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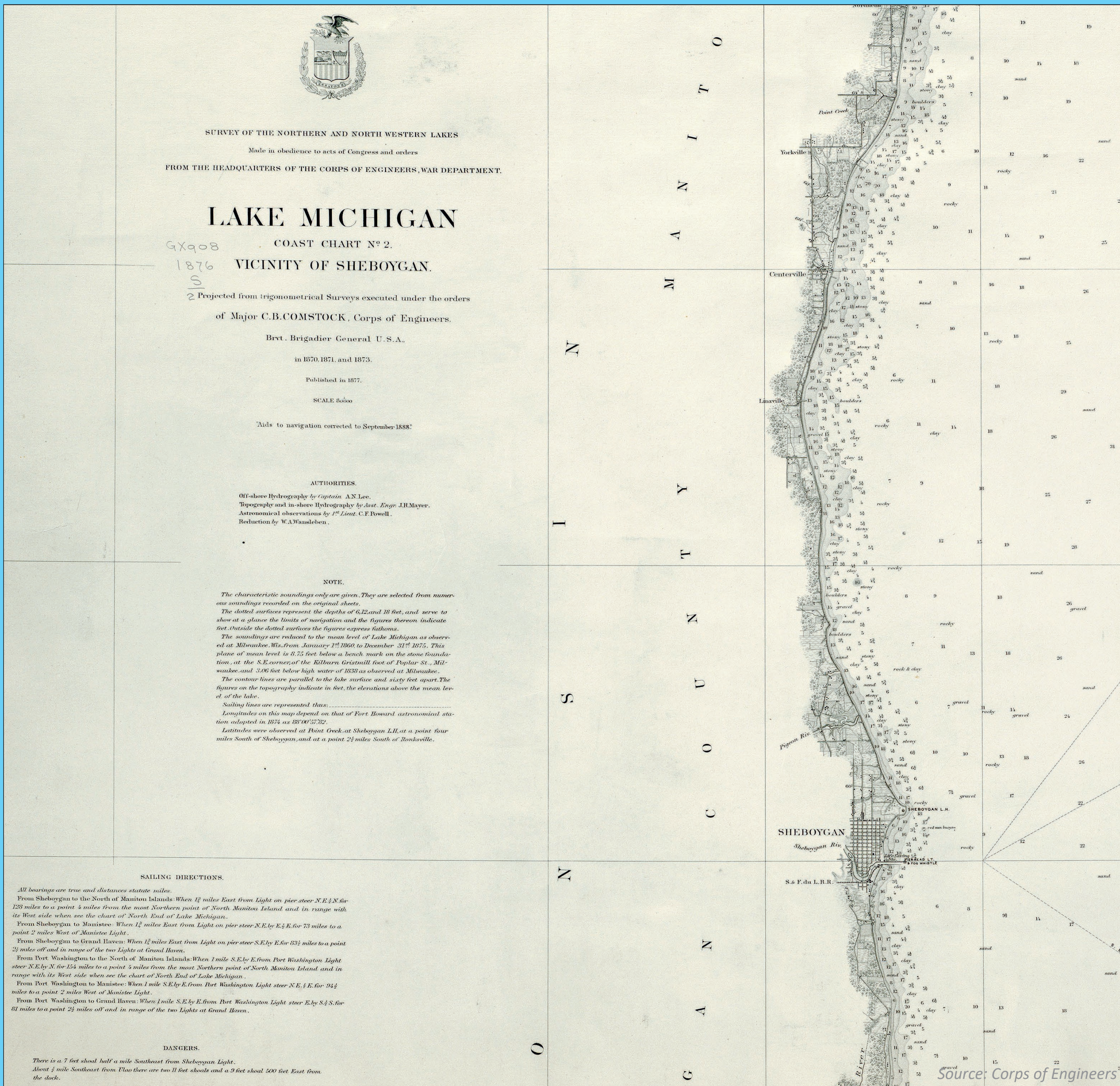
Priorities for Lakebed Mapping in the Proposed Wisconsin-Lake Michigan National Marine Sanctuary



Source: Corps of Engineers

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Priorities for Lakebed Mapping in the Proposed Wisconsin-Lake Michigan National Marine Sanctuary

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May 2018

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NOAA Technical Memorandum NOS NCCOS 246

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Wilbur L. Ross, Jr. Secretary	Timothy Gallaudet Administrator, Acting	Russell Callender Assistant Administrator

View of wreck of the Hetty Taylor's *bow sank off Sheboygan. Credit: Tamara Thomsen, Wisconsin Historical Society.*

Executive Summary

The Wisconsin-Lake Michigan National Marine Sanctuary has been proposed along the western shore of Lake Michigan between the cities of Two-Rivers and Port Washington, Wisconsin. Much of the proposed sanctuary and rest of Lake Michigan were mapped prior to 1950 and therefore suffer from multiple deficiencies by today's standards. New technologies can efficiently provide more accurate and finely resolved depths, and characterize the lakebed. However, the proposed sanctuary is a vast area covering greater than 1,000 sq. miles and the entire area cannot be mapped in a short timeframe. Smaller areas must be prioritized to address the most urgent needs.

To meet this need within the proposed sanctuary, we developed a systematic quantitative approach and on-line 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 groups of individuals with shared interests depending on their area of expertise, the types of mapping products that they need, the rationale used to justify their needs, and of course the locations that they prioritize for lakebed mapping. The online application (https://maps.coastalscience.noaa.gov/wilm/) was customized for the proposed sanctuary using guidance from a Technical Advisory Team and displayed the present status of lakebed maps, and locations of natural and cultural resources.

A total of 22 respondents provided their mapping priorities. We explored multiple ways to determine and display mapping suggestions, including partitioning by the disciplines of the participants, their mapping justifications, and their desired map products. Respondents with primarily geological expertise were interested in mapping two areas, eastward from Two Rivers and along the coast of Port Washington. Respondents with historical expertise prioritized areas south of Manitowoc, around Sheboygan, and off the promontory north of Port Washington. The ecologists were somewhat more diffuse in their priorities and had most interest in the central and northern parts of the area. The most commonly used justifications for mapping included topics such as historical resources, sediment movement, and important natural areas. Commonly selected map products included bathymetry and mapping of surface features. When pooled together, inputs from all respondents identified four high-priority regions: northeast of Two Rivers, in the nearshore waters off Sheboygan and Port Washington, and south of Manitowoc. A few additional areas emerged as highly important using different prioritization methods. None of the 22 respondents placed a single coin in the southeastern 1/3 of the area offshore of Port Washington.

The results are expected to help researchers and managers find locations where their interests overlap with others. This allows them to seek out opportunities for collaboration and more effectively invest limited mapping dollars. Results here highlight several areas with not only a large number of respondents demonstrating an interest in mapping an area, 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. For instance, the National Centers for Coastal Ocean Science will use the priorities revealed here to locate a mapping mission this summer 2018. We recognize 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, and have 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/).

WATER TABLE.

Showing the mean level and the mean fluctuations of Lake Michigan from April to November of each year between 1860 and 1875 from observations at Milwaukee, Wis.

DATE.	Mean level from April to November Incl.	Maximum mean monthly level.	Minimum mean monthly level.	Range for the period of Navigation.
	ft.	ft.	ft.	ft.
1860	+1.15	July +1.50	Nov. +0.47	1.03
1861	+1.29	Aug. +1.73	April +0.78	0.95
1862	+1.16	June +1.39	Nov. +0.71	0.68
1863	+0.55	June +0.84	Nov. -0.05	0.89
1864	-0.05	May +0.39	Nov. -0.73	1.12
1865	-0.05	Aug. +0.33	Nov. -0.59	0.92
1866	-0.43	Aug. -0.11	April -0.90	0.79
1867	+0.02	July +0.46	Nov. -0.67	1.13
1868	-0.55	July -0.12	Nov. -1.00	0.88
1869	-0.29	Aug. +0.30	April -1.20	1.50
1870	+0.63	Sept. +0.94	Nov. +0.14	0.80
1871	+0.47	July +1.08	Nov. -0.56	1.64
1872	-0.84	July -0.60	April -1.25	0.65
1873	+0.03	Aug. +0.41	April -0.84	1.25
1874	+0.20	June +0.54	Nov. -0.32	0.86
1875	+0.14	Aug. +0.43	April -0.51	0.94

The above figures, as their sign is + or -, indicate the number of feet that the level of the lake was above or below the plane to which the soundings are reduced. That plane is the mean level of the lake from 1860 to 1875, inclusive.

LIGHT HOUSES.

LOCALITY.	LATITUDE.	LONGITUDE.	CHARACTER.	HEIGHT OF FOCAL PLANE ABOVE LAKE.	DISTANCE VISIBLE IN STAT. MILES.
Sheboygan	43° 45′ 50″	87° 41′ 49″	F.W.	80 ft.	16
Sheboygan Pierhead	43 44 59	87 42 05	F.R.	32 "	8½
Port Washington	43 23 29	87 52 05	F.W.	113 "	18

ABBREVIATIONS.

F.W. Fixed or steady white light
F.R. Fixed red light

In the above table, distances visible in statute miles *are from an observers eye 10 feet above the lake.*

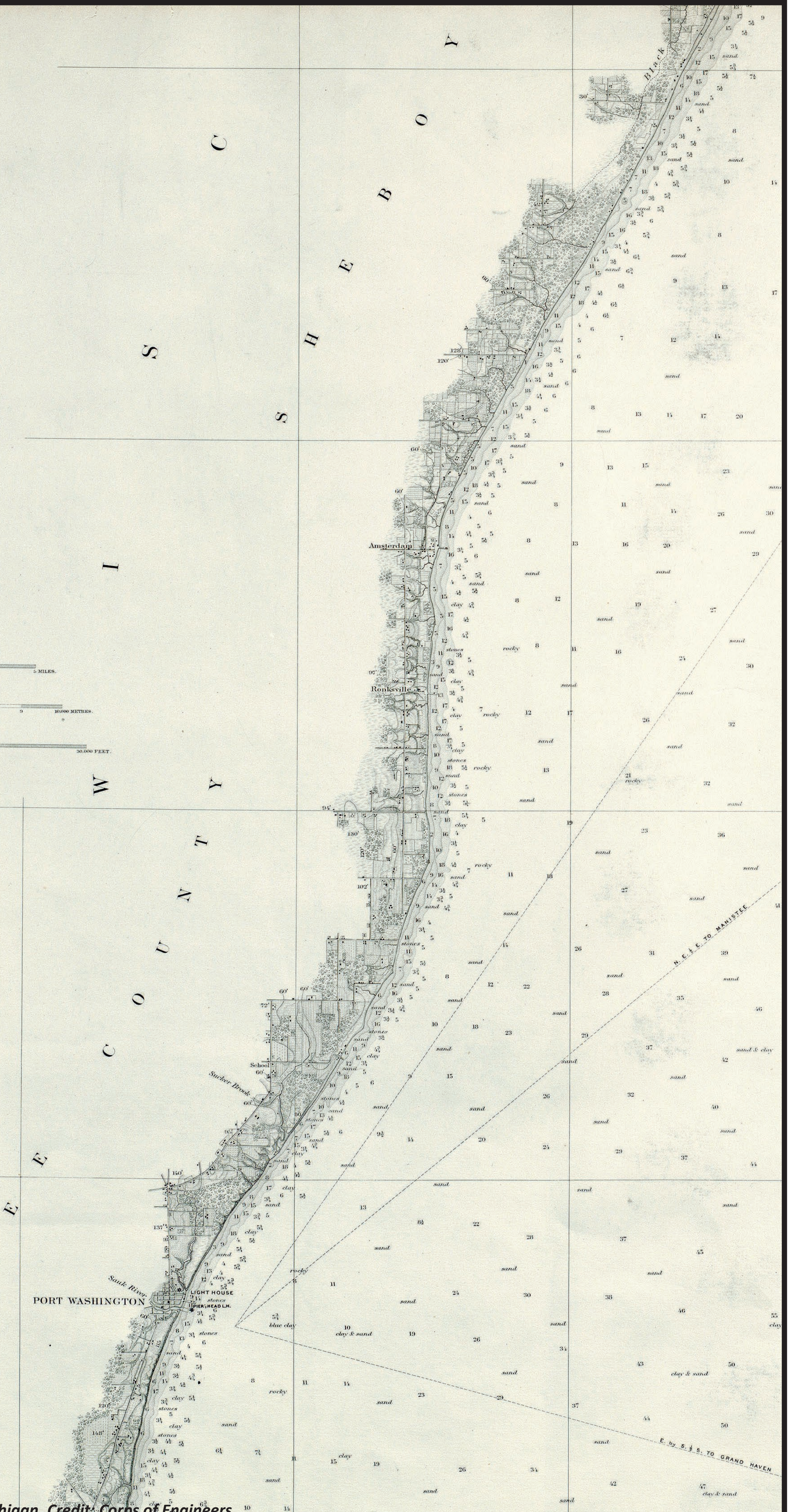
MAGNETIC VARIATION.

