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Final Report

FALL 2001 REMOTS® CHARACTERIZATION REPORT

RHODE ISLAND REGION LONG-TERM DREDGED MATERIAL DISPOSAL SITE EVALUATION PROJECT

Final

Fall 2001 REMOTS® Characterization Report

Rhode Island Region
Long-Term Dredged Material Disposal Site Evaluation Project

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to

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1. INTRODUCTION

The U.S. Army Corps of Engineers New England District (the Corps) is assisting Region I of the U.S. Environmental Protection Agency with development of an Environmental Impact Statement evaluating possible designation of an open water dredged material disposal site in the Rhode Island/Southeastern Massachusetts region. As part of the initial stages of the EIS development, field data are being collected at a number of locations in Rhode Island Sound that are under consideration as potential long-term disposal site(s).

Under contract to Battelle Duxbury Operations, Science Applications International Corporation (SAIC) performed a Remote Ecological Monitoring of the Seafloor (REMOTS®) sediment-profile imaging survey in September 2001, as one part of the initial field data collection effort. The REMOTS® survey involved sampling at four sites (Sites 16, 18, 69A & 69B) in Rhode Island Sound (Figure 1). This report presents and discusses the September 2001 survey results and compares these results to surveys previously conducted. All figures are presented in Appendix A.

2. METHODS

REMOTS® sediment-profile imaging is a benthic sampling technique in which a specialized camera is used to obtain undisturbed, vertical cross-section photographs (*in situ* profiles) of the upper 15 to 20 centimeters (cm) of the seafloor. This is a reconnaissance survey technique used for rapid collection, interpretation and mapping of data on physical and biological seafloor characteristics; it has been successfully employed in estuarine, coastal and deep-sea environments worldwide for almost 20 years. Measurements obtained from sediment-profile images are used to characterize sediment types, evaluate benthic habitat quality, map disturbance gradients, and follow ecosystem recovery after disturbance abatement.

For the September 2001 REMOTS® field survey in Rhode Island Sound, SAIC utilized a Benthos Model 3731 sediment-profile camera (Figure 2). Standard field and QA/QC procedures were followed. These are documented in the SAIC "Standard Operating Procedure for the Collection and Analysis of Sediment Profile Images" (SAIC 2001), as well as in the Battelle Quality Assurance Project Plan (QAPP) for the Rhode Island Sound Study (Battelle, 2001). There were no changes or deviations from these procedures during the implementation of the September 2001 REMOTS® field operations.

The REMOTS® field sampling took place over three days (September 26, 27, and 28, 2001) aboard the M/V *Beavertail* based out of Jamestown, Rhode Island. The original sampling plan called for the REMOTS® sampling to be conducted aboard the Battelle vessel *Aquamonitor*, but due to delays associated with the passage of several storms during September and attendant large swells in Rhode Island Sound, SAIC was instructed to charter the M/V *Beavertail* to meet the sampling deadlines.

SAIC provided personnel to operate the REMOTS® camera system on-board the vessel each day, while the navigator and vessel navigation system were provided and operated by Battelle personnel. The Battelle NavSam© navigation system, which employs differential-GPS, was used to position the vessel accurately at each station. A position fix was logged by the NavSam® system for each drop of the REMOTS® sediment profile camera at each station (i.e., coordinates were logged for each replicate image).

Over the three-day survey, REMOTS® images were obtained at a total of 59 stations, divided among the four sites as follows: 15 stations at Site 69A (Jamestown Bridge Reef, Figure 3), 18 stations at Site 69B (Separation Zone, Figure 4), 18 stations at Site 18 (Brenton-A, Figure 5), and 8 stations at Site 16 (Brenton Reef, Figure 6). The stations at each of these sites included those located within the commonly accepted site boundary, as well as "reference stations", which were stations located outside the boundary to characterize ambient seafloor conditions (Figures 3 to 6). Selection of sampling locations was determined by bottom type. Stations were chosen to represent at least two to three replicate locations within each bottom type, as characterized by previous sediment studies at these sites, including both REMOTS® measurements and side scan imaging. At each station, the REMOTS® sediment-profile camera was lowered into the seafloor at least three times to obtain at least one image suitable for subsequent analysis.

Table 1 provides a summary of the field sampling operations over the three survey days. As indicated in this table, only four stations were sampled at Site 16 on Day 1 of the survey (September 26) before field operations were curtailed due to safety concerns related to large swells emanating from an offshore storm. On Day 2 of the survey (September 27), 44 stations distributed among Sites 16, 18, 69A and 69B were sampled successfully. Day 3 of the survey (September 28) consisted of successful sampling at the remainder of the stations (11 stations located at Site 69B). In addition, station JB6 at Site 69A was re-occupied on September 28 as a "make-up" station to obtain additional replicate images. At least two and, in the majority of cases, three replicate sediment profile images were obtained successfully at each sampling station (Table 1). This satisfied the requirement that at least one image be obtained and analyzed at each station. Following standard procedures, the REMOTS® film was processed and reviewed at the end of each field day to verify that images of suitable quality were being obtained.

The images were analyzed for all the standard REMOTS® measurement parameters (i.e., grain size, habitat type, penetration depth, small-scale surface roughness, Redox Potential Discontinuity (RPD) depth, infaunal successional stage, Organism-Sediment Index (OSI)). REMOTS® grain size values are expressed as phi sizes; Table 2 is provided to allow easy conversion between phi sizes and other common grain size scales. Additionally, a single "benthic habitat" classification was assigned to each image; descriptions of the standard benthic habitat types are provided in Table 3.

One representative image from each station was selected and analyzed, provided the replicate images all showed similar benthic habitat types. At any stations where the replicates showed different habitat types (i.e., small-scale spatial variability), one representative image of each habitat type was analyzed.

Table 1. Summary of the Sites and Stations Sampled on The Three REMOTS® Field Days.

Date	Site	Stations	No. images
26-Sep	Site 16 (Brenton Reef)	BR2	2
		BR1A	2
		BR1C	2
		BR1B	3
27-Sep	Site 16, continued	BRR1	3
		BRR2	3
		BRR3	3
		BR3	3
	Site 18 (Brenton-A)	BA4	3
		BA3	3
		BAR3	3
		BA2	3
		BAR2	3
		BA1	3
		BAR1	3
		BAR9	3
		BA8	2
		BA9	3
		BAR8	3
		BA7	3
		BAR7	3
		BAR6	3
		BAR5	3
		BA6	3
		BA5	3
		BAR4	3
	Site 69a (Jamestown Bridge Reef)	JBR3	3
		JBR4	3
		JB5	3
		JBR5	3
		JB3	3
		JB6	3
		JBR6	3
		JBR7	3
		JBR8	3
		JB4	3
		JBR9	3
		JB2	3
		JB1	3
		JBR1	3
		JBR2	3
	Site 69b (Separation Zone)	SZR9	3
		SZ1	3
		SZR6	3
		SZR1	3
		SZR7	3
		SZR4	3
		SZ4	3
28-Sep	Site 69b, continued	SZ5	3
		SZ2	3
		SZ3	3
		SZR2	3
		SZR8	3
		SZ7	3
		SZ6	3
		SZR5	3
		SZ8	3
		SZ9	3
		SZR3	3

Table 2. Grain Size Scales for Sediments.

ASTM (Unified) Classification[1]	U.S. Std. Sieve[2]	Size in mm	Phi (Φ) Size	Wentworth Classification[3]
Boulder		4096.	-12.0	
		1024.	-10.0	Boulder
	12 in	256.	-8.0	
		128.	-7.0	Large Cobble
Cobble		107.64	-6.75	
		90.51	-6.5	Small Cobble
	3 in	76.11	-6.25	
		64.00	-6.0	
		53.82	-5.75	
		45.26	-5.5	Very Large Pebble
Coarse Gravel		38.05	-5.25	
		32.00	-5.0	
		26.91	-4.75	
		22.63	-4.5	Large Pebble
	3/4 in	19.03	-4.25	
		16.00	-4.0	
		13.45	-3.75	
		11.31	-3.5	Medium Pebble
		9.51	-3.25	
Fine Gravel		8.00	-3.0	
	2.5	6.73	-2.75	
	3	5.66	-2.5	Small Pebble
	3.5	4.76	-2.25	
	4 (4.75 mm)	4.00	-2.0	
	5	3.36	-1.75	
	6	2.83	-1.5	Granule
Coarse Sand	7	2.38	-1.25	
	8	2.00	-1.0	
	10 (2.0 mm)	1.68	-0.75	
	12	1.41	-0.5	Very Coarse Sand
	14	1.19	-0.25	
	16	1.00	0.0	
	18	0.84	0.25	
Medium Sand	20	0.71	0.5	
	25	0.59	0.75	Coarse Sand
	30	0.50	1.0	
	35	0.420	1.25	
	40 (0.425 mm)	0.354	1.5	
	45	0.297	1.75	Medium Sand
	50	0.250	2.0	
	60	0.210	2.25	
	70	0.177	2.5	
	80	0.149	2.75	Fine Sand
Fine Sand	100	0.125	3.0	
	120	0.105	3.25	
	140	0.088	3.5	
	170	0.074	3.75	Very Fine Sand
	200 (0.075 mm)	0.0625	4.0	
	230	0.0526	4.25	
	270	0.0442	4.5	
	325	0.0372	4.75	Coarse Silt
Fine-grained Soil:	400	0.0312	5.0	
		0.0156	6.0	
Clay if PI ³ 4 and plot of PI vs. LL is on or above "A" line*		0.0078	7.0	
Silt if PI < 4 and plot of PI vs. LL is below "A" line*		0.0039	8.0	
		0.00195	9.0	Medium Silt
*and the presence of organic matter does not influence LL.		0.00098	10.0	Fine Silt
		0.00049	11.0	Very Fine Silt
		0.00024	12.0	Coarse Clay
		0.00012	13.0	Medium Clay
		0.000061	14.0	Fine Clay

1. ASTM Standard D 2487-92. This is the ASTM version of the Unified Soil Classification System. Both systems are similar (from ASTM (1993)).
2. Note that British Standard, French, and German DIN mesh sizes and classifications are different. There is no unit for mesh size.
3. Wentworth sizes (in inches) cited in Krumbein and Sloss (1963).

