Prepared in cooperation with the Bureau of Ocean Energy Management

2015 Seafloor Sediment Analysis and Mapping - Midcoast Maine

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For an overview of the Maine Coastal Mapping Initiative (MCMI) information products, including maps, data, imagery, and reports visit http://www.maine.gov/dacf/mcp/planning/mcmi/index.htm.

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ABSTRACT

The collection and analysis of geophysical and seafloor sediment data allow state and federal agencies to proactively identify the resources available to enhance resiliency, improve management of resources within their jurisdiction, and develop a more comprehensive understanding of potential resources. The purpose of this investigation was to describe and characterize marine sediment samples in the focus area to enable benthic habitat classification via the federally-approved Coastal and Marine Ecological Classification Standard (CMECS; FGDC, 2012), help characterize potential sediment resources for beach nourishment as outlined by BOEM, and investigate the relationship between sediment grain size and multibeam backscatter intensity to refine interpretations of seafloor sediment distribution across mapped areas. During the 2015 survey season the Maine Coastal Mapping Initiative mapped approximately 80 mi^2 (207 km^2) of seafloor and collected bottom samples in 61 locations, 43 in state water and 18 in federal waters, in the vicinity of the Kennebec River paleodelta. Grain-size analyses of sediment samples combined with interpretations of backscatter intensity and bathymetric data are consistent with general interpretations of seafloor sediment distribution and morphology in the region (e.g. Barnhardt et al., 1998 and Kelley, et al., 1997). Within the survey area, laterally extensive surficial deposits of predominantly sandy and/or gravelly material were restricted to depths less than 70 m and were most commonly associated with the Kennebec river paleodelta/nearshore ramp. Similarly, backscatter and grab sample data suggest these deposits were even more scarce within federal waters of the survey area.

In the coming months, MCMI plans to utilize final data products for high-resolution backscatter and bathymetry to refine existing seafloor sediment maps and determine the spatial extent of sand deposits within federal water. When combined with existing geophysical (e.g. seismic reflection profiles and side-scan sonar) data, these data may also be used to refine interpretations of coastal/nearshore geomorphology and three-dimensional assessments of potential sediment resources/valley fill in the region. In addition, these data are a critical component of benthic habitat classification and modeling performed by MCMI (see Ozmon, 2015). Overall, these data have a variety of applications and are an invaluable resource to public and private agencies who wish to more effectively manage and understand coastal and marine resources.

Introduction

Sustainable management and exploitation of Maine's coastal and marine resources are necessary to ensure effective coastal resiliency and conservation efforts. The collection and analysis of geophysical and seafloor sediment data allow state and federal agencies to proactively identify the resources available to enhance resiliency, improve management of resources within their jurisdiction, and develop a more comprehensive understanding of potential resources. A key component of coastal resiliency and conservation efforts is access to quality near-shore and off-shore sand and gravel resources. However, quantitative assessments for many of these resources have been conducted in mostly state waters (e.g. Kelley et al., 1997a, b; 2003). Recently, the Bureau of Ocean Energy Management (BOEM) has recognized the need to identify additional outer continental shelf (OCS) sand resources for beach nourishment and coastal restoration projects because sand resources in state waters are either diminishing or are of poor quality, or otherwise unavailable (U.S. Department of the Interior, 2014). The purpose of this investigation is to describe and characterize marine sediment samples in the coverage area to enable benthic habitat classification via the federally-approved Coastal and Marine Ecological Classification Standard (CMECS; FGDC, 2012), help characterize potential sediment resources for beach nourishment as outlined by BOEM, and investigate the relationship between sediment grain size and multibeam backscatter intensity to refine interpretations of seafloor sediment distribution across mapped areas.

Objectives

- Identify and map seafloor sand resources in the North Atlantic OCS focus areas established in MCP's cooperative agreement with BOEM
- Map bathymetry to identify the potential geographic extent of sand deposits
- Investigate the relationship between sediment grain size and multibeam backscatter intensity to map seafloor sediment types
- Ground truth multibeam backscatter intensity with sediment grab sampling and underwater video data
- Characterize sediment grain size distributions and sorting to support benthic habitat classification

Focus Area

The 2015/2016 focus area coincides with the Kennebec River paleodelta, and was selected for this study due to the high probability of being able to identify sand resources at this location (Figure 1; Barnhardt et al., 1997; 1998). This area extends from the southern tip of Southport Island for approximately 11 nautical miles, and to the west along the coast to Orr's Island in Harpswell.

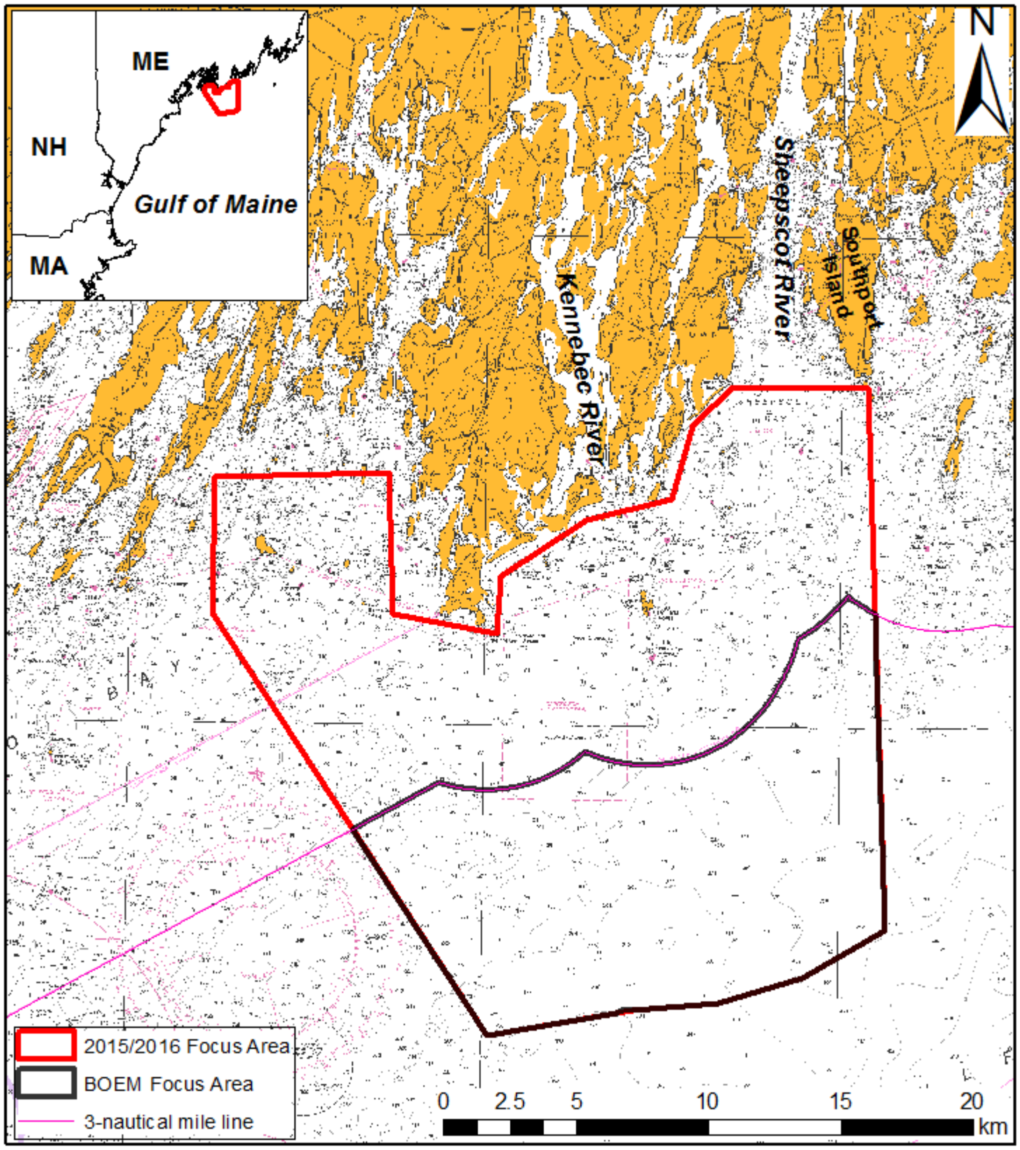

Figure 1. MCMI 2015/2016 focus area (red outline) and BOEM focus area (black outline) in Maine's midcoast region and 3-nautical mile (state-federal water jurisdiction) boundary (magenta line).

Methods

Differences in federal and state sampling objectives resulted in separate sampling plans for their respective jurisdictional waters (e.g. waters seaward of the 3-nautical mile line are federal). In the BOEM focus area, grab sample locations were selected in areas where preliminary analyses of multibeam backscatter intensity data suggested the presence of a predominantly sandy and/or gravelly seafloor. In state waters, a preliminary review of multibeam echosounder (MBES) depth soundings and backscatter intensity was also performed, and sampling locations were distributed in an attempt to obtain comparable sample sizes across a broad range of benthic habitat types (e.g. variety of substrates, depths, morphologies, etc.). Although a variety of environmental, geometric, and other external factors must be considered when interpreting backscatter data, the signal has been shown to directly relate to unconsolidated sediment grain size and seafloor roughness (Lurton and Lamarche, 2015), which makes this technique desirable for the purposes of this investigation. In addition to interpretations of MBES backscatter and depth data, the decision to sample in certain areas was also influenced by a review of existing literature that pertained to the seafloor geology (e.g. Barnhardt et al., 1997; 1998; and Kelley et al., 1997; 1998) of the focus area.

The bottom sampler used was a single platform rig outfitted with a clamshell style Ponar grab sampler, GoPro Hero 3+ digital video camera, Keldan underwater dive light, dive lasers spaced at 11cm for scale, and a Teledyne Odom Hydrographic Digibar S or YSI Exo 1 to collect water column data (salinity, temperature, and pH) (Figure 2). The Digibar S directly measured temperature (±0.2°C) and sound speed (±0.2 m/sec) through the water column for samples M0001 - M0030. Thus, pH was not determined when using this instrument and bottom salinity was predicted using a standard equation that uses physical variables of pressure, temperature, and sound speed (Dakin, 1999). The YSI Exo 1 was used to determine salinity (unitless practical salinity scale), temperature (±0.001°C), and pH (±0.2) for samples M0031 – M0061. With this instrument salinity is determined automatically from the sonde conductivity (±0.001mS/cm) and temperature readings according to algorithms found in Standard Methods for the Examination of Water and Wastewater (ed. 1989). Values of salinity are in reference to the unitless practical salinity scale since the measurements are carried out in reference to the conductivity of standard seawater at 15°C. The 23 x 23 cm Ponar grab was capable of collecting a maximum volume of 8.2 liters of unconsolidated sediment per sampling attempt. Immediately upon retrieval, the sediment surface was photographed and partitioned into two subsamples; a minimum of 1000 cm^3 was set aside for grain-size analysis and the remainder was used for infaunal analysis. Sediment subsamples were then bagged, labeled, and stored in coolers before and during transport to the sedimentology laboratory at the University of Maine (UMaine).

At each location where the sampler returned empty after three attempts a hard substrate (e.g. bedrock, boulders, etc.) was inferred. Sampler-mounted video footage captured during each sampling attempt was used to confirm or deny the presence of rocky substrates in these locations. The x and y coordinates (WGS84, UTM Zone 19N meters; GPS horizontal accuracy at surface ±3 m) of each attempt were logged to account for vessel drift in between sampling attempts. Coordinates were not recorded until the sampler reached bottom and when the wench tether was visually confirmed to have a vertical/near-vertical orientation relative to a flat sea surface. The depth for each location was determined in real time using a hull-mounted single-beam fathometer and was not referenced to a specific vertical datum (e.g. MLLW). Thus, the vertical uncertainty associated with depths recorded for each site may be as much as the typical tidal range in the focus area (approximately 3 m).

See the MCMI Benthic Habitat Classification Report by Ozmon (in progress) for details pertaining to the methods and results of the infaunal classifications, which are not discussed in this report. Also, due to a staffing lapse at the UMaine sediment laboratory, sediment samples M0047 through M0061 were processed at the Maine Department of Transportation sediment laboratory in Bangor, Maine.

Sediment samples were analyzed using standard laboratory techniques for the textural analyses. Sieve methods were used to determine the proportion of gravel-, sand-, and mud-sized particles to classify the overall sample using Folk classification scheme (Folk 1954; Figure 3 and Table 1). Samples (M0001-M0046) analyzed at UMaine used the grain-size scale used by American geologists (Dutro et al., 1989) for major textural splits, whereas samples (M0047-M0061) analyzed at MDOT used the grain-size scale used by engineers (A.S.T.M. D422). The major difference between these two scales, as it pertains to this investigation, lies in the distinction between sand- and mud-sized particles, which are split at 0.062 mm for geologists and 0.074 mm for engineers. The 0.012 mm difference between these scales is thought to have a negligible impact on results and statistical analyses within the scope of this investigation. Grain-size statistical parameters were calculated by graphical and moment methods for the sand-sized portion of samples that contained greater than 20% sand-sized particles. This process was automated for samples processed at the UMaine using a Rapid Sediment Analyzer settling tube. For samples processed at MDOT, statistics were calculated by entering sieve data in to the gran.stats routine of the rysgran package (Gilbert et al., 2014) in R statistics software version 3.2.2 (R Development Core Team, 2008). The remainder of each bulk sample was preserved for archiving at the MCP headquarters in Augusta, ME. For more specific details of the grain-size analysis procedure refer to the MCMI Sediment Analysis SOP 1.0 by Dobbs (2015). This procedure is a modified version of the procedure outlined and described by Poppe et al. (2005), which has been accepted as the standard for marine sediments to be included in the U.S. Geological Survey East-Coast Sediment Texture Database. The modifications of Poppe et al. (2005) for the purposes of this project were made to meet budget and logistic requirements of the Maine Coastal Mapping Initiative, while also striving to maintain the integrity of the data for future inclusion into existing databases.

Figure 2. MCMI grab sampling platform.

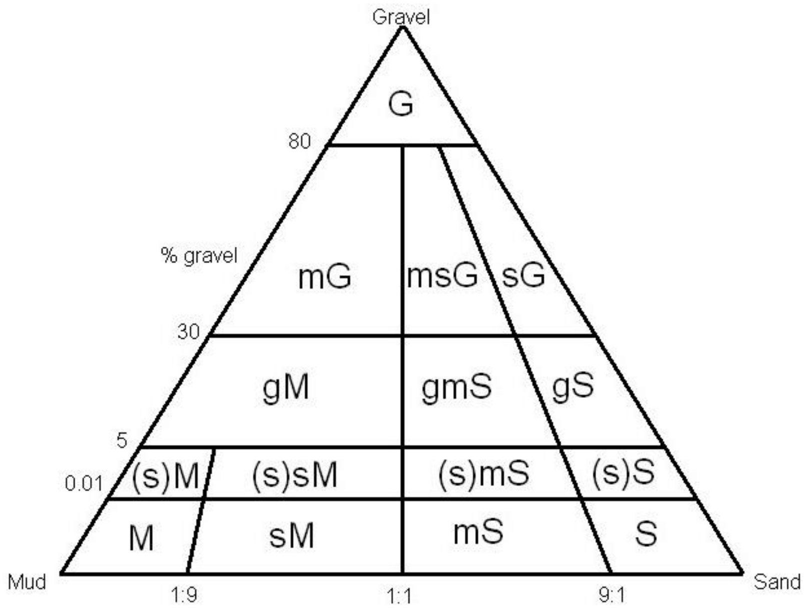

Figure 3. Sediment classification ternary diagram. Uppercase letters indicate predominant size component. (s) = slightly gravelly. (Folk, 1954)

Table 1. Ternary diagram from Figure 3 modified from Folk (1954) to include classification R (rock or boulders) in table format.

Folk Code	Description	% gravel	Sand:Mud
R	Rock or Boulders	-	-
G	Gravel	80-100	-
sG	Sandy gravel	30-80	> 9:1
msG	Muddy sandy gravel	30-80	1:1 – 9:1
mG	Muddy gravel	30-80	< 1:1
gS	Gravelly sand	5-30	> 9:1
gmS	Gravelly muddy sand	5-30	1:1 – 9:1
gM	Gravelly mud	5-30	< 1:1
(s)S	Slightly gravelly sand	0.01-5	> 9:1
(s)mS	Slightly gravelly muddy sand	0.01-5	1:1 – 9:1
(s)sM	Slightly gravelly sandy mud	0.01-5	1:9 – 1:1
(s)M	Slightly gravelly mud	0.01-5	< 1:9
S	Sand	0-0.01	> 9:1
mS	Muddy Sand	0-0.01	1:1 – 9:1
sM	Sandy Mud	0-0.01	1:9 – 1:1
M	Mud	0-0.01	< 1:9

Results

A total of 61 samples (Figures 4 and 5), 43 in state water and 18 in federal waters, were collected in the approximately 80 mi^2 (207 km^2) survey area on 11 separate occasions between May and November 2015. Table 2 contains a summary of sample depth, mean raw backscatter intensity, and grain size analyses.

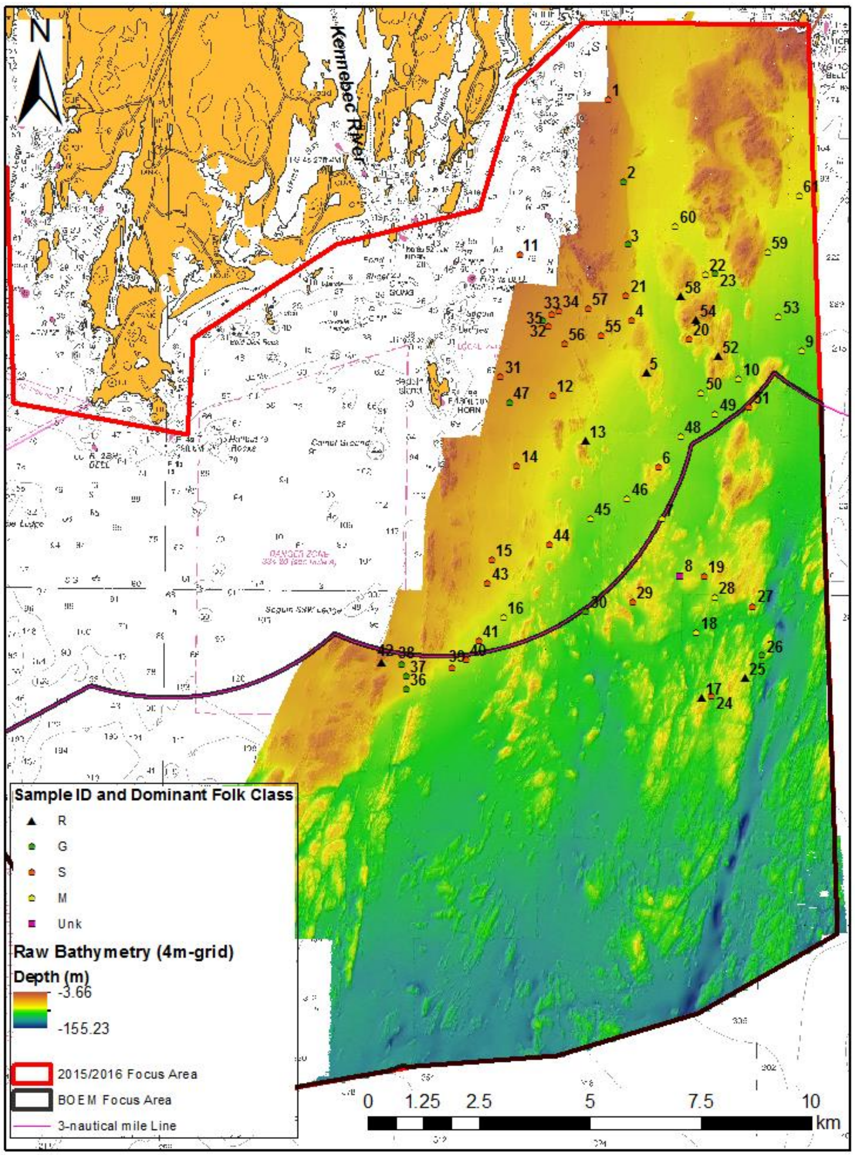

Figure 4. Sediment sample locations (ID#), dominant Folk (1954) classification, and survey area bathymetry (uncorrected 4 m grid with transparent bathymetry hillshade) relative to overall focus areas. See Table 2 for full Folk (1954) classification and corresponding depths for each sample.

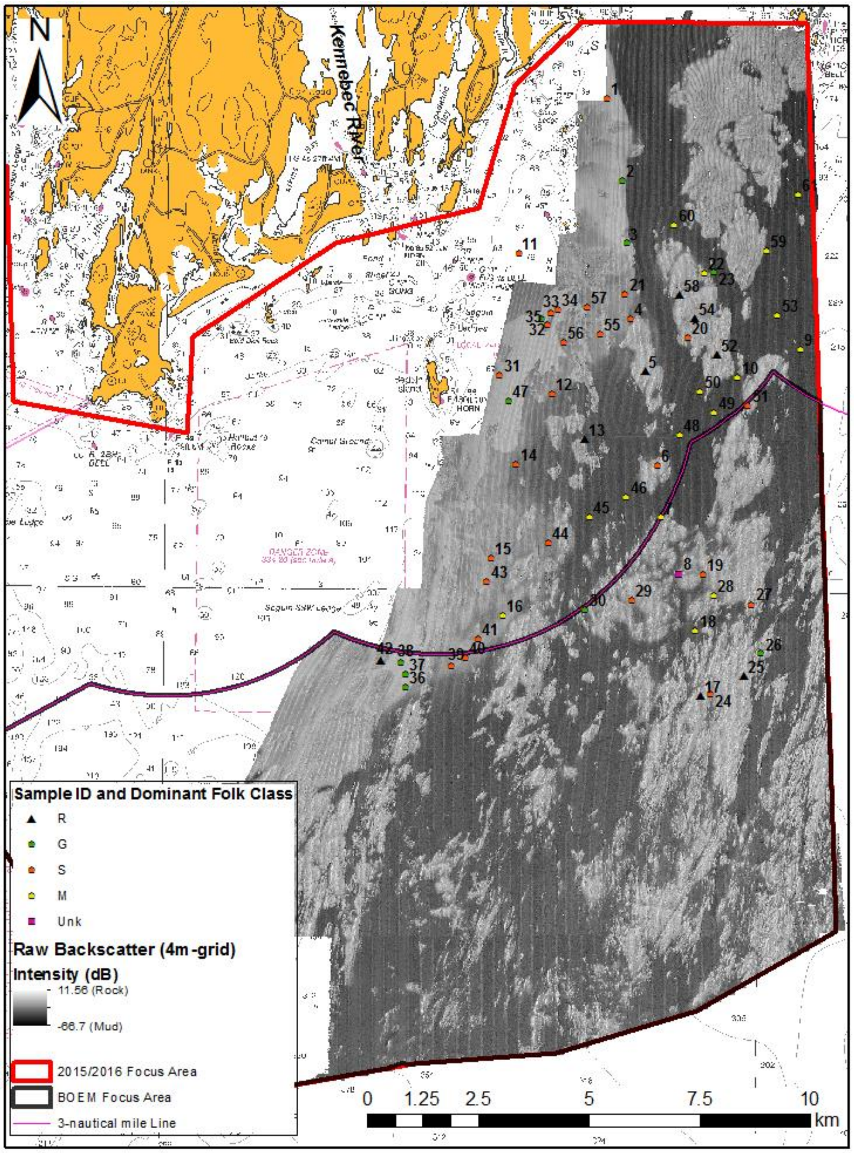

Figure 5. Sediment sample locations (ID#), dominant Folk (1954) classification, and survey area backscatter intensity (unfiltered 4 m grid with transparent bathymetry hillshade) relative to overall focus areas. See Table 2 for full Folk (1954) classification and mean backscatter intensity for each sample.

Table 2. Summary of sediment sample depth, backscatter intensity, and grain size analyses.

