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Establishing seafloor mapping priorities for coastal states

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ABSTRACT

The Florida Coastal Mapping Program (FCMaP) is a consortium of State, Federal and academic partners that is undertaking the coordination of the collection and dissemination of consistent, high-resolution seafloor data for Florida's coastal zone. The coastal zone in the context of FCMaP refers to the area extending from the shoreline to the 200-m isobath. The high-resolution data is critical for a myriad of ocean and coastal resource management applications.

An existing data gap analysis revealed that less than 20% of Florida's coastal waters have been mapped using modern bathymetric methods (multibeam sonar or airborne lidar), and in some areas, less than 5% of the seafloor has modern data; where data do exist, they often date to the 1800s. Addressing the need for a more comprehensive modern map of the seafloor will take an enormous amount of effort and funding, coordination and prioritization will be critical to success.

FCMaP also undertook a formal statewide seafloor mapping prioritization to solicit input from a variety of stakeholders. The results provide the first statewide perspective of user and stakeholder mapping prioritization needs for the State of Florida. The prioritization dataset identifies specific locations that would benefit the most users or stakeholders, which can help to refine targeted mapping strategies. We found that new, consistent data would greatly support and improve multiple management activities. The approach used for this effort demonstrates an effective and replicable approach to addressing the need for seafloor mapping.

1. Introduction

High-resolution elevation data of the coastal seafloor are critical for a myriad of ocean and coastal management applications, which is of particular importance due to increasing hazards and risks from changing climate. Such data are integral to identifying and managing sand resources for beach nourishment, navigation safety, fisheries management, and other coastal and ocean resources that are a fundamental part of the Blue Economy of coastal states. Florida has the longest coastline (2170 km) in the coterminous U.S. and nearly eighty percent of the State's economy relies on its coastal and adjacent ocean resources (Florida Ocean Alliance; https://www.floridaoceanalliance.org/articles-publications/; last accessed 10/26/2020). Florida's 1900 km of sandy beaches draw 22 million visitors each year (Klein and Osleeb, 2010).

Florida's coastal economy is increasingly threatened by sunny-day (high tide) flooding, erosion and inundation from storm surge, and harmful algal blooms that lead to severe ecosystem damage. In 2018, Hurricane Michael caused approximately $5 billion in damage to Tyndall Air Force Base alone in the Panhandle region of Florida, and residential homes and important agricultural resources like the lumber industry were destroyed. According to a University of Florida study (http://blogs.ifas.ufl.edu/extension/2018/12/04/understanding-the-florida-red-tide/; last accessed July 07, 2020), accessed Dec 26, 2019), red tides cause more than $20 million tourism-related losses each year in Florida. Modern, high-resolution elevation data for Florida's coastal waters would help to improve modelling forecasts of currents that carry red tide, and storm surge and inundation predictions in advance of

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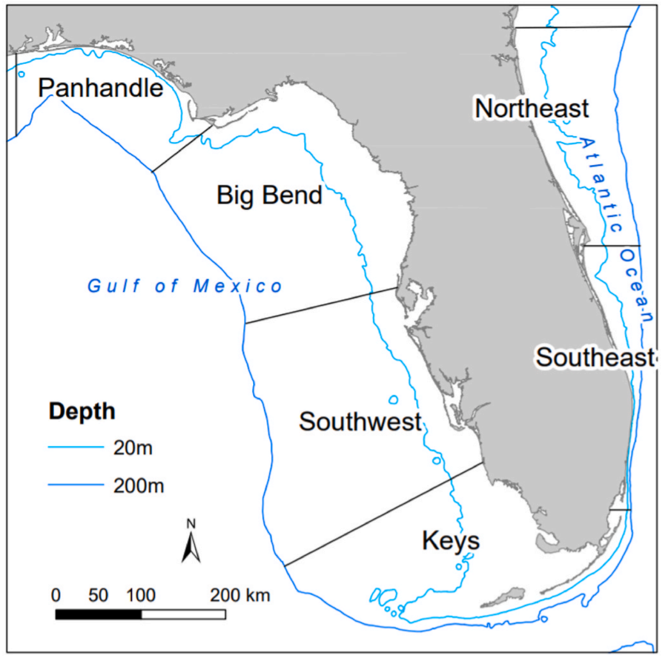

Fig. 1. FCMaP conducted separate prioritizations for the 6 the regions of the State shown here. The map also indicates the extents of the two depth zones: nearshore and shelf.

storms. Given that the coastal regions of Florida are primary drivers of the State's economy, the benefit of comprehensive seafloor mapping to the State would be significant for improvement of integrated management of ocean and coastal resources and vastly improve vulnerability assessments (Rangel-Buitrago et al., 2020).

Coastal and ocean mapping are not just important for the state of Florida. Numerous states, agencies, and international groups recognize the need and importance of seabed mapping for best-practice management of ocean resources (Pickrill and Todd, 2003). This is underscored by the global Nippon Foundation-GEBCO Seabed 2030 Project (Mayer et al., 2018), an initiative to unify coastal nations for a global effort to map the world's oceans in their entirety by 2030. In addition, the National Oceanic and Atmospheric Administration's Integrated Ocean and Coastal Mapping's (NOAA IOCM), "Map Once, Use Many Times" (last accessed 03/15/2021) campaign acknowledges the myriad of sectors involved in the management of ocean and coastal resources that need foundational seafloor information. The NOAA IOCM also has recently released an Implementation Plan for the National Strategy for Ocean Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone (National Ocean Mapping, Exploration, and Characterization Council, 2021) which plans to facilitate comprehensive explorations and mapping efforts in support of resource management and ocean stewardship, along with policymaking, research, or applied mission objectives. The European Marine Observation and Data network (EMODnet) identified the availability of marine data as a primary problem and presents a 10 year vision of engaging stakeholders to connect the diverse communities of the marine knowledge value chain (Míguez, 2019).

A historical effort in Florida that recognized the need and value of seafloor information for resource management began with the Florida Oceans and Coastal Resources Council (FOCRC), established in 2006 by Florida legislation, and identified modern, high-resolution seafloor bathymetry as a top research priority by stakeholders who manage and study Florida's coastal and ocean resources. A priority mapping area identification workshop in 2007 hosted by the U.S. Geological Survey (USGS), Florida Department of Environmental Protection (FDEP), and Southeastern Regional Partnership for Planning and Sustainability also identified a primary need for improved and widespread coordination of coastal mapping across the state (Robbins et al., 2008) to benefit management of resources. Despite the recognized need for mapping and coordination, by 2017 there had been little progress towards the goals of the FOCRC. Mapping efforts across the state have continued in a piecemeal fashion driven by specific and often small project needs with no unified or systematic approach to data formats, access, or distribution.

