodied Stage 3 organisms continued to be present at lower apparent densities within the disposal site boundaries compared to ambient conditions. Furthermore, there was no significant increase in the aRPD depths at the disposal site in 2013 compared to 2009; such deepening would be expected if burrowing and/or conveyor-belt species had been increasingly populating the surface sediments of the disposal site.

All of the disposal site stations had conditions (faunal abundance and evidence of Stage 3 activity) consistent with healthy benthic habitat. Significant differences were observed between RISDS and reference areas benthic communities. It appears that the ambient sediments surrounding the disposal site support a population dominated by surface deposit feeders and suspension feeders with relatively low abundances of Stage 3 subsurface deposit-feeders that bioturbate. The finer, more organic-rich sediments within the disposal site have been colonized by Stage 3 organisms but in relatively low abundance even compared to reference areas. As a result the aRPDs have developed slowly and remain thinner than outside the site.

Based on the findings of the 2013 RISDS survey, the following recommendations are proposed:

R1) Monitoring should be conducted after placement of large (>200,000 m^3) projects at the site scheduled to take place over the next several years.

R2) SPI/PV stations should be focused on areas that receive dredged material and monitor target areas B, C and D if they are not covered by new projects.

R3) Reference areas should be investigated with acoustic monitoring (backscatter and side-scan sonar) to determine if evidence for placement of dredged material is present in REF-E and to assess the suitability of REF-NE for conditions within the disposal site.

6.0 REFERENCES

Battelle. 2002. Fall 2001 REMOTS® characterization report, Rhode Island Region. Long-term dredged material disposal site evaluation project. Report to the U.S. Army Corps of Engineers, New England District, Concord, MA, Contract No. DACW33-01-D-0004, Delivery Order No. 02.

Boothroyd, Jon C.; Oakley, B. A.; Rasmussen, S. A.; McCandless, S. J.; Dowling, M. J.; Freedman, J.; Fugate, G. 2013.Superstorm Sandy: Changes to the Rhode Island Shore, what next? Geological Society of America, Northeastern Section - 48th Annual Meeting (18–20 March 2013). https://gsa.confex.com/gsa/2013NE/webprogram/Paper216556.htmla accessed 6/27/2014.

ENSR. 2007. Monitoring Survey at the Rhode Island Sound Disposal Site, July 2005. DAMOS Contribution No. 176. U.S. Army Corps of Engineers, New England District, Concord, MA, 73 pp.

ENSR. 2008. Providence River and Harbor Maintenance Dredging Project Synthesis Report. DAMOS Contribution No. 178. U.S. Army Corps of Engineers, New England District, Concord, MA, 133 pp.

Fredette, T. J.; French, G. T. 2004. Understanding the physical and environmental consequences of dredged material disposal: history in New England and current perspectives. Mar. Pollut. Bull. 49:93–102.

Germano, J.D. 1999. Ecology, statistics, and the art of misdiagnosis: The need for a paradigm shift. Environ. Rev. 7(4):167–190.

Germano, J. D.; Rhoads, D. C.; Lunz, J. D. 1994. An Integrated, Tiered Approach to Monitoring and Management of Dredged Material Disposal Sites in the New England Regions. DAMOS Contribution No. 87. U.S. Army Corps of Engineers, New England Division, Waltham, MA, 67 pp.

Germano, J. D.; Rhoads, D. C.; Valente, R. M.; Carey, D. A.; Solan, M. 2011. The use of sediment-profile imaging (SPI) for environmental impact assessments and monitoring studies: lessons learned from the past four decades. Oceanogr. Mar. Biol. Ann. Rev. 49:235–285.

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

McBride, G. B. 1999. Equivalence tests can enhance environmental science and management. Aust. New Zeal. J. Stat. 41(1):19–29.

McMullen, K. Y.; Poppe, L. J.; Ackerman, S. D.; Blackwood, D. S.; Schaer, J. D.; Nadeau, M. A.; Wood, D. A. 2011. Surficial Geology of the sea floor in central Rhode Island Sound southeast of Point Judith, Rhode Island, U.S. Geological Survey Open-File Report 2011–1005, DVD-ROM. (Also available online at http://pubs.usgs.gov/of/2011/1005.)

Poppe, L. J.; Danforth, W. W.; McMullen, K. Y.; Blankenship, M. A.; Glomb, K. A.; Wright, D. B.; Smith, S. M. 2012. Sea-floor character and sedimentary processes of Block Island Sound, offshore Rhode Island: U.S. Geological Survey Open-File Report 2012–1005, DVD-ROM. (Also available at http://pubs.usgs.gov/of/012/1005/.)

Rice, D. L.; Bianchi, T. S.; Roper, E. H. 1986. Experimental studies of sediment reworking and growth of Scoloplos spp. (Orbiniidae: Polychaeta). Mar. Ecol. Prog. Ser. 30: 9-19.

SAIC. 1997. REMOTS sediment-profile imaging survey of selected sites in Narragansett Bay and Rhode Island Sound, November 1996, Report Addendum. Submitted to U.S. Army Corps of Engineers, New England Division. SAIC Report No. 390.

SAIC. 2000. REMOTS sediment-profile imaging survey of Sites 69a and 69b in Rhode Island Sound, November 1999. Submitted to Battelle Ocean Sciences. SAIC Report No. 493.

SAIC. 2004. Monitoring Surveys of the Rhode Island Sound Disposal Site, Summer 2003. DAMOS Contribution No.155. U.S. Army Corps of Engineers, New England District, Concord, MA.

SAIC. 2005a. Disposal Plume Tracking and Assessment at the Rhode Island Sound Disposal Site, Spring 2004. DAMOS Contribution No. 166. U.S. Army Corps of Engineers, New England District, Concord, MA, 184 pp.

SAIC. 2005b. Disposal Plume Tracking and Assessment at the Rhode Island Sound Disposal Site, Summer 2004. DAMOS Contribution No. 167. U.S. Army Corps of Engineers, New England District, Concord, MA, 194 pp.

Satterthwaite, F.E. 1946. “An Approximate Distribution of Estimates of Variance Components”, Biometrics Bulletin, Vol. 2, No. 6, pp. 110-114.

Schuirmann, D. J. 1987. A comparison of the two one-sided tests procedure and the power approach for assessing the equivalence of average bioavailability. J. Pharmacokinet. Biopharm. 15:657–680.

Valente, R. M.; Carey, D. A.; Read, L. B.; Wright, C. 2007. Postdisposal Monitoring of Lobster Abundance at the Rhode Island Sound Disposal Site in 2005 Compared to the 1999 Predisposal Survey. DAMOS Contribution No. 174. U.S. Army Corps of Engineers, New England District, Concord, MA, 52 pp.

Valente, R. M.; Read, L. B., Esten, M. E. 2012a. Monitoring Survey at the Rhode Island Sound Disposal Site October 2009. DAMOS Contribution No. 183. U.S. Army Corps of Engineers, New England District, Concord, MA, 72 pp.

Valente, Raymond M.; Carey, D.A.; Read, L.B.; Esten, M.E. 2012b. Monitoring Survey at the Central Long Island Sound Disposal Site October 2009. DAMOS Contribution No. 184. U.S. Army Corps of Engineers, New England District, Concord, MA, 90 pp.

USACE. 1998. Shellfish Sampling and Site Characterization Narragansett Bay and Rhode Island Sound Proposed Disposal Sites. In: Providence River and Harbor Maintenance Dredging Project Final Environmental Impact Statement Appendix C-6. Prepared under Contract No. DACW33- 96-D-0005 Delivery Order No. 14 by Battelle for the U.S. Army Corps of Engineers. January 1998.

USACE. 2001a. Providence River and Harbor Maintenance Dredging Project Final Environmental Impact Statement, Volumes I and II. Prepared by New England District, U.S. Army Corps of Engineers in cooperation with U.S. Environmental Protection Agency, National marine Fisheries Service, and U.S. Fish and Wildlife Service.

USACE. 2001b. Letter Report: Evaluation of Existing Physical Oceanographic Data. Prepared under Contract No. DACW33-01-D-0004 Delivery Order No. 2 by Battelle for the U.S. Army Corps of Engineers.

USACE. 2002a. Fall 2001 Water Column Characterization Report. Rhode Island Region Long- term Dredged Material Disposal Site Evaluation Project. Prepared under Contract No. DACW33-01-D-0004 Delivery Order No. 2 by Battelle for the U.S. Army Corps of Engineers. August 2002.

USACE. 2002b. Spring 2002 Water Column Characterization Report. Rhode Island Region Long- term Dredged Material Disposal Site Evaluation Project. Prepared under Contract No. DACW33-01-D-0004 Delivery Order No. 2 by Battelle for the U.S. Army Corps of Engineers. October 2002.

USACE. 2002c. Fall 2001 Infauna Characterization Report. Rhode Island Region Long-term Dredged Material Disposal Site Evaluation Project. Prepared under Contract No. DACW33-01- D-0004 Delivery Order No. 2 by Battelle for the U.S. Army Corps of Engineers. September 2002.

USACE. 2003a. Final Survey Report for Winter 2002 Physical Oceanography Data Collection Survey. Rhode Island Region Long-term Dredged Material Disposal Site Evaluation Project. Prepared under Contract No. DACW33-01-D-0004 Delivery Order No. 2 by Battelle for the U.S. Army Corps of Engineers.

USACE. 2003b. Benthic Infauna Data for Area E and Area W July 2003. Prepared under Contract No. DACW33-01-D-0004 Delivery Order No. 02 by Battelle for the U.S. Army Corps of Engineers. November 2003.

