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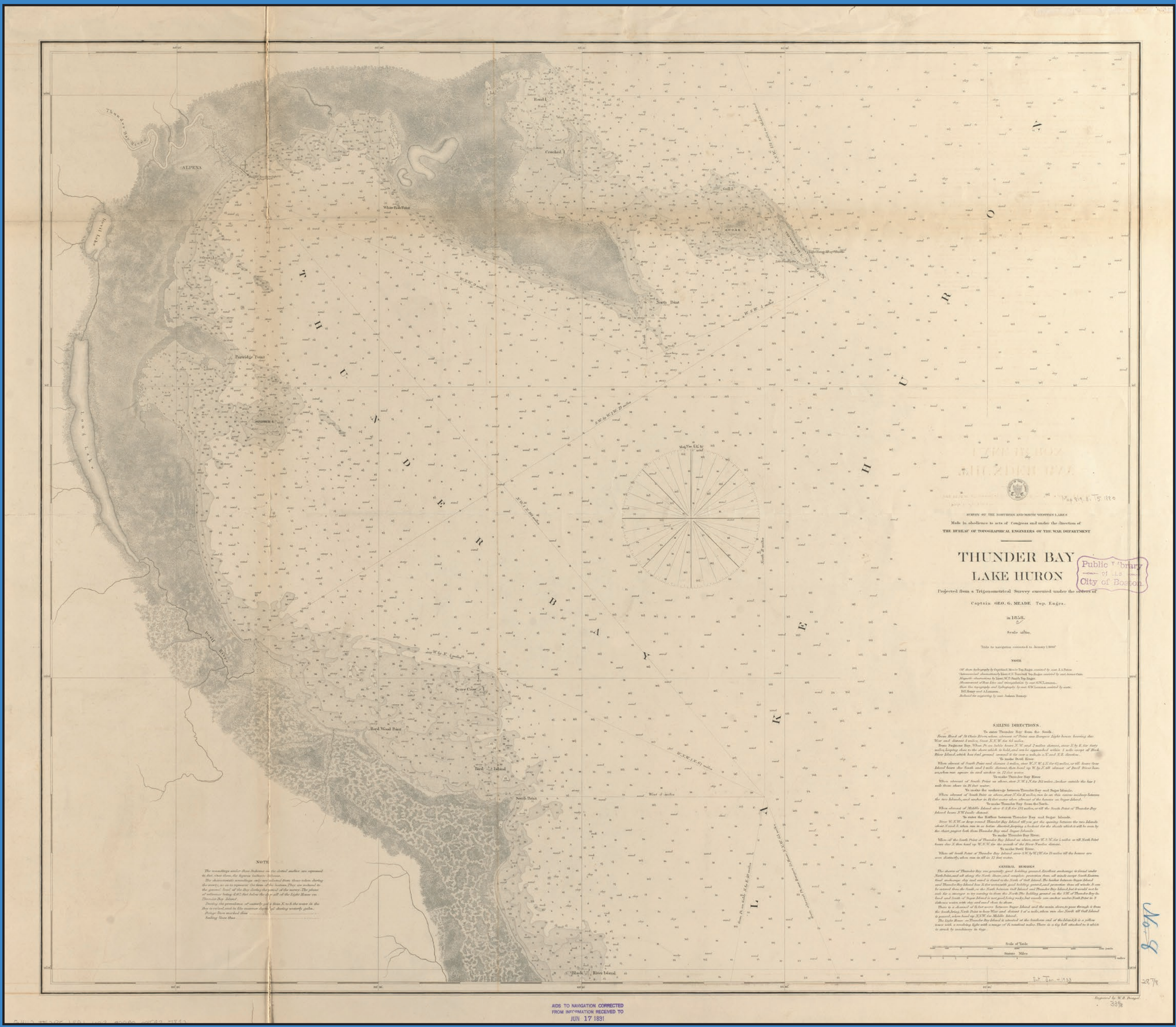
Priorities for Lakebed Mapping in Lake Huron's Thunder Bay National Marine Sanctuary



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The historical chart of Thunder Bay, Lake Huron on the cover was generated by the Bureau of Topographical Engineers of the War Department, available from the Boston Public Library. The back cover photo is the Wooden freighter *Monohansett*, sunk by fire in 1907. Credit: Thunder Bay National Marine Sanctuary research collection.

This report and prioritization effort were part of a larger NCCOS funded project to support mapping in Lake Huron's Thunder Bay National Marine Sanctuary. For more project information, visit: https://coastalscience.noaa.gov/project/lakebed-mapping-in-thunder-bay-national-marine-sanctuary-lake-huron/.

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For more information on this project, please visit:
https://coastalscience.noaa.gov/project/lakebed-mapping-in-thunder-bay-national-marine-sanctuary-lake-huron/

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Priorities for Lakebed Mapping in Lake Huron's Thunder Bay National Marine Sanctuary

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NOAA Technical Memorandum NOS NCCOS 276

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Wilbur L. Ross, Jr. Secretary	Neil Jacobs Administrator, Acting	Nicole Leboeuf Assistant Administrator, Acting

A sanctuary archaeologist explores the wreck of the wooden schooner barge Bay City, lost in Thunder Bay in 1902. Credit: Jennifer Idol, Ocean Artists Society.

Executive Summary

The Thunder Bay National Marine Sanctuary (TBNMS) encompasses 4,300 mi² of Lake Huron off the northeastern shore of Michigan. Much of the lakebed in the sanctuary was mapped prior to 1950 and therefore those data suffer from multiple deficiencies by today's standards. New technologies can efficiently provide more accurate and resolved depths, and also characterize the substrate types of the lakebed. However, the sanctuary is vast and the entire area cannot be mapped in a short timeframe. Smaller areas must be identified to address the most urgent priorities.

To meet this need, NOAA developed a systematic, quantitative approach and online application to gather mapping priorities from researchers and managers spanning a diversity of fields. The application standardized inputs into a GIS framework that enabled us to identify individuals with shared interests based on their area of expertise, the types of mapping data that they need, the rationale used to justify their needs, and the locations that they prioritize for lakebed mapping. The online application was customized for TBNMS using guidance from local experts. Respondents used virtual coins placed on a grid of the study area to express mapping interest and pull-down menus to indicate data needs and rationale for their selections. A total of 24 respondents conveyed their mapping priorities. We explored multiple ways to analyze and summarize their suggestions, including partitioning the responses by the disciplines of the participants, their mapping justifications, and their desired map data.

When pooled together, suggestions from all respondents identified the highest priority areas as being within 20 km of shore and concentrated between Alpena and Rogers City. This area had the highest overall coin totals, a large number of respondents per grid cell, and a similar mix of justifications and desired map data types. Respondents with archaeology expertise allocated most of their coins along a line extending from the mouth of Thunder Bay east-southeastward offshore toward Six Fathom Bank. In contrast, biologists collectively had the most interest in the central parts of the study area within 40 km of Alpena between North Point and Middle Island plus one area near Rogers City. The most commonly used justifications for mapping were to collect information on important habitat, cultural/historical resources, scientific research, and safety/navigation. The most commonly selected map data requested were bathymetry and lakebed surface types. None of the 24 respondents expressed interest in mapping the offshore waters along the Canadian border in the northeastern part of the sanctuary. Similarly, there was very little interest in mapping the deeper water located more than 10 miles off Harrisville except for a small area around Yankee Reef.

The results are expected to help researchers and managers find locations where their interests overlap. This allows them to seek opportunities for collaboration and more effectively invest limited mapping resources. Results here highlight several areas with not only a large number of respondents with overlapping interest in particular areas, but also a variety of justifications. Such areas may have both an ample number of potential collaborators and also multiple rationales for mapping which can appeal to a diversity of partners and funding sources. It will be important to revisit the priorities identified in this report in five to ten years in response to the changing group of experts and interests in the area. Results are linked to broader prioritization initiatives working over longer periods, such as the Great Lakes Bottom Mapping Workgroup and the Integrated Ocean and Coastal Mapping program (https://iocm.noaa.gov/).

Historical chart of Thunder Bay in northwestern Lake Huron. Credit: Bureau of Topographical Engineers of the War Department (Boston Public Library).

1.0 INTRODUCTION

Located in northwestern Lake Huron, the 4,300 square-mile Thunder Bay National Marine Sanctuary (TBNMS, Figure 1.1) protects one of America's best-preserved and historically important collections of shipwrecks. To date, nearly 100 shipwrecks have been discovered within the sanctuary that represent a range of vessel types from an 1844 sidewheel steamer to a modern 500-foot-long freighter. Historical records suggest that an additional 100 or more shipwrecks are believed to await discovery in the unmapped depths of the sanctuary.

To better understand the underwater resources in the sanctuary, TBNMS has partnered with numerous NOAA and outside agencies to survey the lakebed. Since 2001, collaborative mapping activities have occurred with the Institute for Exploration, NOAA's Office of Coast Survey, NOAA's Office of Ocean Exploration and Research, NOAA's Collaborative Center for Unmanned Technologies, US Fish and Wildlife Service, the University of Michigan, the University of Rhode Island, East Carolina University, the University of Texas's Applied Research Lab, the University of Delaware, Michigan Technological University, Northwest Michigan College, Woods Hole Oceanographic Institution, Ocean Exploration Trust, and NOAA's National Centers for Coastal Ocean Science. TBNMS also acquired and outfitted the 50 foot *R/V Storm* in partnership with NOAA's Great Lakes Environmental Research Lab. Surveys and mapping of shipwrecks are a common target, but there are other needs as well.