In 2017, the USGS and the Florida Institute of Oceanography (FIO) revived the effort of unifying how coastal seafloor data in Florida are collected and disseminated through the creation of the Florida Coastal Mapping Program (FCMaP). FCMaP was initiated, as a collaborative body comprised of Florida State and Federal partners with a goal of achieving consistent, statewide, high-resolution seafloor data for Florida's coastal zone within a decade. The collaborative group collectively formed a steering committee of ten federal and state agencies, and presently act as the governing body of the program, with a coordinator from the University of South Florida St Petersburg campus, College of Marine Science (USF CMS). The steering committee oversees various technical teams and working groups that are tasked with implementing the strategic plan of the program (Hapke et al., 2019b). Following the completion of a data inventory, gap analysis, and a partner and stakeholder workshop in 2018, the FCMaP steering committee decided to undertake a formal prioritization of seafloor mapping needs and requirements across the State (Hapke et al., 2019a and b).

Recent literature indicates there is a recognized need and a push worldwide towards prioritizing seafloor mapping for a broad range of ocean and coastal resource management applications. Coleby and Grist (2019) developed a mapping prioritization to help with the management issue of marine plastics in Hong Kong, creating a prioritized area map for plastic waste management. A participatory GIS approach was developed by Hansen et al. (2021), focused on prioritizing mapping to support coastal and marine recreation in Sweden, and they stress the need to get the prioritization into the hands of local planners and managers. The concept of using prioritization for marine spatial planning has also been applied in far-flung locations such as the Falkland Islands where Blake et al. (2017) focused on cultural values associated with particular locations of high importance to the peoples of the region, rather than a direct management application.

Table 1
Results of the mapping data gap analysis as of 2017 (modified from Hapke et al., 2019a and b) showing the percent of seafloor mapped with modern technologies.

Region	Nearshore (%)	Shelf (%)
Panhandle	43	39
Big Bend	3	16
Southwest	28	6
Keys	27	19
Southeast FL	84	20
Northeast FL	61	4
Statewide	27	16

Formal prioritization of seafloor mapping also has precedence. NOAA's Biogeography Branch developed a GIS tool to collect mapping prioritization information in recognition of the need for a systematic approach that results in a geospatial perspective of mapping priorities that include stakeholder mapping needs (Kendall et al., 2015). The first NOAA effort to prioritize mapping needs (Battista and O'Brien 2015) was focused on Long Island Sound, and utilized a participatory geographic information system (PGIS) which allowed for input of mapping priorities from a large variety of stakeholders including agencies and institutions. Similar approaches were implemented for Washington State (Battista et al., 2017), which was expanded to include Oregon and California (Costa et al., 2019),a portion of Lake Michigan (Kendall et al., 2018), and the Caribbean (Kraus et al., 2020).

All of these prioritization efforts utilized PGIS, but the spatial allocation methods differed between efforts. The user input has included a ranking system (Battista and O'Brien, 2015; Battista et al., 2017) or a somewhat more quantitative approach to place votes or allocate coins in grid cells of interest (Kendall et al., 2018; Costa et al., 2019; Kraus et al., 2020). The PGIS tool developed by NOAA not only requested user input on *where* mapping is a priority, but also asks for (or requires) input on *why* the stakeholder needs the data, and what the degree of priority mapping is for an indicated location. For all of the previous studies, the responses were visually summarized as maps and statistically analyzed to identify significant trends in the distribution of priorities.

In our study, we build on the previous efforts to create a mapping prioritization tool that is customized to Florida's coastal mapping needs. The objective of this paper is to describe the prioritization process, and to interpret and discuss the implications of the results based on stakeholder perception. The goal is to develop a path toward the best allocation of resources that can support the collective goal of a comprehensive high-resolution bathymetric dataset for all of Florida's coastal waters and can be used in a myriad of coastal and ocean management sectors to strengthen and sustain Florida's Blue economy into the future.

2. Methods

For the data inventory, gap analysis, and prioritization, the state is divided into 6 geographic regions (Fig. 1), based largely on regional variations in coastal resource management issues and coastal typology (e.g., mangroves, marshes, coral reefs, barrier islands). Inland waterways such as bays, estuaries and lagoons were not included in the prioritization because they are numerous across Florida and beyond the scope of the initial effort. Each region was further divided into 2 depth zones that reflect different sensor and survey design requirements: 0–20 m water depth (nearshore zone), and 20 m to the continental shelf break (shelf zone). Note that the region previously referred to as the West Florida Peninsula Region (Hapke et al., 2019a and b) is herein referred to as the Southwest Region.

2.1. Data inventory and gap analysis

FCMaP was formally established in January 2017 with the formation of a steering committee led by the U.S. Geological Survey (USGS) and the Florida Institute of Oceanography (FIO). The FCMaP vision is accessible, high resolution seafloor data of Florida's coastal waters to support infrastructure, habitat mapping, restoration projects, resource management, emergency response, and coastal resiliency and hazard studies for the citizens of Florida. A number of Florida State and Federal agencies agreed to participate on the steering committee and identified technical staff within their institutions to undertake the data inventory and gap analysis. The technical team included additional expertise from academic institutions with strong mapping programs and its primary purpose was to complete the inventory and analysis.

Seafloor datasets were identified and inventoried with metadata and spatial extent boundaries (also known as footprints) for known mapping efforts based on the FWRI Marine Resource GIS (Florida Fish and Wildlife Conservation Commission, 2021) and made available through a mapping portal hosted by the Florida Fish and Wildlife Research Institute (FWRI; https://fcmap-myfwc.hub.arcgis.com/). The gap analysis considered only recent, high-resolution elevation data with a minimum mapping requirement of one point per 10 m^2. However, the inventory includes older, coarser resolution bathymetry, and other associated data types (e.g., side-scan sonar, subbottom profiles) as they are often the best available.

The results of the gap analysis (Table 1) demonstrate how little of Florida's coastal seafloor had been mapped as of 2017 using modern, high-resolution technologies. There is substantial variation in the mapping coverage from region to region and in the different depth zones. As of 2017, an average of only 27% of the nearshore zone seafloor had been mapped with topobathymetric lidar and multibeam bathymetry sensors (Hapke et al., 2019b). In some of the poorly mapped regions (i.e., Big Bend), the best available data is often limited to lead-line measurements from the late 1800s, with only one data point per 100 m^2.

An initial stakeholder workshop was held in early 2018 to present the results of the data inventory and gap analysis. Seventy-five stakeholders representing a broad array of federal, State, and local entities, as well as private industry, attended the 3-day workshop. Discussions focused on mapping needs and standards in different water depths, sensor requirements, and how to move the effort forward without any identified resources for coastal seafloor mapping in the State. The inventory metadata and footprints were updated based on input from the workshop participants. The stakeholder group reached consensus on the need for FCMaP to undertake a formal mapping prioritization, similar to ongoing NOAA efforts, to establish mapping priorities for when funding became available.

2.2. FCMaP prioritization tool

To accomplish the development of a Florida prioritization, FCMaP formed a technical advisory team to establish a Florida-specific prioritization tool, including selecting the best prioritization method (coin allotment, ranking, or other), establishing the size of the grid cells to be populated and other technical details. There was concurrence that the tool would be based on the coin-allotment method because it allows for more robust statistical analyses, and the size of the grid cells would be 10 km^2. The grid was modeled after the U.S. National Grid (https://usngcenter.org/; last accessed May 28, 2020) in orientation and projection for compatibility with other gridded datasets.

