Cruise Report: Great Lakes Benthic Habitat Characterization
Cruise GL-24-01, April 30-October 16, 2024



September 2025

Great Lakes Environmental Research Laboratory
NOAA Oceanic and Atmospheric Research
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Cruise Report: Great Lakes Benthic Habitat Characterization Cruise GL-24-01, April 30-October 16, 2024

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Contents

Executive Summary....3
Background....3
Objectives....4
Team....4
Operations....5
Sampling Design, Equipment, and Methods....7
Ultra-Short Baseline (USBL) System....10
Remotely Operated Vehicle (ROV)....10
Drop Camera....12
Ponar Sediment Dredge....13
Autonomous Underwater Vehicle (AUV)....14
Complementary AUV imagery collected by the USGS....15
Results and Discussion....16
USBL....19
ROV....19
Drop Camera....21
Ponar....21
AUV....22
Complementary USGS AUV....22
Data Accessibility....23
References....24
Appendix A: Sediment Data Collection Form....26

List of Tables

Table 1. GL2401 crew list and affiliation at time of cruise. 4
Table 2. Projected itinerary for cruise GL2401 5
Table 3. Characteristics of SRSS. 8
Table 4. The distribution of sites by platform and site depth. 9
Table 5. Total samples collected by platform. 16

List of Figures

Figure 1. Map of all potential sites. Image: Jacob Wilson/CPC....6
Figure 2. NOAA Vessel R3105. Photo: Jacob Wilson/CPC....7
Figure 3. The six spatial areas defining primary strata. Image: Charles Menza/NCCOS....8

Figure 4. Sonardyne Microranger2 as set up for GL2301 and 2302. Photo: Ayman Mabrouk/CSS 10
Figure 5. Modified BlueROV2 (left), topside unit and USBL system (right). Photo: Chris Wright/MTU 11
Figure 6. SeaViewer 6000 HD (left), topside unit (center), and deployment (right). Photo: Ossian Foley/CPC and Ayman Mabrouk/CSS.....12
Figure 7. Standard DC transect. Image: Ayman Mabrouk/CSS.....13
Figure 8. Ponar (left) and documentation (right). Photo: Charles Menza/NCCOS and NOAA 14
Figure 9. Standard GL2401 MTU AUV survey. Image: Jamey Anderson/MTU 15
Figure 10. Samples collected by date and platform. Image: Ossian Foley/CPC 16
Figure 11. Survey123 dashboard. Image: Kimberly Edwards/CSS .....**Error! Bookmark not defined.**
Figure 12. View of the Survey123 online form. Image: Kimberly Edwards/CSS.....18
Figure 13. Typical USBL track, raw and smoothed. Image: Ayman Mabrouk/CSS 19
Figure 14. Actual sites surveyed by cruise GL2401. Image: Jacob Wilson/CPC.....20
Figure 15. Mussels atop clay from the ROV's pilot camera (left) and a Thresher image of burbot (right). Photo: MTU.....21
Figure 16. DC images of Alewives after color correction (left) and DC rigging. Photo: NOAA and Ossian Foley/CPC.....22
Figure 17. USGS AUV track lines and completed sites. Image: Nicholas Yaeger/USGS.....23

Acronyms

AUV – Autonomous Underwater Vehicle
DC – Drop Camera
DVL – Doppler Velocity Logger
GLERL – Great Lakes Environmental Research Laboratory
NOAA – National Oceanographic and Atmospheric Administration
NCCOS – National Centers for Coastal Ocean Science
MTU – Michigan Technological University
ROV – Remotely Operated Vehicle
SSS – Side Scan Sonar
TBNMS – Thunder Bay National Marine Sanctuary
USBL – Ultra-short Baseline
WSCNMS – Wisconsin Shipwreck Coast National Marine Sanctuary

Executive Summary

The National Oceanic and Atmospheric Administration (NOAA), National Centers for Coastal Ocean Science (NCCOS), Great Lakes Environmental Research Laboratory (GLERL), and Michigan Technological University Great Lakes Research Center (MTU) completed a 169-day benthic mapping cruise (hereafter, GL2401) between April 30 and October 16, 2024. The goal of the cruise mission was to characterize lakebed habitats in and near the Wisconsin Shipwreck Coast National Marine Sanctuary (WSCNMS) and provide ground-truthing observation data for predictive substrate and biological community models.

The cruise study area comprised 2492 km^2, encompassing depths between 3 and 142 m, extending approximately from 8 km south of Port Washington, WI to 23 km north of Two Rivers, WI, out to a maximum distance of 26.4 km offshore. The cruise collected underwater video imagery with a Seaviewer drop camera (DC) at 845 sites, a BlueROV2 remotely operated vehicle (ROV) at 109 sites, and an Iver3 autonomous underwater vehicle (AUV) at 46 sites. A Ponar dredge was used to characterize fine unconsolidated sediments at 147 sites. Data acquisition occurred from the NOAA Vessel *R3105* stationed successively at Port Washington Marina, Harbor Centre Marina in Sheboygan, WI, and Manitowoc Marina, with one day of operation aboard NOAA Vessel *R3012*, stationed at Manitowoc Marina.

Sample sites were selected to characterize lakebed features and habitats identifiable from several existing nearshore topographic-bathymetry lidar and Multibeam Echo Sounded (MBES) surveys. A stratified random sampling design was employed to select the sampling sites to capture a wide spectrum of depths and habitats within the study area.

A separate cruise, led by the United States Geological Survey (USGS), provided complementary characterization data using an Iver3 AUV. Similar to the ROV and DC, the AUV collected high-resolution, downward-pointing imagery of the lakebed. Data from GL2401 and the USGS cruise are intended to be complementary and will be annotated with similar workflows to provide seamless characterization data coverage and develop benthic maps. These maps will offer spatial insights into lakebed geomorphology, substrates, habitats, anthropogenic impacts, and species distributions.

This report accounts for survey operations, equipment, methodologies, results, and findings from cruise GL2401.

Background

In 2019, NOAA embarked on the *Collaborative Benthic Habitat Mapping in the Nearshore Waters of the Great Lakes Basin Project*, to address a range of emerging littoral management issues, such as invasive species, lake-level changes, and coastal development (project website) . The primary project objectives are to identify, delineate, and assess nearshore spawning reefs, nursery habitats, and other ecologically significant areas, such as Thunder Bay National Marine Sanctuary, WSCNMS, and Apostle Islands National Lakeshore. Additionally, the project aims to identify the potential threats to these critical locations. To achieve these objectives, the project set out to compile existing physical surveys and biological collections and to collect new data to fill data gaps. This collected data will be analyzed to understand various habitats and emergent management issues. Complementing this data-driven approach is the development of intuitive mapping and modeling tools designed to facilitate user-friendly engagement. These tools will empower decision-makers locally and lake wide, guiding informed choices related to

fisheries and the restoration of nearshore, shoreline, and upland areas. This collaborative benthic habitat mapping project is made possible through funding from the Great Lakes Restoration Initiative.

Objectives

The mission aimed to gather comprehensive imagery of the lakebed within the study area using the following methodologies:

- **ROV Transects**: Collect video and images along ROV transects at target sites to validate remotely sensed data and contribute to habitat characterization.
- **AUV Transects:** Collect images and side scan data along AUV transects at target sites to validate remotely sensed data and contribute to habitat characterization.
- **Drop Camera Surveys**: Capture videos at target sites using a DC to validate remotely sensed data and contribute to habitat characterization.
- **Sediment Sampling**: Collect sediment samples from the lakebed using a Ponar sediment grabber, providing detailed information about the lakebed's fine unconsolidated sediment composition and characteristics.
- **Navigating with USBL**: Utilize the Ultra-Short Baseline (USBL) acoustic positioning system with various platforms (ROV, DC, and Ponar grabber) to accurately determine the underwater locations of these platforms.

Team

The cruise field team comprised 16 personnel across GLERL, NCCOS, and MTU (Table 1), that were deployed over the course of the field season in groups of 2 to 4 to accommodate staff schedules, platform expertise, and oversight.

Table 1. GL2401 crew list and affiliation at time of cruise.