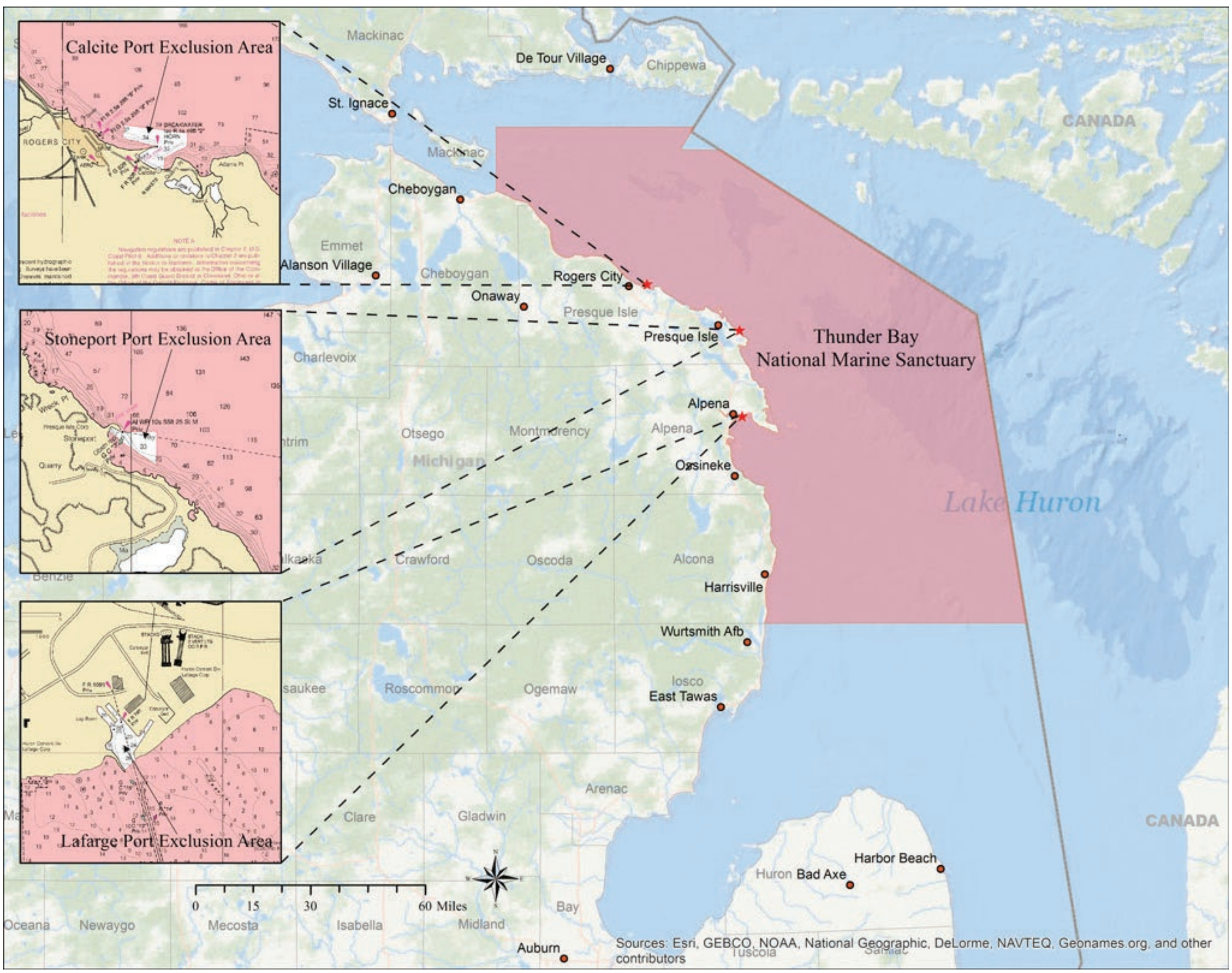


Figure 1.1. Map of Thunder Bay National Marine Sanctuary (red areas). Credit: TBNMS.

Introduction

Other aspects of human use from modern to ancient times include the Lake Huron Overwater Range (Restricted Area 4207 on NOAA Chart 14864 and US4MI67M) for military pilot training exercises, ongoing fishing uses by the Chippewa Ottawa Resource Authority (CORA 2017), and possible Paleo-Indian hunting grounds along a now submerged land bridge (Alpena-Amberley Ridge) that bisected the lake when water levels were lower 7,500 -10,000 years ago (O'Shea and Meadows 2009). Apart from the area's maritime heritage, the sanctuary also encompasses other important features. Geologists are intrigued by the area's glacial past with its mixture of sand, gravel, cobble, and boulder formations. There are a series of karst sinkholes seeping groundwater and supporting an unusual microbial ecosystem (Biddanda et al., 2006; Ruberg et al., 2009). Fisheries biologists are studying features such as Mischley Reef and other important habitats for species such as lake trout and whitefish (Johnson and VanAmburg 1995; Marsden et al., 2016). Invertebrate ecologists are studying the distribution and impacts of invasive benthic mussels (Nalepa et al., 2018; Karatayev et al., 2020). A shared need among these diverse disciplines and the coastal managers that make decisions about lakebed resources is maps of the bottom. Whether searching for shipwrecks, fish habitat, or geological formations, detailed maps of the lakebed including depth and bottom type are an essential tool.

Unfortunately, the existing maps of the lakebed in this area suffer from multiple deficiencies by today's standards. In particular, existing mapping data are coarse, outdated, and typically provide only depth information (Figure 1.2). For approximately 84% of the sanctuary, lakebed mapping data consist of single-beam hydrographic surveys collected before 1950 and at a spacing of 1 to 2 km between soundings. Although high-resolution light detection and ranging (LiDAR) data have recently been conducted within the last few years, these surveys are limited for lakebed mapping. LiDAR surveys typically extend less than 2 km from shore due to limits in optical penetration with increasing depth and are patchy in harbors and river mouths due to turbidity.

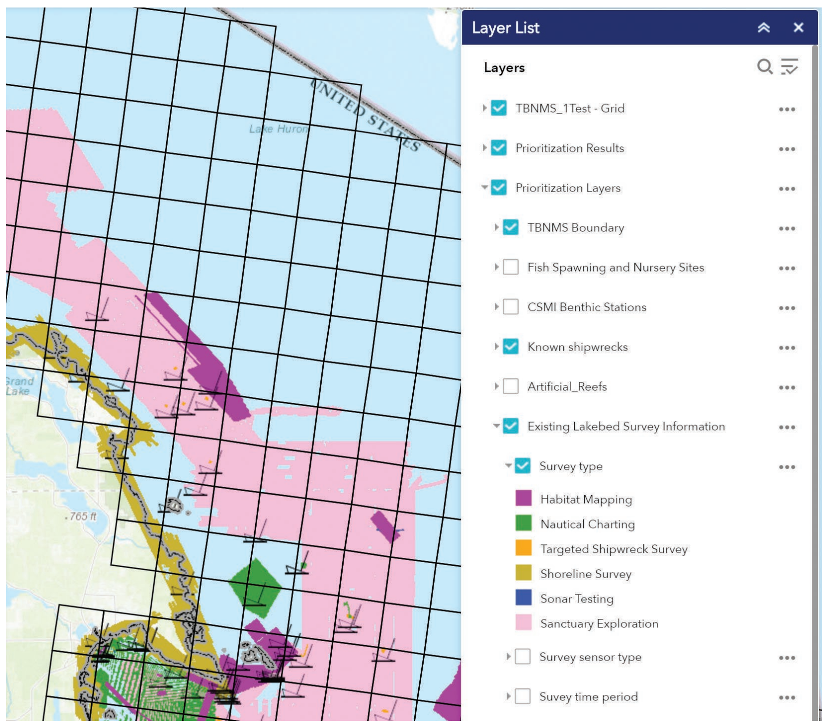


Figure 1.2. Example map showing part of the sanctuary and some of the lakebed mapping data included in the Digital Atlas. Blue areas denote parts of the lakebed with outdated depth information. Colored polygons represent areas of modern lakebed mapping surveys. Symbols denote the position of known wrecks. The nearshore brown area is where LiDAR has been acquired. The grid is the framework that was used by participants when selecting their priorities. Source metadata and additional layers are accessible in the menu at right.

The lack of recent maps for most of the lakebed is due to several factors. The sanctuary alone encompasses 4,300 square-miles which is not only a vast area by itself, but it must also compete with the rest of Lake Huron and the other Great Lakes for mapping resources. The sanctuary is also deep (avg. 195 ft., max. 750 ft.), and much of the lakebed lies below the penetrative capability of airborne and satellite based sensors that can efficiently cover broad areas. This means that mapping must be done from the limited number of survey boats or Autonomous Underwater Vehicles (AUV) in the Great Lakes. These platforms use expensive sensors such as side-scan, interferometric or multibeam sonar, magnetometers, or camera systems depending on the desired map data. For example, a recent NOAA project in the study area required a month of on-water survey time, and mapped 20 mi^2 of lakebed at an acquisition cost of ~\$2,500/mi^2. As a result of these constraints, it is recognized that the entire area cannot be mapped in a short timeframe, and that smaller areas should be prioritized to address the most urgent needs.

Introduction

NOAA's Integrated Ocean and Coastal Mapping (IOCM) Program and the Great Lakes Bottom Mapping Workgroup (BMW) (Esselman et al., 2017) have recognized the need for prioritization and coordination of mapping activities at national and regional scales, respectively. Both the IOCM and BMW focus on sharing mapping data, reducing redundancies, improving efficiencies, and developing common standards. In addition, they seek ways to formally identify, organize, and prioritize mapping activities. We consulted with both groups to understand mapping priorities at the scale of the sanctuary. We developed this project using the concept that coordination of multiple partners where priorities overlap can result in collaborative projects and sharing of resources, but only if everyone's mapping needs are articulated in a structured framework (Kvitek and Bretz 2006; Battista et al., 2017; Kendall et al., 2018a, b).

To better understand the mapping needs within TBNMS, we developed an approach to efficiently and systematically gather quantitative input on mapping priorities from multiple individuals. The system standardized inputs using a geographic information system (GIS) framework that enabled us to identify groups of individuals with shared interests depending on their area of expertise, the types of mapping data that they need, the rationale used to justify their needs, and the locations that they prioritized for lakebed mapping. The objectives of this report were to: 1) describe the process used to gather suggestions for lakebed mapping, 2) analyze the suggestions to locate and characterize hot spots of high priority, and 3) disseminate the results such that others may identify collaborative opportunities in areas where multiple groups have similar mapping priorities.

