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Best Practices for Ground-truthing and Accuracy Assessment of Lakebed Maps in the Great Lakes: A case study offshore the Bayfield Peninsula in Lake Superior

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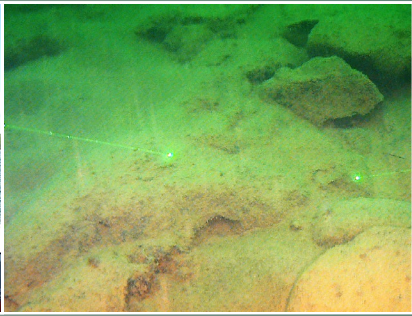

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https://coastalscience.noaa.gov/project/collaborative-lakebed-mapping-off-apostle-islands-to-support-great-lakes-restoration/

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Best Practices for Ground-Truthing and Accuracy Assessment of Lakebed Maps in the Great Lakes: A case study offshore the Bayfield Peninsula in Lake Superior

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April 2022

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NOAA Technical Memorandum NOS NCCOS 295

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Gina M. Raimondo Secretary	Richard W. Spinrad Administrator	Nicole LeBoeuf Assistant Administrator

Lake Superior/Apostle Islands National Lakeshore - WI. Photo: NOAA/NCCOS

1.0 PURPOSE

The purpose of this technical memorandum is to describe the National Centers for Coastal Ocean Science's (NCCOS) best practices for collecting, processing, and analyzing lakebed ground-truthing and accuracy assessment data (underwater photos/videos or sediment samples) required to develop lakebed maps in the Great Lakes. These practices have been refined over years of data collection efforts by NCCOS across various study areas distributed throughout the Great Lakes and marine waters (Costa et al. 2009, Kendall et al. 2017, Menza et al. 2019, Battista et al. 2019).

For this report, we use a 2021 mapping project offshore of the Bayfield Peninsula and Apostle Islands National Lakeshore (APIS) in Lake Superior, Wisconsin, as a case study to describe best practices. This memorandum will immediately support mapping project partners with information needed to collect, process and analyze ground-truthing and accuracy assessment data. It will also be useful to other projects and offices mapping in the Great Lakes with the Coastal and Marine Ecological Classification Standard (CMECS) or other classification systems.

2.0 BACKGROUND

Multibeam echosounders (MBES), light detection and ranging (LIDAR) systems, and side-scan sonar (SSS) systems are used to collect high-resolution remotely-sensed bathymetric and reflectance information across broad swaths of the lakebed. These data can be used to interpret the geophysical and biological properties of the lakebed, such as geoforms, substrates, and benthic organisms. They can also be used to identify submerged features of cultural significance, such as shipwrecks and other underwater artifacts.

Ground-truthing (GT) and accuracy assessment (AA) are two essential steps in developing high-quality habitat maps from remotely-sensed data. In both steps, direct observations and measurements (GT/AA data) of the lakebed are collected and used to characterize geophysical and biological properties of the lakebed at specific sites. These in-situ data are collected using different methods, such as autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), SCUBA or snorkel dives, drop cameras, and sediment grabs/corer samplers.

As part of the GT process, relationships between properties (e.g., geophysical and biological) of GT data and remotely-sensed datasets (e.g., multibeam and its derivatives) are defined. These relationships are used to extrapolate measurements collected at GT sites to the whole remotely-sensed area. The result is a predicted map that shows the lakebed characteristics for the entire remotely-sensed area. The AA process on the other hand, uses the measurements collected at the AA sites to validate the predicted map. An AA also provides information on map class errors using confusion matrices and evaluates the accuracy of the predicted habitat map. For unbiased and accurate tests, GT data and AA data are collected and analyzed independently (Mitchell et al., 2018; EMODnet, 2021).

3.0 SCOPE

This technical memorandum will describe methods, equipment, and staffing needed to collect, process, and analyze underwater videos and sediment samples from the Great Lakes with reference to our study area offshore Bayfield Peninsula in Lake Superior. It also provides detailed information on how to ground-truth and assess the accuracy of the substrate, biological cover, and geoform components of lakebed maps using CMECS.

4.0 STUDY AREA

The study area is located north of the Bayfield Peninsula, Wisconsin, between Bark Point and Sand Island (Figure 1). This area also lies north of the westernmost section of the Apostle Islands National Lakeshore. Multibeam bathymetry and backscatter data were collected by the Great Lakes Environmental Research Laboratory (GLERL) and Cardinal Point Captains, Inc. (CPC) using a Teledyne-Reson 7125 mounted to the Research Vessel (R/V) Echo. The total area surveyed was 83km² with a depth range of 5-66m. The multibeam data were processed and reviewed by David Evans and Associates, Inc. (DEA). The final bathymetry and backscatter surfaces were gridded at 2m resolution. Finer 1m resolution surfaces were also generated, but were not used due to data gaps and inconsistent data density.

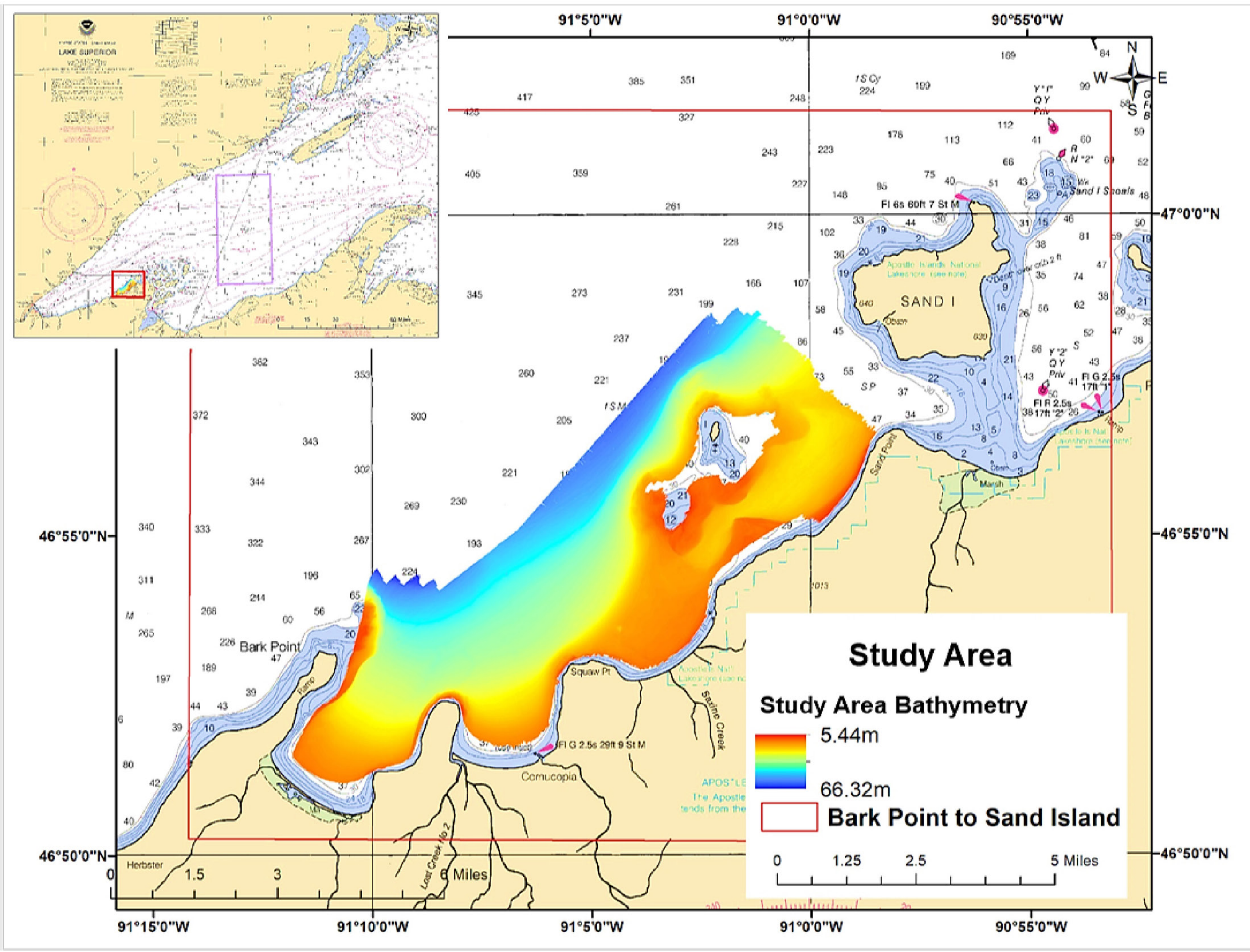

Figure 1. Map shows the bathymetric data collected for the study area between Bark Point and Sand Island, north of the Bayfield Peninsula in Lake Superior, Wisconsin.

5.0 MAP SPECIFICATIONS

Several essential map specifications should be taken into consideration when planning for the collection of GT data. Map requirements will affect decisions about GT and AA site placement, what types of data will be collected, and what tools are needed to collect data. Map specifications should be based on the intended use of the final products, which are determined by early collaborative discussions between map makers and map users. Specifications include information on the estimated coverage and depths of the study area, the types of features to be mapped, the minimum mapping unit (MMU), allowable levels of uncertainty in measurements, and the habitat classification system being used. In addition, requirements often have an explicit spatial dimension, scale, or extent for reference.