LOCALITY.	VARIATION.	DATE.
Sheboygan	5°.15′ East	1865, Aug.
Manitowoc	5.03 "	1870. "

STATUTE MILES.

SCALE OF METRES.

SCALE OF FEET.



The southern portion of a historical chart of Lake Michigan. Credit: Corps of Engineers.

1.0 INTRODUCTION

In December 2014, the state of Wisconsin submitted a National Marine Sanctuary nomination through NOAA to help preserve a nationally significant collection of shipwrecks along the western shore of Lake Michigan between the cities of Two-Rivers and Port Washington, Wisconsin (Figure 1.1) (Lake Michigan Wisconsin National Marine Sanctuary Proposal 2014). The sanctuary nomination focused on a 2,784 km^2 (1,000 sq. mi.) area that includes dozens of known shipwrecks but also over 100 vessels that were reported lost in the area although their positions remain unmapped (Jensen and Hartmeyer, 2014). In addition to this maritime heritage, the nomination noted that the area is of ecological significance and includes a region of pronounced seasonal upwelling that may play a role in the areas vibrant recreational and commercial fishing traditions (Plattner et al., 2006). The area is also of interest geologically. The proposed boundary straddles the southern edge of the maximum extent of the Wisconsin ice sheet 14,500 years ago (Mickelson et al., 1983) and has a complex mosaic of glacial moraines and shifting sediments (Waples et al., 2005) although the details and dynamics of these habitat features remain largely unmapped. A common need among these diverse disciplines and the coastal managers that make decisions upon lakebed resources is maps of the bottom. Whether searching for shipwrecks, fish habitat, or geologic formations, detailed maps of the lakebed including depth and bottom type are an essential tool. Although the proposed sanctuary would only manage cultural resources, it's potential designation is acting as a catalyst for multidisciplinary research.

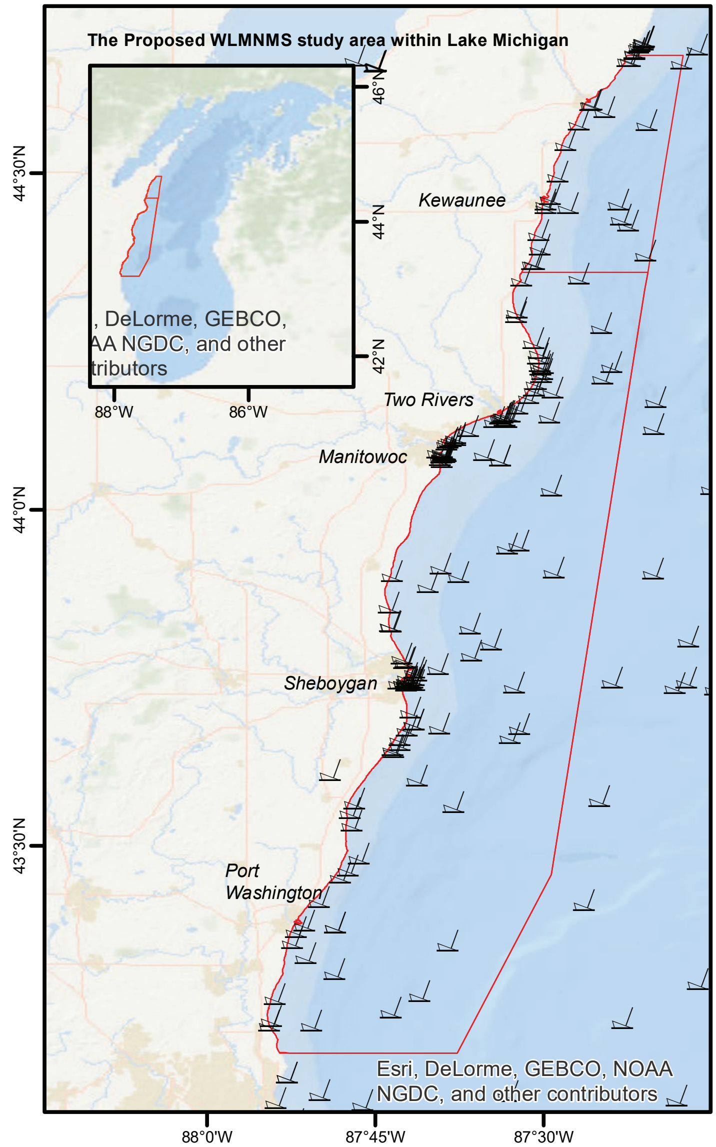


Figure 1.1. Map of the proposed Wisconsin-Lake Michigan National Marine Sanctuary (red line) and the abundance of known or suspected shipwrecks within it (Source: Wisconsin Historical Society). Inset shows the position of the proposed sanctuary within Lake Michigan.

Unfortunately, the existing maps of the lakebed in this area, and throughout much of Lake Michigan, suffer from multiple deficiencies by modern standards. In particular, existing mapping data are coarse, dated, and typically provide only depth information (Figure 1.2). For approximately 90% of the proposed 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) and aerial photo surveys have recently been conducted within the last few years, these are limited for lakebed mapping and 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.

The lack of recent maps of the lakebed is due to several factors. The boundary of the proposed sanctuary alone encompasses 2,784 km^2 which is a vast area by itself but must also compete with the rest of Lake Michigan and the other Great Lakes for mapping resources. The proposed sanctuary is also deep (avg. 215 ft, max. 453 ft.), and much of the lakebed lies below the penetrative capability of airborne and satellite based

Introduction

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 and using expensive sensors such as side-scan, interferometric or multibeam sonar, magnetometers, or camera systems depending on the desired map products. Costs vary significantly among projects and regions but are always a constraint. For example, a 2017 NOAA mapping project in the study area required a month of on-water survey time, and mapped 54 km^2 of lakebed at an acquisition cost of ~$2,000 per km^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.

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 the national and regional scale, 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 more formally identify, organize, and prioritize mapping activities. We consulted with both groups to understand mapping priorities at the scale of the proposed 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 and O'Brien 2015; Battista et al., 2017).

