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Seafloor Sediment Textural Mapping of the Inner Continental Shelf: Cape Small to Cape Newagen, Maine

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This report is preliminary, but data and information published herein are accurate to the best of our knowledge. Data synthesis, summaries and related conclusions may be subject to change as additional data are collected and evaluated. While the Maine Coastal Program makes every effort to provide useful and accurate information, investigations are site-specific and applicability of results to other regions in the state is not yet warranted. The Maine Coastal program does not endorse conclusions based on subsequent use of the data by individuals not under their employment. The Maine Coastal Program disclaims any liability, incurred as a consequence, directly or indirectly, resulting from the use and application of any of the data and reports produced by staff. Any use of trade names is for descriptive purposes only and does not imply endorsement by The State of Maine.

For an overview of the Maine Coastal Mapping Initiative (MCMI) information products, including maps, data, imagery, and reports visit www.mainecoastalprogram.org.

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ABSTRACT

As part of a multi-year cooperative program of the Maine Coastal Mapping Initiative (MCMI), the National Oceanic and Atmospheric Administration (NOAA), and the Bureau of Ocean Energy Management (BOEM), this report presents a compilation of high-resolution maps and spatial data for the seafloor offshore of mid-coast Maine, between Cape Small and Cape Newagen, where approximately 137 mi^2 (355 km^2) of inner (e.g. landward of three nautical mile line)/outer (e.g. seaward of three nautical mile line) continental shelf was mapped with multibeam echosounder (MBES) data. Seafloor sediment textural maps were generated using a supervised classification technique that required MBES (bathymetry and backscatter) data, 1^{st}-order bathymetric derivatives, and grab sample data as inputs. The accuracy of textural output maps was evaluated using 201 sediment samples and/or bottom videos collected by the MCMI and other agencies. The accuracy of model output and its ability to produce areal distribution of sediment types and corresponding depths consistent with general interpretations of seafloor sediment distribution and morphology in the coverage area (Barnhardt, 1994; Kelley et al., 1987; 1997; 1998; 2003; 2007) suggest this is an efficient and effective method for mapping seafloor substrate. Two models identified areas of fine sand with an 80% accuracy. Overall, the products of this investigation are most useful for visualizing spatial trends in sediment and benthic habitat distribution and identifying and/or refining knowledge of resource (abiotic and biotic) potential.

Introduction

Sustainable management of Maine's coastal and marine resources is necessary to ensure effective coastal resiliency, responsible use, 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.

This report presents a synthesis of spatial data and a compilation of high-resolution maps for the seafloor offshore of mid-coast Maine between Cape Small and Cape Newagen. Approximately 137 mi^2 (355 km^2) of inner (landward of three nautical mile line)/outer (seaward of three nautical mile line) continental shelf was mapped, with a focus on waters less than 8 nm from the shoreline. The maps were produced as part of a multi-year cooperative program of the Maine Coastal Mapping Initiative (MCMI), a part of the Maine Coastal Program, the National Oceanic and Atmospheric Administration (NOAA), and the Bureau of Ocean Energy Management (BOEM). The maps are mainly based on multibeam echosounder (MBES) data, sediment samples, and bottom videos collected by the MCMI during the 2015 and 2016 field seasons (e.g. April to November) but have also incorporated sediment data collected previously by the Maine Geological Survey (MGS) in collaboration with the University of Maine (U.S. Department of Interior Minerals Management Service's Continental Margins Program cooperative agreement numbers 14-12-0001-30115 and 14-35-0001-30731; Regional Marine Research Program of NOAA Grant # NA46RM0451). The primary objectives of this program are to describe and characterize marine sediment in the coverage areas to identify potential sand and gravel resources for beach nourishment as outlined by BOEM, refine existing bathymetric and seafloor textural (e.g. sediment classification) maps, and enable benthic habitat classification via the federally-approved Coastal and Marine Ecological Classification Standard (CMECS; FGDC, 2012). These maps also add to the understanding of coastal processes, sediment dynamics in nearshore areas, and the regional geologic framework (see Barnhardt, 1994; Barnhardt et al., 1995; 1998;Dickson, 1999; Kelley et al., 1987; 1997; 1998; 2003; 2007).

This report focuses on the methods and results pertaining to the seafloor textural classification and sediment mapping using advanced geographic information systems (GIS) tools. The methods and results pertaining to the habitat classification objective are presented in Ozmon, 2017. Detailed descriptions of MBES data collection, processing, and related data products (e.g. bathymetric rasters and backscatter mosaics)generated from individual field seasons are presented in Dobbs, 2016a; 2017a. Sediment sampling methods, analyses, and all related data products (e.g. grain-size data, sample locations, etc.) are presented in Dobbs, 2016b; 2017b. All data, maps, imagery, presented here and in the related reports are available for download at www.mainecoastalprogram.org.

Focus Area and Previous Work

The Cape Small-Cape Newagen focus area (Figure 1) lies in the northwestern Gulf of Maine just offshore of the Kennebec River mouth in mid-coast Maine. The general outline of the coast is largely controlled by the structural framework of bedrock in a region characterized by numerous elongate bedrock peninsulas separated by relatively narrow estuaries. Late Quaternary deglaciation and relative sea-level changes caused by widespread isostatic adjustments have resulted in extensive reworking of sediments deposited seaward of the Kennebec River mouth (Kelley et al., 1998).

Previous work in the focus area (Figure 1) is extensive and describes the overall morphology as the submerged Kennebec River paleodelta (Barnhardt, 1994; Kelley et al., 1987; 1997; 1998; 2003; 2007). The lobate submarine expression of this feature consists of a sandy, gently-sloping nearshore ramp that is abruptly terminated to the east and south around the 55-meter isobaths (Figure 2), which has been interpreted as the early Holocene lowstand sea-level (Schnitker, 1974; Kelley et al., 1992; Barnhardt et al., 1995). Beyond the 65-meter isobaths the seabed consists of muddy shelf valleys bound by steep, rocky outcrops. The full extent of the paleodelta sediments were previously mapped (Kelley et al., 1987; Belknap et al., 1989) using seismic reflection profiles, bottom samples, and side-scan sonar. However, the lack of complete bottom sonar coverage and limited sample data have yielded poor resolution overall. The additional seafloor sediment samples and high-resolution multibeam data collected by the MCMI during the 2015 and 2016 field seasons has supplemented existing data resources and enabled considerable refinement of sediment distribution and resource assessments for this region.

Data Collection and Processing

High-resolution MBES data (e.g. bathymetry and backscatter intensity) were used to map approximately 137 mi^2 (355 km^2) of the seafloor in nearshore and offshore areas. The mapping was conducted over the course of the 2015 and 2016 field seasons (April – November), which respectively encompass the eastern and western portions of the focus area (Figure 3). This report focuses on the methods and results pertaining to the seafloor textural classification and sediment mapping, and only briefly summarizes MBES and sediment data collection and processing. Detailed descriptions of MBES data collection, processing, and related data products (e.g. bathymetric rasters and backscatter mosaics) generated from individual field seasons are presented in Dobbs, 2016a; 2017a. Sediment sampling methods, analyses, and all related data products (e.g. grain-size data, sample locations, etc.) are presented in Dobbs, 2016b; 2017b.

Multibeam surveys/bathymetry and backscatter collection

MBES data (e.g. bathymetry and backscatter) were acquired aboard the R/V Amy Gale with a Kongsberg EM2040C set to a survey frequency of 300 kHz, high-density beam forming, with 400 beams per ping. Positioning, navigation, and inertial measurements were logged with dual frequency GNSS antennas and an MRU 5 inertial sensor within a Kongsberg Seapath 330. The EM2040C and Seapath 330 were interfaced with Quality Positioning Services (QPS) QINSy (Quality Integrated Navigation System; v.8.12) software, which was used for real-time navigation, survey line planning, data logging, and visualization. Parallel lines with consistent spacing (based on depth) were run at 6 – 6.5 knots throughout the survey area. Raw bathymetry data were post-processed (e.g. corrected for tidal offsets and referenced to a vertical datum) and gridded at 4-meter resolution using Qimera (v.1.3.6). Time-series backscatter data were processed and mosaicked at 4-meter resolution using QPS' Fledermaus Geocoder Tool (FMGT; v.7.7.0) software. For complete details pertaining to the multibeam data collection and processing refer to Dobbs 2016a; 2017a.

Bottom sampling

In federal waters (seaward of three nautical mile line), most 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 (Territorial Sea), sampling locations were chosen by a stratified random sampling design 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.; inferred from a review of MBES data), as well as to fill in spatial data gaps within pre-existing data sets.

The bottom sampler was a single platform rig (Figure 4) outfitted with a clamshell style Ponar grab sampler, GoPro Hero 3+ digital video camera in a Group B Inc. deepwater dive housing, Keldan underwater dive light, dive lasers spaced at 10 cm for scale, and a Xylem Exo 1 to collect water column data (e.g salinity, temperature, pH, dissolved oxygen, and chlorophyll concentrations; see Ozmon, 2017 for details). 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 (see Ozmon, 2017). Sediment subsamples were then bagged, labeled, and stored in coolers until reaching 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 and confirmed later with video footage captured during each sampling attempt. Coordinates (WGS84, UTM Zone 19N meters; GPS horizontal accuracy at surface ±3 m) were recorded when 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. Due to vessel and/or sampler drift the horizontal positioning error may be as much as ±10 m. The real-time depth for each location was determined using a hull-mounted single-beam fathometer and was not referenced to a specific vertical datum (e.g. mean lower low water, MLLW). As a result, the vertical uncertainty associated with real-time depths recorded in field notes for each site was as much ±3 m (approximate mean tidal range). However, true depth (referenced to MLLW in meters) at each sample site was extracted from the final bathymetric surface (4-m grid) and was included with the sediment sample data.

Sediment samples were analyzed using standard laboratory techniques for the textural analyses of marine sediments (Poppe et al., 2005) by the sedimentology laboratory at the University of Maine. The Wentworth (1922) grain-size scale was used for major textural splits, and in instances where the silt/clay ratio could not be determined accurately (e.g. mud-sized (silt + clay) portion was less than 5% of total weight) total mud was divided evenly between silt (phi size 4 - 8) and clay (phi size 8 - 12) fractions. The proportion of gravel-, sand-, silt-, and clay-sized particles were used to classify the overall sample using Folk (1974). The remainder of each bulk sample was preserved for archiving at the MCP headquarters in Augusta, ME.

Sample site coordinates, depth, grain-size data, and additional attributes are located in Appendix A.

Seafloor textural mapping

The textural diversity in the focus area is a reflection of the processes that took place during late Quaternary (de)glaciation and sea-level changes, which resulted in extensive reworking of sediment. In many cases, distinct textural changes (e.g. unconsolidated sediment within bedrock fractures) occur over spatial scales that are too small to adequately characterize with a traditional sampling scheme. As a result, existing maps of seafloor geology are based on manual interpretations and interpolations between widely spaced side-scan sonar records and bottom samples in the study area(Kelley et al., 1987; Belknap et al., 1989); mainly serving as qualitative maps of sediment distribution.

Within the last two decades geographic information system (GIS) tools have been used to develop quantitative statistical methods (e.g. Rooper and Zimmerman, 2007; Whitmire et al., 2007; Erdey-Heydorn, 2008; Stephens and Diesing, 2014) for mapping seafloor sediment/bottom type with MBES and ground-truthing data. These methods generally employ the use of bathymetric data, first-order bathymetry derivatives (e.g. slope, rugosity, aspect, etc.), backscatter intensity, seafloor sediment grain-size data, and/or seafloor video recordings to employ supervised classification techniques that predict seafloor substrate based on statistical relationships. The supervised textural classification method described by Erdey-Heydorn (2008) was chosen for this investigation because preliminary analyses using a subset of data collected by MCMI in 2015 suggest this technique was suitable for accurately delineating seafloor substrate at relatively large scales (> 1:100,000) that are generally suitable for a variety of applications (e.g. resource assessments, geomorphic interpretations, benthic habitat). This method was also desirable because it incorporates experienced manual interpretation of MBES data and the efficiency of a GIS.

Due to their similar methodology, the results of Erdey-Heydorn (2008) and Whitmire et al. (2007) were used for comparison with results in this investigation. In contrast to this study, both of the former study areas took place in an active continental margin setting off the west coast of the United States (Point Reyes, California and the Hecta Bank offshore Oregon, respectively). However, the overall seabed morphologies were similar to our study area in depth (0 to 150 meters), unconsolidated terrigenous sediment (mud, sand, gravel, and boulders) reworked during lowstands of sea level, and high- and low-relief bedrock exposures.

Two separate textural models were run for this investigation, a 7-class model conforming to a modified version of the CMECS substrate group classification (FGDC, 2012) and a simplified 4-class model (Table 1). The 4-class model was created to determine if simplification of model input classes would increase model accuracy.

The step-by-step procedure used to perform the seafloor textural mapping using ArcGIS (v.10.4.1) is described below.

1. Choose textural classification scheme

First, all sample sites (n = 201; 126 MCMI samples sites plus 75 sites from other agencies; Figure 5) were assigned a textural class based on a modified version of the CMECS substrate groups, where a preliminary analysis of grain-size distributions in unconsolidated samples and backscatter data suggested that grabs/video sites would be confidently represented by the following 7 classes (column 3 in Table 1): bedrock/rocky , gravel/gravel mixes , gravelly medium-coarse sand, fine sand, muddy sand, mud, and slightly gravelly sand-mud mixtures.

For the simplified 4-class model, classes from the 7-class model were generalized into the following 4 classes (column 4 Table 1): bedrock/rocky, gravelly mixtures (gravel/gravel mixes + gravelly medium-coarse sand + slightly gravelly), fine sand (fine sand + muddy sand), and mud.

Once all samples were classified, a shapefile feature class (geometry type = point) containing all sample attributes was created to plot the sample locations on the map. Sample site attributes (e.g. ID, coordinates, grain-size data, etc.) are provided in Appendix A.

Table 1 – Modified CMECS substrate groups (FGDC, 2012) and textural classes used for 7-class model (column 3) and 4-class (column 4) model.

Modified CMECS Substrate Group	**CMECS Substrate SubGroup**	**Modified CMECS Substrate Groups for 7-Class Textural Model**	**Modified CMECS Substrate Groups for 4-Class Textural Model**
Bedrock/rocky		Bedrock/rocky (confirmed with video)	Bedrock/rocky
Gravel	Boulder	Gravel/gravel mixes (samples containing ≥ 30% gravel)	Gravel/gravel mixes/gravelly/slightly gravelly
	Cobble		
	Pebble		
	Granule		
Gravel Mixes	Sandy Gravel		
	Muddy Sandy Gravel		
	Muddy Gravel		
Gravelly	Gravelly Sand	Gravelly medium-coarse sand (includes samples with 5-30% gravel and samples with >90% sand with a mean phi size < 2, even if gravel content is up to 5%)	
	Gravelly Muddy Sand		
	Gravelly Mud		
Sand	Very Coarse Sand		
	Coarse Sand		
	Medium Sand		
	Fine Sand	Fine sand (samples having 0-5% gravel, ≥ 90% sand, and a mean phi size between 2 and 4)	Fine and (fine sand + muddy sand)
	Very Fine Sand		
Muddy Sand	Silty Sand	Muddy sand (silty sand + clayey sand + muddy sand; Folk, 1974)	
	Silty-Clayey Sand		
	Clayey Sand		
Sandy Mud	Sandy Silt	Mud (sandy mud + silt + clay)	Mud
	Sandy Silt-Clay		
	Sandy Clay		
Mud	Silt		
	Silt-Clay		
	Clay		
Slightly Gravelly	Slightly Gravelly Sand	Slightly gravelly sand-mud mixtures (0.01-5% gravel, excluding samples with > 90% sand)	Gravel/gravel mixes/gravelly/slightly gravelly
	Slightly Gravelly Muddy Sand		
	Slightly Gravelly Sandy Mud		
	Slightly Gravelly Mud		

2. Add input rasters and analyze input data

Bathymetry and backscatter rasters (4-m grids) were added to ArcGIS and rasters for 1st-order bathymetry derivatives (hillshade, rugosity, and slope) were created using their respective tools in the 3D Analyst toolbox. Hillshade is a shaded relief raster of bathymetry that serves as an analog for slope aspect. The rugosity layer was computed by determining the ratio between three dimensional surface area and planar surface area using the Surface Area to Planar Area tool in the Benthic Terrain Modeler toolbox available for download at https://coast.noaa.gov/digitalcoast/tools/btm.html.