For this case study, the intended uses of lakebed maps are to locate and improve understanding of coastal erosion, degradation of native fish habitat, invasive species, water quality, and CMECS classification systems for broad Great Lakes application. Consequently, the generated lakebed map was designed to broadly define lakebed geoforms, substrates and biotic components and serve as a baseline to address future lakebed changes. We adopted CMECS, a structured catalog of ecological terms that provides a framework for interpreting, classifying, and inter-relating observational data from all types of sensors and platforms. It has been used extensively and successfully in the Great Lakes (Menza et al., 2019). CMECS has also been endorsed by the Federal Geographic Data Committee as a national standard classification system especially for federally funded projects working with environmental data in marine settings (FGDC 2012).

To get a better idea of what benthic features are present in the study area, existing underwater video, sediment samples, and fisheries data were compiled and interpreted in and around the study area (Table 1). These data were provided to NCCOS by the National Park Service (NPS), the United States Environmental Protection Agency (U.S. EPA),

Table 1. The existing ground-truthing data for the study area.

Dataset Name	Organization	Description	Extent	Contact Person
NCCA underwater videos and sediment samples	U.S. Environmental Protection Agency (U.S. EPA)	Under water videos for the National Coastal Condition Assessment 2010 and 2015 using the Seaviewer camera with interpretation, sediment samples using Ponar sampler with grain size analysis	11 videos 9 of them inside the study area and 4 sediment samples inside the study area	Molly Wick (wick.molly@epa.gov)
NPS scuba activities	National Park Service (NPS)	Photos for substrate	4 sites 2 of them in the study area	Jay Glase and Brenda Lafrancois
NPS drop camera videos	National Park Service (NPS)	Underwater video footage for mussel detection using GoPRO cameras in 2017	23 GoPro videos around Sand Island	Jay Glase (Jay_Glase@nps.gov) and Brenda Lafrancois (monique_lafrancebartley@nps.gov)
TNC historical substrate maps	The Nature Conservancy (TNC)	Map shows nearshore substrate type using historical data from 1800's	10 historical substrate types, samples are inside the study area	Matt Herbert (mherbert@tnc.org) and Gust Annis (gannis@tnc.org)
Glacial geology of Bayfield county	University of Wisconsin-Extension, Geological and Natural History Survey	Map for the pleistocene geology of the Superior region, Wisconsin	Glacial geology of Bayfield County, and the surficial deposits on land adjacent to the study area	Elmo Rawlings (elmo.rawling@wisc.edu)
USGS fish bottom trawling	U.S. Geological Survey (USGS)	Map shows the location of the bottom trawling sites and the associated fish community sampled	Two sites in the study area (Sand Island and Squaw Point) were bottom trawled annually	Mark Vinson (mvinson@usgs.gov)
Fish spawning grounds in Lake Superior	University of Wisconsin SeaGrant	Map digitized by NCCOS from Coberly and Horall 1980 shows the location of the spawning grounds in Lake Superior	Spawning grounds for Lake Herring, Lake Trout and Lake Whitefish in the study area	Ayman Mabrouk (ayman.mabrouk@noaa.gov)

the University of Wisconsin, the US Geological Survey (USGS), and The Nature Conservancy (TNC). Interpreting existing datasets was also helpful to determine that CMECS was an ideal classification system to use for map attribution.

To better understand which map specifications the remotely-sensed data could support, a detailed assessment of the bathymetry and backscatter imagery was conducted. These data were processed and interpreted to define unique bottom shapes and textures, and assess hydrographic artifacts. The bathymetric imagery provides a digital elevation model for the lake bottom, while the backscatter can provide information on the texture, roughness, and composition of the substrate (Battista et al., 2019). These interpretations broadly defined the types and sizes of features to be mapped and the level of measurement uncertainty in source data. Taken together, this information helped identify the ideal MMU of 100 m^2. A smaller MMU would have made it challenging to precisely map discrete features given noise and artifacts in the remotely-sensed data, and a larger MMU would have missed important features readily discernible in the remotely-sensed data. The depth range of underwater features was also important for choosing the sensors and platforms needed to collect GT and AA data.

With a better understanding of the sizes and shapes of bottom features, but still missing more detailed information on substrates and biological composition, the mapping team could proceed with planning the collection of new GT and AA data.

6.0 METHODOLOGY

6.1 SITE SELECTION

GT and AA site selection is determined by the physical and biological properties of the lakebed before the field mission starts. Site selection for GT and AA datasets should be performed independently whenever possible. Ideally, the GT sites are selected, surveyed, and interpreted first to generate a supervised classified habitat map. Then the AA sites are selected based on habitat map classes (i.e., post-classification sampling) to ensure accurate stratified sampling and adequate replication among all bottom classes. However, due to limited budgets, time, and logistics, this sequential selection process often does not occur. Instead, both the GT and AA sites are selected and surveyed simultaneously, but classified independently to avoid bias.

GT sites are purposefully selected to collect information on specific features, shapes, or patterns visible in the remotely-sensed data (e.g., bathymetry and backscatter) and its derivatives (e.g., slope and curvature). It is ideal to collect GT data for every unique pattern detected from the imagery and use both feature size (area) and feature heterogeneity (variance) to inform site selection. More sites should be selected where features are larger and/or more heterogeneous. Selecting GT sites that provide a clear remotely-sensed signal, such as in areas with few data artifacts or away from habitat class boundaries can improve model training. In situations when habitat transitions are of interest, GT sites should purposefully be located across boundaries and cover the range of remotely-sensed values to delineate the transition. To improve sampling efficiency, GT sites can be clustered to minimize travel time between sites. In circumstances where sampling effort is limited, preference can be given to shallower sites or sites closer to shore. However, these choices could potentially bias models and decrease the accuracy of the map in less sampled areas.

Whenever possible, AA sites should be generated using a stratified random sampling design (probability sampling) with proportional allocation based on class type (Olofsson et al., 2014 and Haub et al., 2015). More sites should be selected in larger and more heterogeneous classes. There is no agreement on the minimum number of sites per class for AA; Congalton and Green (2008) and FAO (2016) suggested 20 to 100 samples per strata, INFOMAR (2007) suggests 10 sites per class, and NCCOS has used as few as 5 sites per class with a caveat that associated estimates are less certain (Menza et al., 2019). Efforts must be balanced between GT and AA sites to ensure models are both trained accurately, and maps can be rigorously validated. Mitchell et al. (2018) recommended that 70% of all the planned sample sites are used for GT, and 30% are used for AA.

NCCOS has used 50% for each site type with satisfactory results (Menza et al., 2019). If the footprint of site measurements are substantially smaller than the acoustic footprint as is typical for sediment sampling, intra-site replication (i.e., a minimum of 2 samples per site) is advised to average measurements (INFOMAR, 2007). Intra-site replication is most important when there is a lot of fine-scale patchiness or spatial heterogeneity.

GT and AA sites are typically planned using sample design tools available in a geographic information system (GIS) and there are several GIS tools to support site planning and selection (e.g., NCCOS Sampling Design Tool for ArcGIS, 2016). The GT and AA sites are best managed in a GIS as a feature point layer with a unique site name, X and Y coordinates, and should contain fields for the habitat classification attributes and site depth estimates. These points should be exported from GIS as a table to create a data sheet for the field and entered into the field team's global positioning system (GPS) devices for navigation. Printed maps that show the GT and AA sites are helpful for planning field operation, sites transit and recordkeeping. Records collected on field maps, such as hazards to navigation and important lakebed descriptors will aid future interpretations.

For our study area, a total of 423 sites were selected to exhaustively ground-truth bottom features visible in remote sensing data and assess the accuracy of predicted lakebed types. Of the 423 sites, 203 were for GT, and 220 were for AA (Figure 2). In order to select the GT and AA sites, an unsupervised lakebed bottom type map was