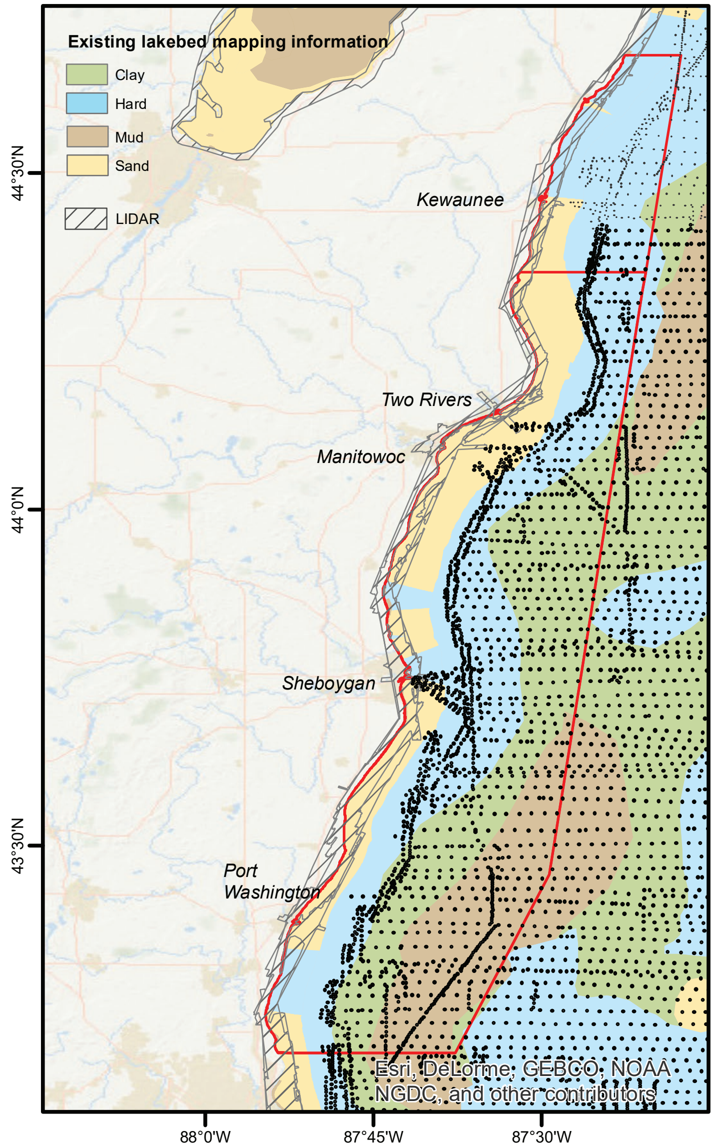
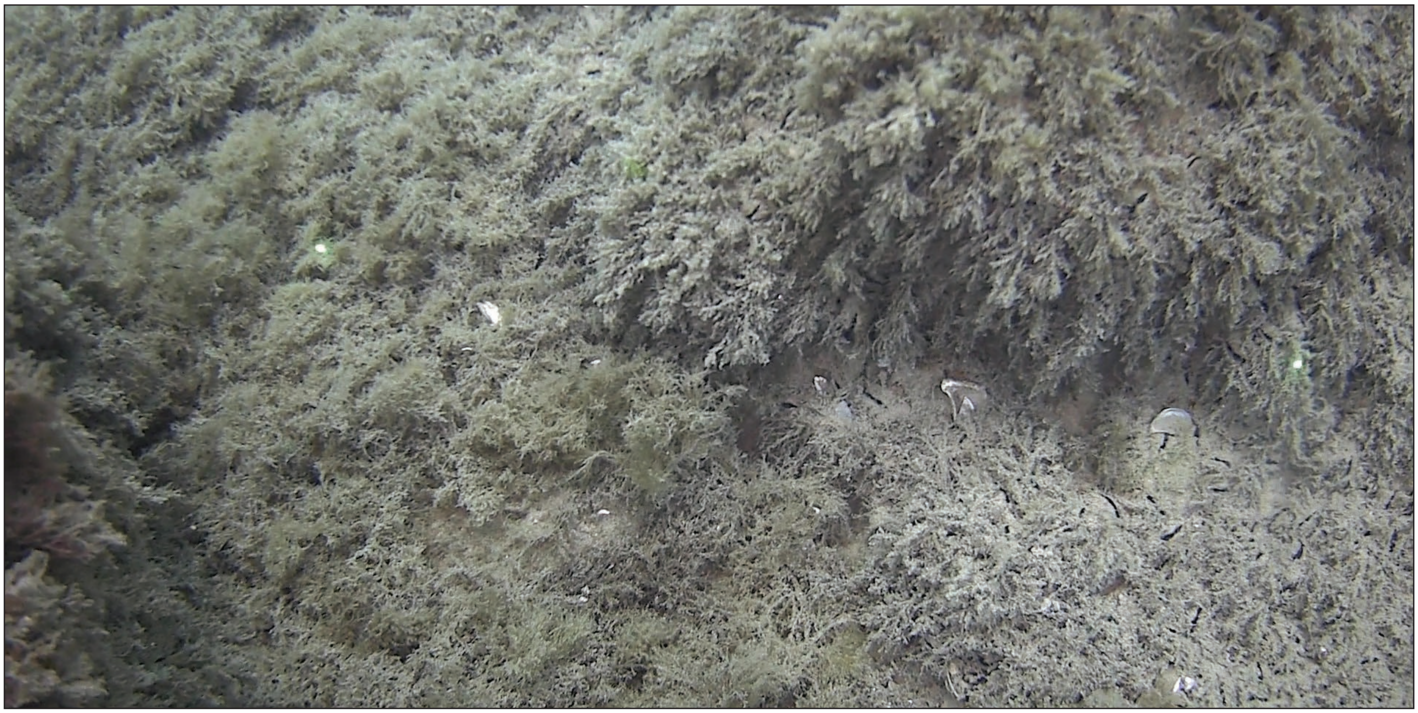
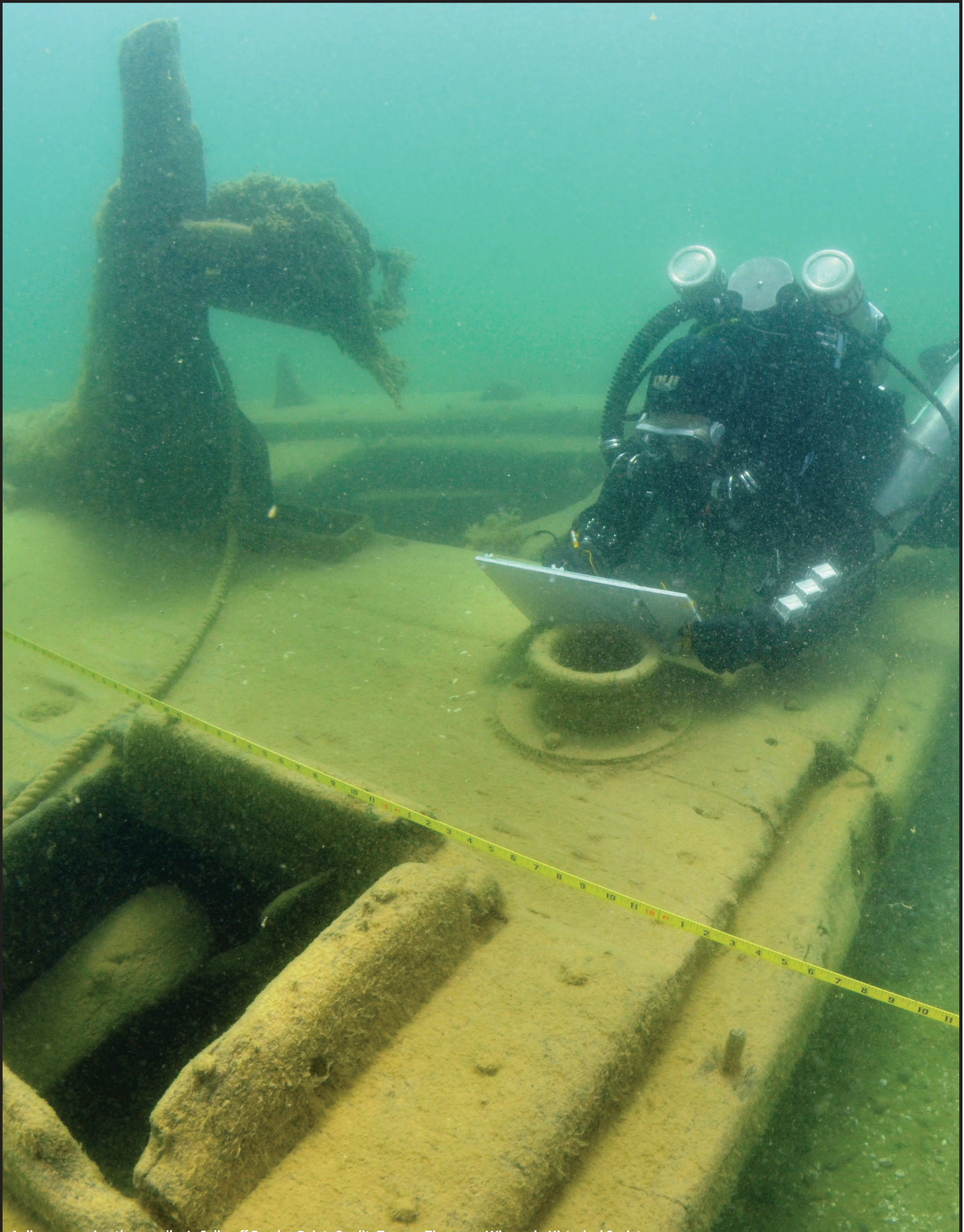


Figure 1.2. Map of the proposed WLMNMS (red line) and some of the lakebed mapping data within it. Dots represent location of available depth soundings (source: NOAA), polygons represent bottom types compiled from multiple sources by the Great Lakes Aquatic Habitat Framework (source: Wang et al., 2015), and the nearshore area where LIDAR has been acquired is indicated (source: Joint Airborne Lidar Bathymetry Technical Center of Expertise).

In 2016, we began a three year effort to compile existing spatial information and understand data gaps within the proposed sanctuary boundary. To better understand the mapping needs within the proposed sanctuary boundary, we developed an approach to efficiently and systematically gather quantitative input from multiple individuals on their mapping priorities. The system standardized inputs into a GIS framework that enabled us to identify groups of individuals with shared interests depending on their area of expertise, the types of mapping products that they need, the rationale used to justify their needs, and of course the locations that they prioritize for lakebed mapping. Our objectives with this report were to: 1) describe the process that we used to gather suggestions for lakebed mapping, 2) analyze the suggestions to locate and characterize hot spots of high priority, 3) use the results to help determine where to conduct our bottom mapping in 2018, and 4) disseminate the results such that others may identify collaborative opportunities in areas where multiple groups have similar mapping priorities.



Rocky outcrop on the lakebed (top left); Sand and gravel waves on the lakebed (top right); Invasive mussels and algae dominate parts of the lakebed (bottom). Credit: NCCOS.



A diver surveying the canaller LaSalle *off Rawley Point. Credit: Tamara Thomsen, Wisconsin Historical Society.*

2.0 METHODS

2.1 WEB-BASED 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 products are needed, when the products are needed, and to provide a justification of why the site is a priority for mapping. The application was built upon similar projects in other areas (Kvitek and Bretz 2006, Battista and O'Brien 2015, Battista et al., 2017) but was modified to enable more quantitative input and customized to incorporate local data and address local issues along the Wisconsin shore of Lake Michigan. This customization was accomplished by convening a Technical Advisory Team (TAT) that consisted of local scientists and managers from the region who have a stake or expertise in lakebed mapping. The TAT reviewed the on-line application, recommended locally relevant datasets and 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, history, and coastal management (Appendix A). They were from federal, state, county, university, and other groups. The common thread among all participants was that they relied heavily on lakebed maps within the proposed 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 it would save their selections as they were made. Respondents were trained how to use the application during in-person meetings or webinars conducted in November 2017. During the training, respondents were provided background on the objectives of the project, shown how to access the menus in the system, and stepped-through some example scenarios during 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 consisted of over 50 layers within six 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/wilm/). 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, 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 100 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 4 by 4 km grid cells to standardize the size of the area designated during coin placement (Figure 2.1). This grid consisted of 261 equal area cells aligned to the US National Grid/Universal Transverse Mercator coordinate system and which intersected the area proposed for the sanctuary. Both of the sanctuary boundary alternatives (Boundary Alternatives A and B) identified in the Draft Environmental Impact Statement (ONMS 2016) were contained in the grid. The only constraint on coin placement was that no more than 10 coins 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. This constraint forced respondents to allocate their limited coins in 10 to 100 cells, or 4% to 38% of the proposed sanctuary (depending on the number of coins allocated per cell).

Methods

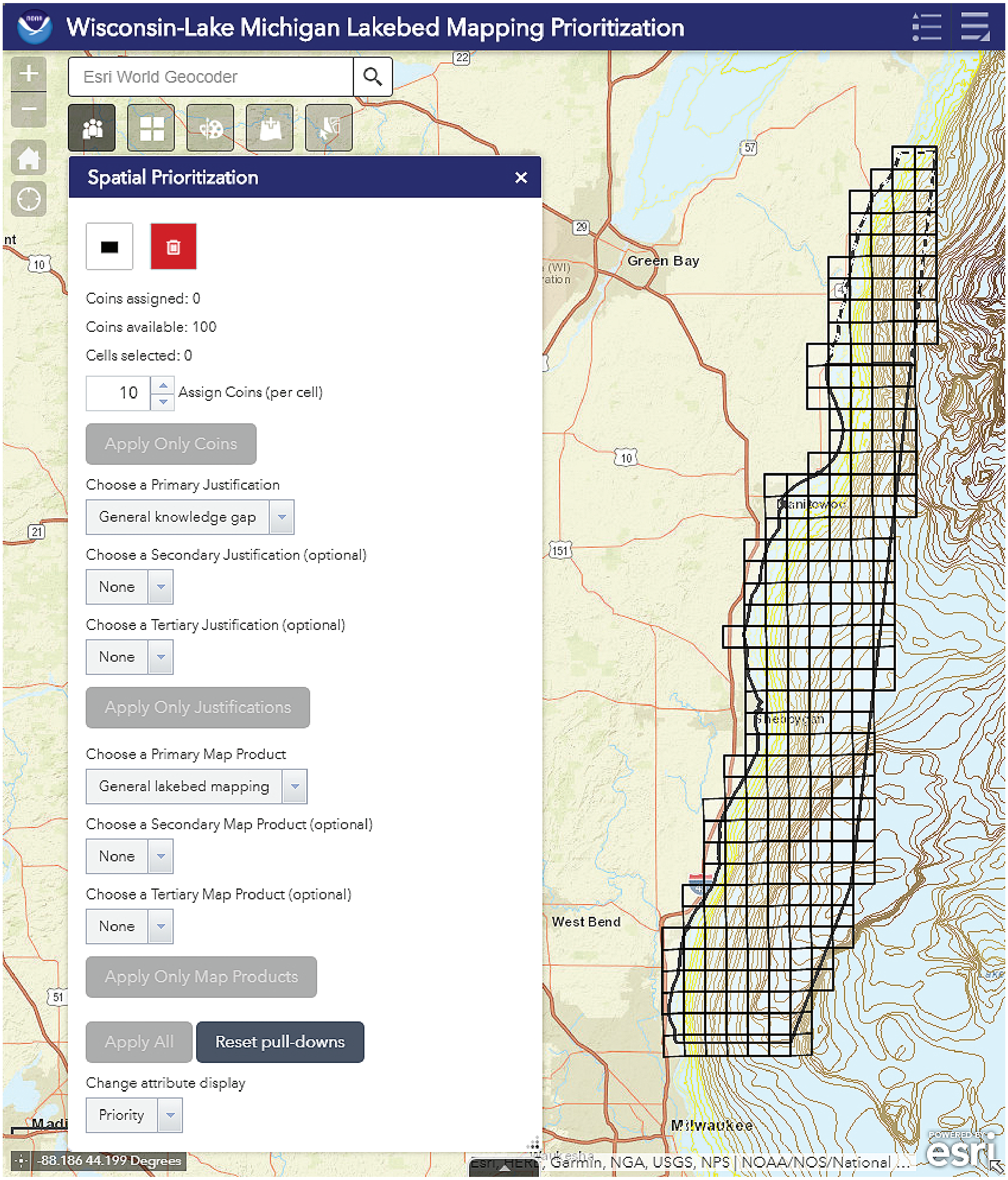


Figure 2.1. A screen shot of the application interface for prioritizing mapping areas. The selection grid overlayed on the study area is at right.