Table 3. Benthic Habitat Categories Assigned to Sediment-profile Images Obtained in this Study.

Habitat AM: *Ampelisca* Mat
Uniformly fine-grained (i.e., silty) sediments having well-formed amphipod (*Ampelisca* spp.) tube mats at the sediment-water interface.

Habitat SH: Shell Bed
A layer of dead shells and shell fragments at the sediment surface overlying sediment ranging from hard sand to silts. Epifauna (i.e., bryozoans, tube-building polychaetes) commonly found attached to or living among the shells. Two distinct shell bed habitats:

SH.SI: Shell Bed over silty sediment - shell layer overlying sediments ranging from fine sands to silts to silt-clay.

SH.SA: Shell Bed over sandy sediment - shell layer overlying sediments ranging from fine to coarse sand.

Habitat SA: Hard Sand Bottom
Homogeneous hard sandy sediments, do not appear to be bioturbated, bedforms common, successional stage mostly Stage I or indeterminate because of low prism penetration.

SA.F: Fine sand - uniform fine sand sediments (grain size: 4 to 3 phi).

SA.M: Medium sand - uniform medium sand sediments (grain size: 3 to 2 phi).

SA.G: Medium sand with gravel - predominately medium to coarse sand with a minor gravel fraction.

Habitat HR: Hard Rock/Gravel Bottom
Hard bottom consisting of pebbles, cobbles and/or boulders, resulting in no or minimal penetration of the REMOTS® camera prism. Some images showed pebbles overlying silty-sediments.

Habitat UN: Unconsolidated Soft Bottom
Fine-grained sediments ranging from very fine sand to silt-clay, with a complete range of successional stages (I, II and III). Biogenic features were common (i.e., amphipod and polychaete tubes at the sediment surface, small surface pits and mounds, large borrow openings, and feeding voids at depth). Several sub-categories:

UN.SS: Fine Sand/Silty - very fine sand mixed with silt (grain size range from 4 to 2 phi).

UN.SI: Silty - homogeneous soft silty sediments (grain size range from >4 to 3 phi). Generally deep prism penetration.

UN.SF: Very Soft Mud - very soft muddy sediments (>4 phi) of high apparent water content and deep prism penetration.

3. RESULTS

The complete set of REMOTS® image analysis results for each site is provided in Appendix A. These results are summarized in Tables 4 through 14 and presented below.

3.1 Site 69A (Jamestown Bridge Reef)

3.1.1 Physical Sediment Characteristics

The surface sediments within the boundary of Site 69A were composed primarily of tan over gray silty sand (fine sand and silt). A major modal grain size of 4 to 3 phi (very fine sand) was observed at all stations (Table 4, Figure 7). The reference stations outside the site boundary displayed more variability in grain size, with grain size major modes ranging from > 4 phi (silt-clay) to < -1 phi (pebbles/cobbles) (Table 5, Figure 7). Tan over gray fine sand and silt and a major modal grain size of 4 to 3 phi characterized the majority of reference area stations (five of nine).

A variety of benthic habitat types (UN.SS, UN.SI, and SA.F) were detected within Site 69A. However, the primary benthic habitat classification was fine sand (habitat type SA.F) or muddy sediment with a high apparent proportion of very fine sand (habitat type UN.SS). Together, these similar habitat types occurred at five of the six sampling stations (Tables 4 and 6, Figures 8 and 9). There is some overlap among habitat types UN.SS, UN.SI, and SA.F; they are distinguished in sediment-profile images mainly on the basis of often subtle differences in apparent grain size and texture (Figure 9). Station JB2, located in the center of Site 69A, exhibited unconsolidated soft sediment that appeared to have a significant silt component (habitat type UN.SI).

Similar to the site stations, the primary benthic habitat classification at the reference area stations was fine sand (habitat type SA.F), present in four of the nine stations (Tables 5 and 6, Figure 8). However, there was variability with respect to benthic habitat types at the reference area stations. Because two replicates from reference area Station JBR6 (outside the southeast corner of the area) showed different habitat types (SA.F and UN.SI), one representative image of each habitat type was analyzed. A number of stations exhibited either unconsolidated soft sediment with a high apparent silt or fine sand component (habitat types UN.SI and UN.SS) or hard sand bottom comprised of clean, fine or medium sand (habitat types SA.F and SA.M). One station, located in the northeast corner of the survey area (Station JBR3), was classified as Hard Rock/Gravel Bottom (habitat type HR).

The penetration depth of the sediment-profile camera prism provides an indication of the degree of sediment density or compaction. Mean camera prism penetration measurements for stations within Site 69A varied from 3.4 cm at Station JB5 to 13.3 cm at Station JB1, with an overall average of 7.2 cm (Table 4, Figure 7). This value falls within the mid-range of possible values (range 0 to 20 cm) and reflects moderately compact sediments due to a relatively high proportion

Table 4. Summary of the September 2001 REMOTS® Sediment-profile Imaging Results for Site 69A (Jamestown Bridge Reef)

Station	Grain Size Major Mode (phi)	Camera Penetration Mean (cm)	Dredged Material Thickness Mean (cm)	Boundary Roughness Mean (cm)	Benthic Habitat	Successional Stages Present	RPD Mean (cm)	Methane Present	OSI Mean
JB1	4-3 phi	13.29	0.0	2.18	UN.SS	ST I on III (1)	2.15	NO	8.0
JB2	4-3 phi	6.81	0.0	2.30	UN.SI	ST II (1)	1.64	NO	6.0
JB3	4-3 phi	9.05	0.0	0.55	SA.F	ST II on III (1)	1.94	NO	8.0
JB4	4-3 phi	3.84	0.0	0.50	SA.F	ST I to II (1)	1.62	NO	5.0
JB5	4-3 phi	3.38	0.0	0.97	SA.F	ST I (1)	1.18	NO	3.0
JB6	4-3 phi	6.51	0.0	0.98	UN.SS	ST II (1)	2.85	NO	7.0
AVG		7.15	0.0	1.25			1.90		6.2
MAX		13.29	0.0	2.30			2.85		8.0
MIN		3.38	0.0	0.50			1.18		3.0

Table 5. Summary of the September 2001 REMOTS® Sediment-profile Imaging Results for Site 69A (Jamestown Bridge Reef) Reference Stations.

Station	Grain Size Major Mode (phi)	Camera Penetration Mean (cm)	Dredged Material Thickness Mean (cm)	Boundary Roughness Mean (cm)	Benthic Habitat	Successional Stages Present	RPD Mean (cm)	Methane Present	OSI Mean
JBR1	4-3 phi	9.23	0.0	0.22	UN.SI	ST II to III (1)	1.76	NO	7.0
JBR2	> 4 phi	14.20	0.0	1.51	UN.SI	ST I on III (1)	1.84	NO	8.0
JBR3	<-1 phi	1.52	0.0	3.04	HR	INDET (1)	INDET	NO	INDET
JBR4	4-3 phi	8.36	0.0	0.55	UN.SS	ST I to II (1)	3.65	NO	7.0
JBR5	3-2 phi	2.95	0.0	1.45	SA.F	ST I (1)	>1.99	NO	4.0
JBR6 rep A	4-3 phi	4.57	0.0	0.78	SA.F	ST II (1)	2.56	NO	7.0
JBR6 rep C	> 4 phi	13.41	0.0	1.72	UN.SI	ST I on III (1)	2.69	NO	9.0
JBR7	2-1 phi	4.06	0.0	1.20	SA.M	ST I (1)	2.02	NO	4.0
JBR8	4-3 phi	2.38	0.0	0.97	SA.F	ST I (1)	>1.67	NO	4.0
JBR9	4-3 phi	4.02	0.0	1.64	SA.F	ST III (1)	1.80	NO	8.0
AVG		6.47		1.31			2.22		6.4
MAX		14.20		3.04			3.65		9.0
MIN		1.52		0.22			1.76		4.0

Table 6. Distribution of Benthic Habitat Types Among Stations at Sites 69A, 69B, 18, and 16, September 2001.

Description	Number Station	AM	SH.S	SH.S	SA.	SA.	SA.	HR	UN.S	UN.S	UN.S
SITE 69A	6	0	0	0	3	0	0	0	2	1	0
REF SITE 69A	10	0	0	0	4	1	0	1	1	3	0
SITE 69B	9	0	0	0	2	0	0	2	1	4	0
REF SITE 69B	9	0	0	0	3	0	1	2	3	0	0
SITE 18	9	0	0	0	2	0	0	0	2	1	4
REF SITE 18	9	0	0	0	3	1	0	0	2	3	0
SITE 16	5	0	0	0	0	1	0	1	1	2	0
REF SITE 16	3	2	0	0	0	0	0	0	0	0	1

of fine sand within the sediment. Mean camera prism penetration measurements were comparable, but slightly lower at the reference area stations, with an overall average of 6.5 cm (Table 5, Figure 7).

Small-scale sediment surface roughness (i.e., "boundary roughness") is the amount of vertical relief measured across the 13.4 cm width of the sediment-profile camera window. Roughness values for stations within Site 69A ranged from 0.5 cm at Station JB4 to 2.3 cm at Station JB2 (average of 1.3 cm), which was comparable to the reference area average of 1.3 cm (Tables 4 and 5). Values in this range reflect only a small amount of small-scale surface relief at the sediment-water interface across the field of view of the sediment-profile camera, due to either physical or biological processes. There was no obvious spatial pattern to these relatively low boundary roughness values at Site 69A stations. Surface roughness was attributed primarily to physical processes (i.e., winnowing of fines by bottom currents, sand rippling) at the sediment-water interface at stations within Site 69A. Two stations, however, exhibited biogenic surface roughness as a result of a fecal layer and a decayed amphipod tube mat (*Ampelisca* sp.) (Figure 10).

Surface roughness at the reference area stations was also attributed to physical disturbance at most stations, with the exception of two stations displaying biogenic surface roughness due to dense amphipod tubes and biological surface reworking by burrowing infauna at the sediment-water interface. A small echinoderm (starfish) was detected at the sediment surface at Station JBR1. Shell fragments were observed at the sediment-water interface in many images of both the site and reference stations.

