National Oceanic and Atmospheric Administration
Office for Coastal Management

Great Lakes Benthic Habitat Mapping: South Manitou Island

Phase 1: Source Data Evaluation

March 2017

DAVID EVANS
AND ASSOCIATES INC.
MARINE SERVICES

2801 SE Columbia Way, Suite 130
Vancouver, WA 98661
(360) 314-3200

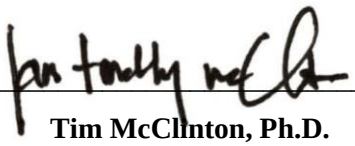
National Oceanic and Atmospheric Administration
Office for Coastal Management

Great Lakes Benthic Habitat Mapping: South Manitou Island

Phase 1: Source Data Evaluation

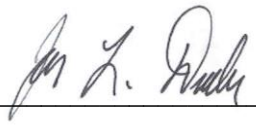
March 2017

Prepared by:



Tim McClinton, Ph.D.
David Evans and Associates, Inc.
Marine Geoscientist / Project Manager
tmcclinton@deainc.com

Reviewed by:



Jon L. Dasler, PE, PLS, CH
David Evans and Associates, Inc.
Director of Marine Services
jld@deainc.com

TABLE OF CONTENTS

Acronyms and Abbreviations ..... *ii*

1.0 INTRODUCTION 1

2.0 SOURCE DATA EVALUATION 2

2.1 DIGITAL REMOTE SENSING DATA 2
2.1.1 Aerial orthoimagery, 2012, 15cm 2
2.1.2 Lidar bathymetry, 2016, 2m 2
2.1.3 Lidar bathymetry, 2007, 1m 2
2.1.4 MBES bathymetry and backscatter, 2011, 1m 4
2.1.5 Side Scan Sonar imagery, 2008-2009, 1m 4
2.2 GROUND REFERENCE DATA 5
2.2.1 USGS underwater videos, 2008-2009 5
2.2.2 USGS underwater videos, 2011-2013 6
2.2.3 National Aquatic Resource Surveys videos, 2010 6
2.2.4 USACE Oblique Aerial Photography, 2011-2012 6
2.3 ANCILLARY GEOSPATIAL DATA 7

3.0 PROPOSED METHODOLOGY 7

3.1 REGION OF INTEREST 8
3.2 MINIMUM MAPPING UNIT 8
3.3 HABITAT CLASSIFICATION SYSTEM 9
3.4 DATA DEVELOPMENT METHODS 9
3.5 INTERPRETATION GUIDELINES 10
3.6 ANTICIPATED CHALLENGES 10

4.0 CONCLUSION 10

List of Figures

Figure 1. South Manitou Island project area. Depths shown in feet from NOAA chart 14912. 1
Figure 2. Primary mapping inputs and ground reference data 3
Figure 3. Example ground reference images and quality 5
Figure 4. Proposed workflow for producing the benthic habitat map and products. 8

List of Tables

Table 1. Summary of available source data and type. 4
Table 2. Summary of available ground reference data and properties. 6
Table 3. Anticipated minimum level of detail in the CMECS hierarchy. 9

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
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
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 provide benthic habitat mapping services in the vicinity of 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.

The first phase of this project consists of an evaluation of available source data and the formulation of recommendations and methodology for the creation of the benthic habitat maps. DEA has 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 has 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. Each data type was also examined to determine the level of CMECS information that could be extracted and utilized for benthic habitat mapping. Following the source data evaluation, DEA formulated recommendations for the benthic habitat mapping process using guidelines provided by the project partners, including the determination of where each data type would serve as the primary mapping medium, recommendations for minimum mapping unit (MMU), suggested methods for deriving the habitat map, methods for quantifying the thematic accuracy of the benthic habitat map products.