Name	Affiliation	Title
Ossian Foley	CPC, Inc., under contract to NOAA GLERL	Captain
Steve Bawks	CPC, Inc., under contract to NOAA GLERL	Captain
Jacob Wilson	CPC, Inc., under contract to NOAA GLERL	Data Manager
Connor Borg	CPC, Inc., under contract to NOAA GLERL	Deck Hand
Brendan Hunter	CPC, Inc., under contract to NOAA GLERL	Data Manager
Todd Roetman	CPC, Inc., under contract to NOAA GLERL	Deck Hand
Kevin Santos	CPC, Inc., under contract to NOAA GLERL	Deck Hand
Melissa Weber	NOAA/GLERL	Data Manager
Kimberly Edwards	CSS, Inc., under contract to NOAA/NCCOS	Marine Ecologist
Ayman Mabrouk	CSS, Inc., under contract to NOAA/NCCOS	Marine Ecologist
Charles Menza	NOAA/NCCOS	Spatial Ecologist
Jamey Anderson	MTU	Head of Marine Operations
Hayden Henderson	MTU	Research Engineer
Chris Wright	MTU	Senior Research Technician
Kora Johnson	MTU	GLRC Intern
Phil Wernette	MTU	Associate Research Scientist

Operations

Between April 30 and October 16, 2024, NCCOS, GLERL, and MTU completed the GL2104 field operations to characterize the lakebed within the WSCNMS. The study area encompassed 2492 km^2 of lakebed located in Lake Michigan off the shores of Wisconsin and within WSCNMS (Figure 1). All work occurred within 30 km from shore (approximately 1 hr. transit time) and in water depths of 3 to 124 meters, with a focus on water shallower than 80m. Cruise operations were accomplished using the *R3105* (except two AUV deployments off *R3012*) sailing out of the major marinas along the Wisconsin lakeshore. The cruise operated during daylight hours, generally between 0800 and 1700 CDT (1300 and 2200 UTC), with occasional trips extending beyond sunset. The *R3105* is a 36 ft Workskiff aluminum-hull vessel operated by GLERL and used primarily for nearshore missions (Figure 2). The vessel is a swift and stable platform with an enclosed aft deck, a moonpool for USBL deployment, a sampling davit and winch with a Working Load Limit of 200 lbs., an 8kw generator, satellite internet, and cabin space for dry scientific equipment and dedicated computer workstations.

The study area was identified as a high-priority site for lakebed mapping by scientists and managers across a range of surveys, including bottom mapping workshops organized by the Interagency Working Group on Ocean and Coastal Mapping to document regional Great Lakes' needs, a spatial prioritization of research and management needs (Gouws et al. 2022), and informal conversations with scientists working in the Great Lakes Bottom Mapping Workgroup. The area possessed robust bathymetric data, making ground truthing efforts particularly attractive. The study area includes several reefs, spawning habitats, and cultural artifacts (Menza and Kendall, 2019, Coberly and Horrall, 1980; Goodyear 1982). In addition to these features, there was wide interest in exploring possible sink-holes suggested by sonar surveys in deeper water.

NCCOS, GLERL, and MTU partners conceived the field season in two major platform groups: collecting benthic videos with the NCCOS SeaViewer DC and Ponar dredges as one grouping, and collecting using the MTU BlueROV2 and Iver3 as a second grouping. The field teams deviated from the projected itinerary due to weather, personnel availability, platform availability, and other factors (see Tables 1 and 2 for the participant list and cruise itinerary, respectively, and Table 3 for collection results).

Table 2. Projected itinerary for cruise GL2401

Date	Operations	Comment
April 30-May 24, 2024	DC, Ponar	SeaViewer, Ponar Dredge, Micro Ranger2
May 25-June 28, 2024	ROV, AUV	BlueROV2, Iver3, Micro Ranger2
June 29-Aug. 16, 2024	DC, AUV, Ponar	SeaViewer, Iver3, Ponar Dredge, Micro Ranger2
Aug. 17-Sept. 13, 2024	ROV, AUV	BlueROV2, Iver3, Micro Ranger2
Sept. 14-Oct. 16, 2024	DC, AUV, Ponar	SeaViewer, Iver3, Ponar Dredge, Micro Ranger2

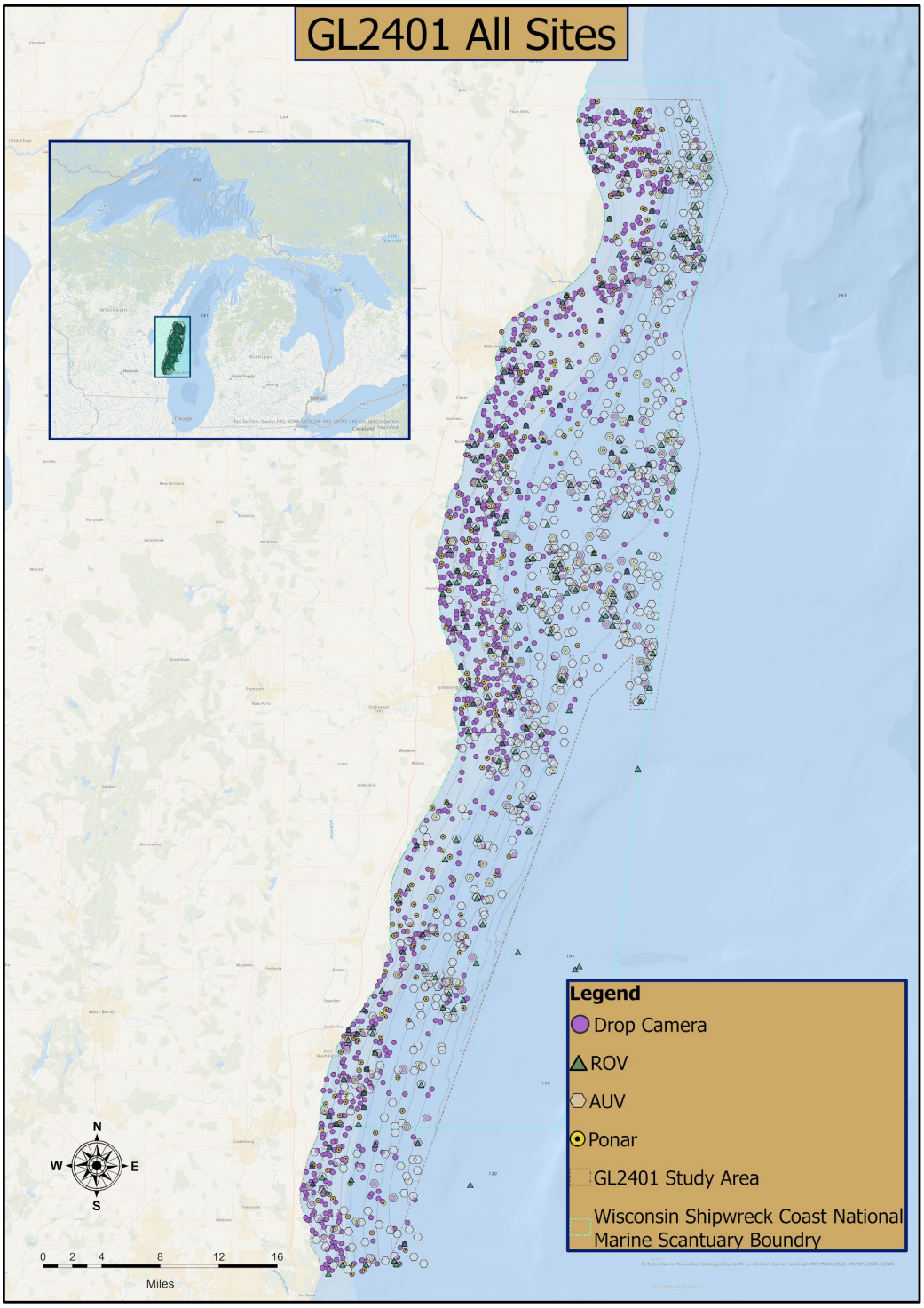


Figure 1. Map of all potential sites.



Figure 2. NOAA Vessel R3105.

Sampling Design, Equipment, and Methods

Benthic imagery and sediment samples (hereafter ground-truthing data) were collected within a survey domain defined by the boundaries of the WSCNMS and areas with existing lidar and Multibeam Echo Sounder (MBES) bathymetry data. Lidar data originated from two USACE surveys, one collected in 2020 and another in 2012. MBES data came from multiple sources. The majority of MBES data came from a 2022 survey completed by Geodynamics/NV5 contracted by the Office of Coast Survey (Project number OPR-Y396-KR-22, H13635-H13643), with additional MBES collected by the NOAA Navigation Response Team in 2021 (H13526, H13527) and NCCOS in 2017 (W00440) and 2018 (W00463). Sampling sites were chosen within the survey domain using a six-stage process:

1. **Blended DEM Generation:** MBES and lidar survey data were combined to generate a blended 4-m resolution digital elevation model (DEM). The DEM resolution was aggregated to 4-m from 1-m source layers, to reduce the presence of survey artifacts and data gaps. A blended backscatter intensity surface was also generated for all MBES surveys at the same 4-m resolution used for the DEM.

2. **Terrain Metrics Calculation:** Terrain metrics were derived from the blended DEM using the 3 x 3 cell neighborhood, including the standard deviation of elevation, bottom aspect, bottom slope, and the bathymetric position index (Lundblad et al., 2006). The DEM and its derivatives, along with the backscatter intensity surface, formed the environmental variables used to stratify sampling site selection.

3. **Primary Strata Delineation:** Six spatial areas were chosen to define sampling design primary strata (Figure 3). These strata were defined by three geographic regions and two coarse-level bottom complexity indices summarized within the Military Grid Reference System (MGRS) 1 km grid framework. The regions delineated areas offshore Manitowoc, Sheboygan, and Port Washington. The bottom complexity indices were defined by relatively high backscatter or

bottom rugosity values. MGRS grids with either average backscatter or average rugosity values in the top 66% percentile were classified as complex habitat.