In considering the grid cell size, a variety of options were explored, such as smaller grid cells for greater resolution, varying the grid cell size relative to water depth, and varying the cell size by region. An overall smaller grid cell size was determined to be potentially overwhelming towards achieving a useable outcome due to the vastness of some the regions. For example, with a 10 km^2 grid cell size, the Big Bend Region alone (Fig. 1) has 619 cells. In discussions across the technical working group, the participants felt that the desired end product to be of most use for guiding mapping across the State would be one where there was both regional and water depth consistency so a strategy could be developed

Table 2
Categories of mapping needs and ancillary data types that stakeholders included with their spatial prioritization. There is no cross-column correlation to the lists in the table.

Mapping Need	Ancillary Data
General knowledge gap	Bottom type – multibeam backscatter (hardness/smoothness)
Habitat mapping and coastal geomorphology	Bottom-type – side-scan sonar (hardness/smoothness)
Resource management (sediment, minerals, restoration, resilience)	Subbottom profiles (geology)
Fishing and fisheries (commercial, recreational)	Ground-truth data (imagery, grab samples, in-situ spectrometry)
Recreation (diving, sailing, non-fishing activities)	Ferrous objects from a magnetometer
Navigation/safety/marine infrastructure	Seafloor color from remotely collected imaging sensor
Scientific research and education (biological, geological)	
Cultural/historical resources (shipwrecks, marine debris)	

for the entire state (i.e. compare apples to apples). It was decided that 10 km^2 cell size provided enough spatial granularity to capture information in coastal waters, and was large to cover the expansive Florida shelf without creating an unwieldy number of cells for participants to assign coins. This cell size is similar to sizes used in other successful prioritization efforts (Kraus et al., 2020).

The Florida-specific tool was configured by FWRI in close collaboration with NOAA, resulting in a web-based GIS application that allows stakeholders to interactively attribute grid cells to indicate their priority data needs – a participatory ArcGIS tool. The interface allows users to identify specific areas of highest priority, and requests responders to indicate their desired ancillary data needs (besides elevation) and the mapping need for which they want the data. The tool allots each agency or institution representative (respondents) an equal number of coins where each region has a total number of coins equal to 20% of the total number of grid cells in the region. Allocating coins as a percentage of the region allows for normalization between different sized regions and limit responses such that respondents had to think carefully about what their priorities were. Respondents assign coins to grid cells to indicate their priority location and assign multiple coins to a grid cell to indicate the degree of mapping priority at the location. A maximum of 10% of the total number of a respondent's coins could be assigned to a single grid cell location. Degree of priority was explained to the respondents in terms of timescale where assigning the maximum number of coins to a location indicates the mapping needs to be done as soon as possible. Within the prioritization tool, ancillary data layers such as the inventory of existing mapping data, NOAA nautical charts, and bathymetry are available to inform the priority decision-making process. The prioritization tool also allows respondents to add their own spatial data layers.

To solicit widespread input from the science and management communities on coastal and seafloor mapping priorities, and to promote the goals of FCMaP, a series of five workshops were held across the State in 2018 and 2019, representing the six FCMaP regions (the Southeast and Keys Regions were a joint workshop). There was a cumulative total of 219 stakeholders in attendance at the five workshops.

At the workshops, representatives from multiple federal, state, academic, and private entities were introduced to FCMaP and the prioritization tool, and engaged in discussions about the relevance of high-resolution seafloor data to their region's science and management mapping needs. Because the prioritization tool is web-based, it allowed respondents to enter information after the workshop and respondents were asked to act as representatives for their respective entities. Larger respondent entities with broader perspectives, such as FWC and NOAA, were allocated two sets of coins for different divisions, such as the scientific research division and the management division. To ensure broad representation within their entities, respondents either divided their coins within their entities or worked together in assigning coins. Post-workshop, representatives from each entity were provided with individual accounts to access the online mapping prioritization tool with the expectation that they work collaboratively within their agency or institution to indicate the collective mapping priorities. For each region, users were assigned a number of coins equal to 20 percent of the total number of grid cells in the region. The maximum number of coins that could be placed in any given cell was limited to 10 percent of the total number of coins allocated in order to force the user to give careful consideration in selecting which grid cells to place coins. This limitation was a recommendation from NOAA based on their rigorous testing and implementation of the tool; therefore, FCMaP adopted the recommendation. Respondents were also instructed that not allocating coins to a particular cell (priority value of 0) did not mean the area has no priority or does not need to be mapped, rather that the immediate mapping need is lower for that location.

The users also indicated their primary, secondary, and tertiary mapping needs and any ancillary mapping data required for their mapping needs (Table 2).

Each region had a different number of grid cells because of differences in spatial coverage, and the number of respondents per region also varied. As a result, and because in some cases respondent's prioritization

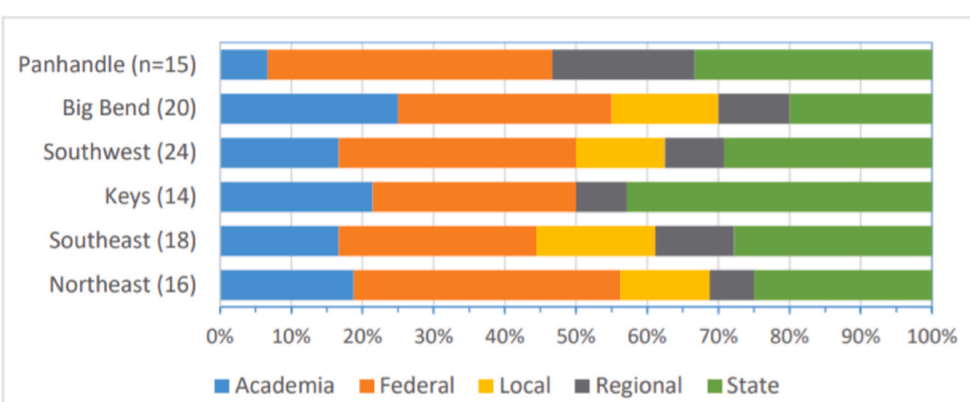

Fig. 2. Distribution of agencies and institutions that participated in the FCMaP prioritization for each region.

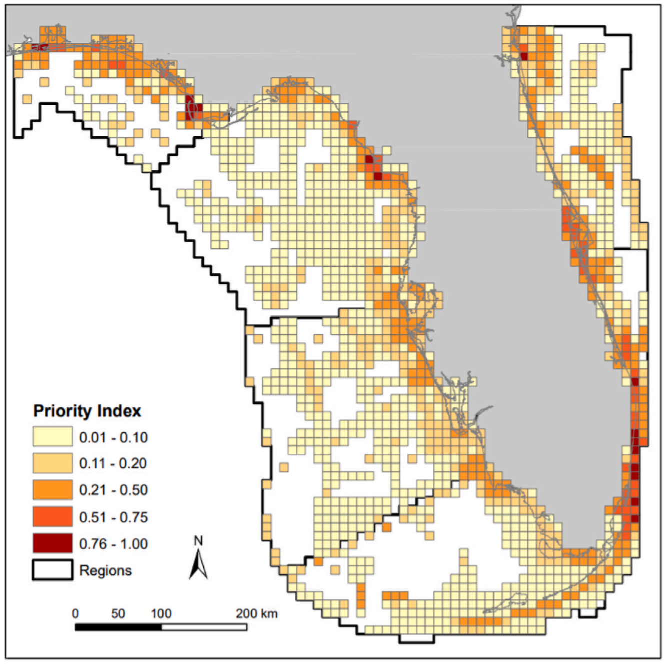

Fig. 3. Map showing results of the statewide prioritization based on a priority index. The index was created by normalizing the results for each individual region by dividing the total coins assigned to each cell by the total cells for each region in order to merge them for the statewide perspective.

was incomplete, the results were quality controlled and normalized to ensure logical consistency for development of a statewide assessment. For example, mapping needs or data type with no coins allocated were not included in analysis. Coin allocation was assessed as percentages based on region size, which allows for comparison across regions. Response data were normalized by the number of responses per region for each region to create an indexed value comparable across regions (a priority index). Respondents were categorized into 5 entity types: Local government, regional government, state government, federal government, and academia.