Respondents were instructed to not only use the coins to convey where mapping is needed, but also when mapping products are needed. More coins denoted greater urgency based on the following general guidance: 8-10 coins is a high priority needed immediately, 4-7 coins means maps are needed in the next 2 to 4 years, and only 1-3 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 pull down menu allows respondents to select the number of coins (up to 10) 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 what types of Map Products are needed in each selected cell. Simple pull-down menus were prepopulated with several types of map products to choose from (Table 2.1) based on input from the TAT along with the default setting of "General Lakebed Mapping". Respondents had to indicate a primary Map Product and could optionally designate a secondary and tertiary Map Product. Last, respondents could indicate why they chose each cell, again using pull-down menus prepopulated with a list of Justifications (Table 2.2) along with the default setting of "General Knowledge Gap". Respondents were required to select a primary Justification, but could also optionally select a secondary and tertiary rationale as well. Respondents were urged to contact us if none of the Map Products or Justification options were suitable for their needs; however, no one expressed any limitations of the prepopulated menus. The application saved each input as it was made on-line, and respondents could return to the system to edit their selections, in any order, as many times as they wished.

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

Map Products	Definition/Examples
General lake bed mapping	various collection methods to understand the spatial distribution of lakebed features
Bathymetry / Digital Elevation Model	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 color	imagery from multispectral satellite or airborne sensors
Lakebed surface type, hardness/smoothness/slope	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
General knowledge gap	general lack of lakebed mapping information
Commercial fishing	popular commercial or charter fishing destinations
Cultural/historical resources	shipwrecks, debris fields
Diving	popular recreational dive site such as ship wrecks
Important biota/natural area	rock outcrop, spawning/nursery area, river mouth, living resources management
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

Methods

2.2 DATA ANALYSIS

2.2.1 Quality Control and Data Compilation

A total of 22 respondents entered mapping suggestions into the on-line prioritization application (Appendix A). The 261 grid cells and corresponding priorities from the 22 respondents were compiled into a single table consisting of 5,742 rows. Each row therefore consisted of a single respondents priorities for a given cell with columns noting the number of coins assigned, justifications (up to three), and map products (up to three). The general areas of expertise for each respondent were also linked to this table (i.e. ecology, geology, history, or other). Several quality control measures were implemented. First, it was confirmed that respondents had allocated a total of exactly 100 coins and that no more than 10 coins were allocated in any one cell by each respondent. Next, grid cells that had no coins assigned to them initially retained the default attributes of "General Knowledge Gap" and "General Lakebed Mapping" or in some cases had been attributed by respondents with a particular Justification or Map Product. Since these cells had no coins allocated, all the Justification and Map Product values were converted to "none". Lastly, to prevent double or triple counting in some analyses, we confirmed that no respondents had assigned the same Justification or Map Product attributes at multiple levels (first, second, and/or third priority) in the same cell. This table was the basis for all subsequent analyses.

2.2.2 Which Justifications and Map Products Were Most Common?

Pie charts were used to determine which Justifications and Map Products were most commonly selected by respondents. For this, the total number of coins associated with primary, secondary, and tertiary Justifications were tallied separately and their relative proportions were visualized using pie charts. In each of these pie charts the total number of coins was 2,200 (22 respondents X 100 coins each). In addition, we tallied coins for each Justification category (excluding "none") across all priority levels. For example, coins would be counted towards "Infrastructure" if that were chosen as the primary, secondary, or tertiary rationale. Similarly, the total number of coins associated with primary, secondary, and tertiary Map Products were tallied and used to produce pie charts, as well as a tally by Map Product at any priority level.

2.2.3 Were Particular Justifications and Map Products Commonly Listed Together?

Hierarchical cluster analysis was used to explore if particular combinations of Justifications and/or Map Products commonly occurred together. For this analysis, a table was created with all 261 grid cells as rows and the total number of coins within each category of Justification and Map Product (any priority level) as columns. Grid cells with no coins were excluded. Remaining grid cells were then subjected to several clustering algorithms using standardized and unstandardized data transformations in order to identify the consistent patterns of clustering regardless of algorithm or approach used. Results are reported using the groupings and values derived from unstandardized data and distance characterized using the Ward Minimum Variance algorithm (JMP v12), which yielded results that were representative of several algorithms. Cells were clustered based on number of coins under each Justification and Map Product. 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/or Map Product category were calculated 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 261 cells were summarized and 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 various fields of expertise, and within the most commonly used Justifications and Map Products 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 type of general expertise of the respondents (i.e. ecological, geological, or historical). Following that, we partitioned responses into the total number of coins per cell within each of the top five Justifications (any priority level) identified in Section 2.2.2. Preliminary analysis revealed these to be "Cultural/historical resources", "Scientific research", "General Knowledge gap", "Sediment movement and management", and "Important biota/natural area". We also partitioned the responses into the total number of coins per cell within each of the top three Map Products (any priority level) as identified in Section 2.2.2. Preliminary analysis revealed these to be "General Lakebed mapping", "Bathymetry/Digital Elevation Model", and "Lakebed surface type". These last eight layers (top five Justifications and top three Map Products) were evaluated by themselves and also combined into a composite layer as described below.

Hotspots representing the highest priorities for future mapping were identified from each of these different maps. Cell values (total number of coins) in each map were ranked from highest to lowest and the top 10 percent of highest value cells (26 cells in each map plus any ties for the 26th value) were marked and labelled as "high priority" cells. We also marked the top 5 percent of cells as "highest priority" cells. We then compared these maps for overlap in high priority cells.

2.2.5 Where Will NCCOS Map in 2018?

We explored several approaches for identifying possible areas that could be surveyed in 2018 given our constraints of funding, vessel time, and availability of sonar equipment. We sought a small number of cells (3-6) based on the size of the area mapped in 2017 (54 km^2) using similar resources. For this part of the analysis we wanted to identify the very highest priority cells of the greatest importance to the broadest diversity of respondents. Three approaches were explored, each with their own strengths and biases. In the first, we began by using 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, converted the rankings to percentiles to standardize them (since there were unequal numbers of ties and raw ranks covered different scales), and then added the percentiles together 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. Next, we combined the highest priority cells (top 5th percentile) of only the 5 most commonly used Justifications and 3 most selected Map Products. The number of times a cell was in the top 5th percentile of any of these 8 categories was tabulated and plotted. These represent the most highly prioritized cells in the most commonly used Justification and Map Product categories. This excludes any influence from the seldom used categories. In the last scenario, we plotted the locations of the Clusters identified in Section 2.2.3 with an emphasis on Cluster 4. Preliminary analysis revealed that Cluster 4 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 others, was based on which Justifications and Map Products actually occur together in each cell.

Charles Menza of NCCOS discusses lakebed mapping. Credit: NCCOS.

NCCOS mapping team with sonar towfish aboard NOAA's RV Storm. Credit: NCCOS.

3.0 RESULTS

A total of 22 respondents entered suggestions into the on-line prioritization tool and allocated a combined total of 2200 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 was more representative of a larger group. It is unknown how many respondents, and to what extent, they may have used the tools in the Digital Atlas or independent datasets to assist with their selections.

3.1 WHICH JUSTIFICATIONS AND MAP PRODUCTS WERE MOST COMMON?

The proportion of coins that were assigned using the Justification categories at the primary, secondary, tertiary, and combined levels (primary, secondary, or tertiary) revealed that there were five main Justifications used most often (Figure 3.1a-d). The topics “Cultural/Historical resources” and “Scientific research” each comprised approximately one-fourth of all the primary Justifications chosen. These were followed by “General knowledge gap”, “Sediment movement and management”, and “Important biota/natural area” which each comprised 14-17% of primary Justifications that were selected. The eight remaining choices (excluding “none”) each accounted for less than 5% of the remaining coins. Approximately two-thirds of the coins allocated by respondents included a secondary Justification, with the same top three categories being used most often.