4. **Stratified Random Site Selection:** Sampling sites were selected independently within each primary stratum using a stratified random design employing the conditioned Latin Hypercube Sampling (cLHS) method (Minasny and McBratney, 2006). This sampling strategy provided an efficient way to sample the full coverage of values within the DEM, terrain variables, and backscatter intensity surfaces. A total of 2501 sites were selected by the cLHS method based on the anticipated field time and the spatial density of sites used to generate high-accuracy benthic maps in other areas (Menza and Kendall, 2019). The number of sites chosen for each primary stratum was a function of its size and bottom complexity. Primary strata defined by high bottom complexity and low bottom complexity received 2 sites and 0.5 sites per square kilometer, respectively.

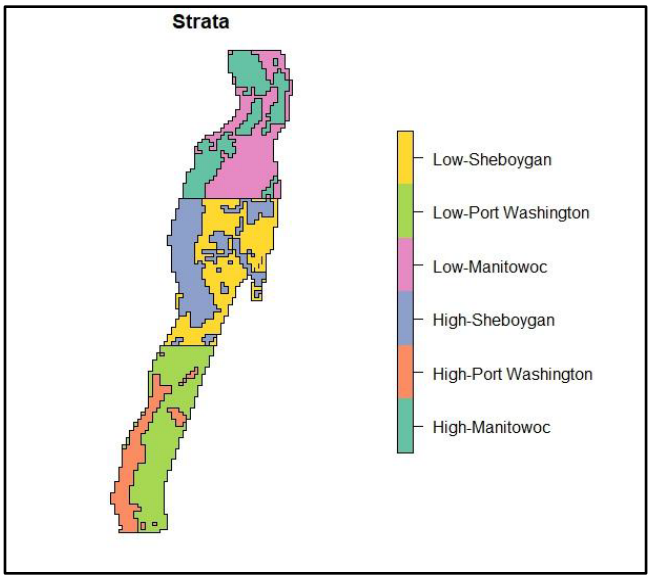


Figure 3. The six spatial areas defining primary strata.

Table 3. Characteristics of SRSS.

Primary Strata	Area (sq. km)	Number of Sample Sites selected by cLHS	Number of targeted ROV Sites
Low - Port Washington	480	240	2
High - Port Washington	206	412	11
Low - Sheboygan	454	227	5
High - Sheboygan	395	790	31
Low - Manitowoc	413	206	3
High - Manitowoc	313	626	18
Total	2261	2501	75

5. **Targeted ROV Sampling**: An additional 75 sites having unique lakebed features identified in blended DEM or backscatter surface but not captured by the stratified random design were chosen by a mapping expert for ROV sampling. These features included isolated structures or sharp transitions discernible in DEMs or the backscatter surface, as well as morphological features with dimensions that exceed the 3 × 3 cell neighborhood used to derive terrain metrics.

6. **Platform Allocation**: Sampling sites were assigned to different platforms based on platform efficiencies and logistic feasibility according to site depth. Sites were grouped into 4 depth categories (0-5 m, 5-30 m, 30-50 m and 50-80 m) and site allocation for each platform were as follows:

    a. 150 ROV sites were randomly selected from sites chosen by the cLHS method and an additional 75 ROV sites were chosen to collect information at targeted features identified in stage 5.

    b. 1400 DC sites were randomly selected from sites chosen by the cLHS method with an emphasis on sites shallower than 50m.

    c. 700 AUV sites were selected from sites chosen by the cLHS method with an emphasis on sites deeper than 50m.

    d. 250 Ponar sites were initially selected from sites chosen by the cLHS method. However, during the course of the field season, Ponar sites were chosen at a subset of sites where data was gathered by the ROV, DC, or AUV, and more information was needed to identify fine substrates.

Table 4. The distribution of sites by platform and site depth.

Depth Category	DC	ROV	AUV	Ponar
0-5 m	105	11	0	19
5-30 m	805	59	100	106
30-50 m	259	22	100	38
50-80 m	231	58	500	87
Sum	1400	150	700	250

Since sites were randomly chosen from the cLHS site set there was some overlap across platforms and not all sites of the 2501 set were selected for data acquisitions. Of the 2501 sites, 2191 were designated for collection by either an ROV, AUV, DC or Ponar. The remaining 310 sites were kept as “extra” sites and were provided to the field team in case a nearby designated site could not be completed or the field team completed data acquisition early.

Ultra-Short Baseline (USBL) System

A Sonardyne Micro-Ranger 2 USBL system was used for precise underwater acoustic positioning of the ROV, DC, and Ponar dredge. The system consisted of a mounted global navigation satellite system (GNSS) antenna vertically co-located with a transceiver (Figure 4), transponders attached to each data collection platform (i.e., ROV, DC, and Ponar), and a topside controller networked with the ship's computer. The transceiver was attached to the bottom of a track-mounted pole inside the moonpool well to allow for deployment of the transceiver into the water prior to data collection or to recover the transceiver for transit to the next site.

The transponder locations were tracked in real-time using Ranger software installed on the ship's computer located in the cabin of the *R3105*. The Micro-Ranger 2 system calculated the range, bearing, and depth from acoustic signals and displayed the results on a radar-style software display (Figure 4). These measurements were combined with geographic coordinates referencing the ship and received from the external GNSS antenna to derive the geographic coordinates of the underwater transponder. Based on the GNSS and Micro-Ranger 2 equipment specifications, horizontal spatial accuracy (horizontal error) was expected to be less than 10 m in water depths down to 80 m and closer to 4 m in water depths less than 10 m.

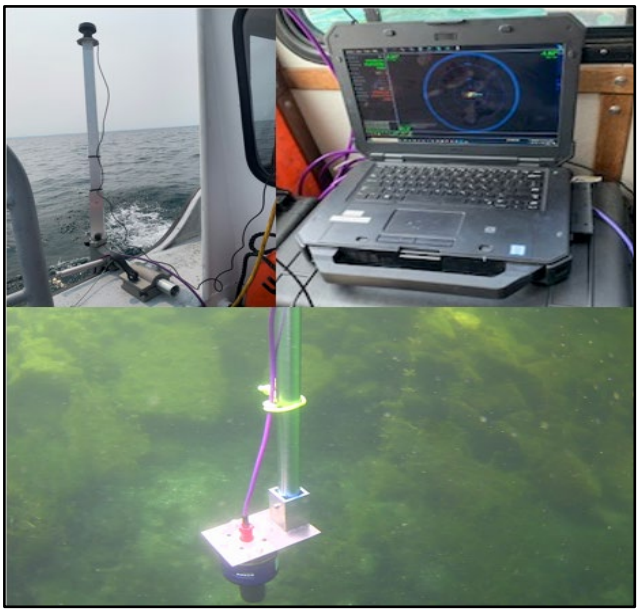


Figure 4. Sonardyne Microranger2 as set up for GL2301 and 2302.

Remotely Operated Vehicle (ROV)

MTU operated a Blue Robotics BlueROV2 heavy configuration, modified with a Mission Robotics electronics package and continuously powered by an Outland Technologies topside power supply (Figure 5). Two different tethers were employed, one floating and one sinking. The sinking tether was incorporated during the second mobilization to improve video and overall ROV performance. The ROV is a relatively small and light (23.1 kg) vehicle with an overall depth rating of 300 m. The ROV is equipped with eight thrusters capable of producing 5.25kg of thrust each, oriented with four vertical and four lateral. The lateral thrusters are configured for vectored thrust allowing greater maneuverability.

The ROV is outfitted with a 180-degree rotation, 1080p HD color on-board camera recording at 60fps with forward lighting provided by four Kree XLamp LED lights mounted on the ROV producing 1500 lumen each and adjustable from 0% to 100% intensity in 25% increments. A downward-pointing Arctic Rays Thresher compact, deep sea 4K ultra-high definition (UHD) camera recording at 1080p and 30fps was mounted between two down pointing Arctic Rays Viperfish dual color LED lights producing 5500 lumen each and equipped with a 520 nm green scaling laser in each, set 25.6 centimeters apart

(25.6 cm is the length used to differentiate cobbles from boulders in the Coastal and Marine Ecological Classification Standard (US Federal Geographic Data Committee and US National Ocean Service, 2012).

Spatial positioning was determined by a Sonardyne Micro-Ranger 2 Ultra Short BaseLine (USBL) acoustic positioning system. The transponder was mounted on the ROV and the transceiver mounted on a rigid pole through the vessel's moon pool. Altitude and speed over ground was measured using a Waterlinked A125 doppler velocity logger (DVL).

The topside control unit, a HP Envy laptop running the Kubuntu version of Linux with an attached Sony Playstation game controller, provided imagery, vehicle telemetry and control.

Real-time video from both cameras was displayed as a picture-in-picture image on the laptop screen. The video from the Thresher was stored locally on the camera requiring daily download of the video files from the ROV while tethered and powered. Video from the ROV camera was recorded on the laptop. Navigation and telemetry data were stored as a .csv file with the ROV video files. Videos and navigation data were transferred to portable hard drives for archiving. Telemetry data and live feed videos, forward and down looking arranged as a picture in picture image were displayed on a NOAA supplied monitor. USBL navigation data was displayed on an ACER 23.8" monitor and the DVL data was displayed on the HP Envy topside control computer positioned directly below the monitor on the topside Outland power supply. The system required 110 VAC of power, provided by the ship's 8kw generator.