To examine the relationship between ancillary data needs and mapping needs, we also conducted a hierarchical cluster analysis, similar to Kendall et al. (2018) and Battista and O'Brien (2015). The cluster analysis considered the mapping needs and ancillary data prioritization per cell to determine if there were significant patterns in the data that might help further refine the prioritization by identifying multiple uses for the same data collection. First, we constructed a matrix populated by the total standardized number of coins within each spatially explicit cell, mapping need and data type using the 'BiodiversityR' R Library (Kindt, 2019), where 16 columns consisted of nine justifications and seven products (Table 2), and rows consisted of U.S. National Grid (USNG) codes representative of spatially explicit cells. The USNG is a system of grid references used in the United States that provides a nationally consistent "language of location", developed for local applications and adopted as a national standard by the Federal Geographic Data Committee (FGDC) in 2001 (https://www.fgdc.gov/usng; last accessed 10/26/2020). Second, we used an agglomerative clustering algorithm with Ward's minimum distance from the 'cluster' R Library (Maechler et al., 2013) to subsequently identify four clusters of spatial cells based on similar standardized coin totals across all 16 justifications and products. Last, we quantified the total number of standardized coins divided by the total number of cells within each cluster to understand how clusters differed from each other in terms of mapping needs and ancillary data types (Table 2).

3. Results

The most responses were received from the Southwest Region (n = 24) and the fewest responses were from the Keys Region (n = 14; Fig. 2). This is likely due to the geographic size of a given region, and the number of stakeholder types. For example, in regions such as the largest, the Southwest Region, there is also sizeable academic presence. In the smallest region, the Keys Region, the number of stakeholders is lower, including lack of significant academic presence. There is likely also a bias due to the membership of the prioritization technical team and the steering committee, which likely influenced the stakeholders they were able to bring to the table. The majority of respondent entities were State and Federal agencies, and the distribution of respondent types was relatively similar across regions. With the exception of Southeast Region, some respondents did not allocate all of the coins made available to them, which was 10% of the total number of coins available for prioritization in each region. In these cases, we assumed that the coins they used adequately addressed their priority needs.

Fig. 3 shows the results of the statewide prioritization for Florida, shown according to the priority index, which is created by normalizing the number of coins in each cell by the number of cells in each region. Visually, it is apparent that the highest priority areas (darker colors) are in the nearshore, although there is still wide distribution of mapping priority across the continental shelf. Thirty-five percent of all grid cells had no coins allocated.

The visual conclusion that the highest priorities are concentrated in nearshore coastal waters is statistically supported by examining the top fifth and tenth percentiles (Fig. 4a), which are clustered along the coast (<20 m water depth). Additionally, the alongshore extent of the high priority areas varies, with the Southeast and Panhandle Regions having the most continuous alongshore priority. Six percent of cells with coins (15,300 km^2; Fig. 4a) fall into the top tenth percentile of the priority index. Of the cells in the tenth percentile, sixty-five percent have some modern high-resolution data according to the FCMaP data inventory conducted in 2017 (Hapke et al., 2019b). That result also indicates that thirty-five percent, or 5400 km^2 (Fig. 4b) have not been mapped with modern technologies (topobathymetric lidar or multibeam sonar). From a broader perspective, of the 1565 cells with coins statewide (Fig. 4c), seventy-two percent have not been mapped (Fig. 4d), highlighting the vast lack of data for Florida's coastal waters in general.