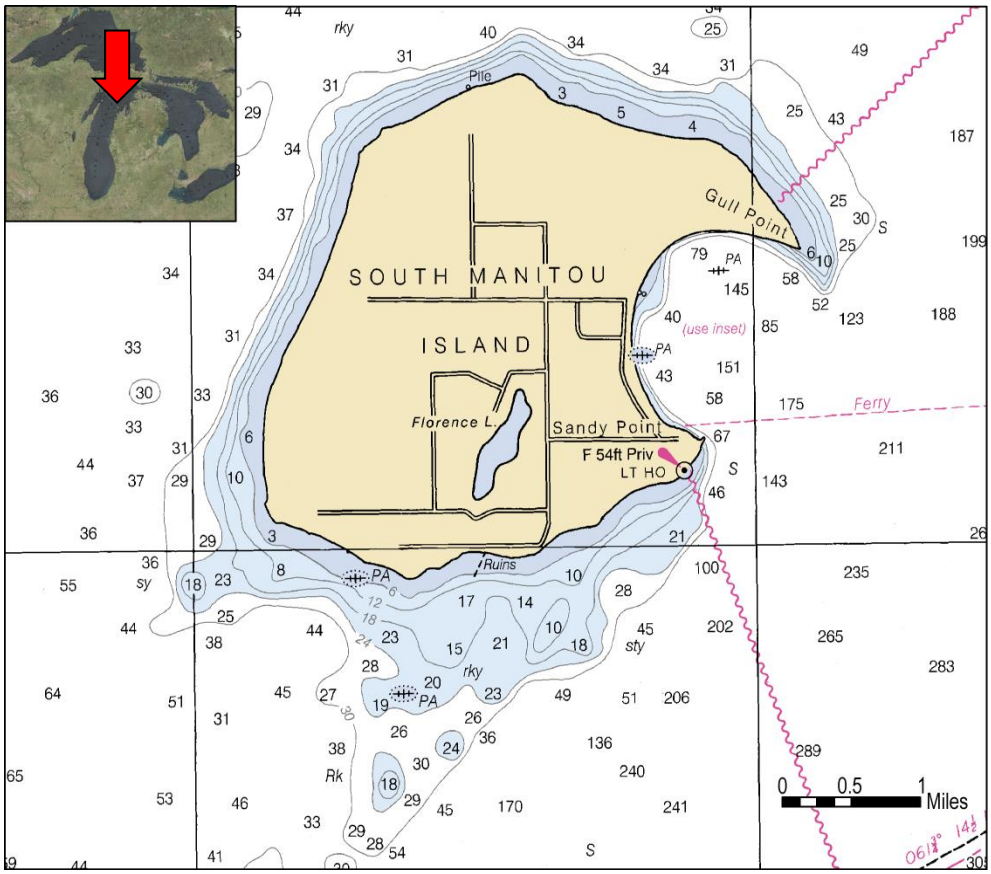


Figure 1. South Manitou Island project area. Depths shown in feet from NOAA chart 14912.

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.

2.1 DIGITAL REMOTE SENSING DATA

2.1.1 Aerial orthoimagery, 2012, 15cm

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 62 millimeter 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) is recommended as a primary input for mapping biotic components. The resolution of this data set is 15cm x 15cm.

2.1.2 Lidar bathymetry, 2016, 2m

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 provides an excellent level of detail that enables the production of functional, second-order terrain metrics such as slope and rugosity. This data set is recommended for use as a primary input for mapping substrate components. The resolution of this data set is 2m x 2m. Full-waveform data are 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.

2.1.3 Lidar bathymetry, 2007, 1m

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 varying between 35-50ft (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 lead to undesirable results when deriving second-order terrain metrics such as slope and rugosity. Therefore, these Lidar data are not recommended for use as a primary mapping input, but perhaps to fill in gaps in other data sets and expand the project ROI beyond the 2016 Lidar survey extent. The resolution of this data set is 1m x 1m.