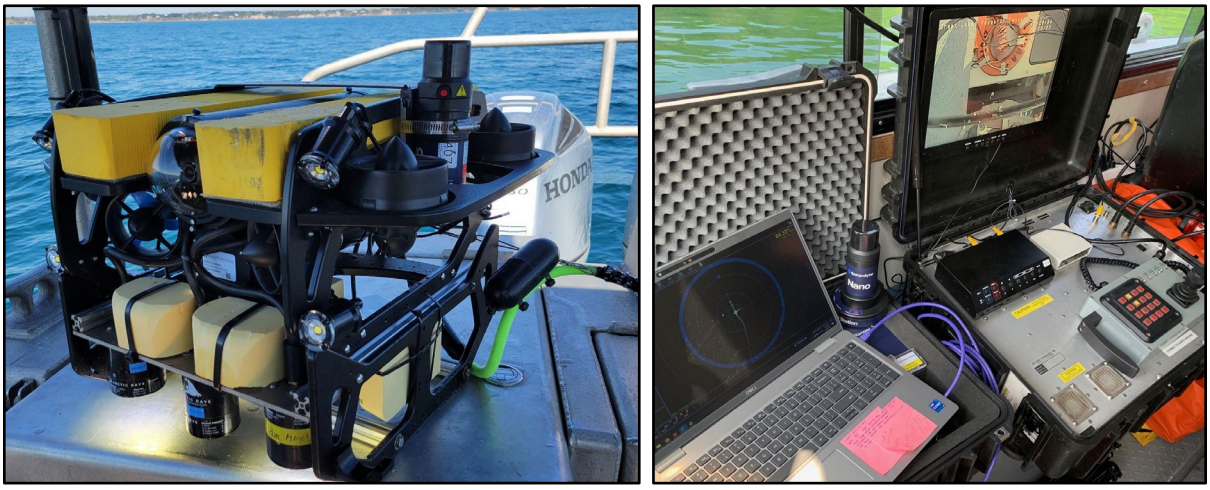


Figure 5. Modified BlueROV2 (left), topside unit and USBL system (right).

The BlueROV2 was deployed along predetermined transects 150 m in length. Transects were positioned according to the stratified random site selection and targeted site selection using bathymetry and backscatter to locate features of interest. Since local wind and currents can affect the choice of the best direction for ROV transects, two perpendicular transects were planned to cover each feature of interest, and only one was surveyed based on the site conditions. The ROV traversed transects along the lakebed at a speed of 0.25–0.6 knots and, depending on conditions, an altitude of 1–1.5 m.

During ROV dives, the USBL system tracked the ROV location while it collected videos and photos across the transect. The transect was occasionally paused to inspect and/or take more detailed videos of specific features. ROV imagery collection was accomplished by a four-person team consisting of a boat captain,

ROV operator, ROV deck hand, and data manager. The ROV deck hand manually deployed and recovered the ROV on the back deck with guidance from the boat captain and ROV operator. A data manager collected deployment information as well as important events encountered on the lakebed. Key data requirements and protocols are derived from Mabrouk et al. (2022).

Drop Camera

A high-definition (HD) drop camera system was used to capture underwater videos. The core component of this system was the SeaViewer 6000 HD camera, which is capable of operating at depths of up to 300 meters. The camera was outfitted with two 900-lumen dive lights, two green lasers positioned 28 cm apart for precise field-of-view measurements, a stabilization fin, and a 1.36 kg dive weight tethered to the bottom hole of the camera housing by a 20 cm-long cord (Figure 6). Additionally, a USBL transponder was affixed inline between a 100 m durable braided winch line and the top hole of the camera housing for camera angle positioning. A camera power/video cable extended from the rear of the housing, connecting to the topside console, which included a 13-inch LCD monitor, a SeaViewer DVR with geographic positioning system (GPS) overlay, and a Blackmagic Design Video Assist DVR (Figure 6). The video output was also sent to a Xenarc 10.1" waterproof, daylight readable monitor mounted on the aft bulkhead to be viewed by the camera operator from the camera station to help with altitude and angle adjustments. The camera system used 110 VAC of power, provided by the ship's 8kw generator. The lasers and dive lights were powered by AA and 18650 lithium rechargeable batteries, respectively.

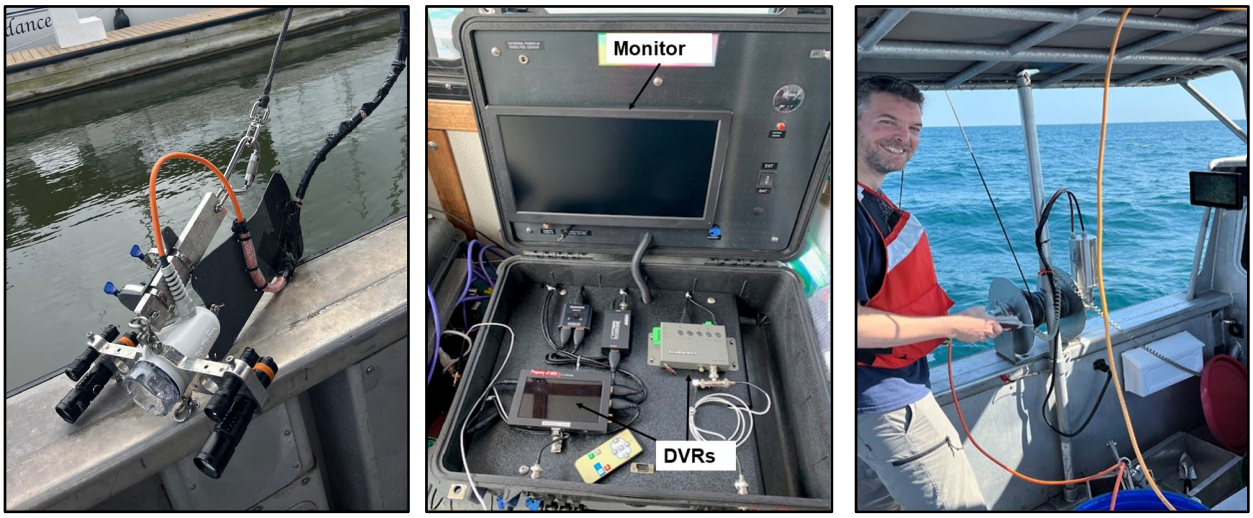


Figure 6. SeaViewer 6000 HD (left), topside unit (center), and deployment (right). Photo: Ossian Foley/CPC and Ayman Mabrouk/CSS

Whenever possible, the camera was deployed upwind of the target sight at a distance determined by depth and drift, so that the camera would descend as close as possible to the site and then pass within 5 m of the target. Because of the high number of sites targeted and collected, and depths involved, the DC was deployed using a davit and winch, which were located on the port side of the vessel (Figure 8). Reaching the bottom with the camera at the deepest sites could take nearly 3 minutes. When conditions were fair, the vessel would set up a drift to pass over the site sufficiently upwind or up current; when conditions were challenging, the vessel would hold station upwind or up current as long as feasible or

until the camera reached the bottom to begin observations, which facilitated better imagery due to having less momentum at the beginning of the video and better accuracy so the camera was not dragging through the water column up to 40 m behind the vessel. With practice, this technique allowed the core DC team to collect usable imagery in 2-3 foot seas and 15-20 kt winds.

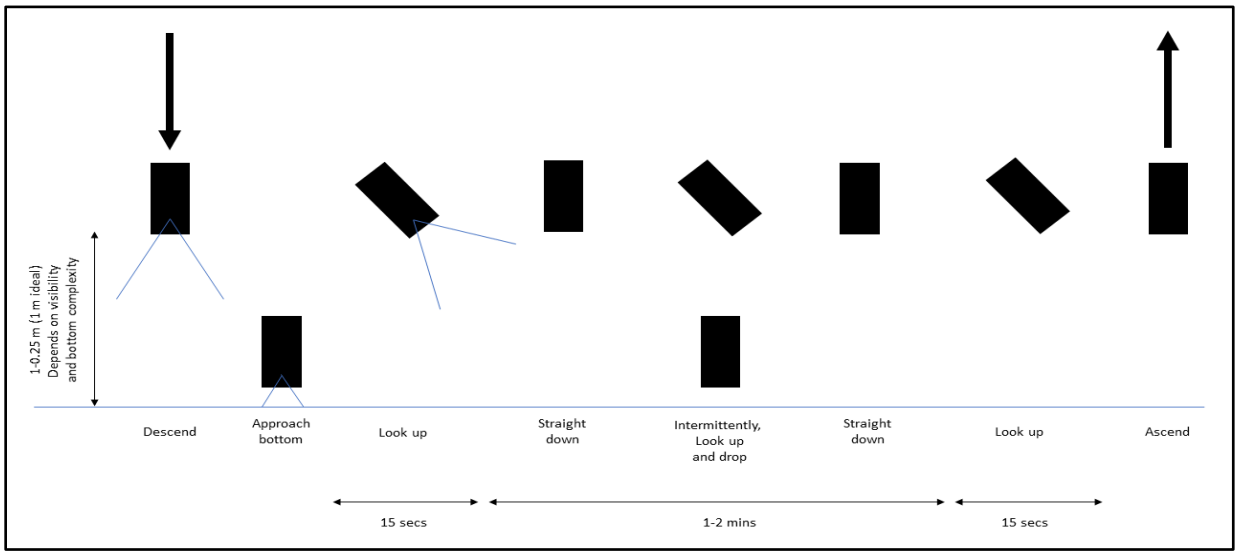


Figure 7. Standard DC transect. Image: Ayman Mabrouk/CSS

Once on the bottom, the camera was positioned approximately 1 m above the lakebed, primarily facing downward. However, at the beginning and end of a dive, the camera orientation was adjusted, using the tether and cable to capture oblique perspectives of the bottom. When there was no risk to the camera, it was lowered closer to the bottom to inspect the substrate and biological cover at closer range. Additionally, the dive weight was used to check the substrate type, especially at sites with fine sediments. If a substrate transition was observed during the deployment, the camera operator would perform an additional mid-deployment bottom inspection and oblique view, then resume annotation observations (Figure 7).