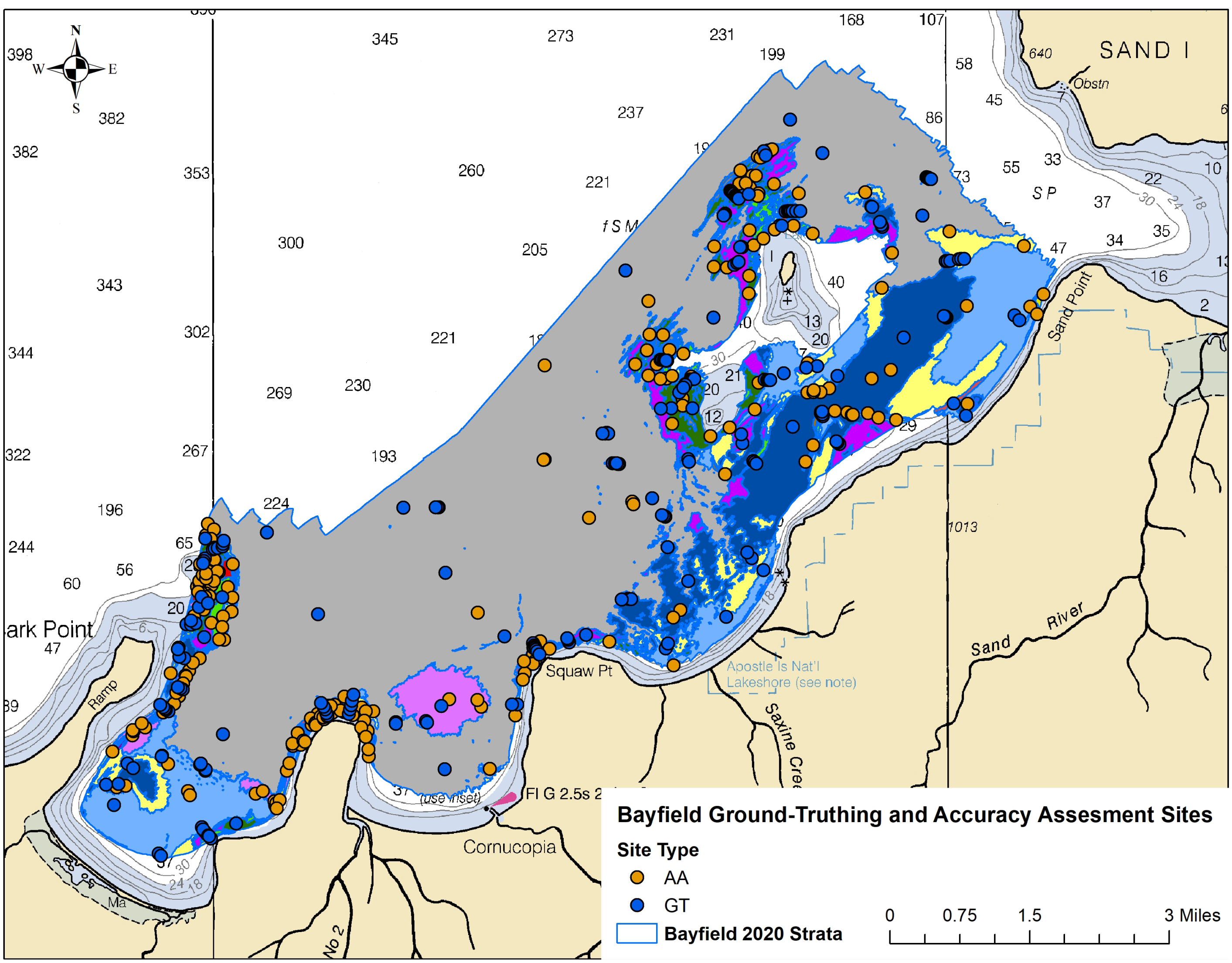

Figure 2. Map shows the selected ground-truthing sites (green) and accuracy assessment sites (red) for the study area north of the Bayfield Peninsula in Lake Superior, Wisconsin. The colored polygons represent the different strata from the unsupervised lakebed bottom type map.

developed to discriminate among bottom types and develop benthic strata from remotely sensed imagery. This preliminary lakebed map was created using feature-based segmentation and multivariate segment clustering. Feature-based segments were derived from principal component analysis (PCA) of bathymetry, backscatter, and depth derivatives (e.g., slope, rugosity, and curvature) using the ENVI (v.4.7) image processing analysis software. Segment-specific zonal averages for each principal component were calculated, and these metrics were clustered by agglomerative hierarchical clustering using custom scripts in R. GT sites were purposefully distributed across the entire study area to collect information among unique features visible in remotely sensed data, across the different strata and through the complete depth range. The AA sites were randomly distributed among strata according to the unsupervised lakebed bottom type map (Figure 2). Each stratum received 5 AA points in an effort to ensure replication in each lakebed bottom type.

6.2 GROUND-TRUTH DATA COLLECTION

Best practices for collecting ground-truth data using underwater drop cameras and sediment grab samplers are described below. These tools are ideal for efficiently achieving map specifications off the Bayfield Peninsula in Lake Superior.

6.2.1 Navigation to GT/AA sites and logging GT/AA observation locations

It is imperative that ground-truth data are collected as close as possible to the predetermined GT and AA sites. Imprecise collections will reduce sampling efficiency and could mean important lakebed features are missed. To improve accuracy, the Global Navigation Satellite System (GNSS) can be used to both direct a boat to a site and provide accurate spatial positioning of the boat while sampling. Accurate positioning is particularly important if sampling is conducted across a transect. NCCOS commonly uses recreational-grade handheld GPS receivers (e.g., Garmin series 76) to navigate to the sample sites and, uploads the points to the boat's navigation console. More accurate map-to-survey grade GPS receivers (e.g., Trimble Geo7X 6000) with corrections applied are used to track the boat over time and enter observations about the sample site into the receiver's attribute table for each point.

Figure 3. The survey team leader coordinates with the boat captain to prepare a daily field work plan. Photo: NOAA/NCCOS

During daily field operations, the survey team plans which GT and AA sites will be visited in coordination with the boat captain to balance efficiency and safety (Figure 3). The captain will then navigate to each site using the provided coordinates from the handheld GPS unit or the boat's navigation system (Figure 4). During transit, the field team should prepare to deploy the sampling equipment and collect the GT/AA data. The survey GPS receiver (Trimble) should be turned on at least 5 minutes before arrival at the site to ensure the system achieves a strong signal. These units need at least three satellite constellations for at least

Figure 4. The boat captain uses a handheld GPS (Garmin) with the preloaded GT/AA sites to navigate. Photo: NOAA/NCCOS

1-meter spatial accuracy. Additionally, the clocks on the GPS receiver and all data collection systems should be synchronized and set to the correct logging frequency. The GPS operator should calibrate these clocks daily and ensure they are recording one track point per second when logging the GT or AA data.

6.2.2 Standard Operating Procedures for Using a Live-Video Drop Camera

High-definition underwater video cameras are one of the most efficient and versatile ways to collect GT and AA data. Underwater camera systems can be configured to collect data in a wide range of environments from various platforms. The cameras can be utilized as a standalone device or mounted to other data collection instruments. Most underwater cameras record the video to an internal memory card like the GoPro Hero, while other camera systems can provide live video of the lake bottom to a topside setup on the research vessel through a cable.

For our study area, the survey team used a Seaviewer 6000 HD live camera system for the field mission. The advantage of this camera is that it provides real-time underwater video to a topside video monitor, which can be used to assess data quality in real-time, avoid underwater obstructions and annotate videos in the field.

Vessel requirements for most types of drop cameras are modest. Drop camera work is typically performed on the back deck or over the side of the vessel. Small research vessels between 6 and 10 meters are preferred because they are able to collect data in shallow waters and are maneuverable, as in our case study (Figure 5). Still, larger vessels may be necessary to be used for further offshore and deeper sites. Lightweight drop camera systems are typically deployed by hand. However, a lifting davit or downrigger on the deck can aid in deploying and recovery of the live camera system more rapidly, especially for deep (>30m) sites and allow the use of larger ground-truthing tools (e.g., sediment sampler).

Figure 5. NOAA vessel (R2512 26' SeaArc) used by NCCOS for the ground-truthing missions for the study area at Siskiwit Bay Marina, Lake Superior-Wisconsin. Photo: NOAA/NCCOS

The live underwater video system requires a sufficient amount of space on the deck for handling the camera gear, as well as room inside the cabin to keep the topside surface console dry. The topside console contains a TV monitor, a HD video receiver, a video recorder, an external hard drive for storage, and a 12 Volt battery (Figure 6; Menza et al., 2019). The whole camera system can also be powered directly through the boat with a 120 Volt AC power adapter in case of battery failure. The HD videos are recorded at 30 frames per second in 1920x1080 pixel MOV files.

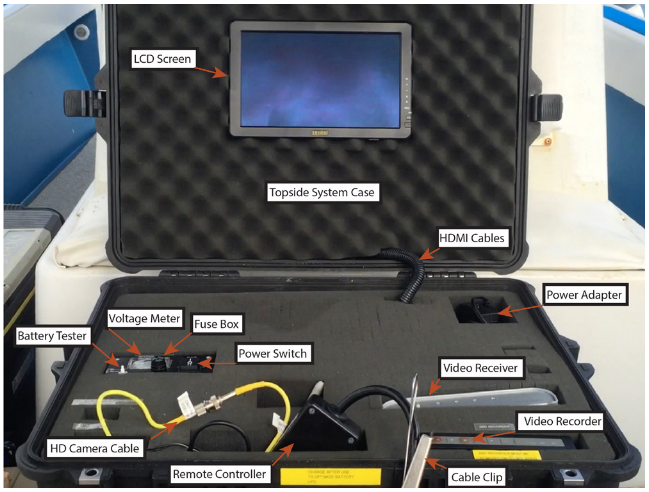

Figure 6. The Seaviewer camera topside console, contains a TV monitor, transformer, video recorder, video receiver, camera remote controller, HDMI adapters and 12V dry battery. Photo: NOAA/NCCOS

The standard setup for the live underwater camera uses a durable braided hand line as the tether, a fiber optic umbilical cable, a dive weight (2-3 kg), and a small plastic fin to position the camera view forward (Figure 7). Other accessories can be attached to the drop camera to enhance the video quality and analysis. For example, dive lights can provide better visibility in deeper or more turbid sites. Mounting a pair of laser beams to the camera can help measure features, estimate scale of geoforms, and help determine substrate types. The dive weight is very important for any drop camera setup. Increasing the weight allows the underwater camera to descend more rapidly and decreases the layback of the tether and umbilical cable from the boat. The weight can also be used to help classify the substrate component of the benthic habitat. As the weight makes contact with the bottom, the analyst can estimate the composition of unconsolidated sediments by observing the settling rate of suspended particles. Coarse sands resettle quickly while fine sands and silts remain suspended in the water column for longer periods of time.