Propeller of the wooden freighter Monohansett, *sunk by fire in 1907. Credit: NOAA, Thunder Bay National Marine Sanctuary.*

2.0 METHODS

2.1 ONLINE PRIORITIZATION APPLICATION

We designed an on-line application using ESRI's Web AppBuilder to collect suggestions for lakebed mapping in the project area. Participants logged into the application over the internet and used a customized suite of selection tools and pull-down menus to easily convey their recommendations about where to map, what types of map data are needed, when the products are needed, and to justify why the site is a priority for mapping. The application was built upon similar projects in other areas (Kvitek and Bretz 2006; Battista et al., 2017; Kendall et al., 2018a, b) but was customized to incorporate regional data and address local issues along Michigan's northeastern shore in Lake Huron. This customization was accomplished by convening a Technical Advisory Team (TAT) comprised of local scientists and managers from the region that have a stake or expertise in lakebed mapping. The TAT reviewed the scope and scale of the online application, recommended locally relevant datasets to aide in setting priorities, set options for users to select in the menus, and helped identify suitable respondents to participate.

Respondents were chosen to span a diversity of fields including ecology, limnology, fisheries, geology, archaeology, and coastal management (Appendix A). They were from federal, state, university, and other groups. The common thread among all respondents was that they relied heavily on lakebed maps within the sanctuary as a key input to their research or management decisions. Each respondent was provided a link to the application and a unique login ID. Respondents could access the application at their convenience from any computer with an internet connection and were trained how to use the application during webinars conducted in April 2020. During the training, respondents were provided background on the objectives of the project, shown how to access the menus in the system, and taken step-by-step through example scenarios in a demonstration of the application. Once trained, the respondents were given several weeks to enter their suggestions for mapping.

The application was comprised of two main components: a data viewer and the prioritization interface. The data viewer was essentially a Digital Atlas and consisted of GIS datasets in several broad categories: maritime heritage sites (i.e. shipwrecks), administrative boundaries, water quality monitoring locations, important ecological areas, and notable physical features (https://maps.coastalscience.noaa.gov/tbnms_sp/). Most importantly, layers depicting the extent, content, date of acquisition, and resolution of presently available lakebed surveys and mapping products were included. Respondents could view and query this information to understand the limitations of existing information, observe gaps in existing maps, and help identify priority areas for future mapping. The other part of the application consisted of a grid-based framework wherein respondents could input their mapping priorities.

Each respondent was given 200 virtual coins to place anywhere within the project area that they felt was a priority for future mapping. Respondents were told to allocate and prioritize the placement of their coins as they would allocate their limited mapping resources over the next several years. The project area was divided into 5 by 5 km grid cells to standardize the size of the areas designated during coin placement (Figure 2.1). This grid aligned to the national grid developed by the 3DEP Lidar program to standardize spatial indexing in the continental U.S. and is used by the IOCM for ocean and Great Lakes survey planning. There were 470 equal area cells which intersected the sanctuary. The only constraint on coin placement was that no more than 20 coins (10% of their total) could be allocated by a respondent into a single cell. This forced respondents to select at least 10 cells when identifying priority areas for mapping. Therefore, respondents could allocate their limited coins in 10 to 200 cells, or 2% to 42% of the sanctuary (depending on the number of coins allocated per cell).

Methods

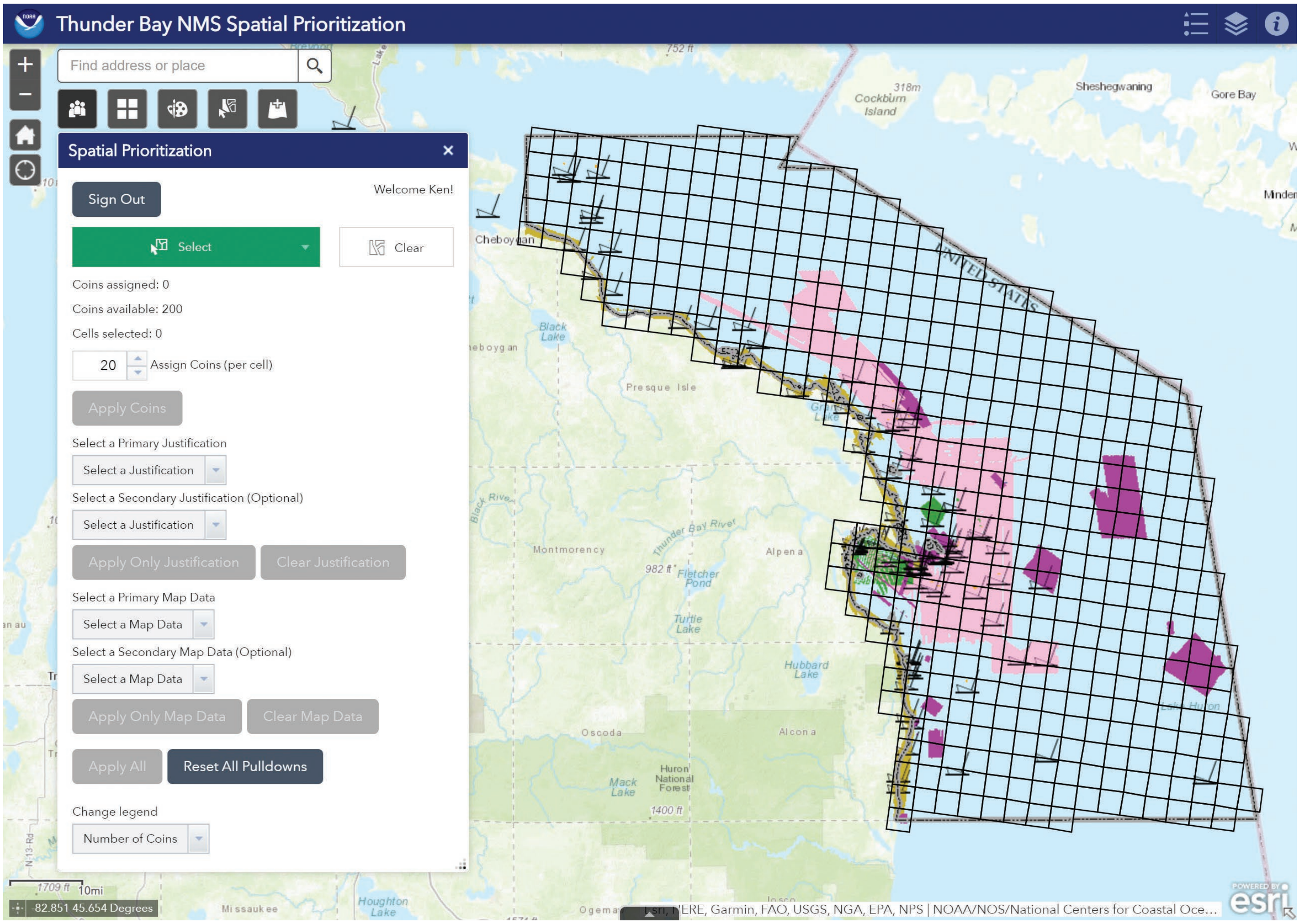


Figure 2.1. A screen shot of the application interface for prioritizing mapping areas. The selection grid overlaid on the study area is on the right.

Respondents were instructed to not only use the coins to convey <u>where</u> mapping is wanted, but also <u>when</u> mapping data are needed. More coins denoted greater urgency based on the following general guidance: 14-20 coins is a high priority needed immediately, 7-13 coins denotes maps are needed in the next 2 to 4 years, and only 1-6 coins indicates a longer term priority needed in 5 to 10 years. In the application, respondents first select the cell (or cells) they wish to prioritize. A numeric box allows respondents to select the number of coins (up to 20) they want to place in that cell. As coins are assigned, the system tracks and displays the number of coins remaining to be allocated.

After assigning coins, respondents then convey <u>what</u> types of Map Data are needed in each selected cell. Simple pull-down menus were preset with several types of Map Data to choose from (Table 2.1) based on input from the TAT. Respondents had to indicate a primary Map Data that was desired and could optionally designate a secondary Map Data. Last, respondents could indicate <u>why</u> they chose each cell, again using pull-down menus preset with a list of Justifications (Table 2.2). Respondents were required to select a primary Justification and could optionally select a secondary rationale as well. Respondents were urged to contact us if none of the Map Data or Justification options were suitable for their needs; however, no one expressed any limitations of the preset menus. The application saved each input as it was made on-line, and respondents could return to the system to edit their selections at any time.

Table 2.1. Map Data listed in the pull-down menus to convey what types of lakebed maps are needed.

Map Data	Definition/Examples
Bathymetry / Digital Elevation Model	elevation or depth surface derived from multibeam, lidar, interferometric sonar
Ferrous object detections / magnetic anomalies	surface characterizing magnetic strength derived from a magnetometer
Ground-truth data	*in situ* lakebed imagery, grabs, or core samples
Lakebed surface type, hardness/smoothness	texture derived from side scan sonar, multibeam sonar backscatter
Sub-bottom geology	information from below the lakebed surface using a sub-bottom profiler

Table 2.2. Justifications listed in the pull-down menus to convey why an area should be mapped.

Justifications	Definition/Examples
Commercial fishing	popular commercial or charter fishing destinations
Tribal use areas	native American special use areas
Cultural/historical resources	shipwrecks, debris fields
Diving	popular recreational dive site such as ship wrecks
Habitat	rock outcrop, spawning/nursery area, river mouth
Infrastructure	existing or potential cable, pipeline, outfall
Managed area	trawling zone, parks, designated use area
Monitoring	key location for bottom samples, mussel growth
Recreational boating	sailing or other non-fishing activities from a private boat
Safety and navigation	shipping lanes, ferry routes, port facilities, marinas
Scientific research	biological, geological
Sediment movement and management	longshore drift, erosion, depositional area, dredging/spoil, sand mining
Sport fishing	recreational fishing

2.2 DATA ANALYSIS

2.2.1 Quality Control and Data Compilation

A total of 24 respondents entered mapping suggestions into the on-line prioritization application. The 470 grid cells and corresponding priorities from the 24 respondents were compiled into a single table consisting of 11,280 rows in R Version 3.6.1 (R Core Team 2019). Each row therefore consisted of a single respondent's priorities for a given cell with columns noting the number of coins assigned, Justifications (up to two), and Map Data (up to two). The general areas of expertise for each respondent were also included in this table (i.e. biology, archaeology, or other). Several quality control measures were implemented. First, it was confirmed that respondents had allocated a total of exactly 200 coins and that no more than 20 coins were allocated in any one cell by each respondent. Next, some grid cells had coins assigned but no secondary Justification or Map Data chosen. Secondary Justification and Map Data attributes were assigned as "none" to those cells. Lastly, to prevent double counting in some analyses, we confirmed that no respondents had assigned the same Justification or Map Data attributes at multiple levels (primary or secondary) in the same cell.