Fig. 5 illustrates the diversity in mapping data needs and types

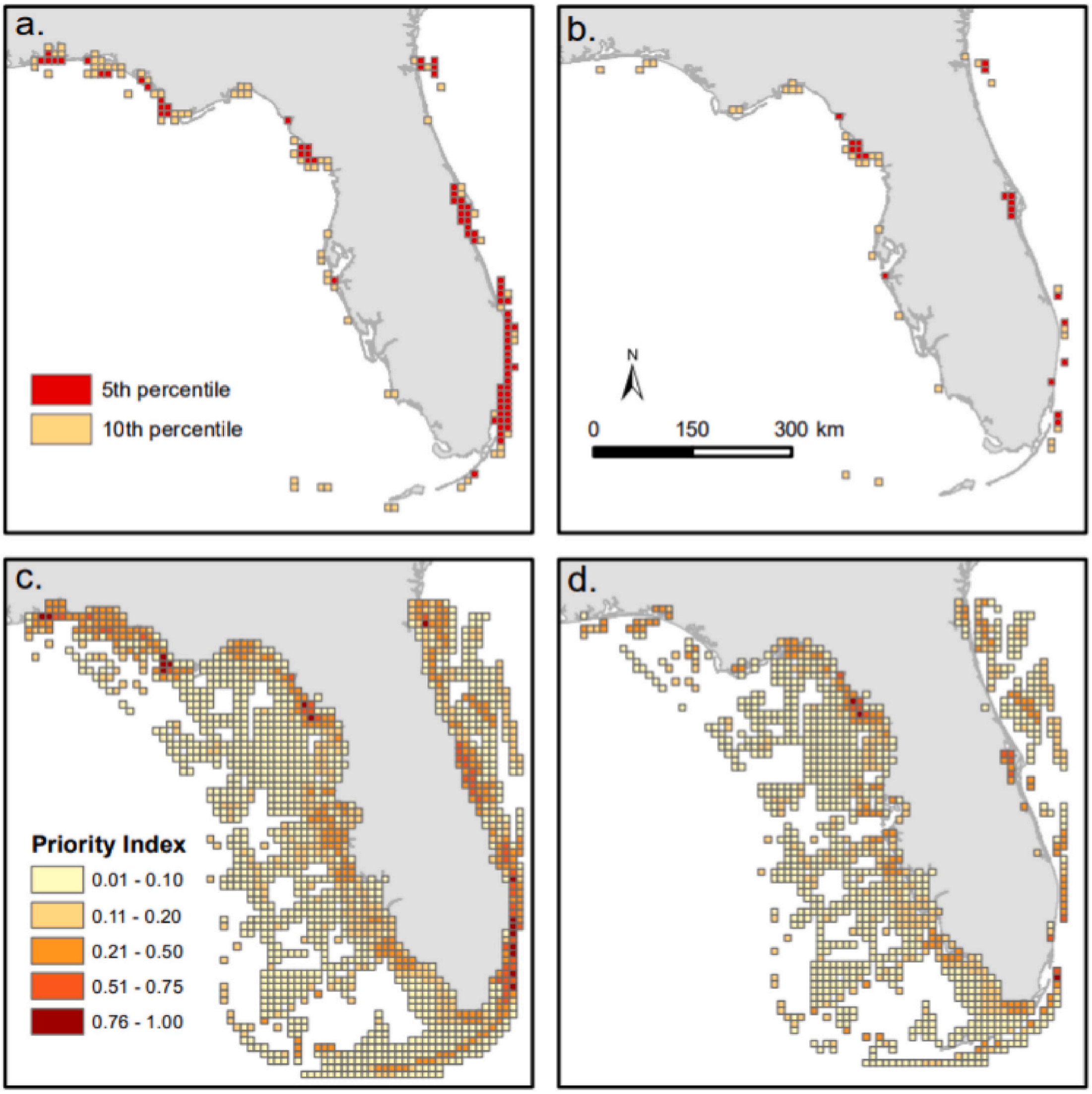

Fig. 4. Distribution of primary data needs (a) and types (b) user require beyond bathymetry, based on respondent survey included on the prioritization tool.

indicated by respondents for primary, secondary and tertiary data. Not all respondents indicated an ancillary data type or mapping need when allocating coins, but when they were selected, a secondary and tertiary were often also selected. Habitat mapping and coastal geomorphology are by far the greatest priority mapping needs with (Fig. 5a) with forty-four percent of respondents indicating this category as the primary mapping need. Resource management is also relatively high, with twenty-eight percent of respondents selecting this mapping need. In terms of primary, ancillary data types, the combination of bottom type (hardness/smoothness) from multibeam and side-scan sonar categories was the highest percentage priority (68%; Fig. 5b). The other primary categories are relatively equal, with the exception of magnetometer data to identify metal objects on the seafloor (one percent).

In order to examine spatial patterns in the distribution of primary ancillary data and mapping needs, the highest four priorities in each of these categories were weighted by coin allocation. With respect to mapping needs, habitat mapping and coastal geomorphology are relatively widely distributed around the State (Fig. 5a), focused primarily in the shallower nearshore zone (0–20 m water depth) with the exception of the Northeast Region where cells of high priority extend offshore. Somewhat surprisingly, resource management was not deemed a priority need in the Keys region (Fig. 5b) nor is it a high priority in the Big Bend. The third and fourth top mapping needs - scientific research and education, and general knowledge gap - show very region-specific distributions. Scientific research and education are a high priority everywhere except in the Big Bend Region (Fig. 5c).

The distributions for the four highest-priority ancillary data types vary significantly by category. The need for multibeam backscatter is quite prevalent throughout the state with the lowest priority in the Big Bend Region (Fig. 6a). For side-scan sonar data, the outcome is more regionalized (Fig. 6b). Certain areas that were not prioritized for multibeam, such as the nearshore zone of the Northeast Region, place high priority for side-scan sonar data, which indicates there is clear widespread need for data that can be used to interpret bottom type and characterize habitat. In the Southwest Region, there is a high priority for both types of acoustic mapping data, which reinforces the need for this data type. Prioritization of sub-bottom data is distinctly limited to three regions – Southeast, Southwest, and Northeast, in order of quartile priority (Fig. 6c).

There are not large areas that prioritized the need for ground-truth data such as sediment grabs and imagery (Fig. 6d), and the localized nature of the priorities is likely related to specific projects or study sites.

For the Florida distributions of ancillary data and mapping needs, a cluster analysis identified commonalities in respondent's choices by evaluating the total number of coins of all categories of data type and mapping need within each of the top four clusters. The clusters indicate

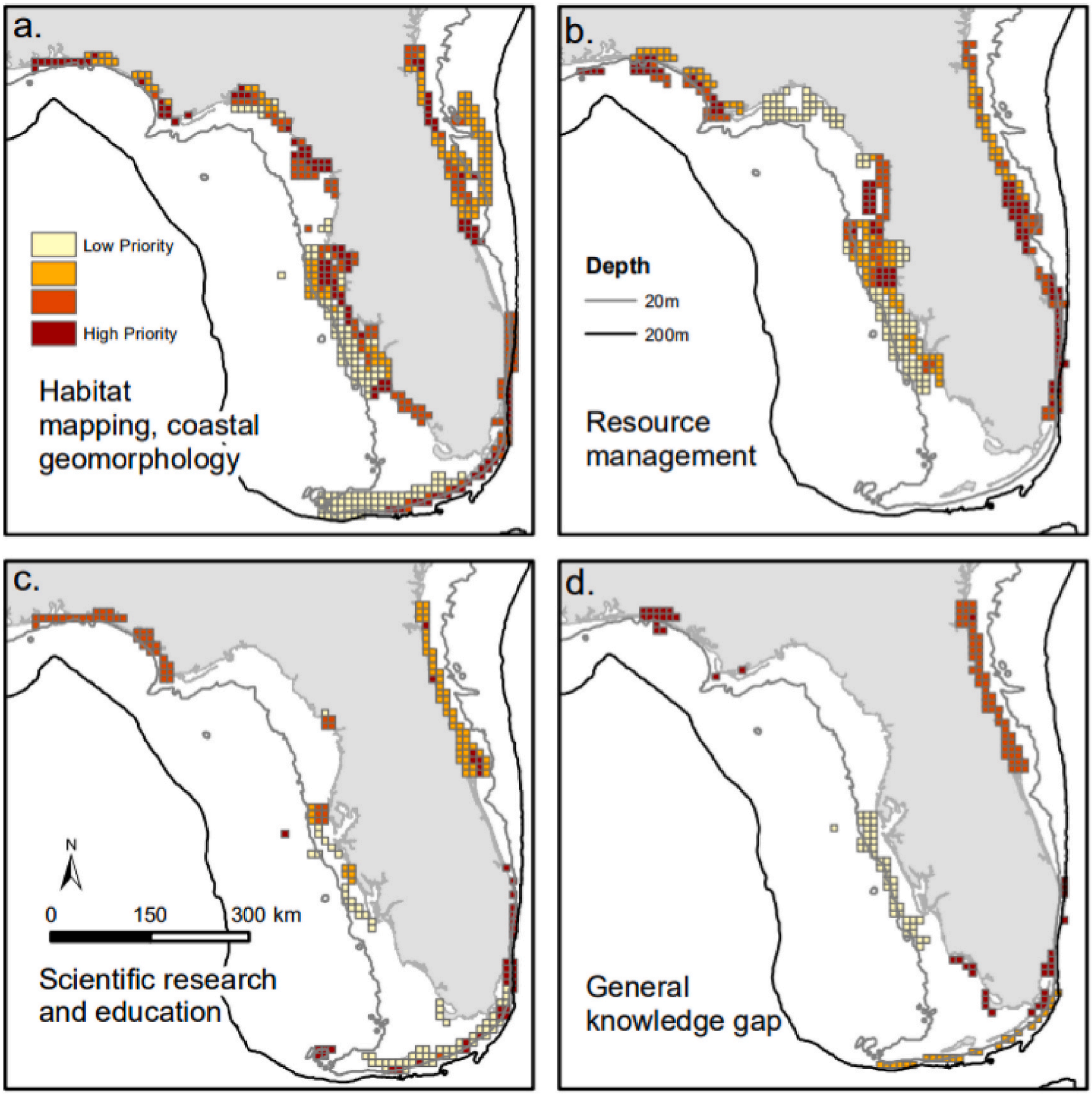

Fig. 5. Geospatial distribution of the top four priority category quartiles of data need as indicated by prioritization tool respondents: a) habitat mapping and coastal geomorphology; b) resource management; c) scientific research and education; and d) general knowledge gap.