USACE. 2003c. Summer 2003 Quahog Survey and Data Report. Rhode Island Region Long- Term Dredged Material Disposal Site Evaluation Project. Prepared under contract DACW33-01- D-0004 Delivery Order No. 2 by Battelle for the U.S. Army Corps of Engineers. October 2003.

USACE. 2013. Hurricane Sandy Coastal Projects Performance Evaluation Study: Disaster Relief Appropriations Act, 2013. Submitted by the Assistant Secretary of the Army for Civil Works. November 6, 2013. http://www.nan.usace.army.mil/Portals/37/docs/civilworks/SandyFiles/USACE_Post-Sandy_Coastal_Projects_Performance_Evaluation_Study.pdf Accessed June 27, 2014

USEPA. 2004. Final Environmental Impact Statement Rhode Island Region Long-Term Dredged Material Disposal Site Evaluation Project. Prepared by U.S. Environmental Protection Agency, New England Region, in cooperation with U.S. Army Corps of Engineers, New England District.

APPENDIX A

TABLE OF COMMON CONVERSIONS

APPENDIX A

TABLE OF COMMON CONVERSIONS

Metric Unit Conversion to English Unit		English Unit Conversion to Metric Unit	
1 meter 1 m	3.2808 ft	1 foot 1 ft	0.3048 m
1 square meter 1 m^2	10.7639 ft^2	1 square foot 1 ft^2	0.0929 m^2
1 kilometer 1 km	0.6214 mi	1 mile 1 mi	1.6093 km
1 cubic meter 1 m^3	1.3080 yd^3	1 cubic yard 1 yd^3	0.7646 m^3
1 centimeter 1 cm	0.3937 in	1 inch 1 in	2.54 cm

APPENDIX B

ACTUAL SPI/PV AND BENTHIC GRAB REPLICATE LOCATIONS

RISDS 2013 SURVEY ACTUAL SPI/PV REPLICATE LOCATIONS

RISDS SPI/PV Replicate Locations					
Replicate	Latitude (N)	Longitude (W)	Replicate	Latitude (N)	Longitude (W)
RISDS-B-01A	41° 13.836'	71° 22.850'	RISDS-C-04A	41° 13.798'	71° 22.443'
RISDS-B-01B	41° 13.835'	71° 22.850'	RISDS-C-04B	41° 13.795'	71° 22.439'
RISDS-B-01C	41° 13.835'	71° 22.849'	RISDS-C-04C	41° 13.796'	71° 22.442'
RISDS-B-01D	41° 13.835'	71° 22.848'	RISDS-C-04D	41° 13.797'	71° 22.442'
RISDS-B-02A	41° 13.907'	71° 22.911'	RISDS-C-05A	41° 13.747'	71° 22.579'
RISDS-B-02B	41° 13.907'	71° 22.909'	RISDS-C-05B	41° 13.747'	71° 22.583'
RISDS-B-02C	41° 13.909'	71° 22.912'	RISDS-C-05C	41° 13.747'	71° 22.584'
RISDS-B-02D	41° 13.909'	71° 22.909'	RISDS-C-05D	41° 13.747'	71° 22.584'
RISDS-B-03A	41° 13.913'	71° 22.756'	RISDS-D-01A	41° 13.483'	71° 22.575'
RISDS-B-03B	41° 13.914'	71° 22.755'	RISDS-D-01B	41° 13.485'	71° 22.579'
RISDS-B-03C	41° 13.916'	71° 22.754'	RISDS-D-01C	41° 13.485'	71° 22.581'
RISDS-B-03D	41° 13.918'	71° 22.755'	RISDS-D-01D	41° 13.483'	71° 22.579'
RISDS-B-04A	41° 13.801'	71° 22.820'	RISDS-D-02A	41° 13.582'	71° 22.523'
RISDS-B-04B	41° 13.804'	71° 22.823'	RISDS-D-02B	41° 13.583'	71° 22.525'
RISDS-B-04C	41° 13.805'	71° 22.821'	RISDS-D-02C	41° 13.581'	71° 22.529'
RISDS-B-04D	41° 13.807'	71° 22.818'	RISDS-D-02D	41° 13.578'	71° 22.530'
RISDS-B-05A	41° 13.769'	71° 22.804'	RISDS-D-03A	41° 13.588'	71° 22.428'
RISDS-B-05B	41° 13.771'	71° 22.804'	RISDS-D-03B	41° 13.590'	71° 22.428'
RISDS-B-05C	41° 13.772'	71° 22.804'	RISDS-D-03C	41° 13.589'	71° 22.426'
RISDS-B-05D	41° 13.770'	71° 22.801'	RISDS-D-03D	41° 13.591'	71° 22.427'
RISDS-C-01A	41° 13.783'	71° 22.561'	RISDS-D-04A	41° 13.468'	71° 22.446'
RISDS-C-01B	41° 13.784'	71° 22.563'	RISDS-D-04B	41° 13.471'	71° 22.442'
RISDS-C-01C	41° 13.785'	71° 22.561'	RISDS-D-04C	41° 13.471'	71° 22.442'
RISDS-C-01D	41° 13.785'	71° 22.560'	RISDS-D-05A	41° 13.452'	71° 22.480'
RISDS-C-02A	41° 13.886'	71° 22.538'	RISDS-D-05B	41° 13.453'	71° 22.480'
RISDS-C-02B	41° 13.888'	71° 22.537'	RISDS-D-05C	41° 13.453'	71° 22.481'
RISDS-C-02C	41° 13.889'	71° 22.541'	RISDS-D-05D	41° 13.453'	71° 22.484'
RISDS-C-02D	41° 13.889'	71° 22.539'			
RISDS-C-03A	41° 13.845'	71° 22.401'			
RISDS-C-03B	41° 13.846'	71° 22.399'			
RISDS-C-03C	41° 13.843'	71° 22.397'			
RISDS-C-03D	41° 13.845'	71° 22.395'			

RISDS 2013 SURVEY ACTUAL SPI/PV REPLICATE LOCATIONS (continued)

Reference SPI/PV Replicate Locations					
Replicate	Latitude (N)	Longitude (W)	Replicate	Latitude (N)	Longitude (W)
REF-E-01A	41° 13.973'	71° 19.468'	REF-NE-03E	41° 15.249'	71° 20.149'
REF-E-01B	41° 13.973'	71° 19.468'	REF-NE-03F	41° 15.248'	71° 20.151'
REF-E-01C	41° 13.974'	71° 19.467'	REF-NE-03G	41° 15.247'	71° 20.153'
REF-E-01D	41° 13.976'	71° 19.465'	REF-NE-04A	41° 15.051'	71° 20.049'
REF-E-02A	41° 13.982'	71° 19.651'	REF-NE-04B	41° 15.052'	71° 20.049'
REF-E-02B	41° 13.982'	71° 19.650'	REF-NE-04C	41° 15.054'	71° 20.048'
REF-E-02C	41° 13.981'	71° 19.650'	REF-NE-04D	41° 15.054'	71° 20.048'
REF-E-02D	41° 13.982'	71° 19.649'	REF-NE-05A	41° 15.088'	71° 19.911'
REF-E-03A	41° 14.112'	71° 19.534'	REF-NE-05B	41° 15.090'	71° 19.912'
REF-E-03B	41° 14.116'	71° 19.534'	REF-NE-05C	41° 15.089'	71° 19.913'
REF-E-03C	41° 14.119'	71° 19.533'	REF-NE-05D	41° 15.090'	71° 19.913'
REF-E-03D	41° 14.121'	71° 19.535'	REF-SW-01A	41° 12.879'	71° 24.963'
REF-E-04A	41° 14.043'	71° 19.408'	REF-SW-01B	41° 12.877'	71° 24.960'
REF-E-04B	41° 14.045'	71° 19.410'	REF-SW-01C	41° 12.875'	71° 24.959'
REF-E-04C	41° 14.046'	71° 19.410'	REF-SW-01D	41° 12.875'	71° 24.958'
REF-E-04D	41° 14.044'	71° 19.408'	REF-SW-02A	41° 12.835'	71° 24.892'
REF-E-05A	41° 14.026'	71° 19.303'	REF-SW-02B	41° 12.835'	71° 24.902'
REF-E-05B	41° 14.027'	71° 19.302'	REF-SW-02C	41° 12.834'	71° 24.901'
REF-E-05C	41° 14.027'	71° 19.301'	REF-SW-02D	41° 12.835'	71° 24.901'
REF-E-05D	41° 14.027'	71° 19.299'	REF-SW-03A	41° 12.841'	71° 25.020'
REF-NE-01A	41° 15.231'	71° 19.946'	REF-SW-03B	41° 12.845'	71° 25.023'
REF-NE-01B	41° 15.232'	71° 19.942'	REF-SW-03C	41° 12.846'	71° 25.025'
REF-NE-01C	41° 15.233'	71° 19.942'	REF-SW-03D	41° 12.848'	71° 25.027'
REF-NE-01D	41° 15.234'	71° 19.941'	REF-SW-04A	41° 12.697'	71° 25.038'
REF-NE-02A	41° 15.272'	71° 20.012'	REF-SW-04B	41° 12.694'	71° 25.048'
REF-NE-02B	41° 15.272'	71° 20.013'	REF-SW-04C	41° 12.691'	71° 25.044'
REF-NE-02C	41° 15.272'	71° 20.016'	REF-SW-04D	41° 12.688'	71° 25.043'
REF-NE-02D	41° 15.272'	71° 20.013'	REF-SW-05A	41° 12.768'	71° 24.808'
REF-NE-03A	41° 15.244'	71° 20.154'	REF-SW-05B	41° 12.765'	71° 24.803'
REF-NE-03B	41° 15.247'	71° 20.153'	REF-SW-05C	41° 12.771'	71° 24.808'
REF-NE-03C	41° 15.248'	71° 20.149'	REF-SW-05D	41° 12.776'	71° 24.808'
REF-NE-03D	41° 15.242'	71° 20.155'			

Notes: 1) Coordinate system NAD83

2) This table reflects all attempts to collect SPI/PV replicates at each target station. The three replicates with the best quality images were used for analysis.