Next, a multivariate analysis was performed on input rasters (bathymetry, hillshade, slope, rugosity, and backscatter intensity) to eliminate co-dependent layers that would later be used to establish relationships within and between textural classes. This was accomplished using the Band Collection Statistics tool in ArcGIS (v.10.4.1) and selecting the 'compute covariance and correlation matrices' option.

3. Create training polygons

This step required manual interpretation of bathymetry, bathymetric derivatives, and backscatter intensity data to manually delineate polygons for each of the textural classes. The samples in this feature class would later serve as the 'training' samples used to establish statistical relationships, or 'signatures' with input rasters. The objective of this step was to outline as many representative polygons as possible for each textural class, with at least two polygons for each class. A total of 60 training polygons were created for the 7-class model (N=60; table 2). The same 60 training polygons were reclassified according to the more generalized 4-class model (Table 3).

Table 2 – Textural classes and polygons (n) created for each class in the 7-class model. Polygons (N=60) were used as the input feature class to create signatures based on relationships between textural classes and input rasters.

Textural Class	**n**
Bedrock/rocky	21
Gravel/gravel mixes	5
Gravelly medium-coarse sand	11
Slightly gravelly sand-mud mixtures	4
Fine sand	7
Muddy sand	4
Mud	8
Total	60

Table 3 – Textural classes and polygons (n) created for each class in the 4-class model. Polygons (N=60) were used as the input feature class to create signatures based on relationships between textural classes and input rasters.

Textural Class	n
Bedrock/rocky	21
Gravelly mixtures	16
Fine sand	14
Mud	9
Total	60

4. Create signatures

Once the final input rasters were selected for further analysis the Create Signatures spatial analyst tool was used to create an ASCII signature (.GSG format) file based on the training sample polygons for each textural class model and the input rasters.

5. Generate output raster

The final step used the Maximum Likelihood Classification (MLC) spatial analyst tool, which uses the signature file and final input rasters to assign a textural class to each cell in an output raster. Several trial-and-error runs (steps 3-5) were performed to visually evaluate the training samples effectiveness before choosing the final output raster used for generalization and analysis. For example, if the MLC output resulted in egregious misclassification of distinct texture classes in certain areas (e.g. rock misclassified as sand), then additional polygons were added to the training feature class until the MLC output raster was deemed reliable. Once the final MLC output raster was chosen, the analysis proceeded by performing raster generalization.

6. Raster generalization

Misclassifications resulting from noisy MBES data are common (Dartnell and Gardner, 2004) and can distract from the overall understanding of final maps generated from these data. Therefore, raster generalization was necessary to eliminate as many areas as possible that were misclassified as a result of noise in the MBES backscatter data. Misclassifications resulting from noise are easily identified in the MLC output, where most appear as diffuse, linear zones in the MBES nadir region parallel to survey tracklines (Figure 6).

Raster generalization began by applying the Boundary Clean tool with the 'descend' sorting technique and choosing the option to run the expansion and shrinking twice. Next, the Majority Filter tool (number of neighbors = 8; replacement threshold = majority) was applied to the boundary clean output raster. The majority filter helps reduce noise in the output raster by replacing cells based on the majority of their contiguous neighbors. Figure 6 illustrates the generalization process and its ability to remove/reduce noise in the original MLC output. Since this simple generalization procedure was unable to remove all noise artifacts from the final output, further generalization was performed manually before proceeding with further analysis.

7. Model Assessment

The accuracy of the final textural classification raster for each model was evaluated by determining whether the value of output raster cells containing sample sites matched the textural class assigned to each sample site (198 total = 126 MCMI samples and 72 MGS/UMaine samples). Three sample sites were removed from the model evaluations due to a distinct location discrepancy between textural class and location. For example, if a site was classified as a mud based on grain-size data but was clearly plotted atop a bedrock outcrop (or vice versa), then it was removed from the final analysis (Figure 7). The excluded samples are denoted with a double asterisk in Appendix A.

Results

Map of predicted seafloor substrate were generated using a 7-class model (Figure 8) and a more generalized 4-class model (Figure 9). The raster input layers (4-m cell size) initially considered for the textural classification included bathymetry, backscatter intensity, rugosity, slope, and hillshade (Figure 10a through e). Raster band collection statistics indicated the slope raster was strongly correlated (r = 0.80) with rugosity and had a low-medium correlation (r = 0.30) with backscatter. Due to the strong correlation with the rugosity layer the slope raster was not considered in the final analyses. Complete input raster band collection statistics are provided in Appendix B.

Overall, the 7-class model did a good job of predicting the distribution of major sediment types, where 67% (134 out of 198) of output raster cell classifications were in agreement with sample site classifications. The 67% accuracy of this model is slightly lower than the 72% accuracy achieved by Erdey-Heydorn (2008) and much higher than the 52% achieved by Whitmire et al. (2007). Although these studies used comparable model inputs, their models used fewer classes and their methods of evaluating model accuracy differed from this investigation. The Erdey-Heydorn (2008) study included only 5 textural classes (fine sand, medium sand, coarse sand, coarse sand/gravel, and rock) and model accuracy was evaluated on a per-area basis by comparing the model output raster with manually delineated textural classes over the entire study area. Whitmire et al. (2007) also included only 5 classes (mud, sand, cobble, boulder, and rock) but used a decision tree model for their analysis.

Similar to Erdey-Heydorn (2008) and Whitmire et al. (2007), model accuracy in this investigation varied between individual classes. The highest accuracy was achieved for rocky sites (83% correct), which was in contrast to Erdey-Heydorn (2008) and Whitmire et al. (2007) where accuracy was the lowest for rocky substrates. The 7-class model also performed well for relatively homogeneous unconsolidated substrates, where fine sand and mud sites achieved 80% and 81% accuracy, respectively. Model accuracy was lower for classes containing heterogeneous mixtures such as muddy sand (67%), gravelly medium-coarse sand (57%), and slightly gravelly (55%) classes. Model performance was very poor for sites classified as gravel/gravel mixes (25% correct), and the majority (70%) of misclassifications at these sites were from a different gravel-themed class (e.g. gravel/gravel mixes site misclassified as gravelly or slightly gravelly). Results of the 7-class textural model assessment are summarized in Table 4.

Table 4 – Evaluation summary for the 7-class textural model.

Textural Class of Sample Site	n	Total Incorrect	Total Correct	% Correct
Bedrock/rocky	41	7	34	82.9%
Mud	57	11	46	80.7%
Muddy sand	15	5	10	66.7%
Gravelly medium-coarse sand	35	15	20	57.1%
Gravel/gravel mixes	20	15	5	25.0%
Fine sand	10	2	8	80.0%
Slightly gravelly sand-mud mixtures	20	9	11	55.0%
Total	198	64	134	67.7%

Distributions of sediment classes in the model output (Figure 8) closely resembled areal distributions reported for the region by Kelley et al. (1998). Mud accounted for the largest portion of the coverage area (37%) and was mostly present at depths greater than 55 m, expect for in the western- and northern-most areas near Casco Bay and Sheepscot Bay, respectively. Bedrock/rocky areas made up the second largest class at approximately 23%. Gravelly medium-coarse sand made up approximately 15% of the coverage area and was typically found at depths between 30 and 50m. Fine sand accounted for approximately 8% of the coverage area and was concentrated in nearshore areas at depths less than 30 m. Slightly gravelly sediment made up approximately 8% and was concentrated along the southern margin of the paleodelta at depths between 40 and 60 m and between rocky outcrops at depths between 50 and 70 m. Muddy sand accounted for approximately 7% of the total area and was concentrated within the eastern and western margins of the paleodelta at depths between 45 and 60 m. Gravel/gravel mixes only accounted for less than 2% of total area and were restricted to the southern portion of the paleodelta at depths between 40 and 50 m; however, grain-size data suggest that gravel mixes are prevalent and intermixed with many areas classified in this model as gravelly medium-coarse sand and are present at depths between 30 and 50 m within the paleodelta surface. Thus, the true percentage of surface area covered by these types of deposits is likely greater than 2% but less than the 15% calculated for gravelly medium-coarse sand.

Although considerable error was present within certain classes, the depths and areal distribution of sediment types generated from the 7-class model output are consistent with general, low-resolution interpretations of seafloor sediment distribution and morphology in the coverage area (Barnhardt, 1994; Kelley et al., 1987; 1997; 1998; 2003; 2007).

The 4-class model performed slightly better than the 7-class model, with 71% (141 out of 198) of raster output classifications in agreement with sample site classifications (Table 5). The model performed best for bedrock/rocky (90% correct), sand (80% correct), and mud (81% correct) classes. Similar to the 7-class model, performance was poorest for the gravelly mixtures class (51% correct).

Table 5 – Evaluation summary for the 4-class textural model.

Textural Class of Sample Site	n	Total Incorrect	Total Correct	% Correct
Bedrock/rocky	41	4	37	90.2%
Mud	57	11	46	80.7%
Gravelly mixtures	75	37	38	50.7%
Fine sand	25	5	20	80.0%
Total	198	57	141	71.2%

Sample site textural classifications and raster output values used to perform the accuracy analysis are provided in Appendix C.

Discussion

The ultimate goal of this investigation was to produce seafloor sediment textural maps using an efficient and effective method of predicting the spatial distribution of seafloor substrate using MBES and grab sample data and seafloor video observations. The efficiency of this method was demonstrated by the limited requirements for model input and a simple means of evaluating model accuracy. The effectiveness of this method was supported through comparison of model accuracy with accuracies reported for similar investigations. Although this investigation has demonstrated this is a viable technique for generating textural maps using MBES and ground-truthing data, it is important to understand the limitations of this supervised classification method as well as the chosen method of evaluating model accuracy and interpreting model outputs.

The supervised classification method used in this investigation was generally limited by the number and spatial distribution of sample sites that adequately represent individual texture classes and the overall spatial heterogeneity and distribution of textural classes within the study area. For example, the poorest performance in the 7-class model was observed within gravelly medium-coarse sand and gravel-based mixtures (> 30% gravel) (Table 4). This result was somewhat expected due to similarities in backscatter data as well as in seabed morphology (e.g broad, gentle slopes and depths between 30 and 50 meters) where these types of deposits occur within the study area.

Although the model separated fine and coarse substrates with a higher amount of accuracy, a visual comparison of backscatter data with textural model output suggests this model lacks the sensitivity to separate bodies of sediment in transition areas where medium-coarse sand and coarse gravelly sediment are intermixed. This result may also be a reflection of the manner in which the model was trained, where training polygons mainly included discrete, homogeneous areas of sediment that could be classified and manually delineated with a high degree of confidence. Likewise, these transition areas lacked physical samples. Thus, these zones were not used for model training.

Similar studies attempting to classify four or fewer substrate types (Dartnell and Gardner, 2004; Stevens and Diesing, 2014) have reported overall accuracies comparable (>70%) to the 4-class model in this investigation, which achieved an overall accuracy of 71%. Those studies, however, typically involved trial-and-error techniques while simultaneously employing multiple statistical models to refine their input and output. Those techniques are inconsistent with the objective of this investigation, which was in part to demonstrate the efficiency and effectiveness of a simple supervised classification method using MBES and ground-truthing data.

When compared to the 7-class model, the 4-class model showed a minor improvement in overall accuracy (71% compared to 67%, respectively). Such marginal improvement in overall accuracy was the result of many misclassified gravelly mixture class samples being located on the margins of outcrops or in transitional areas between distinct bodies of sediment. The similarity between both model outputs also suggests that supervised classification techniques alone are insufficient for highly-detailed characterization of discrete bodies of sediment in such a dynamic study area.

Condensing the 7-class model results in to 4-classes by merging the output from the three lowest performing classes (gravelly medium-coarse sand, gravel/gravel mixes, and slightly gravelly) yielded an overall accuracy of 82%. Although merged results from the 7-class model are an invalid representation of true model output they do provide information about potential areas where the model could be improved. In addition, these merged results differ from those achieved by the true 4-class model in this investigation.

The results of both models and a visual inspection of areas where the models lacked sensitivity suggest this method of textural classification would be improved with additional sampling, more rigorous training, and a greater degree of manual generalization/refinement of textural output polygons based on experienced interpretation of seabed morphology.

Conclusions

The results of this investigation demonstrate the efficiency and effectiveness of using a simple supervised classification method to map seafloor substrate using MBES and ground-truthing data. The modeled areal distribution of seven major textural classes and corresponding depths are consistent with general interpretations of seafloor sediment distribution and morphology in the coverage area (Barnhardt, 1994; Kelley et al., 1987; 1997; 1998; 2003; 2007), although the supervised classification output would benefit from additional refinement of textural polygons using manual interpretations of sediment distribution. The maps based on this model also provide more detailed information about potential sand and gravel resources in federal waters, which the MCMI has combined with existing geophysical and geological data to conduct volumetric assessments (see Dobbs, 2017c). Additionally, these maps expand seafloor substrate information into a large area previously mapped (Barnhardt et al., 1996) as ‘no data’ (Figure 11).

Overall, the products of this investigation are most useful for visualizing spatial trends in sediment and potential benthic habitat distribution and identifying and/or refining knowledge of resource (abiotic and biotic) potential. Future work will include additional refinement of sand- and gravel-based polygons to more accurately reflect the distribution of dominant grain-size classes within these areas (e.g. medium sand vs. coarse sand). These new data will further enable state and federal agencies to readily identify the resources available to enhance resilience and improve management of resources within their jurisdiction.

All data presented in this report can be accessed via the web on the Maine Coastal Program webpage at www.mainecoastalprogram.org.