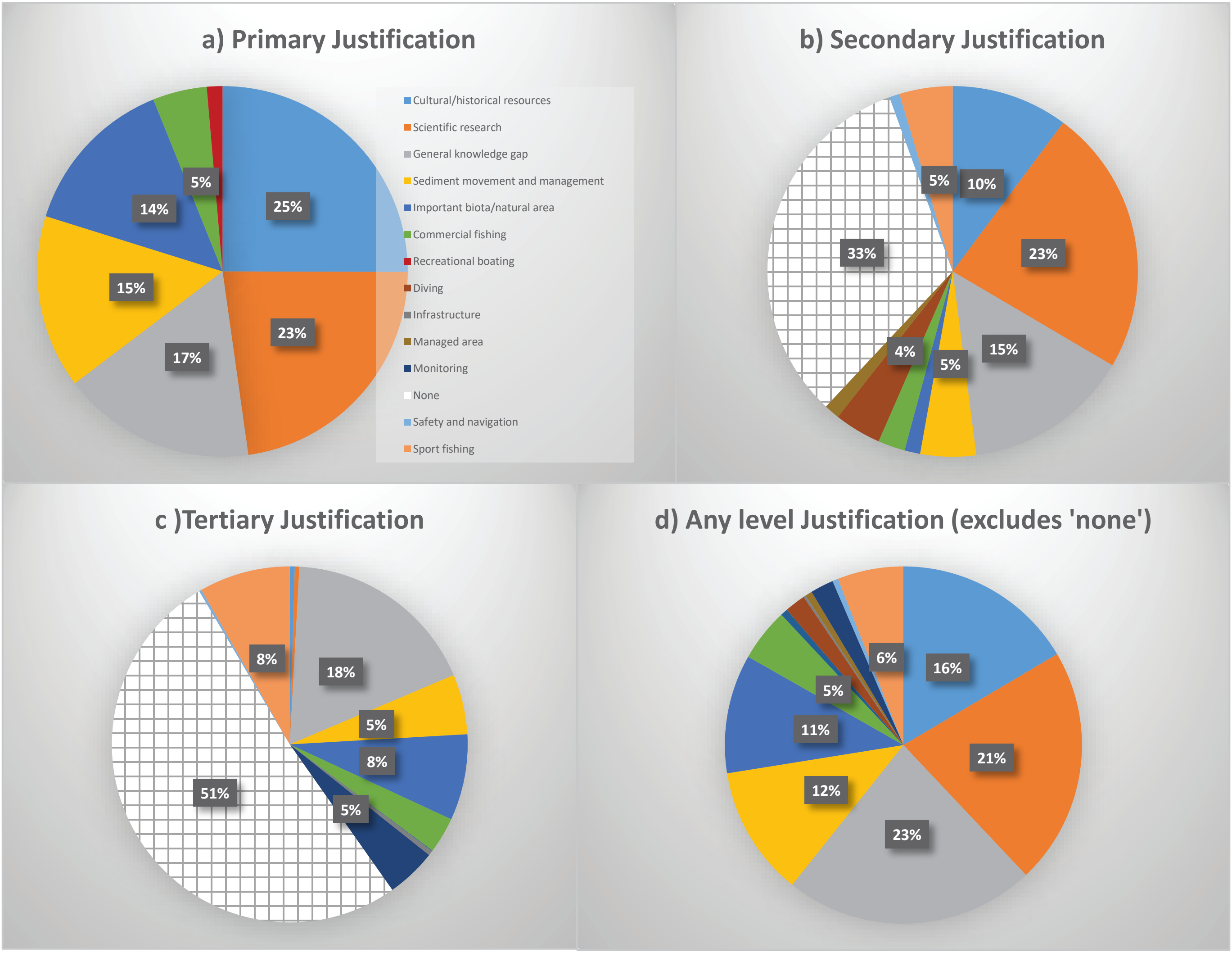


Figure 3.1. The proportion of coins attributed using: a) primary Justification, b) secondary Justification, c) Tertiary Justification, and d) Any level of Justification. Percentages <4% are not listed.

Results

Only approximately half of the coins allocated by respondents included a tertiary Justification, with “General knowledge gap” being the most common selection. Considering all levels of Justification, the same five categories emerged as the most often selected. This indicates that “Cultural/Historical resources”, “Scientific research”, “General knowledge gap”, “Sediment movement and management”, and “Important biota/natural area” were the dominant rationales when identifying priority areas to map. These categories were one focus in the subsequent hotspot analysis to identify high priority areas.

The proportion of coins that were assigned using the Map Products categories at the primary, secondary, tertiary, and combined levels (primary, secondary, or tertiary) revealed three main desired products (Figure 3.2a-d). The products “General Lake-bed mapping” and “Bathymetry/Digital Elevation Model” were by far associated with the greatest number of coins and together comprised ~75% of all primary Map Product types selected. Approximately 2/3 of the coins allocated by respondents included a secondary Map Product, with “Lake-bed surface type” the dominant choice and “Ferrous object detections/magnetic anomalies” replacing “General lake-bed Mapping” in the top three. Only ~60% of the coins allocated by respondents included a tertiary Map Product, with “Sub-bottom geology” and “Ground-truth data” being the most common selections.

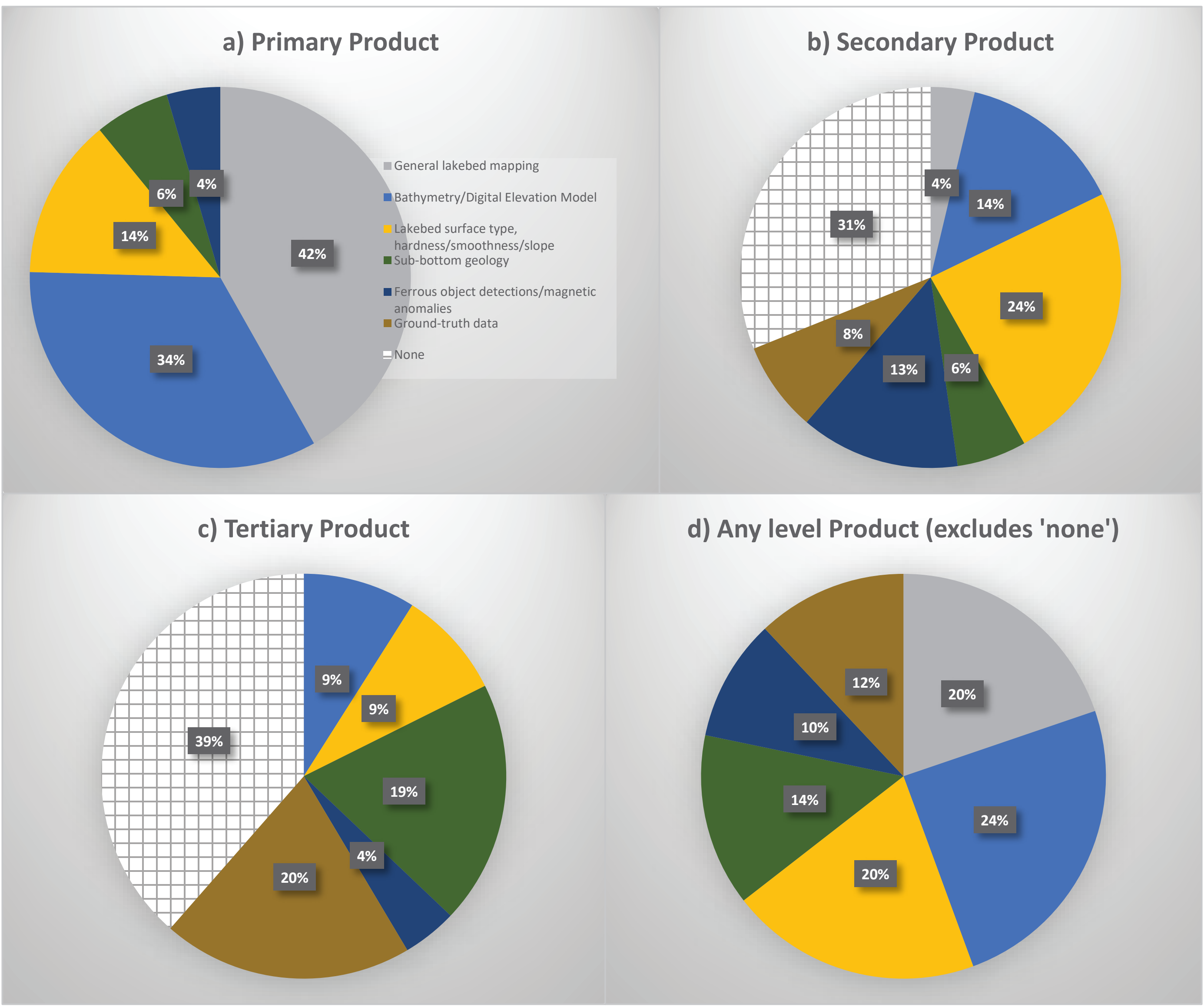


Figure 3.2. The proportion of coins attributed using: a) primary Map Product, b) secondary Map Product, c) Tertiary Map Product, and d) Any level of Map Product. Percentages <4% are not listed.

Considering all levels of Map Product the categories most often selected were "General Lake-bed mapping", "Bathymetry/Digital Elevation Model", and "Lake-bed surface type" although the other Map Products were selected with 10-14% of the coins allocated which reflects an overall diversity in desired Map Products. The 3 most dominant categories for Map Product were used in the subsequent hotspot analysis to identify high priority areas.

3.2 WERE PARTICULAR JUSTIFICATIONS AND MAP PRODUCTS COMMONLY LISTED TOGETHER?

No coins were assigned to 84 of the 261 cells in the study area. The remaining 177 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 two attributes: 1) which Justifications and/or Map Products are typically chosen together, and 2) what unique combinations of Justification and/or Map Product separated the clusters from each other.

Cluster analysis of the 177 cells on the basis of the number of coins associated with the various Justifications and Map Products revealed 4 groups of cells that had a similar suite of attributes (Table 3.1). Cluster 1 was the largest, comprised of 122 cells. This group typically consisted of low coin totals and was not dominated by any particular Justifications or Map Products. Cells in Cluster 2 had moderately high coin totals for "Scientific research" and "Sediment movement and management" as Justifications, and "Bathymetry/Digital Elevation Model" and "Sub-bottom geology" as desired Map Products. Cluster 3 was comprised of 10 cells. Notably, this group had higher totals for "Cultural/historical resources" and "Scientific research" as Justifications almost exclusively. These cells also typically had high coin totals for "Lake-bed surface type" and "Sub-bottom geology", and was different than the other clusters as the only group with high coin totals in the "Ferrous object detections/magnetic anomalies" category. Many of the rest of the Justifications and Map Products had very low values. Lastly, Cluster 4 was comprised of 16 cells with high coin totals in several categories. Justifications occurring together in this cluster were "Cultural/historical resources", "Important biota/natural area", and "Scientific research". Map Products requested together in this cluster were "Bathymetry/Digital Elevation Model", "Lake-bed surface type", and "Sub-bottom geology". This was the only cluster with even a moderate number of coins Justified based on "Commercial Fishing" and "Sport Fishing", and the only cluster with a large number of coins under the "Ground-truth data" category of Map Products.

Table 3.1. Cluster analysis of cells based on the number of coins assigned under each Justification and Map Product. Mean number of coins associated with each Justification or Map Product among cells in each cluster is given. The highest value in each column is highlighted.

		Justification													Map Products					
Cluster	Cell Count	General knowledge gap	Commercial fishing	Cultural/historical resources	Diving	Important biota/natural area	Infrastructure	Managed area	Monitoring	Recreational boating	Safety and navigation	Scientific research	Sediment movement/management	Sport fishing	General lake-bed mapping	Bathymetry/DEM	Lakebed surface type	Ferrous objects/magnetic anomalies	Ground- truth data	Sub-bottom geology
1	122	2.7	0.7	3.0	0.6	1.9	0.0	0.2	0.6	0.1	0.1	2.8	1.0	1.0	4.2	4.2	3.6	1.6	1.6	0.8
2	29	11.7	1.4	4.5	0.7	0.5	0.3	0.0	0.7	0.7	0.3	8.8	10.4	0.8	9.6	11.6	4.7	2.2	7.2	9.3
3	10	15.1	1.1	11.6	0.0	1.0	0.0	0.0	0.0	0.0	0.0	14.7	0.0	1.0	2.1	6.8	15.6	15.8	0.1	11.0
4	16	16.2	5.8	10.8	0.0	16.3	0.0	0.0	0.3	0.0	0.3	17.2	8.7	7.9	12.1	20.6	17.8	4.8	12.5	13.6

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 expertise, Justification, or Map Products. Cells with the highest total number of coins allocated among all respondents occurred in four regions (Figure 3.3a). The largest concentration of cells in the top 5th percentile of total coins was northeast of Two Rivers. This group was also surrounded by many cells in the top 10th percentile. Another group of high priority cells based on total coins was located in the nearshore waters off Sheboygan. Two smaller areas of high-value cells were located in near-shore waters off Port Washington and south of Manitowoc. A somewhat similar pattern was found when considering the number of respondents that allocated coins in each cell (Figure 3.3b). The same general groups of cells off Two Rivers and Sheboygan had the highest value (top 5th percentile) and the cells south of Manitowoc and off Port Washington were also important (top 10th percentile). The number of different Justifications was highest in the middle third of the study area with two concentrations of especially high diversity, off Sheboygan and eastward from Two Rivers (Figure 3.3c). This reflects diverse reasons for mapping those areas. Not only do these three 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 22 respondents placed a single coin in the southeastern one-third of the area offshore of Port Washington.