RISDS 2013 SURVEY ACTUAL BENTHIC GRAB REPLICATE LOCATIONS

Grab Replicate Locations		
Replicate[1]	Latitude (N)	Longitude (W)
B-01A	41° 13.832'	71° 22.855'
B-01B	41° 13.837'	71° 22.854'
B-02B	41° 13.902'	71° 22.916'
B-02D	41° 13.905'	71° 22.917'
B-03A	41° 13.915'	71° 22.771'
B-03B	41° 13.915'	71° 22.767'
C-02A	41° 13.891'	71° 22.542'
C-02B	41° 13.897'	71° 22.544'
C-03A	41° 13.844'	71° 22.408'
C-03B	41° 13.847'	71° 22.408'
C-04A	41° 13.796'	71° 22.447'
C-04B	41° 13.797'	71° 22.448'
NE-01A	41° 15.232'	71° 19.949'
NE-01B	41° 15.228'	71° 19.953'
NE-02A	41° 15.274'	71° 20.022'
NE-02D	41° 15.270'	71° 20.021'
SW-01A	41° 12.885'	71° 24.958'
SW-01B	41° 12.881'	71° 24.961'
SW-02A	41° 12.842'	71° 24.905'
SW-02C	41° 12.843'	71° 24.898'

1 B replicates are grabs sampled within the RISDS-B target area;
C replicates are grabs sampled within the RISDS-C target area;
NE replicates are grabs sampled within the REF-NE reference area;
SW replicates are grabs sampled within the REF-SW reference area.

APPENDIX C

SEDIMENT-PROFILE AND PLAN-VIEW IMAGE ANALYSIS RESULTS FOR RISDS SURVEY, AUGUST 2013

Sediment-Profile Image Analysis Results

Location	Station	Replicate	Date	Time	Stop Collar Setting (in)	# of Weights (per side)	Water Depth (ft)	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	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)
RISDS-B	B-01	A	8/25/2013	14:13:25	12	1	120	14.5	>4	>4	1	145.5	10.0	9.9	10.2	0.4	Biological	30.7	2.1
RISDS-B	B-01	B	8/25/2013	14:14:15	12	1	120	14.5	>4	>4	1	158.7	11.0	9.9	11.3	1.4	Biological	10.7	0.7
RISDS-B	B-01	C	8/25/2013	14:14:58	12	1	120	14.5	>4	>4	1	137.6	9.5	9.1	10.1	1.0	Biological	19.9	1.4
RISDS-B	B-02	A	8/25/2013	14:06:48	12	1	122	14.5	>4	>4	1	169.1	11.7	10.9	12.3	1.5	Biological	19.3	1.3
RISDS-B	B-02	C	8/25/2013	14:08:15	12	1	122	14.5	>4	>4	1	152.0	10.5	10.1	10.8	0.7	Biological	30.7	2.1
RISDS-B	B-02	D	8/25/2013	14:08:58	12	1	122	14.5	>4	>4	1	162.0	11.2	10.9	11.5	0.6	Biological	33.8	2.3
RISDS-B	B-03	A	8/25/2013	13:59:12	12	1	123	14.5	4 to 3/>4	>4	1	127.4	8.8	7.3	9.1	1.8	Biological	18.4	1.3
RISDS-B	B-03	B	8/25/2013	14:00:01	12	1	123	14.5	4 to 3/>4	>4	1	135.3	9.3	8.6	10.0	1.4	Biological	15.2	1.1
RISDS-B	B-03	C	8/25/2013	14:00:51	12	1	123	14.5	4 to 3/>4	>4	1	140.2	9.7	9.4	10.1	0.7	Biological	21.6	1.5
RISDS-B	B-04	B	8/25/2013	14:21:40	12	1	120	14.5	3 to 2/>4	>4	0	136.2	9.4	9.1	9.7	0.5	Biological	24.9	1.7
RISDS-B	B-04	C	8/25/2013	14:22:21	12	1	120	14.5	4 to 3/>4	>4	1	149.9	10.4	10.0	10.6	0.6	Biological	20.6	1.4
RISDS-B	B-04	D	8/25/2013	14:23:06	12	1	120	14.5	4 to 3/>4	>4	1	154.3	10.7	10.4	10.9	0.4	Biological	14.6	1.0
RISDS-B	B-05	A	8/25/2013	14:27:46	12	1	122	14.5	4 to 3/>4	>4	1	158.6	10.9	10.5	11.0	0.5	Biological	36.1	2.5
RISDS-B	B-05	B	8/25/2013	14:28:31	12	1	122	14.5	4 to 3/>4	>4	0	155.7	10.8	10.6	11.0	0.4	Biological	19.0	1.3
RISDS-B	B-05	C	8/25/2013	14:29:20	12	1	122	14.5	4 to 3/>4	>4	1	160.0	11.0	10.8	11.4	0.6	Biological	54.6	3.8
RISDS-C	C-01	B	8/25/2013	12:32:45	12	1	123	14.5	-5	>4	-8	0.0	0.0	0.0	0.0	ind	Physical	ind	ind
RISDS-C	C-02	A	8/25/2013	12:53:02	12	1	125	14.5	>4	>4	1	192.3	13.3	13.1	13.8	0.7	Biological	37.9	2.6
RISDS-C	C-02	B	8/25/2013	12:53:47	12	1	125	14.5	>4	>4	1	177.4	12.2	12.1	12.4	0.3	Biological	41.4	2.9
RISDS-C	C-02	D	8/25/2013	12:55:22	12	1	125	14.5	>4	>4	1	165.3	11.4	11.2	11.6	0.4	Biological	22.2	1.5
RISDS-C	C-03	B	8/25/2013	12:13:58	12	1	125	14.5	>4	>4	1	206.3	14.2	14.0	14.7	0.7	Biological	36.0	2.5
RISDS-C	C-03	C	8/25/2013	12:14:44	12	1	125	14.5	>4	>4	1	243.0	16.8	16.5	17.4	0.9	Biological	34.3	2.4
RISDS-C	C-03	D	8/25/2013	12:15:34	12	1	125	14.5	>4	>4	1	242.3	16.7	16.5	17.0	0.5	Biological	24.9	1.7
RISDS-C	C-04	A	8/25/2013	12:23:56	12	1	125	14.5	>4	>4	1	208.3	14.4	14.2	14.7	0.6	Biological	24.9	1.7
RISDS-C	C-04	B	8/25/2013	12:24:44	12	1	125	14.5	>4	>4	1	199.4	13.8	13.4	14.3	0.9	Biological	29.4	2.0
RISDS-C	C-04	D	8/25/2013	12:26:19	12	1	125	14.5	>4	>4	1	187.3	12.9	12.6	13.2	0.6	Biological	22.9	1.6
RISDS-C	C-05	B	8/25/2013	12:46:25	12	1	123	14.5	3 to 2	>4	0	61.6	4.2	3.1	5.4	2.3	Physical	61.6	ind
RISDS-C	C-05	C	8/25/2013	12:47:15	12	1	123	14.5	3 to 2/>4	>4	0	70.8	4.9	4.4	5.1	0.7	Biological	32.4	2.2
RISDS-C	C-05	D	8/25/2013	12:48:04	12	1	123	14.5	3 to 2	>4	0	49.4	3.4	2.8	4.0	1.1	Physical	ind	ind
RISDS-D	D-01	A	8/25/2013	15:12:21	12	1	118	14.5	4 to 3/>4	>4	0	185.2	12.8	12.1	13.3	1.2	Biological	19.6	1.4
RISDS-D	D-01	B	8/25/2013	15:13:04	12	1	118	14.5	>4	>4	1	191.6	13.2	12.8	13.5	0.7	Biological	6.8	0.5
RISDS-D	D-01	C	8/25/2013	15:13:46	12	1	118	14.5	>4	>4	1	197.7	13.6	13.4	13.9	0.4	Biological	20.5	1.4