Sample ID	Depth[1] (m)	Gravel	Sand	Mud	S:M	Folk (1954)	Mean Raw Backscatter Intensity[2] (dB)	Sand-sized Fraction[3] Wentworth (1922)
M0001	27	10.15	88.35	1.50	58.8	gS	-14.87	coarse sand, well sorted
M0002	40	32.92	61.54	5.54	11.12	sG	-15.94	coarse sand, well sorted
M0003	38	71.29	25.42	3.29	7.72	msG	-11.3	med. sand, poorly sorted
M0004	53	6.63	63.84	29.53	2.16	gmS	-22.16	coarse sand, poorly sorted
M0005	51	-	-	-	-	R	-16.49	-
M0006	59	28.24	47.27	24.49	1.93	gmS	-15.74	coarse sand, well sorted
M0007	73	3.74	23.60	72.66	0.32	(s)sM	-21.67	med. sand, poorly sorted
M0008	70	-	-	-	-	Unknown	-22.51	-
M0009	78	0.00	2.88	97.12	0.03	M	-35.26	-
M0010	73	0.00	5.28	94.72	0.06	M	-33.56	-
M0011	25	0.00	91.71	8.29	11.06	S	not surveyed	med. sand, poorly sorted
M0012	48	6.62	66.11	27.26	2.43	gmS	-17.01	med. sand, poorly sorted
M0013	58	-	-	-	-	R	-15.18	-
M0014	52	0.00	68.45	31.55	2.17	mS	-25.59	fine sand, mod. well sorted
M0015	50	0.00	89.65	10.35	8.66	mS	-20.85	coarse sand, poorly sorted
M0016	64	4.13	45.34	50.54	0.90	(s)sM	-18.5	med. sand, poorly sorted
M0017	60	-	-	-	-	R	-14.39	-
M0018	80	0.00	3.81	96.19	0.04	M	-29.99	-
M0019	68	1.24	55.39	43.36	1.28	(s)mS	-19.18	fine sand, mod. sorted
M0020	58	3.17	57.03	39.80	1.43	(s)mS	-20.49	fine sand, mod. well sorted
M0021	45	4.47	93.95	1.58	59.28	gS	-21.69	coarse sand, poorly sorted
M0022	57	1.35	36.98	61.67	0.60	(s)sM	-17.84	med. sand, poorly sorted
M0023	44	30.96	51.63	17.41	2.97	msG	-34.1	med. sand, mod. well sorted
M0024	75	2.80	40.90	56.30	0.73	(s)mS	-18.48	fine sand, mod. well sorted
M0025	63	-	-	-	-	R	-14.23	-
M0026	75	67.06	8.91	24.04	0.37	mG	-15.19	-
M0027	70	5.59	55.82	38.60	1.45	gmS	-21.61	med. sand, mod. well sorted

M0028	72	1.49	44.73	53.79	0.83	(s)sM	-24.39	med. sand, poorly sorted
M0029	64	4.45	63.34	32.21	1.97	(s)mS	-11.82	med. sand, mod. sorted
M0030	66	44.54	17.38	38.08	0.46	mG	-16.19	-
M0031	34	14.61	84.22	1.17	71.91	gS	-15.49	coarse sand, v. well sorted
M0032	35	43.22	53.57	3.20	16.72	sG	-17.53	coarse sand, mod. well sorted
M0033	36	16.71	82.34	0.95	86.57	gS	-11.92	coarse sand, mod. well sorted
M0034	37	25.56	73.52	0.92	80.05	gS	-12.82	coarse sand, mod. well sorted
M0035	37	2.04	93.74	4.22	22.24	(s)S	-21.23	med. sand, poorly sorted
M0036	58	43.74	31.00	25.26	1.23	msG	-11.7	v. coarse sand, poorly sorted
M0037	51	41.08	41.39	17.53	2.36	msG	-12.14	coarse sand, v. well sorted
M0038	46.5	55.99	28.97	15.04	1.93	msG	-12.06	coarse sand, v. well sorted
M0039	62	3.98	54.33	41.69	1.30	(s)mS	-17.79	coarse sand, poorly sorted
M0040	64	4.75	61.63	33.62	1.83	(s)mS	-17.59	med. sand, mod. sorted
M0041	62	3.07	54.42	42.51	1.28	(s)mS	-15.69	coarse sand, mod. sorted
M0042	37	-	-	-	-	R	-14.37	-
M0043	53	1.87	81.47	16.66	4.89	(s)mS	-18.26	med. sand, mod. sorted
M0044	61	0.00	68.65	31.35	2.19	mS	-24.27	fine sand, mod. well sorted
M0045	72	0.00	7.69	92.31	0.08	M	-32.49	-
M0046	72	0.00	8.18	91.82	0.09	M	-31.13	-
M0047	38	49.10	49.90	1.00	49.90	sG	-15.51	v. coarse sand, mod. sorted
M0048	69	0.00	27.70	72.30	0.38	sM	-33.37	med. sand, poorly sorted
M0049	70	0.00	18.00	82.00	0.22	sM	.-31.86	-
M0050	69	0.00	26.80	73.20	0.37	sM	-32.02	-
M0051	61	16.90	65.80	17.30	3.80	gmS	-10.09	med. sand, poorly sorted
M0052	35	-	-	-	-	R	-19.88	-
M0053	69	0.00	27.10	72.90	0.37	sM	-35.64	med. sand, poorly sorted
M0054	41	-	-	-	-	R	-19.41	-
M0055	47	4.50	82.60	12.90	6.40	(s)mS	-20.26	fine sand, mod. sorted
M0056	42	2.50	90.80	6.70	13.55	(s)S	-22.6	fine sand, mod. sorted
M0057	41	8.30	85.40	6.30	13.56	gS	-21.38	fine sand, poorly sorted
M0058	53	-	-	-	-	R	-12.96	-
M0059	65	0.00	13.80	86.20	0.16	sM	-35.32	-
M0060	61	0.00	16.10	83.90	0.19	sM	-33.28	-
M0061	61	0.00	24.80	75.20	0.33	sM	-36.29	med. sand, poorly sorted

[1]Depth measurements were recorded in real time and may differ from multibeam bathymetry data by ± 3m (or the expected tidal range within the coverage area).

[2]Mean raw backscatter intensity values were derived from raster grid in ArcMap created from 4m grid cell xyz data exported from QINSy Process Manager.

[3]Wentworth (1922) classification performed on sand-sized fraction of samples containing ≥20% sand by weight.

Appendix A contains detailed metadata from sediment sampling, including date, time, coordinates, depth, recovered sediment thickness, water column data, and mean raw backscatter intensity (4-m grid resolution). Appendix B contains a summary of grain-size analyses, including respective percentages of major size fractions (gravel, sand, and mud), sand-to-mud ratio, Folk (1954) classification, Wentworth (1922) classification for qualifying samples (≥20% sand-sized particles), and wet and dry Munsell colors.

Table 3 illustrates the distribution of samples based on 10-m depth intervals. All samples were collected at depths ranging from 20 to 90 m but were mostly concentrated between 30 to 80 m. No samples were collected at depths less than 20 m or greater than 90 m, which generally reflects the lack of unconsolidated substrate at depths less than 20 m, the absence of depths greater than 70 m in state waters, and the scarcity of predominantly sandy material at depths greater than 70 m in federal waters within the survey area. Only two samples, M0026 and M0027, collected at ≥70 m depth were not predominantly (>50% by weight) mud. A total of 9 locations (4 federal, 5 state) resulted in no sample retrieval. Video logs at 8 of these 9 locations confirmed the presence of rocky substrates. The presence of rocky substrate could not be confirmed at the location of sample site M0008 because only one unsuccessful attempt was made due to rough seas and a review of video logs for this site did not contain enough evidence to confirm the presence of a rocky substrate.

Table 3. Summary of sample depth distribution.

Depth (m)	**Number of Samples**
0-19.99	0
20-29.99	2
30-39.99	9
40-49.99	9
50-59.99	12
60-69.99	18
70-79.99	10
80-89.99	1
> 90	0

Table 4 contains a summary of the distribution among samples based on grain-size analyses using the Folk (1954) classification system modified to include rocky/bouldery (R) substrates as well as unknown substrates. A substrate was classified as unknown in the event that a sample was not recovered and when the corresponding video log could not confirm the presence of a rocky substrate; only one location, M0008, was placed in this category. Figure 6 illustrates the general correlation between Folk (1954) class and backscatter intensity, where backscatter intensity decreases with decreasing proportions of gravel and decreasing sand-to-mud ratios. As shown in Table 4, there was considerable overlap between classes due to high standard deviation among individual classifications. However, the lowest standard deviations among the most clean samples (e.g. all samples in M class contained >90% mud) suggests that the overall positive relationship between increasing grain size and higher intensity backscatter may be used as a basis when using backscatter to infer gross scale sediment distribution.

Table 4. Summary of sample distribution based on modified Folk (1954) and mean unfiltered backscatter intensity values for samples within each class.

Folk Code ID	**Folk Class.**	**# of Samples**	**Mean Unfiltered Backscatter Intensity[1] (dB)**	**Std. Dev.**
1	R	8	-15.86	2.54
2	G	0	-	-
3	sG	3	-16.33	1.06
4	msG	5	-16.26	9.98
5	mG	2	-15.69	0.71
6	gS	6	-16.36	4.22
7	gmS	5	-17.32	4.92
8	gM	0	-	-
9	(s)S	2	-21.92	0.97
10	(s)mS	9	-17.73	2.65
11	(s)sM	4	-20.60	3.03
12	(s)M	0	-	-
13	S	1	-	-
14	mS	3	-23.57	2.45
15	sM	7	-34.32	1.67
16	M	5	-32.49	2.06
17	Unknown	1	-	-

[1]Mean raw backscatter intensity values were derived from raster grid in ArcMap created from 4m grid cell xyz data exported from QINSy Process Manager.

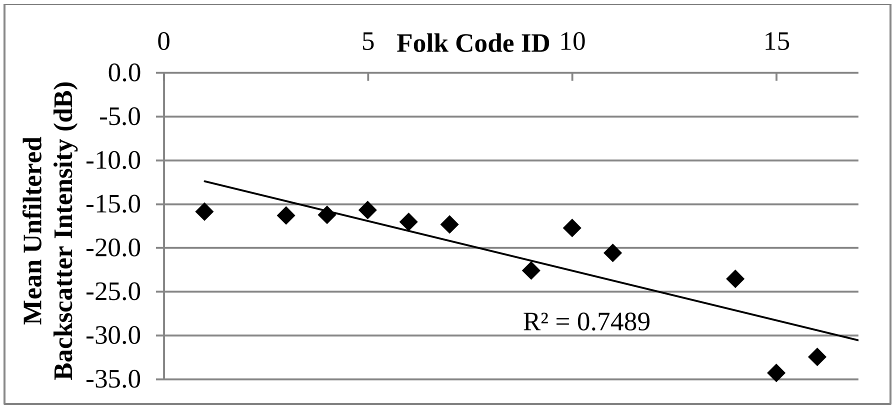

Figure 6. Folk (1954) classification (code ID) vs. mean unfiltered backscatter intensity for sediment samples showing general relationship between grain size and backscatter intensity.

Raw data and calculations of major size-fractions used for determining Folk (1954) classifications are located in Appendix C. A total of 46 samples contained greater than 20% sand-sized fraction by weight. As illustrated in Table 5, the sand-sized fraction of these samples were most frequently composed of coarse sand or medium sand (graphic mean) and were commonly moderately well or poorly sorted. All results of the analyses for these samples are presented in table format in Appendix D. Textural field descriptions typically classified the coarse fraction of samples as sub-angular to sub-rounded. Overall, 3 samples were predominantly (e.g. >50%) gravel, 27 were mostly sand, and 17 mostly mud. Field and laboratory pictures (wet and dry) of samples are provided in Appendix E. Appendix F contains screengrabs from videos that best illustrate the nature of the seafloor at each sample site.

Table 5. Summary of graphic mean and sorting for sand-sized portion of qualifying samples.

Graphic Mean Size	**# of Samples**
V. Coarse Sand	2
Coarse Sand	14
Med. Sand	20
Fine Sand	8
V. Fine Sand	2
Sorting (graphic std. dev.)	**# of Samples**
V. Well Sorted	4
Well Sorted	3
Mod. Well Sorted	14
Mod. Sorted	5
Poorly Sorted	20

Discussion

The distribution of sediment types was consistent with existing interpretations of seafloor morphology within and adjacent to the focus area (e.g. Barnhardt et al., 1997; 1998 and Kelley, et al., 1997a, b). The western portion of the survey area appeared to be a nearshore ramp/relict delta of the Kennebec River that formed about 10,000 to 12,000 years before present when sea level was approximately 60 m below the present stand. The nearshore ramp and south/southeastern extent of the paleodelta are evident in areas landward of the most prominent 60-m isobath, where there is a pronounced increase in the slope (Figure 7a) and coarsening sediment composition of the seafloor (Figure 7b). The northeastern most extent of the paleodelta is generally coincident with the location where the western bank of the submerged Sheepscot river valley meets the 60-m isobath in Figure 7. The current distribution of seafloor sediments reflects the redistribution of those deltaic sediments during subsequent marine transgression. The backscatter intensity map in Figure 7b illustrates the overall distribution of major sediment types, where the darkest shades of gray generally represent fine-grained, muddy sediments (e.g. mostly silt and clay), lighter shades represent progressively coarser material (e.g. sand and gravel), and the lightest shades (e.g. white) represent bare rock. Although these conventions are useful for gross interpretations of sediment composition/distribution, there are many variables that can affect the backscatter intensity for a given substrate (e.g. beam angle incidence, slope, roughness, water content, biota, variations within water column, etc.; Lurton and Lamarche, 2015). For example, the striped appearance of the raw backscatter intensity map in Figure 7b is a result of increased echo return strength at the nadir (0° angle incidence of sonar). High backscatter values at the at nadir decrease rapidly as incidence angle increases (Figure 8), resulting in 'stripes' that are coincident with the direction of survey lines in unfiltered data. Thus, it is recommended that refined interpretations be made using filtered data.

Laterally extensive surficial deposits of predominantly sandy and/or gravelly material within the survey area were restricted to the distal portions of the paleodelta and at depths less than 70 m. The relatively high resolution (4-m) of the map shown in Figure 9 reveals variation within the coarse sediments, indicating the presence of sand and gravel sheets, patches, ribbons, and large scale bedforms (e.g. large ripples/small dunes) at 30-50 m depth. Smaller scale bedforms were also present in videos of select sample sites (see Appendix F). Grain-size data (M0031-M0034, M0047) indicate that moderately sorted, coarse to very coarse sandy gravel and gravelly sand is concentrated at depths between 20-40 m along the southeastern, distal portion of the paleodelta. These data also suggest that the cleanest (e.g. lack of fine-grained/muddy sediment) sands and gravels within the survey area were present in this vicinity and in the area immediately to the north (see M0001-M0003) at similar depths. Along the southern-most portion of the delta relatively uniform backscatter values and grain size data (M0036-M0038) suggest that muddy, sand and gravel may be common at depths between 40-60 m. Samples in this vicinity but located slightly deeper depths (M0039-M0041; 60-70 m) indicate predominantly sandy material is common but contains a considerable portion (e.g. 30-45%) of mud. Variations in backscatter data and grain-size data at depths from 40-60 m suggest considerable variability may exist in sediment composition in the area southeast of Seguin Island. The reclassified, unfiltered backscatter map in Figure 10 contains a more general illustration of sediment distributions inferred from the map in Figure 9.

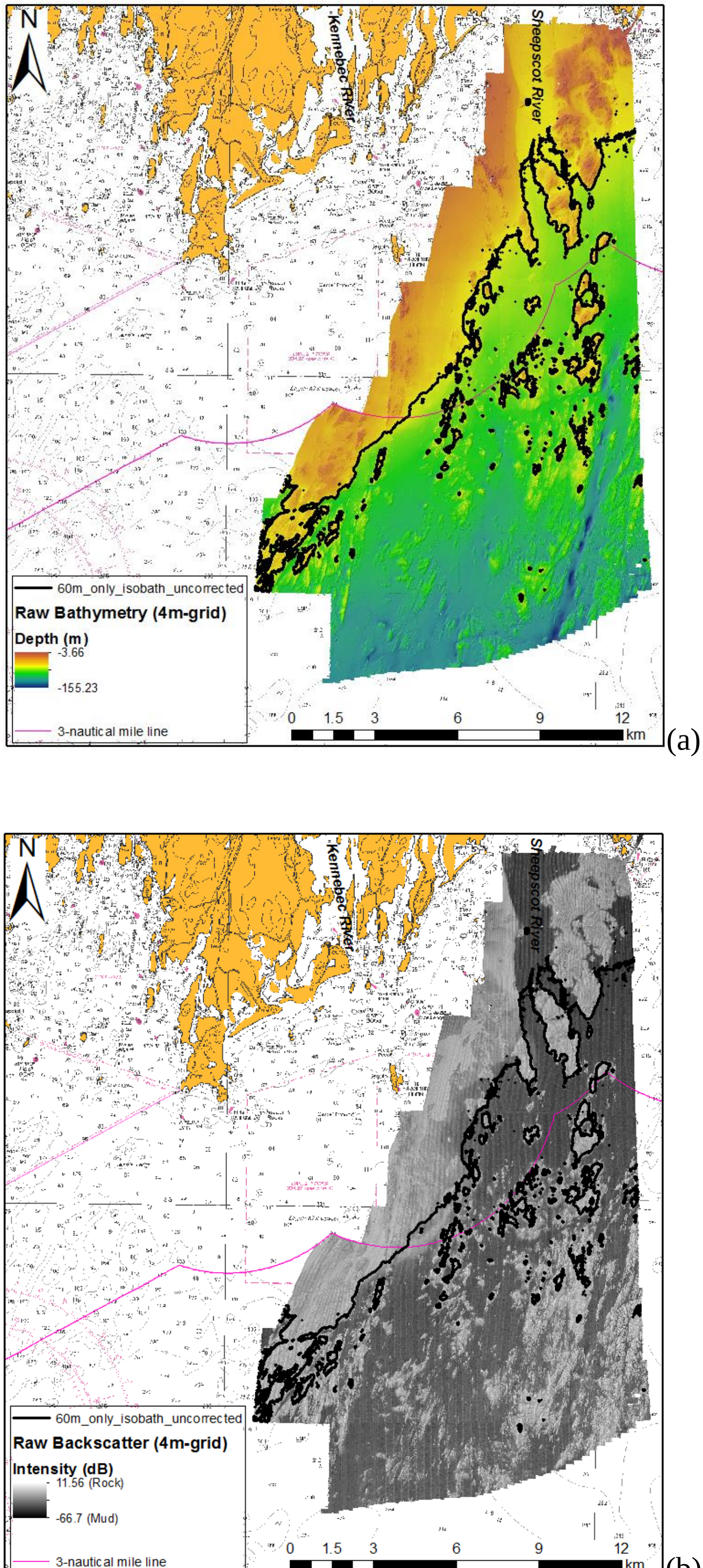

Figure 7. Uncorrected bathymetry (a) and unfiltered backscatter intensity (b) (4 m grid resolution overlain with transparent bathymetry hillshade) and 60-m isobaths.

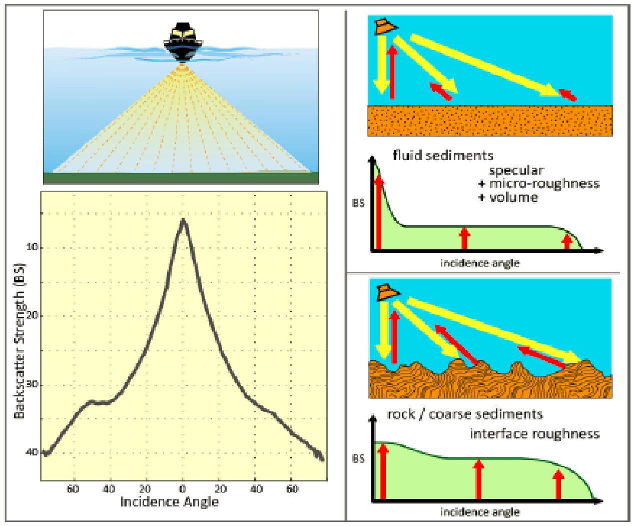

Figure 8. Conceptual illustration of the angular dependence of backscatter strength. High backscatter values at the at nadir decrease rapidly as incidence angle increases, commonly resulting in 'stripes' in unfiltered data that are coincident with the direction of survey lines. From Lurton and Lamarche (2015).

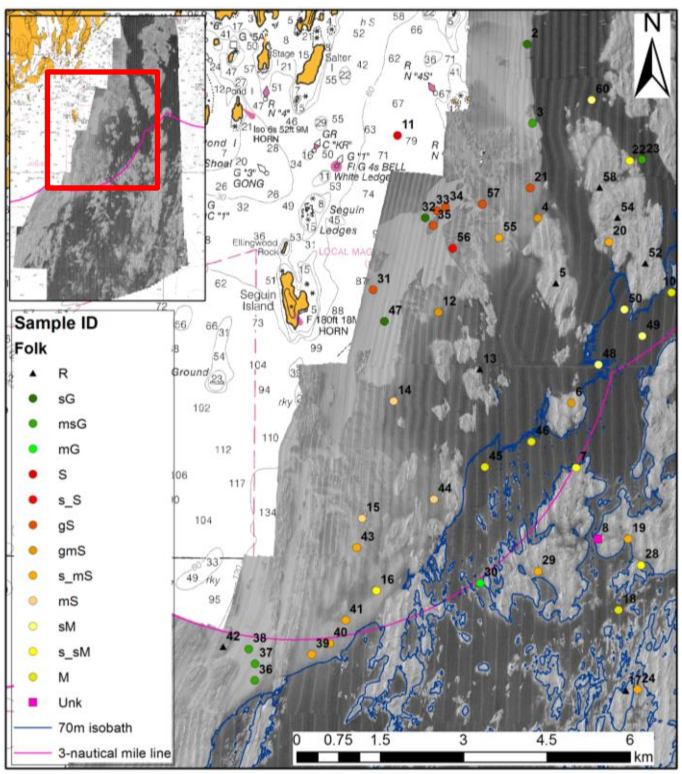

Figure 9. Unfiltered backscatter intensity map zoomed to central portion of survey area showing laterally extensive coarse-grained sediments concentrated along distal portion of paleodelta at depths <70 m. Sediment sample sites (circles) are colored based on Folk (1954).

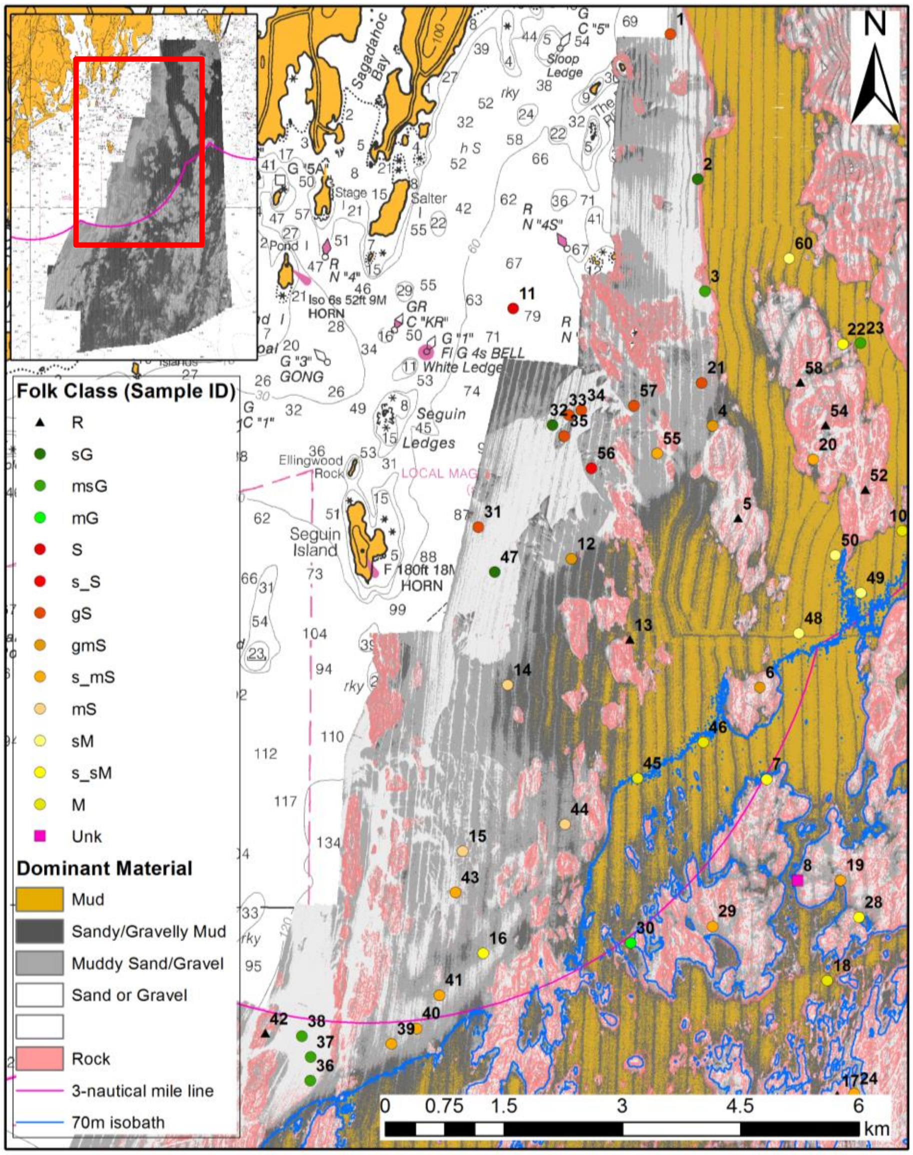

Figure 10. Reclassified, unfiltered backscatter intensity map zoomed to central portion of survey area showing laterally extensive coarse-grained sediments concentrated along distal portion of paleodelta at depths <70 m. Sediment sample sites (circles) are colored based on Folk (1954). N-S trending 'stripes' are artifact of unfiltered data and do not reflect true nature of sediment.

The seafloor seaward (east-southeast) of the paleodelta generally consists of a series of north-northeast to south-southwest-trending shelf valleys draped in mud and bound by steep-sided bedrock outcrops. The occurrence of sandy surficial deposits in areas seaward of the paleodelta were concentrated along the western margins of and in between isolated bedrock outcrops, and to shallow valleys within outcrops at depths less than 70 m. These deposits were spatially discontinuous, presumably thin, and commonly contained a considerable portion of mud (e.g. >20% silt and/or clay; samples M0006, M0019, M0027, M0029; see Table 2). Backscatter and sediment data in in the central portion of the survey area (Figure 11) indicate the presence of an approximately 4.5 km^2 zone containing slightly gravelly, muddy sands, punctuated by E-W trending ridges of presumably coarser material. The heterogeneity of sediment and orientation of bathymetric features within this area are somewhat consistent with ground patterns associated with grounded ice (e.g. till, moraines; Kelley et al., 1997a). However, additional processing of backscatter and bathymetry data, additional video, and a higher density of grab sampling would be necessary to confirm glacial deposition.