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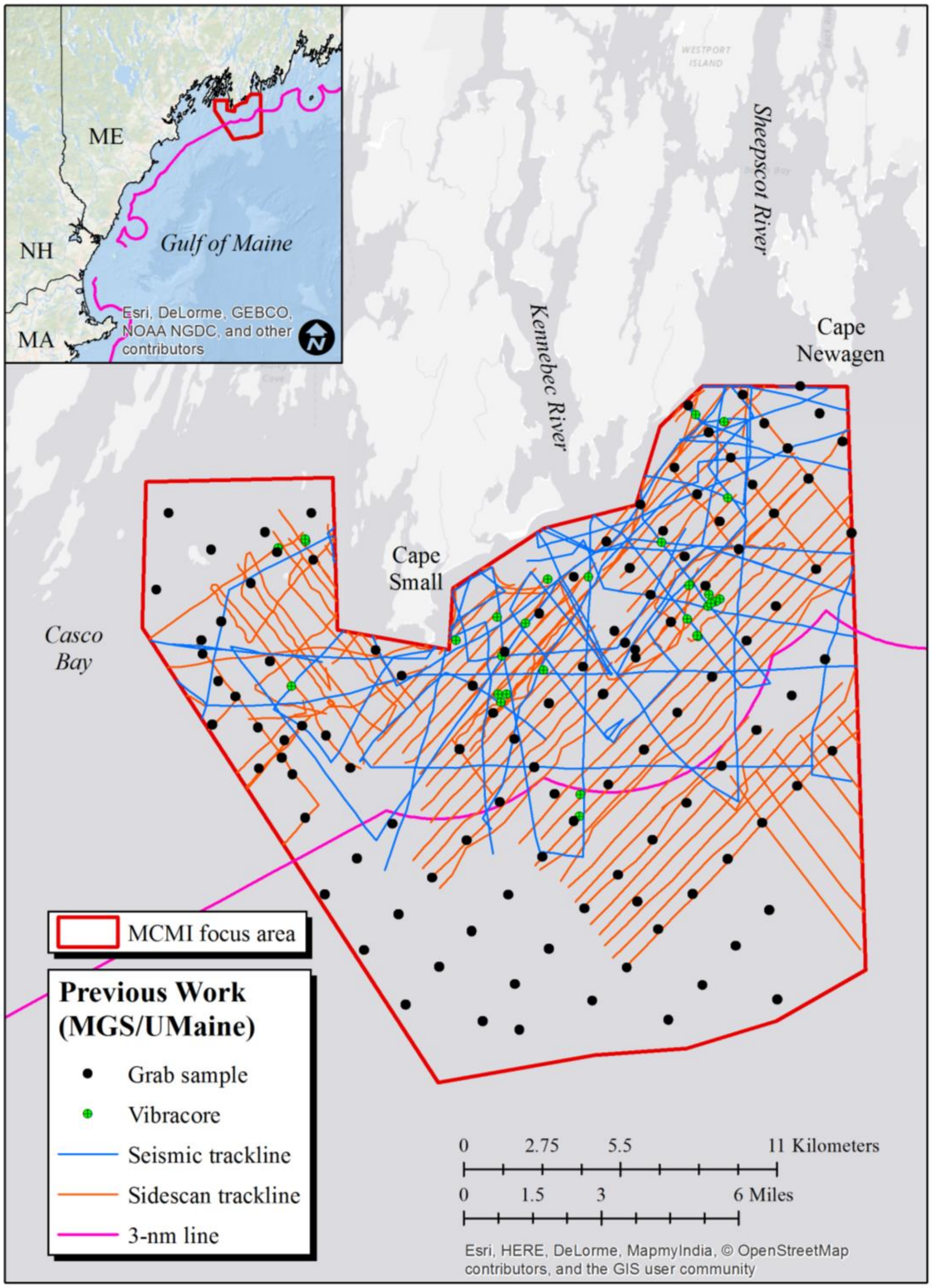

Figure 1. 2015/2016 mid-coast Maine focus area (red outline) and previous geological and geophysical data collected by the Maine Geological Survey in collaboration with the University of Maine; statute miles on scale. (U.S. Department of Interior Minerals Management Service's Continental Margins Program cooperative agreement numbers 14-12-0001-30115 and 14-35-0001-30731; Regional Marine Research Program of NOAA Grant # NA46RM0451)

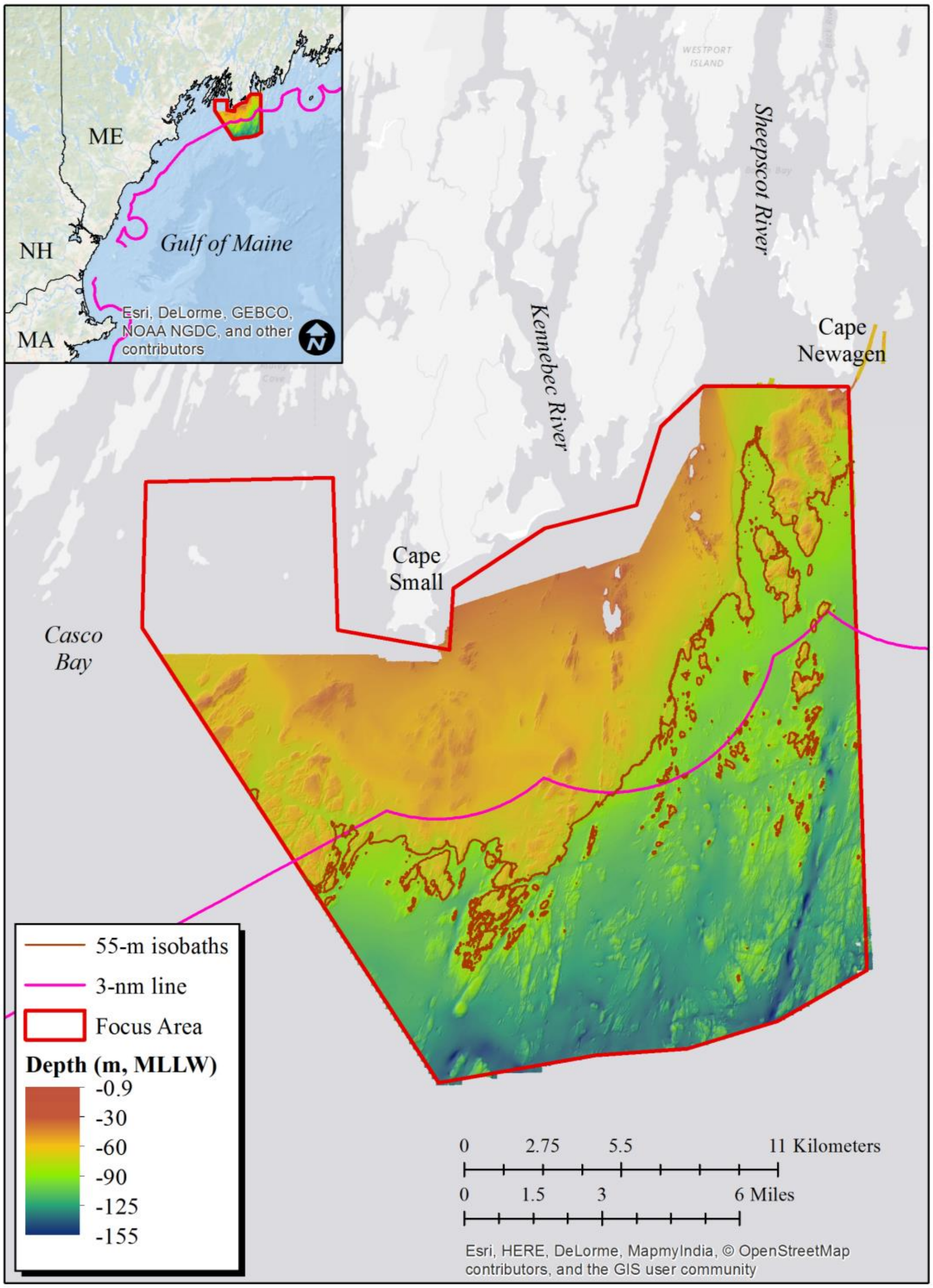

Figure 2. Coverage area bathymetry and 55-meter isobaths (brown lines)/early Holocene lowstand shoreline (Schnitker, 1974; Kelley et al., 1992; Barnhardt et al., 1995).

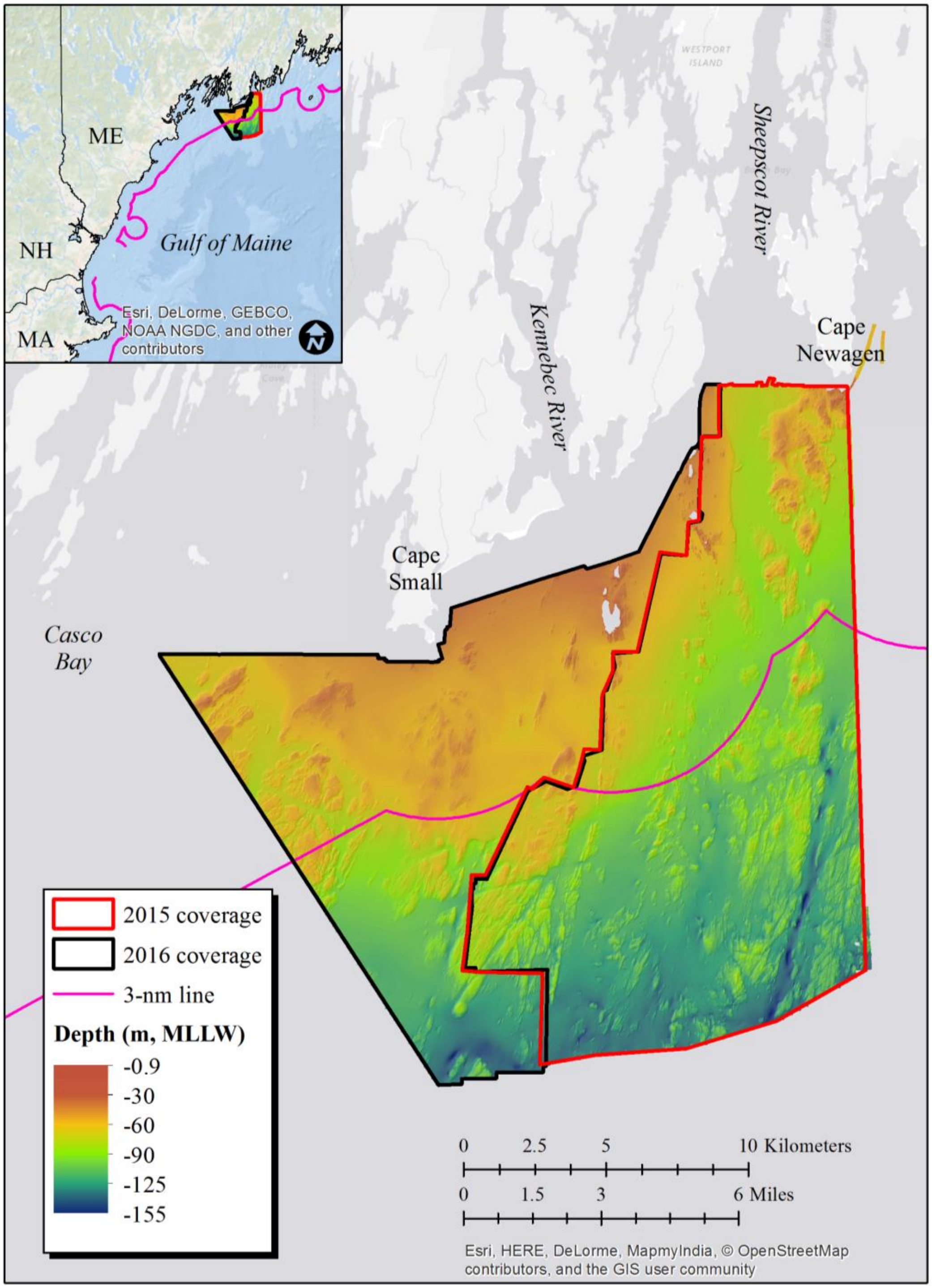

Figure 3. Map showing respective coverage areas for the 2015 (red outline) and 2016 (black outline) field seasons.

Figure 4. MCMI grab sampling platform. This sampling platform was used throughout the 2015 and 2016 field seasons.

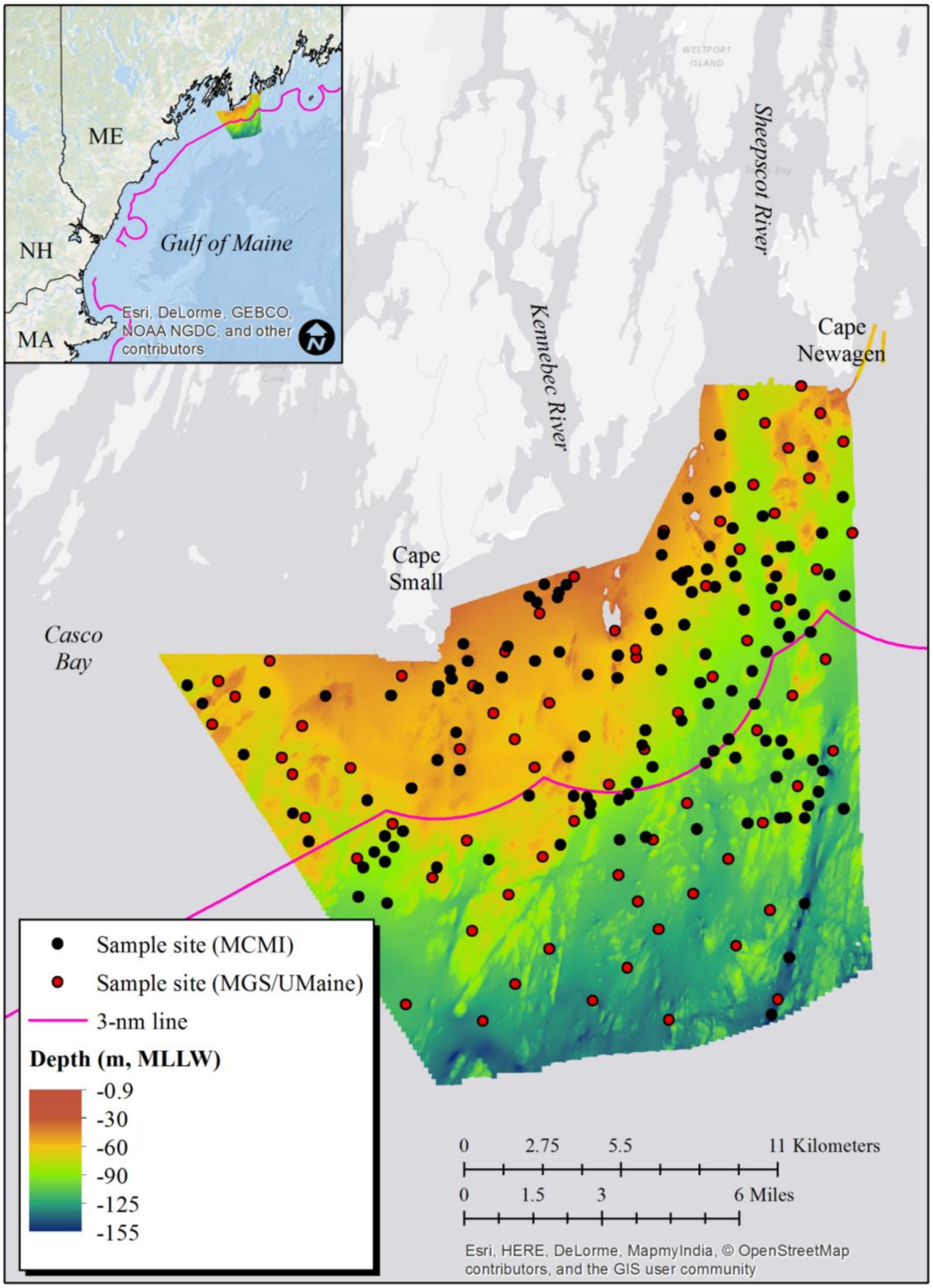

Figure 5. Sample sites collected by MCMI (black) and by MGS/UMaine (red) in the 2015-2016 coverage area. The classifications for these sites were used to evaluate the accuracy of textural model output.

