National Oceanic and Atmospheric Administration
Office for Coastal Management

Great Lakes Benthic Habitat Mapping: South Manitou Island

Phase 2: CMECS Substrate and Biotic Components

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Acronyms and Abbreviations

BTM	Benthic Terrain Modeler
CASI	Compact Airborne Spectrographic Imager
CHARTS	Compact Hydrographic Airborne Rapid Total Survey
CIR	Color Infrared, referring to imagery
CMECS	Coastal and Marine Ecological Classification Standard
DEA	David Evans and Associates, Inc.
DTM	Digital terrain model
EPA	Environmental Protection Agency
ft	Foot, unit of length
GPS	Global Positioning System
HD	high definition
JALBTCX	Joint Airborne Lidar Bathymetry Technical Center of Expertise
Lidar	Light Detection and Ranging
m	meter, unit of length
MBES	Multibeam Echosounder
mi	Miles, unit of distance
min	Minute, unit of time
MMU	Minimum Mapping Unit
NAD83	North American Datum of 1983
NAIP	National Agriculture Imagery Program
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
OBIA	Object-based image analysis
OCM	Office for Coastal Management
RGB	Red-Green-Blue, referring to imagery
ROI	Region of interest
SHOALS	Scanning Hydrographic Operational Lidar Survey
SOW	Scope of work
SSS	Side-scan sonar
USACE	US Army Corps of Engineers
UTM	Universal Transverse Mercator coordinate system

1.0 INTRODUCTION

David Evans and Associates, Inc. (DEA) has been subcontracted by Woolpert, Inc. to produce benthic habitat maps for South Manitou Island in Lake Michigan (Figure 1) for the National Oceanic and Atmospheric Administration's (NOAA) Office for Coastal Management (OCM). This effort is a joint project involving NOAA OCM and the National Park Service (NPS) and is a pilot project for the Coastal and Marine Ecological Classification Standard (CMECS) in the Great Lakes region.

Figure 1. South Manitou Island with project region of interest (ROI) shown as thick red line. Depths shown in meters from NOAA electronic navigation chart. Red arrow in inset map shows project area within Great Lakes region.

The first phase of this project consisted of an evaluation of available source data and the formulation of recommendations and methodology to produce CMECS benthic habitat maps. DEA assembled all provided and available source data for the project area, including digital aerial orthoimagery, bathymetric data derived from aerial Light Detection and Ranging (Lidar) and multibeam echosounder (MBES) surveys, and acoustic imagery from side scan sonar (SSS) surveys. DEA also compiled and evaluated all available ground reference data. These data sets were reviewed to assess quality, spatial extent and resolution, and utility for benthic habitat mapping at the South Manitou Island site. For continuity, clarity, and reference, the results of the source data evaluation are included in this report (Section 2.0). The second phase of this project included the analysis and interpretation of the source data to produce the CMECS benthic habitat maps and field verification of the draft map products. This report is designed to communicate details about the methodology and results of the project.

2.0 SOURCE DATA EVALUATION

Source data were provided to Woolpert and DEA by project partners at NOAA OCM and NPS. For some data sets, additional processing, compilation, and/or analysis has been performed by DEA. Additional data sets were also identified and compiled through research by DEA. All data sets were referenced to the North American Datum of 1983 (NAD83), Universal Transverse Mercator (UTM) Zone 16N, with units in meters as specified in the project work plan. These data sets are described below and summarized in Table 1. Source data marked as "Primary" were used as base layers for object-based image analysis (OBIA) due to high spatial resolution and minimal acquisition artifacts; source data marked as "Secondary" were utilized as additional information during interpretation.

Table 1. Summary of available source data and type.

Remote Sensing Data Type	Benthic Mapping Utility	Date	Resolution	Source
Aerial RGB orthoimagery	Primary; Classification	2012	15cm	State of Michigan
Aerial RGB orthoimagery	Secondary; Interpretation	2016	60cm	NAIP
Lidar bathymetry	Primary; Classification	2016	2m	NOAA OCM
MBES bathymetry	Primary; Classification	2011	1m	NPS/NMC
MBES backscatter	Secondary; Interpretation	2011	1m	NPS/NMC; Processed by DEA
SSS imagery	Secondary; Interpretation	2008-09	1m	USGS; Processed by DEA
Lidar bathymetry	Primary; Classification	2007	1m	USACE JALBTCX

2.1 DIGITAL REMOTE SENSING DATA

2.1.1 Aerial orthoimagery, 2012, 15cm pixel resolution

Aerial orthoimagery was acquired on 4-5 April 2012 by Premier Geospatial, a contractor for the State of Michigan, in support of Michigan's Statewide Partnership Program. The imagery was acquired using a Leica ADS40 digital sensor with a 62mm focal length. Red, Green, Blue (RGB), Color Infrared (CIR) and Panchromatic image bands are available. Coverage area includes all of South Manitou Island and extends offshore to a variable extinction depth, but usually at least 3,000 feet from the shoreline. The geometrically corrected orthoimagery provides an excellent level of detail with minimal to no data artifacts. The RGB image (Figure 2a) was used as a base layer for OBIA due to excellent spatial resolution, image quality, and water penetration.

2.1.2 Aerial orthoimagery, 2016, 60cm pixel resolution

Aerial orthoimagery was acquired in 2016 through the National Agriculture Imagery Program (NAIP). RGB and CIR image bands are available. Coverage area includes all of South Manitou Island and extends offshore past the extinction depth. This imagery provides an excellent level of detail and, along with the 2012 imagery, provides two discrete time points at which to observe the spatial distribution of benthic macroalgae and other biotic components.

2.1.3 Lidar bathymetry, 2016, 2m grid resolution

Lidar bathymetry and intensity data were acquired on 2-3 June 2016 by Leading Edge Geomatics and Dewberry as contractors for NOAA OCM. The Lidar data were acquired with a Leica Chiroptera II system. Coverage area includes all of South Manitou Island and extends offshore to the 7-meter depth contour; however, these data do not provide any coverage of the cove on the eastern side of the island. The bathymetry was delivered as a set of tiles; DEA compiled tiles to produce a digital terrain model (DTM) (Figure 2b). This data set is of a very high quality and provided an excellent level of detail for the production of second-order terrain metrics such as slope and rugosity. This data set was used as a base layer for OBIA. Full-waveform data were available for this data set, however processing and analysis of the full-waveform Lidar data was determined to be beyond the scope of this project.

2.1.4 Lidar bathymetry, 2007, 1m grid resolution

Lidar bathymetry data was acquired on 11-20 September 2007, by the US Army Corps of Engineers (USACE) Joint Airborne Lidar Bathymetry Technical Center of Excellence (JALBTCX) using the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system. The CHARTS system includes a Scanning Hydrographic Operational Lidar Survey (SHOALS) system and a Compact Airborne Spectrographic Imager (CASI) system for acquiring imagery. These data were acquired in support of the National Coastal Mapping Program. Coverage area includes all of the South Manitou Island shoreline and extends offshore to an extinction depth around 15m (Figure 2c); however, these data do not provide any coverage of the cove on the eastern side of the island. This data set provides a good level of detail, but contains a significant amount of data gaps and artifacts. In particular, swath edge artifacts within the data set led to undesirable results when deriving second-order terrain metrics such as slope and rugosity. Therefore, these Lidar data were only used as an OBIA base layer outside the coverage area of the 2016 Lidar data.

2.1.5 MBES bathymetry and backscatter, 2011, 1m grid resolution

Hydrographic surveys were conducted by NPS and Northwestern Michigan College (NMC) Great Lakes Water Studies Institute from 9-30 June 2011. The NMC vessel R/V *Northwestern* was used for the survey. The *Northwestern* was equipped with a Kongsberg-Simrad EM3002 MBES system coupled with Kongsberg's Seapath 200 positioning system. Processed MBES data and a bathymetric DTM (Figure 2d) were provided to DEA. The DTM fills a critical data gap in the cove on the eastern side of South Manitou Island. Therefore, the MBES bathymetric data set was used as an OBIA base layer for the cove area. In addition to bathymetry, DEA used Fledermaus FMGT software to produce acoustic backscatter imagery from the processed MBES data. The MBES backscatter imagery was used as an interpretation aid for the cove area.