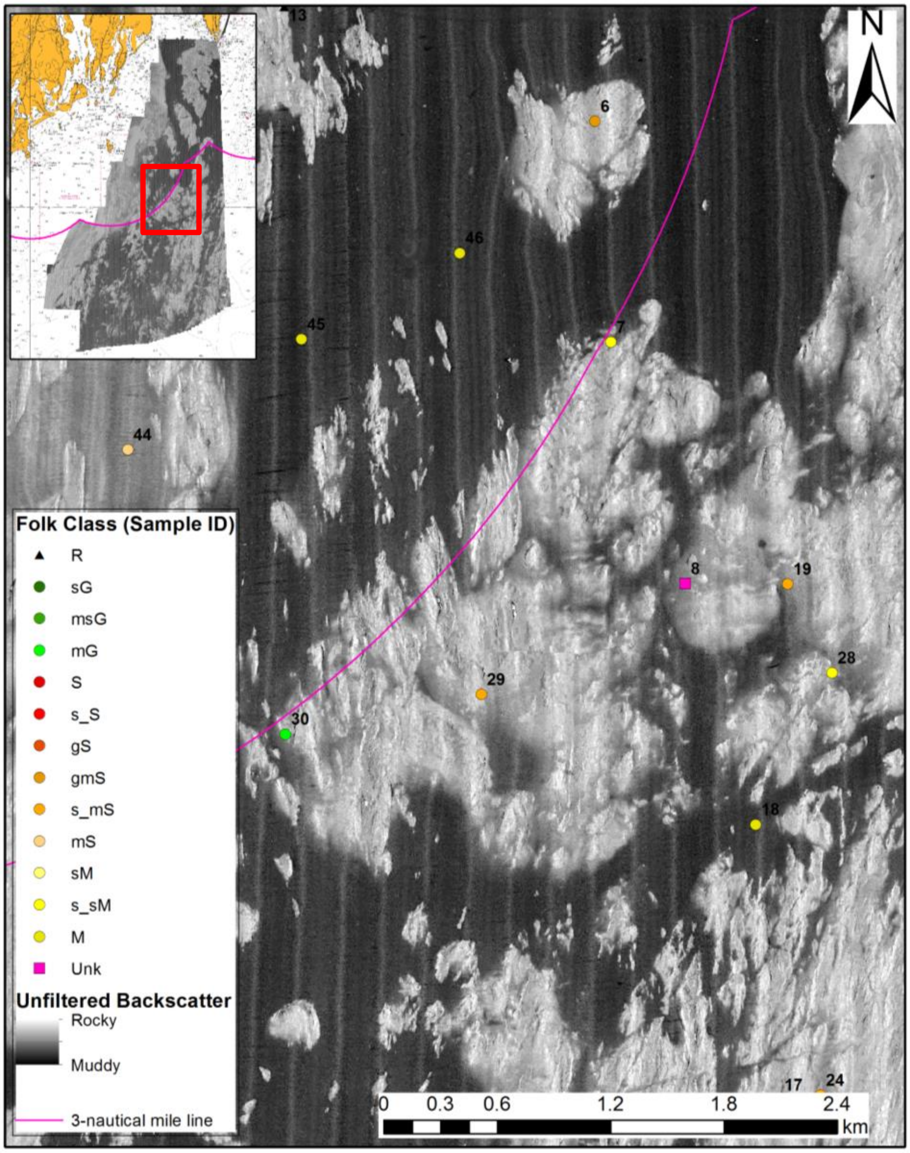

Figure 11. Unfiltered backscatter intensity and grab samples showing concentration of coarse-grained sediment in central portion of survey area and seaward of the paleodelta.

In federal survey waters, laterally extensive sand and/or gravel surficial material was limited to the southern-most distal portion of the paleodelta. Interpretations of backscatter intensity data and existing generalized seafloor sediment maps suggest these deposits extend westward in federal waters at similar depths (e.g. <70 m; Figure 12; Barnhardt et al., 1996). The seafloor sediment map shown in Figure 12 was compiled by Barnhardt et al. (1998) through interpretations of side-scan sonar, seismic reflection, sediment samples, and vibracore data collected throughout the region by many agencies for a variety of projects. Although quite generalized, the high resolution backscatter data verifies the precision with which smaller bodies of sediment and rock were delineated in this map.

BOEM was most interested in sand deposits at depths < 30 m for this investigation. Although the data collected by MCMI suggest that these deposits are most absent in the BOEM focus area, the deeper sampling and survey data allow the characterization of sediment and geographic extent of the paleodelta in federal waters. In addition, the data collected by MCMI can serve as a resource to refine existing seafloor sediment and bathymetric maps of the region. Once final bathymetry and backscatter data products are generated, MCMI plans to perform in-depth spatial assessments of potential sand deposits at pre-defined depth intervals (e.g. 5 m, 10 m) in federal water within the 2015 coverage area.

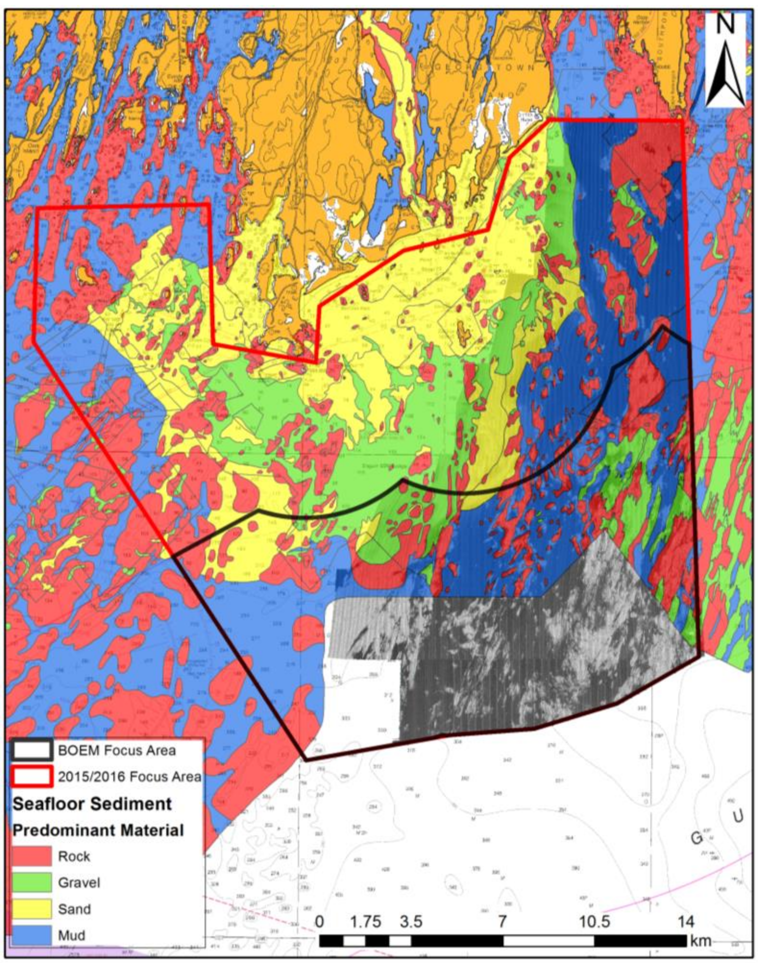

Figure 12. Generalized seafloor sediment map from Barnhardt et al. (1996) showing interpreted extent of sand (yellow) and gravel (green) deposits (Barnhardt et al., 1998) relative to BOEM focus area (outline in black). The extent of backscatter data collected my MCMI can also be seen extending to the south.

Conclusions

During the 2015 survey season the Maine Coastal Mapping Initiative sampled 61 locations, 43 in state water and 18 in federal waters, in the approximately 80mi^2 (207 km^2) survey area. Grain-size analyses of sediment samples combined with interpretations of backscatter intensity and bathymetric data are consistent with general interpretations of seafloor sediment distribution and morphology in the region (e.g. Barnhardt et al., 1998 and Kelley, et al., 1997). Within the survey area, laterally extensive surficial deposits of predominantly sandy and/or gravelly material were restricted to depths less than 70 m and were most commonly associated with the Kennebec river paleodelta/nearshore ramp. Similarly, backscatter and grab sample data suggest these deposits were even more scarce within federal waters of the survey area.

In the coming months, MCMI plans to utilize final data products for high-resolution backscatter and bathymetry to refine existing seafloor sediment maps and determine the spatial extent of sand deposits within federal water. When combined with existing geophysical (e.g. seismic reflection profiles and side-scan sonar) data, these data may also be used to refine interpretations of coastal/nearshore geomorphology and three-dimensional assessments of potential sediment resources/valley fill in the region. In addition, these data are a critical component of benthic habitat classification and modeling performed by MCMI (see Ozmon, 2015). Overall, these data have a variety of applications and are an invaluable resource to public and private agencies who wish to more effectively manage and understand coastal and marine resources.

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Appendix A – Sediment sample metadata

Sample ID	Date	Time (EST)	Coordinates[1] Easting (m)	Northing (m)	Depth[2] (m)	Sample Thickness (cm)	Water Column Data[3] Salinity	Temp. (°C)	pH	Mean Raw Backscatter Intensity[4] (dB)
M0001	5/4/15	8:13	442827	4846221	27	5.5	31.9	4.90	-	-14.87
M0002	5/4/15	8:57	443173	4844385	40	5	31.0	3.89	-	-15.94
M0003	5/6/15	7:48	443268	4842959	38	5	31.8	3.77	-	-11.3
M0004	5/6/15	8:57	443361	4841255	53	6.9	33.2	3.34	-	-22.16
M0005	5/6/15	9:55	443687	4840086	51	N/A	32.9	3.49	-	-16.49
M0006	5/6/15	10:35	443964	4837936	59	4	33.5	3.47	-	-15.74
M0007	5/6/15	11:50	444049	4836769	73	14	32.3	3.34	-	-21.67
M0008	5/6/15	12:52	444441	4835489	70	N/A	33.3	3.59	-	-22.51
M0009	6/15/15	10:33	447196	4840576	78	13	31.2	5.21	-	-35.26
M0010	6/15/15	11:15	445767	4839921	73	12	31.1	4.22	-	-33.56
M0011	6/25/15	6:55	440837	4842739	25	4	29.8	9.19	-	not surveyed
M0012	6/25/15	7:45	441574	4839567	48	8	30.4	6.95	-	-17.01
M0013	6/25/15	8:19	442318	4838543	58	N/A	30.3	6.36	-	-15.18
M0014	6/25/15	8:42	440768	4837964	52	6	29.0	7.06	-	-25.59
M0015	6/25/15	9:14	440198	4835859	50	6	29.5	7.18	-	-20.85
M0016	6/25/15	9:43	440455	4834560	64	9	29.9	6.29	-	-18.5
M0017	7/22/15	8:18	444944	4832762	60	N/A	28.9	8.12	-	-14.39
M0018	7/22/15	9:12	444814	4834214	80	12	31.2	7.09	-	-29.99
M0019	7/22/15	10:05	444983	4835488	68	10	29.6	6.84	-	-19.18

M0020	7/22/15	10:39	444640	4840826	58	11	28.9	7.82	-	-20.49
M0021	7/22/15	11:38	443225	4841797	45	6	24.0	10.04	-	-21.69
M0022	7/22/15	11:57	445014	4842287	57	12	27.6	8.41	-	-17.84
M0023	7/22/15	12:23	445236	4842304	44	6	23.6	9.99	-	-34.1
M0024	7/29/15	7:55	445158	4832782	75	9	31.3	6.95	-	-18.48
M0025	7/29/15	8:50	445922	4833198	63	N/A	30.0	7.61	-	-14.23
M0026	7/29/15	9:12	446293	4833702	75	6	31.0	7.02	-	-15.19
M0027	7/29/15	9:50	446084	4834807	70	10	30.5	7.32	-	-21.61
M0028	7/29/15	10:24	445218	4835018	72	11	30.5	7.43	-	-24.39
M0029	7/29/15	11:01	443363	4834904	64	9	29.8	7.84	-	-11.82
M0030	7/29/15	11:35	442325	4834692	66	8	29.7	7.55	-	-16.19
M0031	8/13/15	7:04	440395	4839970	34	6	32.1	9.88	7.8	-15.49
M0032	8/13/15	7:40	441334	4841261	35	5.5	32.2	9.42	7.9	-17.53
M0033	8/13/15	7:55	441543	4841389	36	8	32.2	9.40	7.9	-11.92
M0034	8/13/15	8:24	441702	4841451	37	6	32.2	9.40	7.9	-12.82
M0035	8/13/15	8:43	441481	4841123	37	5.5	32.2	9.35	7.9	-21.23
M0036	8/19/15	7:20	438265	4832944	58	5.5	32.6	8.49	7.8	-11.7
M0037	8/19/15	7:45	438274	4833246	51	9	32.6	8.70	7.9	-12.14
M0038	8/19/15	8:20	438158	4833508	46.5	8.5	32.5	8.92	7.9	-12.06
M0039	8/19/15	8:45	439292	4833412	62	9	32.7	8.05	7.8	-17.79
M0040	8/19/15	9:29	439615	4833609	64	10	32.6	8.03	7.8	-17.59
M0041	8/19/15	9:59	439902	4834029	62	10	32.6	8.00	7.8	-15.69
M0042	9/10/15	10:58	437700	4833553	37	N/A	32.5	10.74	7.9	-14.37
M0043	9/10/15	11:19	440104	4835332	53	6.5	32.8	9.03	7.9	-18.26
M0044	9/10/15	11:49	441491	4836199	61	9.5	32.8	8.78	7.9	-24.27
M0045	9/10/15	12:19	442410	4836783	72	13	32.8	8.52	7.8	-32.49
M0046	9/10/15	13:05	443247	4837239	72	12	32.8	8.52	7.8	-31.13
M0047	9/16/15	6:26	440602	4839398	38	9	32.5	10.95	7.9	-15.51

M0048	9/16/15	7:02	444455	4838621	69	12	32.8	8.89	7.9	-33.37
M0049	9/16/15	7:37	445240	4839135	70	13	32.8	8.88	7.9	.-31.86
M0050	9/16/15	8:02	444918	4839611	69	13	32.8	8.83	7.9	-32.02
M0051	9/16/15	8:37	446004	4839299	61	7	32.7	9.06	7.9	-10.09
M0052	9/16/15	9:06	445297	4840445	35	N/A	32.6	11.20	8.0	-19.88
M0053	9/16/15	9:20	446658	4841326	69	13	32.8	8.63	7.9	-35.64
M0054	9/16/15	9:56	444795	4841265	41	N/A	32.5	10.04	7.9	-19.41
M0055	9/16/15	10:15	442659	4840900	47	6	32.7	9.24	7.9	-20.26
M0056	9/16/15	10:38	441829	4840713	42	4	32.7	10.17	7.9	-22.6
M0057	9/16/15	10:53	442366	4841506	41	6.5	32.6	9.78	7.9	-21.38
M0058	9/16/15	11:40	444473	4841805	53	N/A	32.7	8.98	7.9	-12.96
M0059	9/16/15	11:53	446410	4842790	65	13	32.7	8.83	7.9	-35.32
M0060	9/16/15	12:17	444332	4843378	61	13	32.7	8.98	7.9	-33.28
M0061	9/16/15	12:43	447129	4844058	61	13	32.7	8.75	7.9	-36.29

[1]Coordinates listed in WGS84 UTM zone 19N (meters)

[2]Depth measurements were recorded in real time and may differ from corrected multibeam bathymetry data by ± 3m (or the expected tidal range within the coverage area).

[3]Water column data represent values measured at the seafloor (e.g. depth of sample). Data for samples M0001-M0030 and M0031-M0061 were collected using the Digibar and Exo1, respectively. Digibar was not capable of measuring pH.

[4]Mean Raw Backscatter Intensity Values derived from mean value for raster grid in ArcMap created from 4m grid cell xyz data exported from QINSy Process Manager. Subject to change if backscatter value is derived from a different grid resolution.

Appendix B – Grain-size analysis results and Munsell colors

Sample ID	Percent by Weight: Gravel	Sand	Mud	S:M	Folk (1954)	Sand-sized Fraction Wentworth (1922)	Munsell Color: Dry	Wet
M0001	10.15	88.35	1.50	58.8	gS	coarse sand, well sorted	10YR 3/3, dark brown	2.5Y 3/2, v. dark grayish brown
M0002	32.92	61.54	5.54	11.12	sG	coarse sand, well sorted	10YR 3/4, dark yellowish brown	2.5Y 3/2, v. dark grayish brown
M0003	71.29	25.42	3.29	7.72	msG	med. sand, poorly sorted	10YR 3/4, dark yellowish brown	2.5Y 3/2, v. dark grayish brown
M0004	6.63	63.84	29.53	2.16	gmS	coarse sand, poorly sorted	10YR 7/2, light gray	2.5Y 3/2, v. dark grayish brown
M0005	-	-	-	-	R	-	-	-
M0006	28.24	47.27	24.49	1.93	gmS	coarse sand, well sorted	10YR 7/2, light gray	10YR 3/2, v. dark grayish brown
M0007	3.74	23.60	72.66	0.32	(s)sM	med. sand, poorly sorted	2.5Y 6/2, light brownish gray	2.5Y 3/2, v. dark grayish brown
M0008	-	-	-	-	Unkown	-	-	-
M0009	0.00	2.88	97.12	0.03	M	-	2.5Y 4/2, dark grayish brown	10YR 3/2, v. dark grayish brown
M0010	0.00	5.28	94.72	0.06	M	-	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0011	0.00	91.71	8.29	11.06	S	med. sand, poorly sorted	2.5Y 6/2, light brownish gray	5Y 3/2, dark olive gray
M0012	6.62	66.11	27.26	2.43	gmS	med. sand, poorly sorted	2.5Y 6/2, light brownish gray	5Y 3/2, dark olive gray
M0013	-	-	-	-	R	-	-	-
M0014	0.00	68.45	31.55	2.17	mS	fine sand, mod. well sorted	2.5Y 6/2, light brownish gray	5Y 3/2, dark olive gray
M0015	0.00	89.65	10.35	8.66	mS	coarse sand, poorly sorted	2.5Y 6/3, light yellowish brown	5Y 3/2, dark olive gray
M0016	4.13	45.34	50.54	0.90	(s)sM	med. sand, poorly sorted	2.5Y 6/2, light brownish gray	2.5Y 3/2, v. dark grayish brown
M0017	-	-	-	-	R	-	-	-
M0018	0.00	3.81	96.19	0.04	M	-	2.5Y 7/2, light gray	2.5Y 3/2, v. dark grayish brown

M0019	1.24	55.39	43.36	1.28	(s)mS	fine sand, mod. sorted	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0020	3.17	57.03	39.80	1.43	(s)mS	fine sand, mod. well sorted	2.5Y 7/2, light gray	2.5Y 4/2, dark grayish brown
M0021	4.47	93.95	1.58	59.28	gS	coarse sand, poorly sorted	10YR 5/2, grayish brown	2.5 Y 4/4, olive brown
M0022	1.35	36.98	61.67	0.60	(s)sM	med. sand, poorly sorted	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0023	30.96	51.63	17.41	2.97	msG	med. sand, mod. well sorted	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0024	2.80	40.90	56.30	0.73	(s)mS	fine sand, mod. well sorted	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0025	-	-	-	-	R	-	-	-
M0026	67.06	8.91	24.04	0.37	mG	-	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0027	5.59	55.82	38.60	1.45	gmS	med. sand, mod. well sorted	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0028	1.49	44.73	53.79	0.83	(s)sM	med. sand, poorly sorted	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0029	4.45	63.34	32.21	1.97	(s)mS	med. sand, mod. sorted	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0030	44.54	17.38	38.08	0.46	mG	-	2.5Y 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0031	14.61	84.22	1.17	71.91	gS	coarse sand, v. well sorted	7.5YR 5/4 , brown	10YR 4/2, dark grayish brown
M0032	43.22	53.57	3.20	16.72	sG	coarse sand, mod. well sorted	7.5YR 5/4 , brown	10YR 4/2, dark grayish brown
M0033	16.71	82.34	0.95	86.57	gS	coarse sand, mod. well sorted	7.5YR 5/4 , brown	10YR 4/2, dark grayish brown
M0034	25.56	73.52	0.92	80.05	gS	coarse sand, mod. well sorted	7.5YR 5/4 , brown	10YR 4/2, dark grayish brown
M0035	2.04	93.74	4.22	22.24	gS	med. sand, poorly sorted	10YR 6/2, light brownish gray	5Y 3/2, dark olive gray
M0036	43.74	31.00	25.26	1.23	msG	v. coarse sand, poorly sorted	7.5YR 5/4 , brown	2.5Y 4/2, dark grayish brown
M0037	41.08	41.39	17.53	2.36	msG	coarse sand, v. well sorted	7.5YR 5/4 , brown	2.5Y 4/2, dark grayish brown
M0038	55.99	28.97	15.04	1.93	msG	coarse sand, v. well sorted	7.5YR 5/4 , brown	2.5Y 4/2, dark grayish brown
M0039	3.98	54.33	41.69	1.30	(s)mS	coarse sand, poorly sorted	10YR 6/1, grey	2.5Y 4/2, dark grayish brown
M0040	4.75	61.63	33.62	1.83	(s)mS	med. sand, mod. sorted	10YR 6/1, grey	2.5Y 4/2, dark grayish brown

M0041	3.07	54.42	42.51	1.28	(s)mS	coarse sand, mod. sorted	10YR 6/1, grey	2.5Y 4/2, dark grayish brown
M0042	-	-	-	-	R	-	-	-
M0043	1.87	81.47	16.66	4.89	(s)mS	med. sand, mod. sorted	10YR 6/2, light brownish gray	2.5Y 4/2, dark grayish brown
M0044	0.00	68.65	31.35	2.19	mS	fine sand, mod. well sorted	10YR 6/1, grey	2.5Y 4/2, dark grayish brown
M0045	0.00	7.69	92.31	0.08	M	-	10YR 6/2, light brownish gray	2.5Y 4/4, olive brown
M0046	0.00	8.18	91.82	0.09	M	-	10YR 6/2, light brownish gray	2.5Y 4/4, olive brown
M0047	49.10	49.90	1.00	49.90	sG	v. coarse sand, mod. sorted	10YR 8/3 to 4/1, v. pale brown to v. dark gray	10YR 4/6 to 3/6, dark yellowish brown
M0048	0.00	27.70	72.30	0.38	sM	med. sand, poorly sorted	2.5Y 6/2, light brownish gray	2.5Y 3/3, dark olive brown
M0049	0.00	18.00	82.00	0.22	sM	-	2.5Y 6/2, light brownish gray	2.5Y 3/3, dark olive brown
M0050	0.00	26.80	73.20	0.37	sM	-	2.5Y 5/2, grayish brown	2.5Y 3/2 v. dark grayish brown
M0051	16.90	65.80	17.30	3.80	gmS	med. sand, poorly sorted	2.5Y 5/2, grayish brown	2.5Y 3/3, dark olive brown
M0052	-	-	-	-	R	-	-	-
M0053	0.00	27.10	72.90	0.37	sM	med. sand, poorly sorted	2.5Y 5/2, grayish brown	2.5Y 3/2 v. dark grayish brown
M0054	-	-	-	-	R	-	-	-
M0055	4.50	82.60	12.90	6.40	(s)mS	fine sand, mod. sorted	2.5Y 5/2, grayish brown	2.5Y 3/2 v. dark grayish brown
M0056	2.50	90.80	6.70	13.55	(s)S	fine sand, mod. sorted	2.5Y 5/2, grayish brown	2.5Y 3/2 v. dark grayish brown
M0057	8.30	85.40	6.30	13.56	gS	fine sand, poorly sorted	2.5Y 5/2, grayish brown	10YR 3/1, v. dark gray
M0058	-	-	-	-	R	-	-	-
M0059	0.00	13.80	86.20	0.16	sM	-	2.5Y 5/2, grayish brown	10YR 3/3, dark brown
M0060	0.00	16.10	83.90	0.19	sM	-	2.5Y 6/2, light brownish gray	10YR 3/2, v. dark grayish brown
M0061	0.00	24.80	75.20	0.33	sM	med. sand, poorly sorted	2.5Y 6/2, light brownish gray	10YR 3/2, v. dark grayish brown

Appendix C – Sieve analysis raw data

Sample ID	Weight (g)									Percent (%) by Weight				S:M	Total (%)
	Container	Sample + container	Net Wet	Net Dry	Water	Corrected Net Dry	Gravel	Sand	Mud	Water	Gravel	Sand	Mud		
M0001	1.01	51.66	50.65	43.26	7.39	43.06	4.39	38.22	0.65	14.59	10.15	88.35	1.50	58.80	100
M0002	1.01	51.39	50.38	43.89	6.49	43.71	14.45	27.01	2.43	12.88	32.92	61.54	5.54	11.12	100
M0003	1.00	51.22	50.22	44.93	5.29	44.79	32.03	11.42	1.48	10.53	71.29	25.42	3.29	7.72	100
M0004	1.03	51.06	50.03	42.26	7.77	42.05	2.80	26.98	12.48	15.53	6.63	63.84	29.53	2.16	100
M0005	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M0006	1.03	51.81	50.78	44.79	5.99	44.63	12.65	21.17	10.97	11.80	28.24	47.27	24.49	1.93	100
M0007	1.02	51.43	50.41	44.88	5.53	44.73	1.68	10.59	32.61	10.97	3.74	23.60	72.66	0.32	100
M0008	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M0009	1.04	51.37	50.33	47.17	3.16	47.08	0.00	1.36	45.81	6.28	0.00	2.88	97.12	0.03	100
M0010	1.03	51.48	50.45	44.51	5.94	44.35	0.00	2.35	42.16	11.77	0.00	5.28	94.72	0.06	100
M0011	1.01	51.51	50.50	39.79	10.71	39.50	0.00	36.49	3.30	21.21	0.00	91.71	8.29	11.06	100
M0012	1.02	51.34	50.32	39.25	11.07	38.95	2.60	25.95	10.70	22.00	6.62	66.11	27.26	2.43	100
M0013	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M0014	1.00	51.99	50.99	37.91	13.08	37.56	0.00	25.95	11.96	25.65	0.00	68.45	31.55	2.17	100
M0015	1.01	51.72	50.71	39.91	10.80	39.62	0.00	35.78	4.13	21.30	0.00	89.65	10.35	8.66	100
M0016	1.01	51.44	50.43	44.82	5.61	44.67	1.85	20.32	22.65	11.12	4.13	45.34	50.54	0.90	100
M0017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M0018	1.03	54.31	53.28	49.62	3.66	49.52	0.00	1.89	47.73	6.88	0.00	3.81	96.19	0.04	100
M0019	1.03	58.58	57.55	47.39	10.16	47.12	0.59	26.25	20.55	17.65	1.24	55.39	43.36	1.28	100
M0020	1.04	57.50	56.46	44.82	11.64	44.51	1.42	25.56	17.84	20.62	3.17	57.03	39.80	1.43	100
M0021	1.02	56.07	55.05	42.28	12.77	41.94	1.89	39.72	0.67	23.20	4.47	93.95	1.58	59.28	100
M0022	1.02	55.48	54.46	46.54	7.92	46.33	0.63	17.21	28.70	14.54	1.35	36.98	61.67	0.60	100
M0023	1.02	58.84	57.82	47.74	10.08	47.47	14.78	24.65	8.31	17.43	30.96	51.63	17.41	2.97	100
M0024	1.02	56.28	55.26	47.12	8.14	46.90	1.32	19.27	26.53	14.73	2.80	40.90	56.30	0.73	100
M0025	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M0026	1.00	59.87	58.87	54.00	4.87	53.87	36.21	4.81	12.98	8.27	67.06	8.91	24.04	0.37	100
M0027	0.99	60.81	59.82	49.95	9.87	49.68	2.79	27.88	19.28	16.50	5.59	55.82	38.60	1.45	100
M0028	1.00	54.41	53.41	43.71	9.70	43.45	0.65	19.55	23.51	18.16	1.49	44.73	53.79	0.83	100
M0029	1.03	53.03	52.00	41.60	10.40	41.32	1.85	26.35	13.40	20.00	4.45	63.34	32.21	1.97	100
M0030	1.00	56.76	55.76	49.84	5.92	49.68	22.20	8.66	18.98	10.62	44.54	17.38	38.08	0.46	100