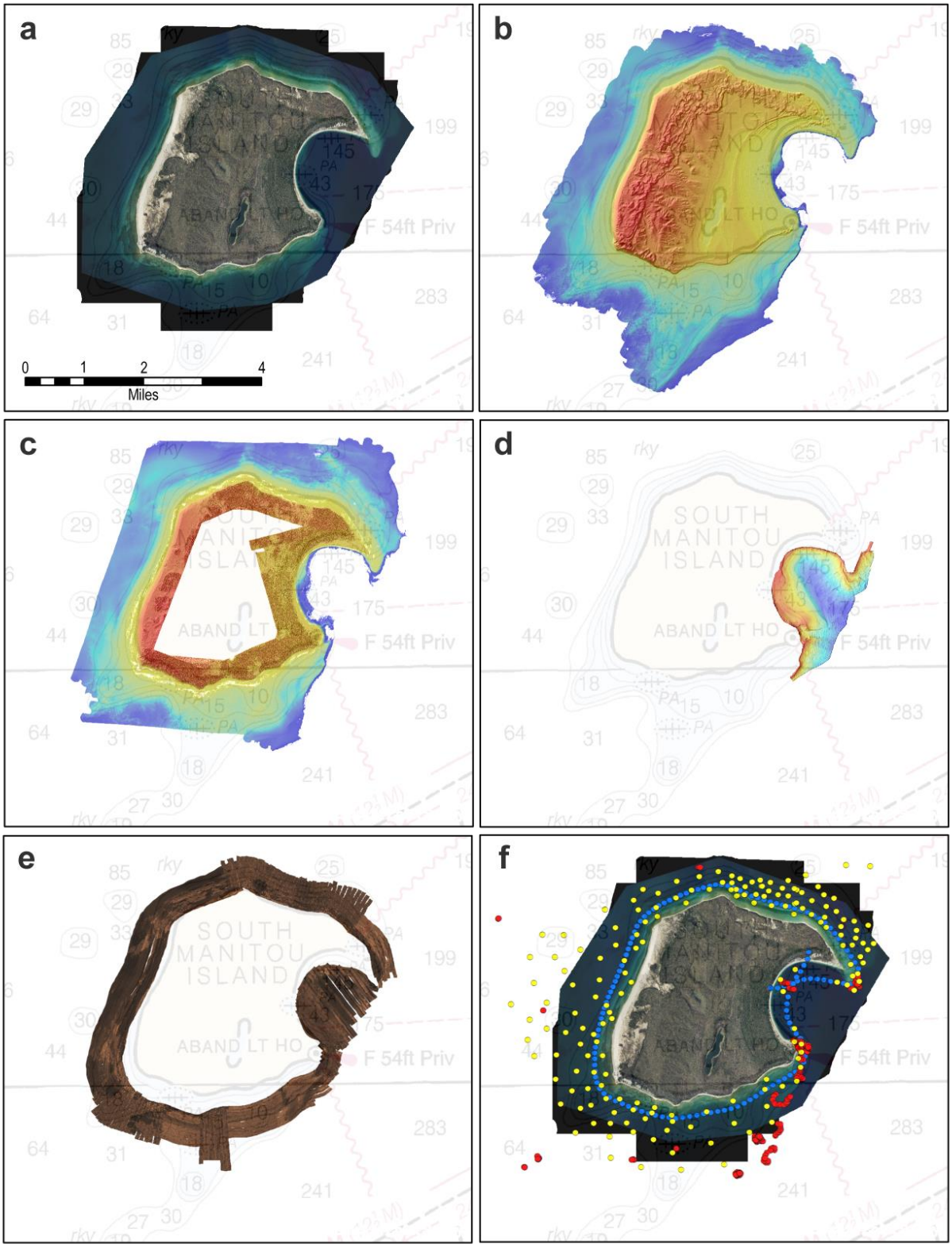


Figure 2. Primary mapping inputs and ground reference data. **a:** 2012 RGB aerial orthoimagery, 15cm resolution; **b:** 2016 Lidar bathymetry, 2m resolution; **c:** 2007 Lidar bathymetry, 1m resolution; **d:** 2011 MBES bathymetry, 1m resolution; **e:** 2008-09 SSS imagery, 1m resolution. **f:** Ground reference data points; Yellow dots are USGS videos from 2008-09, red dots are USGS videos from 2011-2013, blue dots are oblique aerial photos from 2011-2012. Shown over NOAA chart 14912 for reference.