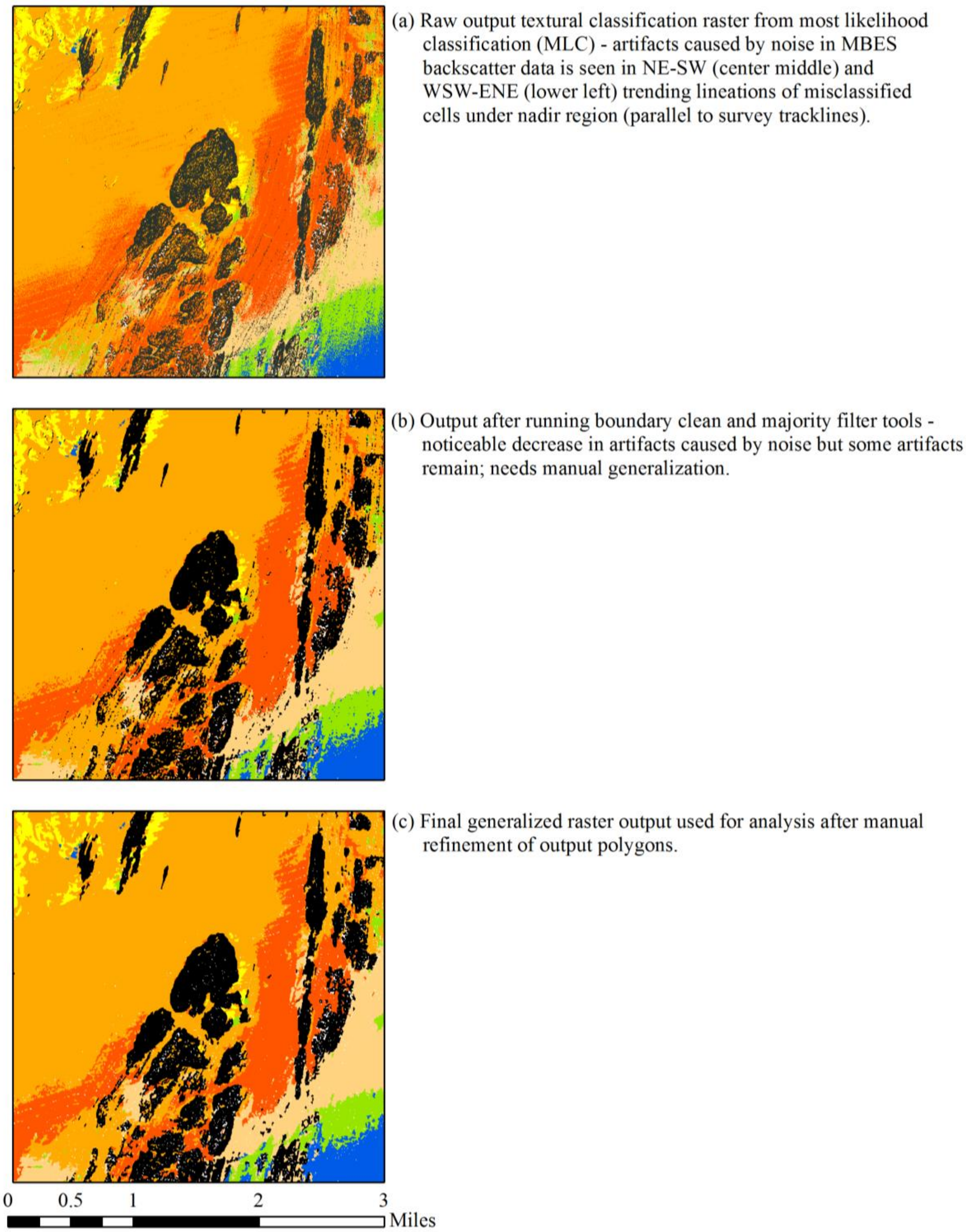

Figure 6. Example of textural classification raster generalization procedure to reduce artifacts caused by noise in backscatter data. Black represents rocky outcrops; all other colors represent unconsolidated sediment.

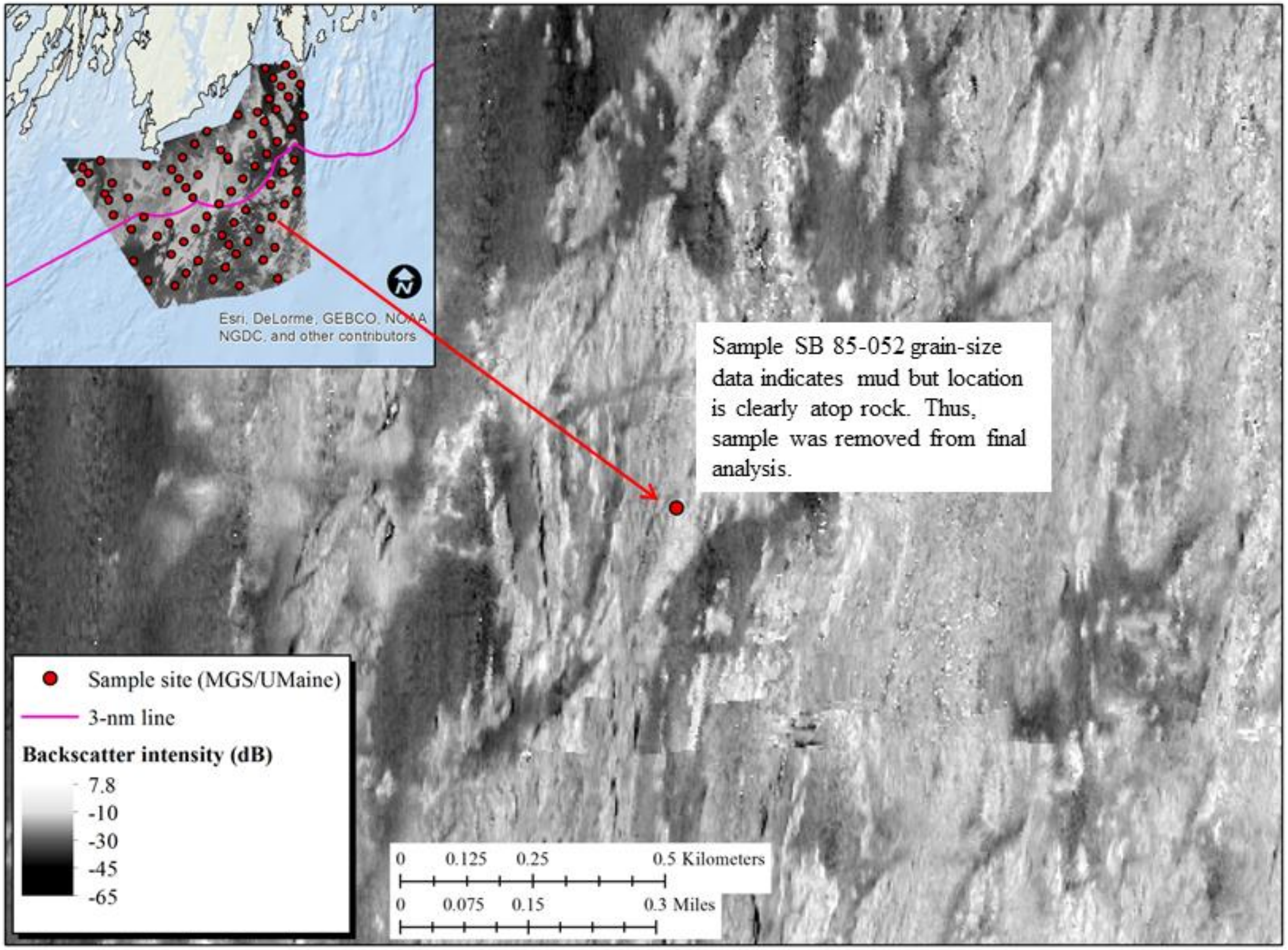

Figure 7. Example of sample site removed from final analysis due to suspected error in coordinates logged for site.

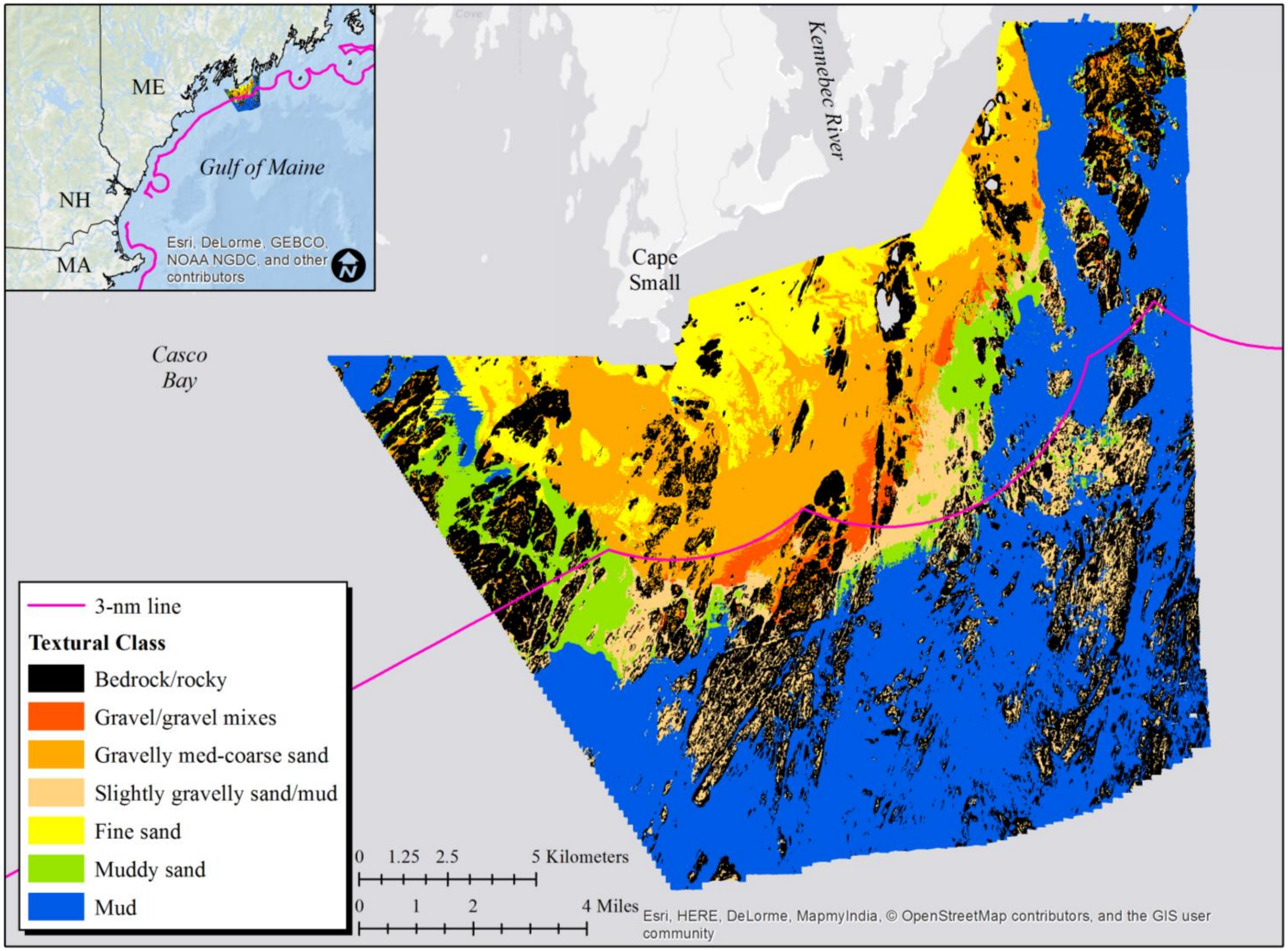

Figure 8. Generalized raster output for7-class seafloor textural classification model. Raster showing textural classifications from initial classification scheme based on a modified version of CMECS (FGDC, 2012) substrate groups corresponding to 7 training polygon classes listed in Table 2.

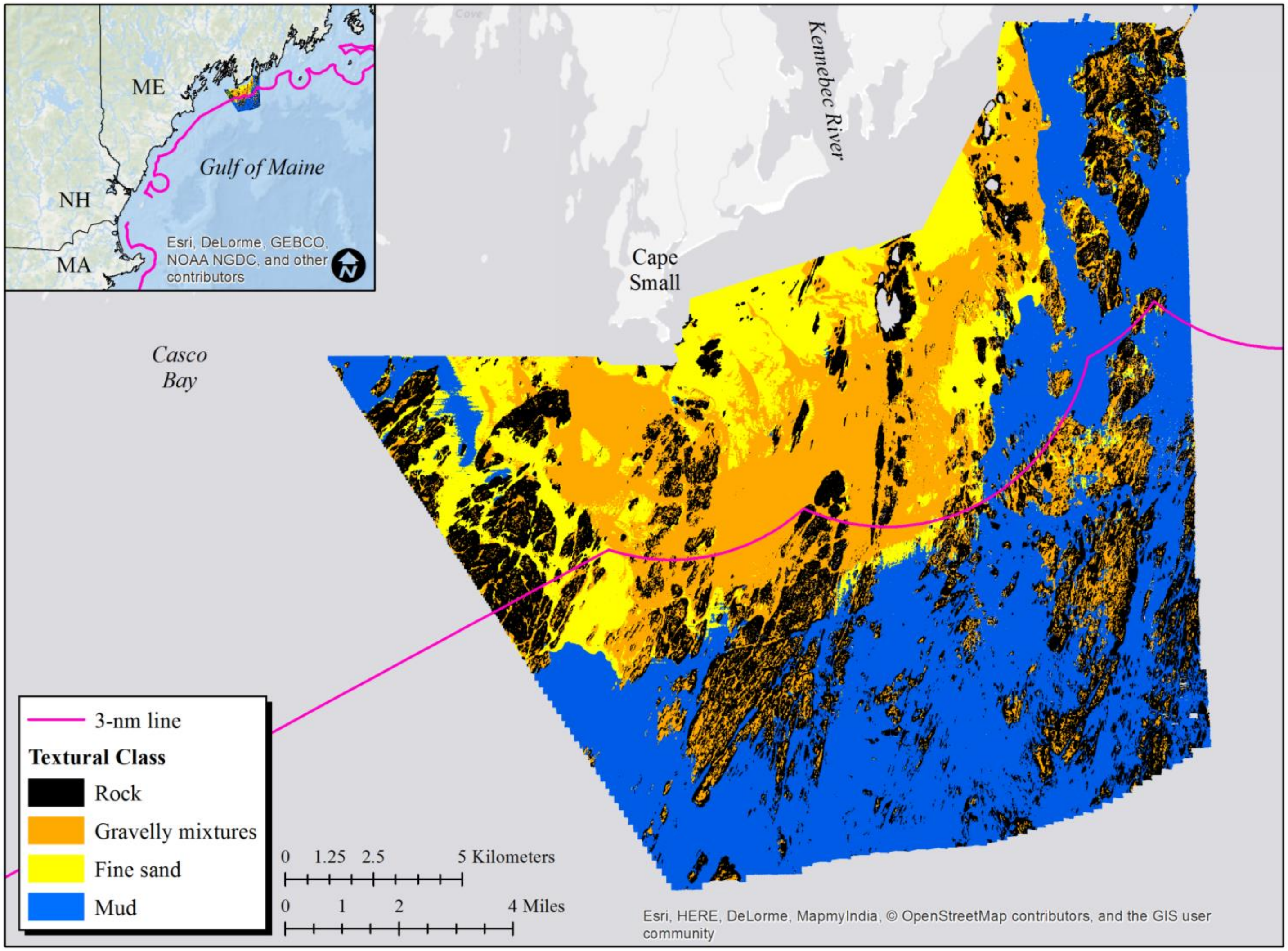

Figure 9. Generalized raster output (no manual generalization performed) for 4-class seafloor textural classification model. Raster showing textural classifications for 4-class model corresponding to training polygon classes listed in Table 3.