Methods

2.2.2 Which Justifications and Map Products Were Most Common?

To determine which Justifications were most commonly selected by respondents, the total number of coins associated with primary and secondary Justifications were tallied separately and their relative proportions were visualized in stacked bar format. Similarly, the total number of coins associated with primary and then secondary Map Data were tallied and graphed. We also isolated only those responses from archaeologists and biologists for a better understanding of those two groups. Primary Justifications and Map Data types were tallied and plotted for them on separate graphs.

2.2.3 Were Particular Justifications and Map Data Commonly Listed Together?

Hierarchical cluster analysis was used to explore if particular combinations of Justifications and/or Map Data commonly occurred together. For this analysis, a table was created with all 470 grid cells as rows and the total number of coins within each category of Justification and Map Data (any priority level) as columns. Grid cells with no coins were excluded. Remaining grid cells were then subjected to several clustering algorithms using the *hclust()* function in R in order to identify the consistent patterns regardless of algorithm or approach used. Cells were clustered based on number of coins under each Justification and Map Data. Results are reported using the groupings and values derived from un-standardized data and Euclidean distance characterized using the Ward Minimum Variance algorithm, which yielded results that were representative of several algorithms. The number of clusters was set to where dissimilarity among clusters was large and multiple algorithms showed similar results. Within each cluster, the average number of coins in each Justification and Map Data category were calculated and displayed in bar charts to understand the important variables responsible for cluster membership.

2.2.4 Where Are Cells of Highest Priority for Future Mapping?

Values within the grid of 470 cells were plotted to identify hotspots of relatively high priority for future mapping. Data were summarized in several ways to examine how the respondents allocated coins overall, within their fields of expertise (biology or archaeology), and within the most commonly used Justifications and Map Data identified in Section 2.2.2. First, general values incorporating all the responses were computed. For this, we calculated the simple sum of all the coins by all respondents in each grid cell, the number of respondents assigning at least one coin in each grid cell, and the number of different Justifications that occurred in each cell. These represent measures of overall importance across all respondents.

We then partitioned the responses into a variety of subsets to understand which variables were responsible for the overall patterns of high priority. First, we plotted the total number of coins per cell based on the two main categories of expertise of the respondents, biological and archaeological. Following that, we partitioned responses into the total number of coins per cell within each of the top four primary Justifications identified in Section 2.2.2. Preliminary analysis revealed these to be “Scientific research”, “Habitat”, “Cultural/historical resources”, and “Safety and Navigation”. We also partitioned the responses into the total number of coins per cell within each of the top two Map Data types as identified in Section 2.2.2. Preliminary analysis revealed these to be “Bathymetry/Digital Elevation Model”, and “Lakebed surface type”.

Hotspots representing the highest priorities for future mapping were identified from each of these different maps. The top 10% of cells based on total number of coins were identified using the *quantile()* function in R, and labeled as “high priority” cells. Only cells with coins were included during this calculation. The top 5% of cells was identified in the same way and labeled as “highest priority” cells. This process was repeated for each map (e.g. coins justified under Habitat, coins from archaeologists) using only cells that included coins within each group. We then compared these maps for overlap in high priority cells.

2.2.5 What Areas Should Be Mapped Next?

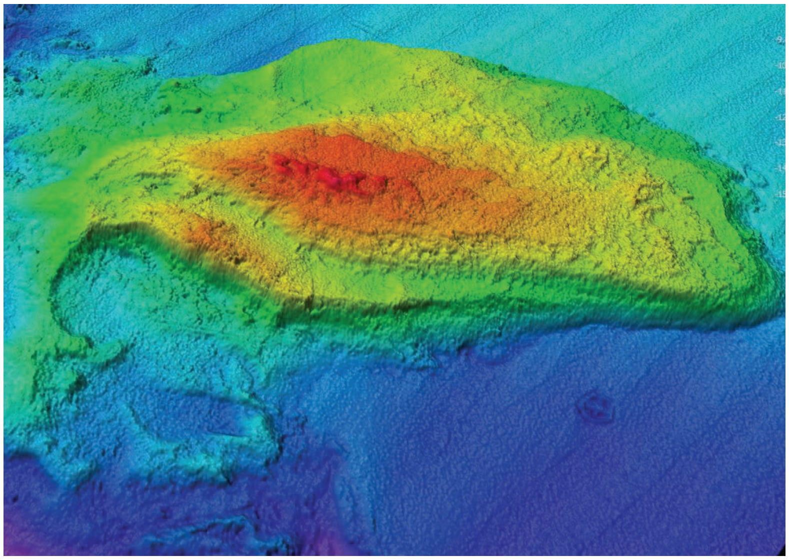
We explored several approaches for identifying possible areas to survey in the near future given reasonable constraints of funding, vessel time, and availability of sonar equipment. We sought a small number of cells (5-10) based on the size of the area NCCOS mapped in 2019 (20 mi^2) using similar resources. For this part of the analysis we used two approaches to identify the highest priority cells for the broadest diversity of respondents. First, we began with the three most general summary values (as described above) including sum of all coins in a cell, the number of respondents in a cell, and the number of different Justifications in a cell. We ranked the cells from smallest to largest values based on these three values, added the three ranks together in each cell, and plotted the results on a continuous scale. This holistic measure of importance yielded a composite value of the highest combined number of coins, number of respondents, and number of Justifications. In the second analysis, we plotted the locations of the clusters identified in Section 2.2.3 with an emphasis on cluster 3. Preliminary analysis revealed that cluster 3 included small groups of the target number of cells with a large number of coins and diversity of Justifications. This was also a holistic measure of importance but unlike the rank-sum approach, was based on which Justifications and Map Data actually occur together in each cell.

NOAA diver, Charles Menza, investigates a lakebed transition on the Alpena-Amberley Ridge, Lake Huron. Credit: Phil Hartmeyer, TBNMS.

The 500-feet long freighter Nordmeer*, sunk in 1966, is an ideal shallow snorkel and dive site. Credit: NOAA, Thunder Bay National Marine Sanctuary.*

3.0 RESULTS

A total of 24 respondents entered suggestions into the on-line prioritization tool and allocated a combined total of 4,800 coins into the grid cells to denote their suggestions for future lakebed mapping. Some respondents made selections entirely on their own whereas others consulted with various colleagues prior to making their selections such that their input represented a larger group. It is unknown how many respondents may have used the information in the Digital Atlas or independent datasets to assist with their selections.



A 3D model of Mischley Reef, Lake Huron, created from mulitbeam echosounder bathymetry data. Credit: Brendan Guthrie, NCCOS/CSS.

3.1 WHICH JUSTIFICATIONS AND MAP PRODUCTS WERE MOST COMMON?

The proportion of coins that were assigned using the Justification categories at the primary and secondary levels revealed that there were four main Justifications used most often (Figure 3.1a). The topics “Cultural/Historical resources” and “Habitat” each comprised ~25% of all the primary Justifications chosen. These were followed by “Scientific research” and “Safety and navigation” which each accounted for 15-20% of the assigned coins. The five remaining choices each accounted for less than 5% of the remaining coins. “Commercial fishing” and “Managed area” were never selected as a primary Justification. Approximately 75% of the coins allocated by respondents included a secondary Justification, with “Monitoring” (13% of the coins), “Scientific research”, and “Habitat” being used most often. The Justifications “Tribal use areas”, “Infrastructure”, “Recreational boating”, and “Sediment movement and management” were not selected at any level. Considering both levels of Justification, four categories emerged as the dominant rationales when identifying priority areas to map. These were “Cultural/ Historical resources”, “Scientific research”, “Habitat”, and “Safety and navigation”.

As expected, among the eight respondents who were archaeologists, 75% of their coins were justified under the “Cultural/Historical resources” category (Figure 3.1b). The 11 respondents working in the general field of biology justified all of their coins under the categories of “Habitat” (46%), ”Scientific research” (36%), and “Monitoring” (18%).

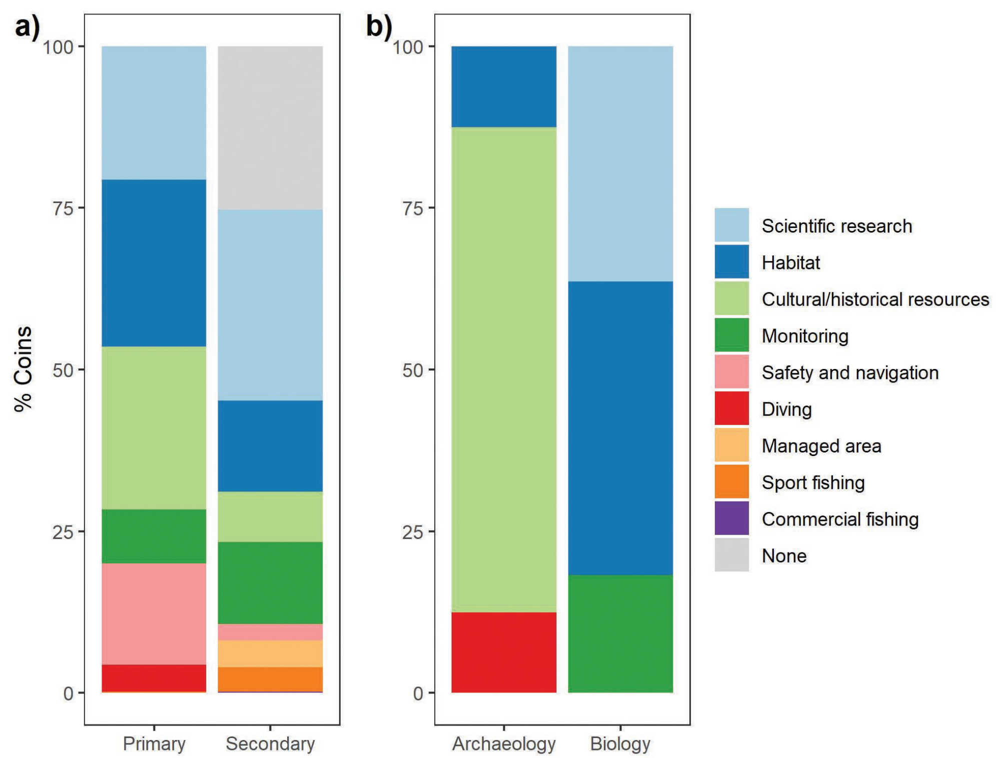


Figure 3.1. The proportion of coins attributed by Justifications among a) all respondents at the primary vs. secondary level, and b) by respondents with archaeological vs. biological expertise at the primary level.