RGB imagery is also included with this data set, but is not corrected orthoimagery, therefore RGB image brightness values are not consistent among images. The RGB imagery is not recommended for use in this project.

2.1.4 MBES bathymetry and backscatter, 2011, 1m

Hydrographic surveys were conducted by 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. The raw MBES data was provided to DEA, from which a DTM was produced (Figure 2d) using Fledermaus software. In addition, Fledermaus FMGT software was used to process and produce backscatter imagery from the raw MBES time-series data. This data set is generally high quality with some artifacts at swath edges. The bathymetric data also fill a critical data gap in the cove on the eastern side of South Manitou Island. Therefore, the MBES bathymetric data set is recommended for use as a primary input for mapping substrate components. The MBES backscatter data is recommended as a supplementary data set for the cove area. The resolution of these data sets is 1m x 1m.

2.1.5 Side Scan Sonar imagery, 2008-2009, 1m

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 SSS imagery mosaics (Figure 2e). The SSS imagery is fairly good quality, but does feature some data gaps in addition to typical image artifacts (e.g. nadir stripes, acoustic shadows) related to the low incident angle of the SSS beams at outer ranges. These data gaps and artifacts would likely lead to problems during feature extraction. Therefore, this data set is not recommended for use as a primary mapping input, but could serve as a valuable supplementary data set to validate signatures observed in primary mapping inputs.

Table 1. Summary of available source data and type.

Remote Sensing Data Type	Benthic Mapping Utility	Date	Resolution	Source
Aerial RGB orthoimagery	Primary	2012	15cm	State of Michigan
Aerial CIR orthoimagery	Supplementary	2012	15cm	State of Michigan
Lidar bathymetry	Primary	2016	2m	NOAA OCM
MBES bathymetry	Primary	2011	1m	NMC; Processed by DEA
MBES backscatter	Supplementary	2011	1m	NMC; Processed by DEA
SSS imagery	Supplementary	2008-09	1m	USGS; Processed by DEA
Lidar bathymetry	Supplementary	2007	1m	USACE JALBTCX
Lidar RGB imagery	Supplementary	2007	30cm	USACE JALBTCX

2.2 GROUND REFERENCE DATA

Available ground reference data are described in detail below and summarized in Table 2.

2.2.1 USGS underwater videos, 2008-2009

USGS acquired underwater videos with a waterproof camera on 9-13 September 2008 and 18-19 June 2009 for the purpose of providing 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 (primary and supplementary) 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 as a result of environmental conditions (Figure 3a). There are a total of 188 videos (Figure 2f in yellow), ranging in duration from 1-5min. Due to the high quality of the videos and the biological analyses, these videos are recommended as primary ground reference data to be utilized for benthic habitat map production as well as accuracy assessment.