3.1.2 Biological Conditions

Three parameters were used to assess overall benthic habitat quality: apparent RPD depth, OSI, and infaunal successional stages. The apparent RPD depth provides a measure of the apparent depth of oxygen penetration into the surface sediments and the degree of biogenic sediment mixing. It is used to distinguish between "healthy" sediments that are well-mixed by organisms and, therefore well-aerated, versus degraded sediments that are anoxic and only support a reduced number or variety of organisms. The infaunal successional stage designation likewise provides an indication of the degree of seafloor disturbance; recently disturbed or degraded sediments are typically characterized by surface-dwelling opportunistic communities (Stage I), while sediments that are non-degraded or not subject to frequent physical disturbance tend to support a more-advanced, well-developed benthic community (Stage III). The Organism-Sediment Index (OSI) has been developed as a summary metric of overall benthic habitat quality; the OSI can range from –10 to +11. In general, OSI values of greater than +6 to +11 indicate non-disturbed or non-degraded benthic habitat conditions characterized by deeper RPD depths and more advanced successional stages (Stages II and III). OSI values between 0 and +6 indicate moderate degradation or disturbance, while values less than 0 to –10 indicated highly degraded benthic habitat conditions (e.g., anoxic sediments with few or no infauna).

The mean RPD depths for Site 69A stations ranged from 1.2 cm at Station JB5 to 2.9 cm at Station JB6 (Table 4, Figure 11). The overall RPD average of 1.9 cm indicates moderately well-

oxygenated surface sediments over the site. The RPD depths over the site were comparable to those at the reference area stations, which ranged from 1.8 cm to 3.7 cm (average of 2.2 cm, Table 5, Figure 11). The RPD depth could not be measured at reference area Station JBR3 (indeterminate), due to underpenetration of the sediment-profile camera in a hard bottom. Furthermore, the RPD depth exceeded the penetration depth of the camera prism at Stations JBR5 and JBR8. None of the stations occupied within Site 69A or the reference areas showed any evidence of low sediment dissolved oxygen conditions, visible redox rebounds, or methane gas bubbles.

A variety of successional stages was observed over Site 69A, including surface-dwelling, opportunistic, Stage I polychaetes, Stage II infaunal amphipods, and Stage III head-down, deposit-feeding infauna (Table 4, Figure 12). Evidence of Stage III, consisting of active feeding voids in the subsurface sediments, was detected at only two of the six stations (33%) and was accompanied by either Stage I pioneering individuals or Stage II taxa at the sediment-water interface. Stage II, alone or in combination with Stage I or III, was most commonly observed at the site stations. Amphipod tubes (*Ampelisca* sp.), representative of Stage II organisms, were visible in the images at four of the six stations (67%) over Site 69A (Figure 10). Some of these amphipod tubes appeared to be in a state of decay, but active tubes were also visible. One station (JB5), displaying a higher sand component, showed only surface-dwelling Stage I organisms present at the sediment-water interface.

A variety of successional stages (Stages I, II, and III) was also observed at the reference area stations. Reference area stations showed a slightly higher occurrence of advanced Stage III organisms (44%) than the site stations; and, similar to the site stations, Stage III organisms were often accompanied by either Stage I or Stage II taxa (Table 5, Figure 12). Successional status determination was not possible at Station JBR3 where a hard bottom prevailed. Comparable to the site stations, Stage I was the only successional stage observed at stations with a high sand fraction (JBR5, JBR7, and JBR8). These results at the reference areas, together with the observation of numerous burrow openings in images, suggest that the benthic community around Site 69A was relatively advanced and diverse, comprised of a mixture of small, surface-dwelling opportunists and deeper-dwelling deposit-feeders. In general, the sandier stations were dominated by Stage I only, while the stations with a higher apparent silt-clay content supported both Stage I and Stage III taxa.

Mean OSI values for the stations in Site 69A ranged from +3 at Station JB5 to +8.0 at Stations JB1 and JB3 (Table 4, Figure 11). The overall value of +6.2 is indicative of undisturbed or non-degraded benthic habitat conditions. Of the six stations, three stations (JB1, JB3, and JB6) displayed mean OSI values > +6 (highly colonized or undisturbed). These relatively high values mainly reflect the relatively well-developed RPD depths at these stations combined with the presence of an apparent diverse benthic community consisting of more advanced successional stages. OSI values for the reference area stations were also variable, ranging from +4.0 at Stations JBR5, JBR7, and JBR8 to +9.0 at Station JBR6 Replicate C (Table 5, Figure 11). The composite mean OSI value of +6.4 was comparable to that observed over the site stations and likewise indicative of undisturbed or non-degraded benthic habitat quality. OSI values ≤ +6, indicative of moderately degraded benthic habitat quality, occurred in 3 of the 10 stations (33%)

located primarily in the south/southwestern corner of the survey grid. These values (+4) reflected the presence of only Stage I taxa at these reference area stations. An unmeasurable RPD depth and indeterminate successional status precluded the OSI calculation at Reference Station JBR3.

3.2 Comparison of the 2001 REMOTS® Site 69A Results to the 1997 and 1999 Surveys

Rhode Island Sound Site 69A has been periodically surveyed over the last four years, with previous surveys conducted in June 1997 and November 1999, enabling comparison to the 2001 survey data. This comparison is limited by the uneven number and distribution of stations in each survey. The six September 2001 REMOTS® sampling stations were chosen to represent the two major sediment types previously identified at this location (fine sand/silt/clay and fine sand) within the site boundary. Although the 2001 survey did not consist of the same number of stations and occupy the same stations visited in 1997 and 1999, some stations were positioned in close proximity to these previous stations. A comparison of the REMOTS® results for the three time periods is presented in Table 7 and Figures 13 through 18.

At Site 69A a grain size major mode of 4 to 3 phi, reflecting fine-grained sediment (fine sand and silt), has remained relatively unchanged over the past surveys (Table 7, Figure 13).

Table 7. Comparison of 1997, 1999, and 2001 REMOTS® Results for All Stations at Sites 69A (Jamestown Bridge Reef) and 69B (Separation Zone).

Rhode Island Sound Site	Grain Size Major Mode -phi (Number of Replicates)			Camera Penetration Mean (cm)			Benthic Habitat Type (Number of Stations)			Successional Stages Present (Number of Stations)			RPD Mean (cm)			OSI Mean		
	1997	1999	2001	1997	1999	2001	1997	1999	2001	1997	1999	2001	1997	1999	2001	1997	1999	2001
SITE 69A	4 to 3 (14), 3 to 2 (4)	4 to 3 (15)	4 to 3 (6)	5.67	4.57	7.15	SA.F(4), UN.SS(14)	SA.F(4), UN.SS(11)	SA.F (3), UN.SS (2), UN.SI (1)	ST I (9), ST I TO II (1), ST II (7), ST III (1)	ST I (8), ST I TO II (3), ST I ON III (4)	ST I (1), ST II (2), ST I TO II (1), ST I ON III (1), ST II ON III (1)	4.53	2.92	1.90	7.8	6.7	6.2
SITE 69B	4 to 3 (11), 3 to 2 (7), <-1 (l)	> 4 (1), 4 to 3 (25), <-1 (1)	> 4 (2), 4 to 3 (5), 3 to 2 (1), <-1 (1)	5.20	6.31	6.65	HR (2), SA.F (6), UN.SS (11)	HR (1), SA.F (4), UN.SS (22)	HR (2), SA.F (2), UN.SS (1), UN.SI (4)	ST I (10), ST I TO II (1), ST II (5), ST II ON III (1)	ST I (13), ST I TO II (7), ST I ON III (6)	ST I (3), ST II (1), ST I ON III (2), ST II ON III (1)	4.10	2.49	2.08	7.2	6.0	6.3

The primary habitat designation of UN.SS had characterized the benthic habitat in the 1997 and 1999 surveys; however, there was more variability in 2001, with habitat types of SA.F, UN.SS, and UN.SI present (Table 7, Figures 14 and 15). In general, apart from this slight deviation in habitat types in 2001, there was no significant changes in habitat type or grain size at the stations sampled over the years within Site 69A. Such results are not unexpected for a near-shore coastal environment that is relatively far removed from localized, land-based sources of pollutants and organic matter and in water that is sufficiently deep to prevent frequent physical disturbance of near-surface sediments.

The overall mean RPD depth at Site 69A sampling stations was shallower in September 2001 than in the previous surveys. There is an apparent trend of declining (shallowing) RPD values at this site, from 4.5 cm in 1997 to 2.9 cm in 1999, and to 1.9 cm in 2001 (Table 7, Figure 16). Although the RPD depths were shallower in September 2001, they are still indicative of moderately well oxygenated surface sediments.

Stage II was found at the majority of Site 69A stations in June 1997, while Stage I and Stage I on III were the predominant successional stages in November 1999 (Table 7, Figure 17). Successional status was more variable in September 2001, as multiple combinations of Stage I, II, and III organisms were observed. From 1997 to 2001, there has been an increase in the occurrence of Stage III activity, from 6% of the stations in 1997, to 27% of the stations in 1999, and to 33% of the stations in 2001. Most noticeably, there has been a reduction in the frequency of stations displaying only Stage I taxa over the three surveys. However, it must be noted that this apparent temporal trend might be an artifact associated with the unequal number of stations used in the three surveys.

Overall, there has been a trend of declining OSI values at Site 69A. The overall mean OSI value decreased from +7.8 in 1997 to +6.7 in 1999, and to +6.2 in 2001 (Table 7, Figure 18). These changes in average OSI values primarily reflect the shallower RPD depths observed during the September 2001 survey (1.9 cm). However, given that the maximum potential range of OSI values is from –10 to +11, the observed year-to-year decreases are considered relatively small and inconsequential. The average value for each of the three surveys was greater than +6, which is considered indicative of non-degraded or relatively undisturbed benthic habitat quality.