Location	Station	Replicate	Date	Time	Stop Collar Setting (in)	# of Weights (per side)	Water Depth (ft)	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	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)
RISDS-D	D-02	B	8/25/2013	14:44:12	12	1	120	14.5	>4	>4	1	171.3	11.8	11.0	12.2	1.2	Biological	14.7	1.0
RISDS-D	D-02	C	8/25/2013	14:45:00	12	1	120	14.5	>4	>4	1	170.1	11.7	11.1	13.0	1.9	Biological	7.7	0.5
RISDS-D	D-02	D	8/25/2013	14:45:47	12	1	120	14.5	>4	>4	1	182.8	12.6	12.1	12.9	0.9	Biological	18.2	1.3
RISDS-D	D-03	A	8/25/2013	14:49:45	12	1	120	14.5	>4	>4	1	258.5	17.8	17.5	18.2	0.6	Biological	21.9	1.5
RISDS-D	D-03	B	8/25/2013	14:50:32	12	1	120	14.5	>4	>4	2	226.4	15.6	15.3	16.0	0.8	Biological	19.4	1.3
RISDS-D	D-03	D	8/25/2013	14:52:05	12	1	120	14.5	>4	>4	2	239.3	16.5	16.4	16.8	0.4	Biological	10.1	0.7
RISDS-D	D-04	B	8/25/2013	15:02:34	12	1	116	14.5	>4	>4	1	183.8	12.7	11.5	13.2	1.8	Biological	18.1	1.2
RISDS-D	D-04	C	8/25/2013	15:03:17	12	1	116	14.5	>4	>4	1	187.6	12.9	12.7	13.1	0.4	Biological	18.9	1.3
RISDS-D	D-04	D	8/25/2013	15:04:04	12	1	116	14.5	>4	>4	1	166.8	11.5	11.3	12.0	0.8	Biological	25.3	1.7
RISDS-D	D-05	A	8/25/2013	14:57:46	12	1	118	14.5	4 to 3/>4	>4	1	223.7	15.4	15.2	15.6	0.4	Biological	24.1	1.7
RISDS-D	D-05	B	8/25/2013	14:58:28	12	1	118	14.5	>4	>4	1	198.3	13.7	13.5	14.0	0.5	Biological	30.8	2.1
RISDS-D	D-05	C	8/25/2013	14:59:07	12	1	118	14.5	>4	>4	0	189.7	13.1	12.8	13.5	0.7	Biological	6.9	0.5
REF-E	REF-E-01	A	8/25/2013	11:37:25	14	4	138	14.5	4 to 3/>4	>4	1	290.2	20.0	19.0	20.4	1.4	Biological	55.2	3.8
REF-E	REF-E-01	B	8/25/2013	11:38:17	14	4	138	14.5	4 to 3/>4	>4	1	292.6	20.2	19.8	20.5	0.7	Biological	68.6	4.7
REF-E	REF-E-01	C	8/25/2013	11:39:05	14	4	138	14.5	>4	>4	1	281.5	19.4	19.0	20.1	1.1	Biological	34.6	2.4
REF-E	REF-E-02	A	8/25/2013	11:45:59	14	4	134	14.5	4 to 3	>4	1	265.1	18.3	18.1	18.6	0.5	Biological	62.0	4.3
REF-E	REF-E-02	C	8/25/2013	11:47:32	14	4	134	14.5	4 to 3/>4	>4	1	259.9	17.9	17.7	18.1	0.4	Biological	46.1	3.2
REF-E	REF-E-02	D	8/25/2013	11:48:17	14	4	134	14.5	4 to 3/>4	>4	1	265.8	18.4	16.2	19.6	3.4	Biological	21.4	1.5
REF-E	REF-E-03	B	8/25/2013	11:10:46	14	4	135	14.5	>4	>4	2	272.1	18.8	18.4	19.2	0.9	Biological	40.6	2.8
REF-E	REF-E-03	C	8/25/2013	11:11:41	14	4	135	14.5	>4	>4	1	271.3	18.7	18.5	18.9	0.4	Biological	53.4	3.7
REF-E	REF-E-03	D	8/25/2013	11:12:35	14	4	135	14.5	>4	>4	1	274.3	18.9	18.8	19.1	0.3	Biological	47.1	3.3
REF-E	REF-E-04	A	8/25/2013	11:21:07	14	4	134	14.5	4 to 3/>4	>4	1	293.2	20.2	20.0	20.6	0.7	Biological	55.9	3.9
REF-E	REF-E-04	B	8/25/2013	11:21:58	14	4	134	14.5	4 to 3/>4	>4	1	292.9	20.2	20.1	20.3	0.2	Biological	36.6	2.5
REF-E	REF-E-04	D	8/25/2013	11:23:35	14	4	134	14.5	4 to 3/>4	>4	1	299.8	20.7	20.4	21.0	0.6	Biological	46.3	3.2
REF-E	REF-E-05	B	8/25/2013	11:30:28	14	4	134	14.5	4 to 3	>4	1	170.4	11.8	11.1	12.3	1.2	Biological	21.0	1.5
REF-E	REF-E-05	C	8/25/2013	11:31:16	14	4	134	14.5	4 to 3	>4	0	224.9	15.5	15.3	15.7	0.4	Biological	43.9	3.0
REF-E	REF-E-05	D	8/25/2013	11:32:04	14	4	134	14.5	4 to 3	>4	0	163.1	11.3	10.8	11.7	0.9	Physical	27.5	1.9
REF-NE	REF-NE-01	A	8/25/2013	10:26:41	16	5	123	14.5	4 to 3	>4	0	167.4	11.6	11.2	12.3	1.2	Biological	12.9	0.9
REF-NE	REF-NE-01	B	8/25/2013	10:27:28	16	5	123	14.5	4 to 3/>4	>4	0	116.8	8.1	7.0	8.6	1.7	Biological	11.1	0.8
REF-NE	REF-NE-01	C	8/25/2013	10:28:24	16	5	123	14.5	4 to 3/>4	>4	0	85.1	5.9	5.4	6.7	1.3	Biological	19.4	1.3
REF-NE	REF-NE-02	A	8/25/2013	10:17:29	16	5	122	14.5	4 to 3	>4	0	37.4	2.6	2.2	2.8	0.5	Biological	ind	ind

Sediment-Profile Image Analysis Results

Location	Station	Replicate	Date	Time	Stop Collar Setting (in)	# of Weights (per side)	Water Depth (ft)	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Maximum (phi)	Grain Size Minimum (phi)	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)
REF-NE	REF-NE-02	B	8/25/2013	10:18:27	16	5	122	14.5	4 to 3	>4	0	54.5	3.8	3.6	4.0	0.5	Biological	ind	ind
REF-NE	REF-NE-02	C	8/25/2013	10:19:14	16	5	122	14.5	3 to 2	>4	-1	48.0	3.3	2.7	3.9	1.2	Biological	ind	ind
REF-NE	REF-NE-03	A	8/25/2013	9:24:38	16	5	121	14.5	4 to 3	>4	0	102.4	7.1	6.9	7.3	0.4	Biological	38.9	2.7
REF-NE	REF-NE-03	B	8/25/2013	9:25:36	16	5	121	14.5	3 to 2	>4	0	84.0	5.8	5.5	6.2	0.7	Biological	52.5	3.6
REF-NE	REF-NE-03	D	8/25/2013	9:27:22	16	5	121	14.5	3 to 2	>4	0	67.5	4.7	4.2	5.5	1.3	Physical	57.0	3.9
REF-NE	REF-NE-04	A	8/25/2013	10:44:36	16	5	123	14.5	4 to 3	>4	1	128.7	8.9	8.5	9.4	0.9	Biological	9.1	0.6
REF-NE	REF-NE-04	B	8/25/2013	10:45:28	16	5	123	14.5	4 to 3	>4	0	94.8	6.5	6.3	7.0	0.7	Biological	6.6	0.5
REF-NE	REF-NE-04	D	8/25/2013	10:47:11	16	5	123	14.5	4 to 3	>4	0	100.5	6.9	6.7	7.2	0.5	Biological	12.9	0.9
REF-NE	REF-NE-05	A	8/25/2013	10:35:31	16	5	123	14.5	3 to 2	>4	0	75.3	5.2	4.8	5.4	0.6	Biological	ind	ind
REF-NE	REF-NE-05	B	8/25/2013	10:36:20	16	5	123	14.5	3 to 2	>4	0	76.3	5.3	4.5	5.7	1.1	Physical	ind	ind
REF-NE	REF-NE-05	C	8/25/2013	10:37:12	16	5	123	14.5	4 to 3	>4	0	81.6	5.6	5.3	6.1	0.7	Biological	ind	ind
REF-SW	REF-SW-01	A	8/25/2013	16:06:36	14	4	131	14.5	4 to 3/>4	>4	2	211.4	14.6	14.2	14.9	0.7	Biological	26.5	1.8
REF-SW	REF-SW-01	B	8/25/2013	16:07:21	14	4	131	14.5	4 to 3/>4	>4	0	220.8	15.2	14.9	15.9	0.9	Biological	29.5	2.0
REF-SW	REF-SW-01	C	8/25/2013	16:08:01	14	4	131	14.5	4 to 3/>4	>4	1	178.7	12.3	10.5	13.7	3.2	Biological	19.0	1.3
REF-SW	REF-SW-02	A	8/25/2013	15:59:42	14	4	125	14.5	4 to 3	>4	1	104.5	7.2	7.0	7.5	0.5	Biological	55.2	3.8
REF-SW	REF-SW-02	B	8/25/2013	16:00:26	14	4	125	14.5	4 to 3/>4	>4	0	152.3	10.5	9.9	10.7	0.8	Biological	35.3	2.4
REF-SW	REF-SW-02	C	8/25/2013	16:01:10	14	4	125	14.5	4 to 3/>4	>4	0	118.4	8.2	7.8	8.6	0.8	Biological	15.2	1.0
REF-SW	REF-SW-03	A	8/25/2013	16:14:01	14	4	126	14.5	4 to 3/>4	>4	1	228.4	15.8	15.5	16.0	0.5	Biological	36.4	2.5
REF-SW	REF-SW-03	C	8/25/2013	16:15:48	14	4	126	14.5	4 to 3/>4	>4	1	225.7	15.6	14.8	15.9	1.1	Biological	51.1	3.5
REF-SW	REF-SW-03	D	8/25/2013	16:16:39	14	4	126	14.5	4 to 3/>4	>4	0	192.1	13.3	12.7	14.0	1.3	Biological	16.1	1.1
REF-SW	REF-SW-04	A	8/25/2013	15:41:43	14	4	128	14.5	4 to 3/>4	>4	1	220.6	15.2	13.7	15.9	2.1	Biological	18.7	1.3
REF-SW	REF-SW-04	B	8/25/2013	15:42:30	14	4	128	14.5	4 to 3/>4	>4	1	238.4	16.5	16.2	16.8	0.6	Biological	23.7	1.6
REF-SW	REF-SW-04	C	8/25/2013	15:43:17	14	4	128	14.5	4 to 3/>4	>4	1	182.4	12.6	12.3	12.9	0.7	Biological	18.3	1.3
REF-SW	REF-SW-05	A	8/25/2013	15:52:11	14	4	122	14.5	4 to 3	>4	0	50.9	3.5	3.2	3.9	0.7	Biological	ind	ind
REF-SW	REF-SW-05	C	8/25/2013	15:53:49	14	4	122	14.5	4 to 3	>4	0	65.8	4.5	3.6	4.9	1.3	Biological	ind	ind
REF-SW	REF-SW-05	D	8/25/2013	15:54:27	14	4	122	14.5	4 to 3	>4	0	64.3	4.4	4.2	4.7	0.5	Biological	ind	ind