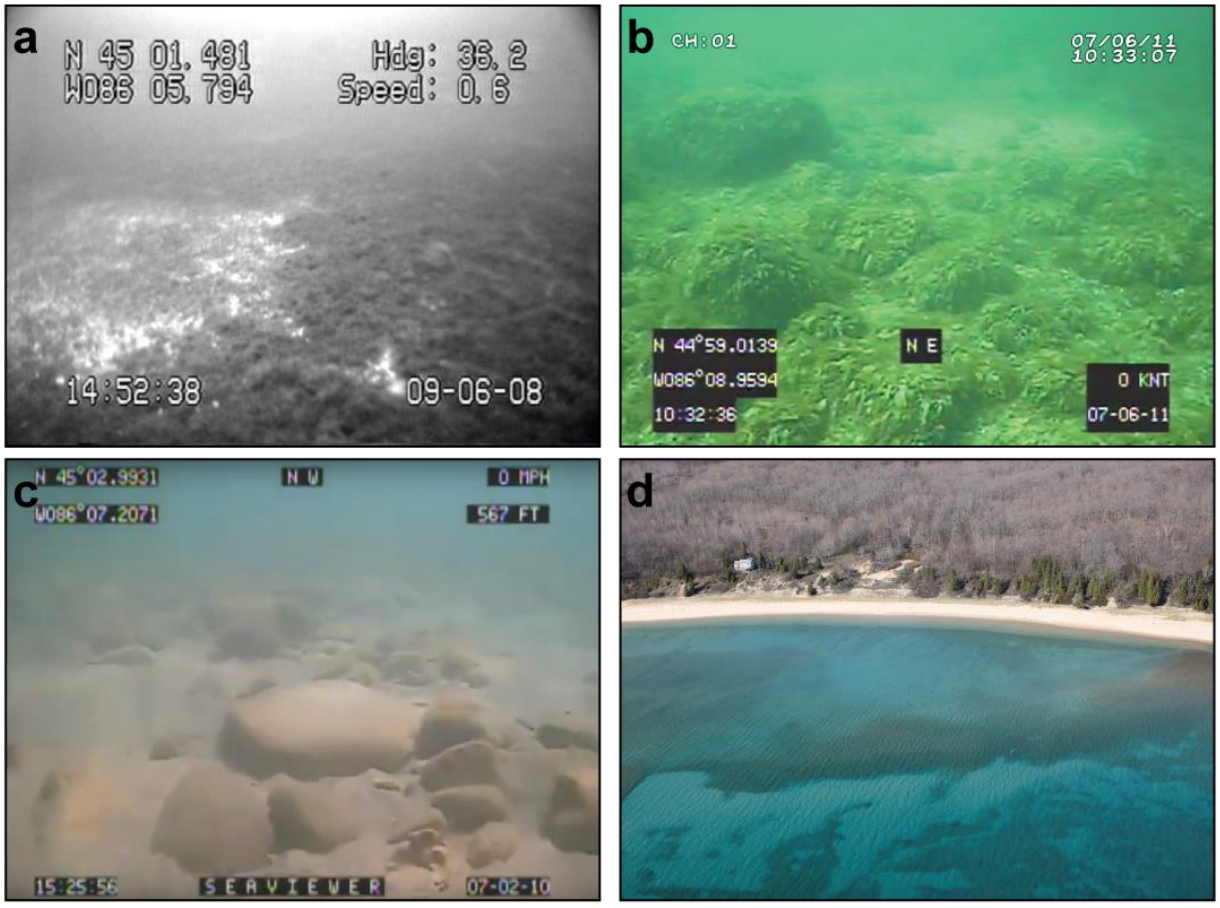


Figure 3. Example ground reference images and quality. **a:** Still image from 2008-09 underwater video; **b:** Still image from 2011-2013 underwater videos; **c:** Still image from EPA NARS surveys in 2010; **d:** Still image from 2011-2012 oblique aerial imagery.

DEA has conducted additional biological analysis of the videos in preparation for their use in the South Manitou Island project. A marine biologist viewed each video to evaluate and calibrate the original substrate and biological assessment, then captured still images from each video that mark exact locations where Cladophora and/or zebra mussels were observed. The position of each still image was determined by utilizing the position data recorded during each video. A total of 408 georeferenced still images were extracted from the underwater videos.

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). Video quality is not as good as the 2008-2009 videos due to a faster tow speed, which degrades image quality and makes interpretation difficult. These videos have not been analyzed for substrate or biotic information. However, these videos are a valuable supplementary ground reference data set for validating signatures observed in primary mapping inputs during map production. There are a total of 73 video files (Figure 2f in red) ranging in duration from 5min to nearly 35min.