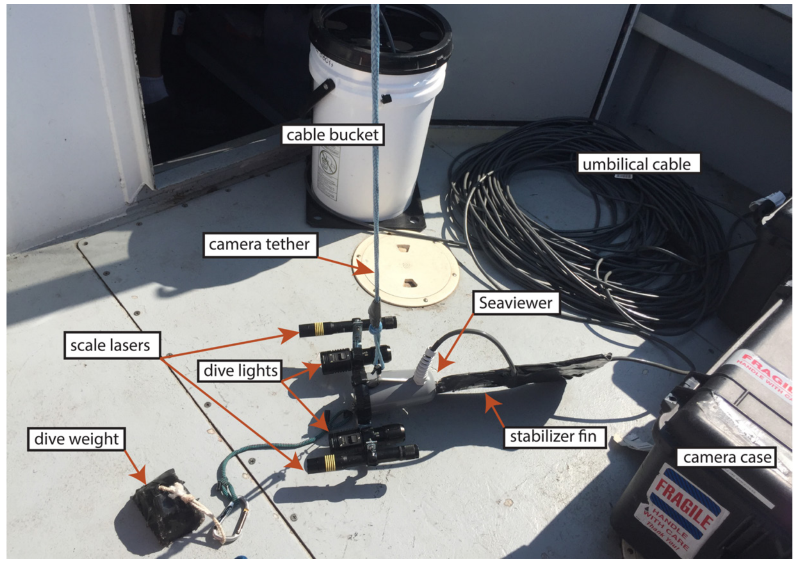

Figure 7. The Seaviewer 6000 HD camera with attached dive lights, laser scale, dive weight, stabilization fin, tether and umbilical cable. Photo: NOAA/NCCOS

The drop camera field survey team typically consists of three people. A boat captain handles the vessel operations and navigates to target sites. A topside console/GPS operator records, annotates, and manages the data collected in the field. A camera operator records a site placard, deploys and retrieves the camera, and manipulates the camera orientation while collecting data.

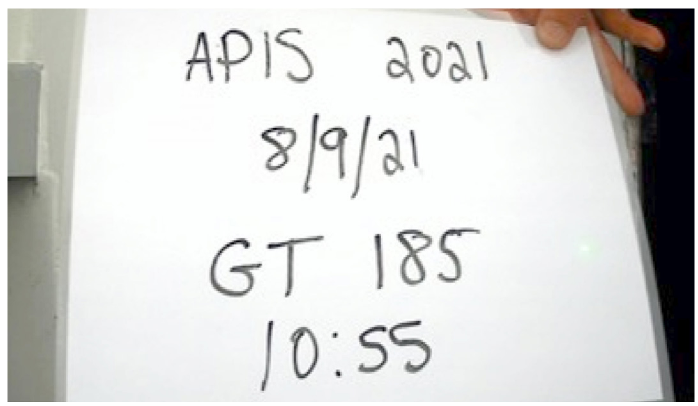

Figure 8. A placard with the site information of a ground-truthing (GT) site. This information must be recorded prior to deployment to identify the site and time of underwater videos. Photo: NOAA/NCCOS

As the team approaches a site, both the topside console/GPS and camera operators begin to prepare the camera for deployment by writing down the site information (type, number, time, and date) on a placard. It is essential to record a short video of the placard with the site information for future reference (Figure 8). Before a drop, the camera operator makes sure that the umbilical cord and tether are prepared for deployment and any supplemental equipment such as camera lights and lasers are turned on and calibrated.

Figure 9. The console/GPS operator logs spatial coordinates on the handheld GPS while the camera operator deploys the camera using the boat davit at one of the sample sites. Photo: NOAA/NCCOS

Once on-site, the captain instructs the camera operator when it is safe to drop the camera, and the camera is deployed off the windward side of the boat. By deploying the drop camera upwind, the boat drifts away from the camera and decreases the chances of the umbilical going under the boat or getting entangled in the propeller. When the lakebed comes into view, the topside console/GPS operator starts recording camera footage and logging spatial coordinates on a handheld GPS (Trimble Geo7X 6000) simultaneously, as well as direct the camera operator to use the umbilical and tether to adjust the camera altitude and view angle (Figure 9).

Figure 10. The Seaviewer camera is in a downward position (left) and the camera downward view at 1m from the lakebed with a footprint ~ 0.5m² (right). Photo: NOAA/NCCOS

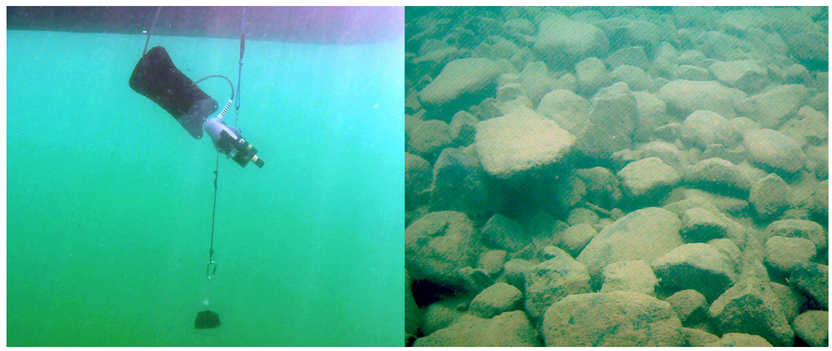

Figure 11. The Seaviewer camera is in a forward/oblique position (left) and the camera forward/oblique view with a larger footprint (right). Photo: NOAA/NCCOS

Some camera movement and positioning can be controlled by pulling on the umbilical and tether at different rates. Maintaining the camera 1 meter off the lakebed surface is ideal for characterizing common lakebed features, substrate classes and biological coverage. In addition, adjusting the camera angle from pointing downward with a limited view with a footprint ~ 0.5m² (Figure 10) to pointing forward (oblique view) can offer additional perspective of 3-dimensional features and cover a larger (0.5m² to >10m²) footprint with the camera (Figure 11).

Video duration will be dependent on the MMU used for mapping, camera drift, and visibility, but typically is between 30 seconds to 2 minutes. The duration should be sufficient to interpret bottom geoforms, substrate types and biological cover within a MMU. While the drop camera is filming the lake bottom and displaying the video to the surface console monitor, the topside console/GPS operator can identify the geoform, substrate, and biogenic components of the habitat using the CMECS classification system, and also provide notes which can serve as metadata and flag important sites. These observations and interpretations can be written down on a paper datasheet, or entered into higher-end GPS units while it is recording the position of each site. NCCOS has used a custom-made CMECS data library within Trimble Geo7X 6000 GPS units to record both annotation and trackpoints at each site. Appendix A identifies hard copy datasheets used to collect this metadata. Once sufficient video is collected at a site, video recording and GPS logging is stopped, and the camera is retrieved. Camera drift (direction and distance) from the boat should be estimated and factored into the final drop camera trackpoint shapefile using GIS software by calculating a centroid from the string of trackpoints. NCCOS is currently experimenting with an ultra-short baseline acoustic positioning system (USBL) receiver that is lowered into the water with the drop camera and can relay a more precise location of the camera without the drift factor. After the surface console/GPS operator has finished logging the data from each site and the camera operator has recovered and secured the drop camera, the captain can then transit to the next site.

A video transect between two or more sites is an efficient alternative to discrete camera deployments at multiple sites when sites are close to each other. Efficiency will depend on the proximity of adjacent sites and boat drift. By strategically placing transect lines across bottom type gradients or multiple adjacent bottom types ground-truthing data can be collected very efficiently. ROVs and AUVs with USBL positioning are also very effective at collecting in-situ information along transects.

At the end of each day, it is recommended that the collected data (videos, field maps, notes, and GPS points) be transferred to two mirrored external hard drives for backup. ViceVersa or other data management software can be used to safely transfer and update the data collection. For the Trimble GPS data, Pathfinder Office (software version 5.81) and Windows Mobile Device Center can download and process the daily GPS data.

6.2.3 Standard Operating Procedures for Non-live Underwater Video Cameras

Small and mobile HD underwater cameras such as the GoPro HD cameras are good examples of non-live video cameras. Mounting accessories, spare housings, and lithium batteries are cheaper than replacement parts for a live video system. Multiple cameras can be mounted and synchronized to a variety of platforms to provide different angles. The camera operator can control the recording and deployment without the need of the GPS/topside console operator. Working with non-live cameras is a good option for smaller vessels for quick and easy field work. However, a major disadvantage of the non-live cameras is that the team cannot watch the video in real-time and make adjustments to the drop camera for better views of features or ensure views are collected across a range of scales to help with interpretations. In addition, real-time videos allow the camera operator to evade overhanging structures, crevices in the rock, or unforeseen debris on the lakebed.

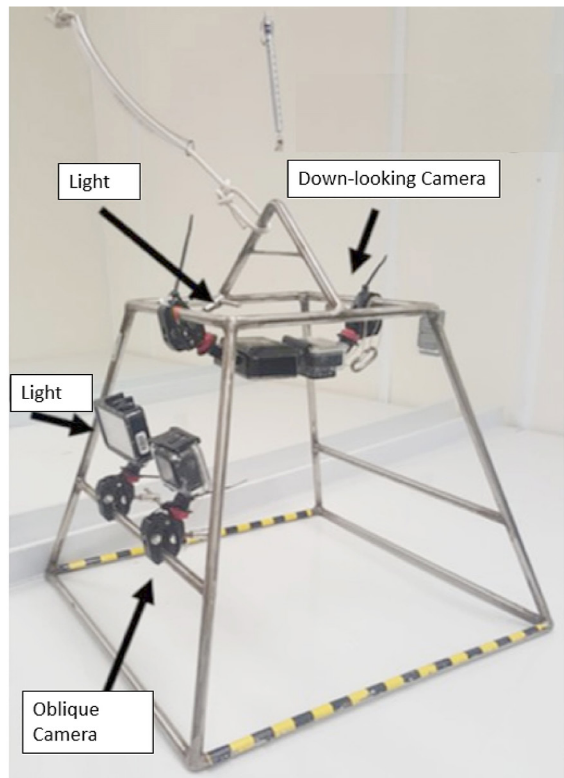

Figure 12. A drop camera frame (60x60x60 cm), with two GoPro cameras and lights, Wick et al., 2020.