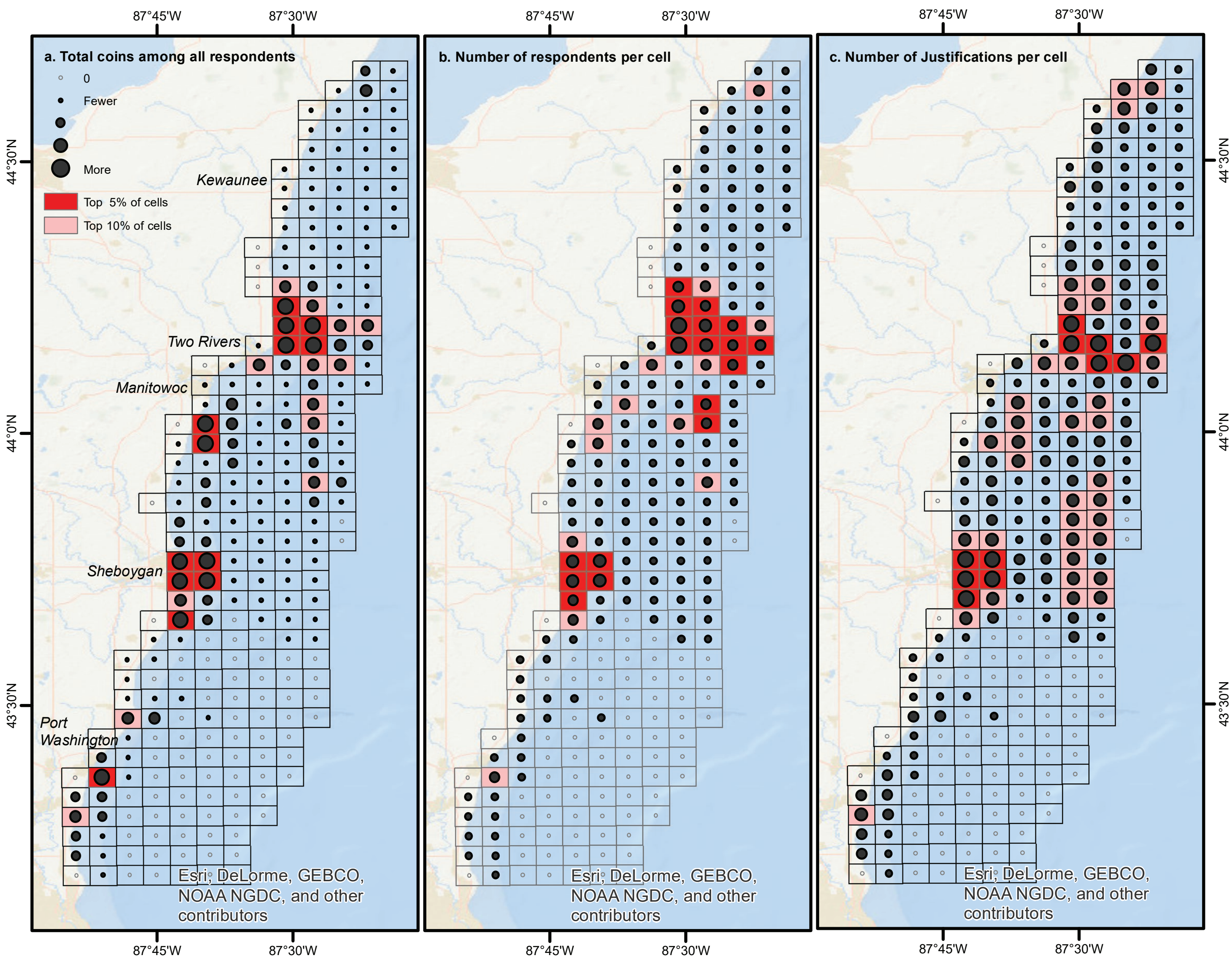


Figure 3.3 a-c. Sum of all coins among all respondents in each cell (a-left). Number of respondents allocating at least one coin in the cell (b- middle). Total number of different Justifications used in each cell (c- right). Note that in this and other figures like it, the cells appear rectangular due to the map projection.

When the coin allocations were partitioned based on the primary area of expertise of the respondents some key differences in priority areas became apparent (Figure 3.4a-c). Respondents in the geologist group (n=4) allocated their coins in only two areas, eastward from the promontory off Two Rivers into deeper waters, and nearshore along the coast south of Port Washington (Figure 3.4a). In contrast, respondents in the historian group (n=5) allocated most of their coins in the space between the top areas selected by the geologists. Historians prioritized a large group of cells extending offshore from south of Manitowoc, three groups of cells north, south, and offshore from Sheboygan, and a strip of cells extending offshore from the promontory north of Port Washington (Figure 3.4b). Due to the large number of ties in this group, the 5th and 10th percentiles of highest values comprise the same group of cells. The ecologists (n=9) were somewhat more diffuse in their allocations, as might be expected with more individuals placing coins. Ecologists had most interest in the central and northern parts of the study area (Figure 3.4c). Four areas comprised the top 5th percentile by ecologists, two cells at the northern extremity of the study area, a group of nearshore cells east of Two Rivers, and also nearshore cells south of Manitowoc and off Sheboygan.

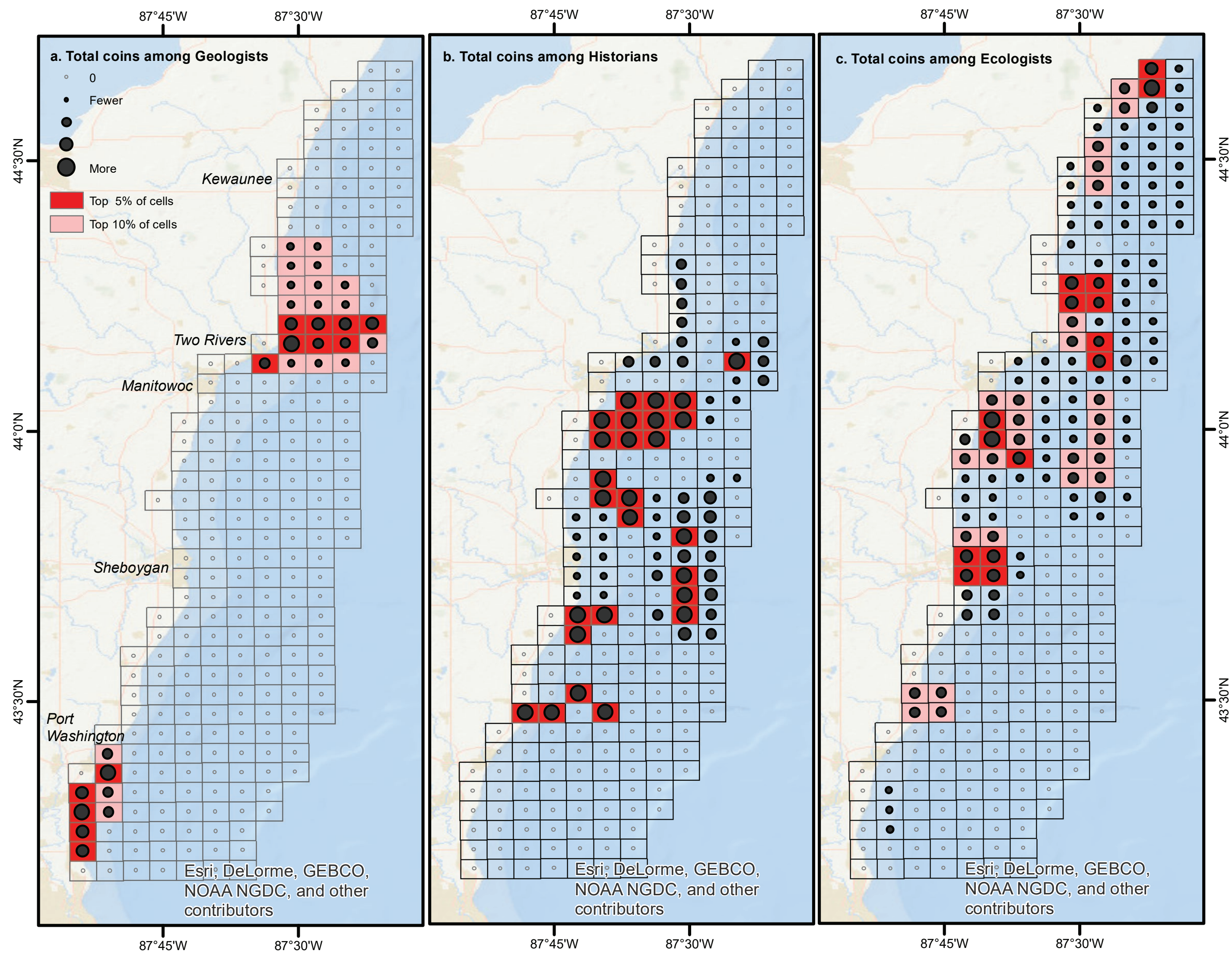
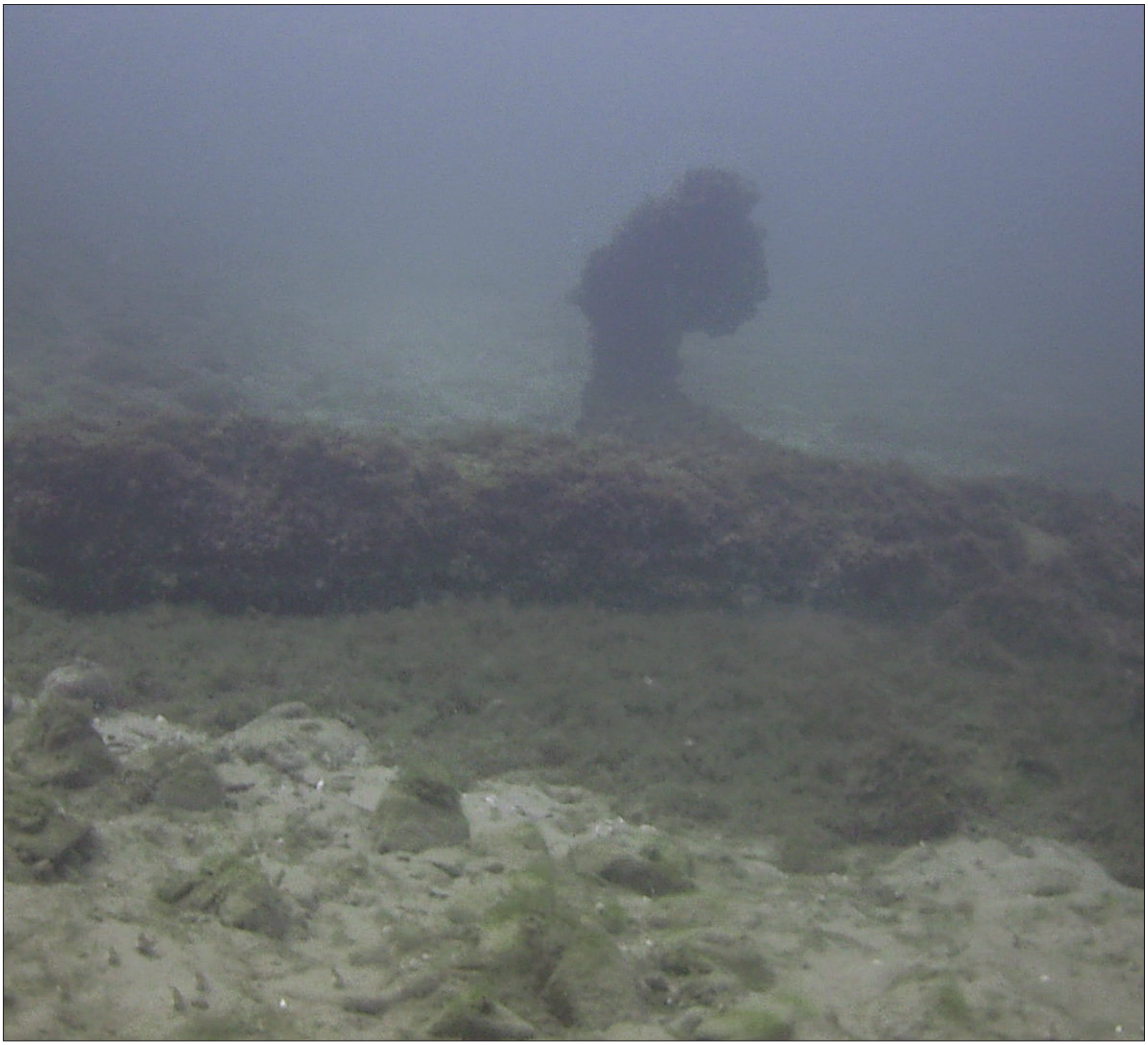