DC video collection was executed by a three-person team composed of a boat captain, a data manager, and a camera operator, who manually deployed and recovered the camera. The USBL system tracked the DC subsurface location throughout the dive. The typical duration of DC video recordings was generally two minutes at high-complexity sites and one minute at low-complexity sites. Key data requirements and protocols are derived from Mabrouk et al. (2022) and refined in Mabrouk et al. (2024) and Menza et al. (2024).

Ponar Sediment Dredge

A standard 23 X 23 cm (9 x 9 in.) Ponar dredge was used to opportunistically collect sediment surface samples from unconsolidated fine substrates, including sand, mud, or clay. These samples provided additional non-visual information for these fine substrates and supplemented sediment identification from imagery data collected by the ROV and DC.

The dredge was deployed off the port side of the vessel using the davit and winch and recovered into a rail-mounted elutriator (Figure 8). The dredge has two arms attached to two opposing semi-circular jaws that close to grab an 8.2-liter sample up to 89 mm depth. It has a dry weight of 23 kg, increasing to 34 kg when loaded with a sample. A weight was attached to each jaw, allowing easier penetration of the sediment. The dredge had a spring trigger mechanism, which was released upon contact with the bottom, closing the jaws on the sediment sample. A safety pin was inserted when the dredge was not in use, preventing the jaws from closing unexpectedly and safeguarding users from injury. A 500 µm AISI 316 stainless steel mesh with a rubber flap at the top of each jaw kept the sediment sample in the dredge while being recovered to the vessel. The USBL transponder was kept in a custom mount linking the dredge to the winch wire (Figure 8).



Figure 8. Ponar (left) and documentation (right).

At each sampling site, the dredge was lowered slowly until within approximately 3 m of the lakebed and then was allowed to freefall to the bottom. This strategy improved depth penetration and reduced the propensity of the Ponar jaws to close prematurely. If a Ponar dredge did not acquire sufficient sediment, the dredge was redeployed until an adequate sample was obtained. When the Ponar dredge was retrieved, the stainless steel meshes were removed, and a photograph was taken to capture a placard with site metadata and to document the sediment sample's color and texture information (Figure 8). The sediment was then assessed using the sediment data collection form (Appendix A) to record the presence of grain sizes according to the Wentworth grain size scale (Wentworth, 1922), the dominant grain size class, the presence of benthos, sediment stiffness, and sediment color. A waterproof geotechnical gauge card was used to facilitate consistent characterizations. The sample was disposed of into the water after it was characterized.

Autonomous Underwater Vehicle (AUV)

MTU operated an Iver3-580 EP AUV rated to 100 m depths with a battery life of 6-8 hours depending on dive depth. The AUV typically flies at an altitude of 2 m, +/- 30 cm at 2.5 kts. Subsurface navigation is achieved by RPI Doppler Velocity Log (DVL), depth sensor and corrected compass, and Imagenex 852 forward looking sonar for obstacle avoidance. Surface navigation comes from WAAS corrected GPS. A laptop with VectorMap software and rugged handheld controller completed the navigation setup. Images to characterize benthic substrates, enumerate benthic species, identify anthropogenic impacts to habitats, and ground-truth remotely sensed lakebed data were captured at 1 fps by a downward looking Allied Vision Mako-G-234C (capable of up to 8 fps) illuminated by a 30K lumen Artic Rays Remora. Additionally, the AUV collected supplementary side scan sonar with an Edgetech 2205 (frequencies 600 and 1600 kHz).

AUV operations complimented and augmented ROV efforts, revisiting sites also surveyed by the BlueROV2. Rather than surveying just one transect for a given site like the BlueROV2, the AUV mission surveyed each of the target site transects. Each mission consists of two 175 m at depth crossing transects that overlay the same waypoints used during the ROV surveys (Figure 9).

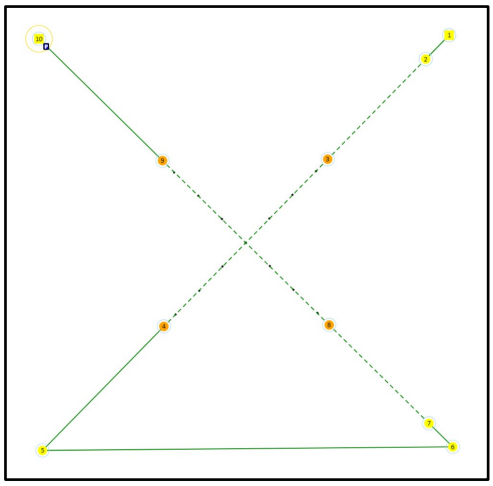


Figure 9. Standard GL2401 MTU AUV survey.

Depending on the depth of the water column, the dive and resurfacing leg lengths are extended. In deep water, each of the two transects could be as long as 500 m even though the sensed lakebed was only 175 m for each transect. Total mission lengths did not often exceed 1500 m in total length or 21 minutes. Most missions were less than 12 minutes in length. Mission planning is completed on a laptop with OceanServers proprietary VectorMap software, allowing for the underlay/overlay of charts, images, waypoint and other ancillary information needed for planning. The planned mission is then copied via wireless network to the Iver vehicle and executed with onboard software. Planning for these missions be completed in an ad-hoc fashion while in transit to the next mission area, providing maximum flexibility and adaptability.

All primary and ancillary data is recorded by their respective systems and stored on a 1 TB solid state hard drive on the vehicle. Comprehensive logging of all vehicle behaviors, including latitude and longitude, is recorded in a log file at a 1 Hz frequency. The latitude/longitude recorded in the log is real at the surface and estimated using dead-reckoning when the vehicle is subsurface. The dead-reckoning uses both a high-resolution on-board compass and a downward looking DVL for these estimates.

Complementary AUV imagery collected by the USGS

The USGS Great Lakes Science Center collected AUV imagery on a separate cruise from April 5 to November 20, 2024. USGS collections were planned in coordination with operations for GL2401 and is a complementary dataset in the WSCNMS study area. USGS imagery will be annotated using the same SOPs for imagery collected on GL2401, and will provide a full view of lakebed habitats in the operation areas.

The USGS AUV is a 200 m depth rated Iver3. It uses a camera system called the "Autonomous Benthic Information and Science System (ABISS)" which includes a Basler color stereo camera, a Basler high-resolution color monocular camera, strobes and control components. The AUV also has an IXBLUE inertial navigation system providing sub-meter positional accuracy. The USGS AUV was deployed to approximately 33% of the sites planned for characterization in WSCNMS, with most sites in water deeper than 10 m to take advantage of its depth agnostic operational efficiency. The USGS AUV collected imagery along a string of sites with each deployment representing a mission. Sites were string together using a traveling salesman algorithm to optimize travel efficiency.

Results and Discussion

The GL2401 cruise accomplished all the primary mission objectives, and the resulting ground-truthing data are expected to meet the requirements to characterize important habitats and create broad-coverage benthic habitat maps. Ground-truthing data collection covered an area of 2492 km² with depths from 3 m to >80 m, completing 109 ROV transects, 46 AUV transects, 845 DC sites, and 147 Ponar dredge samples (Table 5) across 169 days (Figure 10). Of these, 80 days were lost to bad weather, crew changes, weekends and holidays, and illness. Three of these days were lost to equipment failures and vessel repairs. Detailed information on the AUV and ROV transects, DC sites, and dredge samples, including deployment times and coordinates, can be accessed through a link in the Data Accessibility section. An additional 502 sites sampled on 62 AUV missions were completed by USGS.

Table 5. Total samples collected by platform.