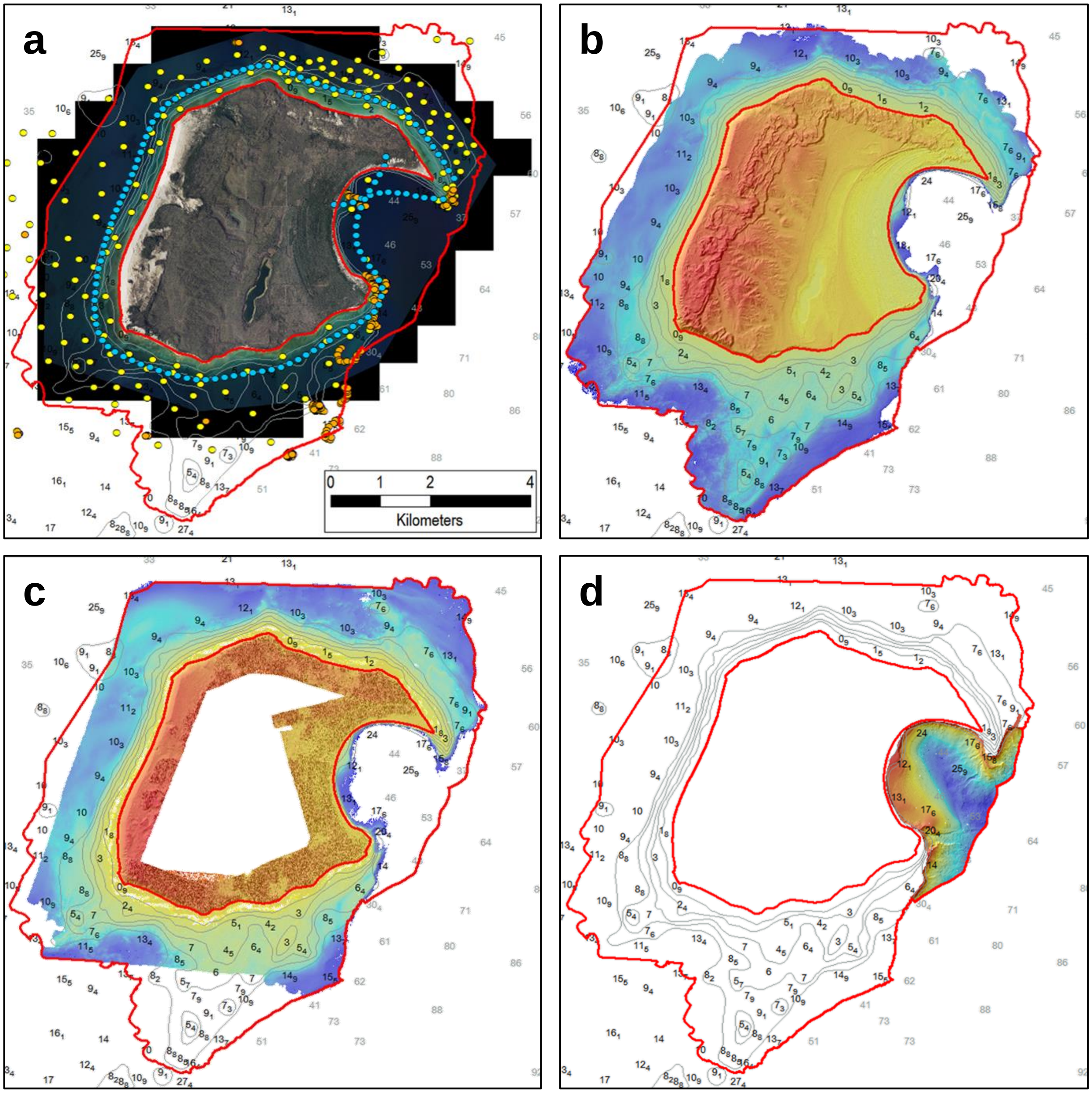

Figure 2. Primary source data and ground reference data. **a:** 2012 RGB aerial orthoimagery, 15cm resolution, and ground reference data points: Yellow dots are USGS videos from 2008-2009, orange dots are USGS videos from 2011-2013, blue dots are USACE aerial photos from 2011-2012. Scale applies to all images. **b:** 2016 Lidar bathymetry, 2m resolution. **c:** 2007 Lidar bathymetry, 1m resolution. **d:** 2011 MBES bathymetry, 1m resolution. Data shown over NOAA electronic navigation chart product with depths in meters. Project ROI shown as thick red line.

2.1.6 Side Scan Sonar imagery, 2008-2009, 50cm pixel resolution

Side scan sonar (SSS) imagery was acquired by the US Geological Survey (USGS) from 7-14 September 2008 and 9-17 June 2009. An EdgeTech 4200 was deployed from a small vessel and used to acquire SSS imagery around South Manitou Island in a series of transects both parallel and orthogonal to the coastline, including the cove on the eastern side of the island. The raw SSS data was provided to DEA. Using SonarWiz software, DEA processed the raw SSS data and produced acoustic imagery. The SSS imagery is good quality but does contain some data gaps in addition to typical SSS image artifacts (e.g. nadir stripes, acoustic shadows) related to the low incident angle of the SSS beams at outer ranges. Due to the data gaps and artifacts, the SSS imagery was not used as an OBIA base layer. However, this data set served as a valuable supplementary data set to validate signatures observed in primary mapping inputs.

2.2 GROUND REFERENCE DATA

Available ground reference data are described in detail below and summarized in Table 2. Ground reference data marked as “Primary” were analyzed for substrate and biotic information and parsed into training and testing data sets for OBIA classification; ground reference data marked as “Secondary” were utilized for additional information during interpretation.

Table 2. Summary of available ground reference data and properties.

Ground Reference Data Type	Benthic Mapping Utility	Date	Number	Source
Underwater videos	Primary; Classification	2008-09	188	USGS
Underwater videos	Secondary; Interpretation	2011-13	73	USGS
Underwater videos	Secondary; Interpretation	2010	6	EPA
Oblique aerial photography	Secondary; Interpretation	2011-12	135	USACE

2.2.1 USGS underwater videos, 2008-2009

USGS acquired underwater videos with a waterproof camera (“dropcam”) on 9-13 September 2008 and 18-19 June 2009 to provide ground reference points for the SSS data acquired during the same periods. From a small vessel, the camera was lowered to the bottom and then towed a short distance while recording video and position, heading, speed, time, and depth data. After acquisition, the video footage was analyzed by USGS for substrate type in addition to the observed abundance and distribution of both *Cladophora* algae and zebra mussels (*Dreissena polymorpha*). The videos are black and white and generally good quality, with some variation in video quality due to decreased water clarity because of environmental conditions (Figure 3a). There is a total of 188 videos (Figure 2f in yellow), ranging in duration from 1-5 minutes. Due to the high quality of the videos, the existing biological analyses, and the apparent positional accuracy, these videos were used as primary ground reference data to be utilized for benthic habitat map production as well as accuracy assessment.

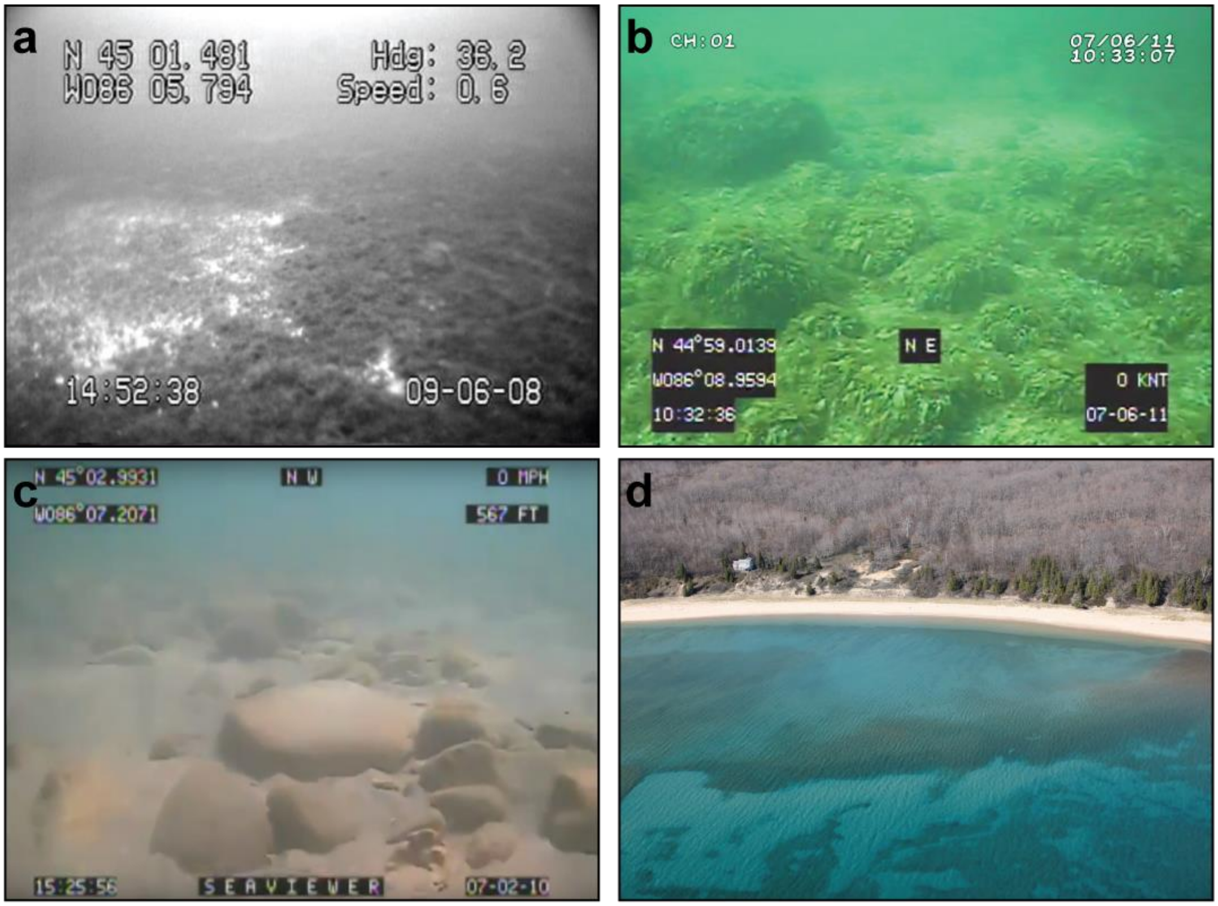

Figure 3. Example ground reference images and quality. a: Still image from 2008-09 underwater video; b: Still image from 2011-2013 underwater videos; c: Still image from EPA NARS surveys in 2010; d: Still image from 2011-2012 oblique aerial imagery.