locations where there are multiple uses (mapping needs) for the same type of required ancillary data. Fig. 7 shows the geospatial distribution of the top four clusters; the results of the analysis are in Table 3 in which the highest number for each category is highlighted. Cluster 1 depicts areas where coins were placed but no or little ancillary data or mapping need was selected (Fig. 7a); therefore, the values are extremely small or zero (Table 3). Cluster 2 (Fig. 7b) represents fairly low cell count (275) but does suggest there is a relationship between the need for side-scan sonar data where the primary mapping needs are for coastal geomorphology and habitat mapping.

Cluster 3 is the largest cluster (598 cells; Table 3) and represents the highest average coin allocation for the nearly all of the ancillary data types and mapping. This cluster depicts areas where mapping efforts would address the most overall priority data type and mapping needs, or the 'biggest bang for the buck'. The distributions highlight the widespread importance of comprehensive mapping for a wide variety of mapping needs, and indicates the desire to have data collections include more than just elevation information to best serve the stakeholders and user of the data. The need for multiple data types appears to be especially true in the shallower water areas of Florida's nearshore zone within all regions with the exception of a continuous stretch in the central portion of the Big Bend area (Fig. 7c). Cluster 4, the smallest cluster (244 cells; Table 3), highlights a relationship between the need to fill general knowledge gaps and for seafloor color mapping products in areas where there is no priority mapping needs identified but still a relatively high need for habitat mapping.

4. Discussion

The development of a mapping prioritization tool allowed FCMaP to implement a systematic approach for understanding where stakeholders in Florida have the greatest need for coastal seafloor mapping data. The tool was principally focused on assessing the geographic locations where the most respondents indicated that they had need for high-resolution elevation information. However, in general, most stakeholders need supporting ancillary data in addition to elevation information for their mapping need. By having a collective sense of what data are needed and who needs it, we hope to facilitate collections of opportunity. In other words, if a particular survey is planned to collect one type of data, can an additional sensor be put on the vessel to collect complimentary data? Understanding why data are needed – what the stakeholders need the data for – is important as well, and can help make the case to funding entities on why baseline data collection is so important.

The results of the ancillary data and mapping needs components of

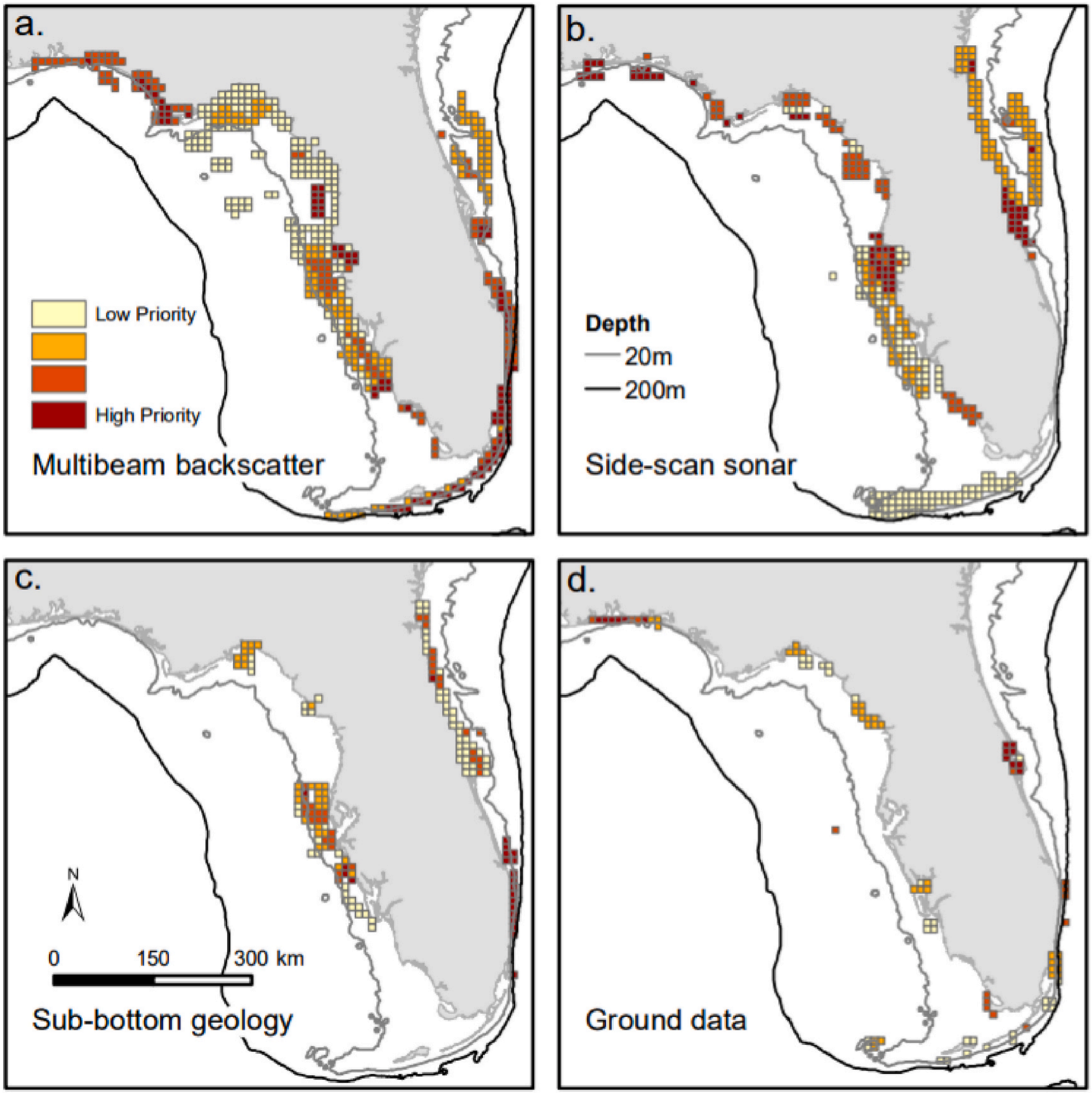

Fig. 6. Geospatial distribution of the top four priority category quartiles of ancillary data type as indicated by prioritization tool respondents: a) multibeam backscatter; b) side-scan sonar; c) sub-bottom geology; and d) ground data.

the prioritization revealed some interesting and unexpected results. For instance, resource management was not identified as a priority application in the Big Bend or Keys regions even though both of these areas are rich in fragile natural resources such as coral reefs and vast seagrass beds. The lack of priority for this application may be a function of not engaging the appropriate stakeholders, such that resource management may have been poorly represented during the prioritization process. Alternatively, resource management needs may be sufficient in these areas and as a result, respondents focused in other priority categories.