2.2.3 National Aquatic Resource Surveys videos, 2010

The US Environmental Protection Agency (EPA) acquired underwater video at 6 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 are an additional set of supplementary ground reference data for validating signatures observed in primary mapping inputs during map production. There are a total of 6 video files ranging in duration from 1-2min. The videos are accessible via the EPA and YouTube websites.

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 photographs are recommended as supplementary ground reference data for the coastline and shallow nearshore areas on South Manitou Island. There are a total of 135 aerial photos (Figure 2f in blue).

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

Ground Reference Data Type	Benthic Mapping Utility	Date	Number	Source
Underwater videos	Primary, biology/substrate	2008-09	188	USGS
Underwater photos	Primary, biology/substrate	2008-09	408	USGS; Analysis by DEA
Underwater videos	Supplementary	2011-13	73	USGS
Underwater videos	Supplementary	2010	6	EPA
Oblique aerial photography	Supplementary	2011-12	135	USACE

2.3 ANCILLARY GEOSPATIAL DATA

DEA conducted a thorough search for ancillary geospatial data to aid in benthic habitat map production. The following additional data sets were identified:

- US Fish and Wildlife Service National Wetlands Inventory
- NOAA OCM Coastal Change Analysis Program
    - *Regional Land Cover and Change*
    - *Wetland Potential*
- Michigan Geological Survey geologic map data
    - *Bedrock Geology*
    - *Quaternary Geology*

An evaluation of these data sets determined that pertinent information was either not present or at too coarse of a scale to provide meaningful information during benthic habitat map production. These data sets will not be used in this project.

3.0 PROPOSED METHODOLOGY

DEA proposes to use a multi-stage approach in the production of the benthic habitat maps for South Manitou Island (Figure 4). Object-based image analysis (OBIA) techniques will be used to transform primary mapping inputs into meaningful spectral and spatial data. In preparation for map production, ground reference data will be separated into "training data", used for classification, and "testing data", used only for the accuracy assessment. In addition, a new DTM will be compiled from the Lidar bathymetry and MBES bathymetry data sets.

In the first stage, an initial substrate map will be produced. Terrain metrics will be derived from the DTM using tools in the Benthic Terrain Modeler (BTM) toolbox in ArcGIS software. OBIA techniques including image segmentation, thresholding, and classification using training data, will be utilized to produce substrate polygons. An expert interpretation phase will use supplementary data sets to reconcile any ambiguities or inconsistencies, working up and down the CMECS hierarchy as the detail of information allows, and utilizing CMECS modifiers where necessary. The final result of the first stage will be a substrate map.

In the second stage, substrate information will be combined with biotic information to produce a draft habitat map product. The substrate map and the high-resolution RGB imagery will serve as inputs to an OBIA segmentation, thresholding, and classification workflow which will produce biotic polygons. As with the substrate map, an expert interpretation phase will utilize supplementary data sets to address any ambiguities or inconsistencies, working up and down the CMECS hierarchy as the detail of information allows, and utilizing CMECS modifiers and biotopes where necessary. The final result of the second stage will be a draft habitat map.