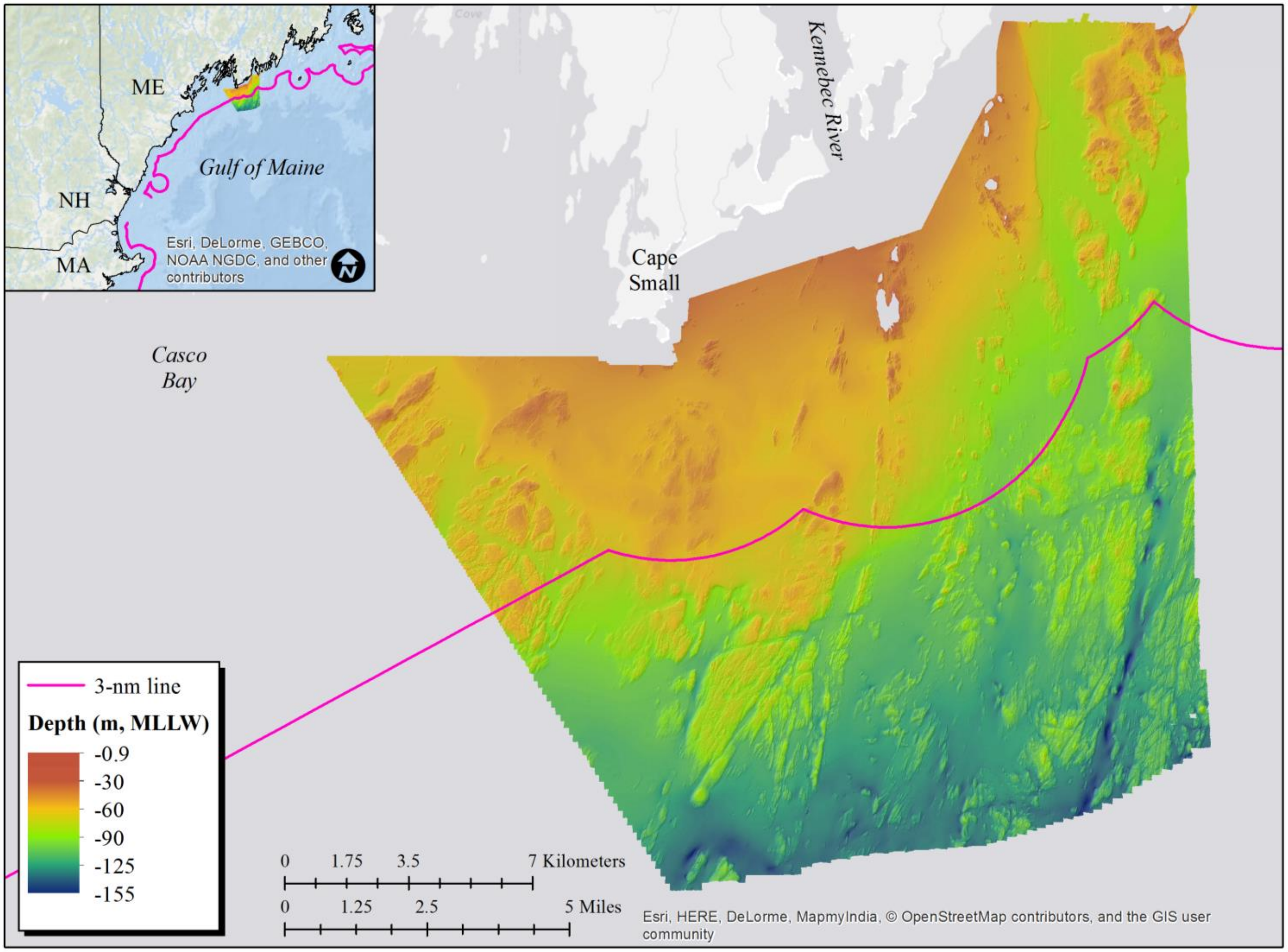

Figure 10a. Bathymetry raster (4-m grid).Depth in meters relative to mean lower low water (MLLW).This input raster was used to create 1st-order derivative input layers (rugosity, slope, and hillshade).

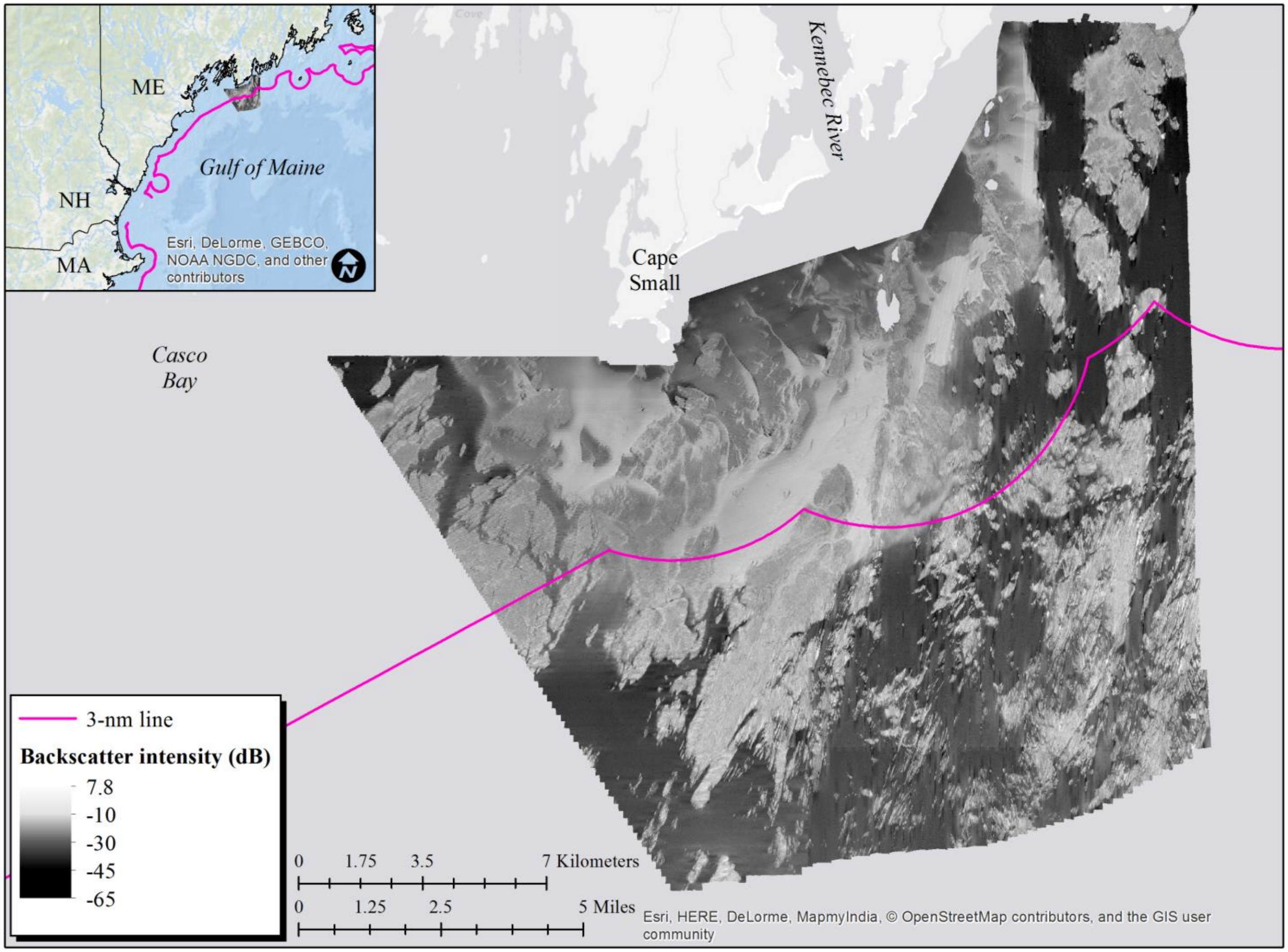

Figure 10b. Backscatter intensity (decibels) input raster (4-m cell size). Lighter tones represent coarse sand and gravel. The darkest tones represent fine grained sediment (e.g. mud). Rocky areas are generally represented by irregular zones with a mix of light-intermediate tones.

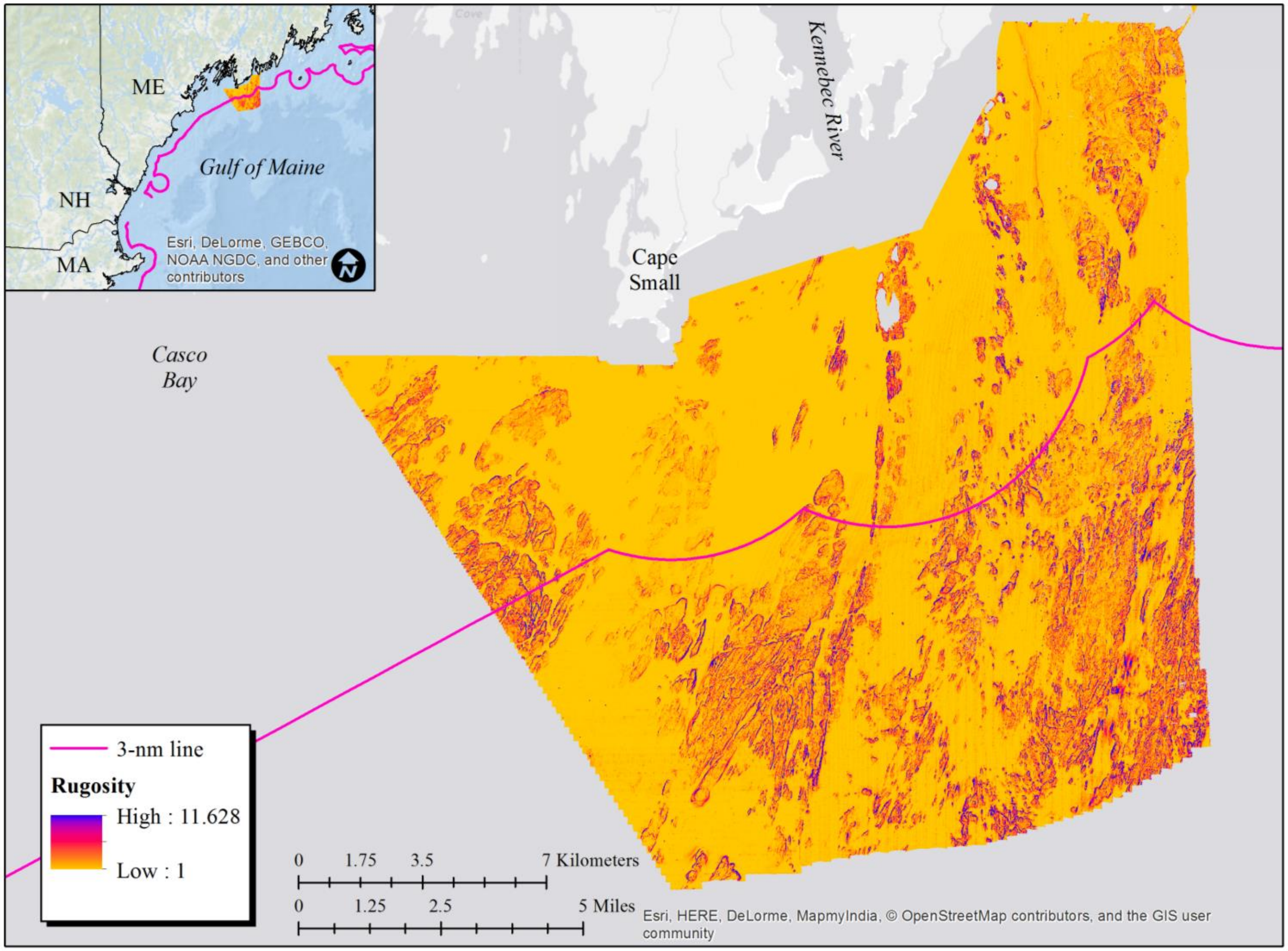

Figure 10c. Rugosity input raster (4-m cell size). The value for rugosity represents the ratio between three-dimensional surface area and planar area. Higher values indicate higher rugosity. MBES noise is more pervasive in the 2015 data (eastern half) and is evident in slightly higher rugosity values in areas with a smooth seafloor.

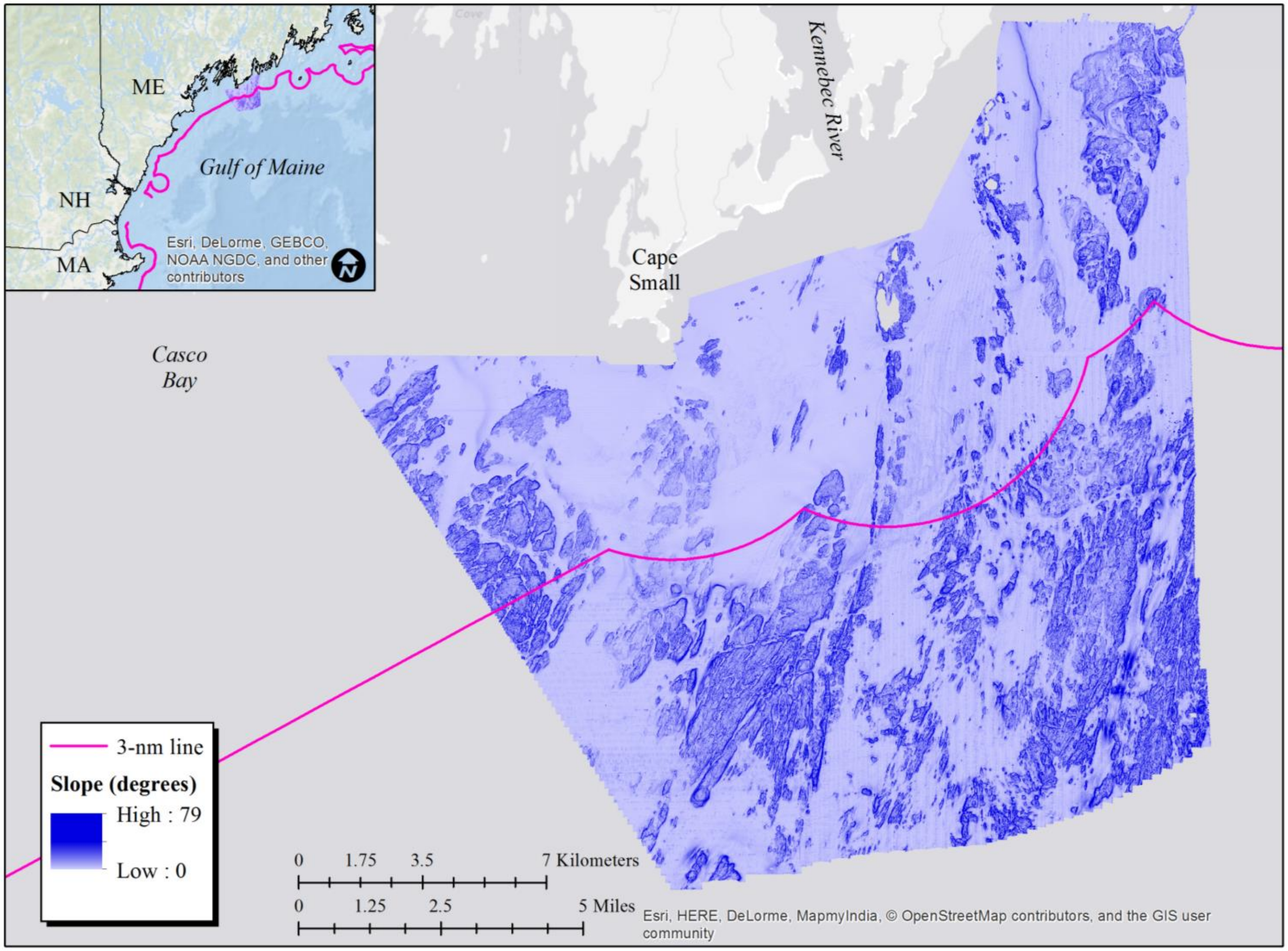

Figure 10d. Bathymetric slope (degrees) input raster (4-m cell size). This layer was not considered in the final analysis due to the correlation with rugosity and backscatter (see Appendix B for multiband collection statistics).