M0031	0.99	54.79	53.80	45.25	8.55	45.02	6.61	38.11	0.53	15.89	14.61	84.22	1.17	71.91	100
M0032	1.04	56.77	55.73	47.45	8.28	47.23	20.51	25.42	1.52	14.86	43.22	53.57	3.20	16.72	100
M0033	1.02	55.93	54.91	46.26	8.65	46.03	7.73	38.09	0.44	15.75	16.71	82.34	0.95	86.57	100
M0034	1.04	52.57	51.53	43.55	7.98	43.33	11.13	32.02	0.40	15.49	25.56	73.52	0.92	80.05	100
M0035	1.02	58.64	57.62	44.60	13.02	44.25	0.91	41.81	1.88	22.60	2.04	93.74	4.22	22.24	100
M0036	1.01	53.57	52.56	46.00	6.56	45.82	20.12	14.26	11.62	12.48	43.74	31.00	25.26	1.23	100
M0037	1.06	49.03	47.97	41.02	6.95	40.83	16.85	16.98	7.19	14.49	41.08	41.39	17.53	2.36	100
M0038	1.02	56.29	55.27	47.88	7.39	47.68	26.81	13.87	7.20	13.37	55.99	28.97	15.04	1.93	100
M0039	1.02	56.48	55.46	46.99	8.47	46.76	1.87	25.53	19.59	15.27	3.98	54.33	41.69	1.30	100
M0040	1.00	57.53	56.53	47.33	9.20	47.08	2.25	29.17	15.91	16.27	4.75	61.63	33.62	1.83	100
M0041	1.01	53.98	52.97	45.33	7.64	45.12	1.39	24.67	19.27	14.42	3.07	54.42	42.51	1.28	100
M0042	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M0043	1.01	67.47	66.46	55.10	11.36	54.79	1.03	44.89	9.18	17.09	1.87	81.47	16.66	4.89	100
M0044	0.99	68.57	67.58	55.16	12.42	54.82	0.00	37.87	17.29	18.38	0.00	68.65	31.35	2.19	100
M0045	1.00	55.23	54.23	48.25	5.98	48.09	0.00	3.71	44.54	11.03	0.00	7.69	92.31	0.08	100
M0046	1.01	52.34	51.33	41.06	10.27	40.78	0.00	3.36	37.70	20.01	0.00	8.18	91.82	0.09	100
M0047	-	-	-	-	-	-	-	-	-	10.20	49.10	49.90	1.00	49.90	100
M0048	-	-	-	-	-	-	-	-	-	168.90	0.00	27.70	72.30	0.38	100
M0049	-	-	-	-	-	-	-	-	-	212.90	0.00	18.00	82.00	0.22	100
M0050	-	-	-	-	-	-	-	-	-	220.90	0.00	26.80	73.20	0.37	100
M0051	-	-	-	-	-	-	-	-	-	37.80	16.90	65.80	17.30	3.80	100
M0052	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M0053	-	-	-	-	-	-	-	-	-	227.40	0.00	27.10	72.90	0.37	100
M0054	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M0055	-	-	-	-	-	-	-	-	-	27.70	4.50	82.60	12.90	6.40	100
M0056	-	-	-	-	-	-	-	-	-	21.10	2.50	90.80	6.70	13.55	100
M0057	-	-	-	-	-	-	-	-	-	20.90	8.30	85.40	6.30	13.56	100
M0058	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M0059	-	-	-	-	-	-	-	-	-	210.80	0.00	13.80	86.20	0.16	100
M0060	-	-	-	-	-	-	-	-	-	140.70	0.00	16.10	83.90	0.19	100
M0061	-	-	-	-	-	-	-	-	-	187.80	0.00	24.80	75.20	0.33	100

Note: Raw data (weights) for samples M0047-M0061 not received by MDOT sediment laboratory.

Appendix D – Grain-size statistics for coarse fraction of qualifying samples

Sample ID	Folk-Ward Statistical Parameters: Graphic Mean	Incl. Graph Std. Dev.	Incl. Graph Skewness	Graphic Kurtosis	Normalized Kurtosis	Method of Moments Parameters: Mean X	Variance	Skewness	Std. Dev.	Kurtosis
M0001	0.9700 coarse sand	0.4067 well sorted	0.1465 fine	0.7883 platykurtic	0.4408	1.1495	0.3305	2.0064	0.5749	11.4010
M0002	0.4358 coarse sand	0.4173 well sorted	0.6090 strongly fine	0.6600 very	0.3976	0.6761	0.5051	2.8440	0.7107	12.8358
M0003	1.5155 med. sand	1.3656 poorly sorted	0.6515 strongly fine	1.0397 mesokurtic	0.5097	1.3891	1.6591	1.0691	1.2881	2.4346
M0004	0.7066 coarse sand	1.5924 poorly sorted	0.1020 fine	0.5091 very	0.3373	0.8432	2.6022	0.1174	1.6131	1.4935
M0005	-	-	-	-	-	-	-	-	-	-
M0006	0.6121 coarse sand	0.4522 well sorted	0.2604 fine	1.5624 very	0.6097	0.8660	0.4635	2.5014	0.6808	10.1868
M0007	1.5922 med. sand	1.2362 poorly sorted	-0.2172 coarse	1.7584 very	0.6375	1.7421	1.3000	-0.5582	1.1482	3.4247
M0008	-	-	-	-	-	-	-	-	-	-
M0009	1.2016 med. sand	1.4941 poorly sorted	0.4409 strongly fine	0.6827 platykurtic	0.4057	1.5284	2.0887	0.2988	1.4452	1.6036
M0010	1.7436 med. sand	0.9821 mod. sorted	0.7030 strongly fine	1.3576 leptokurtic	0.5758	1.7839	0.9549	0.9554	0.9772	2.6538
M0011	1.4522 med. sand	1.6974 poorly sorted	-0.7253 strongly coarse	0.4888 very	0.3283	1.7005	3.0934	-0.7789	1.7588	1.7986
M0012	1.7009 med. sand	1.5901 poorly sorted	-0.5668 strongly coarse	2.1063 very	0.6781	2.0597	2.2425	-1.2095	1.4975	3.0551
M0013	-	-	-	-	-	-	-	-	-	-
M0014	2.7053 fine sand	0.5543 mod. well sorted	0.0340 near symmetrical	1.4185 leptokurtic	0.5865	2.7742	0.3374	-0.8775	0.5809	5.4180
M0015	0.8900 coarse sand	1.4364 poorly sorted	-0.5209 strongly coarse	0.5006 very	0.3336	0.8581	2.4734	-0.2256	1.5727	1.2527

M0016	1.5389 med. sand	1.3699 poorly sorted	-0.0062 near symmetrical	0.8559 platykurtic	0.4612	1.5774	1.8625	-0.3059	1.3647	2.1010
M0017	-	-	-	-	-	-	-	-	-	-
M0018	-	-	-	-	-	-	-	-	-	-
M0019	2.0536 fine sand	0.7617 mod. sorted	0.0742 near symmetrical	1.6895 very	0.6282	2.1401	0.6406	-0.3094	0.8189	4.6854
M0020	2.2622 fine sand	0.6948 mod. well sorted	-0.1698 coarse skewed	2.3468 very	0.7012	2.3120	0.5649	-1.3060	0.7516	5.6856
M0021	0.9358 coarse sand	1.1092 poorly sorted	-0.5001 strongly coarse	2.0675 very	0.6740	1.1966	1.1198	-1.1498	1.0582	3.2771
M0022	1.1692 med. sand	1.6065 poorly sorted	-0.4930 strongly coarse	0.4934 very	0.3304	1.2775	2.6298	-0.4222	1.6217	1.5866
M0023	1.7749 med. sand	0.6239 mod. well sorted	0.0471 near symmetrical	1.7243 very	0.6329	1.8695	0.4680	-0.3845	0.6841	5.0048
M0024	2.0902 fine sand	0.6681 mod. well sorted	0.1081 fine	1.3736 leptokurtic	0.5787	2.1775	0.5014	-0.3839	0.7081	4.4653
M0025	-	-	-	-	-	-	-	-	-	-
M0026	-	-	-	-	-	-	-	-	-	-
M0027	1.9615 med. sand	0.6655 mod. well sorted	0.0018 near symmetrical	1.2302 leptokurtic	0.5516	2.0181	0.5858	-1.0134	0.7654	5.6670
M0028	1.1858 med. sand	1.6010 poorly sorted	-0.5341 strongly coarse	0.4777 very	0.3233	1.2558	2.8117	-0.3523	1.6768	1.4387
M0029	1.3342 med. sand	0.9437 mod. well sorted	-0.3661 strongly coarse	1.5489 very	0.6077	1.3412	1.0979	-1.0404	1.0478	3.6138
M0030	-	-	-	-	-	-	-	-	-	-
M0031	0.2375 coarse sand	0.2199 very well sorted	0.4015 strongly fine	1.2040 leptokurtic	0.5463	0.4233	0.1693	4.6420	0.4115	30.8257
M0032	0.7056 coarse sand	0.5104 mod. well sorted	-0.0277 near symmetrical	0.9502 mesokurtic	0.4872	0.8596	0.2844	0.8337	0.5333	5.1907

M0033	0.7345 coarse sand	0.5568 mod. well sorted	0.0430 near symmetrical	0.9838 mesokurtic	0.4959	0.8840	0.3311	0.9363	0.5754	5.2469
M0034	0.7586 coarse sand	0.6268 mod. well sorted	0.0791 near symmetrical	0.7436 platykurtic	0.4265	0.8867	0.4101	0.4985	0.6404	2.5758
M0035	1.1062 med. sand	1.5021 poorly sorted	-0.5809 strongly coarse	2.2482 very	0.6921	1.5883	1.7937	-1.1202	1.3393	2.9376
M0036	-0.1005 v. coarse	1.0447 poorly sorted	-0.0240 near symmetrical	1.1008 mesokurtic	0.5240	0.2281	1.2641	1.0488	1.1243	4.0334
M0037	0.3461 coarse sand	0.3360 very well sorted	0.5460 strongly fine	1.0635 mesokurtic	0.5154	0.5297	0.2413	3.3279	0.4912	18.2525
M0038	0.3565 coarse sand	0.2284 very well sorted	0.1196 fine	2.1140 very	0.6789	0.5659	0.2119	4.3977	0.4604	27.5168
M0039	0.9366 coarse sand	1.0397 poorly sorted	0.1524 fine	2.4145 very	0.7071	0.9903	1.1644	0.2226	1.0791	3.4963
M0040	1.5184 med. sand	0.8698 mod. sorted	0.6026 strongly fine	0.8205 platykurtic	0.4507	1.6380	0.7863	0.7693	0.8867	2.6077
M0041	0.9561 coarse sand	0.7794 mod. sorted	0.5860 strongly fine	2.1454 very	0.6821	1.1153	0.7108	1.6026	0.8431	4.7400
M0042	-	-	-	-	-	-	-	-	-	-
M0043	1.9727 med. sand	0.7247 mod. sorted	-0.1569 coarse	1.5993 very	0.6153	2.0370	0.5651	-0.9673	0.7517	4.5036
M0044	2.2359 fine sand	0.5217 mod. well sorted	0.0096 near symmetrical	1.4445 leptokurtic	0.5909	2.3398	0.3112	-0.3672	0.5570	4.5096
M0045	3.2023 v. fine sand	0.5409 mod. well sorted	-0.1824 coarse	1.1330 leptokurtic	0.5312	3.2827	0.3215	-1.2062	0.5670	4.8480
M0046	3.4998 v. fine sand	0.2863 very well sorted	0.0330 near symmetrical	0.8705 platykurtic	0.4654	3.5660	0.3576	-6.1212	0.5980	47.2743
M0047	-0.5180 v. coarse	0.7119 mod. sorted	0.7404 strongly fine	1.1604 leptokurtic	-	-	-	1.1185	1.0558	3.9607
M0048	1.7915444 med. sand	1.1282 poorly sorted	0.1582 fine	0.6446 platykurtic	-	1.7916	-	0.2202	1.0643	1.3623
M0049	-	-	-	-	-	-	-	-	-	-

M0050	1.3319 med. sand	1.3676 poorly sorted	0.1595 fine	0.8110 platykurtic	-	1.3342	-	0.1615	1.2604	1.7687
M0051	1.4672 med. sand	1.2744 poorly sorted	-0.2597 coarse	1.0146 mesokurtic	-	1.4315	-	-0.7328	1.2824	2.8918
M0052	-	-	-	-	-	-	-	-	-	-
M0053	1.1370 med. sand	1.5385 poorly sorted	0.1160 fine	0.6764 platykurtic	-	1.1264	-	0.0669	1.4796	1.6942
M0054	-	-	-	-	-	-	-	-	-	-
M0055	2.3437 fine sand	0.8887 mod. sorted	-0.1911 coarse	2.1510 very	-	2.2140	-	-2.1569	0.9934	8.7009
M0056	2.2792 fine sand	0.8969 mod. sorted	-0.1572 coarse	1.2957 leptokurtic	-	2.1996	-	-1.3969	0.9200	5.8980
M0057	2.3748 fine sand	1.1281 poorly sorted	-0.3079 strongly coarse	1.3624 leptokurtic	-	2.2161	-	-1.6385	1.1862	5.4981
M0058	-	-	-	-	-	-	-	-	-	-
M0059	-	-	-	-	-	-	-	-	-	-
M0060	-	-	-	-	-	-	-	-	-	-
M0061	1.7160 med. sand	1.3194 poorly sorted	-0.0128 near symmetrical	0.7337 platykurtic	-	1.6627	-	-0.1131	1.2601	1.6453

Appendix E – Field and laboratory pictures of sediment samples

Note: diameters of round (samples M0001-M0046) and square (samples M0047-M0061) sediment trays are approximately 10 cm and 15 cm, respectively.