3.3 Site 69B (Separation Zone)

3.3.1 Physical Sediment Characteristics

The surface sediments comprising Site 69B were characterized primarily as fine-grained (tan over gray fine sand and silt). Grain size varied from < -1 to >4 phi, suggesting some variability in sediment grain size within Site 69B. However, the majority of the stations (56%) exhibited a major modal grain size of 4 to 3 phi (Table 8, Figures 19 and 20). Station SZ4 had a major modal grain size of <-1 phi and was characterized by large pebbles over sand. Most of the Site 69B reference stations (six of the nine stations or 67%) exhibited surface sediments having a

Table 8. Summary of the September 2001 REMOTS® Sediment-profile Imaging Results for Site 69B (Separation Zone).

Station	Grain Size Major Mode (phi)	Camera Penetration Mean (cm)	Dredged Material Thickness Mean (cm)	Boundary Roughness Mean (cm)	Benthic Habitat	Successional Stages Present	RPD Mean (cm)	Methane Present	OSI Mean
SZ1	4-3 phi	3.28	0.0	1.47	HR	ST I	2.58	NO	5.0
SZ2	4-3 phi	8.29	0.0	0.82	UN.SI	ST I on III	2.40	NO	9.0
SZ3	4-3 phi	4.80	0.0	1.32	UN.SS	INDET	2.44	NO	INDET
SZ4	< -1 phi	1.35	0.0	0.02	HR	INDET	INDET	NO	INDET
SZ5	4-3 phi	3.76	0.0	1.24	SA.F	ST I	1.70	NO	4.0
SZ6	4-3 phi	9.12	0.0	1.33	UN.SI	ST I on III	1.74	NO	8.0
SZ7	>4phi	12.62	0.0	0.89	UN.SI	ST II to III	0.89	NO	6.0
SZ8	3-2 phi	2.42	0.0	3.24	SA.F	ST I	>2.41	NO	5.0
SZ9	> 4 phi	14.25	0.0	0.78	UN.SI	ST II	2.49	NO	7.0
AVG		6.65	0.0	1.23			2.08		6.29
MAX		14.25	0.0	3.24			2.58		9.0
MIN		1.35	0.0	0.02			0.89		4.0

grain size major mode of 4 to 3 phi, while the sediments at the remainder of the stations had grain size major modes ranging from 3 to 2 phi to <-1 phi (Table 9, Figure 19). These results for stations both within and surrounding Site 69B indicate station variability in sediment grain size.

The primary benthic habitat classification within Site 69B was silty (habitat type UN.SI), occurring in four of the nine stations (44%) (Tables 6 and 8, Figures 20 and 21). Various stations, located primarily at the outer edge of the site boundary, showed variability and exhibited either unconsolidated soft sediment, which appeared to have a significant fine sand component (habitat type UN.SS); hard sand bottom comprised of uniform fine sand sediments (habitat type SA.F); or hard rock/gravel bottom (habitat type HR). Similarly, a number of benthic habitat types were observed within the reference stations for Site 69B.

A combination of habitat types UN.SS (three stations), SA.F (three stations), HR (two stations), and SA.G (medium sand and gravel, one station) were detected within reference stations (Figure 22). In general, stations characterized by sand and hard bottom were concentrated within the northern and eastern portions of the survey area.

Mean camera prism penetration measurements for stations within Site 69B ranged from 1.4 cm at Station SZ4 to 14.3 cm at Station SZ9, with an overall average of 6.7 cm indicating a relatively high proportion of sand present within the sediment that tended to resist deep penetration by the sediment-profile camera (Table 8, Figure 19). Lower camera prism penetration measurements corresponded primarily to benthic habitat types SA.F and HR. Mean camera prism penetration measurements were lower at Site 69B reference stations, with values ranging from 1.1 cm to 9.9 cm (overall average of 4.6 cm) (Table 9, Figure 19). The mean value of 4.6 cm reflects the significant amount of coarser-grained sediment at many of the reference stations.

Boundary roughness values at Site 69B ranged from 0.0 cm to 3.2 cm, with an overall average of 1.2 cm, suggesting only minor small-scale surface relief (Table 8). This value was comparable to the reference area average of 1.2 cm (Table 9). Surface roughness was attributed to both physical processes and biogenic activity at the sediment-water interface for stations both within and surrounding Site 69B. Shells and shell fragments were observed at the sediment-water interface at most stations, while rocks and pebbles were present at many reference stations. Biogenic surface roughness within Site 69B was a result of dense polychaetes and/or amphipod tubes, fecal mounds, and biological surface reworking by burrowing infauna at the sediment-water interface (Figure 20). In addition, a dense aggregation of sand dollars (*Echinarachnius parma*) was present at the sediment-water interface at Station SZ8 within Site 69B (Figure 23).

3.3.2 Biological Conditions

Apparent RPD measurements ranged from 0.9 cm at Station SZ7 to 2.6 cm at Station SZ1 within the sediment of Site 69B (Table 8, Figure 24). The overall average of 2.1 cm, indicative of moderately well-aerated surface sediments, was slightly lower than the value observed at the reference stations (2.4 cm, Table 9). The RPD depth was unmeasurable in one site station and

Table 9. Summary of the September 2001 REMOTS® Sediment-profile Imaging Results for Site 69B Reference (Separation Zone) Reference Stations.

Station	Grain Size Major Mode (phi)	Camera Penetration Mean (cm)	Dredged Material Thickness Mean (cm)	Boundary Roughness Mean (cm)	Benthic Habitat	Successional Stages Present	RPD Mean (cm)	Methane Present	OSI Mean
SZR1	4-3 phi	1.42	0.0	2.26	HR	INDET	INDET	NO	INDET
SZR2	4-3 phi	7.39	0.0	0.71	UN.SS	ST I to II	3.07	NO	7.0
SZR3	3-2 phi	1.77	0.0	1.18	SA.F	ST I	>1.21	NO	3.0
SZR4	4-3 phi	9.93	0.0	1.77	UN.SS	ST I on III	3.29	NO	10.0
SZR5	1-0 phi	4.34	0.0	1.60	SA.G	ST I	2.26	NO	5.0
SZR6	4-3 phi	4.16	0.0	1.40	SA.F	ST I	1.50	NO	4.0
SZR7	< -1 phi	1.08	0.0	0.07	HR	INDET	INDET	NO	INDET
SZR8	4-3 phi	6.57	0.0	0.55	UN.SS	ST I on III	2.10	NO	6.0
SZR9	4-3 phi	4.43	0.0	1.23	SA.F	ST I	3.25	NO	4.0
AVG		4.57	0.0	1.20			2.38		5.57
MAX		9.93	0.0	2.26			3.29		10.0
MIN		1.08	0.0	0.07			1.50		3.0

two reference stations due to underpenetration of the sediment-profile camera in a hard bottom. Furthermore, the RPD depth exceeded the camera prism penetration depth at Stations SZ8 and SZR3 (i.e., RPD > pen). None of the stations occupied over the site and surrounding reference stations showed any evidence of low sediment dissolved oxygen conditions, visible redox rebounds, or methane gas bubbles.

The successional stage recolonization status for stations within Site 69B included Stage I opportunistic polychaetes, Stage II infaunal amphipods, and Stage III head-down, deposit-feeding infauna (Table 8, Figure 25). When present, Stage III activity was marked by active feeding voids in the subsurface sediments, and was consistently accompanied by either Stage I or Stage II taxa at the sediment-water interface (i.e., Stage I on III or Stage II on III successional status, Figure 20). Evidence of Stage III activity occurred in three of the nine stations within Site 69B (33%), compared to two of the nine reference stations (22%) (Table 9, Figure 25). Stage I organisms were the only benthic infauna observed at three of the nine site stations (SZ1, SZ5, and SZ8) and four of the nine reference stations (SZR3, SZR5, SZR6, and SZR9), primarily where hard sandy bottom conditions existed. Stations characterized by softer, unconsolidated sediment (habitat types UN.SS or UN.SI) tended to display a higher frequency of Stage III taxa; this soft environment is more capable of supporting the burrowing and feeding activity of these deeper-dwelling organisms.

Mean OSI values for Site 69B stations ranged from +4.0 at Station SZ5 to +9.0 at Station SZ2 (Table 8, Figure 24). The overall mean OSI value of +6.3 is indicative of undisturbed or non-degraded benthic habitat quality (OSI values > +6) and was higher than the observed value of +5.6 at the reference stations. A higher occurrence of only Stage I organisms served to diminish the mean OSI values to reflect moderately degraded or disturbed benthic habitat quality at the reference stations (OSI values between +3 and +6). The majority of the site and reference stations had OSI values ≤ +6 (44% and 55%, respectively). This suggests there was some variability in OSI values both within and surrounding Site 69B, mainly attributed to patchiness in successional status. Reference Station SZR4 displayed superior benthic habitat quality (OSI +10) with a well-developed RPD and advanced successional status. OSI determination was not possible at two site stations and two reference stations due to unmeasurable RPD depths and indeterminate successional status in hard bottom conditions.

3.4 Comparison of the 2001 REMOTS® Site 69B Results to the 1997 and 1999 Surveys

Previous surveys at Rhode Island Sound Site 69B were conducted using REMOTS® in June 1997 and November 1999. In this earlier survey work, the putative site boundary was roughly diamond-shaped and centered slightly to the west of the current square, putative site boundary. The nine September 2001 REMOTS® sampling stations were selected to represent the three major sediment types previously identified at this location (fine sand/silt/clay, mixed fine sand, and hard bottom) within the current square, putative site boundary. A comparison of the REMOTS® results for the past and present surveys is presented in Table 7 and in Figures 26 through 31.

Sediment grain size has typically been fine grained at Site 69B, with a predominant grain size major mode of 4 to 3 phi observed in the 1997, 1999, and 2001 surveys. However, one station in each of the three surveys displayed a very coarse grain size major mode of <-1 phi (pebbles); these stations were located primarily in the northern region of the former and current site boundaries (Figure 26). The southern boundary and southeast corner of this site (as presently configured) consists of fine sand (3 to 2 phi).