Note: 1) "ind" indicates that the sample result was indeterminate
2) "mean" indicates the mean value across a single sediment profile image

Sediment-Profile Image Analysis Results

Location	Station	Replicate	Mud Clast Number	Mud Clast State	Methane?	Low DO?	Comment	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Average Depth (cm)	Successional Stage
RISDS-B	B-01	A	0	-	n	n	Silt-clay with some very fine sand in the upper 2-3 cm; some bits of lighter sed at SWI; slight organic enrichment in subsurface sediment	0	-	-	-	2 ->3
RISDS-B	B-01	B	0	-	n	n	Silt-clay with some very fine sand in surface layer, sign of deeper burrower at center below aRPD; surface appears disturbed by previous replicate sampling	0	-	-	-	2 ->3
RISDS-B	B-01	C	0	-	n	n	Silty-clay with some very fine sand; subsurface clay inclusions typical of DM profile; patches of lighter sediment on surface	1	8.9	10.1	9.5	1 on 3
RISDS-B	B-02	A	0	-	n	n	Silt-clay with some very fine sand in upper 1-2 cm, lighter sed at SWI and in background, DM > pen as with previous station. Evidence of burrowing at depth; burrow openings visible in PV image	0	-	-	-	1 on 3
RISDS-B	B-02	C	0	-	n	n	Silty-clay with some very fine sand; subsurface clay inclusions typical of DM profile; patches of lighter sediment on surface	1	6.0	6.1	6.1	1 on 3
RISDS-B	B-02	D	1	reduced	n	n	Silty-clay with some very fine sand; subsurface clay inclusions typical of DM profile; patches of lighter sediment on surface, small polychaete tubes visible @ SWI	2	4.3	4.8	4.5	1 on 3
RISDS-B	B-03	A	0	-	n	n	Silty, very fine sand; transected burrow opening at surface; most of surface covered with gray organic debris or reduced sediment; aRPD; evidence of burrowing throughout profile	2	5.0	5.5	5.3	1 on 3
RISDS-B	B-03	B	4	oxidized	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, burrowing throughout profile	1	6.9	7.2	7.0	1 on 3
RISDS-B	B-03	C	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, small bivalves visible in upper 1 cm, multiple depositional horizons.	1	5.5	5.7	5.6	1 on 3
RISDS-B	B-04	B	0	-	n	n	Silty, fine sand over silt clay, noticeably coarser fraction surface than previous stations; clay inclusions, DM > penetration, burrowing throughout profile.	1	5.5	5.8	5.7	2 on 3
RISDS-B	B-04	C	2	both	n	n	Silty-clay with some very fine sand; subsurface clay inclusions typical of DM profile; patches of lighter sediment on surface, small polychaete tubes visible @ SWI	2	6.8	9.6	8.2	1 on 3
RISDS-B	B-04	D	0	-	n	n	Silty-clay with some very fine sand; subsurface clay inclusions typical of DM profile; patches of lighter sediment on surface, small polychaete tubes visible @ SWI	1	7.1	7.6	7.3	1 on 3
RISDS-B	B-05	A	0	-	n	n	Silty, very fine sand over silt clay; dense small tubes @ SWI, burrowing throughout profile, DM > penetration	1	4.9	8.6	6.7	1 on 3
RISDS-B	B-05	B	1	reduced	n	n	Silty, very fine sand over silt clay; small bivalves prominent in upper 2 cm and on surface, burrowing throughout profile, DM > penetration	1	6.9	7.4	7.1	2 on 3

Sediment-Profile Image Analysis Results

Location	Station	Replicate	Mud Clast Number	Mud Clast State	Methane?	Low DO?	Comment	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Average Depth (cm)	Successional Stage
RISDS-B	B-05	C	4	both	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, reduced clast artifact from camera frame, DM > penetration	1	4.4	5.4	4.9	2 on 3
RISDS-C	C-01	B	0	-	n	n	Rocks and boulders covering surface at this station (see PV images); no penetration in any of the SPI photos	ind	ind	ind	ind	ind
RISDS-C	C-02	A	10+	oxy	n	n	Silty-clay with some very fine sand in surface 1-2 cm; patches of lighter sediment on surface, dense tubes @ SWI, burrow openings in PV image - low density of Stage 3 taxa	0	-	-	-	1 on 3
RISDS-C	C-02	B	0	-	n	n	Silty-clay with some very fine sand in surface 1-2 cm; patches of lighter sediment on surface, small tubes @ surface, shallow burrowing evident	0	-	-	-	2
RISDS-C	C-02	D	4	both	n	n	Silty-clay with some very fine sand in surface 1-2 cm; dense tubes and some Cnidaria @ SWI, burrowing in profile, low density of Stage 3 taxa	0	-	-	-	1 on 3
RISDS-C	C-03	B	0	-	n	n	Silty-clay with some very fine sand in surface 1-2 cm; small bivalves evident in upper cm, evidence of subsurface burrowing	2	4.8	8.3	6.6	2 on 3
RISDS-C	C-03	C	0	-	n	n	Silty-clay with some very fine sand in surface 1-2 cm; small polychaetes in upper cm, evidence of subsurface burrowing, burrow openings visible in PV image	1	4.5	4.5	4.5	1 on 3
RISDS-C	C-03	D	4	red/oxy	n	n	Silty-clay with some very fine sand in surface 1-2 cm; small bivalves evident in upper cm, small tubes @ SWI, transected vertical burrow	1	7.4	7.5	7.4	2 on 3
RISDS-C	C-04	A	0	-	n	n	Silty-clay with some very fine sand in surface 1-2 cm; small polychaetes in upper cm, evidence of subsurface burrowing, burrow openings visible in PV image	0	-	-	-	1 on 3
RISDS-C	C-04	B	0	-	n	n	Silty-clay with some very fine sand in surface 1-2 cm; bivalves evident in upper cm, small tubes @ SWI, transected burrow at depth	1	7.4	8.0	7.7	2 on 3
RISDS-C	C-04	D	0	-	n	n	Silty-clay with some very fine sand in surface 1-2 cm; small polychaetes in upper cm, evidence of subsurface burrowing, 7.8 cm depositional horizon with sandy silt (former aRPD at depth)	0	-	-	-	2 ->3
RISDS-C	C-05	B	0	-	n	n	Fine sand; sand ripple; possible tubes in background; penetration too shallow to determine stage, aRPD > penetration depth	0	-	-	-	ind
RISDS-C	C-05	C	0	-	n	n	Silty very fine and fine sand; some evidence of shallow burrowing; penetration too shallow to determine stage	0	-	-	-	ind
RISDS-C	C-05	D	0	-	n	n	Silty fine sand; sand ripple; penetration too shallow to determine stage, aRPD > prism penetration	0	-	-	-	ind
RISDS-D	D-01	A	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, burrowing throughout profile; DM > penetration	2	1.7	2.9	2.3	1 on 3
RISDS-D	D-01	B	8	reduced	n	n	Silty-clay with some very fine sand in surface top cm; small polychaetes in upper cm, evidence of shallow subsurface burrowing; DM > penetration	0	-	-	-	2