In the case of the Big Bend Region, this part of Florida is very remote, and little of the region has been mapped. The region is characterized by a shallow sloping continental shelf that is very wide, thus multibeam data collection is inefficient and lidar data are not generally flown very far offshore. The lack of perceived need may be related to the general lack of knowledge of the seafloor in this areas and the low population density. Understanding why certain areas that are poorly mapped also are identified as lower priority by stakeholders is important – modern, high resolution seafloor data in these areas may shed light on potentially critical resources that could have a positive economic impact on low-income counties like those in the Big Bend Region.

Based on the results, the need for filling a general knowledge gap is highest in the Northeast Region (Fig. 6d), likely because this portion of the Florida coast is highly populated and the gap analysis (Table 1) indicates that very little of the shelf area has been mapped. There is a high demand in this region for sand resources for beach nourishment projects, and filling a general knowledge gap may reflect the desire to identify future possible sand resources.

In three of the six regions, there was a strong prioritization for sub-bottom ancillary data – the Southeast, Southwest, and Northeast Regions (Fig. 6c). The focus for subbottom data in these regions is attributed to the nature of the respondents, with more clusters of academic and government research entities that have coastal and marine geological interests in these three regions over the others. The focus on subbottom mapping data may also be driven by the large demand for sediment sources for beach nourishment projects.

The seafloor mapping prioritization presented herein provides a valuable perspective on the mapping needs and priorities compiled from a large group of stakeholders in Florida. Although we attempted to reach as many and as diverse a group of stakeholders as possible, we recognize the results are biased by the types of stakeholders that participated in our study. For example, there was consistent input provided for all regions from federal and state agencies, but the level of participation was generally lower from academics and local government and entities, and varied from region to region. Additionally, there was not total

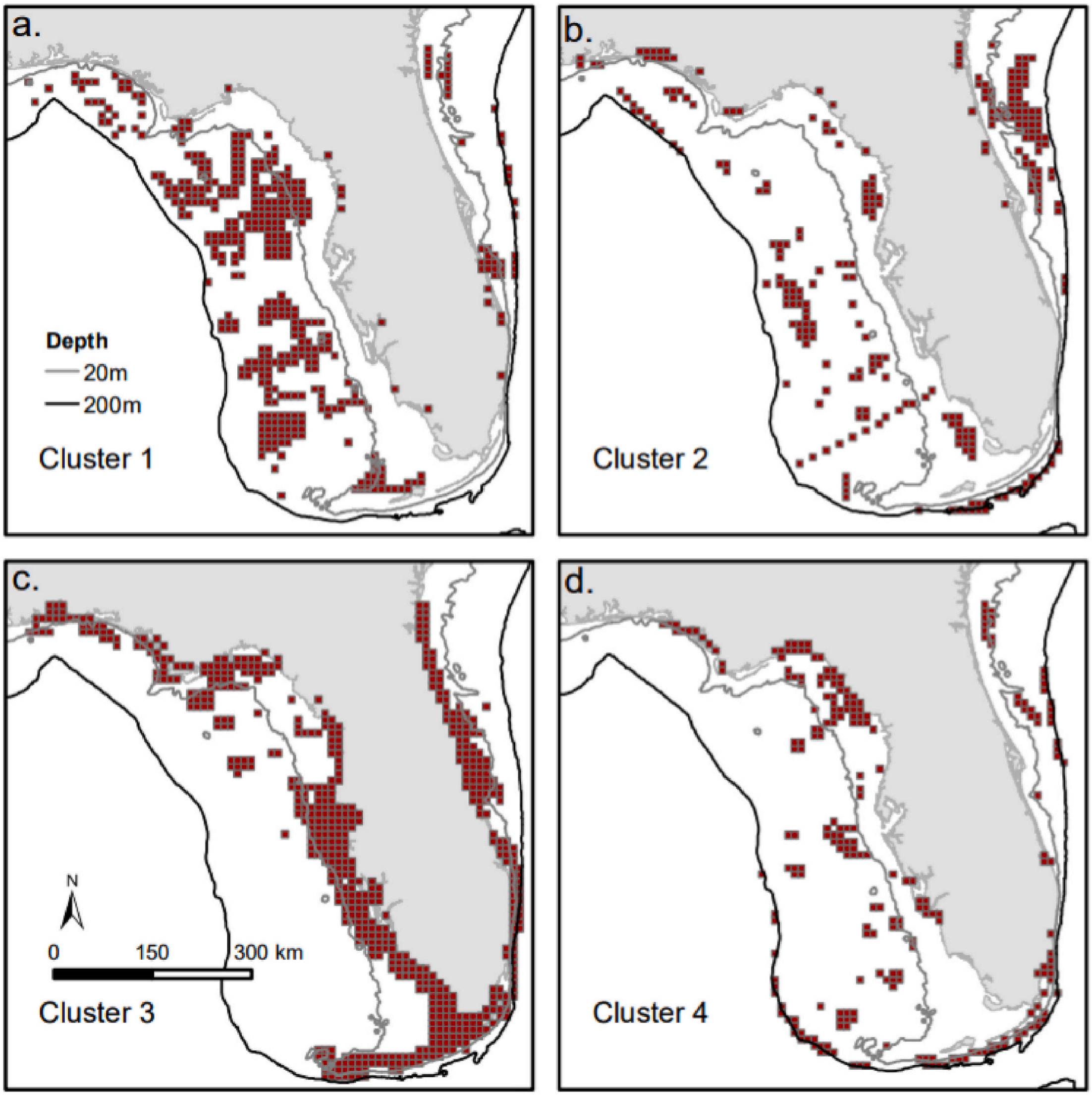

Fig. 7. Results of a cluster analysis identifying locations where there are multiple mapping needs satisfied by the same type of ancillary data. The maps are for the top four clusters, and results indicate cluster 3 will provide the most benefit to the most stakeholders.

consistency in *how* respondents populated the tool. Some respondents did not allocate all their available coins, others did not include ancillary data types and mapping need. Regardless of these limitations, the results provide guidance for creation and implementation of a comprehensive mapping plan for the state.

The results demonstrate the strong demand for updated and comprehensive seafloor mapping in Florida's coastal waters that is consistent with mapping initiatives worldwide. Through the prioritization process, we have established a Florida-based community of practice in coastal mapping that encourages collaboration and communication for the common good of the group. The prioritization and discussions across the community identified certain areas, for example, the Big Bend Region has having low priority, which very well may be due to the fact that it is a remote and relatively lightly populated region. Mapping in areas such as the Big Bend may lead to the creation of new economic drivers in the form of increased recreational use in currently low-income areas.