There are many configurations for mounting non-live video cameras. A useful strategy for using non-live cameras is to deploy at least two cameras mounted on a frame with different views of the bottom (Battista et al., 2019; Trebitz et al., 2019; Wick et al., 2020). One camera faces downward to provide a view of the lakebed directly at the drop site, while the other camera points at an oblique angle to capture a wider view of the surrounding habitat. Combined, they offer different perspectives of lakebed features, which can aid in estimating the size and shape of bottom features. Frames can be manufactured specifically for camera surveys (e.g. Wick et al., 2020; Figure 12). Small non-live cameras can also be mounted to the frames of other sampling instruments such as the Van Veen grab sampler (Batista et al., 2019) or a CTD probe. NCCOS has also mounted the GoPro to a frame designed for the Seaviewer system as a backup camera in case the live feed gets disconnected (Figure 13).

Figure 13. An NCCOS scientist holding a Seaviewer (live-video camera) with a GoPro Hero4 mounted to the top. Photo: NOAA/NCCOS

NCCOS has successfully used GoPro Hero 4s mounted on a small frame for GT/AA fieldwork, that record HD video (1080 x 1920 pixels at 60 frames/second) directly to a 64 GB internal memory card. A crew of two are all that are needed; one to drive the boat and one to operate the GoPro cameras, and accessory equipment (e.g. GPS). Additional accessories such as a pair of lasers set apart for scale and dive lights have also been mounted to the frame. Battery life on GoPros may only last for an hour of normal use or even less as the deeper and colder the water the faster the battery will drain. Having spare batteries charged up and ready to go is essential. Additional battery pack mounts can be purchased for the GoPro Hero 4 to double battery life. There are also wireless GoPro remote controls available for easy on and off recording. It is essential to update the firmware on the GoPro to avoid having the camera shut down during a dive or to lose track of time. Keeping the cameras in the shade will prolong their battery life and potentially avoid shut offs from overheating as well. To prevent the lens from fogging up while underwater, clean the interior housing glass with a microfiber cloth, and insert anti-fog paper into the housing.

The procedures for navigating and approaching a GT/AA site are similar to the live video drop camera. When arriving at a site, the camera operator should record the site placard (Figure 8) and leave the camera on as it is dropped in the water. The GPS operator should simultaneously logs the trackpoints on the handheld GPS as the camera enters the water. Once the frame hits the bottom, the camera operator should immediately begin to retrieve the camera. As the frame is brought on board, video and GPS trackpoint recording should be stopped simultaneously. Once safely stowed, the team can proceed to the following site. Contrary to the Seaviewer drop camera method, the GoPro should not stay at depth for long (~10 sec maximum) and should not be trolled behind a boat to avoid potential snagging on lakebed structures. At the end of each day, the collected data (videos and GPS) should be transferred to hard drives for backup and to be processed in the office.

6.2.4 Standard Operating Procedures for Collecting a Sediment Sample

Sediment grab sampling is one of the main ground-truthing methods that validate surficial substrate properties, and can significantly enhance the geological and benthic habitat mapping of the lakebed (Brown et al., 2019). Sediment samples can provide detailed information on the composition of surficial sediments and with additional processing can measure chemical and biological processes. Collection of sediment samples is accomplished by way of various mechanical tools, such as Ekman, Ponar, Peterson, and Van Veen samplers (USGS, 2005). This report will focus on modified Van Veen grab sampler (also known as Young grab), as a common sediment grab sampler used by NOAA and the EPA (NOAA, 2010 and U.S. EPA, 2009).

The frame of the sampler is usually made of steel, which adds weight and stability, and ensures the bucket grabs a sufficient and leveled sample (NOAA, 2010; Dauer & Lane, 2005). NCCOS has used a modified Van Veen grab sampler (250 cm², 3.14 L capacity) on a stainless steel frame with 2 GoPro cameras, a Seaviewer camera, dive lights, a pair of lasers and extra dive weights mounted to the frame (Figure 14). This combination of equipment enabled NCCOS to collect live streaming and recorded videos of the seafloor while collecting sediment samples. The advantage of this technique is that it combines two ground-truthing methods, sediment sampling and collecting video data, in one operation, reducing the cost and needed capacity (Battista et al., 2019).

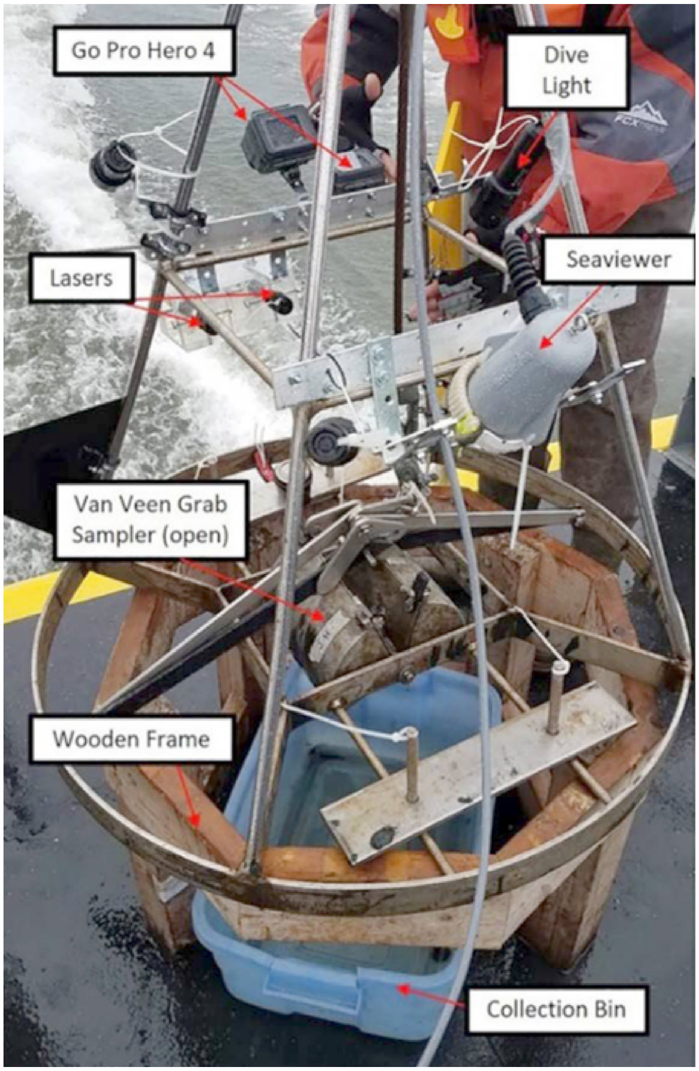

Figure 14. Modified Van Veen sediment grab sampler used by NCCOS with Seaviewer camera, GoPro cameras, lasers, and dive lights mounted on it. Photo: NOAA/NCCOS

The total weight of the sampler used by NCCOS was approximately 200 pounds and was deployed using a 1,700 pound working-load deck winch. Due to their size and weight, sediment samplers typically require a larger vessel than visual ground-truthing by a drop camera. The vessel size should be adequate to provide sufficient deck space to secure the equipment and the vessel should possess a heavy lifting davit with a winch to deploy and recover the instrument.

A team of 3-4 people (depending on the sediment sampler's size) is needed for operation. The boat captain navigates to the target sites and operates the winch. The GPS operator is responsible for site selection, logging the GPS positions, and conducting the data management of the samples. A third person, and possibly assisted by a fourth person, coordinates deck operations and makes sure all of the systems are working, and gets the sampler cleaned and ready in the open position for the drop. The GPS operator must log the GPS positions of the grab sampler site. If the grab sampler has mounted video cameras, the deck operators should create a placard with the site information and take a short reference video from each camera as the team approaches the site. At the site, the captain informs the GPS operator when it is safe to drop the frame and begin logging GPS and video camera data. Once the frame hits the bottom, the camera operator should allow the frame to settle into the substrate for about 10 seconds. The deck operators can then retrieve the sampler and stop camera recording and GPS logging simultaneously. Contrary to the live video drop camera method, the frame should not stay at depth or on the bottom for longer than 30 seconds to avoid dragging across sensitive lakebed habitats or entanglement.

Upon recovery of the sediment grab sampler onboard, the GPS operator will end logging the GPS and any of the video systems, while the other researchers will finish the sampling process. First the top lid of the Van Veen or PONAR grabber is opened to check if the sample was successful. If the sample was washed out, partially filled, or had debris caught in the sampler jaws, the sample must be discarded and the grab sampler has to be redeployed at the site. If the sample was successful, then the researchers will take a photo of sediment with the placard before it is dumped into the container (see Figure 15 for acceptable and unacceptable samples; U.S. EPA, 2001). After taking the photo (Figure 16), the grab sampler jaws are opened, the sample is released into the sediment collection bin (Figure 17), and homogenized using a power drill with an auger attachment. Then the deck operators will scoop out a ~250g subsample of the sediment, place it in a labeled sample bag, and then store it in a refrigerator for phi (ϕ) and grain size analysis in the laboratory. After the sample has been collected, one of the deck operators will spray down the entire sampler with water to remove any sediments from the previous grab.