Drop Camera	ROV	MTU AUV	Ponar
845	109	46	147

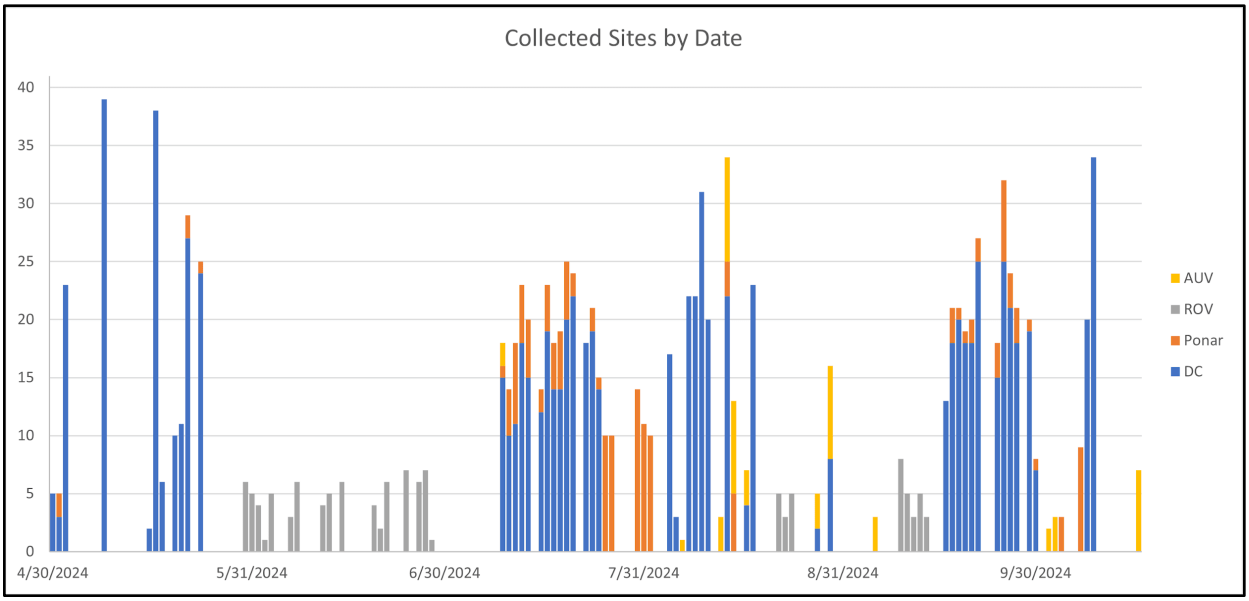
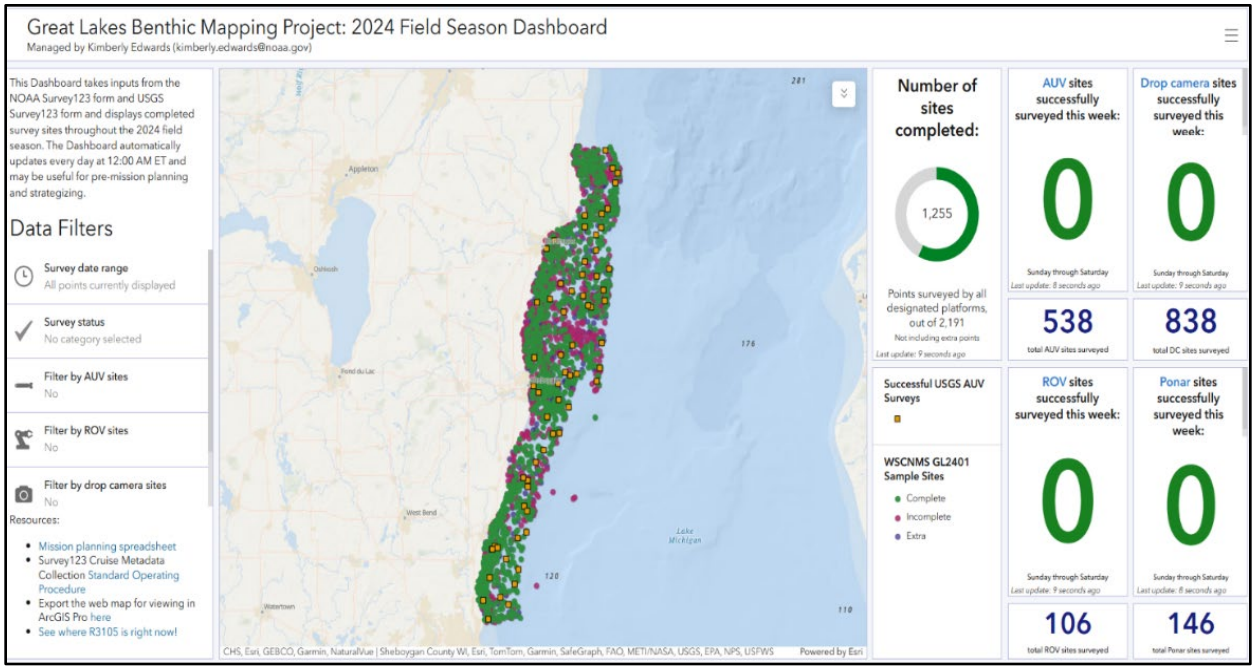


Figure 10. Samples collected by date and platform.

Imagery data and sediment sample collection followed standard operating procedures developed before the cruise (Menza et al., 2023), with adjustments made based on the lessons learned over the course of the cruise. Beginning during GL2401 with an anticipated conclusion prior to the next field season, data collected from GL2401 will be processed, undergo quality assessment and control, and will be annotated to characterize substrates, geomorphology, and benthic community coverage of the lakebed. The cloud-based Tator image annotation platform (CVision AI, Inc.) is planned to be used to coordinate and standardize benthic annotations.

Survey123 was used specifically in this project for all metadata and data collection across the platforms, for dashboard tracking of sampling progress over the season, and for data outputs for scientific analyses (Figures 11 and 12). Survey123 is an online ESRI platform allowing researchers to collect data in the field and use form-based surveys to collect data, generate GIS layers, and conduct data analyses. It is an ideal platform when working on multi-agency collaborative projects for accessibility and consistency across regions and agencies. Users can also build tracking tools to monitor progress of a project over a range of time scales.

Figure 11. Survey123 dashboard.



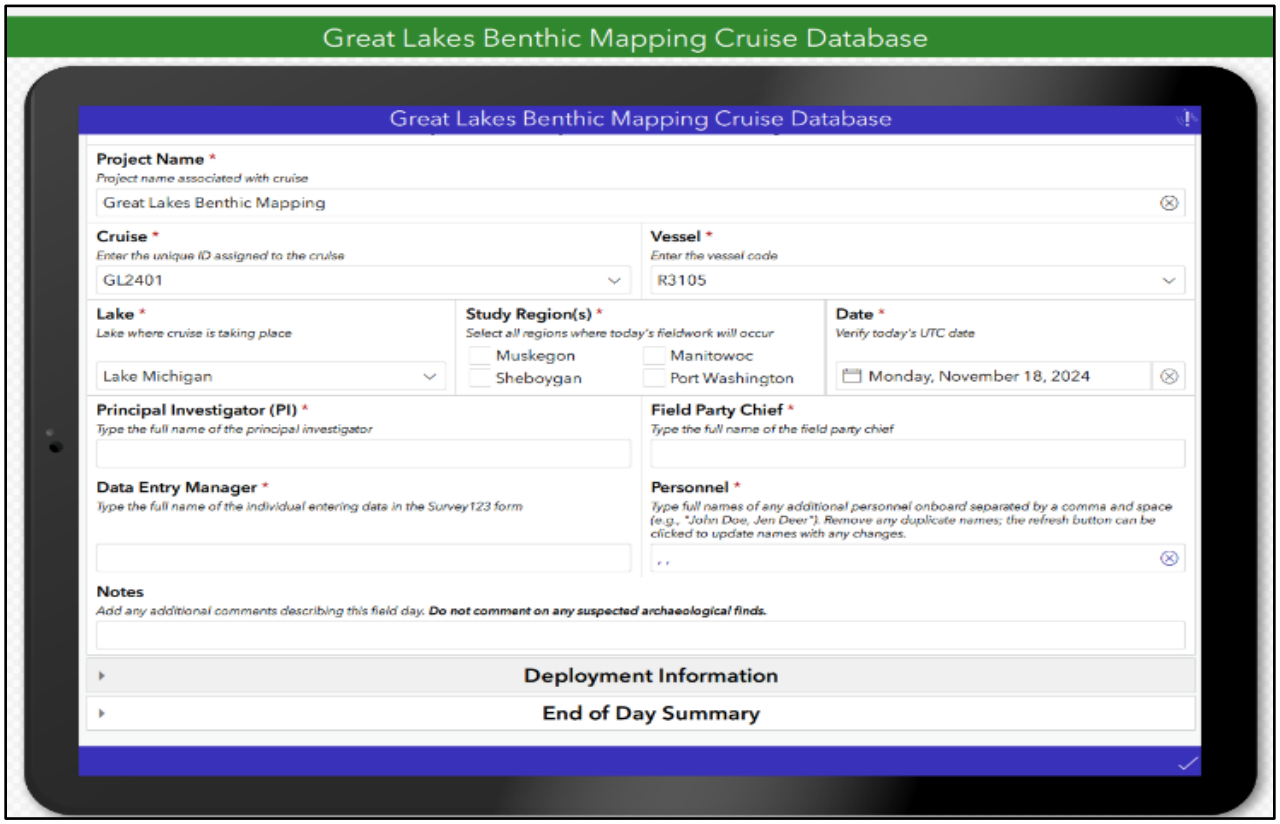


Figure 12. View of the Survey123 online form.