2.2.2 USGS underwater videos, 2011-2013

USGS acquired additional underwater videos with similar equipment on various dates between 2011 and 2013. Each video includes time, position, heading, and depth data (Figure 3b), however the source data included with the videos listed some positioning uncertainties. Video quality was not as good as the 2008-2009 videos due to a faster tow speed which degraded image quality. These videos were not analyzed for substrate or biotic information. These videos were a valuable secondary ground reference data set for substrate and biotic interpretation. There is a total of 73 video files (Figure 2a in yellow) ranging in duration from 5 minutes to nearly 35 minutes.

2.2.3 National Aquatic Resource Surveys videos, 2010

The US Environmental Protection Agency (EPA) acquired underwater video at six locations around South Manitou Island during June-July 2010 (Figure 3c). The videos were acquired as part of the EPA's National Aquatic Resource Surveys (NARS), which are designed to assess the quality of coastal waters, lakes and reservoirs, rivers and streams, and wetlands. Video quality is variable. These videos have not been analyzed for substrate or biotic information. These videos were a valuable secondary ground reference data set for substrate and biotic interpretation. There is a total of six video files ranging in duration from 1-2 minutes. The videos are accessible via the EPA and YouTube websites (https://gispub.epa.gov/NCCA/).

2.2.4 USACE Oblique Aerial Photography, 2011-2012

The USACE acquired high resolution oblique aerial photographs of the entire coast of the Great Lakes, including South Manitou Island, as part of the Great Lakes Coastal Flood Study. The aerial photographs were used to determine ground conditions during the production of updated coastal flood maps. The photographs were acquired from low-flying aircraft with a Canon EOS-1Ds Mark III digital single lens reflex (DSLR) camera and 50mm focal length lens. The aircraft flight path traces the entire coastline of South Manitou Island. Time, position, altitude, and image metadata were recorded with each photograph. The photographs are high-resolution and excellent quality (Figure 3d). These photos were a valuable secondary ground reference data set for substrate and biotic interpretation, particularly for the coastline and shallow nearshore areas on South Manitou Island. There is a total of 135 aerial photos (Figure 2a in blue).

3.0 HABITAT MAPPING METHODOLOGY

DEA implemented a multi-stage approach to produce CMECS substrate component and biotic component maps for the South Manitou Island project area. Source data and ground reference data were assembled in an ArcGIS geodatabase and referenced to the project datum (NAD83 UTM 16N). Terrain modeling and OBIA techniques (segmentation and classification), were used to transform primary source data sets into preliminary benthic habitat maps, using substrate and biotic cover information extracted through photointerpretation of ground reference data. An expert-guided, manual interpretation phase refined the habitat maps based on secondary source data, ground reference data, and expert knowledge of benthic geologic processes. Preliminary map products were evaluated in the field by NOAA and DEA in late summer 2017 and the habitat maps were subsequently refined based on field observations and additional ground reference data. A final accuracy assessment was performed to quantify the overall thematic accuracy of the benthic habitat maps.

3.1 PHOTOINTERPRETATION

DEA conducted additional analyses of the primary ground reference data (2008-2009 USGS underwater video) in preparation for use as training and testing data during classification and accuracy assessments. The videos were interpreted separately by a marine biologist and a marine geologist who collaborated extensively in order to calibrate interpretations. Each video was viewed to evaluate biotic and substrate type and coverage. Still images that represented each type of biotic and substrate cover were captured and extracted from the videos. Each still image represented a single biota or substrate type at a scale and extent appropriate to match the specified minimum mapping unit (MMU) of 10m x 10m. A total of 642 images were extracted from the videos. The position of each still image was determined by utilizing the position data recorded during each video. The image locations were converted to an ESRI shapefile and imported into the project geodatabase. During map production, each image location was hyperlinked directly to the image for quick reference.

3.2 PRELIMINARY MAP PRODUCTION

3.2.1 Substrate Component

The workflow for mapping the CMECS Substrate Component (SC) included terrain modeling, OBIA segmentation and classification techniques, and expert manual interpretation. The primary source data for the SC were the 2012 RGB orthoimagery, the 2007 and 2016 Lidar bathymetry data, and the 2012 MBES bathymetry data. These image layers were imported to Trimble eCognition software for OBIA segmentation and classification. The multiresolution image segmentation procedure was an iterative process designed to optimize segmentation results while minimizing redundant data layers (and thus computation power and time). A sensitivity analysis was performed using different combinations of the DTM geomorphometry input layers and segmentation parameters. The best result, determined qualitatively as the most natural segmentation of the imagery, was attained using the Slope, Rugosity, Ruggedness, and Shaded Relief layers, a segmentation scale parameter of 10, a color parameter of 0.2, and a smoothness parameter of 0.5. After segmentation, a thresholding operation was applied to flag all image objects corresponding to data gaps or areas outside of the project ROI. An additional operation was performed to remove all objects containing less than 25 pixels ($100m^2$), in accordance with the specified MMU.

A supervised classification was performed using training data parsed from the primary ground reference data. Using an object-based decision tree classifier algorithm, each object in the segmentation data set was classified as either "fine unconsolidated sediment" or "coarse unconsolidated sediment" CMECS Substrate Subclasses. After classification, a preliminary accuracy assessment was performed to determine and document the accuracy of the automated SC classification. The preliminary accuracy assessment was conducted using a separate set of testing data points parsed from the primary ground reference data. The results of this accuracy assessment showed that the supervised classification did not meet map accuracy standards as defined in the project SOW, possibly due to positioning errors in the ground reference data. Therefore, the classified image objects were converted to vector polygon format (ESRI shapefile) and exported to the project geodatabase for additional manual interpretation and analysis.

The CMECS SC polygons produced by automated classification were reviewed and manually refined through expert interpretation. In addition to the DTM, all relevant supplemental mapping data and all available ground reference data were queried during this process. Supplemental source data for the SC classification included the 2012 RGB orthoimagery, the 2016 aerial imagery, the 2008-2009 SSS imagery, and the 2012 MBES acoustic backscatter imagery. Each polygon or group of polygons were selected, and the assigned SC was compared with available mapping and/or ground reference data in the vicinity. If necessary, the original SC classification was edited to reflect the geologic context of the polygon. If required, OBIA polygon boundaries were edited. Four charted shipwrecks within the project ROI were identified and mapped as Anthropogenic Metal or Wood Rubble. After expert interpretation, an accuracy assessment indicated >90% agreement between the preliminary SC map and ground reference data.

3.2.2 Biotic Component

The workflow for mapping the CMECS Biotic Component (BC) was similar to the workflow for mapping the SC, with additional steps designed to account for the multiple acquisition dates of mapping data and ground reference data and the seasonality of the biotic cover. The primary source data for the BC was the 2012 RGB orthoimagery. In preparation for analysis, the orthoimagery was resampled from the original 25cm pixel resolution to 2m pixel resolution.

The orthoimagery was imported to Trimble eCognition software for OBIA segmentation and classification. The multiresolution image segmentation procedure was an iterative process designed to optimize segmentation results A sensitivity analysis was performed using various segmentation parameters. The best result, determined qualitatively as the most natural segmentation of the imagery, was attained using a scale parameter of 10, a color parameter of 0.1, and a smoothness parameter of 0.5. After segmentation, a thresholding operation was applied to flag all image objects corresponding to data gaps or areas outside of the project ROI. An additional operation was performed to remove all objects containing less than 25 pixels ($100m^2$), in accordance with the specified MMU.