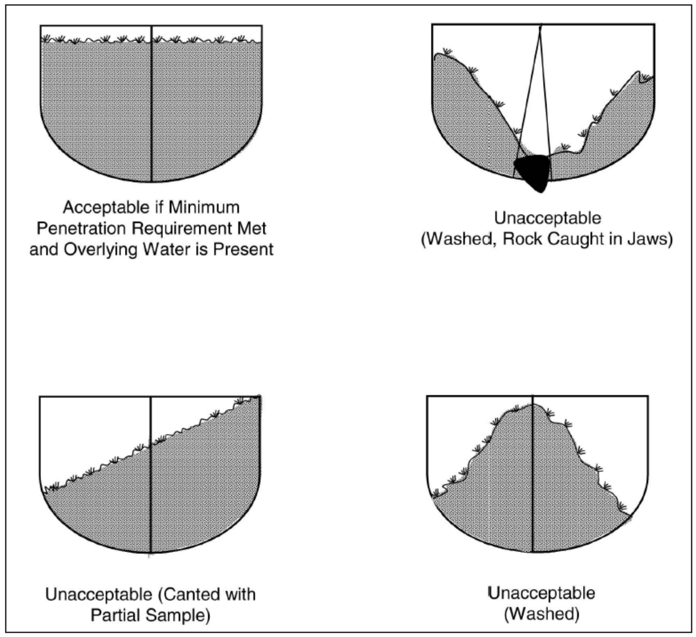

Figure 15. Illustrations show the acceptable and unacceptable sediment grab samples (U.S. EPA, 2001).

Figure 16. Surface photo of a sediment grab prior to releasing the sample into a sediment collection bin for further processing. Photo: NOAA/NCCOS

A rapid field characterization for the sediment sample will be recorded by the GPS operator to describe the sediment texture and composition in the handheld GPS unit or on a paper data sheet Appendix B. The GPS operator will visually characterize the present/absent of different grain size (clay, silt, sand, granule, pebble, or cobble) according to the Wentworth Scale (Table 2; Wentworth, 1922) and benthos (mollusk, shell, anthropogenic, algae, wood, vegetation). Information is also collected on the presence/absence of surface oxidation, stiffness (very soft, soft, stiff, or very stiff), color, stratification (coarse to fine or fine to coarse) and the presence/absence of hydrogen sulfide odor (Appendix B). Particular characteristics of each sample site are noted in the general comments section of the field maps or log book, such as “second try” or “laser battery died”. At the end of each day, the video, photo, and GPS data will be transferred to two mirrored external hard drives for backup and further processing.

Figure 17. CSS, NCCOS scientist opening the modified Van Veen grab sampler to release the sediment sample into the bin below. Photo: NOAA/NCCOS

Table 2. Sediment grain size scale (Wentworth,1922)

Descriptor	Grain Size (mm)	Class Sizes (phi)
Boulder	256 to < 4,096	-8 to < -12
Cobble	64 to < 256	-6 to < -8
Pebble	4 to < 64	-1 to < -6
Granule	2 to < 4	-1 to < -2
Gravel	2 to < 4,096	-1 to < -1
Fine sediment	<2	> -1
Sand	0.0625 to < 2	4 to < -1
Mud	< 0.0625	> 4
Silt	0.004 to < 0.0625	> 4 to 8
Clay	< 0.004	> 8

6.3 DATA POST-PROCESSING

After observations and measurements are collected in the field they need to be processed to standardize data formats and ensure data are analysis-ready. This phase also typically includes quality assurance and quality control checks to ensure data are acceptable to use in analysis.

6.3.1 Post-processing GPS data

GPS data collected in the field need to be post-processed to provide improved and corrected positioning for the boat (GPS antenna) with sub-meter accuracy, if possible. To post-process GNSS data collected with a Trimble Geo7X 6000 handheld GPS receiver, the GPS Pathfinder Office software version 5.10 or later (with the latest updates) is required. Post-processing uses the Differential Global Navigation Satellite System to correct errors in the collected GPS data using the nearest Continuously Operating Reference Station (CORS) or GPS base station. Data collected at the base stations are used to determine GNSS measurement errors and compute corrections. Differential files used for this process are usually not available from the CORS site until ~24 hours after data collection, so processing must wait at least one day after the last day of the field mission.

Two shapefiles are exported when GPS data are post-processed. The first shapefile provides the average location (or centroid) from the tracking points at each GT/AA site and the associated in-situ observations. The second shapefile provides all of the individual GPS tracking points (one position every second) at each GT/AA collection site. A GIS analyst conducts quality control of the data to detect entry mistakes and reviews the field comments for any discrepancies.

6.3.2 Post-processing video/image data

Videos collected from the field should be standardized to simplify data management, remove extraneous information, save storage space and support online video sharing. Standardization includes clipping, transforming file formats, and renaming files using the dive number on the reference placard. Additionally, they need to be reviewed for errors, duplication, and missing data before interpreting and classifying them. Video processing can be performed using open-source software such as VLC media player. NCCOS has used DaVinci Resolve software to effectively edit the videos (clipping, merging, enhancement, etc.), while HandBrake software was used for video batch conversion from MOV files to MP4 files and reformatting the videos to the H.2644 codec. A post-processing tracking sheet can help track processing steps, versions, file locations, metadata for each video. An example of the attributes needed for the tracking sheet are shown in Appendix C.

For the live feed drop camera systems (e.g., Seaviewer), a single video clip should represent each GT/AA site. To ensure consistency across sites it is advisable to select a clip based on a consistent duration which on average represents the MMU. For a $100m^2$ MMU, NCCOS has found a 30 second clip of the video is ideal and typically represents a 5 to 20 m long lakebed transect, depending on camera drift speed. Typically, the selected video clip starts when the lakebed first comes into view, but occasionally is delayed if the first few seconds of the lakebed are dramatically different from the remainder of the video. If necessary, the full site video will be divided into two or more separate non-overlapping clips to represent two or more dissimilar lakebed habitats. The geographic position of each video clip is commonly determined by the average position of the GPS unit during the duration of the video clip. If the bearing and distance of the camera relative to the boat is measured in the field, these data can be used to improve the accuracy of clip location.

If the field team uses multiple non-live GoPro cameras mounted to a frame (oblique view and downward view), the analyst will use the recorded video from the oblique camera as the primary video platform for the interpretation. It provides a larger field of view than the downward-facing camera, which can also be used as a backup to assist in the analysis. The position of the videos is determined by the average boat position during the few seconds (~10 seconds) when the frame at the bottom. The spatial footprint of the video clip, in this case, represents a much smaller area ($1\text{-}2m^2$) than that from the Seaviewer camera.

7.0 INTERPRETATION OF GT AND AA DATA

Before video or sediment sample data are interpreted, it is important to ensure measurements will be sufficient to classify lakebed features, and if two or more analysts are interpreting data, they have to agree on how to measure features. A pilot study of collected videos or sediment collections is valuable in this regard. The study will also confirm if the new data will fit within CMECS, indicate the need for schema modifications and identify attributes which are challenging to measure.

NCCOS has developed a measurement schema to interpret videos across multiple studies in the Great Lakes (Appendix D), so that they can be classified according to CMECS. This schema uses percent cover measurements of different substrate and biological cover types, as well as observations of substrate characteristics to define and differentiate the lakebed.

A habitat mapping analyst with basic knowledge of the geology and biology of the area should interpret each video to characterize substrate, biological cover and other descriptive features of the lakebed. During interpretation, analysts estimate the percent coverage of surficial substrate types (i.e. boulders, cobbles, pebbles, hash, coarse sand, fine sand, hard clay, and bedrock), biological cover types (mussels, fleshy macroalgae, turf algae, macrophytes) and man-made objects seen in the video. Substrate and biological cover types need to be estimated independently because of the need to separate the underlying substrate from overlaid benthic colonization. In areas where hard clay is found, NCCOS has found it is helpful to divide clay outcrops and clay hardpan based on heights above the surface of greater than or less than 10 cm, respectively. These two clay feature types are notably different in both MBES and sidescan sonar datasets. Additionally, the presence of sediment waves, holes, fractures, burrows, fish and human disturbance should be recorded to improve the detail of CMECS classification (Appendix D).

8.0 CLASSIFICATION OF GT AND AA DATA USING CMECS

Lakebed measurements can be classified using CMECS through a set of decision rules to differentiate quantitative and qualitative measurements into a series of unique bottom types. GT and AA data described above can provide information for geoform, substrate, and biotic CMECS components, but not the water column component. Different tools than those identified in this report are needed to collect water column data such as conductivity, temperature and depth probes (CTD's) or Nansen bottles.