USBL

USBL coordinates display concise, well-defined lines, suggesting that the data will be straightforward to process and integrate with the DC videos. The primary limitations of this system occur when used with the ROV. Lengthy transects in shallow water remove the platform-affixed transponder outside the acoustic communication cone of the vessel-affixed transducer. Additionally, seas greater than 1 ft can impact the trigonometric calculations performed by the USBL software, creating plots that make navigation challenging, especially at extremities of the given transect and at deeper sites.Smoothing of data afterwards shows clear progress across the transects. Mitigation strategies are discussed in the following ROV section.

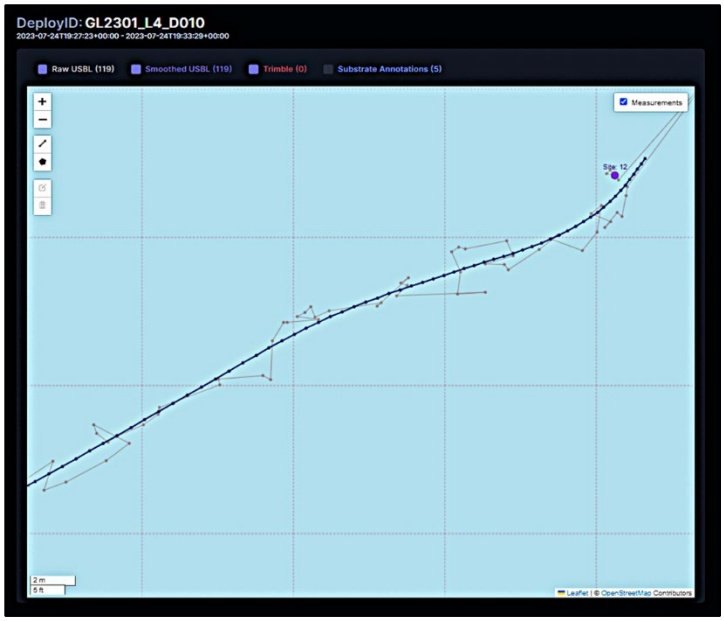


Figure 13. Typical USBL track, raw and smoothed.

ROV

One hundred-nine ROV dives were completed during GL2401 at sites between 3 m and 90 m water depth (Figure 13). ROV transects were spread across major geomorphological features, providing high-resolution imagery across key target sites and other complex habitats. The imagery and video collected is excellent quality and the BlueROV2 promises increasingly agile and precise maneuverability and collection (Figure 14).

Some opportunities for improvement presented themselves this season. The two primary equipment improvements concern the tether and thrust. First, MTU engineers will upgrade the ROV's tether to allow increased power and data transfer over the stock BlueROV tether's capabilities in such a way as to avoid negatively impacting navigation, maneuverability, and recovery time. Second, the current vector thrust configuration achieves precise low-speed control but struggles to pull a long tether lead through currents. An increase in fore and aft thrust would allow the ROV to better negotiate currents and speed recovery without negatively impacting transect navigation and video capture. Multiple solutions are being explored to reduce tether drag and increase available power to the thrusters.

Two areas of focus for operational improvements are deployment time and position accuracy. First, shortening deployment times through improvements in anchor set up and live boating when conditions allow to do so safely, could save significant time over the duration of the field season. Second, significant savings of time and safeguarding of personnel can be achieved by better managing the vessel position relative to the ROV to retain USBL accuracy in the two most challenging scenarios: shallow water transects, especially up-slope, and deep water transects with seas >1 ft. In depths under 3 m, the ROV exits the acoustic cone well before reaching the half-way point of a transect, functionally eliminating positional accuracy. In sufficient depths, even gentle rolling imparted by the sea, can lead to large divergence between successive position fixes, requiring the pilot to hold station along the transect in an

attempt to ascertain ROV position. Both scenarios, especially the shallow water condition, are improved by managing the vessel to remain over the top of the ROV, following the transect at an offset, either by maneuvering under power or releasing anchor to allow the vessel to settle downwind during the ROV's transit.

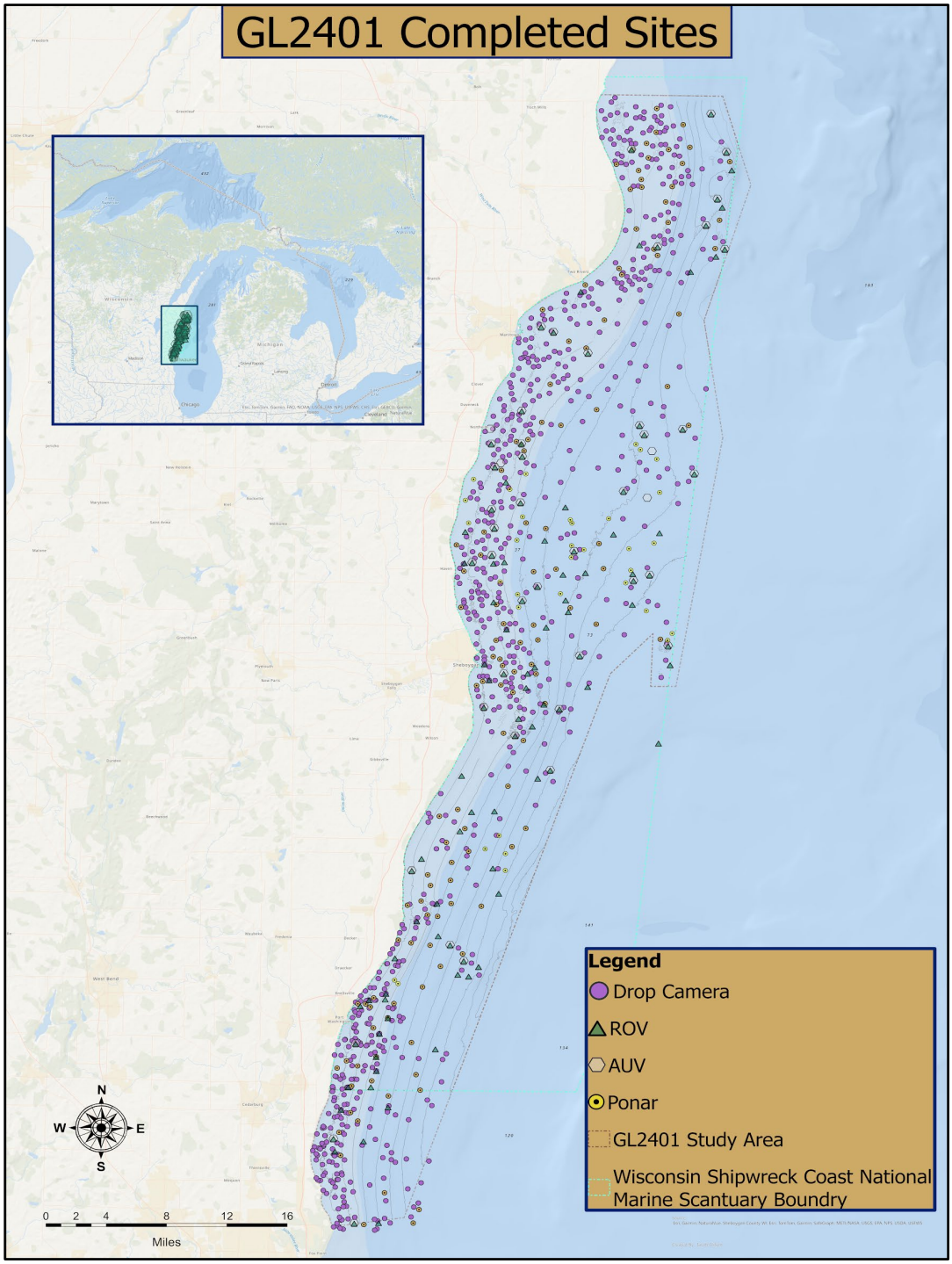


Figure 14. Actual sites surveyed by cruise GL2401. Image: Jacob Wilson/CPC

Admittedly, some of these challenges are inherent when utilizing a small, trailered vessel for this type of work. However, even marginal reductions in deployment time and frustration add up significantly over the course of numerous transects.