A supervised classification was performed using training data parsed from the primary ground reference data. Using an object-based decision tree classifier algorithm with binary logic, each object in the segmentation data set was classified as either "benthic macroalgae present" or "no benthic macroalgae present". After classification, a preliminary accuracy assessment was performed to determine and document the accuracy of the automated BC classification. The preliminary accuracy assessment was conducted using a separate set of testing data points parsed from the primary ground reference data. The results of this accuracy assessment showed that the supervised classification did not meet map accuracy standards as defined in the project SOW, possibly due to the temporal differences in ground reference data and orthoimagery and positioning errors in the ground reference data. Therefore, the classified image objects were converted to vector polygon format (ESRI shapefile) and exported to the project geodatabase for additional manual interpretation and analysis.

The CMECS BC polygons produced by automated classification were reviewed and manually refined through expert interpretation. In addition to the orthoimagery, all relevant supplemental source data and all available ground reference data were queried. Expert interpretation was a difficult task given the small extent of the primary mapping data (RGB orthoimagery) relative to the overall project ROI. Outside of the extent of the RGB orthoimagery, no optical data was available and therefore BC mapping was limited to manual interpretation of the DTM and interpolation and extrapolation of spatially coarse ground reference data. In addition, the acquisition dates of the mapping data and ground reference data varied widely and included dates from 2008-2013.

An initial expert interpretation phase focused on areas within the extent of the RGB orthoimagery. Supplemental mapping data available within this area included the 2008-2009 SSS imagery, the 2012 MBES acoustic backscatter imagery, and the Green and Blue bands of the RGB orthoimagery. Each polygon or group of polygons were selected, and the assigned BC was compared with available mapping and/or ground reference data in the vicinity. If necessary, the original BC classification was edited to reflect the geologic context of the polygon. If required, the OBIA polygon boundaries were edited.

The result of the initial expert interpretation process was essentially a deterministic product depicting the spatial distribution of BC types as captured on the acquisition data of the RGB orthoimagery (4/5/2012). Expanding the initial expert interpretation to the full extent of the project ROI was problematic given that the initial BC map showed the distribution of both active and senescent *Cladophora* material at a discrete point in time. As a solution, the spatial distribution of BC and SC Subclasses were further examined to identify any potential biotopes that could facilitate extrapolation of the BC map over the remaining project area. Biotopes, or combinations of abiotic and biotic characteristics that form a specific habitat, are commonly used within the CMECS hierarchy. In the South Manitou Island project area, the majority of active *Cladophora* growth occurs on cobbles, boulders, rubble, and other coarse unconsolidated sediment. This association between substrate and biota is supported through empirical observations compiled during the photointerpretation and expert interpretation processes, through comparisons between the SC map and the RGB orthoimagery, and by the ecology of *Cladophora* algae, which preferentially colonizes on coarser, rougher substrates (e.g. Dodds and Gudder 1992). This relationship formed the basis of a CMECS biotope that was used to expand the CMECS BC map to the full spatial extent of the project ROI. The final expert interpretation phase expanded the CMECS BC map to the full project ROI using the identified biotope and the distribution of coarse unconsolidated substrate as a guide. After expert interpretation, an accuracy assessment indicated >90% agreement between the preliminary BC map and ground reference data.

3.3 FIELD EVALUATION

NOAA and DEA conducted a site visit to the South Manitou Island project area on 8-9 August 2017 (Figure 4). The objective of the site visit was to acquire additional field observations and ground reference data to evaluate the thematic accuracy of the preliminary SC and BC map products. A vessel was provided and operated by Northwestern Michigan College (NMC) and the team mobilized from Leland, MI. In preparation for the site visit, NOAA and DEA compiled a list of locations at which to obtain substrate and biotic cover observations to address ambiguities or potential disagreement in the preliminary SC and BC maps.

Underwater photographic and video equipment were provided by NOAA and consisted of a JW Fisher TOV towed video system and a GoPro digital camera with underwater housing. The video feed from the TOV was displayed real-time on a monitor mounted in the cabin of the vessel. Initially the GoPro and TOV were operated separately; however, due to technical difficulties that prevented recording of the TOV video stream, the GoPro camera was attached to the TOV to enable high definition (HD) recording of underwater observations. Positioning for the photographic and video data were provided by a handheld global positioning system (GPS) device, which also continuously recorded the track of the vessel. At each previously determined observation point, the TOV and GoPro were lowered to the bottom. The altitude of the TOV was adjusted in real time while monitoring the video feed. Detailed observations of substrate cover, biotic cover, bottom morphology, and co-occurring elements were documented. A total of 36 GoPro videos were recorded. At six sites, sediment samples were also obtained with a Ponar grab sampler.

SSS imagery was acquired along three short transects using an EdgeTech 4125 provided by NMC. Positioning was provided by the vessel's onboard GPS. The SSS towfish was deployed by hand from the starboard aft quarter of the vessel and the amount of cable out was recorded. The system was operated in 400kHz and 900kHz modes. The raw SSS data were processed by DEA using SonarWiz software. During processing, the amount of cable out was used to calculate layback for accurate positioning of the towfish relative to the vessel position. The SSS transects were designed to investigate specific morphological signatures and ambiguities. Two transects south of the island captured a transition from coarse to fine sediment. A third transect north of the island confirmed an area of sand, rather than rocky substrate as shown on NOAA chart 14912.

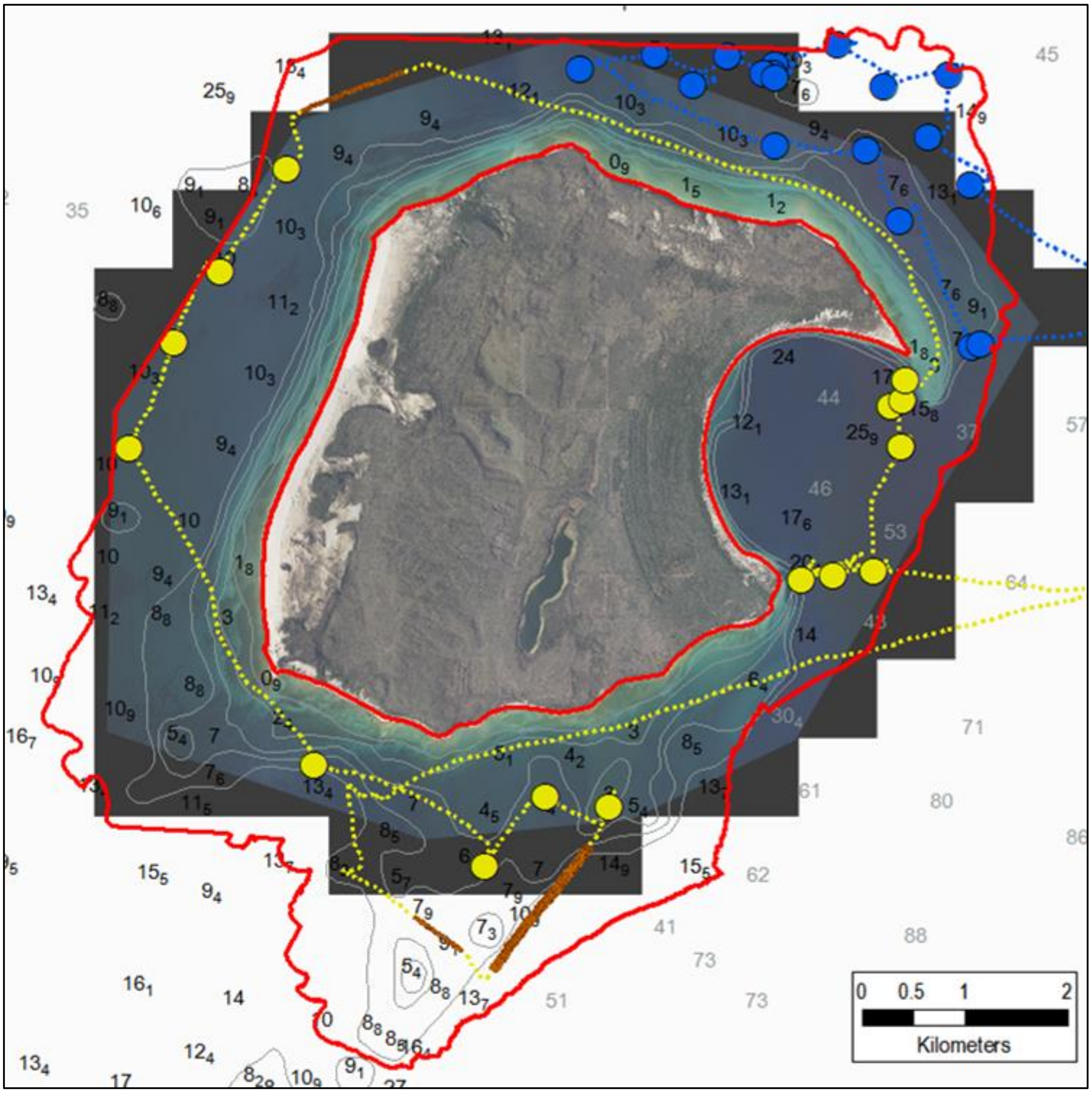

Figure 4. Field evaluation conducted by NOAA and DEA on 8-9 August 2017. Blue dashed line and points indicate 8 August vessel track and observation points. Yellow dashed line and points indicated 9 August vessel track and observation points. SSS imagery acquired on 9 August is shown over vessel track. Data shown over 2012 RGB orthoimagery and NOAA electronic navigation chart with depths in meters.