Within each component, the lakebed can be classified into distinct units based on major geomorphic, structural, material, or biological characteristics. Geoform classes require a broader spatial perspective and are identified for the lakebed features using in-field observations, geographic position, and lakebed characteristics from adjacent features. For geologic substrate component classes CMECS uses the standard sediment grain size definitions provided by Wentworth (1922; Table 2) and grain size mixtures used by Folk (1954). The biotic component of CMECS uses a hierarchical classification to identify the composition of the swimming, suspended, sessile, and interstitial flora and fauna. Analysts should also try to identify any species of aquatic life observed from the videos (if the video quality allows), and note the presence of wooden debris, tree falls, or anthropogenic debris at the sample site (Figure 18). CMECS is also used to classify biotope, a

*Figure 18. A burbot (*Lota lota*) observed peering out from the roots of a large fallen tree at the bottom of Lake Superior in the Apostle Islands National Lakeshore. Photo: Hans VanSumeren*

combination of abiotic (as substrate) and biotic components. Biotopes are defined as consistently observed combinations of abiotic features and associated species or the biotic community. It is a useful ecological tool to describe different habitats and the interaction between its abiotic and biotic elements. Relative abundance of the biotopes should also be included in the descriptions as appropriate. For more detailed information on the classification of these components see FGDC (2012).

9.0 ACCURACY ASSESSMENT

Accuracy assessment is an essential process to develop high-quality and reliable habitat maps. In this process, classified maps are evaluated to identify map errors. Such errors (i.e., data acquisition, processing, analysis, and modeling) accumulate through the multiple steps of the mapping process, and without measuring these errors, the accuracy of the produced maps will remain as an untested hypothesis (Strahler et al., 2006 and Mitchell et al., 2018). Consequently, measuring the agreement between the assigned classes in the predicted classified map and the independent accuracy assessment observations is necessary. To assess map errors, the assigned classes for the AA sites are compared with the corresponding values from the predicted map using an error matrix, which is also called a confusion matrix or a contingency table (Table 3). This matrix is commonly organized where the reference data from the AA sites are located across columns, and classified map data are located across rows (Congalton and Green, 2008). In this orientation, the diagonal entries in the confusion matrix (e.g., Table 3) represent the correct classifications, and the off-diagonal values the misclassifications.

Map accuracy should be quantified for all map classes. Accuracy is measured using metrics to designate overall map accuracy, user's accuracy, and producer's accuracy. The producer's and user's accuracies are calculated to characterize the classification accuracy of individual map categories. The producer's accuracy (omission/exclusion error) is a measure of how well the cartographer classified a particular habitat. The user's accuracy (commission/inclusion error) is a measure of how often map polygons of a certain habitat type were classified correctly. Each diagonal element is divided by the column total to yield a producer's accuracy and by the row, total to yield a user's accuracy. The overall accuracy is calculated as the sum of the major diagonal (i.e., correctly classified sample units) divided by the total number of AA samples (Table 3).

Table 3. Error matrix for habitat map from Menza et al. 2019, AA sites are listed as columns and corresponding mapped habitats as rows.

Accuracy Assessment (i)

Classified Map (j)

	Outcrops	Cobbly Mussel Bed	Fine Sed	Fine Sed, Mussel Bed	Fine Sed, SurfWave	n_{-j}	User's Accuracy (%)
Outcrops	**17**	2	0	0	0	19	89%
Cobbly Mussel Bed	1	**34**	1	0	1	37	92%
Fine Sed	0	0	**27**	0	0	27	100%
Fine Sed, Mussel Bed	0	0	0	**8**	0	8	100%
Fine Sed, SurfWave	0	0	1	0	**6**	7	86%
n_{i-}	18	36	29	8	7	**98**	
Producer's Accuracy (%)	94%	94%	93%	100%	86%	**Overall Accuracy (17+34+27+8+6)/98 =**	**93.9%**

When stratified random sampling is used to collect AA data, the proportion of area within each map class should be used to correct bias introduced from different levels of sampling density. If not, rare map categories will be sampled at a greater density than widespread map categories (Costa et al., 2009) and corresponding map errors from rare map classes will have an outsized impact on map accuracy statistics (Walker and Foster, 2009). If possible, a proportional-to-area stratified random sampling design can keep sampling densities constant among map classes. Another approach is to use the map marginal proportions (i.e., the proportional areas of map categories relative to the total map area) to produce more precise overall producer's and user's accuracies (Card 1982).

An additional measure of map error which standardizes across maps with different numbers of map classes is the Tau coefficient. Tau is a measure of the improvement of the classification scheme over a random assignment of polygons to categories. It adjusts the overall accuracies based on the number of map categories, allowing for statistical comparison of error matrices of different sizes and provides an intuitive and relatively precise quantitative measure of classification accuracy (Ma and Redmond, 1995). NCCOS has developed an excel spreadsheet and R scripts to automate calculations for map accuracy metrics.

10.0 CONCLUSION

The best practices presented in this report provide vetted field methods, instructions on handling the equipment, and information on the sampling design required to collect ground-truthing data and assess the accuracy of lakebed maps in the Great Lakes. The report uses a relatively shallow (less than 60m) nearshore study area offshore of the Bayfield Peninsula as a case study for data collection and this case study should support the majority of mapping efforts in most of the Great Lakes. Deeper study areas may warrant different collection methods and equipment, but the overall strategies to consider predetermined map specifications and use steps to develop analysis-ready data for map-making will be applicable.

NCCOS plans to work with project partners to analyze the GT and AA data collected in the case study area to generate lakebed maps of geoforms, substrates or biological cover types. The specific approach to extrapolate interpretations from GT sites to the larger domain is under investigation, but will most likely apply spatial predictive modeling. All data collected and generated from this mapping case study, including underwater videos, GT and AA interpretations, and classified lakebed maps is planned to be distributed to project partners, resource managers and the public. NCCOS plans to use a custom-built web application similar to the Wisconsin-Lake Michigan BIOmapper to display all data together.

For more information on the project, track task progress and access data, please visit:
https://coastalscience.noaa.gov/project/collaborative-lakebed-mapping-off-apostle-islands-to-support-great-lakes-restoration/

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Appendix

Appendix A. Ground-truthing and Accuracy Assessment Field Form for Data Collection

Date:

Site ID:	Site ID:	Site ID:	Site ID:
Depth:	Depth:	Depth:	Depth:
Time:	Time:	Time:	Time:
Drift Direction:	Drift Direction:	Drift Direction:	Drift Direction:
Drift Distance:	Drift Distance:	Drift Distance:	Drift Distance:
Substrate	**Substrate**	**Substrate**	**Substrate**
☐ Bedrock	☐ Bedrock	☐ Bedrock	☐ Bedrock
☐ Outcrop	☐ Outcrop	☐ Outcrop	☐ Outcrop
☐ Boulders/Cobbles	☐ Boulders/Cobbles	☐ Boulders/Cobbles	☐ Boulders/Cobbles
☐ Pebbles	☐ Pebbles	☐ Pebbles	☐ Pebbles
☐ Fine Sediment	☐ Fine Sediment	☐ Fine Sediment	☐ Fine Sediment
☐ Unknown	☐ Unknown	☐ Unknown	☐ Unknown
Biological	**Biological**	**Biological**	**Biological**
☐ Mussels	☐ Mussels	☐ Mussels	☐ Mussels
☐ Algae	☐ Algae	☐ Algae	☐ Algae
☐ Fish	☐ Fish	☐ Fish	☐ Fish
Modifier	**Modifier**	**Modifier**	**Modifier**
☐ Man-Made	☐ Man-Made	☐ Man-Made	☐ Man-Made
☐ Disturbance	☐ Disturbance	☐ Disturbance	☐ Disturbance
☐ Transition	☐ Transition	☐ Transition	☐ Transition
Notes:	Notes:	Notes:	Notes:

Appendix B. Sediment Sample Characteristic Form

Field Team:	**Recorder:**

Site Code	**Date** (mm/dd/yyyy)	**Time** (local)	**Local Depth (ft)**

STATION LOCATION		GPS:	
Station Coordinates		Description	
Latitude:			
Longitude:			

Grab # 1	**SEDIMENT DESCRIPTION (Check)**					Depth:		Photo ID:			
Grain Size (Circle Dominance)				Benthos				Color		Stiffness	
	Present	Absent	Comments		Present	Absent	Comments	Black		Very Soft	
Clay				Wood				Brown		Soft	
Silt				Shell				Gray		Stiff	
Sand				Molluscs				Green		Very Stiff	
Granule				Live Veg				Rust		Stratification	
Pebble				Algae				Other		Fine to course	
Cobble				Anthro						Course to fine	
				Other						None	
Comments:				Comments:				Oxidized		H2 Sulphide	
								Yes	No	Yes	No

Grab # 2	**SEDIMENT DESCRIPTION (Check)**					Depth:		Photo ID:			
Grain Size (Circle Dominance)				Benthos				Color		Stiffness	
	Present	Absent	Comments		Present	Absent	Comments	Black		Very Soft	
Clay				Wood				Brown		Soft	
Silt				Shell				Gray		Stiff	
Sand				Molluscs				Green		Very Stiff	
Granule				Live Veg				Rust		Stratification	
Pebble				Algae				Other		Fine to course	
Cobble				Anthro						Course to fine	
				Other						None	
Comments:				Comments:				Oxidized		H2 Sulphide	
								Yes	No	Yes	No

Additional Comments: (e.g. photos, sources, weather/seas, access…)

Total # Grabs (site)	