Sediment-Profile Image Analysis Results

Location	Station	Replicate	Mud Clast Number	Mud Clast State	Methane?	Low DO?	Comment	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Average Depth (cm)	Successional Stage
RISDS-D	D-01	C	0	-	n	n	Silty-clay with some very fine sand in surface 1-2 cm; small bivalves in oxidized layer; DM > penetration	0	-	-	-	2
RISDS-D	D-02	B	6	both	n	n	Silty-clay with some very fine sand in surface top cm; evidence of subsurface burrowing; DM > penetration	3	3.3	6.7	5.0	1 on 3
RISDS-D	D-02	C	5	reduced	n	n	Silty-clay with some very fine sand in surface top cm; DM > penetration, bivalve shells on surface, reduced fecal pellet collection at burrow opening on left edge of image corresponding to large void directly underneath opening.	1	9.3	11.4	10.3	1 on 3
RISDS-D	D-02	D	0	-	n	n	Silty-clay with some very fine sand in surface top cm; evidence of subsurface burrowing; DM > penetration	3	4.3	10.5	7.4	1 on 3
RISDS-D	D-03	A	0	-	n	n	Silty-clay with some very fine sand in surface top cm; evidence of shallow subsurface burrowing; DM > penetration; burrow openings in PV, low density of Stage 3 taxa	0	-	-	-	1 on 3
RISDS-D	D-03	B	0	-	n	n	Silty-clay with some very fine sand in surface top cm; evidence of low density of shallow deposit feeders, DM > penetration	0	-	-	-	2
RISDS-D	D-03	D	0	-	n	n	Silty-clay with some very fine sand in surface top cm; organically enriched sediment at depth, DM > penetration	0	-	-	-	1
RISDS-D	D-04	B	3	reduced	n	n	Silty-clay with some very fine sand in surface top cm; buried clay inclusions typical of DM, DM > penetration, evidence of subsurface burrowing	1	6.5	7.5	7.0	1 on 3
RISDS-D	D-04	C	1	reduced	n	n	Silty-clay with some very fine sand in surface top cm; buried clay inclusions typical of DM, DM > penetration, evidence of subsurface burrowing & polychaete against faceplate	0	-	-	-	1 on 3
RISDS-D	D-04	D	1	reduced	n	n	Silty-clay with some very fine sand in surface top cm; buried clay inclusions typical of DM, DM > penetration, prominent subsurface void	1	5.2	6.8	6.0	1 on 3
RISDS-D	D-05	A	0	-	n	n	Silty, very fine sand over silt clay; small bivalves prominent in upper 2 cm and on surface, burrowing throughout profile, DM > penetration	2	6.5	7.2	6.9	1 on 3
RISDS-D	D-05	B	1	reduced	n	n	Silty-clay with some very fine sand in surface top cm; small tubes @ SWI, DM > penetration, evidence of subsurface burrowing	1	5.8	6.0	5.9	1 on 3
RISDS-D	D-05	C	1	reduced	n	n	Silty-clay with some very fine sand in surface 1-2 cm; small bivalves near surface and in oxidized layer; DM > penetration, burrowing throughout profile	4	3.4	10.1	6.8	2 on 3
REF-E	REF-E-01	A	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, appears to be relict aRPD at depth	2	7.0	15.0	11.0	1 on 3
REF-E	REF-E-01	B	5	reduced	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, appears to be relict aRPD at depth; mud clasts on surface are camera wiper blade artifacts; transected burrows at depth	0	-	-	-	1 on 3

Location	Station	Replicate	Mud Clast Number	Mud Clast State	Methane?	Low DO?	Comment	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Average Depth (cm)	Successional Stage
REF-E	REF-E-01	C	7	reduced	n	n	Silty-clay with some very fine sand in surface top cm; evidence of subsurface burrowing; mud clasts are camera artifacts, portion of Cerianthid against faceplate at base of profile	1	5.5	5.6	5.6	1 on 3
REF-E	REF-E-02	A	0	-	n	n	Silty, very fine sand over silt clay over silty very fine sand (stratum at depth); small tubes @ SWI, appears to be relict aRPD at depth	1	7.3	8.0	7.7	1 on 3
REF-E	REF-E-02	C	5	reduced	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, appears to be relict aRPD at depth, reduced clasts at surface are camera sled artifacts, Cerianthid against faceplate at depth	1	16.3	16.7	16.5	1 on 3
REF-E	REF-E-02	D	8	oxidized	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, relict aRPD at depth, clasts at surface are camera sled artifacts, Cerianthid against faceplate at depth, large void transected at left edge	2	10.2	15.8	13.0	1 on 3
REF-E	REF-E-03	B	4	both	n	n	Silty-clay with some very fine sand in surface top cm; transected burrow at depth, relict aRPD present at base of image, mud clasts are camera artifacts, dense assemblage of small tubes @ SWI	1	3.0	3.4	3.2	1 on 3
REF-E	REF-E-03	C	0	-	n	n	Silty-clay with some very fine sand in surface top cm; small tubes @ SWI, portion of subsurface deposit feeder against faceplate mid left quadrant, transected burrows at depth	2	6.9	11.8	9.3	1 on 3
REF-E	REF-E-03	D	0	-	n	n	Silty-clay with some very fine sand in surface top cm; small bivalves in oxidized surface layer, transected burrows at depth	2	3.8	9.8	6.8	2 on 3
REF-E	REF-E-04	A	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, relict aRPD as well as transected burrow & voice at depth, larger void just below aRPD at zone of maximum microbial turnover	3	4.4	18.0	11.2	1 on 3
REF-E	REF-E-04	B	10	reduced	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, appears to be relict aRPD at depth; mud clasts on surface are camera wiper blade artifacts; transected burrows at depth	1	1.6	1.9	1.7	1 on 3
REF-E	REF-E-04	D	1	reduced	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, appears to be relict aRPD at depth; transected burrows at depth; small polychaete just above void at base of aRPD	1	3.1	4.2	3.6	1 on 3
REF-E	REF-E-05	B	0	-	n	n	Silty very fine sand; short tubes at SWI; polychaete just below aRPD on left; shallow burrowing; void at depth	1	8.4	11.1	9.8	1 on 3
REF-E	REF-E-05	C	0	-	n	n	Silty very fine sand; signs of deeper burrower at base of aRPD; 3 of voids are large and connected at depth	4	7.2	14.4	10.8	2 on 3
REF-E	REF-E-05	D	0	-	n	n	Silty very fine sand, coarser grains near surface; bits of small polychaetes visible near base of aRPD, transected burrows at depth, burrow openings in PV image	0	-	-	-	2 on 3

Sediment-Profile Image Analysis Results

Location	Station	Replicate	Mud Clast Number	Mud Clast State	Methane?	Low DO?	Comment	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Average Depth (cm)	Successional Stage
REF-NE	REF-NE-01	A	1	reduced	n	n	Silty very fine sand, coarser grains near surface; shallow burrowing; 2 thin polychaetes and voids at depth; looks like portions of asteroid at depth on lower right corner	2	7.3	10.8	9.1	1 on 3
REF-NE	REF-NE-01	B	0	-	n	n	Sand/mud/sand layering with evidence of burrowing throughout profile, small tubes @ SWI	1	4.0	4.1	4.1	1 on 3
REF-NE	REF-NE-01	C	0		n	n	Silty fine to very fine sand, fairly consolidated sediment despite extensive reworking by infauna	3	3.4	5.2	4.3	1 on 3
REF-NE	REF-NE-02	A	0	-	n	n	Silty very fine sand; few shell fragments on surface; penetration too shallow to determine successional stage, aRPD > penetration	0	-	-	-	ind
REF-NE	REF-NE-02	B	0	-	n	n	Silty very fine sand; penetration too shallow to determine successional stage, aRPD > penetration; transected large tube just to the right of center, most likely Stage 3 present	0	-	-	-	ind
REF-NE	REF-NE-02	C	0	-	n	n	Silty fine sand over silt clay; large tubes on surface; penetration too shallow to determine stage, aRPD > penetration	0	-	-	-	ind
REF-NE	REF-NE-03	A	0	-	n	n	Silty very fine sand; few shell frag on surface; some evidence of burrowing in aRPD, high density of small bivalves in top 5-8 cm	0	-	-	-	2 on 3
REF-NE	REF-NE-03	B	0	-	n	n	Silty very fine sand; few shell frag on surface; burrowing throughout aRPD, high density of small bivalves in entire profile	0	-	-	-	2 on 3
REF-NE	REF-NE-03	D	0	-	n	n	Silty very fine sand; few shell frag on surface; burrowing throughout aRPD, evidence of small bivalves in entire profile	0	-	-	-	2 on 3
REF-NE	REF-NE-04	A	0	-	n	n	Silty very fine sand, coarser well-sorted grains near SWI; small infauna on right below aRPD, transected burrows at depth, burrow openings visible in PV image	0	-	-	-	1 on 3
REF-NE	REF-NE-04	B	0	-	n	n	Silty very fine sand; small tubes on surface; shallow burrowing; small infauna on far right below aRPD; burrowing extends below penetration depth	0	-	-	-	1 on 3
REF-NE	REF-NE-04	D	0	-	n	n	Silty very fine sand; small shallow burrowing, v. small polychaete visible at left at base of aRPD, transected burrow at depth	0	-	-	-	1 on 3
REF-NE	REF-NE-05	A	0	-	n	n	Silty fine sand; small shell frag and org debris at surface; penetration too shallow to determine stage, aRPD > penetration depth	0	-	-	-	ind
REF-NE	REF-NE-05	B	0	-	n	n	Silty fine sand; multiple tubes in background; penetration too shallow to determine stage, aRPD > penetration depth	0	-	-	-	ind
REF-NE	REF-NE-05	C	0	-	n	n	Silty fine to very fine sand; sand tube with infauna on surface; penetration too shallow to determine stage, aRPD exceeds penetration depth	0	-	-	-	ind