Sample ID: M0001

Wet

Dry

Sample ID: M0002

Wet

Dry

Sample ID: M0003

Wet

Dry

Sample ID: M0004

Wet

Dry

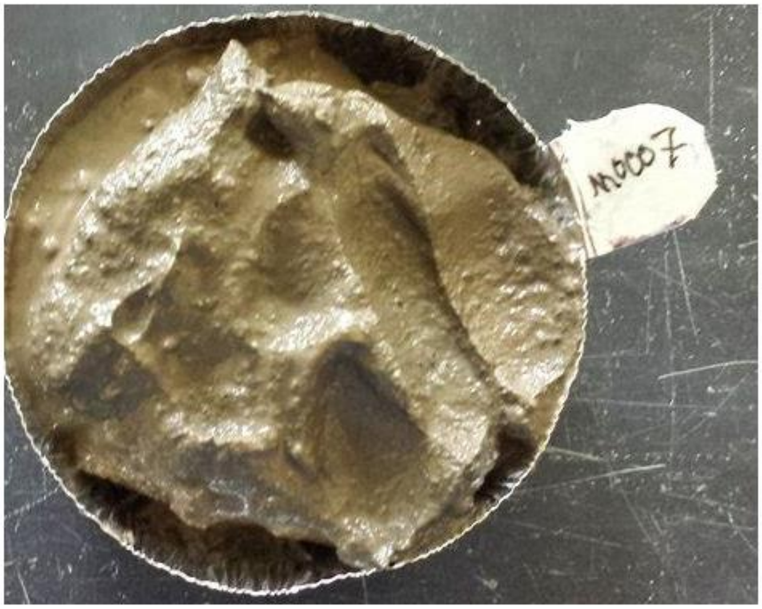
Sample ID: M0005
NO SAMPLE RECOVERED

Video Screen Capture

Sample ID: M0006

Wet

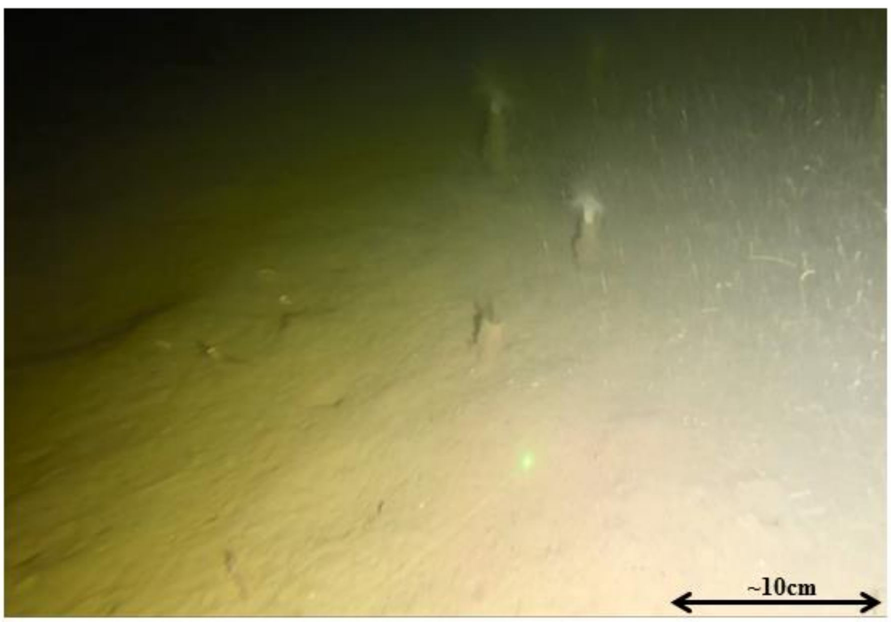
Dry

Sample ID: M0007

Wet

Dry

Sample ID: M0008

NO SAMPLE RECOVERED



Video Screen Capture

Sample ID: M0009

Wet

Dry

Sample ID: M0010

Wet

Dry

Sample ID: M0011

Wet

Dry

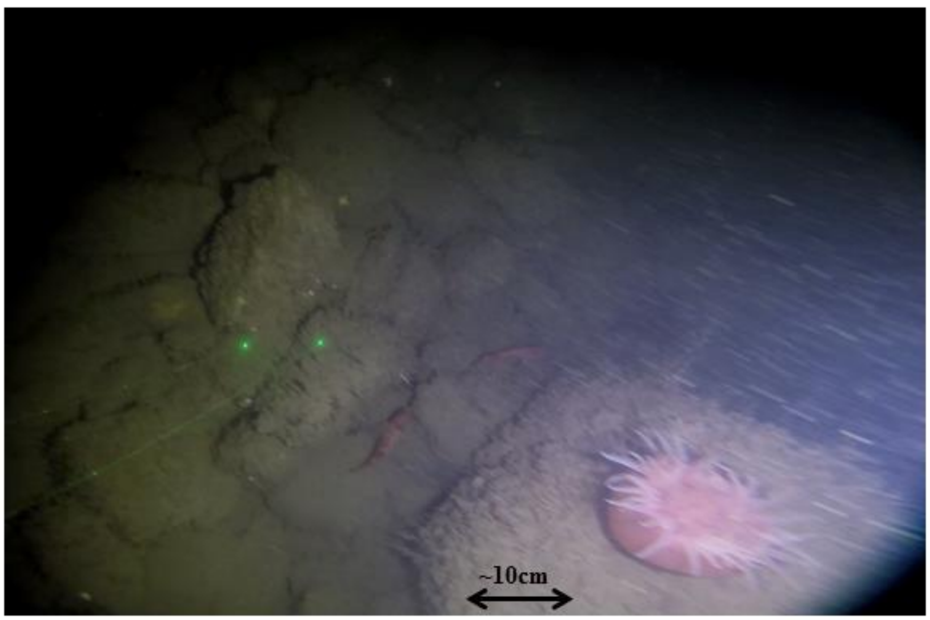
Sample ID: M0012

Wet

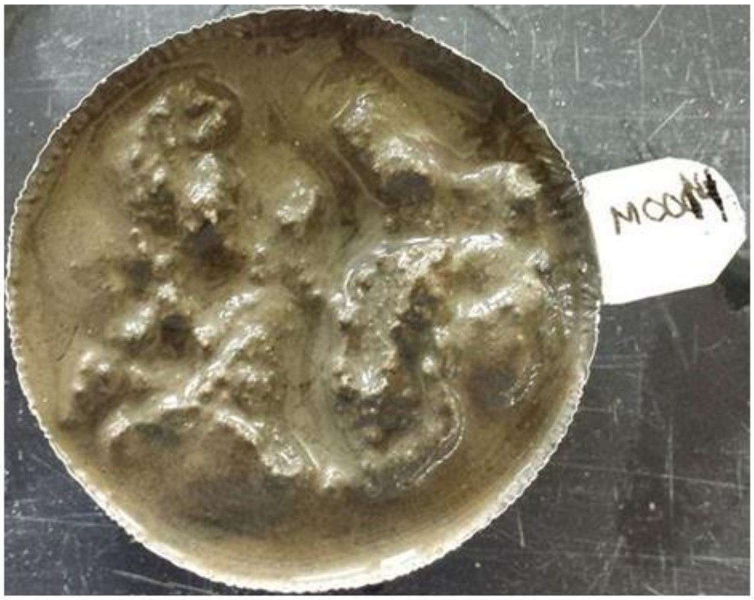
Dry

Sample ID: M0013

NO SAMPLE RECOVERED



Video Screen Capture

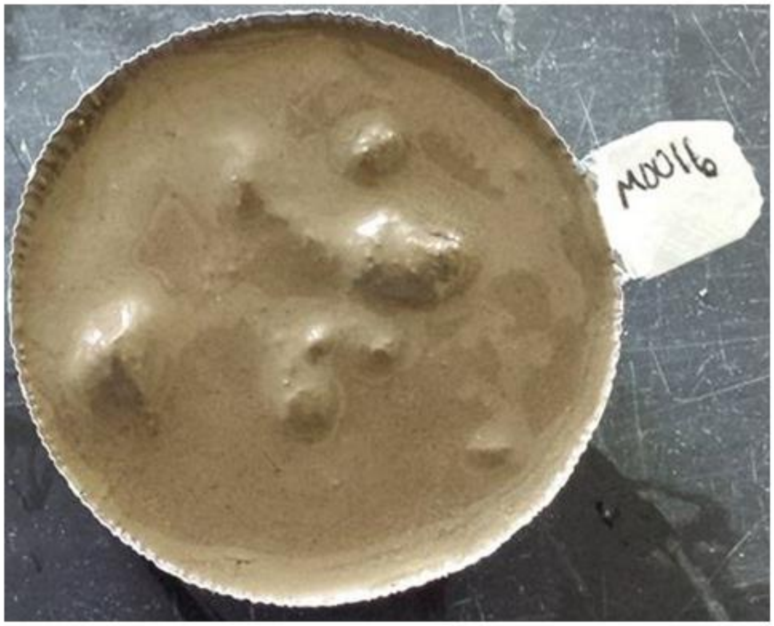
Sample ID: M0014

Wet

Dry

Sample ID: M0015

Wet

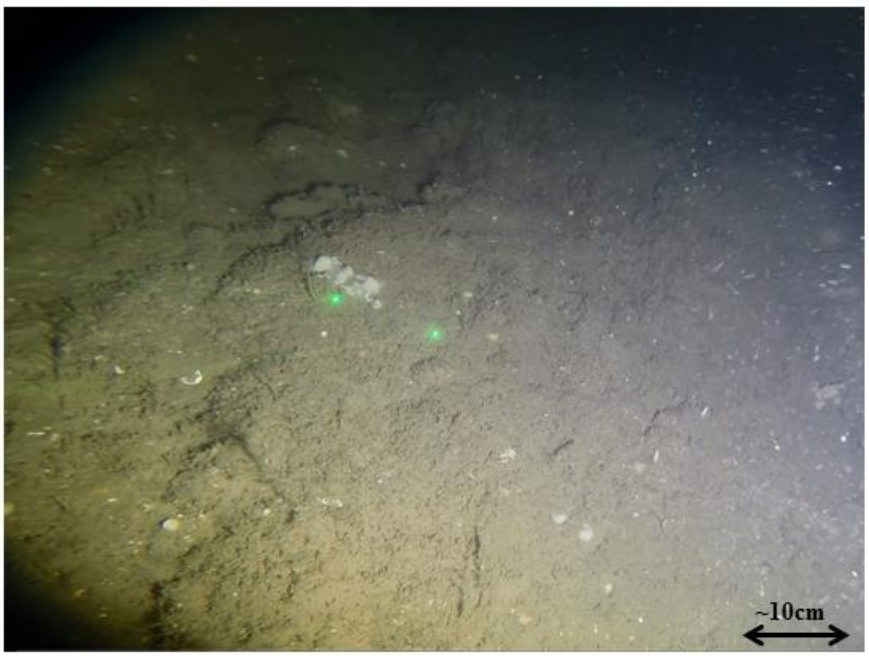
Dry

Sample ID: M0016

Wet

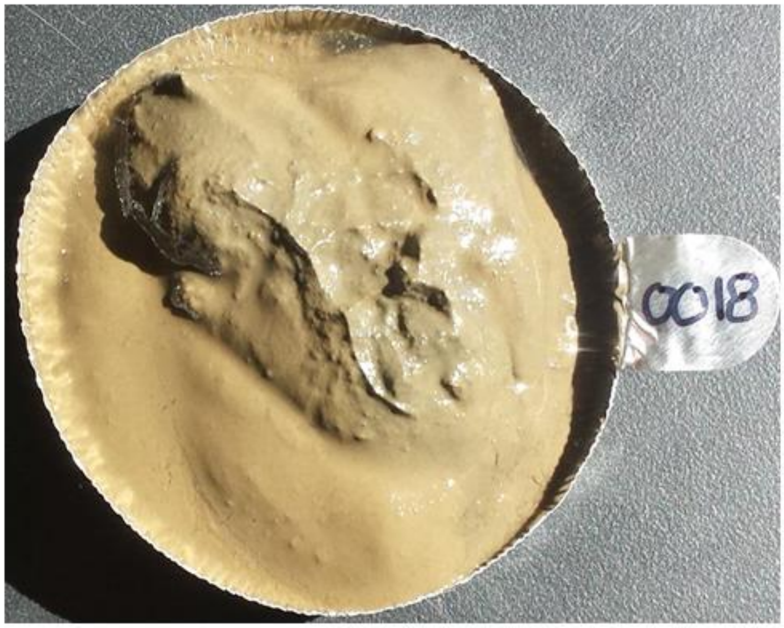
Dry

Sample ID: M0017

NO SAMPLE RECOVERED



Video Screen Capture

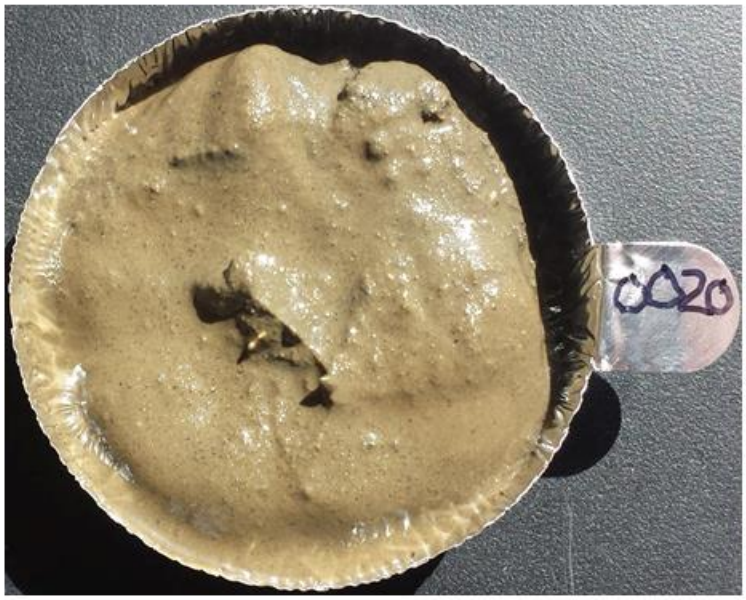
Sample ID: M0018

Wet

Dry

Sample ID: M0019

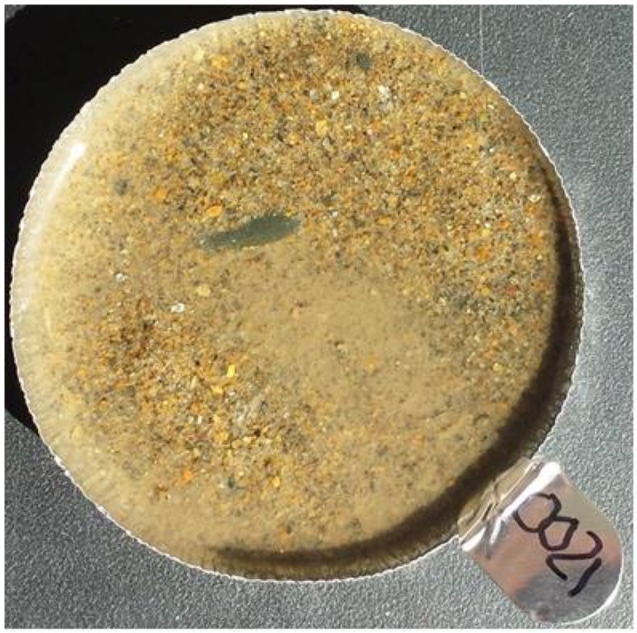
Wet

Dry

Sample ID: M0020

Wet

Dry

Sample ID: M0021



Wet

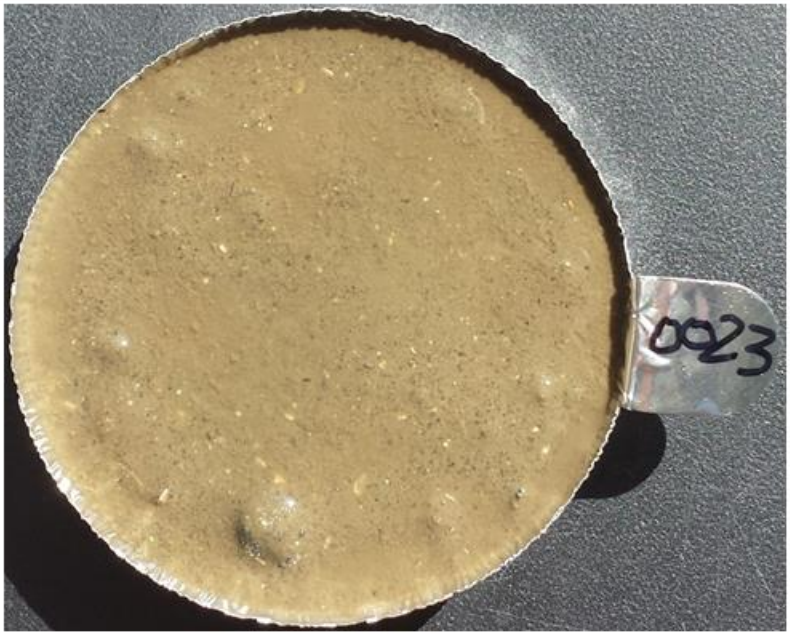
Dry

Sample ID: M0022

Wet

Dry

Sample ID: M0023



Wet

Dry

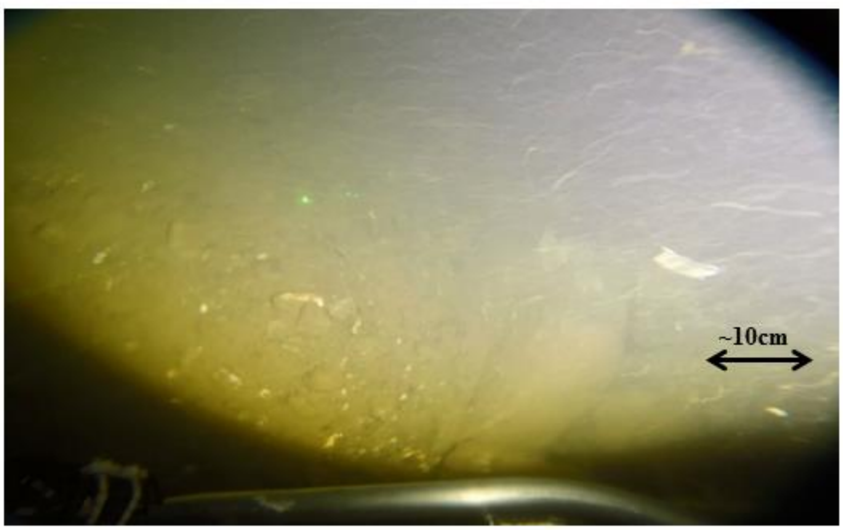
Sample ID: M0024

Wet

Dry

Sample ID: M0025

NO SAMPLE RECOVERED



Video Screen Capture

Sample ID: M0026

Supplemental Field Picture

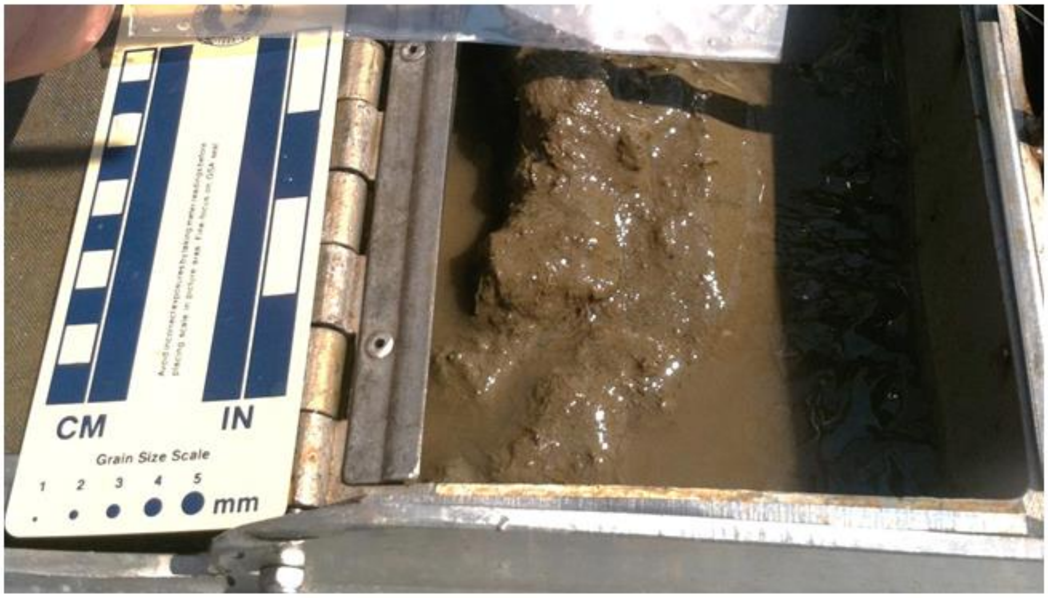
	
Dry	**Wet**

Sample ID: M0027

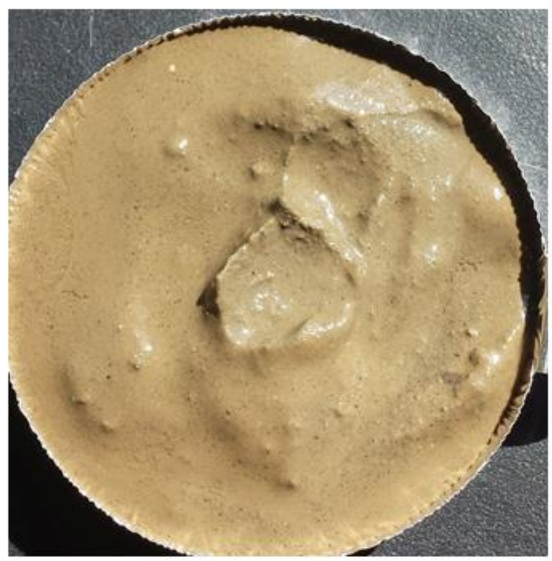
Field Picture

Dry	**Wet**

Sample ID: M0028



Field Picture

	
Dry	**Wet**

Sample ID: M0029

Field Picture

	
Dry	**Wet**

Sample ID: M0030

Field Picture

Dry	**Wet**

Sample ID: M0031

Field Picture

Dry	**Wet**

Sample ID: M0032	
	
Field Picture	
	
Dry	**Wet**

Sample ID: M0033	
	
Field Picture	
	
Dry	**Wet**

Sample ID: M0034

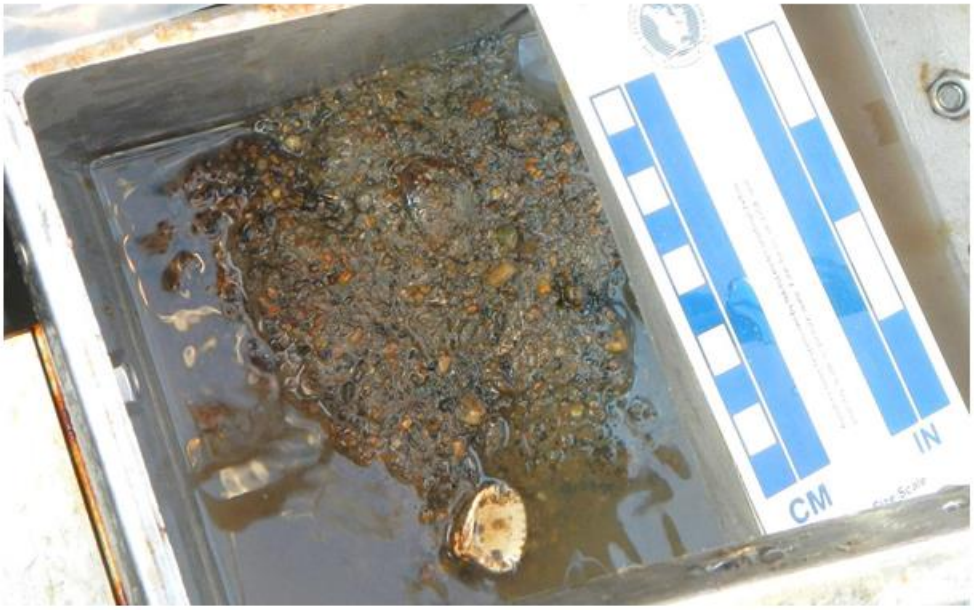
Field Picture

	
Dry	**Wet**

Sample ID: M0035

Field Picture

	
Dry	**Wet**

Sample ID: M0036	
	
Field Picture	
	