At Site 69B, the primary habitat designation of UN.SS, present in 11 of the 19 stations in 1997 and in 22 of the 27 stations in 1999 (other stations displayed habitat types HR and SA.F), remained unchanged from 1997 to 1999. However, in September 2001, the primary habitat classification was UN.SI (silty) occurring in four of the nine stations sampled (Table 7, Figures 27 and 28). This is considered a minor difference since there is much similarity between the UN.SS and UN.SI habitat types (Figure 9). This difference is also due to the different locations of stations in the three surveys, as the 1997 and 2001 stations occurred largely to the east of the 1999 stations.

The overall average apparent RPD depth calculated for the site has been decreasing over the years, from 4.1 cm in 1997, to 2.5 cm in 1999, and to 2.1 cm in 2001 (Table 7, Figure 29). This may be either a real temporal trend reflecting increased organic loading to the sediment or decreased biogenic sediment mixing, or else it is simply a consequence of the different station locations in the three surveys. Although the overall average values have declined, they are still considered indicative of well-oxygenated surface sediments. There was an apparent temporal increase in the frequency of Stage III activity between the 1997, 1999, and 2001 surveys, from 6% of stations in 1997 to 23% in 1999, and to 43% in 2001 (Table 7). However, all three surveys reflected a diverse mixture of Stage I pioneering polychaetes, State II infaunal tubicolous amphipods, and Stage III head-down, deposit feeding organisms (Figure 30). Despite the higher relative frequency of Stage III in the more recent surveys, generally shallower RPD depths have resulted in lower overall mean OSI values at Site 69B stations. Overall, OSI values decreased from +7.2 in 1997 to +6.0 in 1999, while slightly increasing to +6.3 in 2001 (Table 7). However, these changes are considered to be within the year-to-year "noise", as they are largely inconsequential compared to the maximum potential range of OSI values (-10 to +11). Spatial variability in benthic habitat quality has been detected throughout the three survey time periods (Figure 31). With the exception of the 1999 overall OSI value, the values from the 1997 and 2001 surveys are indicative of non-degraded or undisturbed benthic habitat quality (OSI values >+6).

3.5 Site 18 (Brenton-A)

3.5.1 Physical Sediment Characteristics

Site 18 consisted mostly of fine-grained sediments (tan over gray silt), mainly exhibiting major modal grain sizes of 4 to 3 phi and > 4 phi (Table 10, Figures 32 and 33). Although the majority of stations had soft, unconsolidated sediment, the presence of sand produced a major modal grain size of 2 to 1 phi at Station BA1 (Table 10). Brown sand, as well as tan over gray sandy silt

(major modal grain sizes of 4 to 3 phi and 3 to 2 phi), characterized most sediment within the Brenton-A reference stations (Table 11).

The benthic habitat within Site 18 was primarily classified as very soft mud (benthic habitat type UN.SF), present at four of the nine stations (44%, Tables 6 and 10, Figures 33 and 34). The remainder of the stations exhibited a variety of benthic habitat types including UN.SS, SA.F, and UN.SI. The northwest and southeast corners of this site were characterized by compact, fine sand sediments (habitat type SA.F).

Table 10. Summary of the September 2001 REMOTS® Sediment-profile Imaging Results for Site 18 (Brenton-A).

Station	Grain Size Major Mode (phi)	Camera Penetration Mean (cm)	Dredged Material Thickness Mean (cm)	Boundary Roughness Mean (cm)	Benthic Habitat	Successional Stages Present	RPD Mean (cm)	Methane Present	OSI Mean
BA1	2-1 phi	2.70	0.0	2.49	SA.F	ST I	>2.24	NO	4.0
BA2	> 4 phi	14.35	0.0	0.70	UN.SF	ST I on III	2.34	NO	9.0
BA3	> 4 phi	17.25	0.0	1.14	UN.SF	ST I on III	3.33	NO	10.0
BA4	> 4 phi	13.07	0.0	0.63	UN.SF	ST I on III	3.37	NO	10.0
BA5	4-3 phi	7.93	0.0	0.82	UN.SI	ST I	1.77	NO	4.0
BA6	4-3 phi	3.37	0.0	0.91	SA.F	ST I	>2.16	NO	4.0
BA7	> 4 phi	12.38	0.0	0.83	UN.SF	ST I on III	1.99	NO	8.0
BA8	4-3 phi	8.23	0.0	1.09	UN.SS	ST I on III	1.66	NO	8.0
BA9	4-3 phi	10.31	0.0	0.97	UN.SS	ST II	2.64	NO	7.0
AVG		9.95	0.0	1.06			2.44		7.1
MAX		17.25	0.0	2.49			3.37		10.0
MIN		2.70	0.0	0.63			1.66		4.0

Table 11. Summary of the September 2001 REMOTS® Sediment-profile Imaging Results for Site 18 (Brenton-A) Reference Stations.

Station	Grain Size Major Mode (phi)	Camera Penetration Mean (cm)	Dredged Material Thickness Mean (cm)	Boundary Roughness Mean (cm)	Benthic Habitat	Successional Stages Present	RPD Mean (cm)	Methane Present	OSI Mean
BAR1	2-1 phi	5.22	0.0	2.85	SA.M	ST I	>3.97	NO	7.0
BAR2	4-3 phi	7.55	0.0	1.91	UN.SS	ST I to II	2.30	NO	6.0
BAR3	> 4 phi	9.65	0.0	2.20	UN.SI	ST I on III	2.26	NO	9.0
BAR4	3-2 phi	3.55	0.0	1.13	SA.F	ST I	INDET	NO	INDET
BAR5	3-2 phi	2.87	0.0	0.63	SA.F	ST I	1.85	NO	4.0
BAR6	> 4 phi	9.58	0.0	1.61	UN.SI	ST I to II	1.34	NO	4.0
BAR7	3-2 phi	3.90	0.0	1.44	SA.F	ST II	1.55	NO	6.0
BAR8	4-3 phi	10.46	0.0	1.68	UN.SI	ST I to II	1.65	NO	5.0
BAR9	4-3 phi	2.83	0.0	2.94	UN.SS	ST II to III	2.19	NO	7.0
AVG		6.18	0.0	1.82			2.14		6.0
MAX		10.46	0.0	2.94			2.30		9.0
MIN		2.83	0.0	0.63			1.34		4.0

A combination of habitat types UN.SS (two stations), SA.F (three stations), UN.SI (two stations), and SA.M (one station) were detected at the reference stations (Table 11, Figures 34 and 35). There was no obvious spatial pattern to the observed benthic habitat types both within and surrounding the Site 18 boundary.

Mean camera prism penetration measurements ranged from 2.7 cm at Station BA1 to 17.3 cm at Station BA3, with an overall average of 10.0 cm indicating moderately high proportions of fine sand mixed with softer, fine-grained sediment (Table 10, Figure 32). Deeper camera prism penetration measurements corresponded to stations displaying major modal grain sizes of >4 phi, located primarily in the northeastern portion of the site. The overall camera penetration value observed at the Site 18 reference stations was considerably lower (6.2 cm), reflecting the dominance of sand outside the site boundary (Table 11, Figure 32).

Small-scale boundary roughness values for stations within Site 18 were relatively low, ranging from 0.6 cm at Station BA4 to 2.5 cm at Station BA1, with an overall average of 1.1 cm reflecting only a small amount of surface relief (Table 10). Boundary roughness values were higher at the reference stations, with an overall average of 1.8 cm (Table 11). Surface roughness was attributed primarily to physical processes at the site stations (78%) and biological activity at the reference stations (56%). Bedforms (sand ripples) were observed at two stations (BA1 and BA6) within the site boundary, possibly reflecting a shallower, higher-energy seafloor environment in the northwest and southeast corners of the site. Survey results from the Site 18 reference stations suggested a biologically active environment in the area surrounding the site boundary. Biogenic surface roughness at the reference stations were the result of numerous biological features including dense aggregations of sand dollars, dense polychaete and amphipod tubes, and/or biological surface reworking by burrowing infauna (burrow openings) at the sediment-water interface (Figure 36).

3.5.2 Biological Conditions

Apparent RPD depth measurements for Site 18 ranged from 1.7 cm at Station BA8 to 3.4 cm at Station BA4 (Table 10, Figure 37). The overall RPD average of 2.4 cm indicates moderately well-oxygenated surface sediments over the site. The RPD depths at the Site 18 were comparable to those at the reference stations, which ranged from 1.3 cm to >4.0 cm (average of 2.1 cm; Table 11, Figure 37). A select number of stations (BA1, BA6, and BAR1) had RPD depths that exceeded the camera prism penetration depth. Although patches of reduced sediment were observed in the subsurface sediment of various reference stations, none of the stations occupied within and surrounding Site 18 showed any evidence of low sediment dissolved oxygen conditions, visible redox rebounds, or methane gas bubbles in the sediment-profile images.

The successional status was relatively advanced, with Stage I, Stage II, or Stage I on III communities inhabiting the sediment within the site (Table 10, Figure 38). Evidence of Stage III activity (active feeding voids) was detected in five of the nine stations (56%), and when present, Stage III taxa were consistently accompanied by Stage I individuals (Figure 33). A dense mat of amphipod tubes, representative of Stage II successional status, was visible at the sediment-water interface of Station BA9 (Figure 39). The rippled sand stations in the northwest and southeast

corners of the site were dominated by surface-dwelling Stage I taxa only. These organisms are adapted to the frequent physical disturbance associated with rippled sand bottoms.

Successional status within the Site 18 reference stations appeared to be less advanced than stations within the site boundary. Although the reference areas also exhibited a combination of successional stages, advanced Stage III activity was present in only two of the nine stations (22%) (Table 11). Furthermore, 33% of the stations displayed a Stage I to II successional status, due to the combined presence of small, opportunistic polychaete tubes (Stage I) and amphipod tubes (Stage II) at the sediment surface (Figure 39). Overall, there was a diverse mixture of successional stages at stations both within and surrounding Site 18.