Results

The proportion of coins that were assigned using the Map Data categories at the primary and secondary levels revealed two main desired data types (Figure 3.2a). “Lakebed surface type” and “Bathymetry/Digital Elevation Model” were by far associated with the greatest number of coins and together comprised 87% of all primary Map Data types selected. Eighty five percent of the coins allocated by respondents included a secondary Map Data, with “Lake-bed surface type” the dominant choice followed by “Ground-truth data” and “Sub-bottom geology” in the top three.

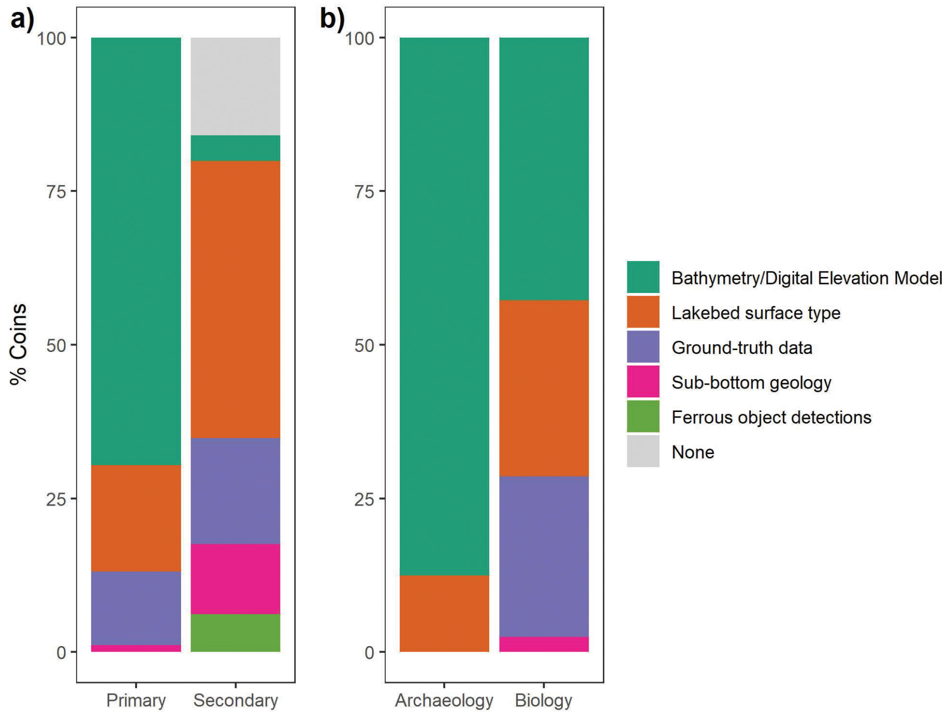


Figure 3.2. The proportion of coins attributed by Justifications among a) all respondents at the primary vs. secondary level, and b) by respondents with archaeological vs. biological expertise at the primary level.

Archaeologists requested “Bathymetry /Digital Elevation Model” as the primary information need for 88% of their coins (Figure 3.2b). Biologists more evenly expressed their primary data needs within the categories “Bathymetry/Digital Elevation Model”, “Lake-bed surface type”, and “Ground-truth data”.

3.2 WERE PARTICULAR JUSTIFICATIONS AND MAP DATA COMMONLY LISTED TOGETHER?

Zero coins were assigned to 221 of the 470 cells in the study area. The remaining 249 cells had at least one coin assigned by at least one respondent and were subjected to cluster analysis. Results of these analyses are focused on: 1) which Justifications and/or Map Data needs are typically chosen together, and 2) what unique combinations of Justification and/or Map Data separated the clusters from each other.

Cluster analysis based on the number of coins associated with the various Justifications and Map Data revealed four groups of cells that had a similar suite of attributes (Figure 3.3a-b). Cluster 1 was the largest, comprised of 177 cells. This group consisted of cells with low coin totals and was not dominated by any particular Justifications or Map Data. Cells in cluster 2 had moderately high coin totals for “Cultural/historical resources” and “Scientific research” as Justifications, and “Bathymetry/Digital Elevation Model” and “Lake-bed surface type” as desired Map Data. Cluster 3 was comprised of 21 cells. Notably, this group had the broadest suite of Justifications including “Habitat”, “Scientific research”, and “Cultural/historical resources”, as well as small contributions from other Justifications. This cluster also had high coin totals for “Bathymetry/Digital Elevation Model” and “Lake-bed surface type”, and was unique as the only cluster with high coin totals in the “Ground-truth data” category. Lastly, cluster 4 was comprised of 10 cells with very high coin totals in the “Scientific research” category with “Monitoring” being another important rationale. Map Data requested together in this cluster were “Bathymetry/Digital Elevation Model” and “Sub-bottom geology” which was not emphasized strongly in any other groups and appears to be an important distinction for cells in this cluster.

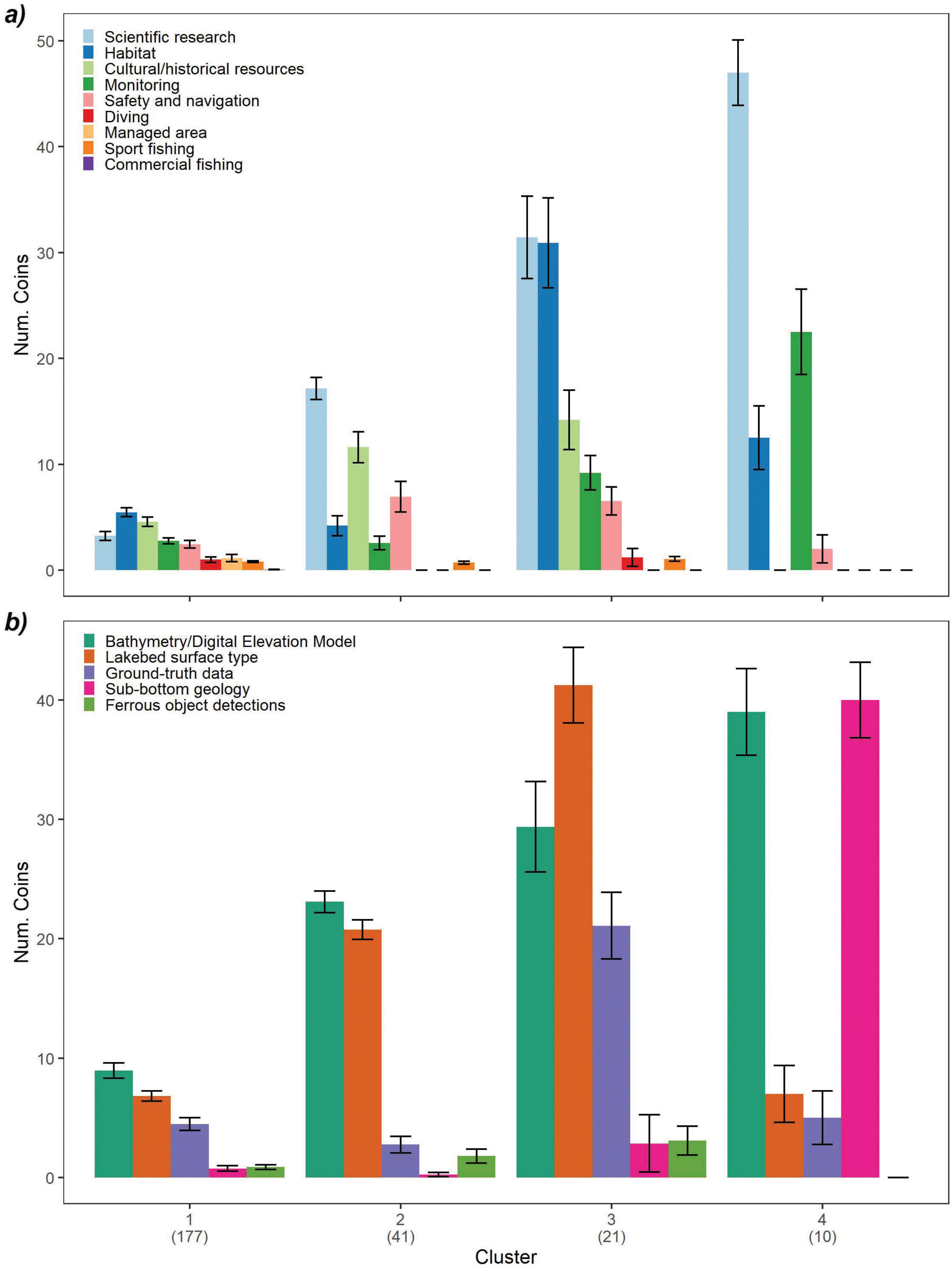


Figure 3.3a-b. The Justifications (a) and Map Data types (b) associated with the 4 main clusters of cells based on the Ward's Minimum Variance algorithm.

Results

3.3 WHERE ARE CELLS OF HIGHEST PRIORITY FOR FUTURE MAPPING?

Locations of highest priority for future mapping differed depending on whether the input of the respondents was considered holistically or was partitioned by Justification, expertise, or Map Data. Cells with the highest total number of coins among all respondents occurred primarily offshore of Alpena, around North Point and Thunder Bay Island, and onto the most nearshore sections of the Alpena-Amberly Ridge (also known as Six-Fathom Scarp) (Figure 3.4a). Two smaller areas with high-value cells were located in near-shore waters off Rogers City and the promontory north of Alpena off Stoneport. A somewhat similar pattern was found when considering the number of respondents that allocated coins in each cell (Figure 3.4b). Cells with the most respondents (top 5%) were in a tight group off Alpena around North Point and Thunder Bay Island as well as near Rogers City. There were also important cells (top 10%) for many respondents north and east of Cheboygan. High priority areas based on the number of different Justifications showed a different pattern with the top cells all along the shore from Cheboygan to Alpena and also just south of the mouth of Thunder Bay (Figure 3.4c). This reflects diverse reasons for mapping those areas. Not only do these 3 figures convey areas of high priority, but they also show large parts of the study area where there was little or no interest in lakebed mapping. None of the 24 respondents placed a single coin in the offshore waters along the Canadian border in the northeastern part of the sanctuary. Similarly, there was very little interest in mapping the deeper water greater than 10 mi off Harrisville except for a group of cells around Yankee Reef.