Sediment-Profile Image Analysis Results

Location	Station	Replicate	Mud Clast Number	Mud Clast State	Methane?	Low DO?	Comment	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Void Average Depth (cm)	Successional Stage
REF-SW	REF-SW-01	A	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, transected burrows at depth; thin polychaete against faceplate on right below aRPD; larger polychaetes against faceplate below aRPD at center and at depth on left; voids at depth	2	7.6	12.7	10.1	1 on 3
REF-SW	REF-SW-01	B	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, larger polychaete against faceplate at depth on left; transected large burrow	1	3.3	4.2	3.8	1 on 3
REF-SW	REF-SW-01	C	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, transected burrows and void at depth.	1	6.9	8.1	7.5	1 on 3
REF-SW	REF-SW-02	A	0	-	n	n	Silty very fine sand; some tubes at SWI and in background; multiple burrow openings in PV, evidence of burrowing throughout profile	0	-	-	-	1 on 3
REF-SW	REF-SW-02	B	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, transected large burrow and small polychaetes visible against faceplate	1	3.1	10.5	6.8	1 on 3
REF-SW	REF-SW-02	C	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, evidence of burrowing at depth, burrow openings visible in associated PV image	0	-	-	-	1 on 3
REF-SW	REF-SW-03	A	0	-	n	n	Silty, very fine sand over silt clay; small and large tubes @ SWI, transected burrows and portion of large polychaete at depth.	0	-	-	-	1 on 3
REF-SW	REF-SW-03	C	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, polychaete at depth as well as transected burrow at surface and large void in lower left quadrant.	3	1.0	14.4	7.7	1 on 3
REF-SW	REF-SW-03	D	0	-	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, polychaete at depth as well as multiple burrow openings in associated PV image	0	-	-	-	1 on 3
REF-SW	REF-SW-04	A	0	-	n	n	Silty, very fine sand over silt clay; multiple small tubes (both worm & amphipod) @ SWI, large transected burrow at right as well as subsurface void on left	1	4.7	5.6	5.1	2 on 3
REF-SW	REF-SW-04	B	4	both	n	n	Silty, very fine sand over silt clay; small tubes @ SWI, transected burrow at depth, mud clasts are artifacts from wiper blade.	1	14.4	14.9	14.7	1 on 3
REF-SW	REF-SW-04	C	0	-	n	n	Silty, very fine sand over silt clay; small tubes & podocerid stick @ SWI, evidence of burrows at depth, portion of animal against faceplate mid-subsurface	0	-	-	-	1 on 3
REF-SW	REF-SW-05	A	0	-	n	n	Silty very fine sand; dense assemblage of short tubes at SWI and in background; penetration too shallow to determine stage, aRPD > penetration; burrow openings visible in PV	0	-	-	-	ind
REF-SW	REF-SW-05	C	0	-	n	n	Silty very fine sand; shell fragments and small tubes at SWI and in background; penetration too shallow to determine stage, aRPD > penetration.	0	-	-	-	ind
REF-SW	REF-SW-05	D	0	-	n	n	Silty very fine sand; shell fragments and small tubes at SWI and in background; penetration too shallow to determine stage, aRPD > penetration.	0	-	-	-	ind

Note: 1) "ind" indicates that the sample result was indeterminate

Plan-View Image Analysis Results

Location	Station	Replicate	Date	Time	Image Width (cm)	Image Height (cm)	Field of View Imaged (m^2)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Debris	Comment
RISDS-B	B-01	C	8/25/2013	14:14:34	111.8	74.1	0.8	silt-clay	n	y	y	y	n	y	mud bottom; small-med burrows; few large shell frag, foraging tracks evident
RISDS-B	B-02	A	8/25/2013	14:06:26	ind	ind	ind	silt-clay	n	y	y	y	n	n	Linear series of large burrow openings in right half of image, some shell fragments on surface, shrimp & crab foraging tracks
RISDS-B	B-02	D	8/25/2013	14:08:36	ind	ind	ind	silt-clay	n	y	y	y	n	n	Large burrow openings and some disarticulated shells on surface; poor visibility.
RISDS-B	B-03	A	8/25/2013	13:58:50	ind	ind	ind	silt-clay	n	y	ind	y	y	n	Large crab and burrow openings visible in surface; poor visibility
RISDS-B	B-03	D	8/25/2013	14:01:21	ind	ind	ind	silt-clay	n	y	ind	y	y	n	large flatfish in upper right quadrant
RISDS-B	B-04	A	8/25/2013	14:20:25	ind	ind	ind	silt-clay	n	y	ind	y	n	n	burrow openings and many disarticulated bivalve shells on surface
RISDS-B	B-04	B	8/25/2013	14:21:17	ind	ind	ind	silt-clay	n	y	ind	y	n	y	mud bottom; small-med burrows; few large shell frag, piece of metal at right edge of image
RISDS-B	B-04	C	8/25/2013	14:21:59	ind	ind	ind	silt-clay	n	y	ind	y	n	n	mud bottom; small-med burrows; few large shell frag, foraging tracks evident
RISDS-B	B-05	A	8/25/2013	14:27:23	ind	ind	ind	silt-clay	n	y	ind	y	n	y	mud bottom; small-med burrows; few large shell frag, poor visibility; piece of cable or pipe on bottom
RISDS-C	C-01	A	8/25/2013	12:31:30	120.0	79.5	1.0	muddy sed, rocks, boulders	n	n	n	n	y	n	cobble bottom with fine-grained detrital settlement on rocks; shrimp
RISDS-C	C-01	C	8/25/2013	12:33:26	110.8	73.4	0.8	muddy sed, rocks, boulders	n	n	n	n	y	n	muddy sed with small rocks and boulders; barnacle, crab
RISDS-C	C-01	D	8/25/2013	12:34:15	117.0	77.4	0.9	muddy sed, rocks, boulders	n	n	n	n	y	n	muddy sed with small rocks and boulders; barnacle, crab
RISDS-C	C-02	A	8/25/2013	12:52:41	ind	ind	ind	silt-clay	n	y	y	y	n	n	mud bottom; small burrows; shrimp and crab tracks
RISDS-C	C-03	A	8/25/2013	12:12:48	ind	ind	ind	silt-clay	n	y	y	y	n	n	mud bottom; small burrows; shrimp and crab tracks

Plan-View Image Analysis Results

Location	Station	Replicate	Date	Time	Image Width (cm)	Image Height (cm)	Field of View Imaged (m^2)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Debris	Comment
RISDS-C	C-03	B	8/25/2013	12:13:36	ind	ind	ind	silt-clay	n	y	y	y	n	n	mud bottom; small burrows; shrimp and crab tracks
RISDS-C	C-03	C	8/25/2013	12:14:22	ind	ind	ind	silt-clay	n	y	y	y	n	n	mud bottom; small and 1 large burrow; short tracks
RISDS-C	C-04	A	8/25/2013	12:23:34	ind	ind	ind	silt-clay	n	y	y	y	n	n	mud bottom; small burrows; tracks
RISDS-C	C-04	B	8/25/2013	12:24:22	ind	ind	ind	silt-clay	n	y	y	y	n	n	mud bottom; small burrows; tracks
RISDS-C	C-04	C	8/25/2013	12:25:09	ind	ind	ind	silt-clay	n	y	y	y	n	n	mud bottom; small burrows; tracks, Cerianthid anemone
RISDS-C	C-05	A	8/25/2013	12:45:14	116.5	77.2	0.9	silt-clay with few rocks, boulders	n	n	ind	n	y	y	silt-clay with handful of scattered rocks, boulders; small shell fragments, cable, crab
RISDS-C	C-05	B	8/25/2013	12:46:03	ind	ind	ind	silt-clay	n	y	ind	n	n	n	mud bottom; small burrows; tracks, poor visibility
RISDS-D	D-01	A	8/25/2013	15:12:00	ind	ind	ind	silt-clay	n	y	ind	y	y	y	silt-clay; small burrows; shell frag, bivalve shells, hermit crab
RISDS-D	D-01	C	8/25/2013	15:13:24	ind	ind	ind	silt-clay	n	y	ind	y	y	n	silt-clay; one large and small burrows; tracks; crab
RISDS-D	D-02	A	8/25/2013	14:43:10	ind	ind	ind	silt-clay	n	y	ind	y	n	y	silt-clay; small to med burrows; some shell fragments
RISDS-D	D-02	B	8/25/2013	14:43:50	ind	ind	ind	silt-clay	n	y	ind	y	n	n	mud bottom; small burrows; tracks, poor visibility, shell fragments
RISDS-D	D-02	C	8/25/2013	14:44:38	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med burrows; poor visibility
RISDS-D	D-03	A	8/25/2013	14:49:22	ind	ind	ind	silt-clay	n	y	ind	y	n	y	silt-clay; small burrows; tracks- one long one in upper right; few shell frag
RISDS-D	D-03	B	8/25/2013	14:50:09	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med burrows; poor visibility
RISDS-D	D-03	D	8/25/2013	14:51:42	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; medium and one giant burrow (upper right quadrant); poor visibility
RISDS-D	D-04	A	8/25/2013	15:01:28	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small and medium burrows; some shell fragments
RISDS-D	D-04	B	8/25/2013	15:02:11	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; high density of medium burrows; poor visibility
RISDS-D	D-04	D	8/25/2013	15:03:42	ind	ind	ind	silt-clay	n	y	ind	y	y	n	silt-clay; small to med burrows; poor visibility; fish in large burrow at lower right