Dry	**Wet**

Sample ID: M0037

Field Picture

Dry	**Wet**

Sample ID: M0038	
	
Field Picture	
	
Dry	**Wet**

Sample ID: M0039

Field Picture

Dry	**Wet**

Sample ID: M0040

Field Picture

Dry	**Wet**

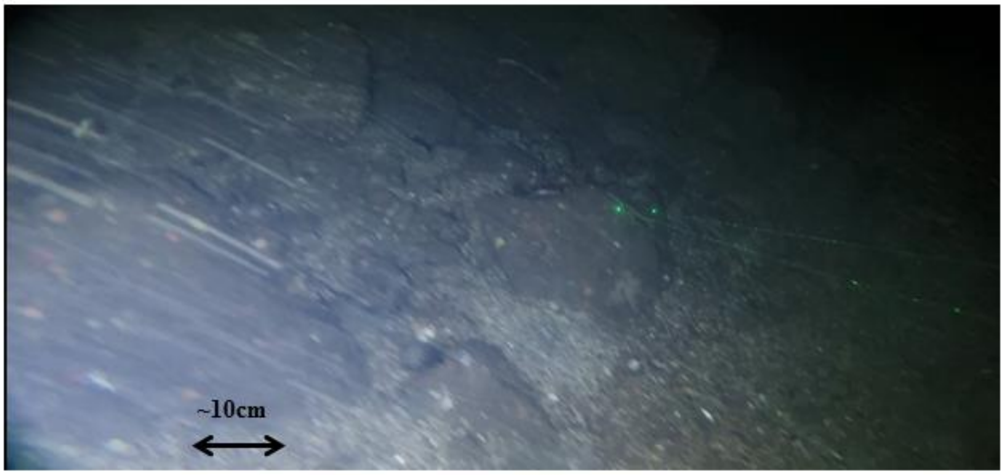
Sample ID: M0041

Field Picture

	
Dry	**Wet**

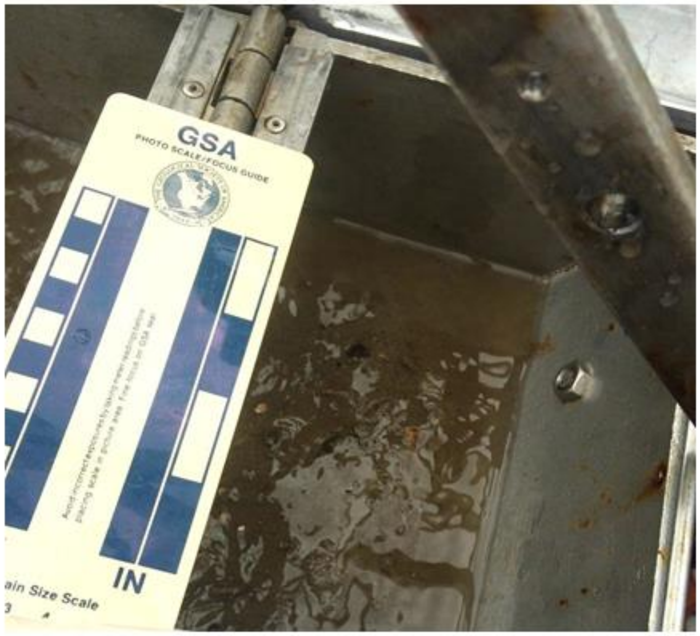
Sample ID: M0042

NO SAMPLE RECOVERED

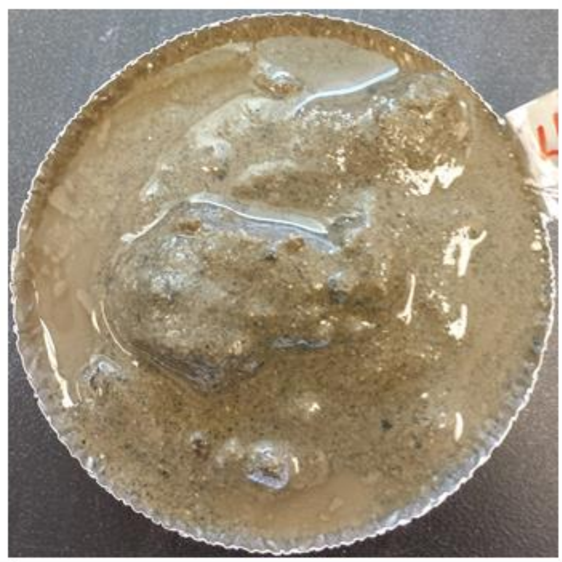


Video Screen Capture

Sample ID: M0043



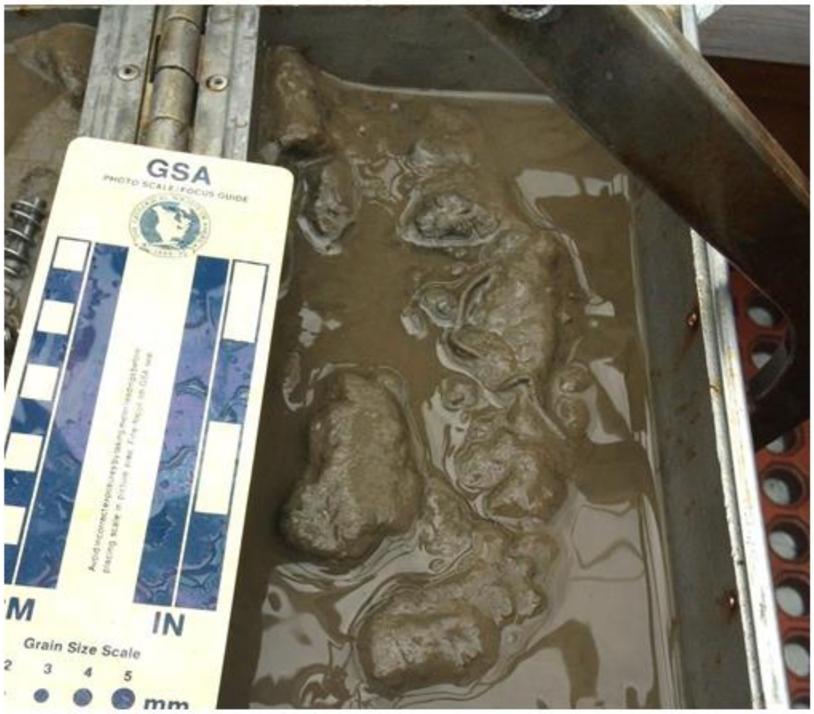
Field Picture

NOT RECORDED	
Dry	**Wet**

Sample ID: M0044	
	
Field Picture	
NOT RECORDED	
Dry	Wet

Sample ID: M0045	
	
Field Picture	
NOT RECORDED	
Dry	**Wet**

Sample ID: M0046



Field Picture

NOT RECORDED	
Dry	**Wet**

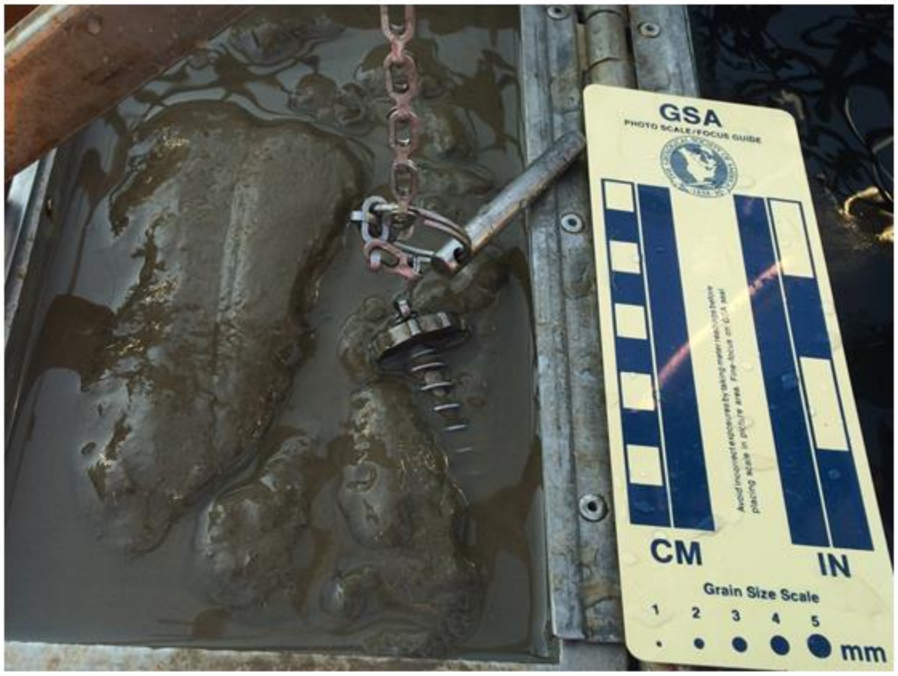
Sample ID: M0047	
	
Field Picture	
	
Dry	**Wet**

Sample ID: M0048

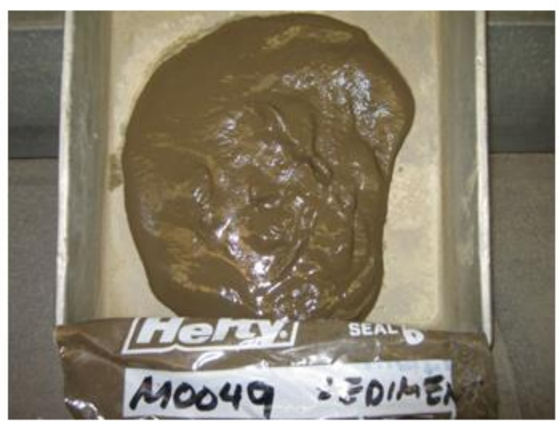
Field Picture

Dry	**Wet**

Sample ID: M0049



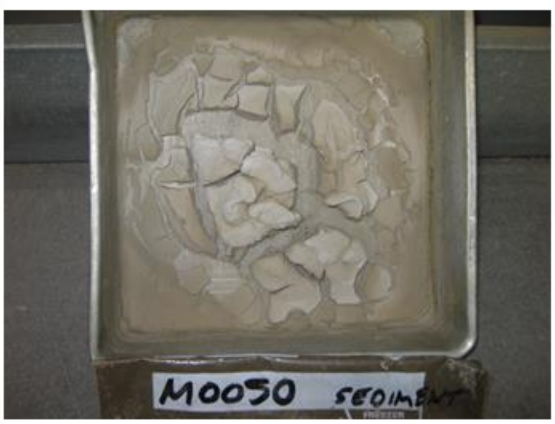
Field Picture



Dry	**Wet**

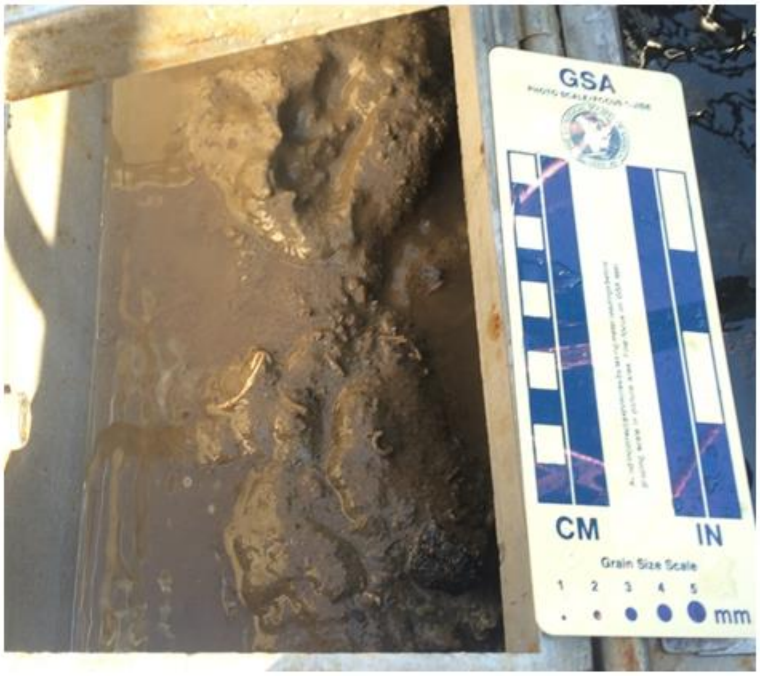
Sample ID: M0050

Field Picture



Dry	**Wet**

Sample ID: M0051

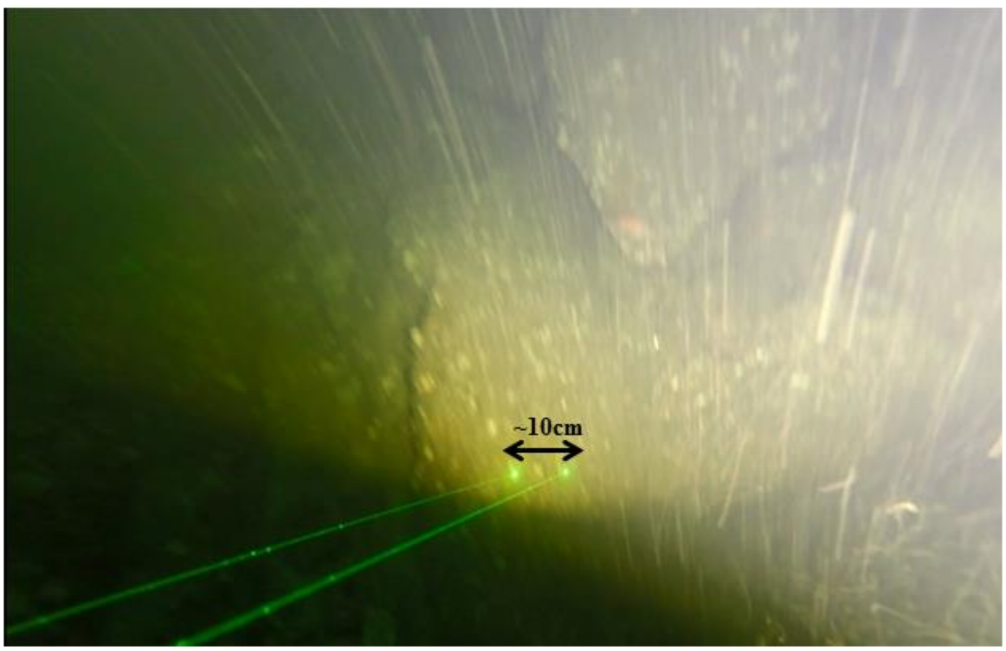


Field Picture

	
Dry	**Wet**

Sample ID: M0052

NO SAMPLE RECOVERED



Video Screen Capture

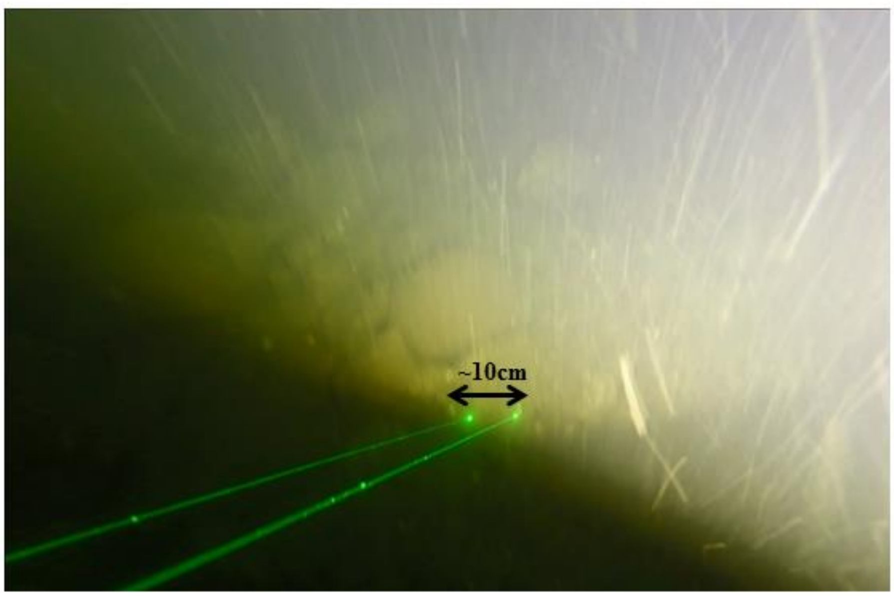
Sample ID: M0053

Field Picture

Dry	Wet

Sample ID: M0054

NO SAMPLE RECOVERED



Video Screen Capture

Sample ID: M0055

Field Picture

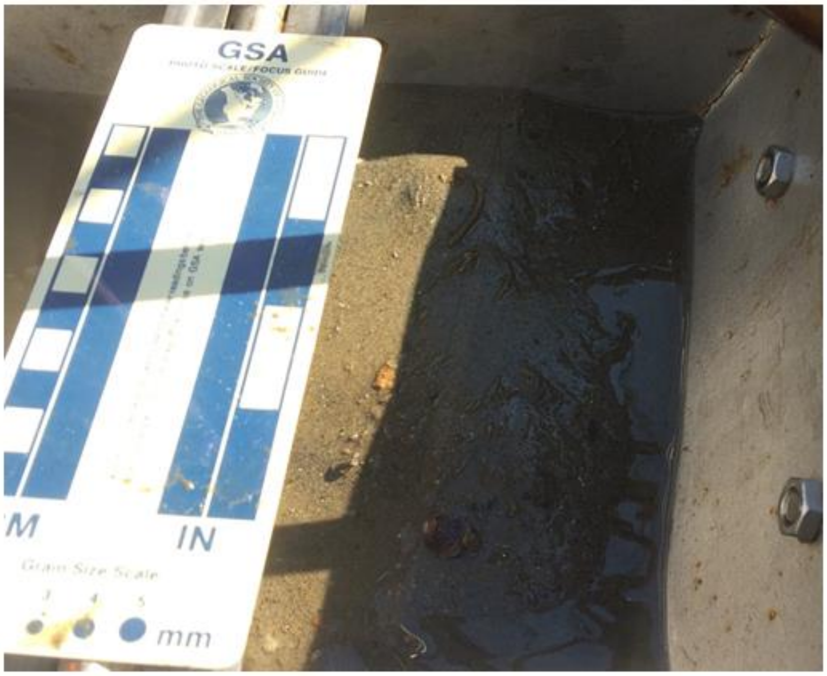
Dry	**Wet**

Sample ID: M0056

Field Picture

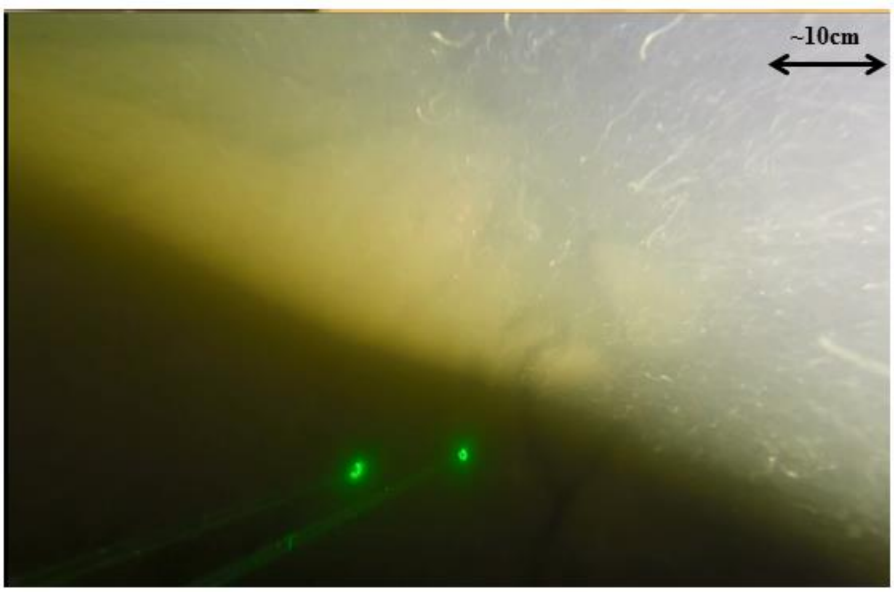
	
Dry	**Wet**

Sample ID: M0057



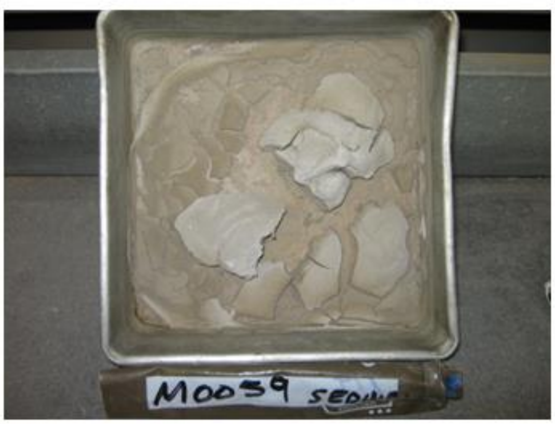
Field Picture

Dry	**Wet**

Sample ID: M0058
NO SAMPLE RECOVERED

Video Screen Capture

Sample ID: M0059

Field Picture



Dry	**Wet**

Sample ID: M0060

Field Picture

Dry	**Wet**

Sample ID: M0061

Field Picture

	
Dry	**Wet**

Appendix F – Video screengrabs of seafloor in sampling locations

Note: distance between lasers in screen grabs is approximately 10 cm.