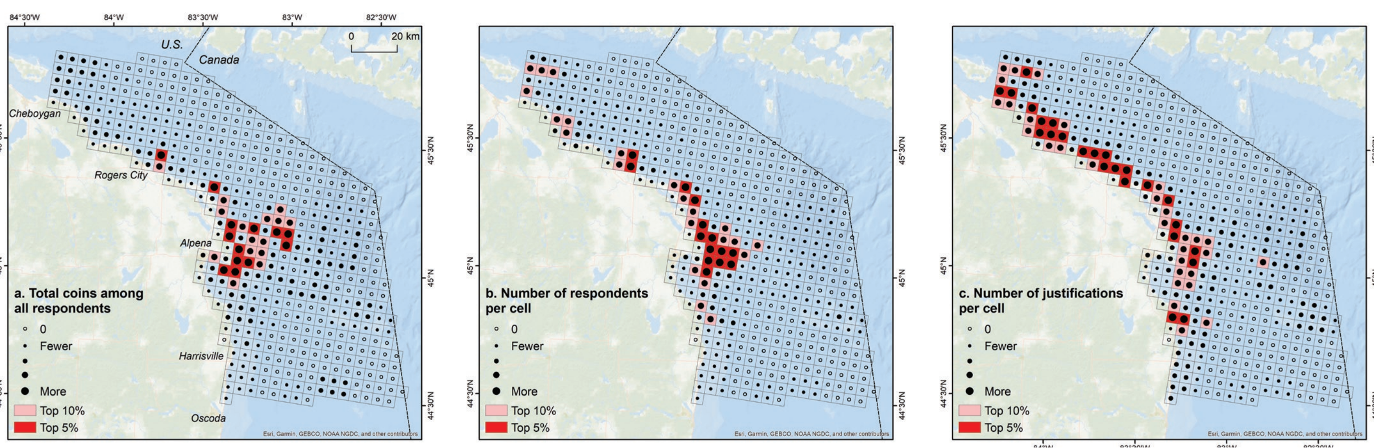


Figure 3.4a-c. Sum of all coins among all respondents in each cell (a-left). Number of respondents allocating at least one coin in the cell (b- middle). Total number of different Justifications used in each cell (c- right).

A fish resting on the lakebed of Mischley Reef, Lake Huron. Credit: Phil Hartmeyer, TBNMS.

A sanctuary diver collects microbial mat from the bottom of the Middle Island Sinkhole in Thunder Bay National Marine Sanctuary. Credit: NOAA, Thunder Bay National Marine Sanctuary.

When the coin allocations were partitioned based on the respondent's primary area of expertise, some key differences in priority areas became apparent (Figure 3.5a-b). Respondents in the archaeology group allocated most of their coins along a line extending from the mouth of Thunder Bay east-southeastward onto the Alpena-Amberley Ridge (i.e. Six Fathom Scarp) toward Six Fathom Bank. A smaller area north of Alpena off Middle Island was also of importance. Areas at the northern and southern extremities of the study area were also in the top 10%. One was east of Bois Blanc Island, and the other was west of Yankee Reef and Six Fathom Scarp (Figure 3.5a). In contrast, biologists collectively had most interest in the central parts of the study area within 25 mi of Alpena between North Point and Middle Island plus two cells near Rogers City (Figure 3.5b).

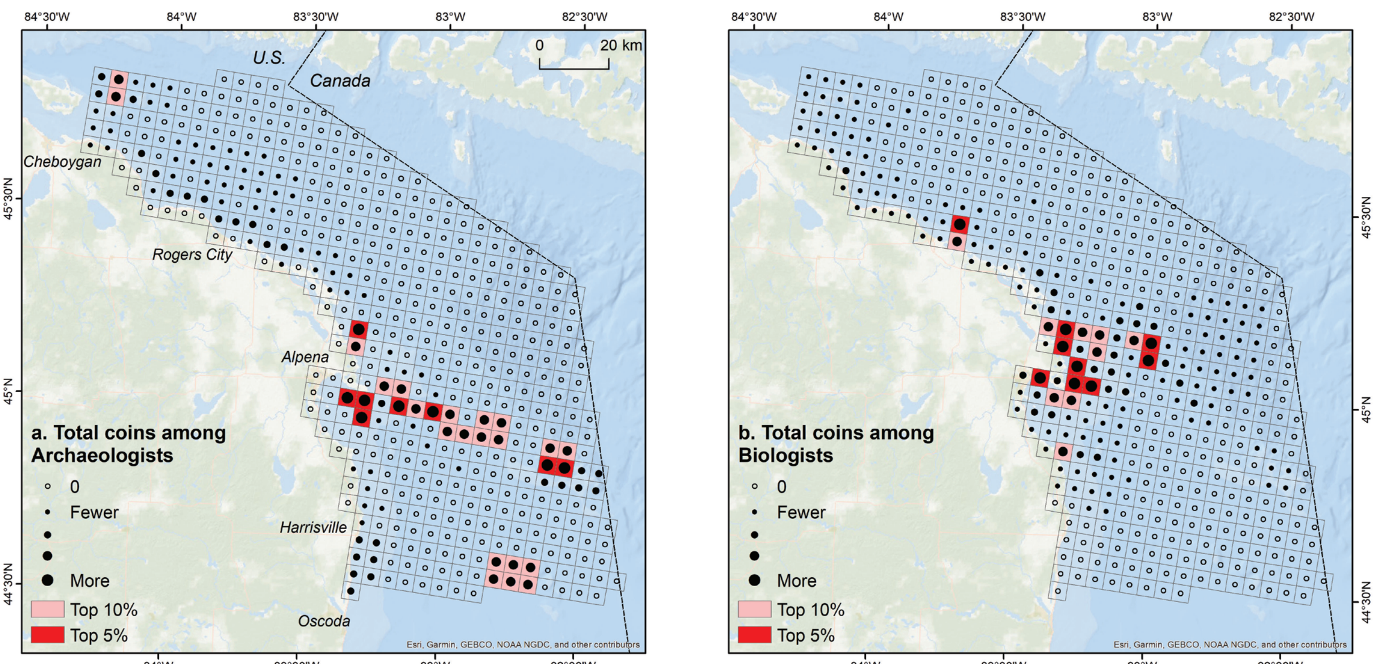


Figure 3.5a-b. Sum of all coins in each cell among respondents with expertise in archaeology (a-left) or biology (b- right).

Results

Examining the top four Justifications (from Section 3.1) separately revealed some additional patterns of interest. High priority areas for the "Habitat" Justification were very tightly focused around the nearshore area east of Alpena, around North Point and islands east of it, then alongshore northward toward Middle Island (Figure 3.6a). Not surprisingly the "Cultural/historical resources" Justification very closely corresponded to the area prioritized highly by archaeologists (Figure 3.6b). The more broadly applicable Justification "Scientific research" had highest values in the middle of the study area east-northeast of Alpena to a distance of ~25 mi offshore (Figure 3.6c). Last, the "Safety and navigation" Justification had a rather different pattern with highest value cells occurring in three groups (Figure 3.6d). The largest area in the top 5% with this Justification was a conspicuous "U" shaped pattern located centrally in the Lake Huron Overwater Range (Restricted Area-4207) managed by the Michigan Air National Guard's Alpena Combat Readiness Training Center (CRTC). Other high