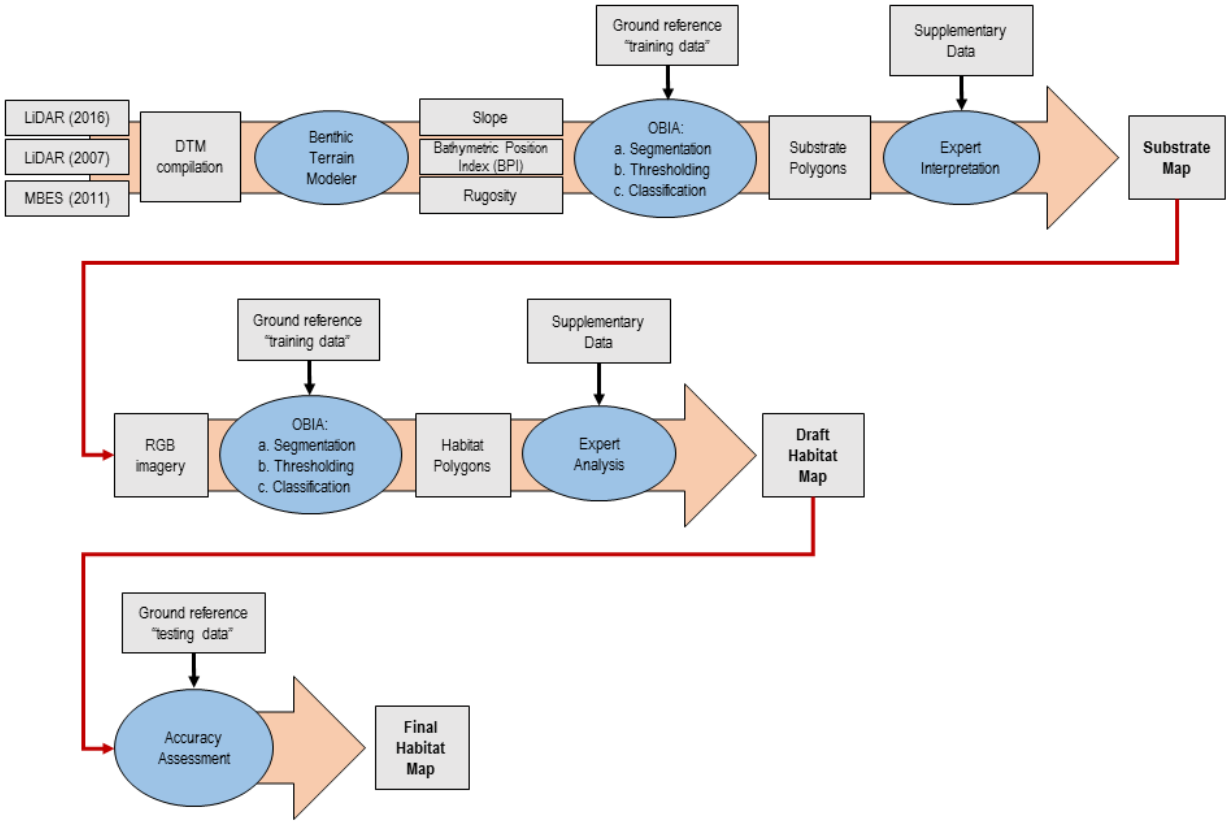


Figure 4. Proposed workflow for producing the benthic habitat map and products.

The thematic accuracy of the draft habitat map product will be assessed using testing data derived from ground reference data, but not used during classification, and also in the field by NOAA OCM personnel. Input from project partners will also be important in this process. Inaccuracies, inconsistencies, and ambiguities will be addressed as needed to ensure project requirements (85% overall accuracy; 80% accuracy per habitat type) are met. Thematic accuracy measures will be displayed in a standard error matrix with producer's and user's accuracy.

3.1 REGION OF INTEREST

DEA proposes a new project region of interest (ROI) polygon, which is based on the spatial extent of the source data identified as primary mapping inputs. The proposed ROI encompasses approximately 14.5mi^2 and represents an area from which both terrain and spectral information can be extracted from primary mapping inputs. An ArcGIS shapefile of the polygon will be delivered with this report.

3.2 MINIMUM MAPPING UNIT

As specified in the project scope of work (SOW), the minimum mapping unit (MMU) is 10m x 10m. The identification of co-occurring elements will be made based on the percent of spatial coverage within the polygon or MMU.

3.3 HABITAT CLASSIFICATION SYSTEM

Final benthic habitat polygons will be attributed according to the CMECS system. Biotic and Substrate units will be attributed to at least the subclass level. Modifiers will be used as needed. The final benthic habitat map product will be a vector data set that identifies the presence and delineates perimeter boundaries of individual benthic habitats, specifically unconsolidated sediments such as gravel or sand, invasive mussel beds, and algal beds. Table 3 shows the expected CMECS categories and minimum levels of detail. Modifiers, co-occurring taxa, and biotopes will be used as necessary.