Plan-View Image Analysis Results

Location	Station	Replicate	Date	Time	Image Width (cm)	Image Height (cm)	Field of View Imaged (m^2)	Sediment Type	Bedforms	Burrows	Tubes	Tracks	Epifauna	Debris	Comment
RISDS-D	D-05	A	8/25/2013	14:57:25	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small burrows; some shell fragments
REF-E	REF-E-05	A	8/25/2013	11:29:16	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med burrows
REF-E	REF-E-06	D	8/25/2013	11:31:43	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med-large burrows; few large shell fragments
REF-NE	REF-NE-01	A	8/25/2013	10:26:20	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med burrows, poor visibility
REF-NE	REF-NE-02	B	8/25/2013	10:27:07	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med burrows, poor visibility
REF-NE	REF-NE-03	C	8/25/2013	10:28:04	ind	ind	ind	silt-clay	n	y	ind	y	n	y	silt-clay; small to med burrows, poor visibility, small piece of trash or rock lower right quadrant
REF-NE	REF-NE-02	A	8/25/2013	10:17:09	ind	ind	ind	silt-clay	n	y	ind	y	n	y	silt-clay; small and medium burrows; some shell fragments, debris in lower left quadrant; poor visibility
REF-SW	REF-SW-01	A	8/25/2013	16:06:16	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med burrows
REF-SW	REF-SW-02	A	8/25/2013	15:59:21	ind	ind	ind	silt-clay	n	y	ind	y	y	n	silt-clay; small to med-large burrows, starfish
REF-SW	REF-SW-02	B	8/25/2013	16:00:04	ind	ind	ind	silt-clay	n	y	ind	y	y	n	silt-clay; small to med-large burrows, fish in lower left quadrant
REF-SW	REF-SW-03	A	8/25/2013	16:13:41	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med burrows
REF-SW	REF-SW-03	B	8/25/2013	16:14:39	ind	ind	ind	silt-clay	n	y	ind	y	y	n	silt-clay; small to med burrows; skate
REF-SW	REF-SW-03	D	8/25/2013	16:16:18	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to large burrows
REF-SW	REF-SW-04	C	8/25/2013	15:42:55	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med-large burrows
REF-SW	REF-SW-04	D	8/25/2013	15:43:42	ind	ind	ind	silt-clay	n	y	ind	y	n	n	silt-clay; small to med-large burrows, decomposing crab body
REF-SW	REF-SW-05	A	8/25/2013	15:51:49	119.8	79.3	1.0	silt-clay	n	y	ind	y	n	n	silty; small to med burrows; scattered shell fragments
REF-SW	REF-SW-05	B	8/25/2013	15:52:37	110.1	72.9	0.8	silt-clay	n	y	ind	y	n	n	silt-clay; small to med-large burrows; mud clasts; bits of shell fragments
REF-SW	REF-SW-05	C	8/25/2013	15:53:27	122.5	81.1	1.0	silt-clay	n	y	ind	y	n	n	silt-clay; small to med burrows; mud clasts; shell frag

Note: 1) “ind” indicates that the sample result was indeterminate

APPENDIX D

GRAIN SIZE SCALE FOR SEDIMENTS

APPENDIX D

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 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 $y_1^*, y_2^*, \ldots y_B^*$ 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 EquationsA- 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

APPENDIX F

BENTHIC BIOLOGY RESULTS FOR RISDS AUGUST 2013 SURVEY

	NE-01A	NE-02A	SW-01A	SW-02A	B-01A	B-02B	B-03A	C-02A	C-03A	C-04A
ANNELIDA										
POLYCHAETA										
EUNICIDA										
Arabella iricolor	8	-	-	-	-	-	-	-	-	-
Drilonereis magna	10	-	-	-	-	-	-	-	-	-
Lumbrinerides acuta	-	6	8	8	-	-	4	-	-	-
Lumbrineris acicularum	26	-	15	7	-	5	-	5	6	13
PHYLLODOCIDA										
Aphroditella hastata	-	-	2	1	-	-	-	-	-	-
Eumida sanguinea	-	5	-	-	-	-	-	-	-	-
Exogone dispar	9	9	-	-	-	-	-	-	-	-
Goniada maculata	-	-	3	-	-	-	-	-	-	-
Lepidonotus squamatus	-	-	1	-	-	-	-	-	-	-
Nephtys incisa	-	-	-	-	-	-	-	-	-	1
Odontosyllis fulgurans	-	12	-	-	-	-	-	-	-	-
Parapionosyllis longicirrata	-	2	-	-	-	-	-	-	-	-
Podarkeopsis spp.	2	-	-	-	-	-	-	-	-	-
SABELLIDA										
Chone infundibuliformis	-	-	-	2	2	-	-	5	2	-
Euchone incolor	-	-	-	-	-	-	-	-	-	3
Myxicola infundibulum	-	-	-	-	-	-	-	-	2	-
Owenia fusiformis	-	-	-	7	-	-	-	-	-	-
Potamilla neglecta	-	-	-	-	-	-	-	-	1	-
Sabellaria vulgaris	-	-	-	-	-	-	-	-	-	1
SCOLECIDA										
Aricidea spp.	-	-	-	-	-	-	-	-	2	-
Capitella capitata	5	10	4	2	1	-	-	5	12	3
Clymenella torquata	2	-	3	6	-	-	-	-	-	-
Leitoscoloplos robustus	-	-	-	-	-	-	-	1	-	-
Levinsenia gracilis	-	-	-	-	-	2		-	-	-
Ophelina acuminata	3	2	-	-	-	1	2	-	-	-
Paraonis fulgens	1	-	-	-	-	-	-	-	-	-
Paraonis gracilis	-	-	-	-	-	-	1	-	-	-
Phylo ornatus	1	1	4	6	2	3	17	18	26	42
Polyphysia crassa	29	19	-	2	-	-	-	-	-	-
SPIONIDA										
Apistobranchus tullbergi	-	-	-	-	-	-	-	-	1	-
Pygospio elegans	-	-	6	3	-	-	-	-	-	-
Scolelepis squamata	1	-	-	3	-	-	-	-	-	-

	NE-01A	NE-02A	SW-01A	SW-02A	B-01A	B-02B	B-03A	C-02A	C-03A	C-04A
Spio filicornis	-	-	-	-	-	1	-	-	-	3
TEREBELLIDA										
Dodecaceria concharum	56	8	14	47	3	103	36	-	3	9
Flabelligera affinis	-	-	-	-	-	-	-	3	2	2
Hobsonia florida	-	-	1	-	-	-	-	-	-	-
Pectinaria gouldii	11	4	23	22	32	16	14	49	38	77
Terebellides stroemii	6	1	2	22	-	-	-	-	-	-
Tharyx setiger	-	-	-	-	-	4	-	30	61	55
NEMATODA										
Nematoda spp.	1	68	-	1	-	-	-	5	1	3
MOLLUSCA										
BIVALVIA										
ANOMALODESMATA										
Thracia conradi	-	-	1	-	-	-	-	-	-	-
CARDITOIDA										
Astarte undata	2	2	-	20	-	-	-	-	5	31
Cyclocardia borealis	5	5	19	39	-	-	-	-	-	-
EUHETERODONTA										
Ensis directus	1	-	-	1	-	-	-	1	-	-
LUCINOIDA										
Lucinoma filosa	11	1	19	22	1	12	20	21	55	130
NUCULANOIDA										
Yoldia limatula	1	-	12	17	1	-	2	4	17	9
NUCULIDA										
Nucula proxima	103	8	363	433	62	449	2119	2782	1697	1512
VENEROIDA										
Parvicardium pinnulatum	1	2	12	12	-	-	-	9	20	15
Spisula solidissima	7	-	14	15	1	-	-	4	16	41
GASTROPODA										
CEPHALASPIDEA										
Acteocina canaliculata	-	-	-	-	-	-	-	-	11	-
LITTORINIMORPHA										
Amauropsis islandica	-	-	-	-	-	-	-	1	-	-
Hydrobia spp.	-	-	-	-	-	-	-	11	8	3
NEOGASTROPODA										
Colus pygmaeus	-	-	-	-	-	-	-	-	2	-

	NE-01A	NE-02A	SW-01A	SW-02A	B-01A	B-02B	B-03A	C-02A	C-03A	C-04A
ARTHROPODA										
MALACOSTRACA										
AMPHIPODA										
Ameroculodes edwardsi	-	-	-	-	-	-	-	3	5	-
Ampelisca spp.	-	-	16	7	-	-	-	-	-	-
Ampelisca vadorum	26	-	-	-	-	-	-	-	-	-
Byblis serrata	17	455	-	31	1	-	-	-	3	-
Caprella linearis	1	-	2	7	-	-	-	-	-	-
Casco bigelowi	1	-	-	-	-	-	-	-	-	-
Dexamine thea	-	-	-	-	-	-	-	2	2	-
Eobrolgus spinosus	-	-	-	1	-	-	-	-	-	-
Gammarus annulatus	32	-	-	10	-	-	-	-	-	-
Haustorius canadensis	-	-	-	-	-	-	1	-	-	-
Idunella spp.	-	1	-	-	-	-	-	-	-	-
Listriella clymenellae	4	-	-	1	-	-	-	-	-	-
Pontoporeia femorata	-	-	3	-	-	-	-	-	-	-
Unciola spp.	3	19	8	25	-	-	-	-	-	-
CUMACEA										
Diastylis polita	13	-	-	16	-	-	-	-	-	-
Diastylis sculpta	-	-	12	-	-	-	-	1	-	-
Oxyurostylis smithi	-	-	-	-	-	-	-	-	1	-
Pseudoleptocuma minus	26	3	-	15	-	-	-	-	-	-
DECAPODA										
Pandalus borealis	-	-	-	2	-	-	-	-	-	-
Portunus sayi	2	-	-	-	-	-	-	2	-	-
EUPHAUSIACEA										
Meganyctiphanes norvegica	-	-	-	-	2	-	-	-	-	-
ISOPODA										
Cyathura polita	-	-	1	-	-	-	-	-	-	-
Edotia triloba	-	6	-	1	-	-	-	-	-	-
MYSIDA										
Neomysis americana	-	-	-	-	-	-	1	-	-	-
MAXILLOPODA										
CALANOIDA										
Anomalocera spp.	2	5	11	2	-	-	-	2	3	4
Eurytemora spp.	-	-	2	-	-	-	-	-	-	-
ECHINODERMATA										
OPHIUROIDEA										

	NE-01A	NE-02A	SW-01A	SW-02A	B-01A	B-02B	B-03A	C-02A	C-03A	C-04A
OPHIURIDA										
Ophiopholis aculeata	-	-	-	5	-	-	-	-	-	-
CNIDARIA										
ANTHOZOA										
ACTINIARIA										
Actinothoe modesta	-	-	1	-	3	5	3	2	7	2
TOTALS										
# of Species	35	24	29	36	12	11	12	23	28	21
# of Individuals	429	654	582	821	111	601	2220	2966	2009	1959