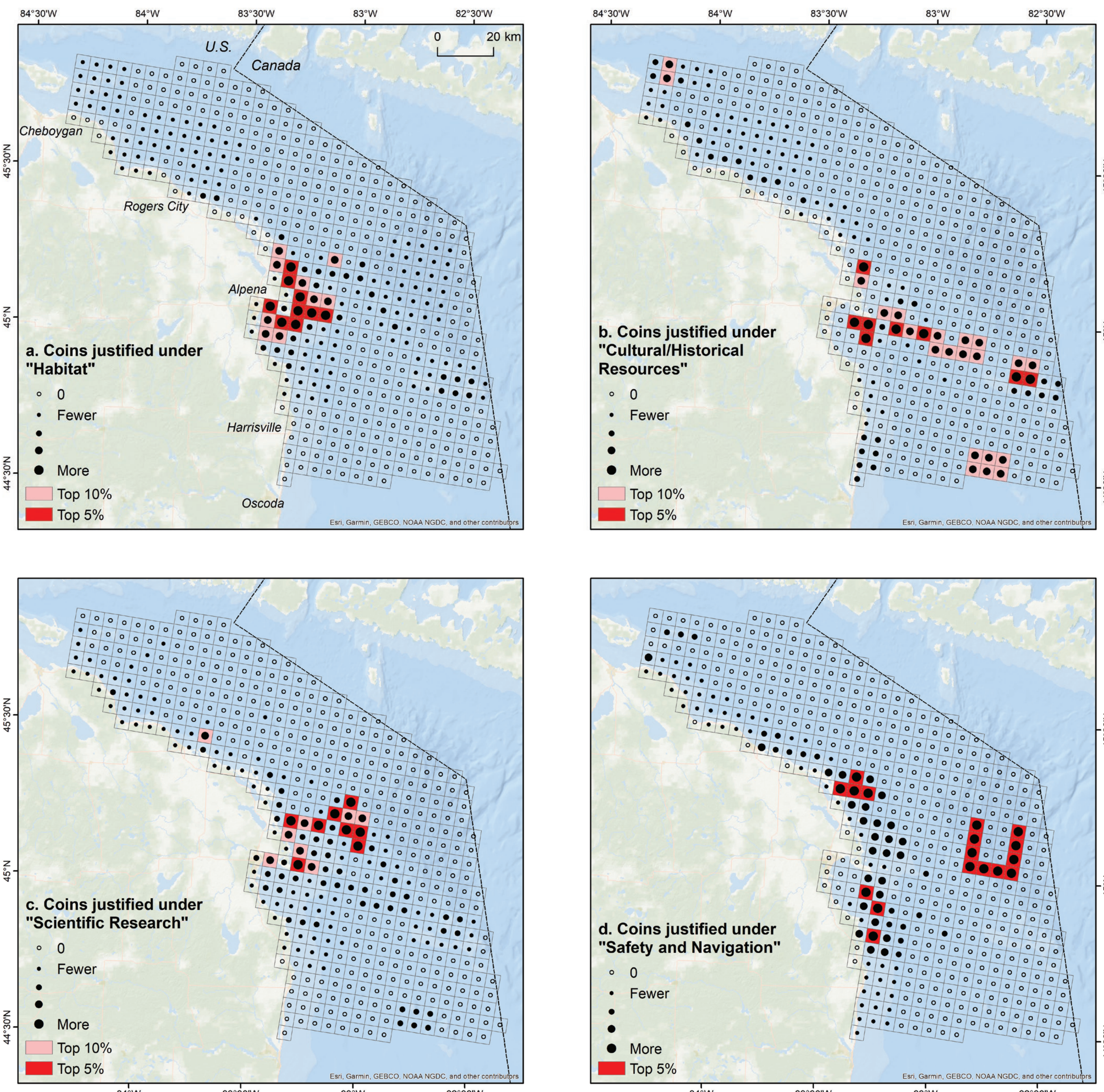


Figure 3.6a-d. Sum of all coins in each cell Justified under "Habitat" (a- top left), "Cultural/historical resources" (b- top right), "Scientific research" (c-bottom left), and "Safety and navigation" (d- bottom right). Due to the large number of tied ranks, the top 5 and 10% of cells are combined in 3.6d.

priority areas under this Justification were located nearshore adjacent to Stoneport and along the approaches to Thunder Bay.

When we partitioned the responses based on the two most commonly selected Map Data types, additional patterns became apparent (Figures 3.7a-b). Highest ranking cells linked to the Map Data category of “Bathymetry/Digital Elevation Model” were located east of Alpena within 25 mi of shore (Figure 3.7a). Two additional cells in the top 5%, one including Middle Island and the other off Stoneport. The Map Data “Lakebed surface type” had highest values in the nearshore cells east of Alpena around North Point, another pair of cells near Roger City, and another location in CRTC Restricted Area over Six-Fathom Bank (Figure 3.7b).

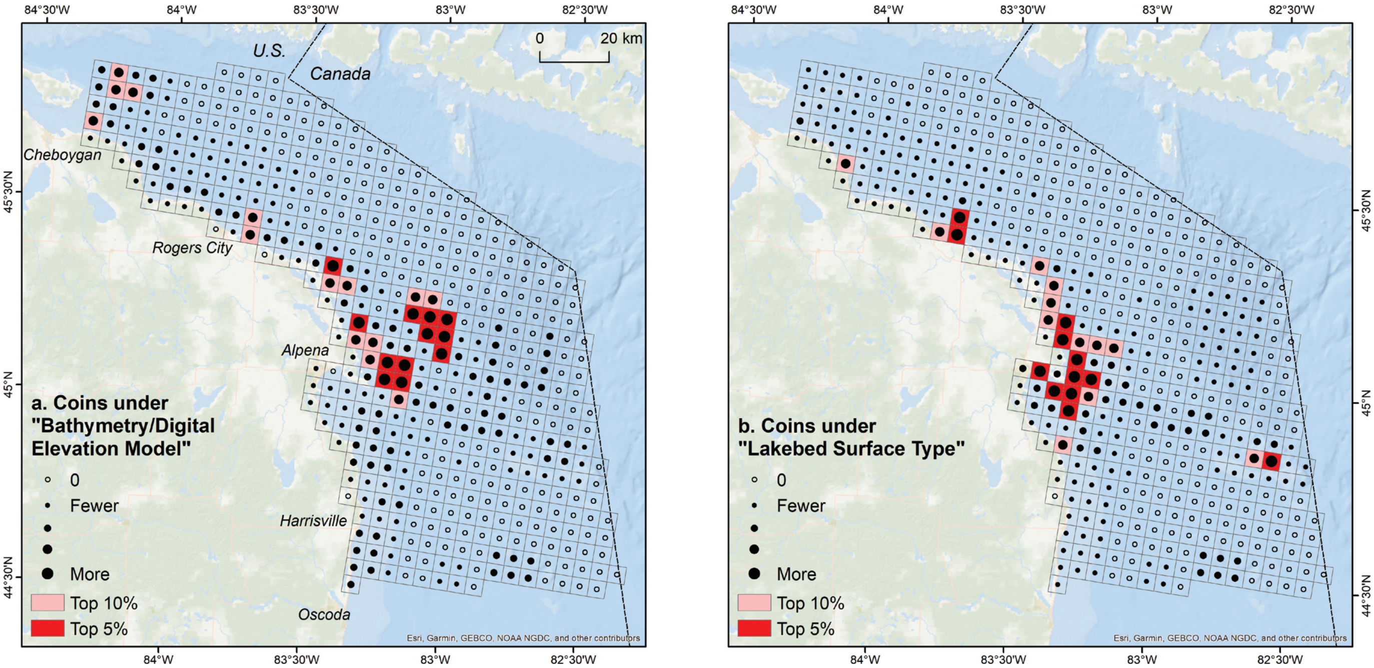


Figure 3.7a-b. Sum of all coins in each cell associated with the Map Data “Bathymetry/Digital Elevation Model” (a-left) or “Lakebed surface type” (b- right).

A diver photo-documents purple and white microbial mats in the Middle Island Sinkhole in Thunder Bay National Marine Sanctuary. Credit: NOAA, Thunder Bay National Marine Sanctuary.

Results

Last, we considered the composite analyses to guide future surveys. The cells with the highest combined ranks based on total number of coins, number of respondents, and diversity of Justifications were plotted in Figure 3.8a. Highest values were concentrated east of Alpena off North Point, offshore from Stoneport, and near Rogers City. Moderately high values generally surrounded those cells but also occurred in other areas such as north and east of Cheboygan, and south of the mouth of Thunder Bay.

Plotting the clusters that resulted from the combined analysis of all Justifications and Map Data types (Section 3.2) revealed that cells in Cluster 4 were the most geographically constrained and occurred 10-40 km offshore northeast of Alpena (Figure 3.8b). Cluster 3 was primarily located in cells nearshore especially around North Point but also in a pair of cells off Rogers City and well offshore in the CRTC Restricted Area over Six-Fathom Bank. Cluster 2 was comprised of cells more widely separated but with some concentrations of cells off Stoneport, the mouth of Thunder Bay, a line from Thunder Bay toward Six Fathom Bank, and around Yankee Reef. Cluster 1, characterized by low coin totals in general, filled in the spaces between the other clusters.

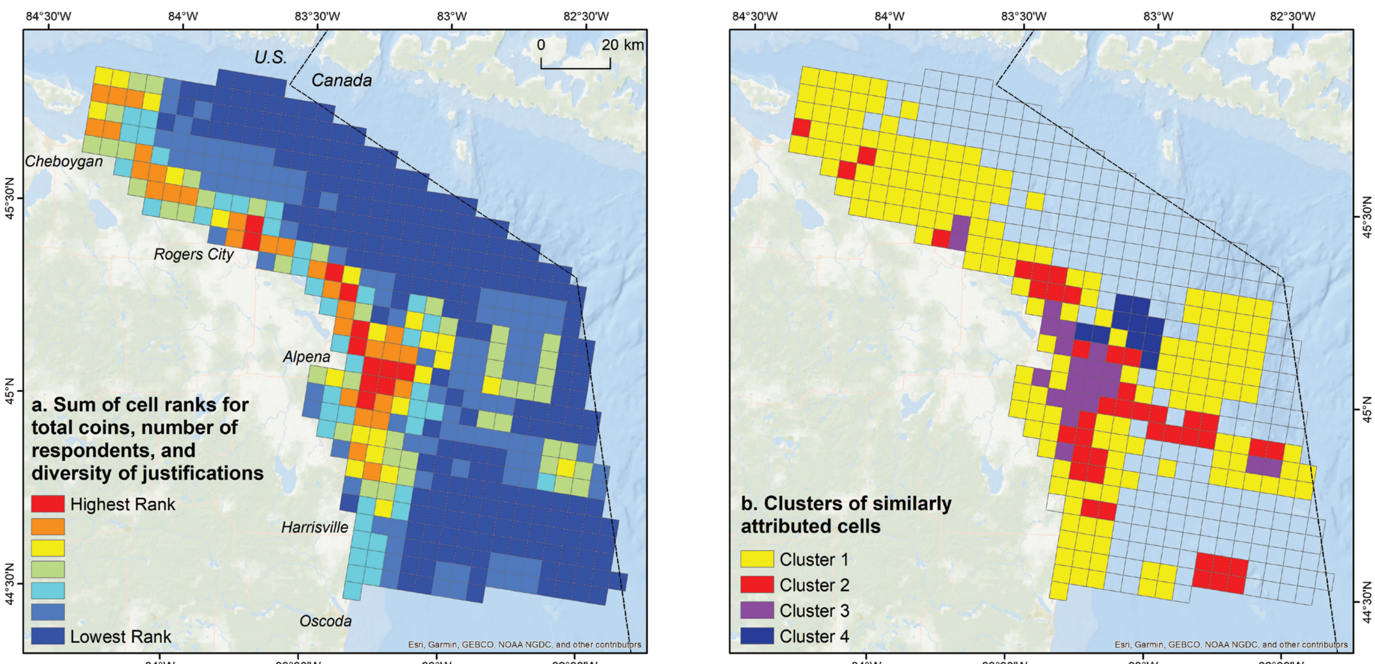
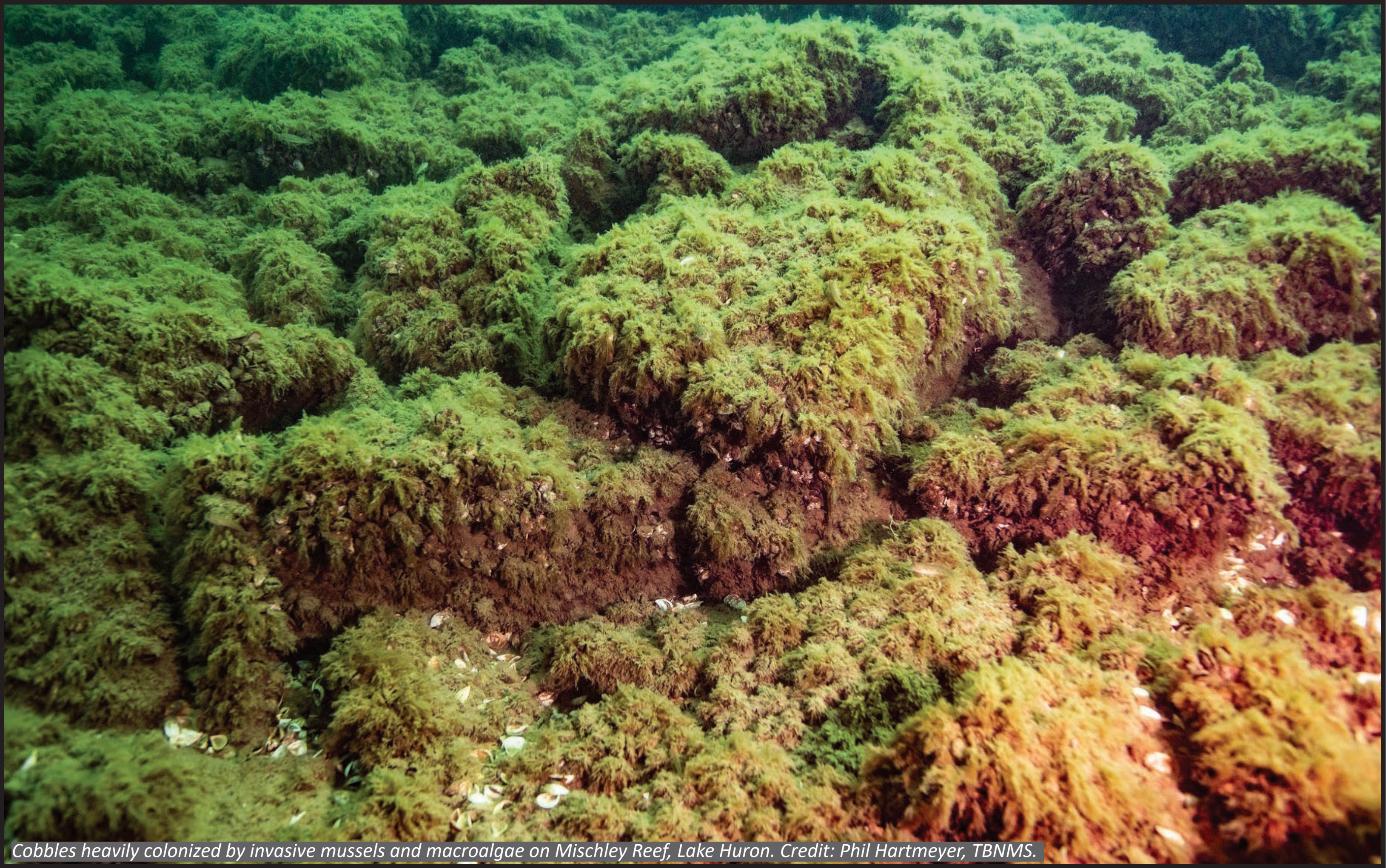