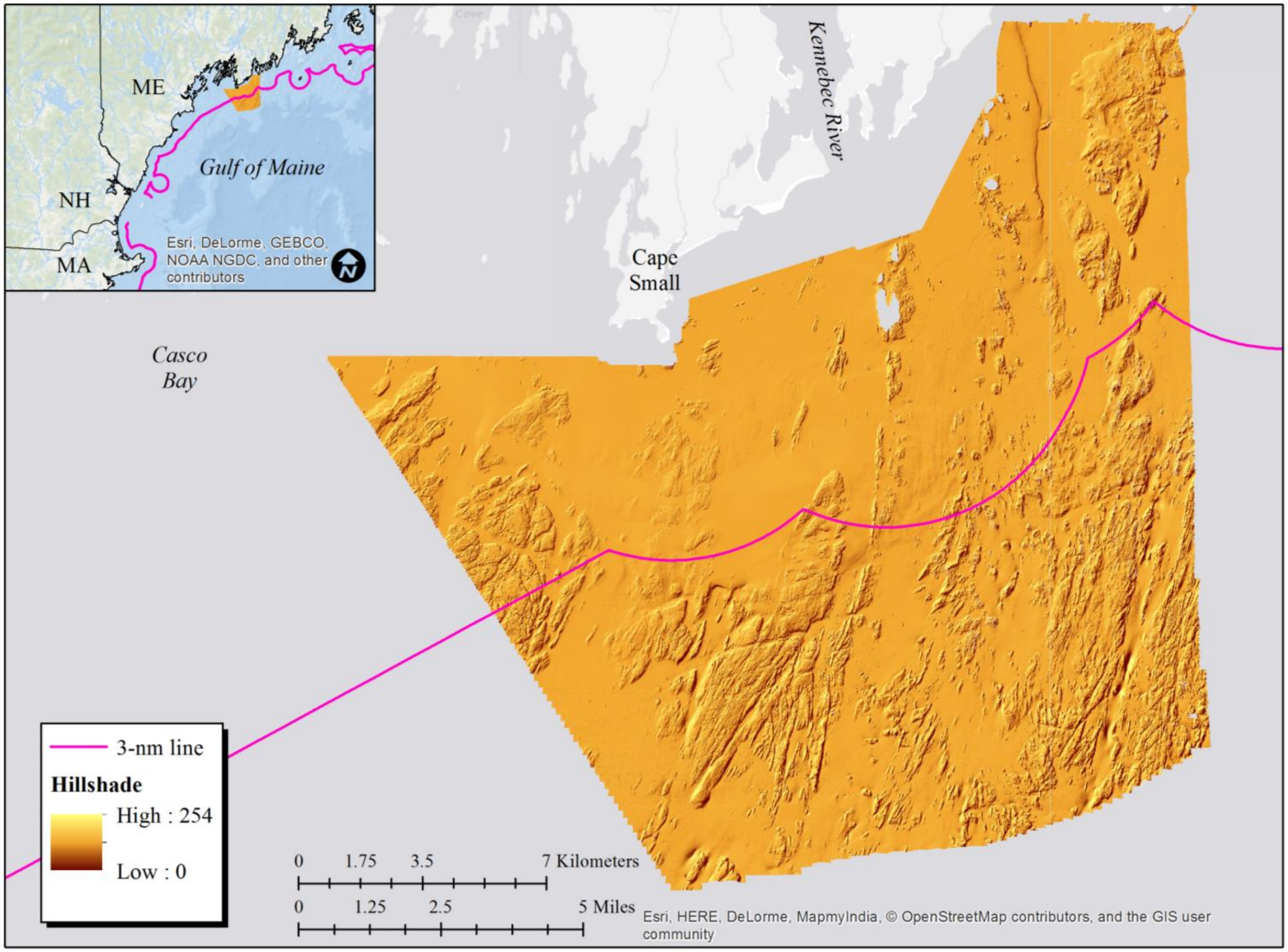

Figure 10e. Bathymetric hillshade (unitless; illumination angle = 45°; azimuth = 315°) input raster (4-m cell size).

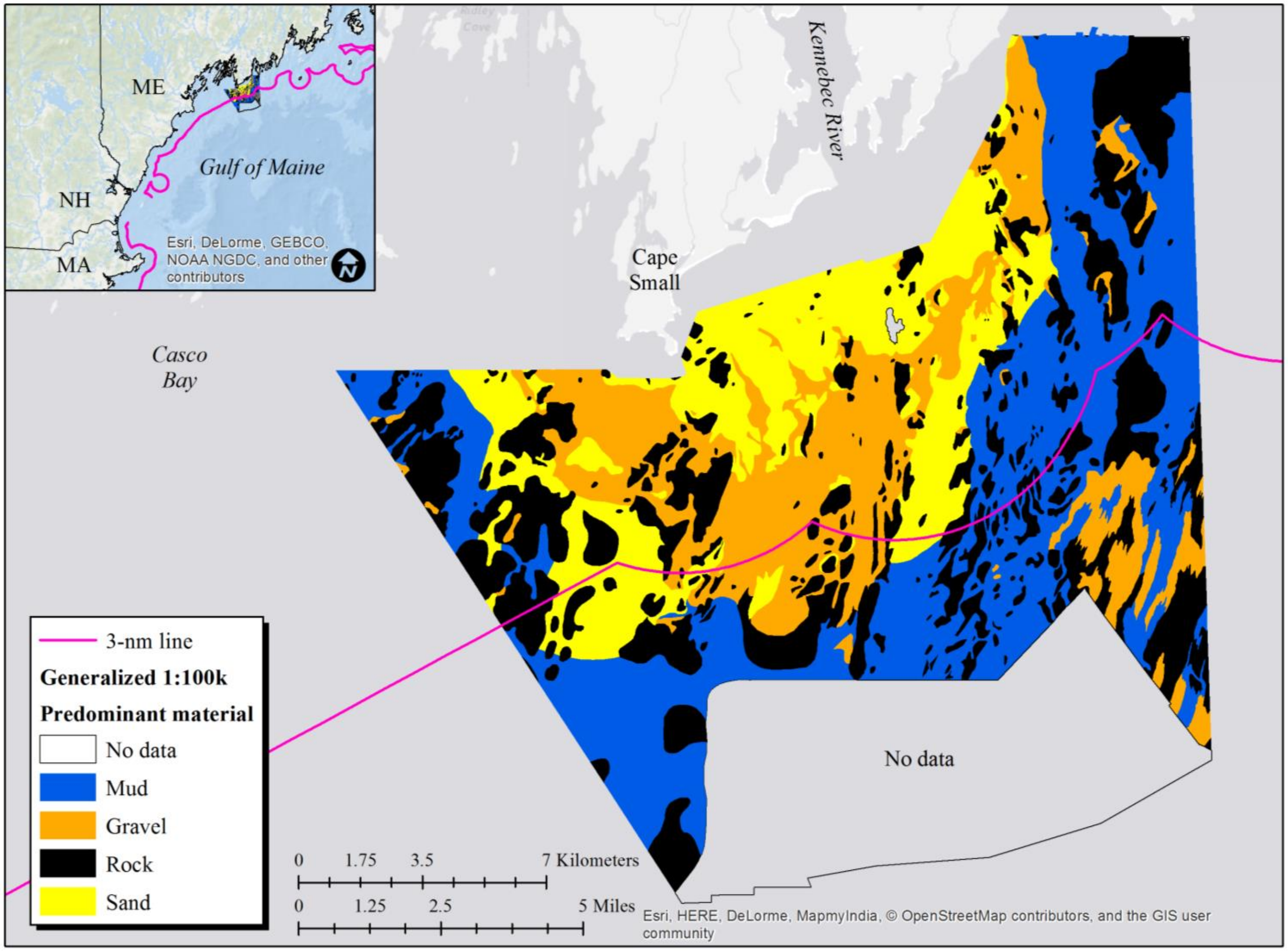

Figure 11. Pre-existing generalized seafloor textural map (modified from Barnhardt et al., 1996) within coverage area. The new data produced by MCMI refines this map and expands into large area of 'no data' in southern-most portion of coverage area.

Appendix A – Sample site attributes

Sample ID[1]	Easting[2] (m)	Northing[2] (m)	Depth[3] (m)	Folk (1974)	Gravel %	Sand %	Silt %	Clay %	Mud %	Phi Mean	Phi SD	Textural Class: 7-class model[4]	Textural Class: 4-class model[5]
M0001	442827	4846221	26.3	gS	10.1	88.3	-	-	1.5	1.1	0.6	Gravelly med-coarse sand	Gravelly mixtures
M0002	443173	4844385	38.1	sG	32.9	61.5	-	-	5.5	0.7	0.7	Gravel/gravel mixes	Gravelly mixtures
M0003	443268	4842959	40.0	msG	71.3	25.4	-	-	3.3	1.4	1.3	Gravel/gravel mixes	Gravelly mixtures
M0004	443361	4841255	52.2	gmS	6.6	63.8	-	-	29.5	0.8	1.6	Gravelly med-coarse sand	Gravelly mixtures
M0005	443687	4840086	49.0	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0006	443964	4837936	57.1	gmS	28.2	47.3	-	-	24.5	0.9	0.7	Gravelly med-coarse sand	Gravelly mixtures
M0007	444049	4836769	66.4	(g)sM	3.7	23.6	-	-	72.7	1.7	1.1	Slightly gravelly	Gravelly mixtures
M0008*	444441	4835489	65.8	(g)sM	-	-	-	-	-	-	-	Slightly gravelly	Gravelly mixtures
M0009	447196	4840576	73.4	M	0.0	2.9	-	-	97.1	1.5	1.4	Mud	Mud
M0010	445767	4839921	68.7	M	0.0	5.3	-	-	94.7	1.8	1.0	Mud	Mud
M0011	440837	4842739	22.7	S	0.0	91.7	-	-	8.3	1.7	1.8	Gravelly med-coarse sand	Gravelly mixtures
M0012	441574	4839567	46.4	gmS	6.6	66.1	-	-	27.3	2.1	1.5	Gravelly med-coarse sand	Gravelly mixtures
M0013	442318	4838543	58.4	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0014	440768	4837964	49.1	mS	0.0	68.5	-	-	31.5	2.8	0.6	Muddy sand	Fine sand
M0015	440198	4835859	47.5	mS	0.0	89.7	-	-	10.3	0.9	1.6	Muddy sand	Fine sand
M0016	440455	4834560	62.0	(g)sM	4.1	45.3	-	-	50.5	1.6	1.4	Slightly gravelly	Gravelly mixtures

M0017	444944	4832762	62.9	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0018	444814	4834214	79.3	M	0.0	3.8	-	-	96.2	-	-	Mud	Mud
M0019	444983	4835488	68.5	(g)mS	1.2	55.4	-	-	43.4	2.1	0.8	Slightly gravelly	Gravelly mixtures
M0020	444640	4840826	57.5	(g)mS	3.2	57.0	-	-	39.8	2.3	0.8	Slightly gravelly	Gravelly mixtures
M0021	443225	4841797	44.8	(g)S	4.5	93.9	-	-	1.6	1.2	1.1	Gravelly med-coarse sand	Gravelly mixtures
M0022	445014	4842287	56.5	(g)sM	1.4	37.0	-	-	61.7	1.3	1.6	Slightly gravelly	Gravelly mixtures
M0023	445236	4842304	59.5	msG	31.0	51.6	-	-	17.4	1.9	0.7	Gravel/gravel mixes	Gravelly mixtures
M0024	445158	4832782	73.7	(g)mS	2.8	40.9	-	-	56.3	2.2	0.7	Slightly gravelly	Gravelly mixtures
M0025	445922	4833198	62.6	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0026	446293	4833702	76.8	mG	67.1	8.9	-	-	24.0	-	-	Gravel/gravel mixes	Gravelly mixtures
M0027	446084	4834807	69.9	gmS	5.6	55.8	-	-	38.6	2.0	0.8	Gravelly med-coarse sand	Gravelly mixtures
M0028	445218	4835018	68.4	(g)sM	1.5	44.7	-	-	53.8	1.3	1.7	Slightly gravelly	Gravelly mixtures
M0029	443363	4834904	59.9	(g)mS	4.4	63.3	-	-	32.2	1.3	1.0	Slightly gravelly	Gravelly mixtures
M0030	442325	4834692	72.8	mG	44.5	17.4	-	-	38.1	-	-	Gravel/gravel mixes	Gravelly mixtures
M0031	440395	4839970	33.0	gS	14.6	84.2	-	-	1.2	0.4	0.4	Gravelly med-coarse sand	Gravelly mixtures
M0032	441334	4841261	34.5	sG	43.2	53.6	-	-	3.2	0.9	0.5	Gravel/gravel mixes	Gravelly mixtures
M0033	441543	4841389	34.8	gS	16.7	82.3	-	-	1.0	0.9	0.6	Gravelly med-coarse sand	Gravelly mixtures
M0034	441702	4841451	35.2	gS	25.6	73.5	-	-	0.9	0.9	0.6	Gravelly med-coarse sand	Gravelly mixtures
M0035	441481	4841123	35.5	(g)S	2.0	93.7	-	-	4.2	1.6	1.3	Gravelly med-coarse sand	Gravelly mixtures

M0036	438265	4832944	56.7	msG	43.7	31.0	-	-	25.3	0.2	1.1	Gravel/gravel mixes	Gravelly mixtures
M0037	438274	4833246	51.1	msG	41.1	41.4	-	-	17.5	0.5	0.5	Gravel/gravel mixes	Gravelly mixtures
M0038	438158	4833508	46.4	msG	56.0	29.0	-	-	15.0	0.6	0.5	Gravel/gravel mixes	Gravelly mixtures
M0039	439292	4833412	61.8	(g)mS	4.0	54.3	-	-	41.7	1.0	1.1	Slightly gravelly	Gravelly mixtures
M0040	439615	4833609	63.2	(g)mS	4.8	61.6	-	-	33.6	1.6	0.9	Slightly gravelly	Gravelly mixtures
M0041	439902	4834029	61.7	(g)mS	3.1	54.4	-	-	42.5	1.1	0.8	Slightly gravelly	Gravelly mixtures
M0042	437700	4833553	35.3	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0043	440104	4835332	48.7	(g)mS	1.9	81.5	-	-	16.7	2.0	0.8	Slightly gravelly	Gravelly mixtures
M0044	441491	4836199	59.5	mS	0.0	68.7	-	-	31.3	2.3	0.6	Muddy sand	Fine sand
M0045	442410	4836783	70.2	M	0.0	7.7	-	-	92.3	3.3	0.6	Mud	Mud
M0046	443247	4837239	70.4	M	0.0	8.2	-	-	91.8	3.6	0.6	Mud	Mud
M0047	440602	4839398	38.0	sG	49.1	49.9	-	-	1.0	0.6	1.1	Gravel/gravel mixes	Gravelly mixtures
M0048	444455	4838621	68.8	sM	0.0	27.7	-	-	72.3	1.8	1.1	Mud	Mud
M0049	445240	4839135	69.5	sM	0.0	18.0	-	-	82.0	-	-	Mud	Mud
M0050	444918	4839611	68.7	sM	0.0	26.8	-	-	73.2	1.3	1.3	Mud	Mud
M0051	446004	4839299	60.6	gmS	16.9	65.8	-	-	17.3	1.4	1.3	Gravelly med-coarse sand	Gravelly mixtures
M0052	445297	4840445	35.7	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0053	446658	4841326	68.4	sM	0.0	27.1	-	-	72.9	1.1	1.5	Mud	Mud
M0054	444795	4841265	41.6	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky

M0055	442659	4840900	45.2	(g)mS	4.5	82.6	-	-	12.9	2.2	1.0	Slightly gravelly	Gravelly mixtures
M0056	441829	4840713	40.0	(g)S	2.5	90.8	-	-	6.7	2.2	0.9	Fine sand	Fine sand
M0057	442366	4841506	39.5	gS	8.3	85.4	-	-	6.3	2.2	1.2	Gravelly med-coarse sand	Gravelly mixtures
M0058	444473	4841805	53.5	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0059	446410	4842790	62.3	sM	0.0	13.8	-	-	86.2	-	-	Mud	Mud
M0060	444332	4843378	58.7	sM	0.0	16.1	-	-	83.9	-	-	Mud	Mud
M0061	447129	4844058	58.5	sM	0.0	24.8	-	-	75.2	1.7	1.3	Mud	Mud
M0062*	444644	4825876	134.1	sM	-	-	-	-	-	-	-	Mud	Mud
M0063*	445254	4827868	146.6	sM	-	-	-	-	-	-	-	Mud	Mud
M0064*	445808	4829769	148.9	sM	-	-	-	-	-	-	-	Mud	Mud
M0065	445800	4832771	63.3	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0066*	446439	4834430	85.7	M	-	-	-	-	-	-	-	Mud	Mud
M0067*	447174	4833099	91.8	M	-	-	-	-	-	-	-	Mud	Mud
M0068*	443801	4832579	74.5	M	-	-	-	-	-	-	-	Mud	Mud
M0069	442024	4832385	65.4	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0070*	440224	4832106	78.7	M	-	-	-	-	-	-	-	Mud	Mud
M0071*	439309	4831998	79.2	M	-	-	-	-	-	-	-	Mud	Mud
M0072	437235	4831833	48.6	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0073	427835	4832930	31.0	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky

M0074	428394	4831950	30.3	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0075	430138	4830012	72.4	sM	0.0	34.2	27.4	38.4	65.8	7.8	3.8	Mud	Mud
M0076	431155	4829781	71.7	sM	0.0	26.4	29.9	43.7	73.6	8.4	3.7	Mud	Mud
M0077	431066	4831232	62.6	mS	0.0	62.4	13.0	24.7	37.6	5.8	3.9	Muddy sand	Fine sand
M0078	430307	4831040	64.0	(g)mS	0.2	65.1	13.9	20.8	34.7	5.7	3.7	Muddy sand	Fine sand
M0079	430700	4831580	58.9	mS	0.0	78.1	7.1	14.8	21.9	4.7	3.4	Muddy sand	Fine sand
M0080	431378	4831756	59.8	(g)mS	0.1	68.7	13.4	17.8	31.2	5.1	3.7	Muddy sand	Fine sand
M0081	431700	4832303	52.9	(g)mS	0.2	75.6	8.8	15.4	24.2	4.4	3.6	Muddy sand	Fine sand
M0082	431072	4832143	52.8	(g)cS	0.4	86.4	3.4	9.8	13.2	3.9	2.9	Muddy sand	Fine sand
M0083	432886	4831039	39.6	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0084	434721	4831308	44.9	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0085	436113	4833569	38.7	sG	56.9	39.0	0.2	4.0	4.2	0.5	2.7	Gravel/gravel mixes	Gravelly mixtures
M0086	437493	4834930	13.6	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0087	433689	4834472	19.2	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0088	432950	4837408	29.8	sM	0.0	9.8	38.5	51.7	90.2	9.9	2.5	Mud	Mud
M0089	433978	4838294	10.5	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0090	435169	4837714	28.0	(g)S	0.7	98.3	0.0	0.0	1.0	0.3	1.1	Gravelly med-coarse sand	Gravelly mixtures
M0091	439231	4837696	28.3	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0092	442601	4835134	69.2	msG	29.5	44.1	5.7	20.7	26.4	2.9	5.4	Gravelly med-coarse sand	Gravelly mixtures

M0093	443138	4835550	65.6	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0094	442135	4837519	50.3	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0095	434333	4837339	29.1	(g)S	0.1	90.3	2.7	6.9	9.6	1.4	3.2	Gravelly med-coarse sand	Gravelly mixtures
M0096	432913	4834821	21.8	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0097	433361	4837960	26.9	(g)mS	2.2	83.9	5.0	8.9	13.9	3.5	3.1	Slightly gravelly	Gravelly mixtures
M0098	435365	4838804	23.5	(g)S	0.4	95.8	1.2	2.6	3.8	2.8	1.8	Fine sand	Fine sand
M0099	436338	4838284	28.6	gS	25.1	73.4	0.2	1.3	1.5	0.1	1.9	Gravelly med-coarse sand	Gravelly mixtures
M0100	439244	4838490	19.0	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0101	438193	4837811	28.6	sG	40.3	56.7	0.0	0.0	3.0	0.2	2.2	Gravel/gravel mixes	Gravelly mixtures
M0102	436402	4840351	19.2	(g)S	1.1	91.1	1.5	6.3	7.8	3.5	2.4	Fine sand	Fine sand
M0103	436139	4840544	16.9	S	0.0	97.7	0.7	1.7	2.4	3.1	1.3	Fine sand	Fine sand
M0104	436671	4840971	15.3	gS	13.0	86.2	0.0	0.0	0.8	0.2	1.7	Gravelly med-coarse sand	Gravelly mixtures
M0105	437448	4840954	13.0	(g)S	0.1	98.2	0.0	0.0	0.0	2.9	1.1	Fine sand	Fine sand
M0106	437183	4840692	15.1	(g)S	1.1	95.7	0.0	0.0	3.2	1.4	1.7	Gravelly med-coarse sand	Gravelly mixtures
M0107	437126	4840513	15.3	(g)S	0.8	97.8	0.0	0.0	1.4	1.3	1.2	Gravelly med-coarse sand	Gravelly mixtures
M0108	442460	4842312	13.6	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0109	441695	4844004	24.0	sG	38.5	55.9	0.0	0.0	5.5	0.0	2.8	Gravel/gravel mixes	Gravelly mixtures
M0110	442685	4844239	27.5	sG	33.0	67.0	0.0	0.0	0.0	0.6	1.0	Gravel/gravel mixes	Gravelly mixtures
M0111	446095	4845486	18.3	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky

M0112	432929	4837234	30.4	sM	0.0	15.6	41.9	42.5	84.4	8.8	3.3	Mud	Mud
M0113	433581	4835769	27.0	G	99.3	0.6	0.0	0.0	0.0	4.6	0.9	Gravel/gravel mixes	Gravelly mixtures
M0114	440791	4842003	25.7	(g)S	1.3	96.0	0.4	2.4	2.7	2.9	1.6	Fine sand	Fine sand
M0115	438070	4835651	35.5	sG	46.7	52.8	0.0	0.0	0.5	0.7	1.5	Gravel/gravel mixes	Gravelly mixtures
M0116	430456	4833406	33.0	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0117	424130	4837446	44.5	C	0.0	5.4	31.2	63.4	94.6	10.3	2.5	Mud	Mud
M0118	424664	4836784	13.9	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0119	426115	4834993	30.6	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0120	426856	4837193	37.7	sM	0.0	41.3	27.5	31.2	58.7	7.3	3.7	Mud	Mud
M0121	428981	4837064	13.7	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
M0122	431289	4837079	26.0	(g)S	0.4	99.6	0.0	0.0	0.0	0.6	0.4	Gravelly med-coarse sand	Gravelly mixtures
M0123	433415	4837650	28.5	M	0.0	5.1	41.8	53.1	94.9	9.9	2.5	Mud	Mud
M0124	433825	4838881	22.1	sM	0.0	36.4	38.8	24.9	63.7	8.0	3.2	Mud	Mud
M0125	437201	4838606	31.8	sM	0.0	12.0	52.8	35.2	88.0	8.2	3.2	Mud	Mud
M0126*	432002	4833820	33.2	S	-	-	-	-	-	-	-	Gravelly med-coarse sand	Gravelly mixtures
CB-86-048	4837770	431669	22	(g)S	3.0	93.0	2.0	2.0	4.0	0.7	0.7	Gravelly med-coarse sand	Gravelly mixtures
CB-86-049	4835200	433697	19	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
CB-86-051	4831411	436600	62	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
CB-86-053	4828190	436831	93	C	0.0	9.0	28.0	63.0	92.0	9.4	3.2	Mud	Mud

CB-86-054	4826929	435630	80	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
CB-86-057	4826224	431792	89	C	0.0	4.0	28.0	68.0	96.0	9.4	2.9	Mud	Mud
CB-86-064	4828136	430332	85	C	0.0	4.0	26.0	70.0	96.0	10.0	2.9	Mud	Mud
CB-86-066	4830677	432728	48	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
CB-86-067	4831987	433948	43	S	0.0	96.0	2.0	2.0	4.0	1.4	0.4	Gravelly med-coarse sand	Gravelly mixtures
CB-86-068	4830072	435401	53	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
CB-86-069	4828809	434118	52	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
CB-86-070	4832577	431340	44	S	0.0	92.0	2.0	6.0	8.0	2.3	1.3	Fine sand	Fine sand
CB-86-071	4834535	429845	36	S	0.0	96.0	2.0	2.0	4.0	1.6	0.7	Gravelly med-coarse sand	Gravelly mixtures
CB-86-073	4836006	428162	30	S	0.0	96.0	0.0	4.0	5.0	2.4	0.5	Fine sand	Fine sand
CB-86-074	4838288	427026	28	gS	14.0	85.0	1.0	1.0	2.0	1.6	1.6	Gravelly med-coarse sand	Gravelly mixtures
CB-86-075	4837593	425218	22	msG	50.0	36.0	2.0	12.0	14.0	-0.6	4.0	Gravel/gravel mixes	Gravelly mixtures
CB-86-076	4837046	425816	34	mS	0.0	53.0	29.0	18.0	47.0	4.9	3.0	Muddy sand	Fine sand
CB-86-079	4834902	427442	44	sM	0.0	44.0	24.0	33.0	56.0	6.3	3.9	Mud	Mud
CB-86-080	4834315	427818	44	mS	0.0	67.0	17.0	17.0	33.0	4.3	3.0	Muddy sand	Fine sand
CB-86-081	4832785	428276	53	(g)sC	3.0	42.0	12.0	43.0	55.0	7.0	4.4	Slightly gravelly	Gravelly mixtures
CB-86-123	4831352	430081	58	gmS	18.0	64.0	7.0	12.0	19.0	2.1	4.0	Gravelly med-coarse sand	Gravelly mixtures
CB-86-196	4836059	424993	29	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
CB-87-001	4827512	439580	116	C	0.0	6.0	21.0	73.0	94.0	9.8	2.8	Mud	Mud

CB-87-002	4826354	438365	118	C	0.0	2.0	24.0	75.0	98.0	10.0	2.6	Mud	Mud
CB-87-004	4825646	434511	114	C	0.0	2.0	25.0	74.0	98.0	10.1	2.7	Mud	Mud
SB-85-005	4845991	447147	52	C	0.0	4.0	26.0	69.0	96.0	-	-	Mud	Mud
SB-85-006	4844708	445959	40	cS	0.0	84.0	5.0	11.0	16.0	1.7	0.7	Muddy sand	Fine sand
SB-85-007	4843469	444741	39	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
SB-85-008	4842222	443519	59	M	0.0	6.0	36.0	58.0	94.0	-	-	Mud	Mud
SB-85-009	4840934	442327	40	gS	6.0	89.0	2.0	4.0	6.0	1.7	0.7	Gravelly med-coarse sand	Gravelly mixtures
SB-85-011	4838402	439893	40	gS	21.0	77.0	1.0	1.0	2.0	0.3	0.7	Gravelly med-coarse sand	Gravelly mixtures
SB-85-014	4834555	436311	32	gS	18.0	80.0	1.0	1.0	2.0	0.4	0.6	Gravelly med-coarse sand	Gravelly mixtures
SB-85-016	4832664	437713	52	gS	5.0	87.0	4.0	4.0	8.0	0.2	0.4	Gravelly med-coarse sand	Gravelly mixtures
SB-85-017	4833952	438929	38	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
SB-85-018	4835183	440168	52	cS	0.0	79.0	7.0	14.0	21.0	2.2	0.7	Muddy sand	Fine sand
SB-85-019	4836475	441360	59	(g)cS	2.0	71.0	5.0	23.0	28.0	2.2	0.7	Slightly gravelly	Gravelly mixtures
SB-85-020	4837743	442573	67	sC	0.0	22.0	25.0	53.0	78.0	3.3	0.4	Mud	Mud
SB-85-021	4838994	443772	65	sM	0.0	17.0	34.0	49.0	83.0	3.0	0.5	Mud	Mud
SB-85-022	4840209	444805	67	M	0.0	7.0	31.0	63.0	93.0	-	-	Mud	Mud
SB-85-023	4841511	446227	67	C	0.0	4.0	26.0	70.0	96.0	-	-	Mud	Mud
SB-85-024	4842790	447464	65	M	0.0	6.0	29.0	66.0	94.0	-	-	Mud	Mud
SB-85-041	4838346	446544	75	C	0.0	5.0	26.0	69.0	95.0	-	-	Mud	Mud

SB-85-042	4837078	445376	57	G	87.0	9.0	1.0	3.0	4.0	1.4	0.9	Gravel/gravel mixes	Gravelly mixtures
SB-85-043	4835856	444126	62	msG	63.0	22.0	4.0	11.0	15.0	0.9	0.9	Gravel/gravel mixes	Gravelly mixtures
SB-85-045	4833294	441669	82	M	0.0	6.0	28.0	66.0	94.0	-	-	Mud	Mud
SB-85-046	4832010	440467	82	C	0.0	4.0	22.0	74.0	96.0	-	-	Mud	Mud
SB-85-047	4830783	439264	87	M	0.0	5.0	30.0	66.0	95.0	-	-	Mud	Mud
SB-85-048	4829841	439943	87	sC	0.0	10.0	22.0	69.0	90.0	-	-	Mud	Mud
SB-85-049	4828856	440676	91	C	0.0	3.0	23.0	74.0	97.0	-	-	Mud	Mud
SB-85-050	4830111	441884	88	(g)sC	1.0	25.0	20.0	54.0	74.0	2.3	0.9	Slightly gravelly	Gravelly mixtures
SB-85-051	4831341	443111	86	sC	0.0	11.0	23.0	66.0	90.0	3.0	0.5	Mud	Mud
SB-85-052**	4832606	444335	67	M	0.0	3.0	22.0	75.0	97.0	-	-	Mud	Mud
SB-85-053	4833903	445559	72	(g)cS	3.0	50.0	9.0	38.0	46.0	1.9	1.0	Slightly gravelly	Gravelly mixtures
SB-85-054	4835135	446803	86	sC	0.0	10.0	24.0	66.0	90.0	3.1	0.4	Mud	Mud
SB-85-071	4846998	446356	17	sC	0.0	12.0	15.0	73.0	88.0	-	-	Mud	Mud
SB-85-072	4845768	445221	25	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
SB-85-073	4844476	443993	57	sM	0.0	14.0	32.0	55.0	87.0	3.3	0.4	Mud	Mud
SB-85-074	4843185	442835	32	sG	54.0	45.0	0.0	1.0	1.0	0.0	0.5	Gravel/gravel mixes	Gravelly mixtures
SB-85-077	4839348	439144	6	R	-	-	-	-	-	-	-	Bedrock/rocky	Bedrock/rocky
SB-85-080	4836807	436824	31	S	0.0	97.0	0.0	3.0	3.0	1.0	0.2	Gravelly med-coarse sand	Gravelly mixtures
SB-85-081	4835544	435623	37	(g)S	1.0	95.0	2.0	2.0	4.0	0.6	0.3	Gravelly med-coarse sand	Gravelly mixtures

SB-85-082	4836459	434867	30	S	0.0	97.0	1.0	2.0	3.0	1.4	0.4	Gravelly med-coarse sand	Gravelly mixtures
SB-85-083	4837423	434153	28	mS	0.0	85.0	7.0	9.0	16.0	2.2	0.6	Muddy sand	Fine sand
SB-85-084	4838624	435287	23	S	0.0	92.0	0.0	8.0	8.0	2.0	0.4	Fine sand	Fine sand
SB-85-085	4839962	436495	19	S	0.0	97.0	1.0	3.0	3.0	1.1	0.2	Gravelly med-coarse sand	Gravelly mixtures
SB-85-086	4841237	437713	11	S	0.0	95.0	3.0	3.0	5.0	2.6	0.8	Fine sand	Fine sand
SB-85-091	4847635	443643	48	sM	0.0	13.0	31.0	56.0	87.0	2.7	0.3	Mud	Mud
SB-85-093	4847933	445666	29	R	0.0	0.0	0.0	0.0	0.0	-	-	Bedrock/rocky	Bedrock/rocky
SB-85-095	4846638	444405	51	sM	0.0	21.0	35.0	45.0	79.0	3.2	0.4	Mud	Mud
SB-85-098	4842850	440862	22	mS	0.0	87.0	5.0	8.0	13.0	2.7	0.3	Muddy sand	Fine sand
SB-87-001**	4829551	444582	94	(g)sC	3.0	24.0	7.0	66.0	73.0	1.4	1.1	Slightly gravelly	Gravelly mixtures
SB-87-002**	4828282	443404	85	R	0.0	0.0	0.0	0.0	0.0	-	-	Bedrock/rocky	Bedrock/rocky
SB-87-003	4826406	444850	134	C	0.0	2.0	23.0	75.0	99.0	-	-	Mud	Mud
SB-87-011	4825686	441044	118	C	0.0	4.0	20.0	76.0	96.0	1.1	0.9	Mud	Mud
SB-88-001	4838688	439868	35	(g)mS	2.0	86.0	4.0	8.0	13.0	-	-	Slightly gravelly	Gravelly mixtures

[1]Sample ID M0001 through M0072 collected/visited by MCMI during the 2015 field season; grain-size analyses did not separate mud-sized particles into silt and clay components. M0073 through M0126 collected/visited by MCMI during the 2016 field season. All other sites collected by MGS/UMaine.