Mean OSI values for Site 18 stations ranged from +4 at Stations BA1, BA5, and BA6 to +10 at Stations BA3 and BA4, with an overall site average of +7.1 (Table 10, Figures 33 and 37). Well-developed RPD depths (overall 2.4 cm) coupled with a relatively advanced successional status resulted in OSI values indicative of undisturbed or non-degraded benthic habitat quality for stations within the site boundary. Site 18 mean OSI values were slightly greater than the values observed at the reference stations, which varied between +4.0 to +9.0 (overall average of +6.0) (Table 11, Figure 37). The composite mean OSI value for the reference stations (+6.0) is indicative of moderately degraded or physically disturbed benthic habitat quality (OSI values ≤ +6) and reflects a decreased presence of advanced Stage III taxa. In general, stations exhibiting elevated OSI values (+9.0 and +10) were located in the muddier northeastern region of the survey area, while the majority of low OSI values (+4) occurred at stations in the northwestern and southeastern portions of the Site 18 survey area, reflecting the dominance of Stage I taxa (and relative absence of more advanced stages) at these sandier locations.

3.6 Comparison of the 2001 REMOTS® Site 18 Results to the 1996 Survey

Prior to the 2001 REMOTS® survey, Site 18 was last surveyed in November 1996. The nine September 2001 REMOTS® sampling stations were selected to represent the three major sediment types previously identified at this location (filt, fine sand/silt/clay, and fine sand) within the site boundary. A comparison of the REMOTS® results for the 1996 and 2001 surveys is presented in Table 12 and in Figures 40 through 45).

The majority of the stations within this site were characterized as muddy, very fine sand that had a major modal grain size of 4 to 3 phi for both the 1996 and 2001 surveys (Table 12). In the northwest and southeast corners of this site, rippled sand was detected in REMOTS® images from both the 1996 and 2001 surveys, suggesting a higher-energy seafloor environment in these locations. Consistent with previous results, a coarser grain size of 2 to 1 phi was observed at 2001 Station BA; this station corresponded to a 1996 northwest corner station that also displayed a major modal grain size of 2 to 1 phi (Figure 40). Most of the stations from both the 1996 and 2001 surveys had unconsolidated soft bottom (habitat types UN.SI and UN.SS) or rippled fine sand (habitat type SA.F). When positioned in close proximity to each other, the 1996 and 2001 stations showed relatively good agreement in both habitat types and camera penetration depths (Table 12, Figures 41 and 42).

Table 12. Comparison of 1987, 1996, and 2001 REMOTS® Results for Stations at Sites 18 and 16.

Rhode Island Sound Site	Grain Size Major Mode -phi (Number of Replicates)			Camera Penetration Mean (cm)			Benthic Habitat Type (Number of Stations)			Successional Stages Present (Number of Stations)			RPD Mean (cm)			OSI Mean		
	1987	1996	2001	1987	1996	2001	1987	1996	2001	1987	1996	2001	1987	1996	2001	1987	1996	2001
SITE 18		> 4 (2), 4 to 3 (20), 3 to 2 (13), 2 to 1 (1)	> 4 (4), 4 to 3 (4), 2 to 1 (1)		10.62	9.95		SA.F (11), SA.M (1), UN.SS (6), UN.SI (18)	SA.F (2), UN.SS (2), UN.SI (1), UN.SF (4)		ST I (13), ST II (8), ST I ON III (12), ST II ON III (1)	ST I (3), ST II (1), ST I ON III (5)		3.37	2.39		6.9	7.1
SITE 16	>4 (8), 4 to 3 (21), 3 to 2 (2), 2 to 1 (5), 0 to -1 (1), < -1 (6)		> 4 (3), 2 to 1 (1), <-1 (1)			12.65			HR (1), SA.M (1), UN.SS (1), UN.SS (2)	ST I (1), ST III (5), ST I ON III (1), ST II ON III (19)		ST I (1), ST II ON III (3)	4.62		3.88	10.7		9.3

Apparent RPD depths were well-developed at Site 18 in 1996 (3.4 cm). RPD depths were shallower during the September 2001 survey, with an overall mean of 2.4 cm (Table 12, Figure 43). A mixture of Stage I, II, and III successional stages were observed in both surveys (Figure 44). Stage III taxa appeared slightly more frequently in September 2001 (56%) than in November 1996 (41%) (Figure 44). Furthermore, Stage II infaunal amphipods were more prevalent in 1996, occurring in 10 of the 34 sampling stations in 1996 (29%) and in 1 of the 9 stations in 2001 (11%). Overall OSI values were comparable between the two surveys, with values of +6.9 and +7.1 calculated for the 1996 and 2001 sampling stations, respectively (Table 12, Figure 45). Well-developed RPD depths and relatively advanced successional status in both surveys resulted in the majority of OSI values indicating undisturbed or non-degraded benthic habitat quality.

3.7 Site 16 (Brenton Reef)

3.7.1 Physical Sediment Characteristics

Apparent historic or "relic" dredged material from past disposal (1971) was observed at all of the stations located inside the boundary of Site 16 (Brenton Reef) (Table 13). The thickness of the historic dredged material layer exceeded the penetration depth of the REMOTS® camera at all five stations (indicated with a "greater than" sign in Table 13). The historic dredged material comprising the surface sediments within Site 16 were mostly fine-grained, composed primarily of tan over gray sandy silt (Figure 46). A major modal grain size of >4 phi was observed at three stations, while the remaining two stations exhibited coarser grained sediment consisting of medium/coarse sand and pebbles (grain size major modes of 2 to 1 phi and < -1 phi (Table 13, Figure 47). Sediments within the reference area stations were also characterized as fine-grained (tan over gray silt), with a major modal grain size of > 4 phi present in two of the three stations (Table 14, Figure 47). The reference stations most likely were characterized by natural Rhode Island Sound sediments (i.e., ambient sediments) as opposed to the historic or relic dredged material observed at the stations within the site boundary (Tables 13 and 14).

A variety of benthic habitat types (UN.SI, UN.SS, SA.M, and HR) were detected within Site 16; however, the most common benthic habitat classification was silty (habitat type UN.SI) occurring in two of the five sampling stations (Table 13, Figures 46 and 48). Stations BR1A, BR1B, and BR1C, located in the northern region of the site boundary, all exhibited unconsolidated soft sediment (habitat types UN.SI or UN.SS), while the remaining stations revealed hard sand bottom comprised of medium sand (habitat type SA.M), and Hard Rock/Gravel Bottom (habitat type HR) that represented a lag deposit resulting from the past dredged material disposal activity. Contrary to the disposal site stations, the primary benthic habitat classification at the Site 16 reference stations was *Ampelisca* Mat (habitat type AM), present in two of the three stations; well-formed amphipod tube mats were observed within the fine-grained sediment at the sediment-water interface (Table 14, Figures 48 and 49).

Mean camera prism penetration measurements ranged from 7.5 cm at Station BR3 to 16.0 cm at Station BR1B, with an overall average of 12.7 cm, indicating relatively soft sediments with a fine sand component (Table 13, Figure 47). As expected, the deepest camera penetration measurements occurred in the northern stations that displayed grain sizes of > 4 phi. Mean

Table 13. Summary of the September 2001 REMOTS® Sediment-profile Imaging Results for Site 16 (Brenton Reef).

Station	Grain Size Major Mode (phi)	Camera Penetration Mean (cm)	Dredged Material Thickness Mean (cm)	Boundary Roughness Mean (cm)	Benthic Habitat	Successional Stages Present	RPD Mean (cm)	Methane Present	OSI Mean
BR1A	> 4 phi	14.70	>14.7	0.95	UN.SS	ST II on III	3.44	NO	10.0
BR1B	> 4 phi	15.95	>15.95	2.73	UN.SI	ST II on III	3.76	NO	11.0
BR1C	> 4 phi	14.94	>14.94	0.34	UN.SI	ST II on III	3.81	NO	9.0
BR2	2-1 phi	10.16	>10.16	1.54	SA.M	ST I	4.50	NO	7.0
BR3	< -1 phi	7.51	>7.51	5.98	HR	INDET	INDET	NO	INDET
AVG		12.65	>12.65	2.31			3.88		9.25
MAX		15.95	>15.95	5.98			4.50		11.0
MIN		7.51	>7.51	0.34			3.44		7.0

Table 14. Summary of the September 2001 REMOTS® Sediment-profile Imaging Results for Site 16 (Brenton Reef) Reference Stations.

Station	Grain Size Major Mode (phi)	Camera Penetration Mean (cm)	Dredged Material Thickness Mean (cm)	Boundary Roughness Mean (cm)	Benthic Habitat	Successional Stages Present	RPD Mean (cm)	Methane Present	OSI Mean
BRR1	> 4 phi	17.32	0.0	1.36	UN.SF	ST II on III	2.24	NO	8.0
BRR2	>4 phi	12.86	0.0	0.91	AM	ST II on III	2.13	NO	8.0
BRR3	4-3 phi	5.32	0.0	0.91	AM	ST II	2.00	NO	6.0
AVG		11.83	0.0	1.06			2.12		7.3
MAX		17.32	0.0	1.36			2.24		8.0
MIN		5.32	0.0	0.91			2.0		6.0

camera prism penetration measurements were comparable, but slightly lower at the reference stations, with an overall average of 11.8 cm (Table 14, Figure 47).

The mean boundary roughness values for Site 16 stations ranged from 0.3 cm to 6.0 cm (overall average of 2.3 cm) (Table 13). This value was significantly higher than the reference station average of 1.1 cm and suggests a moderate amount of surface relief (Table 14). Surface roughness was attributed to biogenic activity in the majority of both site and reference stations as a result of dense amphipod tubes and biological surface reworking (burrow openings) by burrowing infauna at the sediment-water interface (Figure 49). However, two stations within the historic disposal site boundary (characterized by a hard sand bottom) exhibited physical surface roughness.

3.7.2 Biological Conditions

The mean RPD depth measurements for stations within the Site 16 boundary were fairly deep, ranging from 3.4 cm at Station BR1A to 4.5 cm at Station BR2 (Table 13, Figure 50). The overall RPD average of 3.9 cm indicates well-oxygenated surface sediments. The RPD depths at the reference stations were also well developed; however, they were slightly shallower with a composite average of 2.1 cm (Table 14, Figure 50). The RPD depth was unmeasurable in one site station due to underpenetration of the sediment-profile camera in a hard, rocky bottom. This hard bottom is a lag deposit of coarser-grained sediment occurring near the apex of the former disposal mound. At the apex, the currents are stronger and have winnowed away the finer-grained sediment, leaving a "lag" deposit consisting of harder bottom. None of the stations occupied within and surrounding the site boundary showed any evidence of low sediment dissolved oxygen conditions, visible redox rebounds, or methane gas bubbles.