3.4 FINAL MAP PRODUCTION

The field evaluation data were imported into the project geodatabase and compared with the preliminary map products, source data, and ground reference data. Each video was analyzed to evaluate biotic and substrate type and coverage, in addition to bottom morphology and co-occurring elements, and compared with the preliminary map products. The preliminary SC and BC maps were refined using the original OBIA-derived polygon architecture as a guide. All available primary and secondary source data and ground reference data were utilized.

4.0 RESULTS

A workflow combining photointerpretation, OBIA techniques, field evaluation, and expert interpretation produced benthic habitat maps including CMECS Substrate and Biotic Components for the 42km^2 project area at South Manitou Island. The Substrate and Biotic Components were classified to the CMECS Subclass level, as specified in the project SOW. For both components, Co-Occurring Elements and Modifiers (i.e. Percent Cover, Induration, Surface Pattern) were added to provide further detail to CMECS units. Example images and corresponding CMECS classifications are included in Appendix A.

The Substrate Component endmembers and the resulting map are shown in Table 3 and Figure 5, respectively. The dominant substrate types within the project area are coarse unconsolidated sediment (granule to boulder size on the Wentworth Scale) with interstitial accumulations of loose shell hash material, fine unconsolidated sediment with rippled bedforms and loose shell hash material, and a fine/coarse unconsolidated sediment mixture with loose shell hash material. North of the island is a region of semiconsolidated, highly compacted “hardpan clay” accompanied by loose shell hash material and coarse unconsolidated sediments. The hardpan clay is likely present elsewhere within the project area but is obscured by overlying sediments or biotic cover. South Manitou Bay is ringed by irregular deposits of fine and coarse unconsolidated sediments that appear to have formed through natural shoreline slumping events. Relatively major slumps offshore Sandy Point and Gull Point have resulted in prominent “chutes” by which organic debris and detritus is transported to the deeper portions of the bay.

Four shipwrecks were also identified from the source data and mapped with the substrate components. To the south of the island, the wreckage of the *Walter L. Frost* and the *Francisco Morazan* were classified as metal reef. In South Manitou Bay, the remains of the *Three Brothers* and the *Congress* were classified as wood reef substrate.

Table 3. CMECS Substrate Component classification with modifiers, co-occurring elements (COE), geologic description, and relative abundances.

Substrate Origin	Substrate Class	Substrate Subclass	Modifier	COE1	COE2	Description	Relative Abundance
Geologic	Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	-	Shell Hash	-	Coarse unconsolidated sediment (grain sizes 2mm-4096mm) with interstitial accumulations of loose shell hash material (particle sizes 2mm-64mm)	31.8%
Geologic	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Substrate Pattern: Rippled	Shell Hash	-	Fine unconsolidated sediment (grain sizes <2mm) with rippled bedforms and loose shell hash material (particle sizes 2mm-64mm)	26.7%
Geologic	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	-	Coarse Unconsolidated Substrate	Shell Hash	Predominantly fine unconsolidated sediment (grain sizes <2mm) with co-occurring coarse unconsolidated sediment (grain sizes 2mm-4096mm) and loose shell hash material (particle sizes 2mm-64mm)	25%
Geologic	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Substrate Pattern: Scarred	Coarse Unconsolidated Substrate	Organic Detritus	Mixtures of fine (grain sizes <2mm) and coarse (grain sizes 2mm-4096mm) unconsolidated sediment with surface morphology suggestive of natural slumping	7.3%
Geologic	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Substrate Descriptor: Compacted	Shell Hash	-	Highly compacted fine sediment ("hardpan clay") with accumulations of loose shell mash material (particle sizes 2mm-64mm)	3.6%
Geologic	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Substrate Descriptor: Compacted	Coarse Unconsolidated Substrate	Shell Hash	Highly compacted fine sediment ("hardpan clay") with coarse unconsolidated sediment (grain sizes 2mm-4096mm) and shell hash (particle sizes 2mm-64mm)	2.5%
Geologic	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	Substrate Pattern: Smooth	Organic Detritus	Shell Hash	Smooth, fine unconsolidated sediment (grain sizes <2mm) with organic detritus and shell hash	2.4%
Geologic	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	-	Shell Hash	-	Fine unconsolidated sediment (grain sizes <2mm) with loose shell hash material (particle sizes 2mm-64mm) and organic detritus	<1%
Geologic	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	-	Organic Debris	Organic Detritus	Fine unconsolidated sediment (grain sizes <2mm) with co-occurring woody rubble (particle sizes 64mm-4096mm) and organic detritus	<1%
Anthropogenic	Metal	Metal Reef Substrate	-	-	-	Wreckage of the Walter L. Frost (1903) and the Francisco Morazan (1960)	<1%
Anthropogenic	Anthropogenic Wood	Anthropogenic Wood Reef Substrate	-	-	-	Wreckage of the Congress (1904) and the Three Brothers (1911)	<1%

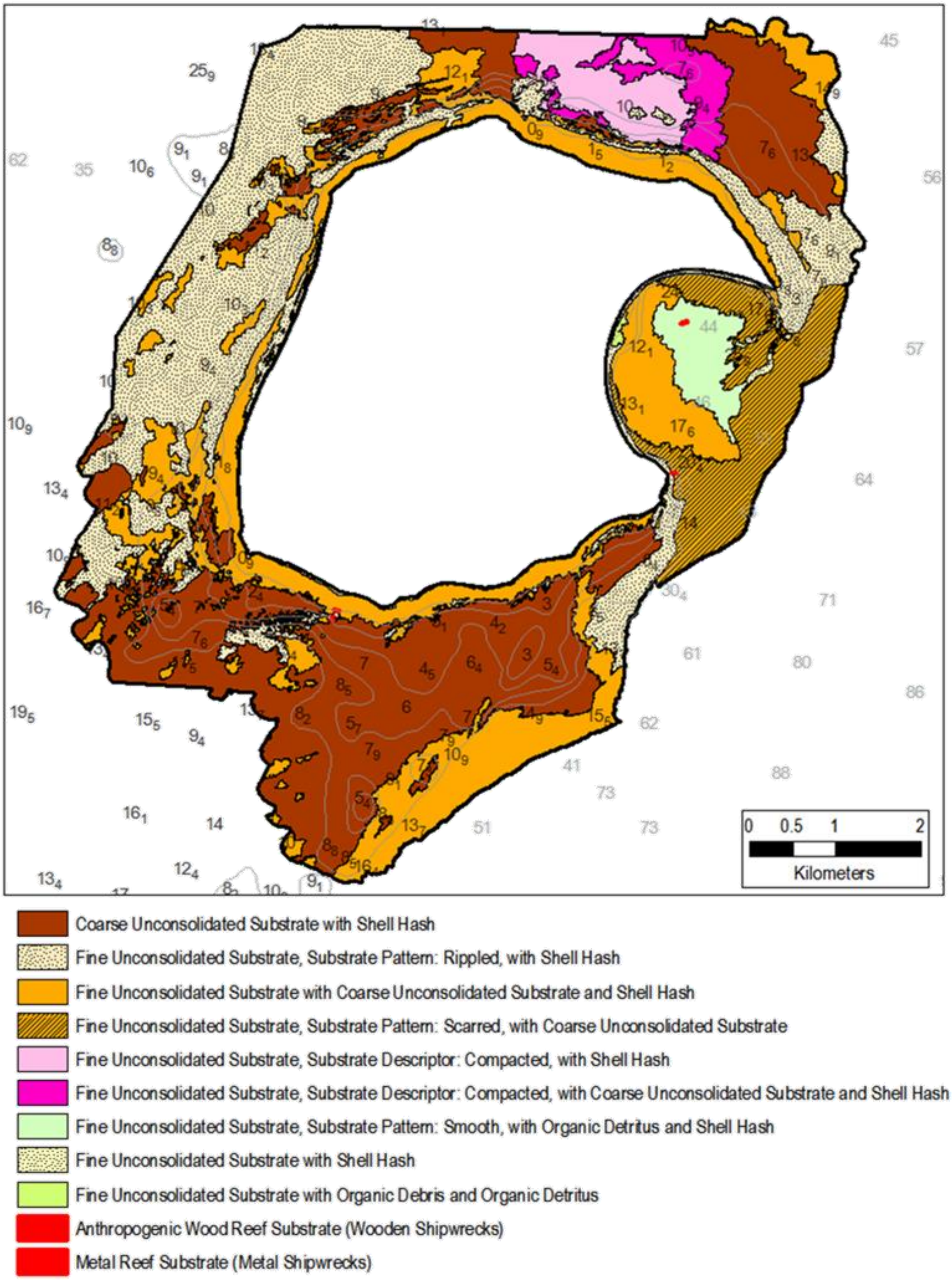

Figure 5. CMECS Substrate Component map and accompanying legend for the South Manitou Island project area. Project ROI shown as thick black line. Shown with NOAA electronic navigation chart, depths in meters. Example images are included in Appendix A.