Figure 3.8a-b. Sum of the cell ranks based on total coins, number of respondents, and diversity of Justifications in each cell (a- left). Cluster membership of the cells from Section 3.2 based on Justification and Map Data that were selected (b- right).

The massive bow of the freighter Florida rests well-preserved 200-feet deep in sanctuary waters. Credit: Doug Kesling, NOAA, Thunder Bay National Marine Sanctuary.



Cobbles heavily colonized by invasive mussels and macroalgae on Mischley Reef, Lake Huron. Credit: Phil Hartmeyer, TBNMS.

Wreck of the wooden schooner Lucinda VanValkenburg, sunk in a collision in 1897. Credit: NOAA, Thunder Bay National Marine Sanctuary.

4.0 DISCUSSION

We used an online application to gather opinions from 24 local experts regarding their priorities for lakebed mapping within TBNMS. The system allowed respondents to indicate where mapping is needed, the types of map data that are required, the urgency of the need, and a rationale to justify their priorities. Based on analysis of the responses, a few groups of cells emerged as the highest overall priority for mapping. These were primarily located within 15 mi of shore and were concentrated between Alpena and Rogers City. They had the highest overall coin totals, a large number of respondents per cell, and a similar mix of justifications and desired map data types based on the cluster analysis (Cluster 3). Several additional areas emerged as highly important for certain groups or data needs.

What caused these patterns of high priority cells? Plotting the data in various ways allowed us to disentangle the various priorities among experts from different fields. We not only identified important areas that were unique to each group, but perhaps more importantly, we also identified areas that are a high priority for more than one field of experts.

Overlapping interest among many respondents in the same cell(s) may represent some of the best opportunities for collaboration. These were made apparent and quantified through this analysis that brought together professionals with a variety of interests and backgrounds that otherwise would have been unlikely to connect and share their mapping interests. Some noteworthy examples of collaborative opportunities from the results include the cells near Rogers City, off Presque Isle, Middle Island, and the islands off North Point. These cells had the highest number of respondents and the greatest diversity of Justifications used during coin allocation. This suggests there are both ample numbers of potential collaborators in this area but also multiple rationales for mapping those areas which can attract partners and funding from various sources. In more specific examples, several cells in the mouth of Thunder Bay and the cell that includes Middle Island were high priorities for not only biologists but also archaeologists. The combined presence of “Habitat” and “Cultural/Historical resources” in these cells makes them of interest to both groups, but for different reasons. Furthermore, these cells often had the same suite of desired Map Data types including “Bathymetry/DEMs” and “Lakebed Surface Types” which can often be combined on survey vessels using sonar, backscatter, and their derivatives. Apart from the examples with high coin totals noted here, there are also collaborative opportunities in many cells with lower coin totals but that are of interest to multiple groups. Groups that encourage and facilitate partnerships such as the BMW (Esselman et al., 2017) can use these results as outreach for collaborators and the rationale for proposals to seek funding or share resources.

It is also useful to recognize that some places were identified as high priority but only for one particular group or purpose. For example, only the archaeologists were interested in cells around Six Fathom Bank and Yankee Reef in the southern areas of the sanctuary despite the potential for important habitat. Similarly, portions of the CRTC Restricted Area were of great interest to some respondents for the purposes of “Safety and navigation”, but few others expressed interest. This is important to know, so these groups can recognize that they may have to work independently in these areas. They could either focus their mapping resources at those sites (since it appears less likely that others may be interested) or they may wish to refocus their interest someplace else where greater resource sharing and collaborative opportunities may be had. Also of note, some areas received no coins at all from any of the respondents. This doesn’t mean that those areas are unimportant, it was just not a priority to this particular group of regional experts at this time relative to other parts of the study area.

For planning future mapping, targeting some combination of the highest priority cells is a good starting point. However, refining the area based on survey optimization and finer scale considerations than were allowed in

Discussion

this cell-based prioritization is necessary. For example, the tools and effort needed to map various grid cells differs depending on depth, water clarity, and bathymetric variation. Effort to meet mapping needs should be assessed at a finer spatial scale than the grid cells once a defined area of interest has been determined. Additionally, mapping surveys are typically focused and aligned to specific lakebed features of interest, and features will rarely align with the grid and not all of a grid may need to be surveyed in order to map a key feature of interest. A cursory analysis of overlap between high priority cells and existing data showed that some cells already have extensive lakebed survey data. Future surveys should exclude any high priority areas that have already been mapped unless additional data types are needed.

How can others access and use this information for planning their activities? The individual contact information of respondents is provided for reference at the end of this document (Appendix A), summary grid values are posted at the National Center for Environmental Information (https://www.ncei.noaa.gov/) and available as an ArcGIS Map Service (https://gis.ngdc.noaa.gov/arcgis/rest/services/nccos/BiogeographicAssessments_TBNMSPrioritizationResults/MapServer), and the findings of the report are being shared with the Bottom Mapping Workgroup and NOAA's Integrated Ocean and Coastal Mapping program (https://iocm.noaa.gov/). We designed this process and report to facilitate outreach among groups that would perhaps not normally collaborate. Eventually, the goal is to facilitate proposal writing since the Justifications and Map Data are already articulated and quantified in this document. These facts can be cited to funding entities to support mapping initiatives. Collaboration need not be limited to those interested in the exact same place and mapping product. For example, perhaps two groups need the same sonar unit but in different places. The cost and time of renting and/or mobilizing such units on survey vessels is not trivial and could be the basis of cost sharing for back to back survey missions even in different areas. Using the data collected here, respondents can identify other groups with similar equipment needs. There are also collaborative opportunities when the map product and equipment needs differ, but the area of interest is the same. In these cases, more than one type of survey instrument can often be deployed concurrently on the same survey vessel to collect multiple data streams for differing map data. For example, multibeam-, side-scan, and split-beam sonar systems can be deployed all at once to map bathymetry, surface types, and fish populations.

Apart from actually mapping the suggestions provided here, there are several topics for further investigation. We will seek additional information on high priority cells along the edges of the study area. For example, cells along the northwestern edge of the sanctuary boundary offshore from Cheboygan were attributed with a diversity of justifications. Similarly, at Yankee Reef appears to be on the edge of a feature that extends farther south beyond the southern edge of the study area. Six Fathom Bank is part of a larger underwater ridge that extends across the international border with Canada (O'Shea and Meadows 2009). Additional inquiries should determine if these areas are merely smaller parts of more extensive high-priority areas or if the cells identified here represent the core of important features to be mapped. The extent of these priority areas should be further defined by the respondents that identified them here, but it would also be important to engage additional respondents with a specific interest or expertise in adjacent areas outside the sanctuary to more thoroughly identify mapping priorities more broadly. On that point, although this process included a cross section of respondents with a strong interest in lakebed mapping within the sanctuary, the outcome might have changed had a different suite of individuals and interest groups participated. It will be important to revisit the priorities identified here in 5 to 10 years in response to the changing group of experts and interests in the area. It is also important to review mapping priorities as new, more efficient technologies and instruments (e.g. sonar equipped AUVs) become more widely available.

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Appendix

Appendix A: List of respondents and their affiliations.

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