Figure 3.4a-c. Sum of all coins in each cell among respondents with expertise in the field of geology (a-left). Sum of all coins in each cell among respondents with expertise in the field of history (b- middle). Sum of all coins in each cell among respondents with expertise in the field of ecology (c- right). Note that the top 5th and 10th percentile include the same cells for historians due to the large number of ties in cell value (thus no pink cells are visible).

Results

When we partitioned the responses based on the Justifications that were selected in each cell, additional patterns became apparent (Figure 3.5a-e). Examining the top 5 Justifications (from Section 3.1) separately revealed some additional patterns of interest. The more broadly applicable Justifications of “General knowledge gap” and “Scientific research” were somewhat diffuse in their spatial distribution but were primarily used in the middle and northern thirds of the study area (Figures 3.5a-b). Not surprisingly the “Cultural/historical resources” Justification was used primarily in the middle one-third of the study area and generally corresponded to the area prioritized highly by historians (Figure 3.5c). The “Sediment movement and management” Justification had the highest values and overlaps with the two areas selected most often by geologists (Figure 3.5d). There was however, an additional area near Sheboygan justified with that rationale that was not picked by geologists. Last, the “Important biota/natural area” Justification had a somewhat different pattern (Figure 3.5e). The largest area in the top 5th percentile with this Justification was south of Manitowoc and extended offshore. Interestingly, this group of cells overlapped the same block of cells that were noted as a high priority by the respondents with historical expertise.



Anchor found off Manitowoc during NOAA 2017 mapping mission. Credit: NCCOS.

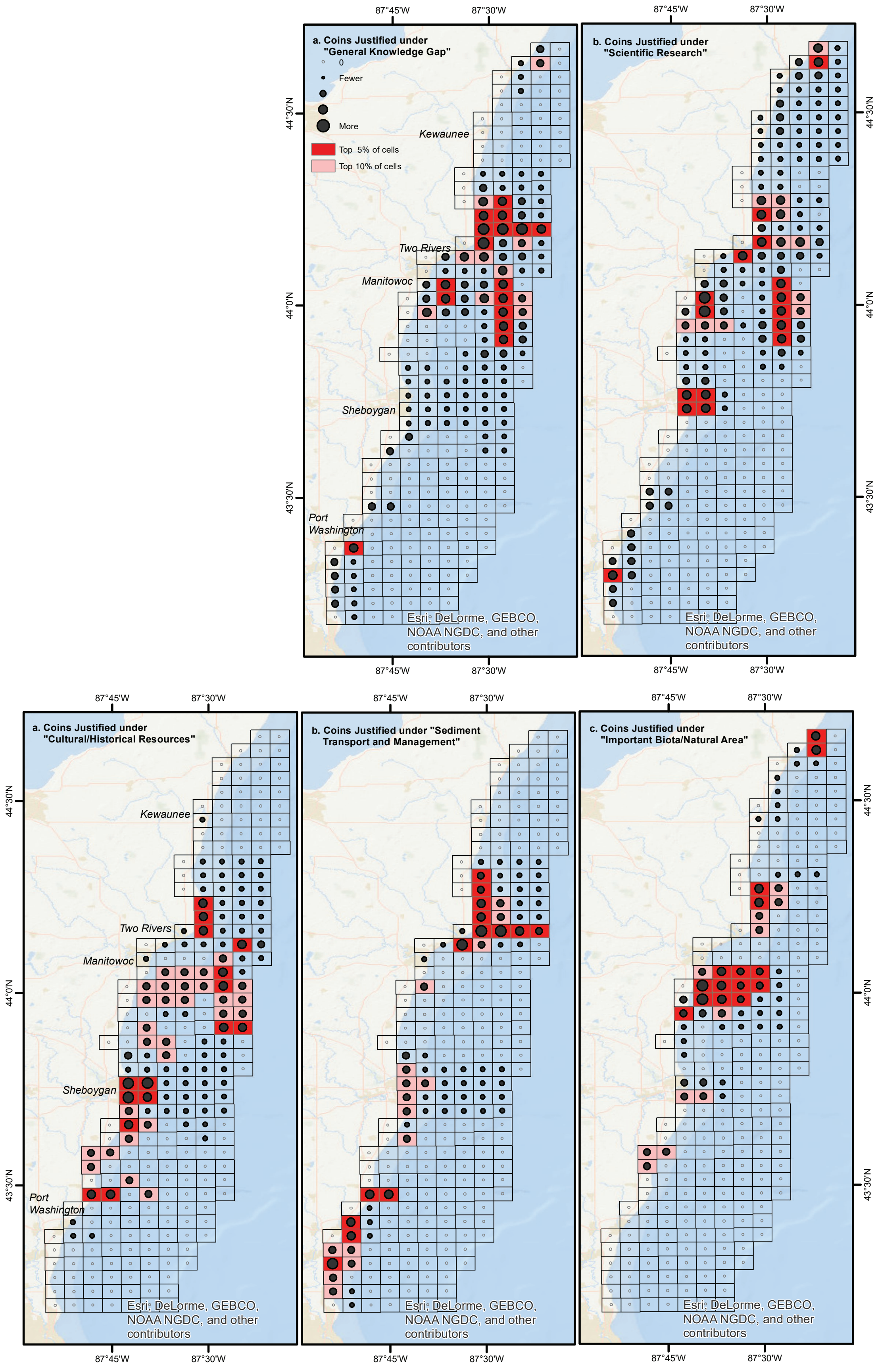


Figure 3.5a-e. Sum of all coins in each cell Justified on the basis of "General knowledge gap" (a- top left). Sum of all coins in each cell Justified on the basis of "Scientific research" (b- top right). Sum of all coins in each cell Justified on the basis of "Cultural/historical resources" (c-bottom left). Sum of all coins in each cell Justified on the basis of "Sediment movement and management" (d- bottom middle). Sum of all coins in each cell Justified on the basis of "Important biota/natural area" (e- bottom right).

Results

When we partitioned the responses based on the three most commonly selected Map Products, additional patterns became apparent (Figure 3.6a-c). Most of the coins allocated in the broad Map Product category of "General Lake-bed mapping" were located in the middle one-third of the study area with highest priority cells eastward off Two Rivers, south of Manitowoc, and near Sheboygan (Figure 3.6a). The Map Product "Bathymetry/Digital Elevation Model" covered a similar pattern (Figure 3.6b) whereas "Lake-bed surface type" was selected almost exclusively in the northern two-thirds of the study area (Figure 3.6c). The highest priority cells in the top 5th percentile were off Two Rivers and south of Manitowoc in the same area that was prioritized highly by historians and on the basis of "Important biota/natural area".

The cells with the highest combined ranks based on total number of coins, number of respondents, and diversity of Justifications are plotted in Figure 3.7a. Highest values were concentrated in small groups of cells off Sheboygan and eastward from Two Rivers. Moderately high values were more diffuse with a loose grouping of cells south of Manitowoc and Two Rivers and a couple of isolated cells elsewhere.

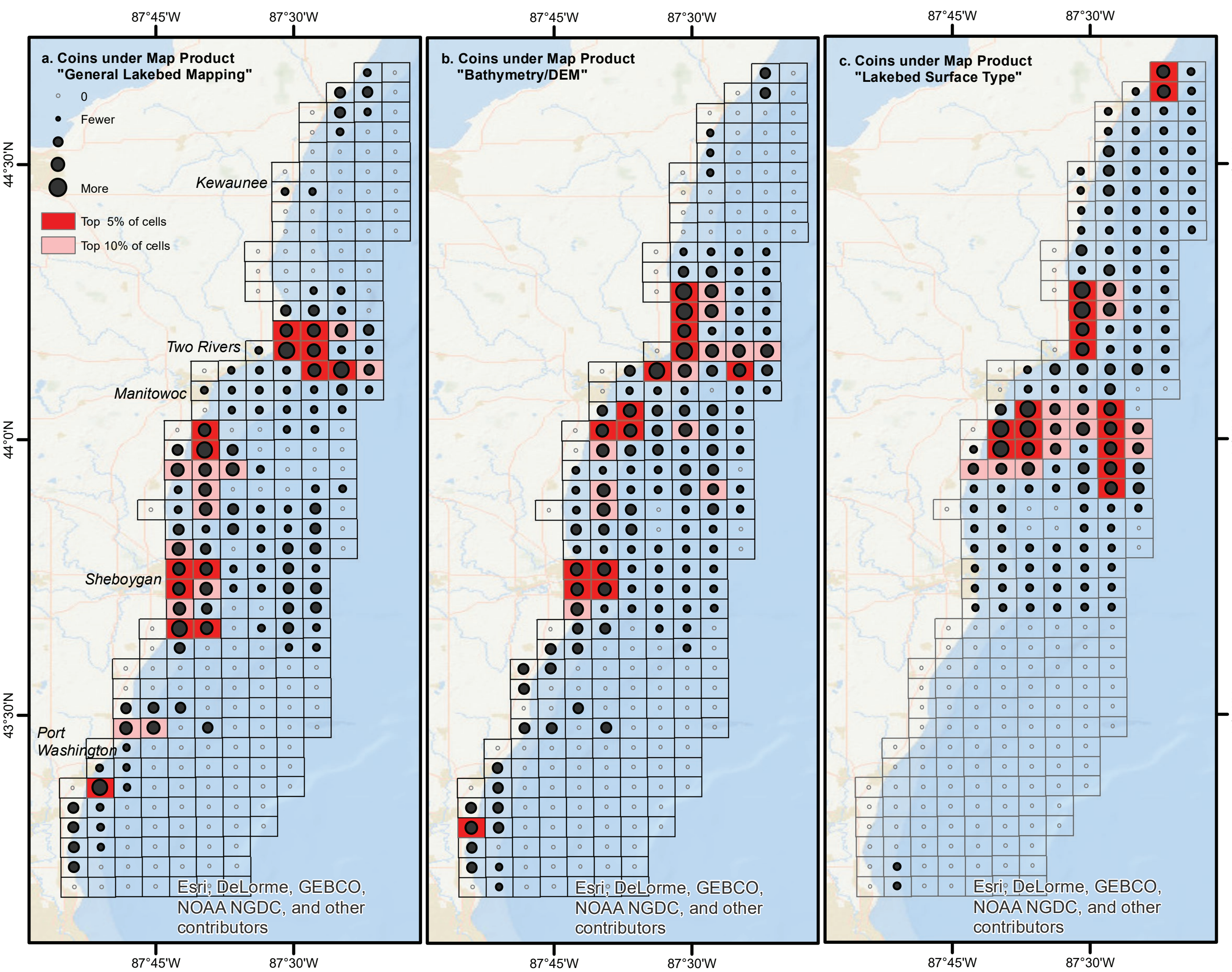


Figure 3.6a-c. Sum of all coins in each cell associated with the Map Product "General Lakebed mapping" (a-left). Sum of all coins in each cell associated with the Map Product "Bathymetry/Digital Elevation Model" (b- middle). Sum of all coins in each cell associated with the Map Product "Lakebed surface type" (c- right).