The Biotic Component endmembers and the resulting map are shown in Table 4 and Figure 6, respectively. Overall, benthic macroalgae was present in approximately 87% of the project area. A "Percent Coverage" modifier was added to the attribute table to distinguish areas with varying algae coverage. Dense accumulations of algae were found on coarse substrates along with attached mussels. Sparse amounts of algae were observed on fine substrates; where present, the algae were commonly located in the troughs of rippled bedforms. Note the sparse algae coverage on the highly compacted "hardpan clay" north of the island. While the algae have extensively colonized hard substrates in the area, coverage is sparse to none on the hardpan clay except where accompanied by coarse substrate material.

Active mussel beds were only observed in smooth, soft, and less mobile sediments of South Manitou Bay. Similar mussel beds may be present elsewhere in the project area but may be obscured by overlying algae material. No other mussel beds were identified in the ground reference data.

Table 4. CMECS Biotic Component classification with modifiers, co-occurring elements (COE), description, and relative abundances.

Biotic Setting	Biotic Class	Biotic Subclass	Modifier	COE1	COE2	Description	Relative Abundance
Benthic/Attached Biota	Aquatic Vegetation Bed	Benthic Macroalgae	Percent Coverage: Dense	Attached Fauna	-	Dense areal coverage (70%-90%) of benthic macroalgae with co-occurring attached mussels on hard substrates	38.5%
Benthic/Attached Biota	Aquatic Vegetation Bed	Benthic Macroalgae	Percent Coverage: Light	-	-	Light areal coverage (10%-30%) of benthic macroalgae	26.3%
Benthic/Attached Biota	Aquatic Vegetation Bed	Benthic Macroalgae	Percent Coverage: Moderate	Soft Sediment Fauna	-	Moderate areal coverage (30%-70%) of benthic macroalgae with co-occurring mussel beds in soft sediment	10.1%
Benthic/Attached Biota	Aquatic Vegetation Bed	Benthic Macroalgae	Percent Coverage: Moderate	Attached Fauna	-	Moderate areal coverage (30%-70%) of benthic macroalgae with co-occurring attached fauna on hard substrates	9.5%
Benthic/Attached Biota	Aquatic Vegetation Bed	Benthic Macroalgae	Percent Coverage: Dense	Soft Sediment Fauna	-	Dense areal coverage (70%-90%) of benthic macroalgae with co-occurring mussel beds in soft sediment	2.9%
Benthic/Attached Biota	Faunal Bed	Soft Sediment Fauna	-	Benthic Macroalgae	-	Mussel bed with moderate areal coverage (30%-70%) of benthic macroalgae	<1%

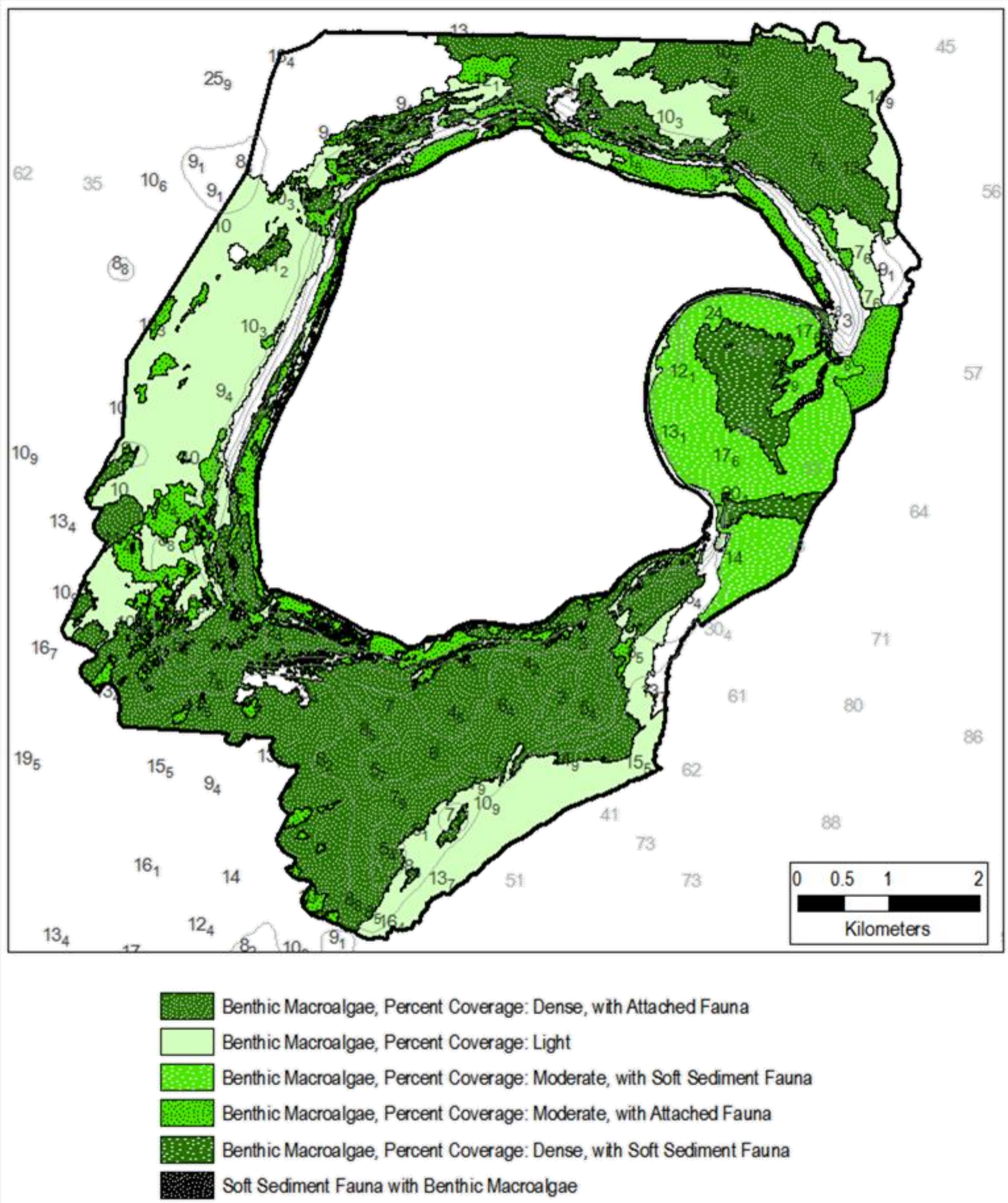

Figure 6. CMECS Biotic Component map and accompanying legend for the South Manitou Island project area. Project ROI shown as thick black line. Shown with NOAA electronic navigation chart, depths in meters. Example images are included in Appendix A.

Figure 7 shows the relative density of source data and ground reference data as a qualitative method for assessing map confidence. The overlapping coverage of the 2012 RGB orthoimagery, the 2016 Lidar topobathymetry, the 2011 MBES bathymetry and backscatter, and the 2008-2009 SSS backscatter imagery provided an excellent level of spectral and spatial detail and often enabled direct interpretation of substrate and biotic cover information and comparisons with spatially coincident data. However, this overlapping coverage was limited to South Manitou Bay and a 0.75-1km wide swath around the island. The majority of the ground reference data are located within this region as well. Outside of this area of overlapping coverage, interpretations of substrate and biotic cover were based on the 2007 and 2016 Lidar data and extrapolations of ground reference data.