M0001

M0002

M0003

M0004

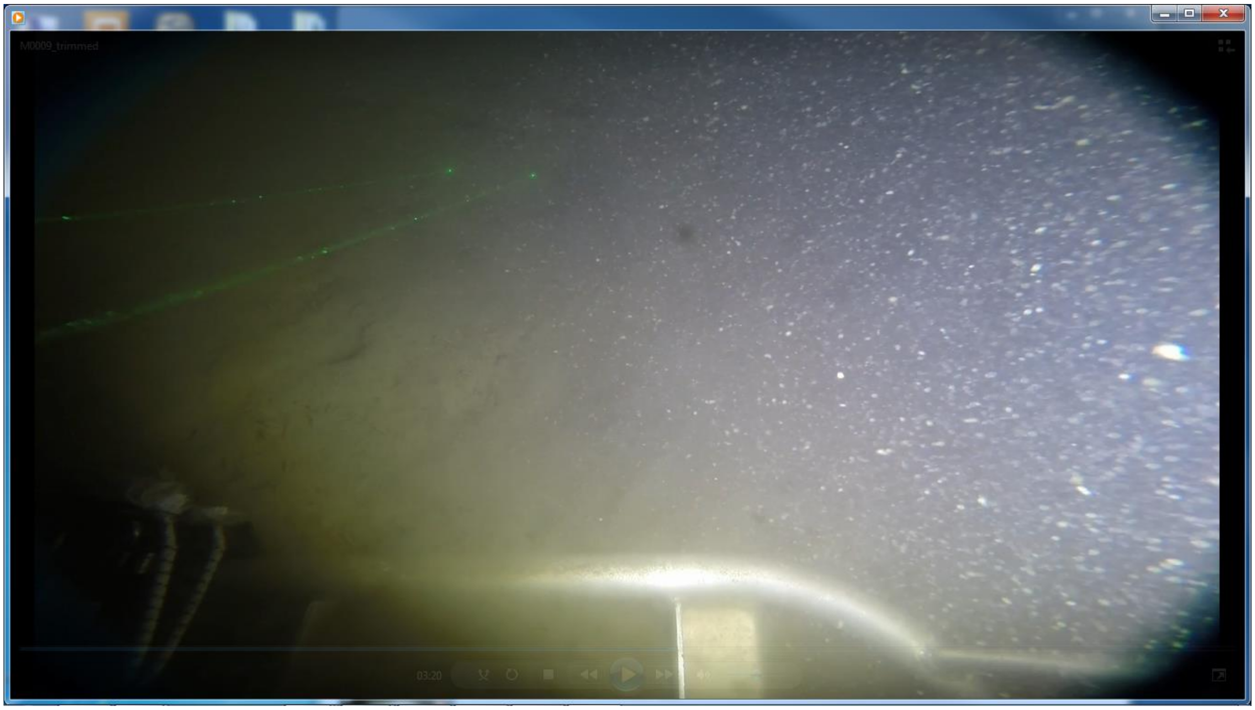
M0005 –video tipped 90 degrees

M0006

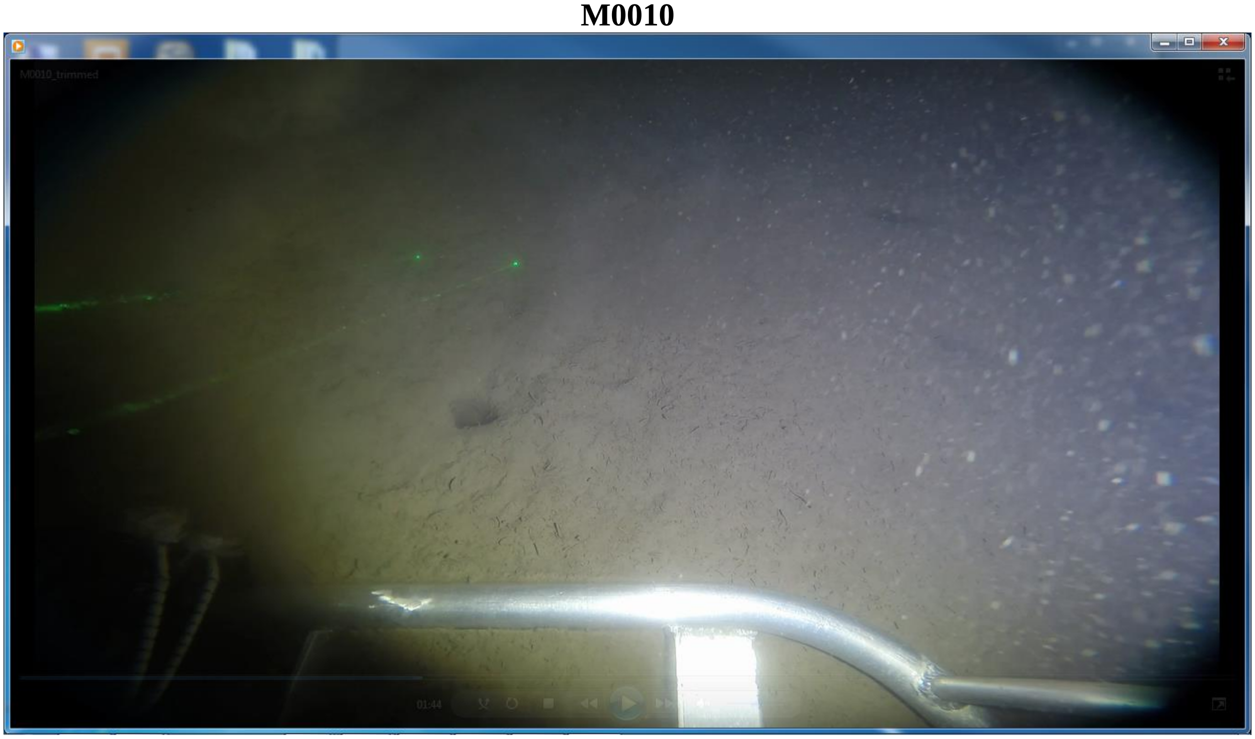
M0007

M0008

M0009

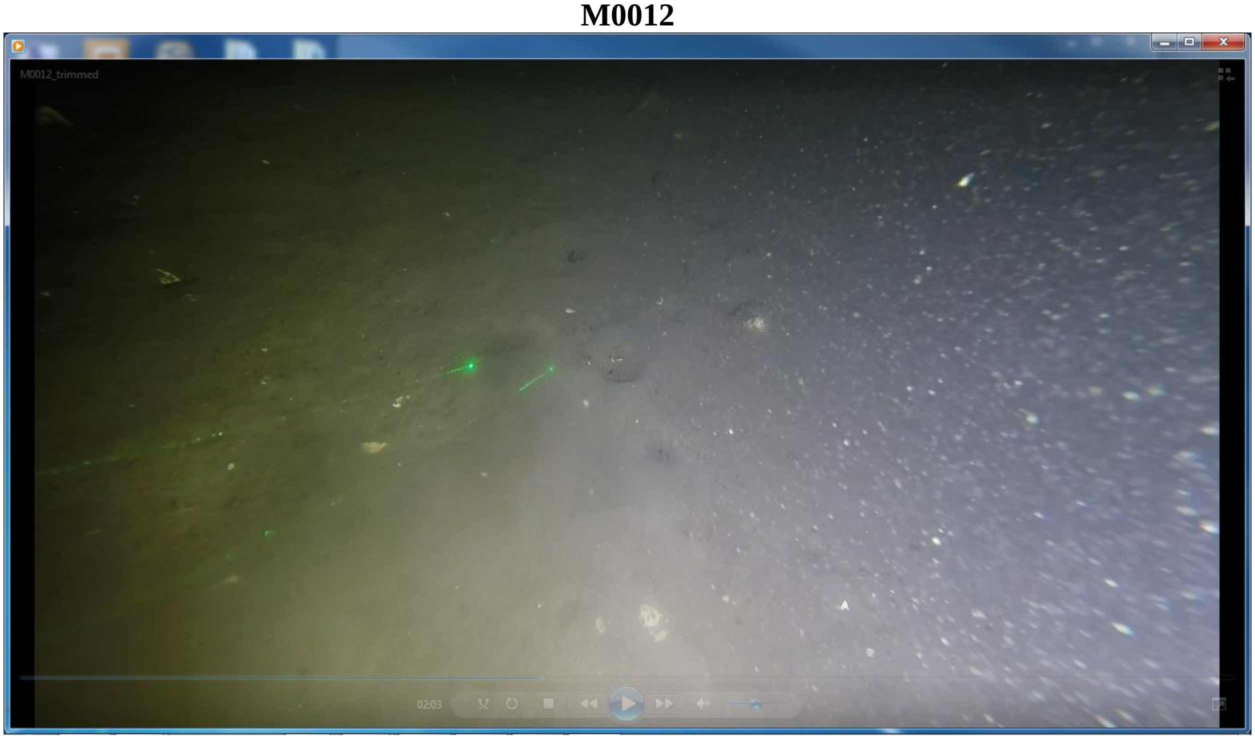


M0010



M0011

M0012



M0013

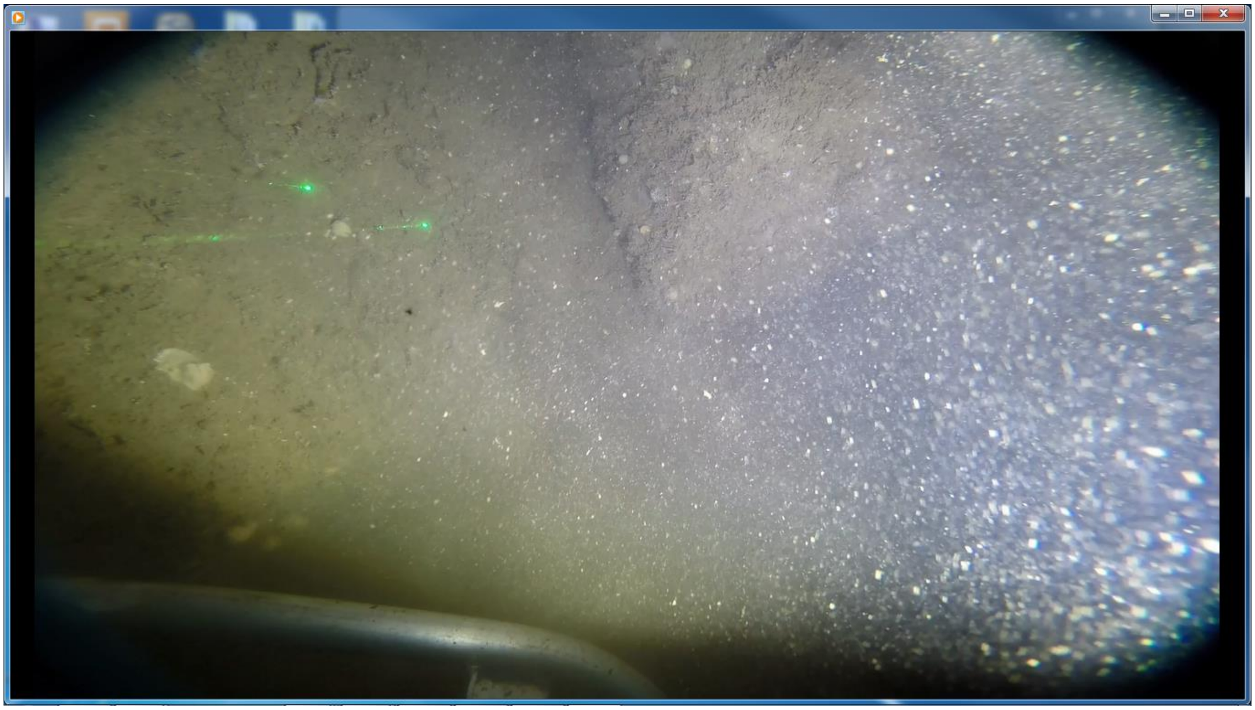
M0014

No video

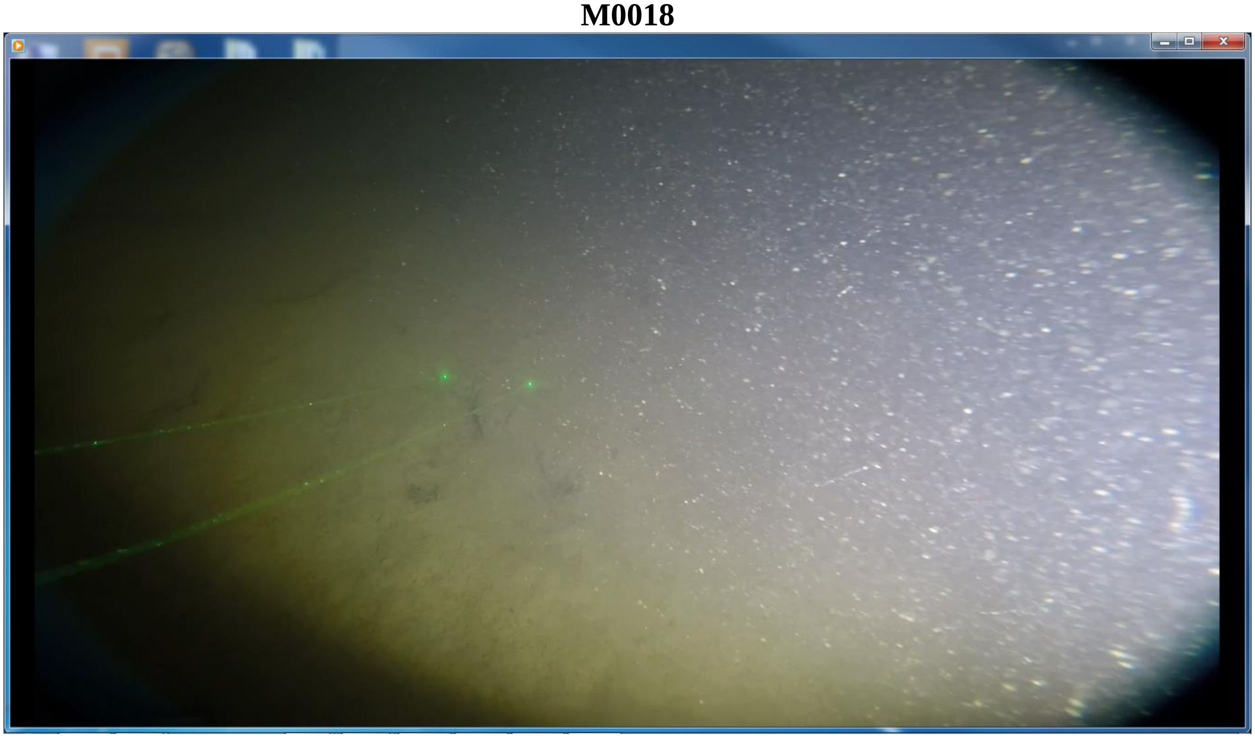
M0015

M0016

M0017

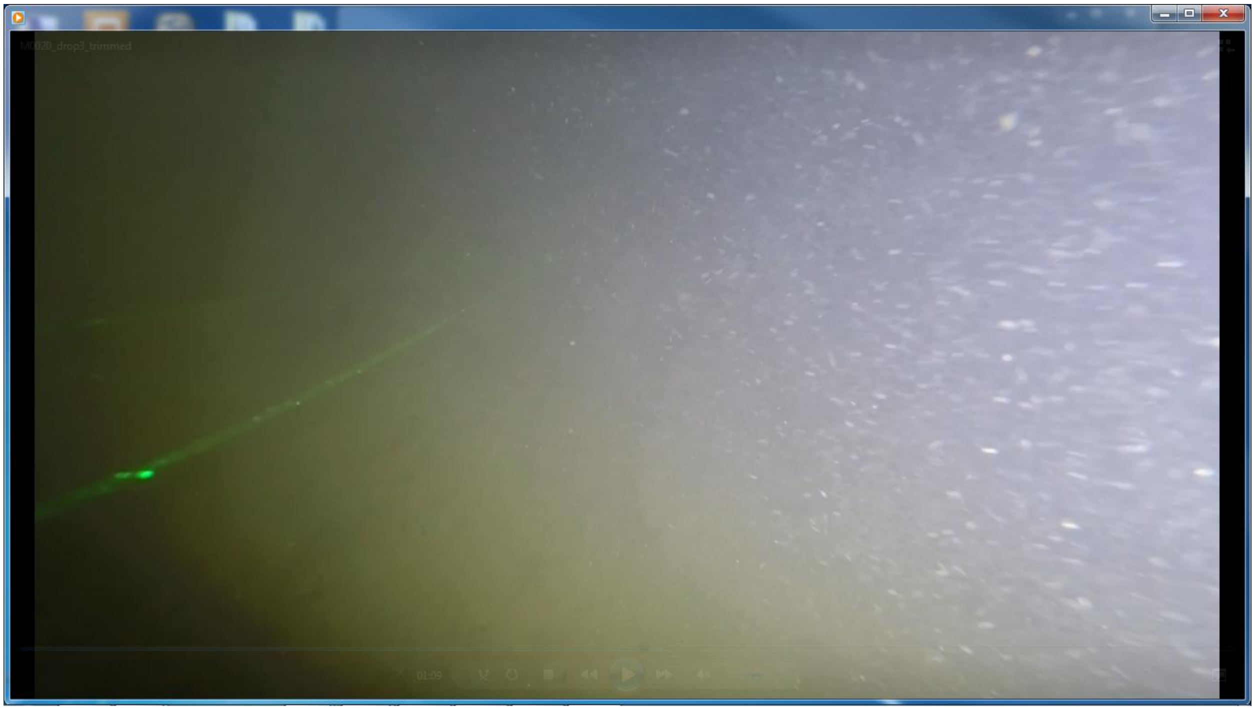


M0018

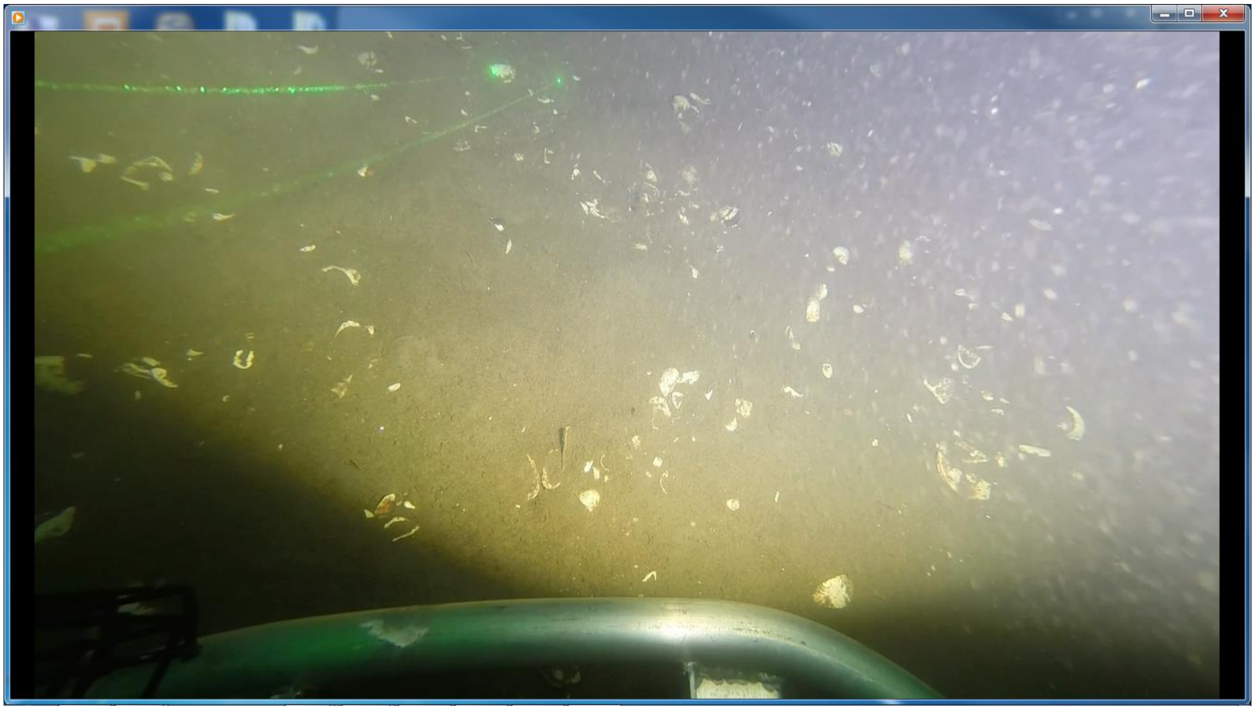


M0019

M0020



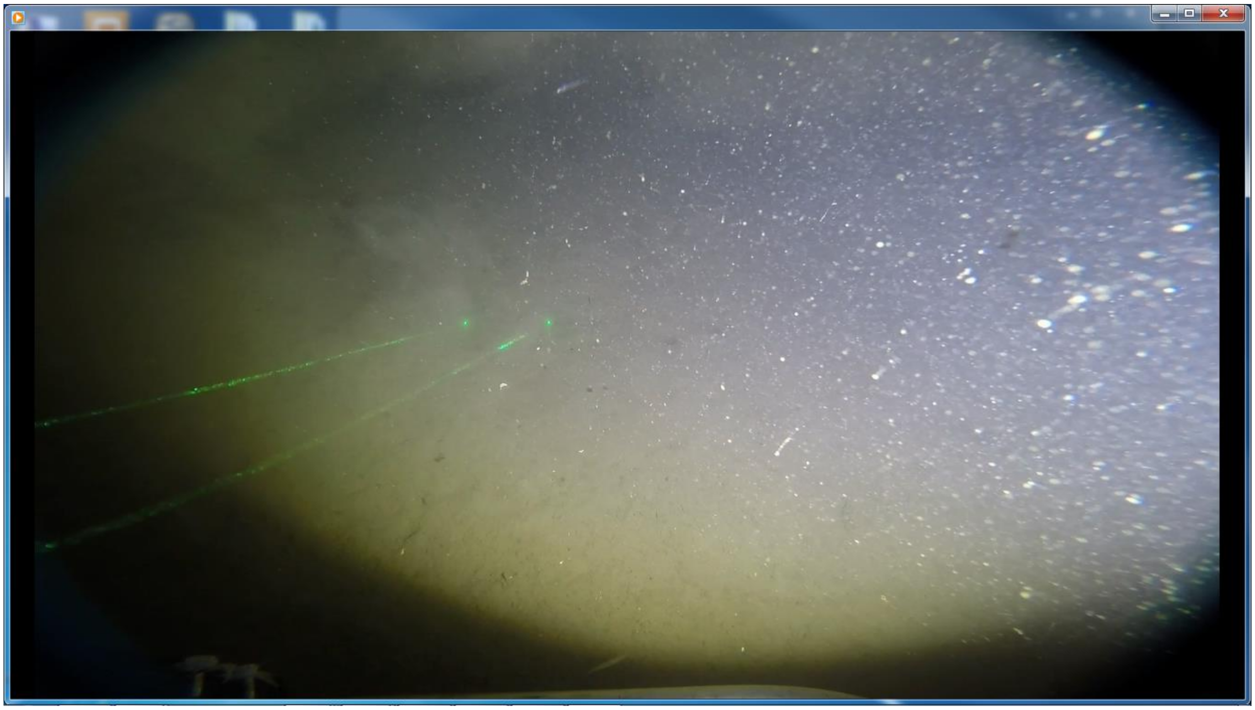
M0021



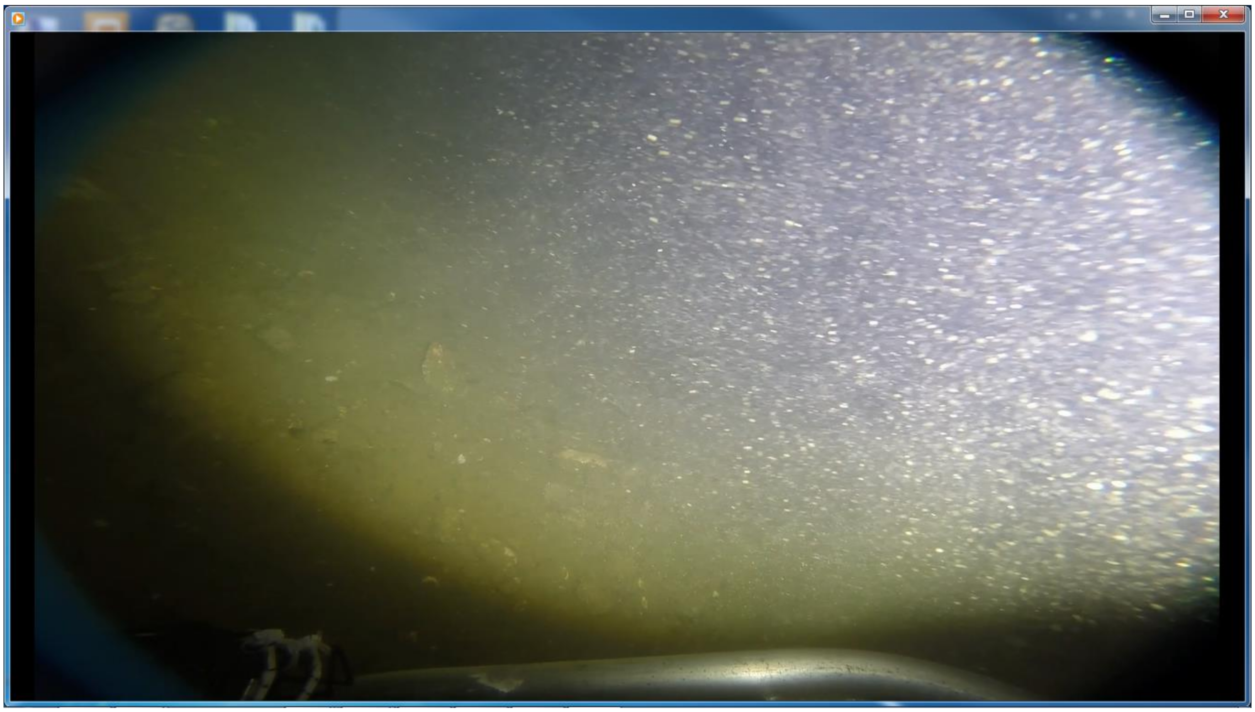
M0022

M0023

M0024

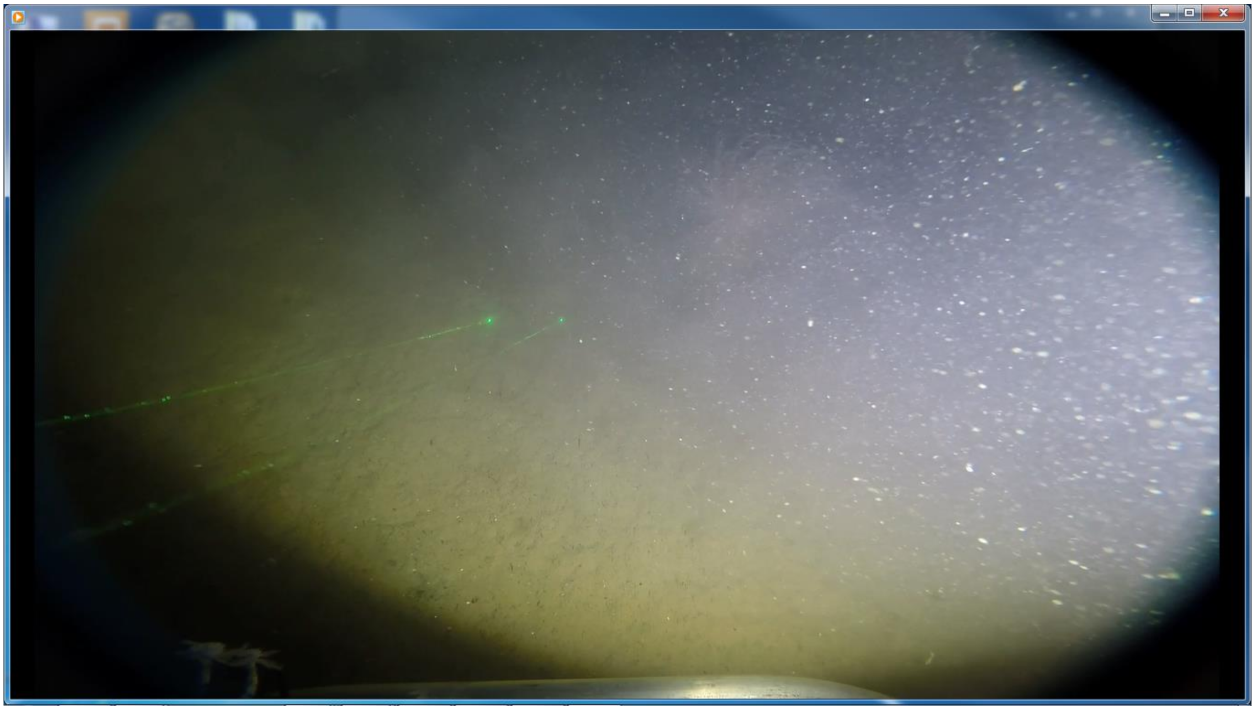


M0025



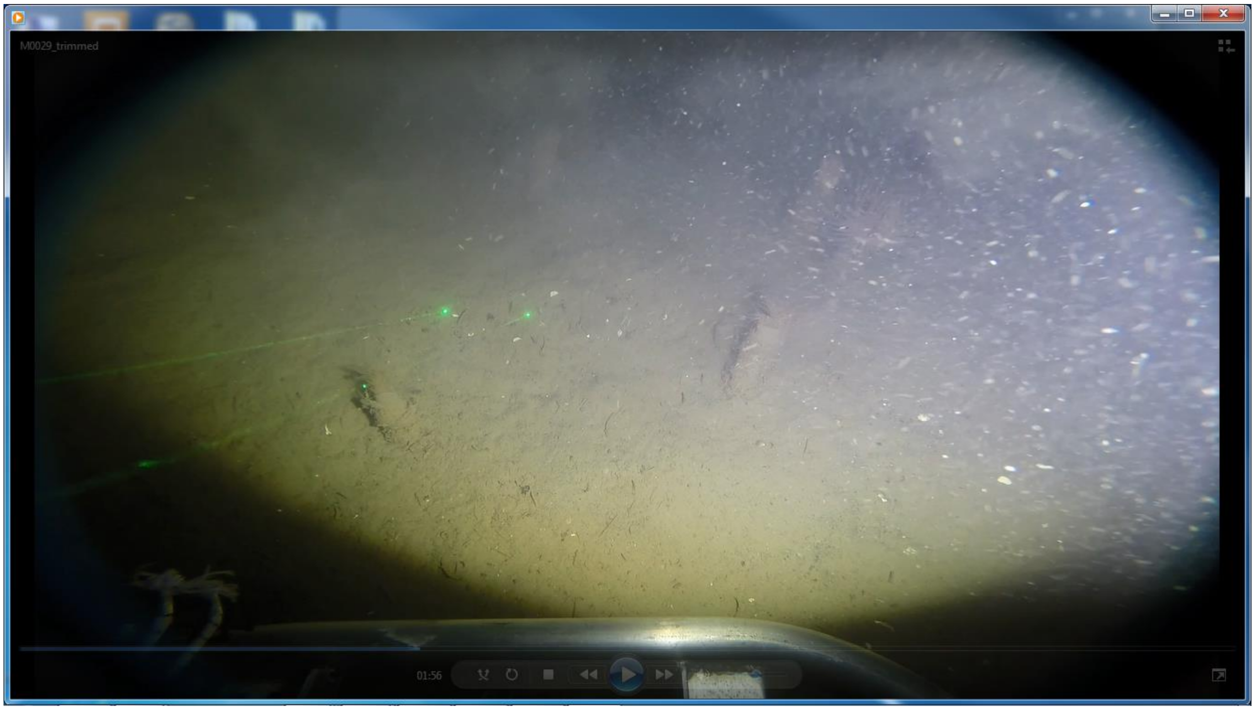
M0026

M0027



M0028

M0029



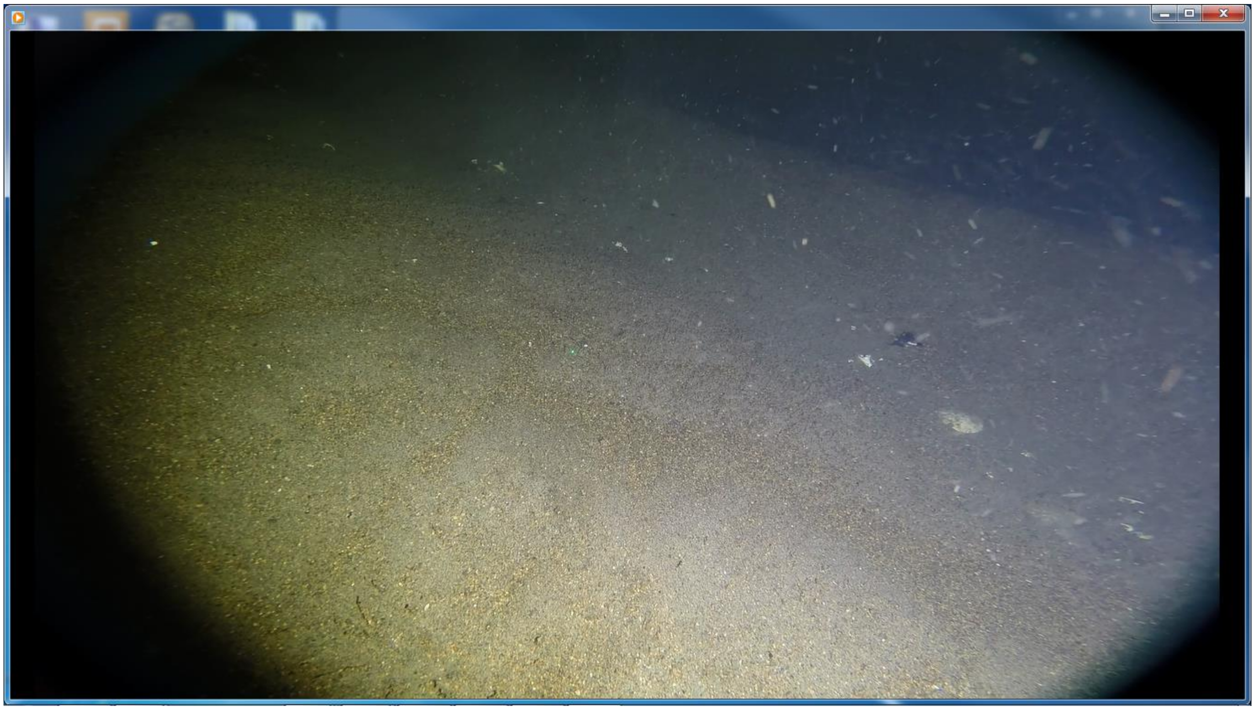