3.4 DATA DEVELOPMENT METHODS

All procedures used to produce the final benthic habitat map products will be documented and presented in a final report. Procedures will meet the spatial and thematic accuracies and classification detail as specified in the project SOW. Final habitat polygons will be delineated with a high level of detail and the digitized vector boundaries will be meet or exceed the following specifications:

- Vertex Distance: < 1.0 m
- Node Snap Distance: < 4.0 m
- Arc Snap Distance: < 4.0 m

Topological development tools within ArcGIS software may be used to aid in data development and data set precision. All deliverables will meet or exceed requirements set forth in the project SOW.

Table 3. Anticipated minimum level of detail in the CMECS hierarchy.

	Substrate Origin	Substrate Class	Substrate Subclass	
SUBSTRATE COMPONENT	Geologic Substrate	Rock Substrate	Bedrock	
			Megaclast	
		Unconsolidated Mineral Substrate	Coarse Unconsolidated Substrate	
			Fine Unconsolidated Substrate	
	Biogenic Substrate	Organic Substrate	Organic Debris	
	Biotic Setting	**Biotic Class**	**Biotic Subclass**	**Biotic Group**
BIOTIC COMPONENT	Benthic/Attached Biota	Faunal Bed	Attached Fauna	
			Soft Sediment Fauna	
		Aquatic Vegetation Bed	Benthic Macroalgae	Filamentous Algal Bed

3.5 INTERPRETATION GUIDELINES

As a means of standardizing the mapping and interpretation process, the following guidelines were included in the project SOW:

- Outer boundaries of habitats are equally important to the internal density categorizations (percent cover).
- It is more important to include small isolated habitat patches than similar sized patches that are part of a larger matrix.
- In cases where an area within the MMU may have multiple small habitat components, then the primary polygon label shall reflect the majority habitat within the area. Secondary habitat components will be captured using the CMECS co-occurring element approach.
- Areas that are un-interpretable due to depth shall be labeled as unknown benthic habitat.
- All habitat delineations shall be made with the highest precision practicable, to better reflect actual habitat boundaries on the ground.

3.6 ANTICIPATED CHALLENGES

The main challenge to accurate benthic habitat map production is the varying acquisition dates of the source data and ground reference information. The abundance of the Cladophora algae has a seasonal nature with apparent growth peak(s) in mid-summer. The acquisition dates of the source data and ground reference information vary between April to August over a five-year timespan from 2007 to 2013. As a result, the spatial distribution and abundance of Cladophora may not be adequately and/or equally represented by these data sets. For this project, the 2012 aerial RGB orthoimagery, which was acquired 4-5 April, will serve as the baseline data for Cladophora distribution.

The proposed workflow requires the construction of a DTM from three different bathymetric data sets acquired in 2007, 2011, and 2016 using different sensors and survey methods. The varying acquisition dates could have bearing on the spatial distribution of substrate types. However, in this particular setting, substrate components are not expected to have a significant amount of spatial or geologic variation over the time periods in question.

4.0 CONCLUSION

DEA has evaluated the quality, spatial extent, resolution, and utility of multiple source data and ground reference data sets for the production of benthic habitat maps in the vicinity of South Manitou Island in Lake Michigan. Primary and supplemental mapping inputs and ground reference data sets have been identified and presented. DEA has proposed a revised ROI and a workflow that combines OBIA techniques, expert interpretation, and standardized accuracy assessment methods. Specific details involving the CMECS habitat classification system, expected level of detail, and anticipated challenges have been presented and discussed.

The following deliverables are included with this report:

- ArcGIS shapefile of proposed ROI around South Manitou Island
- ArcGIS shapefiles of primary and supplemental mapping input coverage
- ArcGIS shapefile of ground reference data locations

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