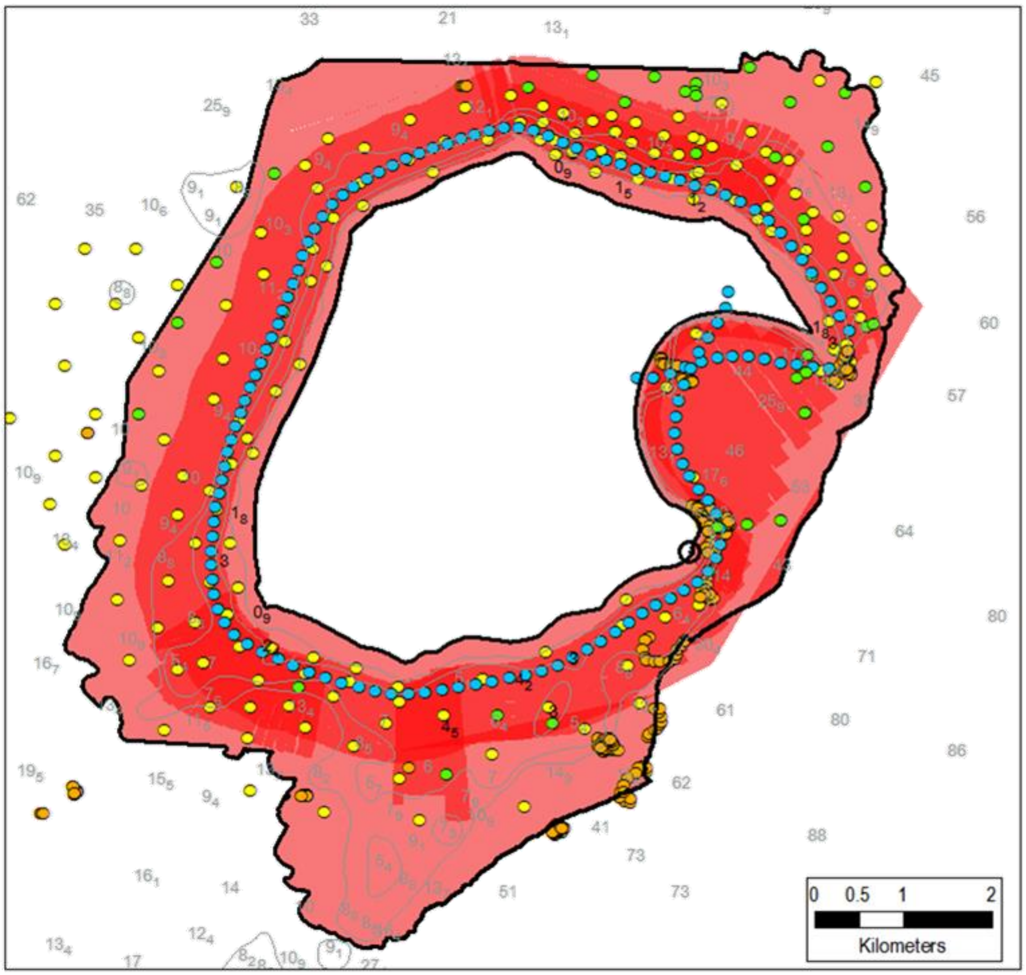

Figure 7. Density of source data in South Manitou Island project area. Darker red colors indicate higher confidence due to overlaps between data sets. Ground reference data also shown: Yellow dots are 2008-2009 USGS videos, orange dots are 2011-2013 USGS videos, blue dots are 2011-2012 USACE aerial photos, green dots are 2017 NOAA/DEA field evaluation videos. Project ROI shown as thick black line. Shown with NOAA electronic navigation chart, depths in meters.

An accuracy assessment was conducted to assess the thematic map accuracy of the final CMECS SC and BC maps relative to project specifications, which stated a minimum overall map accuracy of 80% for individual categories and 85% overall at the subclass level. The accuracy assessment was performed using testing data points parsed from the 2008-2009 USGS videos that were not used as training data during image classification, in addition to points acquired during the 2017 field evaluation. Substrate and biotic cover observations from each testing data point were compared to the classified polygon in which the point was located. Correct and incorrect classifications were tabulated in ArcGIS. Accuracy metrics were calculated using standard methods. Error matrices and accuracy metrics are presented in Tables 5 and 6. All accuracy statistics are above stated project requirements.

Table 5. Error matrix and calculated accuracy statistics for the CMECS SC map.

		REFERENCE		
		Fine Unconsolidated Substrate	Coarse Unconsolidated Substrate	Row Totals
CLASSIFIED	Fine Unconsolidated Substrate	115	5	120
	Coarse Unconsolidated Substrate	8	56	64
	Column Totals	123	61	184

Fine Unconsolidated Substrate Producer's Accuracy: 115/123 = 93.5%

Fine Unconsolidated Substrate User's Accuracy: 115/120 = 95.8%

Fine Unconsolidated Substrate Overall Accuracy: 115/123 = 93.5%

Coarse Unconsolidated Substrate Producer's Accuracy: 56/61 = 91.8%

Coarse Unconsolidated Substrate User's Accuracy: 56/64 = 87.5%

Coarse Unconsolidated Substrate Overall Accuracy: 56/61 = 91.8%

Overall Accuracy: 161/184 = 87.5%

Table 6. Error matrix and calculated accuracy statistics for the CMECS BC map.

		REFERENCE		
		Benthic Macroalgae Present	Benthic Macroalgae Absent	Row Totals
CLASSIFIED	Benthic Macroalgae Present	325	2	327
	Benthic Macroalgae Absent	9	120	129
	Column Totals	334	122	456

Benthic Macroalgae Producer's Accuracy: 325/334 = 97.3%

Benthic Macroalgae User's Accuracy: 325/327 = 99.4%

Benthic Macroalgae Overall Accuracy: 325/334 = 97.3%

Overall Accuracy: 445/456 = 97.6%

5.0 CONCLUSION

DEA has produced CMECS benthic habitat maps within a project area around South Manitou Island in Lake Michigan. OBIA techniques were used to transform primary source data sets into preliminary maps of substrate and biotic cover, using information extracted through photointerpretation of ground reference data. Field evaluation and manual, expert interpretation then refined the preliminary habitat maps to produce the final CMECS map products. Accuracy assessments were performed to quantify the overall and internal thematic accuracy of the final benthic habitat map products. All accuracy metrics exceed requirements specified in the project SOW.

Along with this report, the following draft deliverables are included in an ArcGIS geodatabase:

- ESRI shapefile of the project ROI around South Manitou Island
- ESRI shapefile containing CMECS Substrate Component polygons
- ESRI shapefile containing CMECS Biotic Component polygons

All files are referenced to the project datum, NAD83 UTM 16N, with units in meters.

6.0 REFERENCES

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APPENDIX A: EXAMPLE IMAGES

CMECS SUBSTRATE COMPONENT
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Fine Unconsolidated Sediment
Modifier: Surface Pattern: Rippled

CMECS BIOTIC COVER
None observed

CMECS SUBSTRATE COMPONENT
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Fine Unconsolidated Sediment
Modifier: Surface Pattern: Rippled

Co-Occurring Element 1
Origin: Biogenic
Class: Shell Substrate
Subclass: Shell Hash

CMECS BIOTIC COVER
Setting: Benthic/Attached Biota
Class: Aquatic Vegetation Bed
Subclass: Benthic Macroalgae
Spatial Modifier: Percent Cover: Sparse

CMECS SUBSTRATE COMPONENT
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Fine Unconsolidated Sediment
Modifier: Surface Pattern: Rippled

Co-Occurring Element 1
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Coarse Unconsolidated Sediment

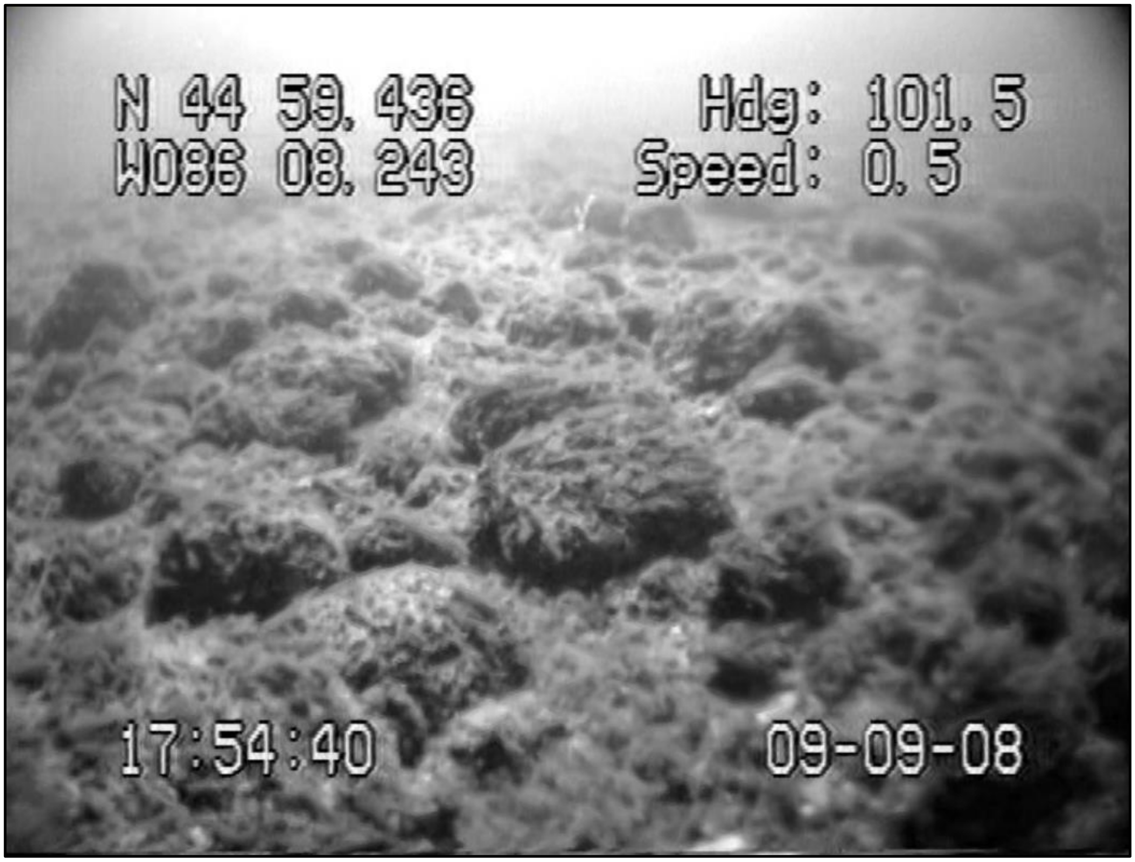
CMECS BIOTIC COVER
None observed

CMECS SUBSTRATE COMPONENT
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Coarse Unconsolidated Substrate