M0030

M0031

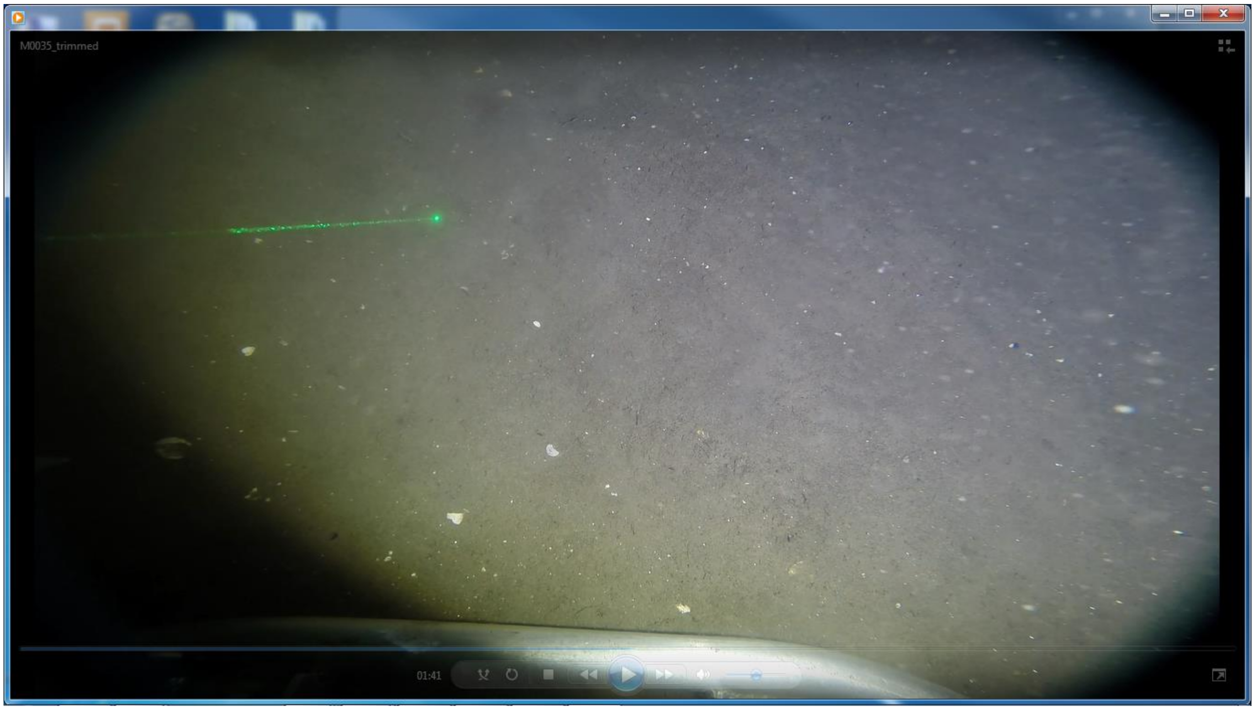
M0032

M0033

M0034



M0035



M0036

M0037

M0038

M0039

M0040

M0041

M0042

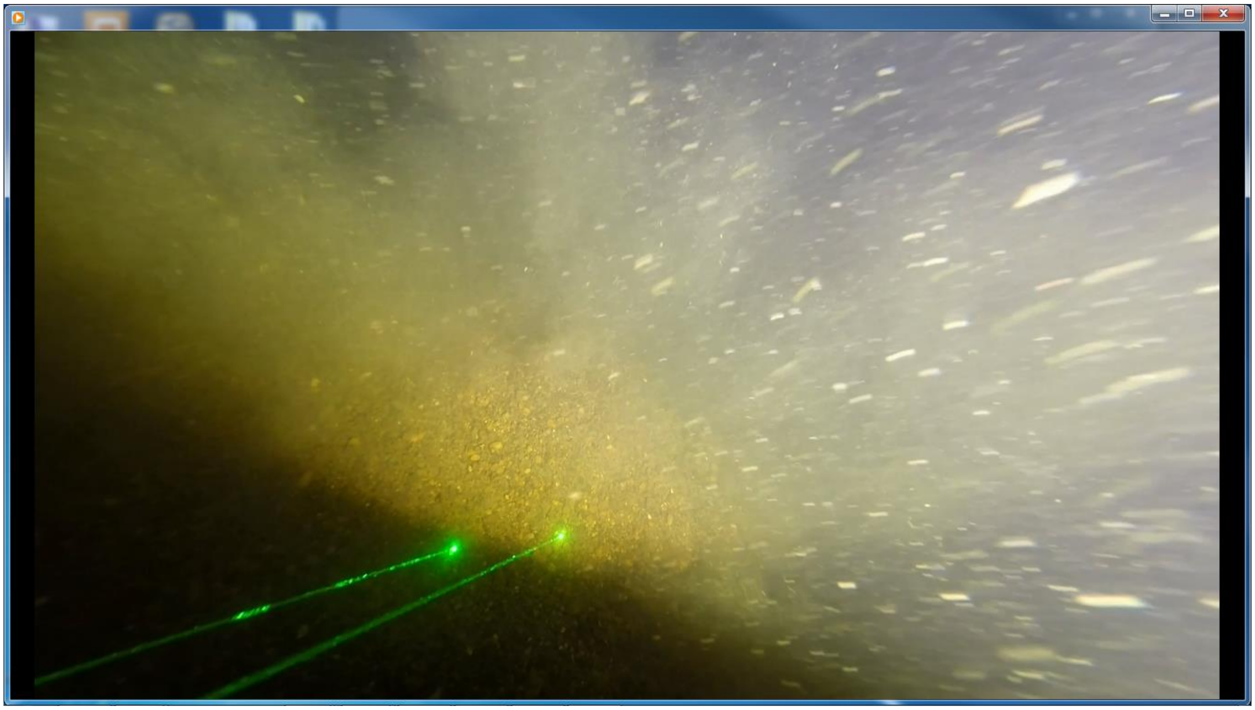
M0043

M0044

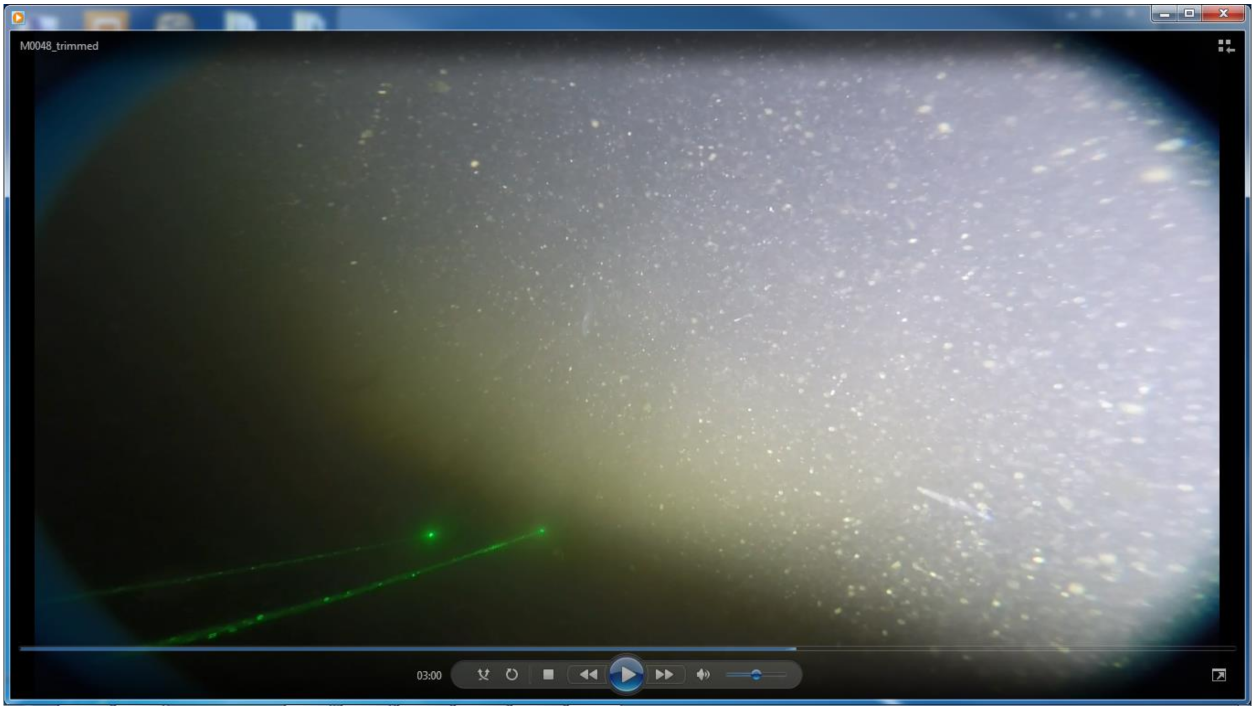
M0045

M0046

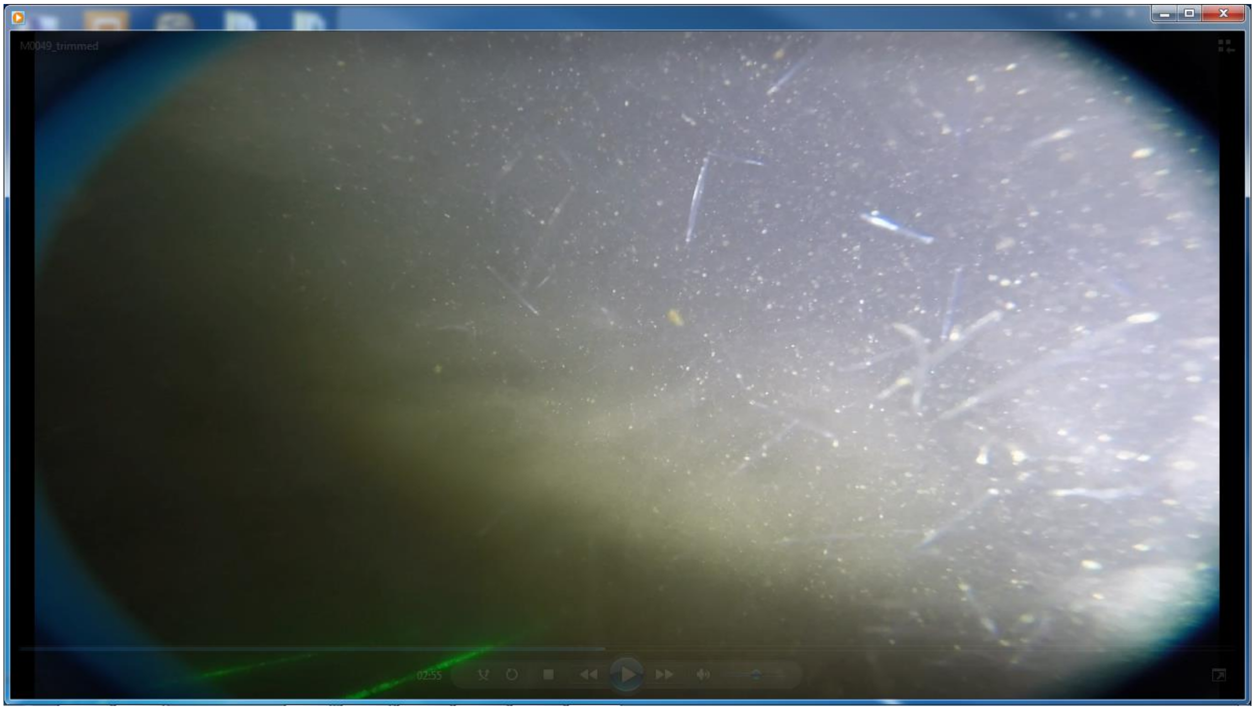
M0047



M0048

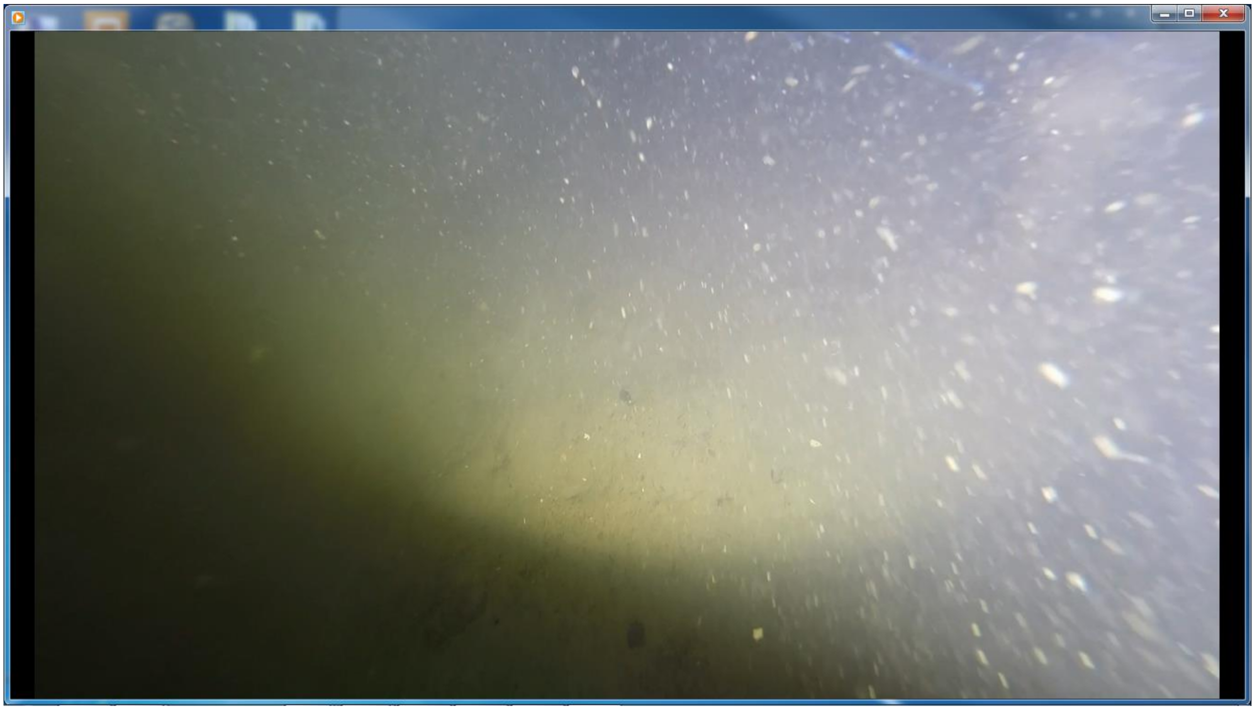


M0049



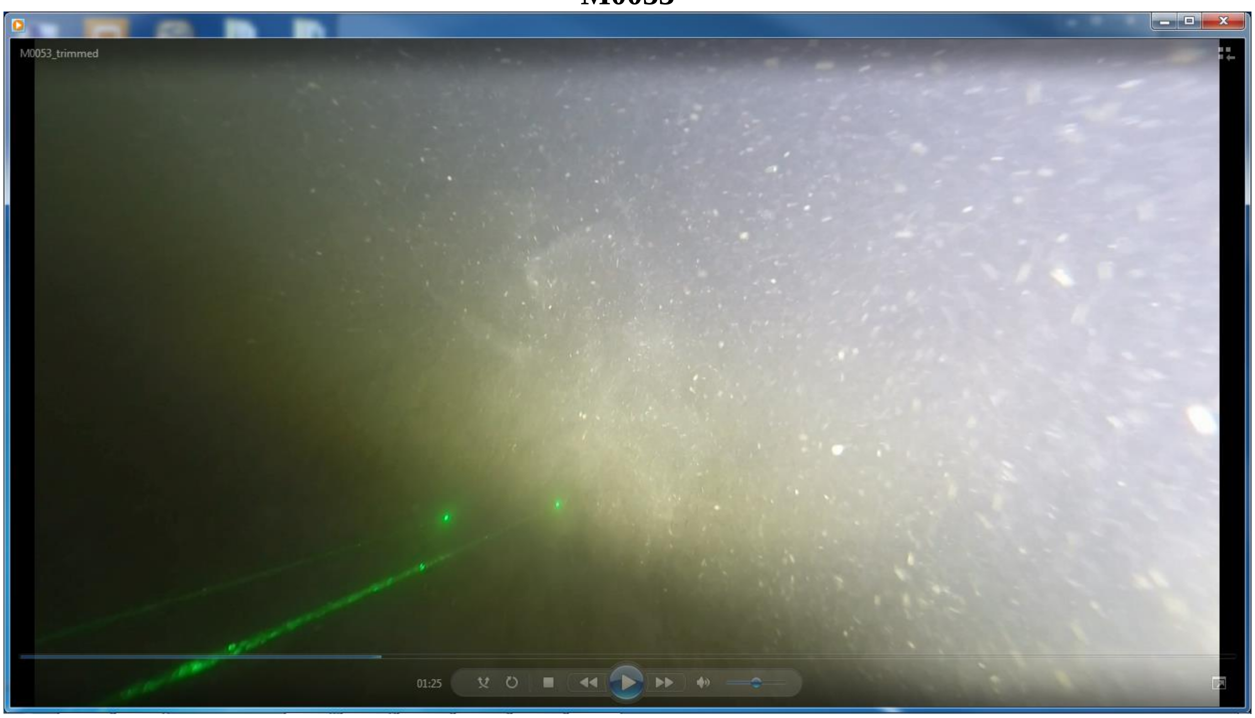
M0050

M0051



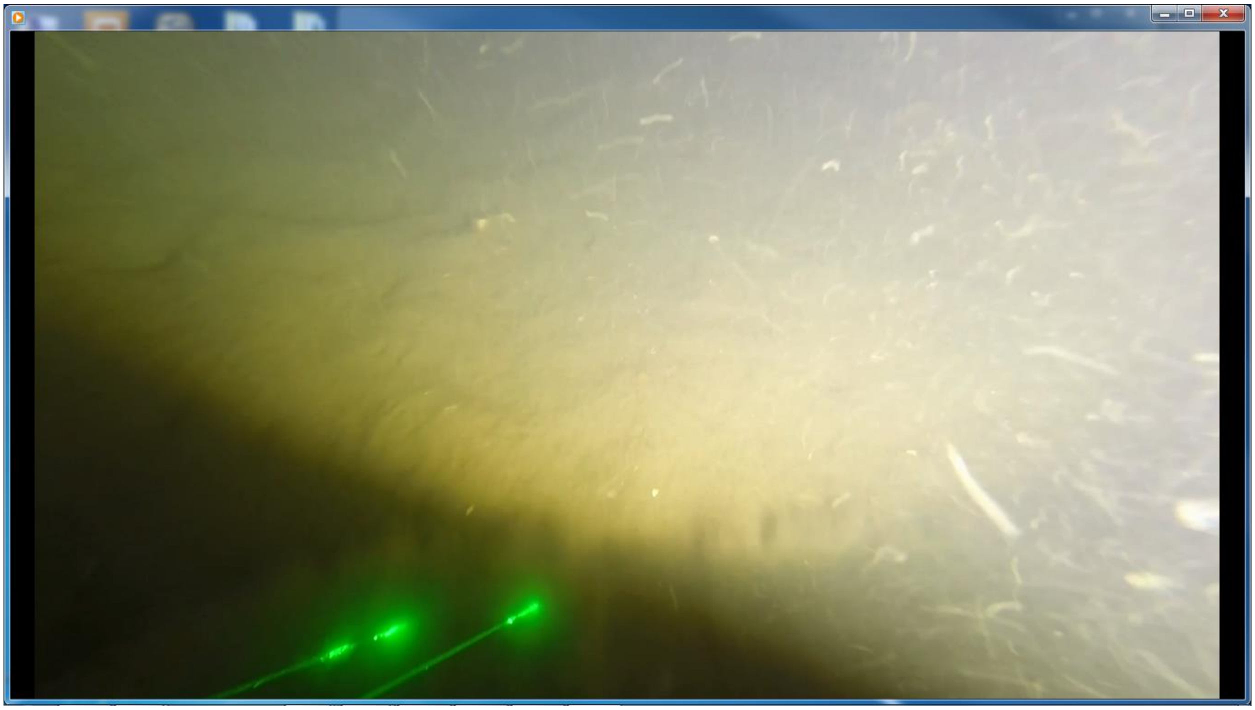
M0052

M0053

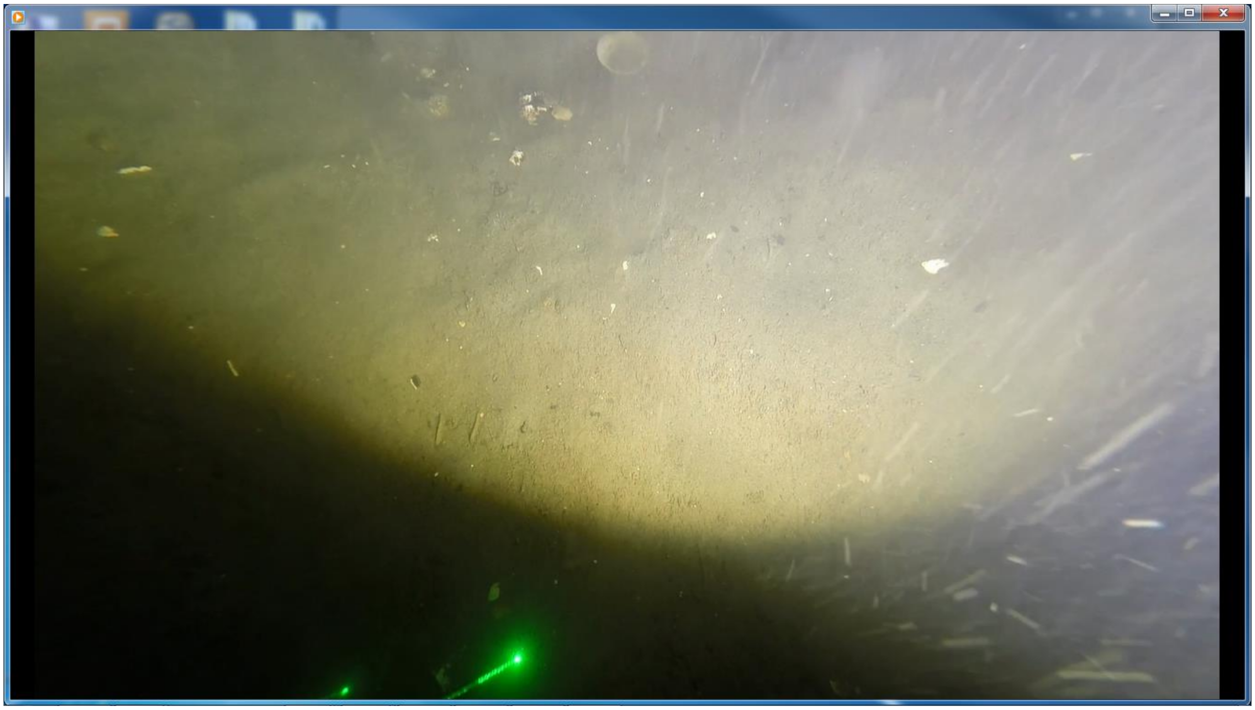


M0054

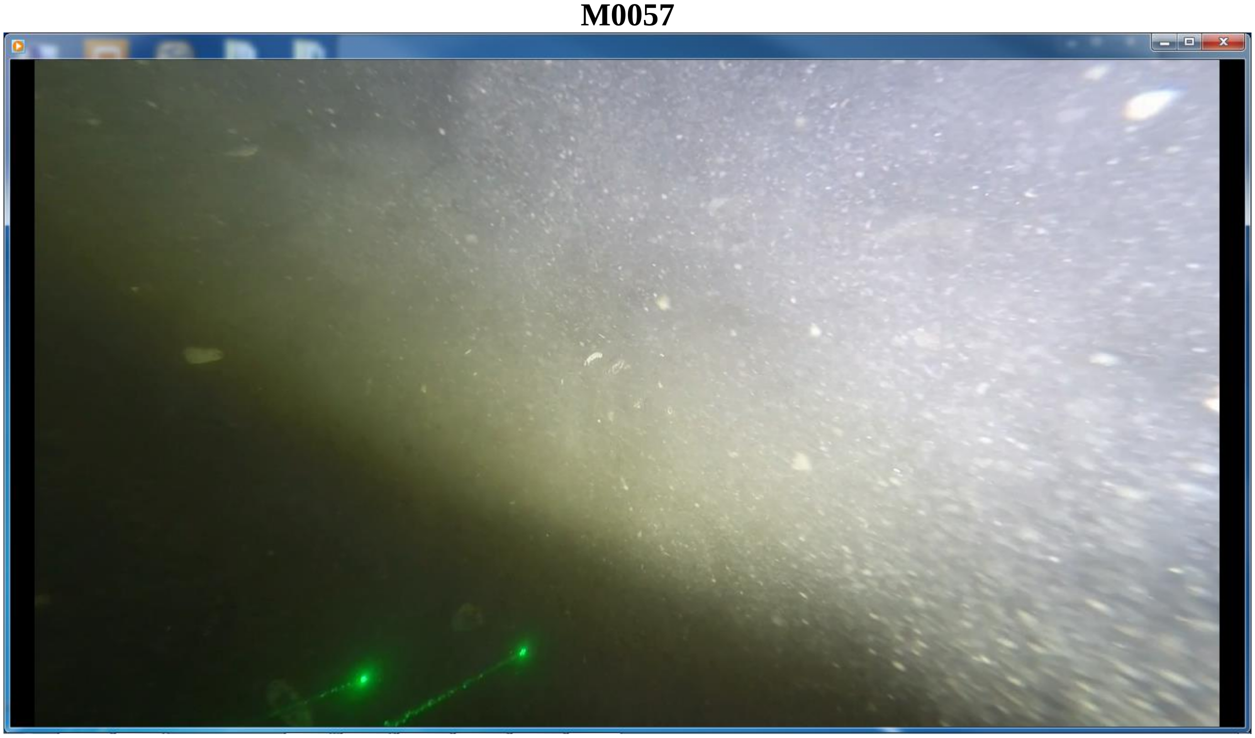
M0055



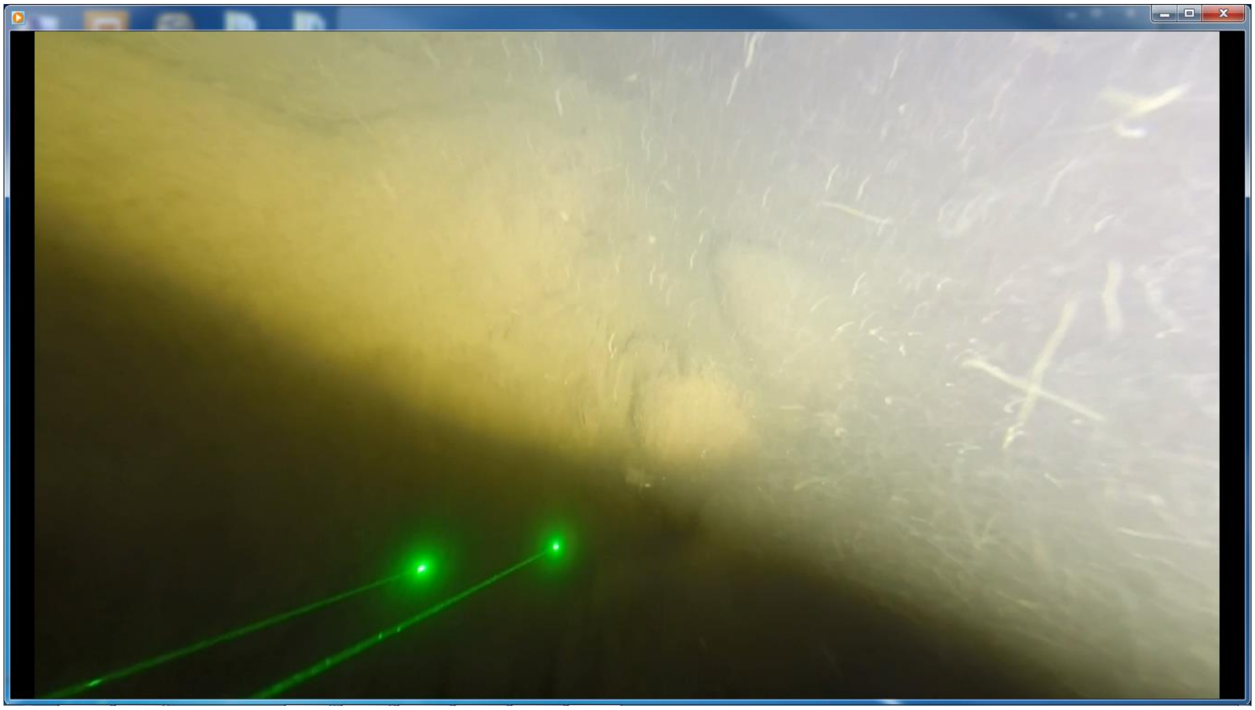
M0056



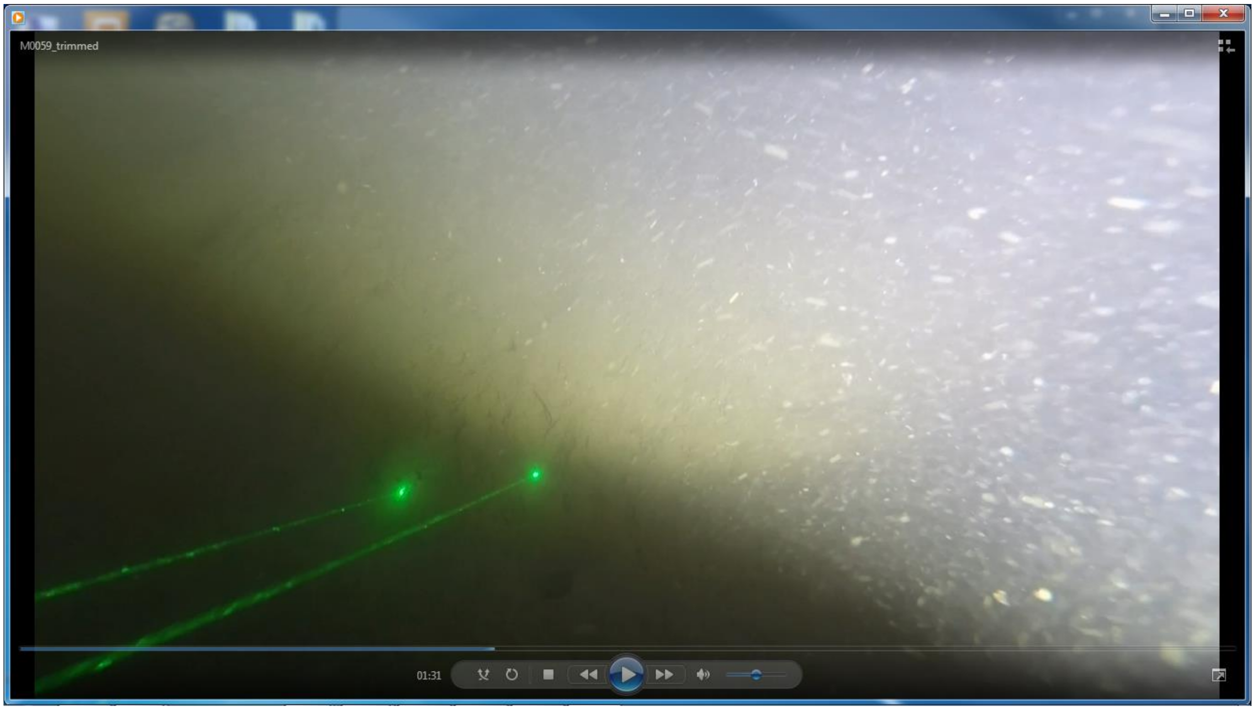
M0057



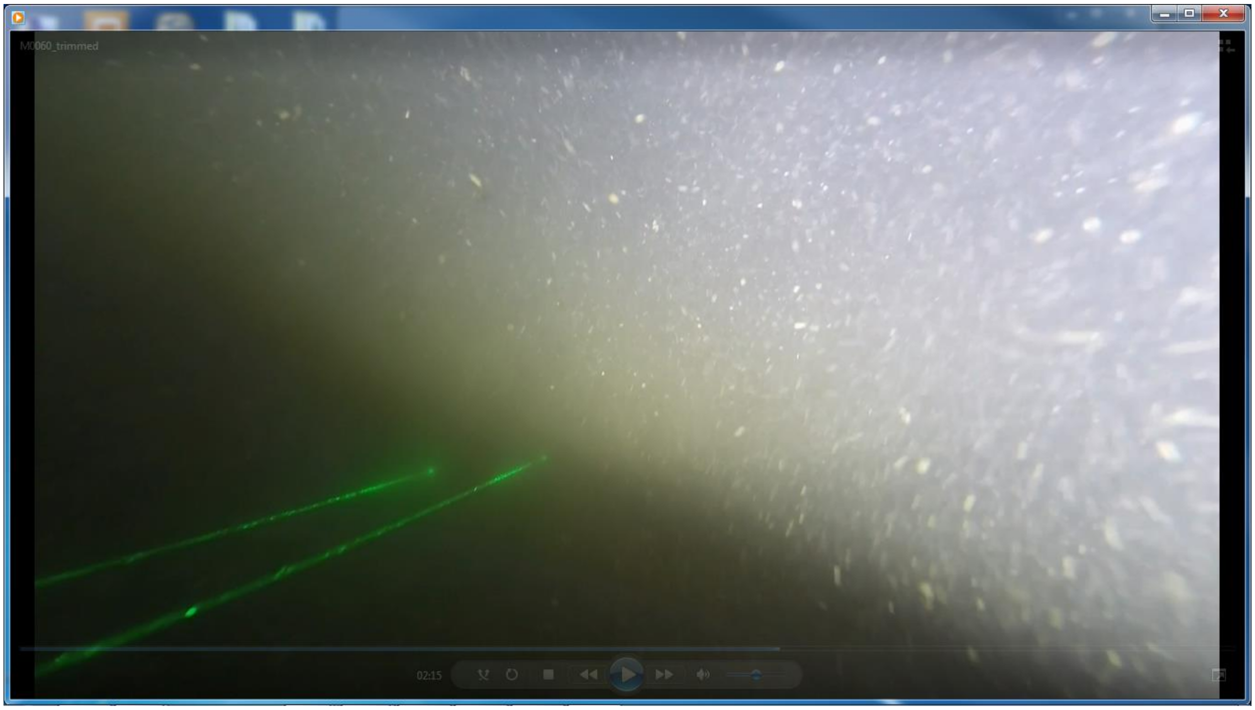
M0058



M0059



M0060



M0061