As a case in point, agencies and private industry have started to invest in areas that have been identified as either never mapped with modern, high resolution technologies or identified by the FCMaP prioritization or both. For example, NOAA has significantly increased mapping efforts in the eastern Panhandle and Big Bend Regions, both multibeam bathymetry and topobathymetric lidar data collections. Priority areas are also being used to identify locations to test innovative new technologies, such as unmanned surface vessels (USVs), which are ideal for mapping areas like the vast, relatively unmapped West Florida Shelf. This area is especially difficult because much of it is in water too deep for topobathymetric lidar systems, and too shallow for efficient multibeam surveying from manned vessels. In addition, USVs will substantially reduce the expense of mapping shallow water areas because ship time is greatly reduced or eliminated.

A number of coastal states in the U.S. have undertaken, or are undertaking, the development of comprehensive coastal seafloor mapping programs, including California (Johnson et al., 2017) and Massachusetts (https://www.mass.gov/seafloor-and-habitat-mapping-program; last accessed 06/18/2020). In addition, NOAA, working with states in some instances, has undertaken mapping prioritization along the U.S. west coast (Costa et al., 2019), Great Lakes (Kendall et al., 2018), Long Island Sound (Battista and O'Brien, 2015), and is finalizing an effort to prioritize the southeast U.S. which will incorporate Florida's already completed prioritization. These efforts are important not only for the individual states, but support national mapping initiatives such as 3D Nation (https://communities.geoplatform.gov/ngda-elevation/3d-nation-study/; last accessed 06/18/2020), the first effort to consider the

Table 3
Outcomes of the cluster analysis showing the top 4 clusters. The bold, underlined numbers in the table indicate the cluster with the highest overlapping value for each category.

	Cluster	1	2	3	4
	Cell count	448	275	598	244
Priority mapping need (justification)	General knowledge gap	0.01	2.1	1.99	**2.49**
	Habitat mapping	0	5.17	**7.47**	3.78
	Resource mgmt.	0	0.96	**6.26**	1.8
	Fishing & fisheries	0	0.35	**0.66**	0.15
	Recreation	0	0.07	**0.87**	0.24
	Navigation & safety	0	0.39	**2.2**	0.56
	Science & education	0	4.21	**4.87**	3.12
	Cultural & historical resources	0	0.07	**0.77**	0.12
	No stated justification	2.71	0.28	2.96	**6.75**
Priority data type	Side-scan sonar	0	**4.7**	4.46	2.69
	Multi- beam	0	5.03	**5.74**	3.25
	Sub-bottom geology	0	0.3	**3.58**	0.54
	Ferrous objects	0	0	**0.48**	0
	Ground data	0	2.43	**4.61**	2.29
	Seafloor color	0	0.14	1.33	**2.3**
	No stated product	2.72	0.51	3.65	**7.45**

need and required technologies for mapping coastal waters at a national scale. When implemented, 3D Nation agencies can utilize existing prioritizations and gap analyses to target data collection in the most beneficial and needed areas.

The combination of a comprehensive mapping strategy and mapping prioritization will be crucial to support the growth of the Blue Economy, especially in the Gulf of Mexico, which to date does not have a unified approach for mapping. Louisiana has undertaken substantial mapping as part of the LA Coastal Protection and Restoration Authority (CPRA) 2023 Coastal Master Plan, but is focused specifically on LA. An integrated effort applied Gulf-wide using a similar strategy to the approach developed for Florida would provide a unique perspective that could guide future mapping across the Gulf in the coming decades. Such a program could dovetail with existing efforts to create inventories of data and monitoring efforts like the Gulf of Mexico Alliance (GOMA) Data and Monitoring Team's Master Mapping Plan A.

The prioritization presented in this study provides a formal framework that can be adapted broadly by other states or regions to develop a mapping strategy for their specific needs. NOAA has undertaken regional mapping prioritizations which provide a solid baseline for the effort described herein (Costa et al., 2019), but the Florida prioritization is the most extensive to date given the extent of Florida's coastal waters relative to other areas of the country. The Florida effort provides a level of granularity that can support both larger mapping initiatives and more localized management applications. In addition, the process of holding informational, in-person workshops and engaging users and stakeholder ranging from local, state and federal groups, created a statewide coastal mapping community of practice around the development of a strategic mapping plan for the state of Florida.

The formation and implementation of a formal mapping program and resulting comprehensive stakeholder prioritization will influence management and policy decision for many years. In 2021, the Florida legislature passed a bill designating $100 million for mapping Florida's seafloor; the prioritization effort will directly inform the mapping administered by the State. Under this initiative, many areas will be remapped on a regular basis to help guide decision-making and may lead to the implementation of new policy or guidance for entities in the coastal zone.

5. Conclusions/summary

The ocean and coastal management community worldwide has identified the importance of the need for foundational seafloor mapping for the management of vast ocean and coastal resources that support economies, enhance risk assessment, and aid in marine conservation. Utilizing processes for prioritization of mapping is critical for identifying locations that will provide the highest value to the most stakeholders.

The decision to undertake a comprehensive, formal mapping prioritization was reached by Florida coastal mapping users and stakeholders during a workshop in 2018, when the enormity of the lack of high-resolution seafloor data for Florida was recognized (Hapke et al., 2019b). The realization that the level of funding required for extensive mapping needed for the State would likely become available at a relatively slow pace highlighted the need to identify both the top priorities areas and the areas that had highest benefit to the most users.

Building off existing prioritization tools, and in order to be consistent with other prioritization efforts, an interactive, participatory GIS tool was developed for use specific to Florida's coastal seafloor. The tool provided an interface for users and stakeholders to indicate the geographic location of their priorities, as well as indicate what they would use the data for, and what other type of mapping information they required for their use. The prioritization tool can be imported and customized to be used by others in different locations and for different needs.

The cumulative, statewide results from the individual regional prioritizations reveal the widespread need for modern, high resolution seafloor data of Florida's coastal waters. Areas in the shallower water zone (zero to 20 m water depth) overall have a higher priority, but the compelling need for large, regional mapping efforts in deeper areas is still highly supported by the study results. Further analyses of the data highlight the significant need for additional data beyond bathymetry, especially acoustic data such as multibeam or side-scan sonar used to identify bottom type. The most efficient way to meet this need is to collect backscatter data simultaneously with the multibeam data collection – most modern systems have this capability.

The statistical cluster analysis analyzed different combinations of data uses and mapping needs within each grid cell. The results pinpoint specific areas where the highest numbers of respondents would benefit from data collection or yield the most "bang for the buck". Agencies and private industry can use this information to target data collection efforts and potentially establish test beds for testing new technologies, such as new lidar sensors and unmanned surface vessels.

We acknowledge that some of the results from the analysis may have biases due to factors such as variable participation from different regions, imbalances in the number of user-type participants, and variable resource management needs. The biases might be reduced by more strategic planning of who is invited to participate and careful balancing of stakeholder types for each given region but any study that requires human response will always have some implicit bias. The study results, even with potential bias, are a valuable and important contribution to coastal resource management for the state of Florida.

Formalized mapping programs can have significant influence on the management of ocean and coastal resources, especially in states where little modern seafloor data exist. Mapping data in shallower water may impact policies related to coastal development, habitat designation, and navigation. Prioritizing assures that areas identified by stakeholders as the most important are considered first, especially in cases where funding is limited.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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