Co-Occurring Element 1
Origin: Biogenic
Class: Shell Substrate
Subclass: Shell Hash

CMECS BIOTIC COVER
Setting: Benthic/Attached Biota
Class: Aquatic Vegetation Bed
Subclass: Benthic Macroalgae
Spatial Modifier: Percent Cover: Moderate

Co-Occurring Element 1
Setting: Benthic/Attached Biota
Class: Faunal Bed
Subclass: Attached Fauna



CMECS SUBSTRATE COMPONENT
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Coarse Unconsolidated Substrate

Co-Occurring Element 1
Origin: Biogenic
Class: Shell Substrate
Subclass: Shell Hash

CMECS BIOTIC COVER
Setting: Benthic/Attached Biota
Class: Aquatic Vegetation Bed
Subclass: Benthic Macroalgae
Spatial Modifier: Percent Cover: Dense

Co-Occurring Element 1
Setting: Benthic/Attached Biota
Class: Faunal Bed
Subclass: Attached Fauna

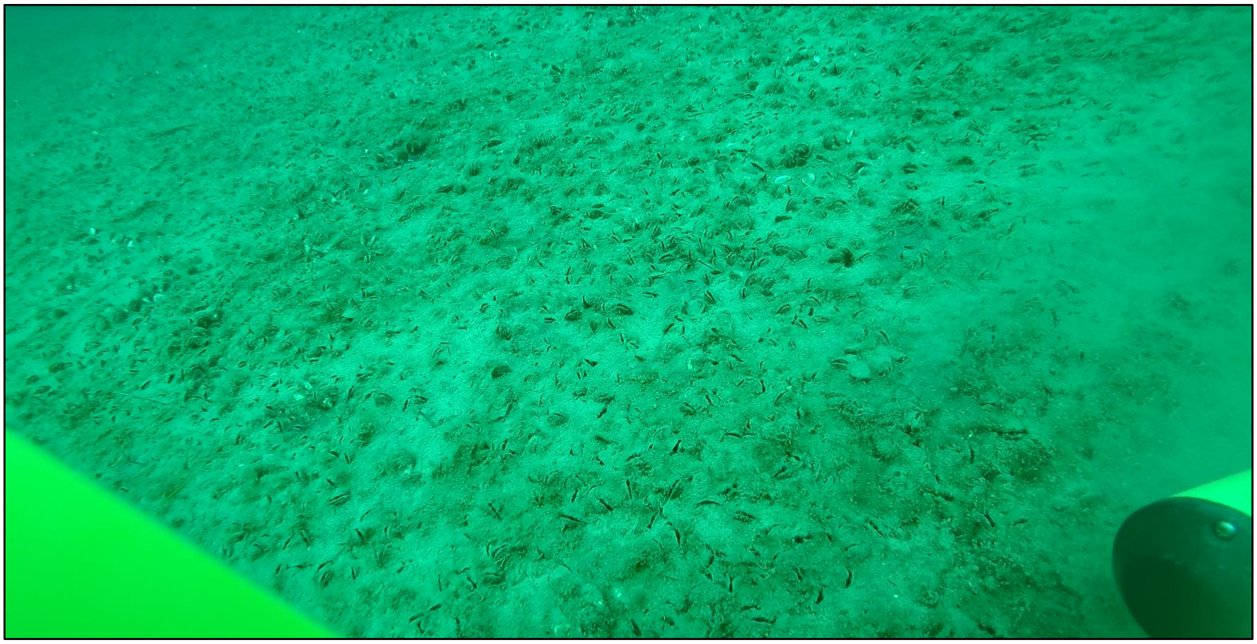
CMECS SUBSTRATE COMPONENT
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Fine Unconsolidated Sediment
Modifier: Substrate Descriptor: Compacted

Co-Occurring Element 1
Origin: Biogenic
Class: Shell Substrate
Subclass: Shell Hash

Co-Occurring Element 2
Origin: Biogenic
Class: Shell Substrate
Subclass: Shell Hash

CMECS BIOTIC COVER
Setting: Benthic/Attached Biota
Class: Aquatic Vegetation Bed
Subclass: Benthic Macroalgae
Spatial Modifier: Percent Cover: Moderate

Co-Occurring Element 1
Setting: Benthic/Attached Biota
Class: Faunal Bed
Subclass: Attached Fauna



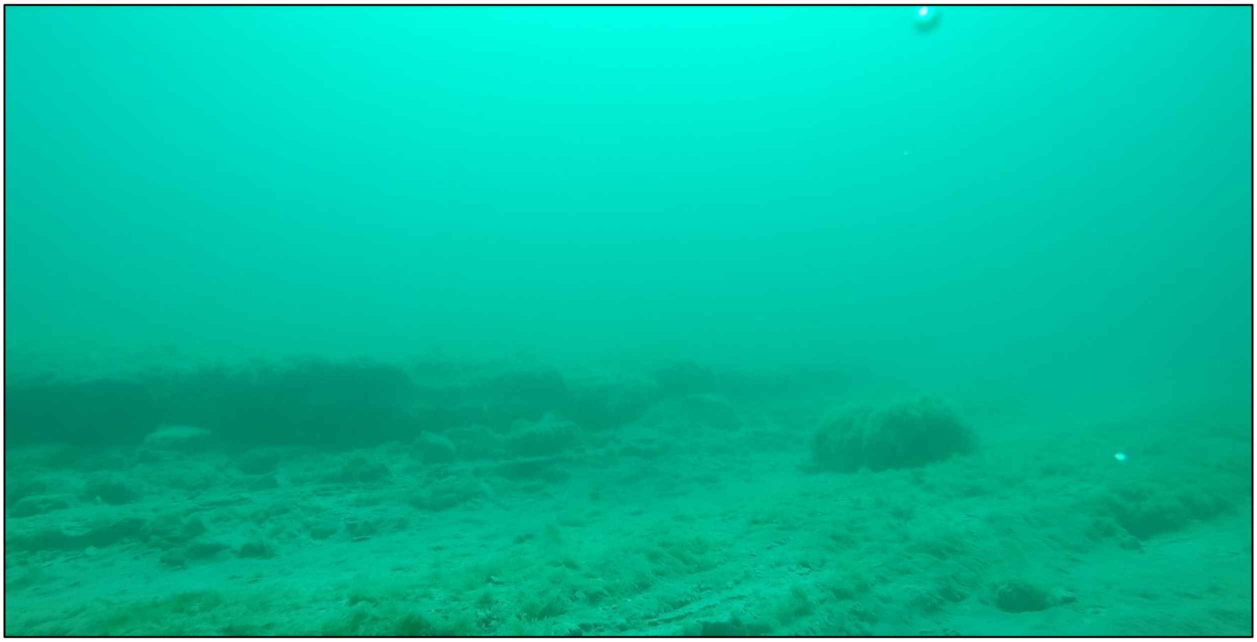
CMECS SUBSTRATE COMPONENT
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Fine Unconsolidated Sediment
Modifier: Substrate Pattern: Smooth

Co-Occurring Element 1
Origin: Biogenic
Class: Organic Substrate
Subclass: Organic Detritus

Co-Occurring Element 2
Origin: Biogenic
Class: Shell Substrate
Subclass: Shell Hash

CMECS BIOTIC COVER
Setting: Benthic/Attached Biota
Class: Faunal Bed
Subclass: Soft Sediment Fauna

Co-Occurring Element 1
Setting: Benthic/Attached Biota
Class: Aquatic Vegetation Bed
Subclass: Benthic Macroalgae



CMECS SUBSTRATE COMPONENT
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Fine Unconsolidated Sediment
Modifier: Substrate Descriptor: Compacted

Co-Occurring Element 1
Origin: Geologic
Class: Unconsolidated Mineral Substrate
Subclass: Coarse Unconsolidated Substrate

CMECS BIOTIC COVER
Setting: Benthic/Attached Biota
Class: Aquatic Vegetation Bed
Subclass: Benthic Macroalgae
Spatial Modifier: Percent Cover: Moderate