The benthic community within Site 16 was in an advanced stage of recolonization with predominately Stage II infaunal amphipods, and Stage III head-down, deposit-feeding infauna (Table 13, Figure 51). Stage III activity was present in three of the four analyzable stations (75%), and was consistently accompanied by Stage II taxa at the sediment-water interface (i.e., Stage II on III successional status) (Figures 46 and 49). As expected, Stage I organisms were the only benthic infauna observed in the sandy sediments at Station BR2; larger grained sediments serve as a barrier, restricting the lateral and downward movement of adult Stage III individuals. Low numbers of Stage III organisms are expected in these sandy areas due to the limitations on burrowing and reduced organic matter content within the sediment. Successional status determination was not possible at one station characterized by hard bottom conditions. Site 16 reference stations also exhibited relatively advanced successional status, with both Stage II and Stage III taxa present (Table 14, Figure 51). Similar to the historic disposal site stations, Stage III was present in 67% of the stations and always associated with Stage II individuals.

Mean OSI values at the Site 16 stations were high, ranging from +7.0 at Station BR2 to +11 at Station BR1B (Table 13, Figure 50). The overall average of +9.3 was considerably higher than the observed value at the reference stations (+7.3). Nonetheless, these values both indicate that undisturbed or non-degraded benthic habitat quality characterizes this historic disposal site and its surrounding area (Table 14). Because of an unmeasurable RPD and indeterminate successional status, an OSI calculation at Station BR3 was not possible. Deep RPD depths and a

dominance of advanced Stage II and Stage III communities served to elevate the OSI values at the historic disposal site (Figure 46). Conversely, the lower mean OSI values at the reference stations reflected shallower RPD depths. Overall, the benthic habitat quality throughout Site 16 and surrounding reference stations was non-degraded and appeared to be supporting a mature and stable infaunal population.

3.8 Comparison of Site 16 2001 REMOTS® Results to the 1987 Survey

Prior to the 2001 REMOTS® survey, Site 16 was last surveyed in October 1987 to gather information for a feasibility assessment of offshore dredged material disposal sites. The five September 2001 REMOTS® sampling stations were selected to represent the three major sediment types previously identified at this location (mud, sand/mud, cobble/sand) within the historic site boundary. A comparison of the REMOTS® results for the 1987 and 2001 surveys is presented in Table 12.

Consistent with results from the 1987 survey, historically-deposited dredged material was detected within the Site 16 stations in 2001. In 1987, a wide-range of sediment grain sizes was observed (> 4 phi to < -1 phi) (Table 12). Although the historic dredged material was comprised of fine-grained sandy silt (grain sizes of > 4 or 4 to 3 phi) at most stations (60% in 2001 and 67% in 1987), the sediment of the remaining stations consisted of medium/coarse sand and pebbles.

The RPD depths remained relatively deep during the September 2001 survey, with depths decreasing from 4.6 cm in 1987 to 3.9 cm in 2001 (Table 12). These values suggest that the apparent depth of oxygen penetration into the surface sediments within the historic disposal site has remained high over the years and is still indicative of well-aerated surface sediment. Evidence of Stage II infaunal amphipods and Stage III deeper-dwelling infauna was widespread during the October 1987 survey; most stations had a Stage II on III successional status designation (73%). Results of the October 1987 REMOTS® survey revealed a high density and diversity of infaunal organisms within the historic disposal site. Likewise, REMOTS® images from the September 2001 survey displayed advanced successional status, with 75% of the stations characterized by Stage II on III. While still considered high, OSI values have decreased slightly from the 1987 survey, from +10.7 to + 9.3 in 2001 (Table 12). This reduction in OSI values mainly reflects a slight decrease in RPD depths over the site. Consistent OSI values of this magnitude suggest that benthic habitat quality has remained undisturbed or non-degraded and that the benthic environment is supporting a mature and stable infaunal assemblage.

4. DISCUSSION

4.1 Site 69A (Jamestown Bridge Reef)

4.1.1 Physical Sediment Characteristics

The REMOTS® images collected in 2001 indicated that surface sediments in and around Site 69A were predominantly fine and very fine sands, containing varying proportions of finer-

grained sediment fractions (i.e., silts and clays). Subtle differences in sediment texture resulted in assignment of three different, but closely related, benthic habitat types (SA.F, UN.SS, and UN.SI) (Figure 9). The grain size analyses performed on separate box core/grab samples (Battelle, 2002a) indicated high total sand content at most stations, generally confirming the REMOTS® interpretation.

At three stations (JB3, JB6, and JBR2), the grain size analysis indicated a higher percentage of fines (>22%) than found at the other Site 69A stations. However, there was no comparable, consistent evidence of increased fines in the REMOTS® images at these stations, as all three were assigned a grain size major mode of 4-3 phi (very fine sand). The habitat classification of UN.SI suggests a slightly higher proportion of fines visible in the images at Station JBR2, but the benthic habitat classifications of SA.F and UN.SS at stations JB3 and JB6 both reflect higher apparent proportions of very fine sand. These apparent small differences between the grain size analyses and REMOTS® interpretation are attributed to small-scale spatial variability in the relative proportion of fines existing at the site, as well as the inability to distinguish minor differences in grain size composition based solely on sediment texture in the images.

There was good agreement between the September 2001 REMOTS® results and those from past years. All surveys have consistently shown silty, fine and very fine sand (grain size major modes of 4 to 3 and 3 to 2 phi) to be the dominant sediment types within and around the site, with corresponding SA.F and UN.SS habitat types observed at the majority of stations (Figures 13 and 14). There appears to be a weak association between sediment grain size/habitat type and bottom topography at this site (Figure 52). At stations located at depths <120 ft (or 37 m) in the southwest and northeast corners of the site, there was a higher frequency of habitat type SA.F compared to stations in slightly deeper water (>37 m) in the center and southeast corner of the site, where habitat types UN.SS and UN.SI predominated (Figure 52). Station JBR3, located outside the northeast corner of the site at a depth of 36.2 m, was characterized by hard rock bottom.

Overall, the REMOTS® results suggest that the central area of Site 69A, below a depth of 37 m, appears to favor the long-term accumulation of fines (silts and clays) compared to surrounding, slightly shallower areas. Because the majority of stations in the shallower water outside the site boundary appear consistently to have a lower proportion of fines than those inside the boundary (i.e., higher frequency of habitat type SA.F versus UN.SS), the appropriateness of using these stations as reference stations for any long-term site monitoring should be re-visited. The appropriateness of these stations as reference locations is in part dependent on the physical characteristics of dredged material that might be placed at this site.

4.1.2 Sediment Biological Conditions

The REMOTS® images indicated that the sediments within and around Site 69A were relatively well-aerated and inhabited by a diverse infaunal community consisting of both small, surface-dwelling opportunists (Stage I and, to some extent, Stage II) and larger-bodied, deeper-dwelling taxa (Stage III). Surface tubes constructed by amphipods (*Ampelisca* sp., considered a Stage II organism) were clearly visible in many images at stations both within and surrounding the site (Figure 10). These distinct tubes were seen either by themselves or together with thinner tubes

created by surface-dwelling, Stage I polychaetes. The consistent presence of a surface-dwelling community resulted in almost all of the sediment-profile images at Site 69A (except for those at the hard bottom station JBR3) being assigned either a Stage I or II successional designation. In addition to the Stage I polychaete tubes and/or Stage II amphipod tubes visible at the sediment surface, a few stations distributed throughout the site also showed evidence of Stage III feeding voids or burrows at depth, resulting in a Stage I on III or Stage II on III designation.

The REMOTS® results agreed well with the benthic community results (Battelle, 2002b), which showed that the site was dominated numerically by the surface-dwelling, Stage II tubicolous amphipod *Ampelisca agassizi*. Also among the numerical dominants were the near-surface-dwelling, late Stage II/early Stage III bivalve *Nucula annulata* and the Stage I polychaetes *Exogone hebes* and *Tharyx acutus*. Although numerically abundant in the grab samples, individual *Nucula* were rarely visible in the REMOTS® images, due to the inability to discern these small bivalves within the sediment matrix, just below the sediment-water interface. A smaller number of images showed occasional evidence of Stage III (in the form of a single feeding void or burrow at depth). The taxonomic data likewise showed that at least two, deeper dwelling, Stage III polychaetes (the lumbrinerids *Scoletoma hebes* and *Ninoe nigripes*) were among the numerical dominants at the site.

The overall picture that emerges from the taxonomic data is of a benthic community dominated by small, surface- and near-surface-dwellers (particularly the amphipod *Ampelisca agassizi*). These results are accurately reflected in the frequent observation of amphipod and polychaete tubes at the sediment surface, and the resultant assignment of Stages I or II to almost all the sediment-profile images. The taxonomic data showed significantly fewer numbers of larger-bodied, deeper-dwelling, Stage III taxa present across the site. This is reflected in only the occasional feeding void or burrow observed at depth in the sediment-profile images. These results largely reflect the sandy nature of the surface sediments, both at Site 69A and throughout Rhode Island Sound. Benthic communities dominated by larger-bodied, deposit-feeding, Stage III taxa are more readily found in strongly depositional, organic-rich, soft mud environments.

4.2 Site 69B (Separation Zone)

4.2.1 Physical Sediment Characteristics

Similar to Site 69A, the REMOTS® images indicated that surface sediments in and around Site 69B were predominantly fine and very fine sands, containing varying proportions of finer-grained sediment fractions (i.e., silts and clays). The grain size analyses performed on separate box core/grab samples (Battelle, 2002a) indicated that stations in and near the northeast corner of the site had relatively high gravel content; the sediment-profile images confirmed that this area is dominated by sands and hard gravel bottom (habitat types SA.F and HR). The REMOTS® images also indicated fine to medium sands and gravel near the southeast corner of the site (habitat types SA.F and SA.G at stations SZ8, SZR3, and SZR5).