The most highly prioritized cells in the most commonly used Justification and Map Product categories are plotted in Figure 3.7b. There were four groups of somewhat continuous cells that had high values. Nearshore areas east of Two Rivers, south of Manitowoc, and off Sheboygan can be considered top priorities using the approach. An area offshore from Manitowoc and Two Rivers was a priority as well.

Plotting the Clusters that resulted from the combined analysis of all Justifications and Map Products (Section 3.2) revealed that cells in Cluster 4 occurred in four regions (Figure 3.7c). Cluster 4 had the highest coins totals in the most Justification and Map Product categories. These cells consisted of the same general groups as were identified from the previous two approaches (Figures 3.7a-b), but also a group of two cells at the northern extremity of the study area. Cluster 3 was located entirely in a strip offshore from Manitowoc. Cluster 2 was located around the periphery of Cluster 4 and also nearshore around Port Washington. Cluster 1, filled in the spaces between the other Clusters.

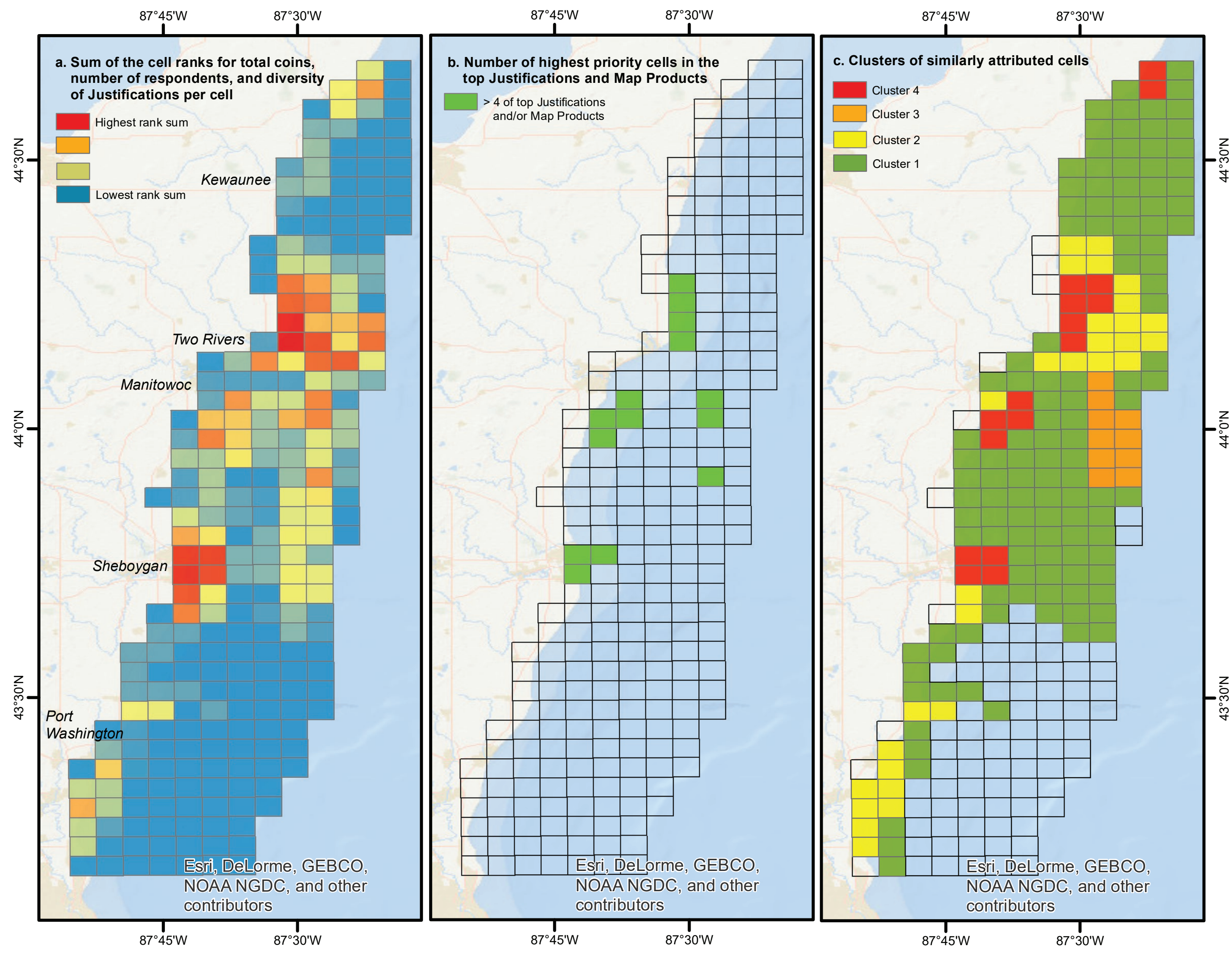


Figure 3.7a-c. Sum of the cell ranks based on total coins, number of respondents, and diversity of Justifications in each cell (a- left). Sum of times each cell was in the top 5th percentile of the top 5 Justifications and/or top 3 Map Products selected by respondents. Cells with 4 or more incidences of top 5th percentile values are highlighted in Green (b- middle). Cluster membership of the cells from Section 3.2 based on Justification and Map Products that were selected (c- right).


Wreck of the Francis Hinton *off Manitowoc. Credit: NCCOS.*


Wreck of the Hetty Taylor *off Sheboygan. Credit: Tamara Thomsen, Wisconsin Historical Society.*

4.0 DISCUSSION

We used an on-line application to gather opinions from 22 local experts regarding their priorities for mapping the lakebed within the proposed WLMNMS. The system allowed respondents to indicate where mapping is needed, the types of map products that are required, the urgency of the need, and a rationale to justify their priorities. Based on analysis of the responses, 3-4 small groups of cells emerged as the highest priority for many experts. These were located east of Two Rivers, off Sheboygan, and south of Manitowoc and consisted of 3-5 contiguous cells. They were identified consistently using three different techniques of summarizing the data even though each technique emphasized different aspects of the data and was subject to different biases and strengths. A few additional areas emerged as highly important in at least two analyses. These were an offshore area southeast of Two Rivers and an area at the northern extremity of the proposed sanctuary.

We will likely focus our mapping in 2018 on some combination of these highest priority cells. However, we will refine the area based on survey optimization and finer scale considerations than were allowed in this cell-based prioritization. For example, the tools and effort needed to map various grid cells differs depending on depth, water clarity, and bathymetric variation. Estimating and scaling effort to meet mapping needs will 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 we recognize 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 have extensive lakebed survey data. As we focus on a 2018 mapping site, we will exclude any high priority areas that we mapped in 2017 and those areas recently covered or planned to be covered by LIDAR.

What caused these patterns of high priority cells? Plotting the data in a diversity of 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 nearshore cells off Sheboygan and the cells extending offshore eastward from Two Rivers. 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. The inshore cells east of Two Rivers in particular were high priorities for ecologists and geologists to map “Important Biota/Natural Areas” and “Sediment Transport/Management”. These same cells were also often justified as important to map due to “Cultural/Historical resources”. Furthermore, these cells often had the same suite of desired Map Products including “Bathymetry/DEMs” and “Lakebed Surface Types” which can often be combined on survey vessels using sonar, backscatter, and their derivatives. Another group of nearshore cells with high potential for collaborative mapping were located south of Manitowoc. These were important to both historians and ecologists and also had the same combination of mapping products desired of “Bathymetry/DEMs” and “Lakebed Surface Types”. 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.

Discussion

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 geologists interested in "Sediment Transport/Management" selected the nearshore cells off Port Washington as a high priority. Similarly, only the historians were particularly interested in the cells in the deepest part of the proposed sanctuary offshore from Sheboygan, and only the ecologists seemed interested in the northernmost cells of the area. 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 elsewhere 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 cross section of regional experts at this time relative to other parts of the study area.

How can others access and use this information for planning their activities? The individual contact information (Appendix A) is provided for reference at the end of this document, summary grid values are posted at the National Center for Environmental Information (https://www.ncei.noaa.gov/), 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 Products 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 products. 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 the two cells along the shoreline at the northern extremity of the proposed sanctuary before planning future mapping. These two northernmost cells were a high priority to many ecologists and were justified due to "Important biota/natural area". However, it appears that this may be only a small part of a broader, more contiguous feature of importance. Additional inquiries should determine if this is merely the southern edge of a more extensive high-priority area or if the cells identified here represent the core of a small but important stand-alone feature to be mapped. The extent of this priority area should be further defined by the respondents that selected it here, but it would also be important to engage additional respondents with a specific interest or expertise in areas north of the proposed sanctuary to more thoroughly identify mapping priorities in that region. On that point, although this process included a cross section of respondents with a strong interest in lakebed mapping within the proposed 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 if the sanctuary is implemented. 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.

Respondent	Email	Affiliation
Harvey Bootsma	hbootsma@uwm.edu	University of Wisconsin- Milwaukee
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P.J. Creviere	syberdiver1@yahoo.com	Independent
Peter Esselman	pesselman@usgs.gov	United States Geological Survey
William Fetzer	william.fetzer@wisconsin.gov	Wisc. Department of Natural Resources
Russ Green	russ.green@noaa.gov	NOAA/Office of National Marine Sanctuaries
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John Jensen	jjensen2@uwf.edu	University of West Florida
Brandon Krumwiede	brandon.krumwiede@noaa.gov	NOAA/Office for Coastal Management
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Catherine Riseng	criseng@umich.edu	University of Michigan
Ed Rutherford	ed.rutherford@noaa.gov	NOAA/Great Lakes Env. Res. Laboratory
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Ethan J. Theuerkauf	ejtheu@illinois.edu	U. Illinois at Urbana-Champaign, State Geological Survey
Tamara Thomsen	tamara.thomsen@wisconsinhistory.org	Wisconsin Historical Society
Ted Treska	ted_treska@fws.gov	US Fish and Wildlife Service
Philip Willink	pwillink@sheddaquarium.org	Shedd Aquarium, Chicago
Caitlyn Zant	caitlin.zant@wisconsinhistory.org	Wisconsin Historical Society
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U.S. Department of Commerce

Wilbur L. Ross, Jr., *Secretary*

National Oceanic and Atmospheric Administration

Timothy Gallaudet, *Acting Under Secretary for Oceans and Atmosphere*

National Ocean Service

Russell Callender, *Assistant Administrator for National Ocean Service*

The mission of the National Centers for Coastal Ocean Science is to provide managers with scientific information and tools needed to balance society's environmental, social, and economic goals. For more information, visit: https://coastalscience.noaa.gov/