[2]WGS84 UTM Zone 19N meters

[3]Depths listed from sites M0001 through M0126 are referenced to mean lower low water in meters. Depths listed for other sites are not referenced to a vertical datum (estimated error ±3m).

[4]Textural class assigned to samples in 7-class model based on modified version of CMECS substrate groups (FGDC, 2012) shown in Table 1.

[5]Textural class assigned to samples in 4-class model based on modified version of CMECS substrate groups (FGDC, 2012) shown in Table 1.

*Folk classification for unconsolidated sample was determined in the field; no grain-size analysis data.

**Site was removed from model assessment due to suspected error in coordinates recorded for sample site.

Appendix B – Input raster band collection statistics

STATISTICS of INDIVIDUAL LAYERS (RASTERS)

Layer	MIN	MAX	MEAN	STD
Bathymetry (meters)	-155.4100	-0.9200	-59.2629	26.9579
Backscatter (decibels)	-64.0200	7.7900	-23.5059	6.7997
Rugosity (unitless)	1.0000	11.6280	1.0153	0.0525
Slope (degrees)	0.0000	79.5855	3.9241	5.9626
Hillshade (unitless)	0.0000	254.0000	177.6006	17.1435

COVARIANCE MATRIX

Layer	Bathymetry	Backscatter	Rugosity	Slope	Hillshade
Bathymetry	325.57565	25.14807	-0.04400	-8.09873	3.46062
Backscatter	25.14807	20.73197	0.02439	5.46339	-3.55247
Rugosity	-0.04400	0.02439	0.00122	0.11213	-0.07465
Slope	-8.09873	5.46339	0.11213	15.92750	-8.70706
Hillshade	3.46062	-3.55247	-0.07465	-8.70706	130.58318

CORRELATION MATRIX (values are correlation coefficients)

Layer	Bathymetry	Backscatter	Rugosity	Slope	Hillshade
Bathymetry	1.00000	0.30610	-0.06972	-0.11246	0.01678
Backscatter	0.30610	1.00000	0.15316	0.30065	-0.06828
Rugosity	-0.06972	0.15316	1.00000	0.80324	-0.18677
Slope	-0.11246	0.30065	0.80324	1.00000	-0.19092
Hillshade	0.01678	-0.06828	-0.18677	-0.19092	1.00000

Appendix C – Textural model sample classifications and model output classifications

Sample ID[1]	Textural Class: 7-class model[2]	Class value[3]	7-class model output value[4]	Textural Class: 4-class model[2]	Class value[3]	4-class model output value[4]
M0001	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0002	Gravel/gravel mixes	5	4	Gravelly mixtures	3	3
M0003	Gravel/gravel mixes	5	4	Gravelly mixtures	3	3
M0004	Gravelly med-coarse sand	4	3	Gravelly mixtures	3	4
M0005	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0006	Gravelly med-coarse sand	4	7	Gravelly mixtures	3	3
M0007	Slightly gravelly	7	1	Gravelly mixtures	3	1
M0008*	Slightly gravelly	7	7	Gravelly mixtures	3	1
M0009	Mud	2	2	Mud	2	2
M0010	Mud	2	2	Mud	2	2
M0011	Gravelly med-coarse sand	4	6	Gravelly mixtures	3	4
M0012	Gravelly med-coarse sand	4	3	Gravelly mixtures	3	4
M0013	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0014	Muddy sand	3	3	Fine sand	4	4
M0015	Muddy sand	3	3	Fine sand	4	4
M0016	Slightly gravelly	7	7	Gravelly mixtures	3	1
M0017	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0018	Mud	2	2	Mud	2	2
M0019	Slightly gravelly	7	7	Gravelly mixtures	3	1
M0020	Slightly gravelly	7	7	Gravelly mixtures	3	3
M0021	Gravelly med-coarse sand	4	7	Gravelly mixtures	3	1
M0022	Slightly gravelly	7	7	Gravelly mixtures	3	1
M0023	Gravel/gravel mixes	5	3	Gravelly mixtures	3	2
M0024	Slightly gravelly	7	7	Gravelly mixtures	3	1
M0025	Bedrock/rocky	1	7	Bedrock/rocky	1	1
M0026	Gravel/gravel mixes	5	7	Gravelly mixtures	3	2
M0027	Gravelly med-coarse sand	4	7	Gravelly mixtures	3	1
M0028	Slightly gravelly	7	7	Gravelly mixtures	3	1
M0029	Slightly gravelly	7	1	Gravelly mixtures	3	1
M0030	Gravel/gravel mixes	5	7	Gravelly mixtures	3	1

M0031	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0032	Gravel/gravel mixes	5	4	Gravelly mixtures	3	3
M0033	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0034	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0035	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0036	Gravel/gravel mixes	5	7	Gravelly mixtures	3	1
M0037	Gravel/gravel mixes	5	5	Gravelly mixtures	3	3
M0038	Gravel/gravel mixes	5	5	Gravelly mixtures	3	3
M0039	Slightly gravelly	7	7	Gravelly mixtures	3	3
M0040	Slightly gravelly	7	7	Gravelly mixtures	3	4
M0041	Slightly gravelly	7	7	Gravelly mixtures	3	3
M0042	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0043	Slightly gravelly	7	7	Gravelly mixtures	3	3
M0044	Muddy sand	3	3	Fine sand	4	4
M0045	Mud	2	2	Mud	2	2
M0046	Mud	2	2	Mud	2	2
M0047	Gravel/gravel mixes	5	5	Gravelly mixtures	3	3
M0048	Mud	2	2	Mud	2	2
M0049	Mud	2	2	Mud	2	2
M0050	Mud	2	2	Mud	2	2
M0051	Gravelly med-coarse sand	4	7	Gravelly mixtures	3	1
M0052	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0053	Mud	2	2	Mud	2	2
M0054	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0055	Slightly gravelly	7	4	Gravelly mixtures	3	3
M0056	Fine sand	6	4	Fine sand	4	3
M0057	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0058	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0059	Mud	2	3	Mud	2	2
M0060	Mud	2	2	Mud	2	2
M0061	Mud	2	2	Mud	2	2
M0062*	Mud	2	2	Mud	2	2
M0063*	Mud	2	2	Mud	2	2
M0064*	Mud	2	2	Mud	2	2
M0065	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0066*	Mud	2	2	Mud	2	2

M0067*	Mud	2	2	Mud	2	2
M0068*	Mud	2	2	Mud	2	1
M0069	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0070*	Mud	2	2	Mud	2	2
M0071*	Mud	2	2	Mud	2	2
M0072	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0073	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0074	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0075	Mud	2	2	Mud	2	2
M0076	Mud	2	2	Mud	2	2
M0077	Muddy sand	3	3	Fine sand	4	2
M0078	Muddy sand	3	3	Fine sand	4	2
M0079	Muddy sand	3	3	Fine sand	4	4
M0080	Muddy sand	3	3	Fine sand	4	4
M0081	Muddy sand	3	3	Fine sand	4	4
M0082	Muddy sand	3	3	Fine sand	4	4
M0083	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0084	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0085	Gravel/gravel mixes	5	5	Gravelly mixtures	3	3
M0086	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0087	Bedrock/rocky	1	4	Bedrock/rocky	1	3
M0088	Mud	2	6	Mud	2	4
M0089	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0090	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0091	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0092	Gravelly med-coarse sand	4	1	Gravelly mixtures	3	1
M0093	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0094	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0095	Gravelly med-coarse sand	4	6	Gravelly mixtures	3	4
M0096	Bedrock/rocky	1	1	Bedrock/rocky	1	4
M0097	Slightly gravelly	7	6	Gravelly mixtures	3	4
M0098	Fine sand	6	6	Fine sand	4	4
M0099	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0100	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0101	Gravel/gravel mixes	5	4	Gravelly mixtures	3	3
M0102	Fine sand	6	6	Fine sand	4	4

M0103	Fine sand	6	6	Fine sand	4	4
M0104	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0105	Fine sand	6	6	Fine sand	4	4
M0106	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	4
M0107	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0108	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0109	Gravel/gravel mixes	5	4	Gravelly mixtures	3	3
M0110	Gravel/gravel mixes	5	4	Gravelly mixtures	3	3
M0111	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0112	Mud	2	6	Mud	2	4
M0113	Gravel/gravel mixes	5	4	Gravelly mixtures	3	3
M0114	Fine sand	6	6	Fine sand	4	4
M0115	Gravel/gravel mixes	5	4	Gravelly mixtures	3	3
M0116	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0117	Mud	2	2	Mud	2	2
M0118	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0119	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0120	Mud	2	2	Mud	2	4
M0121	Bedrock/rocky	1	1	Bedrock/rocky	1	1
M0122	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
M0123	Mud	2	6	Mud	2	4
M0124	Mud	2	6	Mud	2	4
M0125	Mud	2	6	Mud	2	4
M0126*	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	4
CB-86-048	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
CB-86-049	Bedrock/rocky	1	1	Bedrock/rocky	1	1
CB-86-051	Bedrock/rocky	1	4	Bedrock/rocky	1	1
CB-86-053	Mud	2	1	Mud	2	1
CB-86-054	Bedrock/rocky	1	1	Bedrock/rocky	1	1
CB-86-057	Mud	2	2	Mud	2	2
CB-86-064	Mud	2	2	Mud	2	2
CB-86-066	Bedrock/rocky	1	1	Bedrock/rocky	1	1
CB-86-067	Gravelly med-coarse sand	4	5	Gravelly mixtures	3	3
CB-86-068	Bedrock/rocky	1	7	Bedrock/rocky	1	1
CB-86-069	Bedrock/rocky	1	1	Bedrock/rocky	1	1
CB-86-070	Fine sand	6	3	Fine sand	4	4

CB-86-071	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
CB-86-073	Fine sand	6	6	Fine sand	4	4
CB-86-074	Gravelly med-coarse sand	4	6	Gravelly mixtures	3	4
CB-86-075	Gravel/gravel mixes	5	7	Gravelly mixtures	3	1
CB-86-076	Muddy sand	3	6	Fine sand	4	4
CB-86-079	Mud	2	3	Mud	2	4
CB-86-080	Muddy sand	3	3	Fine sand	4	4
CB-86-081	Slightly gravelly	7	1	Gravelly mixtures	3	1
CB-86-123	Gravelly med-coarse sand	4	1	Gravelly mixtures	3	1
CB-86-196	Bedrock/rocky	1	1	Bedrock/rocky	1	1
CB-87-001	Mud	2	1	Mud	2	1
CB-87-002	Mud	2	2	Mud	2	2
CB-87-004	Mud	2	2	Mud	2	2
SB-85-005	Mud	2	2	Mud	2	2
SB-85-006	Muddy sand	3	7	Fine sand	4	1
SB-85-007	Bedrock/rocky	1	7	Bedrock/rocky	1	1
SB-85-008	Mud	2	2	Mud	2	2
SB-85-009	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
SB-85-011	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
SB-85-014	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
SB-85-016	Gravelly med-coarse sand	4	7	Gravelly mixtures	3	1
SB-85-017	Bedrock/rocky	1	1	Bedrock/rocky	1	1
SB-85-018	Muddy sand	3	7	Fine sand	4	3
SB-85-019	Slightly gravelly	7	3	Gravelly mixtures	3	4
SB-85-020	Mud	2	2	Mud	2	2
SB-85-021	Mud	2	2	Mud	2	2
SB-85-022	Mud	2	2	Mud	2	2
SB-85-023	Mud	2	2	Mud	2	2
SB-85-024	Mud	2	2	Mud	2	2
SB-85-041	Mud	2	2	Mud	2	2
SB-85-042	Gravel/gravel mixes	5	7	Gravelly mixtures	3	1
SB-85-043	Gravel/gravel mixes	5	7	Gravelly mixtures	3	1
SB-85-045	Mud	2	2	Mud	2	2
SB-85-046	Mud	2	2	Mud	2	2
SB-85-047	Mud	2	2	Mud	2	2
SB-85-048	Mud	2	2	Mud	2	2

SB-85-049	Mud	2	2	Mud	2	2
SB-85-050	Slightly gravelly	7	2	Gravelly mixtures	3	2
SB-85-051	Mud	2	2	Mud	2	2
SB-85-052**	Mud	2	1	Mud	2	1
SB-85-053	Slightly gravelly	7	1	Gravelly mixtures	3	1
SB-85-054	Mud	2	2	Mud	2	2
SB-85-071	Mud	2	1	Mud	2	1
SB-85-072	Bedrock/rocky	1	4	Bedrock/rocky	1	3
SB-85-073	Mud	2	2	Mud	2	2
SB-85-074	Gravel/gravel mixes	5	5	Gravelly mixtures	3	3
SB-85-077	Bedrock/rocky	1	1	Bedrock/rocky	1	1
SB-85-080	Gravelly med-coarse sand	4	6	Gravelly mixtures	3	4
SB-85-081	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	3
SB-85-082	Gravelly med-coarse sand	4	6	Gravelly mixtures	3	4
SB-85-083	Muddy sand	3	6	Fine sand	4	4
SB-85-084	Fine sand	6	6	Fine sand	4	4
SB-85-085	Gravelly med-coarse sand	4	4	Gravelly mixtures	3	4
SB-85-086	Fine sand	6	6	Fine sand	4	4
SB-85-091	Mud	2	2	Mud	2	2
SB-85-093	Bedrock/rocky	1	4	Bedrock/rocky	1	3
SB-85-095	Mud	2	3	Mud	2	2
SB-85-098	Muddy sand	3	6	Fine sand	4	4
SB-87-001**	Slightly gravelly	7	1	Gravelly mixtures	3	1
SB-87-002**	Bedrock/rocky	1	2	Bedrock/rocky	1	2
SB-87-003	Mud	2	2	Mud	2	2
SB-87-011	Mud	2	2	Mud	2	2
SB-88-001	Slightly gravelly	7	4	Gravelly mixtures	3	3

[1]Sample ID M0001 through M0072 collected/visited by MCMI during the 2015 field season; grain-size analyses did not separate mud-sized particles into silt and clay components. M0073 through M0126 collected/visited by MCMI during the 2016 field season. All other sites collected by MGS/UMaine.

[2]Textural class assigned to samples in 7-class and 4-class model based on modified version of CMECS substrate groups (FGDC, 2012) shown in Table 1.

[3]Raster value corresponding to assigned textural class for respective model; used for comparison with respective textural model output raster values in columns 4 and 7.

[4]Output raster value of cell containing sample site for respective model; used for comparison with respective textural model class values assigned in columns 3 and 6.

*Folk classification for unconsolidated sample was determined in the field; no grain-size analysis data.

**Site was removed from model assessment due to suspected error in coordinates recorded for sample site.