There was good consistency between the September 2001 REMOTS® results and those from previous surveys with respect to bottom types within and outside the site (Figure 53). Similar to Site 69A, the distribution of sediment types at Site 69B observed in the present and past surveys

appears to be related to bottom topography (Figure 53). Mixtures of coarser sediments (i.e., fine to medium sands, gravel, and pebbles) have been observed consistently at depths shallower than about 37 m near and outside both the northeast and southeast corners of the site; while very fine sand mixed with a significant proportion of silts and/or clay occurred in the deeper water (>37 m) comprising the majority of the site (Figure 53). Habitat types UN.SI and UN.SS, indicative of very fine sand containing varying proportions of fines, dominate the stations in the deeper center of the site and to the west of the site (Figure 53). The presence of a significant proportion of silt at several of these stations (habitat type UN.SI) again suggests that the seafloor depression or trough over which Site 69B is centered appears to favor long-term accumulation of fines compared to the coarser-grained, shallower areas immediately to the northeast and southeast.

4.2.2 Biological Conditions

Similar to Site 69A, the REMOTS® images indicated that the sediments within and around Site 69B were relatively well-aerated and inhabited by an infaunal community consisting predominantly of small, surface-dwelling opportunists (Stages I and II). Amphipod and/or polychaete tubes were visible at the sediment surface in most of the images, resulting in a Stage I or II successional designation at the majority of stations. Evidence of Stage III accompanying Stages I or II was relatively rare; a limited number of subsurface feeding voids or burrows were observed mainly at stations having a significant proportion of fines (i.e., habitat type UN.SI and, to a lesser extent, UN.SS) (Figure 20). The infaunal successional stage could not be determined at several of the hard bottom stations to the northeast of the site.

The relative scarcity of larger-bodied, Stage III deposit-feeders suggested by the REMOTS® interpretation is echoed in the taxonomic results (Battelle, 2002b). These results confirm that Site 69B was dominated by Stage I and II surface-dwellers, including *Ampelisca agassizi* and *Nucula annulata* among the top ten numerical dominants. Also among the dominants were other surface-dwelling, tubicolous forms, including Oligochaetes and the Stage I polychaetes *Tharyx acutus*, *Exogone hebes* and *Spiophanes bombyx*. Unlike Site 69A, there were no Stage III polychaetes among the top ten numerical dominants at Site 69B. This relative scarcity of deeper-dwelling, subsurface-deposit-feeding organisms is reflected in the REMOTS® results showing Stage III present at only 5 of the 18 Site 69B stations (28%).

Overall, the surface sediments at Site 69B, comprised mainly of silty, very fine sand or clean, fine sand, are inhabited by a surface-dwelling benthic community dominated by tubicolous amphipods and small polychaetes. Where higher proportions of silt and clay exist, mainly in the deeper portion of the depression over which the site is centered, there is some evidence that the sediments are able to support limited numbers of deeper-dwelling, Stage III taxa.

4.3 Site 18 (Brenton A)

4.3.1 Physical Sediment Characteristics

In contrast to Sites 69A and 69B, sediments within Site 18 were characterized by REMOTS® as more consistently fine-grained, ranging from either silt-clay (grain size major mode of >4 phi) or very fine sand with a significant silt-clay component (grain size major mode of 4 to 3 phi). Softer, more fine-grained sediments (>4 phi; habitat type UN.SF) were observed most

consistently at a group of stations in the northeast corner of the site (Stations BA2, BA3, BA4 and BAR3), as well as at Station BA7 in deeper water southwest of the site center (Figure 54).

There was overall agreement between the REMOTS® grain size/habitat type classifications and the actual grain size analysis data from the co-located grab samples (Battelle, 2002a). Stations identified by the grab samples as having moderate to high fines (BA2, BA3, BA4, BA7, BA9, BAR3 and BAR6) were classified predominantly as having the unconsolidated, soft mud (UN.SF) or soft silty (UN.SI) REMOTS® habitat types. Sediments identified as having either high medium sand or high total sand content were predominantly classified by REMOTS® as having either the SA.M (medium sand), SA.F (fine sand) or UN.SS (fine sand mixed with silt) habitat types.

The general association between grain size/habitat type and bottom topography observed at Sites 69A and 69B likewise is applicable to Site 18. The results of both the September 2001 REMOTS® survey and the previous 1996 survey indicate that sediments in the deeper, central portion of the site (between 37 m and 40 m) are consistently finer-grained (i.e., soft mud and silty fine sand) than the fine to medium sands occurring in the shallower areas (depths <37 m) surrounding the site (Figure 54). The occurrence of very soft mud at station BA7 near the site center and at several stations in the northeast corner suggest that the bathymetric depression comprising Site 18 is more strongly depositional than the depressions associated with Sites 69A and 69B.

4.3.2 Biological Conditions

The REMOTS® analysis indicated that the finer-grained sediments comprising the deeper central portion of Site 18 were inhabited by an abundant and diverse benthic community comprised of Stage I, II and III taxa. Evidence of sub-surface deposit-feeding, Stage III infauna was observed at the majority (56%) of stations having fine-grained sediment within the site boundary, compared with only 22% of the stations in the shallower, sandier areas to the southeast, south and northwest. Where present, Stage III was consistently accompanied by Stage I present at the sediment surface, resulting in a Stage I on III successional designation (Figure 33). Dense Stage II amphipod tubes (*Ampelisca* sp.) were observed at Station BA9.

The benthic taxonomic analysis (Battelle, 2002b) generally supports the REMOTS® interpretation, in showing that surface- or near-surface-dwelling, Stage I and II taxa (i.e., *Ampelisca agassizi*, *Nucula* sp., *Byblis serrata*, and *Tharyx acutus*) were ubiquitous and numerically dominant across the site. However, the list of the top ten numerical dominants for Site 18 stations also includes the Stage III polychaetes *Levinsenia gracilis* and *Ninoe nigripes*. There were also additional Stage III polychaetes found in significant numbers at the Site 18 stations having moderate to high silt-clay content. Given the dominance of softer mud within the depression comprising Site 18, this site appears to be supporting a benthic community having significant numbers of larger-bodied, deeper-dwelling, deposit-feeding taxa. Surface-dwelling, Stage I and II taxa and a lower apparent density of Stage III organisms characterize the benthic community at the sandier stations surrounding the site.

4.4 Site 16 (Brenton Reef)

4.4.1 Physical Sediment Characteristics

At Site 16, the 2001 REMOTS® images showed relic or historic dredged material to be present at the three stations (BR1, BR2 and BR3) located within the historic site boundary. There was good agreement among the three closely-spaced BR1 stations in terms of both grain size major mode (>4 phi) and habitat type (UN.SS or UN.SI, which are closely related). All of the images at stations BR1A, B and C, located on the flanks or apron region of the historic mound, were consistent in showing fine-grained, historic dredged material (Figure 46). The other two stations located within the site boundary displayed relic dredged material consisting of either medium sand (Station BR2 located on the northern flank of the historic mound) or hard-bottom comprised of pebbles (Station BR3 located near the historic mound apex).

The results suggest a gradient in sediment coarseness moving from the mound apex (coarsest sediment [habitat type HR] at station BR3) to the outer mound apron regions (progressively finer sediment [habitat types SA.M and UN.SI] at stations BR2 and BR1, respectively) (Figure 55). This apparent pattern is consistent with that observed in a past monitoring survey (USACE, 1989) and attributed to more intensive winnowing of sediment fines near the mound apex; resultant armoring of the mound by a coarse lag deposit; and, re-distribution of the winnowed, finer-grained sediment fractions to areas of ambient depths surrounding the mound.

The stations outside the site boundary had fine-grained sediments (i.e., silt-clay or very fine sand) that were presumed to be naturally occurring as opposed to relic dredged material. Dense amphipod tubes occurred at two of these stations (BRR2 and BRR3), resulting in a habitat designation of AM rather than UN.SF that was assigned to the third station (BRR1). There was agreement between the REMOTS® results and the sediment grain size analysis from the grab samples (Battelle, 2002a). The grain size analysis showed Stations BR2 and BR3 to be characterized by a mixture of sand and coarser sediment (i.e., gravel), while the triplicate BR1 stations and the three reference stations were characterized by relatively high proportions of fines, with the highest fines content at Stations BRR1 consistent with the REMOTS® habitat type designation of UN.SF.

4.4.2 Biological Conditions

The REMOTS® images indicated that the relic dredged material at the stations within the site boundary was well-aerated, with well-developed RPD depths suggesting a high level of bioturbation. The benthic community at the stations having fine-grained sediment, both within and outside the site boundary, appeared to be both diverse and abundant. This community was comprised of both Stage II, tubicolous amphipods (*Ampelisca* sp.), as well as subsurface-deposit-feeding Stage III infauna, resulting in numerous Stage II on III successional designations. The successional stage could not be determined at the hard bottom Station BR3 near the mound apex, while Stage I only was found within the medium sand at Station BR2 on the mound apron.

The benthic taxonomic data (Battelle, 2002b) confirmed that a diverse mixture of Stage I, II and III taxa were numerically abundant at the BR stations. Similar to candidate sites 69A, 69B and 18, the Stage II amphipod *Ampelisca agassizi* and the bivalve *Nucula annulata* were

overwhelmingly the top two numerical dominants. Other abundant taxa included *Oligochaeta* sp., *Tharyx acutus*, and *Mediomastus ambiseta* (Stage I), as well as the Stage III subsurface deposit feeders *Ninoe nigripes*, *Levinsenia gracilis*, and *Aricidea catherinae*. The REMOTS® results indicated Stage I only at Station BR2 and an indeterminate successional stage at BR3, compared to Stages II or II on III at the other BR stations, are generally consistent with the taxonomic results indicating a strong difference in community structure at BR2 and BR3 compared to the other stations.

Overall, the results of both the REMOTS® and benthic taxonomic evaluations indicate that the fine-grained sediments comprising the apron of Site 16, as well as nearby stations on ambient bottom, are presently inhabited by an abundant and diverse benthic community, indicating no long-term effect of past disposal.

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