See reverse side for additional grabs

Appendix

Appendix C. Tracking Sheet Attributes

Region	Region where work was conducted (e.g., Bayfield)
Site_No	Number from Site ID (0-9999)
Site_Type	Site interpretation type. Either GT (ground-truth) or AA (accuracy assessment)
Video_Segment	Unique video name derived from site name and video segment after processing (e.g., GT2019_269_beg)
Site_Name	Unique Site Name includes site type, year and site number (e.g., GT2019_269)
Field_ID	A unique identifier for a field sample which is derived from the day and time the sample was collected. (e.g. 2021-23-09-14-52)
Field_Date	Date video was collected in the field (YEAR-MO-DY)
Field_Time	Time on plaque recorded in video (hh:mm:ss)
Vid_Start	Time at which video interpretation begins. Relative to raw video collected in the field (hh:mm:ss)
Vid_End	Time at which video interpretation ends. Relative to raw video collected in the field (hh:mm:ss)
Processor	Person responsible for video processing
Field_Vid	Filename of raw video file collected in the field (e.g., Capture0001.mov)
TrimbleProcessed	Yes/No
VideoClipped	Yes/No
VideoAnnotated	Yes/No
VideoRename	Yes/No
MakeHDmp4	Yes/No
New_Video_Name	Filename of processed video (e.g., AA2019_355.mp4)
HDVideo_location	Location on local drive where high-definition video is stored
MakeSDmp4	Yes/No
SDVideo_location	Location on local drive where standard-definition video is stored
Proc_Notes	Processing notes

Appendix D. Video Interpretation Schema

Attribute	Type	Description
Region	Metadata	Region where work was conducted (e.g., Bayfield)
Site_Name	Metadata	Unique Site Name includes site type, year and site number (e.g., GT2019_269)
Site_No	Metadata	Number from Site ID (0-9999)
Site_Type	Metadata	Site interpretation type. Either GT (ground-truth) or AA (accuracy assessment)
Lat_Site	Metadata	Latitude WGS84 (DD)
Long_Site	Metadata	Longitude WGS84 (DD)
Depth_m	Metadata	Depth in meters from DEM (0-9999)
Depth_ft	Metadata	Depth in feet from DEM (0-9999)
Field_ID	Metadata	A unique identifier for a field sample which is derived from the day and time the sample was collected. (e.g. 2021-23-09-14-52)
Field_Gear	Metadata	Type of equipment used to collect data (e.g., Seaviewer, ROV)
Field_Date	Metadata	Date video was collected in the field (YEAR-MO-DY)
Field_Name	Metadata	Site name on plaque recorded in video. References planned site
Field_Time	Metadata	Time on plaque recorded in video (hh:mm:ss)
Drop_Time	Metadata	Time recorded in field notes for beginning site visit (hh:mm:ss)
Recov_Time	Metadata	Time recorded in field notes for end site visit (hh:mm:ss)
Drift_Dir	Metadata	Bearing in degrees between GPS and estimated camera position (0-360)
Drift_Dist	Metadata	Distance in meters between GPS and estimated camera position in water (0-9999)
Field_Vid	Metadata	Filename of raw video file collected in the field (e.g., Capture0001.mov)
Vid_Start	Metadata	Time at which video interpretation begins. Relative to raw video collected in the field (hh:mm:ss)
Vid_End	Metadata	Time at which video interpretation ends. Relative to raw video collected in the field (hh:mm:ss)
Anno_vid	Metadata	Filename of processed and annotated video referring to lakebed site. (e.g. GT2019_269)
Processor	Metadata	Person responsible for video annotation
Data_flag	Metadata	Data flag. 0=no concern. 1=data should be interpreted with caution. 2=data highly uncertain, as in turbid sites
Bedrock	Substrate Cover	% bottom covered by bedrock, increments of 5% and trace amounts identified as 1%
Boulder	Substrate Cover	% bottom covered by boulders, increments of 5% and trace amounts identified as 1%
Cobble	Substrate Cover	% bottom covered by cobbles, increments of 5% and trace amounts identified as 1%
Pebble	Substrate Cover	% bottom covered by pebbles, increments of 5% and trace amounts identified as 1%
Gravel	Substrate Cover	Boulder+Cobble+Pebble
CrsSand	Substrate Cover	% bottom covered by coarse sand, increments of 5% and trace amounts identified as 1%
SiltSand	Substrate Cover	% bottom covered by silt and fine sand, increments of 5% and trace amounts identified as 1%
FineSed	Substrate Cover	CrsSand + SiltSand
HardClay	Substrate Cover	% bottom covered by hard clay, increments of 5% and trace amounts identified as 1%
Hash	Substrate Cover	% bottom covered by mussel shell hash, increments of 5% and trace amounts identified as 1%

Appendix

Appendix D cont. Video Interpretation Schema

Attribute	Type	Description
WoodDebris	Substrate Cover	%bottom covered by woody debris (e.g. logs, sticks, bark, decomposing wood), increments of 5% and trace amounts identified as 1%
Anthro	Substrate Cover	% bottom covered by anthropogenic objects or material, increments of 5% and trace amounts identified as 1%. Describe object or material in comments.
Unknown	Substrate Cover	% bottom which cannot be defined by other criteria or is unknown, increments of 5% and trace amounts identified as 1%
Sub_Check	Substrate Cover	Sum of all substrate types. Should add to 100%.
Mussels	Biotic Cover	% of bottom substrate layer covered by mussels, increments of 5% and trace amounts identified as 1%
Macroalgae	Biotic Cover	% of bottom substrate layer covered by fleshy macroalgae, increments of 5% and trace amounts identified as 1%
McrAlgLoos	Biotic Cover	% of bottom substrate layer covered by detached, loose or floating macroalgae, increments of 5% and trace amounts identified as 1%
MatAlg	Biotic Cover	% of bottom substrate layer covered by matted or turf macroalgae, increments of 5% and trace amounts identified as 1%
Macrophyte	Biotic Cover	% of bottom substrate layer covered by macrophytes, increments of 5% and trace amounts identified as 1%
BareBed	Biotic Cover	% of total bottom substrate which is bedrock AND not colonized by mussels or macroalgae, increments of 5% and trace amounts identified as 1%
BareGravel	Biotic Cover	% of total bottom substrate which is gravel (boulders, cobbles, pebble) AND not colonized by mussels or macroalgae, increments of 5% and trace amounts identified as 1%
BareSoft	Biotic Cover	% of total bottom substrate which is fine sediment (coarse sand, silt and fine sand and clay) AND not colonized by mussels or macroalgae, increments of 5% and trace amounts identified as 1%
Bio_Check	Biotic Cover	Sum of all biotic cover types. Should add to 100%
Bio_Unk	Modifier	1= presence of unknown biological cover
Druses	Modifier	1= presence of conglomerate mussels
SmBenFish	Modifier	1=small benthic fish observed. Small is FL less than 20 cm
SmPlgFish	Modifier	1=small pelagic fish observed. Small is FL less than 20 cm
LgFish	Modifier	1=large bodied observed. Large is FL of 20 cm or more
Fish_ID	Modifier	Lowest taxonomic ID, if possible
Benthic_Inv	Modifier	1 = presence of benthic invertebrate
Benthic_ID	Modifier	Lowest taxonomic ID, if possible
Clay_Outcr	Modifier	% of bottom substrate which is hard clay AND has a maximum relief greater than or equal to 10 cm relative to the surrounding lakebed, increments of 5% and trace amounts identified as 1%
Flat_Clay	Modifier	% of bottom substrate which is hard clay AND has a maximum relief less than 10 cm relative to the surrounding lakebed, increments of 5% and trace amounts identified as 1%
Rock_Scarp	Modifier	1= A steep or vertical bedrock formation separating surfaces lying at different levels

Appendix D cont. Video Interpretation Schema

Attribute	Type	Description
Rock_Platf	Modifier	1= An area where flat bedrock is exposed at the Earth's surface
Rock_Overh	Modifier	1= A rock mass jutting out from a slope, especially the upper part or edge of an eroded cliff projecting out over the lower, undercut part
Slope	Modifier	Overall slope modifier for observational unit.
Channeled	Modifier	1= Channels or linear furrows observed in the clay substrate
Fractured	Modifier	1= Fractures observed in the bedrock substrate
Pitted	Modifier	1= Pits observed in the bedrock substrate
IntSpace	Modifier	1= Interstitial spaces observed in the substrate. Only spaces a large bodied fish can hide in are noted
Veneer	Modifier	1= A thin sediment veneer obscured an underlying substrate
Ripples	Modifier	1= Ripples in sediment. Ripples are smaller than waves with a wave legth less than 10 cm.
Waves	Modifier	1= Waves in sediment. Waves are larger than ripples with a wave legth greater than 10 cm.
Megaripples	Modifier	1= Waves in sediment. Megaripples are larger than waves with a wave length greater than 1 m.
Tree_Fall	Modifier	1= Trees or woody parts that have sunk to the lakebed
Divets	Modifier	1= Irregular shallow dimples, pock marks or divets observed in unconsolidated sediment
Bioturb	Modifier	1= Holes observed in unconsolidated sediment with likely biological origin
Holes	Modifier	1= Small holes observed in unconsolidated sediment with likely geophysical origin. Small refers to holes less than 10 cm diameter
Fld_Class	Analyst Notes	Notes recorded in the field pertaining to substrate class
Fld_Notes	Analyst Notes	Field notes
Proc_Notes	Analyst Notes	Processing notes
Int_Notes	Analyst Notes	Interpretations Notes
Questions	Analyst Notes	Questions about field work, processing or interpretation

U.S. Department of Commerce

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