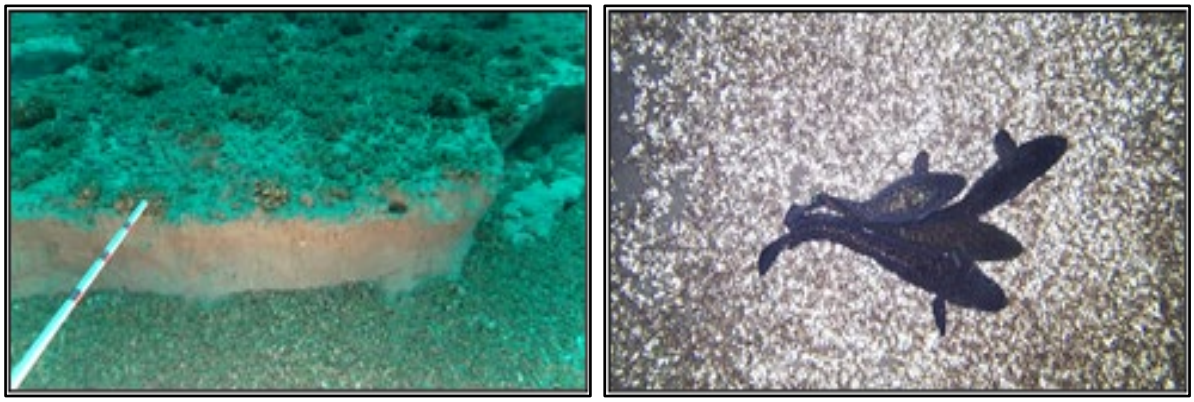


Figure 15. Mussels atop clay from the ROV's pilot camera (left) and a Thresher image of burbot (right). Photo: MTU

Drop Camera

The drop camera was successfully deployed at 845 sites across the study area (Figure 14). A preliminary evaluation of the collected videos and USBL data indicates that the data aligns with the project's objectives. The camera's adjustable orientation underwater proved advantageous, functioning similarly to the dual-camera setup of the ROV. Forward-facing orientation allowed for better identification of large-scale structures and hazard avoidance, while downward orientation provided more accurate assessments of benthic cover. The DC's efficiency was notable in shallow areas, enabling data collection up to 44 sites per day.

Due to the high number of deployments and the use of the davit, combined with working in challenging winds and sea states in order to meet the site number goals, one DC was returned to SeaViewer during the cruise for repairs to the tether. A reserve SeaViewer DC also experienced data and power issues toward the end of the mission. Stress on the tether was minimized by fashioning a two-block set up to maintain the proper relationship between tether and winch wire, greatly reducing the amount of force and manipulation needed to articulate the camera to collect usable annotation imagery (Figure 16). Furthermore, the ability to make some field repairs, such as swapping out a tether rather than a whole camera system, would be of great benefit to future crews.

Ponar

The Ponar dredge was used to collect samples at 147 sites (Figure 14) of unique or rare types of fine unconsolidated sediment substrate, substrate which could not be differentiated into mud or sand by video, and at remote locations.

AUV

The MTU AUV collected optical imagery and sidescan imagery (SSS) at 46 sites (Figure 14). The initial plan was to have MTU collect ROV video and AUV imagery simultaneously. However, it was quickly determined that deploying the AUV alongside the DC was an ideal combination of platforms for efficiency and deck space considerations, if appropriate personnel were available. Combining the AUV and DC platforms greatly increased the efficiency of the ROV legs and had a positive impact on efficiency and morale of the DC crew without negatively impacting DC collection rates. AUV-collected images and positioning data passed initial quality assessments and controls. The images will be annotated with the GL2401 DC and ROV imagery.



Figure 16. DC images of Alewives after color correction (left) and DC rigging.

Complementary USGS AUV

The USGS AUV collected imagery at 506 sites (62 missions) throughout the study area between April 5 to November 20, 2024 (Figure 17). Another 194 sites (22 missions) are planned to be surveyed in spring of 2025. Unlike other platforms, the AUV also collected imagery between sites along transects. Each transect was generated prior to the field season, based on a traveling-salesman algorithm to maximize site to transect length efficiency for the AUV's missions. Currently, the plan is to focus on only annotating images within a short (i.e., 10 m radius) buffer around each site to correspond with the other datasets, Preliminary reviews of the AUV imagery indicate they will complement imagery collected during GL2401 but there is the potential to extend annotations to the rest of the imagery collection if needed.

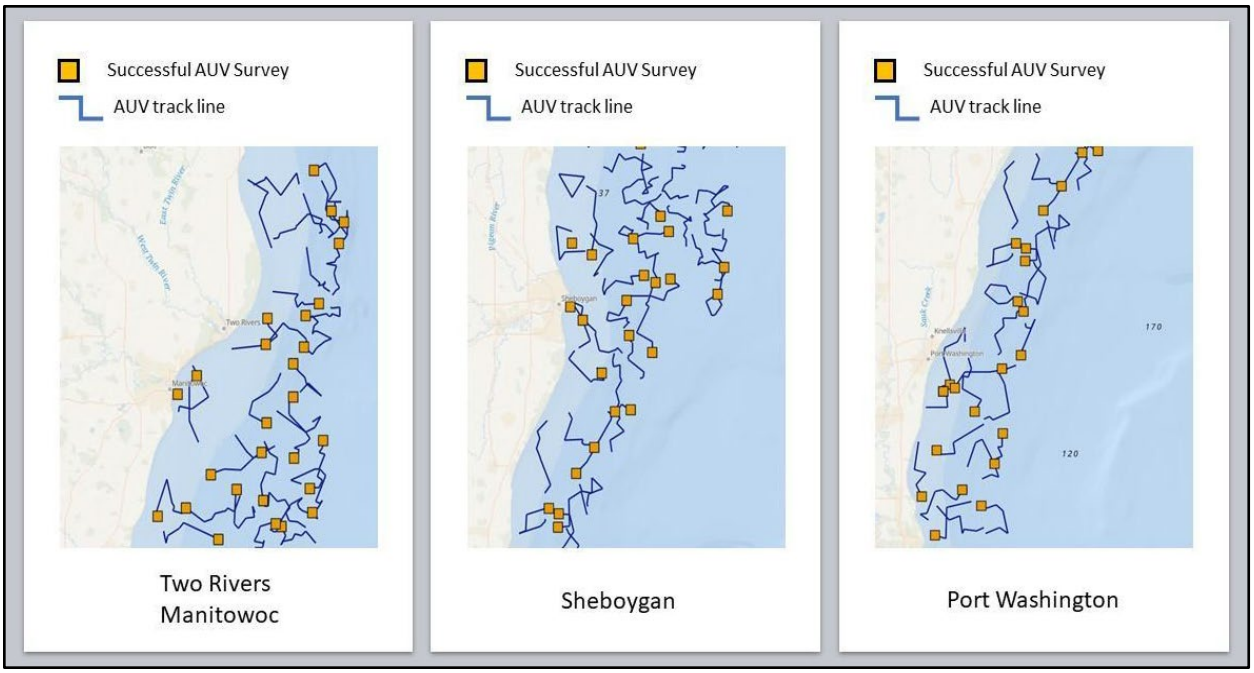


Figure 17. USGS AUV track lines and completed sites.

Data Accessibility

The data from this cruise and video annotations of lakebed characteristics will be archived at the NOAA National Centers for Environmental Information (NCEI) within one year of completing quality assurance procedures. NCEI is one of the NOAA National Data Centers which satisfy the requirements of the NOAA Environmental Data Management Framework, US Open Data Policy (OMB Memorandum M-13-13), and Office of Science and Technology Policy Memorandum on Increasing Public Access to the Results of Federally-Funded Research (PARR). All cruise data will be archived in the following data collection: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:NCCOS-GLBM-GL2401

Cruise locations described in this report are archived in the following data accession:

NCCOS Mapping: Collaborative Benthic Habitat Mapping in the Nearshore Waters of the Great Lakes Basin – Collection locations of GL-24-01 cruise benthic imagery and sediment samples in the Wisconsin Shipwreck Coast National Marine Sanctuary (WSCNMS) Lake Michigan, 2024-04-30 to 2024-10-16. https://www.ncei.noaa.gov/archive/accession/0306219

Benthic videos and ponar dredge information for this cruise are planned to be added as separate data accessions to the cruise data collection. A separate data collection with derived products generated from cruise data, including habitat maps and models, and other environmental information is planned to be archived at NCEI and will be linked to this data collection.

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Appendix A: Sediment Data Collection Form

Example of the Ponar sample data sheet collected in the field.

PONAR SAMPLE LOG: For use with Ponar deployments

CRUISE ID: _____ DEPLOYMENT ID: _____

SITE ID: _____ DATE: _____ UTC Time:_____

SEDIMENT COLOR: Can mark more than one. __Black __Brown __Gray __Green __Red __Other	**GRAIN SIZES PRESENT:** Indicate presence with an X. __Clay __Silt __Sand __Granule __Pebble __Cobble __Shell Hash __Wood	**DOMINANT GRAIN SIZE:** Indicate with an X. __Clay __Silt __Sand __Granule __Pebble __Cobble __Shell Hash __Wood
GRAIN COMMENTS:		
SILT/CLAY DESCRIPTION: Mark one. __Very Soft __Stiff __Soft __Very Stiff __NA **H2 SULPHIDE:** __Yes __No	**SAND DESCRIPTION:** Mark one. __Loose __Dense __NA **OXIDIZED:** __Yes __No	**STRATIFICATION:** Mark one. ____Coarse/Fine ____Fine/Coarse ____None **REQUIRED PHOTOS TAKEN:** __Yes __No
BENTHOS PRESENT: Indicate presence with an X. __Mollusc __Live Veg __Algae __Other	**ANTHRO PRESENT:** Indicate presence with an X. __Marine Debris __Microplastics __Other	**BENTHOS/ANTHRO COMMENTS:**
ADDITIONAL COMMENTS:		